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Contaminants in Surficial Sediment in Coral and Fish Bays (St. John, U.S. Virgin Islands)

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Abstract

Land based sources of pollution have the potential to negatively impact coral reef ecosystems. Many coral systems, including environmentally sensitive marine protected areas, do not have baseline assessments of their chemical contaminant status (magnitude and extent). Without a baseline assessment, it is impossible to measure change in a system. This study presents surficial sediment data from Coral and Fish Bays (St. John, US Virgin Islands(USVI)). Portions of both bays are included in Virgin Islands National Park, and Virgin Islands Coral Reef National Monument. A suite of analytes (PCBs, PAHs, pesticides, heavy metals, butyltins) was quantified and compared against other regional data and against previously published sediment quality guidelines (SQG). Contamination in the system was generally low. Exceptions to this were copper and total chlordane which exceeded the Effects Range Low (ERL) sediment quality guideline, indicating possible sediment toxicity. This baseline will be useful to coastal managers for tracking environmental change, and ensuring that this marine protected area remains relatively free from contamination.

Keywords: reefs, pollution monitoring, sediment pollution, heavy metals, pesticides, organotins, hydrocarbons

1. Introduction

1.1 Land Based Sources of Pollution

A variety of anthropogenic stressors, such as climate change, overfishing and land based sources of pollution, have the potential to impact corals reef ecosystems. Although pollution is frequently cited as adversely affecting coral reef health (Fabricius 2005, Dubinsky and Stambler 1996), the concentration of chemical contaminants present in coral reef ecosystems is not well characterized, and typically even less is known regarding linkages between contaminants and coral condition. Developing an understanding of which chemical contaminants are present, how and to what extent they affect the health of corals and coral reefs would help focus management efforts, especially in marine protected areas such as national parks.

1.2 Contaminants in the Marine Environment

Since 1986, NOAA's National Status and Trends Program (NS&T) has monitored and assessed the nation's estuarine and coastal waters for chemical contaminants in a variety of matrices (e.g. bivalve tissues, sediments). Characterization of contaminants in coral reef ecosystems represents a relatively recent expansion of NS&T activities. A baseline of environmental contamination is critical to the management of ecosystems; it is impossible to detect change, or understand how well management actions are working without a baseline.

The suite of NS&T chemical contaminants analyzed for this project is shown in Table 1. The analytes include 58 polycyclic aromatic hydrocarbons (PAHs), 31 organochlorine pesticides, 38 polychlorinated biphenyls (PCBs), four butyltins, and 16 trace and major elements. The nature, sources and environmental significance of each of the contaminant classes to coral reef ecosystems have been discussed in detail previously (Pait et al. 2007, Pait et al. 2010). In summary these pollutants can have a variety of deleterious effects on corals (including coral zooxanthelle), aquatic plants, fish, macroinvertebrates and benthic infauna.

1.3 Study Site Description

The island of St. John is mostly covered by second generation forest growth. Almost the entire island was clear-cut to make way for sugar cane production during the colonial era, and this had dramatic impacts to hydrology and soil composition of the island. Most of the vegetation on St. John today consists of both native and nonnative species competing for space.

The seascape surrounding the island of St. John consists of coral reefs, seagrass beds, algal meadows, rock outcrops and sand plains. It too has seen dramatic changes caused by anthropogenic and natural disturbances. Intensive fishing has caused the loss of several spawning aggregations, as well as severe declines in size and abundance of important fish species (Beets & Friedlander 1999; Beets & Rogers 2002). Coral and seagrass habitat loss due to hurricanes and coral diseases has led to an ecosystem that is now dominated by macroalgae (Beets & Rogers 2002).

Virgin Islands National Park (VIIS) was established in 1956 to protect significant marine and terrestrial resources on the island of St. John. Submerged lands were added to the park in 1962 to further protect and preserve coral reefs and seascapes. The park consists of almost 30 square kilometers including approximately 2/3 of the island of St. John. The need to protect reefs from further degradation led to a Presidential Proclamation establishing Virgin Islands Coral Reef National Monument (VICR) in January 2001, which designated approximately 50 square kilometers of federally owned submerged lands to be protected. VIIS and VICR were established in part to protect the coral reef ecosystem from anthropogenic disturbances.

Coral Bay is a large bay on the eastern side of St. John. It is a specific area of management concern for the USVI Department of Planning and Natural Resources due to its proximity to human populations and unique physical and biological attributes. Different portions of the bay are within the limits of VIIS and VICR. Some areas are not within park boundaries. Coral Bay is 13.3 km^2 and encompasses over 16 km of shoreline, including some of St. John's largest salt ponds, extensive mangrove habitat, sea grass beds and fringing reefs. The bay the receiving waters for the largest catchment area on St. John draining into an individual bay. Coral Bay supports protected *Acropora* corals and sea turtle nesting areas and may be an important juvenile habitat for several commercially important fisheries species such as yellowtail snapper, schoolmaster snapper, and several species of parrotfishes (Friedlander et al 2012). The watershed adjacent to Coral Bay is characterized by steep slopes (averaging 18%, with a large percentage over 35%), highly erodible soils, and high runoff volumes associated with average rain events. These factors, combined with a large percentage of dirt roads, active construction, and no existing storm water management, have been shown to contribute to excessive sediment loading to the bay (Devine et al. 2003, Ramos-Sharron 2005, Brooks et al, 2007). In addition, the watershed experienced an approximate 80% population increase between 1990 and 2000, making it the fastest growing area in the USVI. The Coral Bay Community Council, Inc. (CBCC), a local nonprofit watershed management association, identified erosion and bay sedimentation as priority issues threatening both marine ecosystem health and the community's quality of life. Fish Bay is a small bay on the south shore of St. John. Although significantly smaller than Coral Bay, Fish Bay is also an area of management concern and was identified as a high management priority by coral reef managers to achieve stable, sustainable coral reef ecosystems (USVI and CRCP 2010). Fish Bay represents a significant land surface area draining into an individual bay on St. John and includes extensive mangrove habitat, seagrass beds and coral reefs. A portion of the bay is within the VIIS. The watershed adjacent to Fish Bay is characterized by steep slopes, highly erodible soils, and high runoff volumes associated with average rain events and is also undergoing rapid development.

2. Materials and Methods

2.1 Sampling Design

A stratified random sampling scheme was used in order to assess the overall contaminant condition of the ecosystem, and to be able to make explicit conclusions about how pollutants vary spatially.

Six geographic soft-bottom strata were initially articulated based on natural geographic breaks (e.g. harbors): four within Coral Bay (Main Bay (MB), Hurricane Hole (HH), Round Bay (RB) and Coral Harbor (CH)) and two within Fish Bay (Fish Bay North (FBN), and Fish Bay South (FBS)). In each of these six strata, five sites were randomly selected (Figure 1). If a site could not be sampled (e.g. if the site was inaccessible) a pre-selected randomly determined alternate site from within that strata was sampled. Due to weather issues during the field mission, only 3 sites were sampled in Fish Bay South. Additionally, 12 targeted sediment sites (4 in Fish Bay, 8 in Coral Bay) were sampled (Figure 1). These targeted sites are co-located with sediment trap sites sampled by researchers from the University of the Virgin Island and the University of San Diego, which will allow future comparisons of contaminant data with sediment flux.

Surface sediments were selected as the analytical matrix because they tend to integrate hydrophobic contaminants from the water column. Unlike water chemistry, which can change on the order of hours, sediment chemistry is representative of the system over a much longer period of time (i.e. years).

2.2 Field and Laboratory Methods

Sampling was conducted from June 14th to June 17th 2010 aboard a small boat using a GPS programmed with the station coordinates. Sediment samples were collected using standard NOAA National Status and Trends (NS&T) Program protocols (Apeti et al. 2012a). Briefly, a Ponar sediment grab was deployed to collect the sediment samples. Rocks, shell fragments or bits of seagrass were removed. If an individual grab did not result in 200-300 g of sediment, a second grab was collected and composited with material from the first grab. If enough sediment had not been collected after three deployments of the grab, the site was abandoned and the boat moved on to a site randomly selected from a list of predetermined alternate sites.

To avoid contamination of samples by equipment and cross contamination between sites, the equipment was rinsed with acetone followed by site water just prior to use. Field personnel handling the samples also wore disposable nitrile gloves. The top 3 cm of sediment were collected from the sediment grab using a Kynar-coated sediment scoop. Sediments were placed into a certified clean (IChem®) 250 ml labeled jar, capped and then placed on ice in a cooler. Sediments for grain size analysis were placed in a WhirlPak® bag, sealed and placed on ice in a cooler. After returning from the field each day, sediment samples were frozen (-15°C) and the WhirlPak® bags for grain size analysis were refrigerated (4°C), to avoid altering the grain size structure of the sediment that could occur during freezing. At the end of the mission, samples were shipped overnight to the NS&T contract laboratory (TDI Brooks, International) for analysis.

Analytical methods for each chemical analytes followed the protocols described in Kimbrough et al. (2006) and Kimbrough and Lauenstein (2006). Sediment samples were also analyzed for total organic carbon (TOC) and grain size. These two pieces of ancillary data are important for assessing the potential for accumulation of contaminants in sediments. In general, for freshwater, estuarine, and coastal waters, a positive correlation exists between sediment TOC and chemical contaminants, particularly organic contaminants (Shine and Wallace 2000, Hassett et al. 1980, Fabricius 2005). Sediment grain size is also an important characteristic that can influence contaminant concentrations. Organic contaminants, as well as a number of metals bind to the smaller silt and clay grain size fractions of sediments, due to the larger surface areas of these fractions. The charge characteristics of clays (in addition to the small grain size) lend themselves to preferential attachment of trace and major elements.

TOC was quantified via high temperature combustion and subsequent quantification of the CO_2 produced (McDonald et al. 2006). Grain size analysis was carried out using a series of sieving and settling techniques (McDonald et al. 2006).

2.3 Statistical Analysis

All contaminant data were analyzed using JMP® statistical software. The data were first tested for normality using the Shapiro-Wilk test. The data were not normally distributed. A nonparametric multiple comparisons test (Dunn Method for Joint Ranking, α=0.05) was used to evaluate difference between strata. Spearman rank correlation was used to examine relationships between analytes. Data from the targeted sites were included in the summary statistics as representative of the entire study area, but were not included in the analysis of differences between strata.

2.4 *Providing Context for Results*

In addition to comparing contamination results between strata, there are two primary ways to evaluate the relative level of contamination of Coral and Fish Bays and the surrounding reef ecosystems. First, and most simply, these findings can be compared to the contaminant concentrations from a similar study in St. Thomas, USVI (Pait et al, in press). Second, the degree of sediment contamination in Coral and Fish Bay can be assessed using NOAA's numerical sediment quality guidelines (SQG) known as ERL (effects range-low) and ERM (effects range-median) developed by Long and Morgan (1990) and Long et al. (1995). Individual NOAA SQG values have not been defined for all analytes; existing ERL and ERM values are presented in Table 2. These guidelines are statistically derived levels of contamination above which toxic effects would be expected to be observed in benthic organisms with at least a 50% frequency (ERM), and below which effects were rarely (<10 %) expected (ERL).

3. Results

Every analyte was detected in sediment samples from at least one site, with the exception of total hexachlorocyclohexane (HCH) which was below the limit of detection at all sites. Summary statistics are shown in Tables 3 and 4. Spatial distributions of detected compounds ranged from present at all sites (PAHs, PCBs, a variety of metals) to only occurring at fewer than five sites (nickel, cadmium, chlorpyrifos, aldrin, dieldrin, endosulfan).

3.1 Comparison to Sediment Quality Guidelines

In general, potential toxicity in the study area was low. The only two pollutants which exceeded the ERL, suggesting possible toxicity, were copper (at 3 sites; Figure 2) and total chordane (at 2 sites; Figure 3). No pollutants exceeded the ERM guidelines, which would have suggested probable toxicity, although it should be pointed out that there are not SQG for all analytes (e.g. TBT).

3.2 Comparison to Regional Studies

Contaminants measured in the St. Thomas East End Reserves (STEER; Pait et al. in press) were generally higher than observed in this study (Table 5), suggesting that Coral and Fish Bays do not have high contamination for the region. Other than major crustal elements (e.g. Si, Fe), the exception to this was silver, which was detected in St. John, but not in the STEER. It should be noted that the silver levels measured in St. John were low (below detection at all but seven sites). Cadmium also had higher maximum values in St. John, although the mean values were higher in the STEER.

3.3 Spatial Patterns

Coral Harbor in Coral Bay had significantly higher concentrations of butyltins and PAHs than many of the other strata (Dunn's test, $\alpha=0.05$). This is likely indicative of current and historical boat usage in the area. Distribution of butyltins between tributyltin (TBT) and its breakdown products (monobutyltin and dibutyltin) ranged from entirely TBT to primarily breakdown products. This suggests that there may be “new” sources of TBT to the system, such as boats of non-U.S. origin (i.e. countries where TBT is still used). When compared to other strata, Coral Harbor also had statistically high concentrations of arsenic, mercury and lead, but the absolute magnitude of these concentrations is relatively low (i.e. not of ecological concern).

Of the contaminants which were at levels of environmental concern (copper and chlordane) only copper showed a statistically significant spatial difference with Fish Bay North strata being higher than Hurricane Hole. It is unclear what might be driving that pattern, but it is not likely to be due to heavy boat traffic as North Fish Bay is quite shallow and not heavily used by boaters. No other analytes had statistically significant concentration differences between strata.

4. Discussion

4.1 Potential Sources of Pollutants in the Watershed

A search of the USEPA National Pollution Discharge Elimination System (NPDES) database shows that there is only one permitted discharger in the study area, and this facility in the Coral Bay watershed does not appear to be actively discharging effluent (EPA 2013). Other potential sources of pollutants to the bays include drain pipes, several ghuts (i.e. stream channels), runoff from the town dump site and an abandoned gas station.

Copper has a number of uses such as in boat antifouling paints, wood preservatives, heat exchangers in power plants, electrical wires, coinage, and in agriculture. Based on land use and site observations, boat paint and wood preservatives are the most likely sources of copper to Coral and Fish Bays.

Chlordane was used until 1988 as an insecticide against termites. Prior to 1983 it was used for a more broad set of application including agriculture, lawns and gardens (EPA 2000). Like other organochlorine pesticides, chlordane is extremely environmentally persistent. Therefore, high levels of chlordane are likely due to legacy contamination in the watershed, rather than a new source. Because NS&T samples surface sediments to assess current deposition, the presence of chlordane probably reflects continuing low level input from the watershed during runoff events.

4.2 Relationship of Contaminants with Grain Size and Total Organic Carbon

None of the analytes measured in this study were well correlated with percent total organic carbon (TOC) (i.e. statistically significant with a Spearman ρ value greater than 0.7). This is somewhat surprising given the tendency for contaminants, especially organics, to bind to sediments with higher organic content. Similarly, no contaminants were well correlated with grain size, expressed as percent fines (clay and silt). This is also surprising because the increased surface area in fine grained sediments offers more binding sites for contaminants. This may be a function of relatively low contaminant concentrations for most analytes.

4.3 Relating Contaminant Levels to Crustal Erosion

Another way to examine the nature of the source of these metals is to look at the ratio of each metal to Al, the primary element in the Earth's crust and generally not considered to be a pollutant. If a metal is well correlated with Al, it is more likely to have a natural (erosional) source (see also, Apeti et al. 2012b). The following trace elements were well correlated ($\rho >$ 0.70) with Al (Spearman, α=0.05): As, Cr, Cu, Fe, Mn, Pb, Si, Sn, and Zn. Elements which make up large portions of the Earth's crust (e.g. Si, Mn and Fe) are especially well correlated with Al (i.e. ρ values of 0.95 or greater). Cu, which exceeded sediment quality guidelines at 3 sites, was also well correlated with Al, although sites with disproportionately high concentrations (relative to Al) were observed (Figure 4). These "outliers", located in Coral Harbor and Fish Bay North (red points in Figure 1) may suggest that anthropogenic sources of these metals are prevalent at those sites.

4.4 Ecological Significance of Findings

Elevated levels of copper can impact aquatic organisms, including adverse effects on reproduction and development in mysid shrimp (Eisler 1998). In corals, Reichelt-Brushett and Harrison (2005) found that a copper concentration of 20 μg/L significantly reduced fertilization success in brain coral *Goniastrea aspera*. At copper concentrations at or above 75 μg/L, fertilization success was reduced to one percent or less. Fertilization success was also significantly reduced in the coral *Acropora longicyathus* at 24 μg/L, a similar concentration level to when effects were observed in *G. aspera*. Zinc and cadmium may be less toxic to coral gametes than copper (Reichelt-Brushett and Harrison 1999). High levels of metals such as Cd and Cu can cause coral mortality (Mitchelmore et al 2007), though there is some evidence that corals have some potential to acclimate to metal exposure over time (Harland and Brown 1989). These pollutants also have the potential to impact other trophic levels, such as corals and fish. Previous studies in the Caribbean (Pait et al. 2009, Pait et al. 2010) have demonstrated that a wide variety of contaminants do accumulate in coral tissues, although the ecological significance of this is not well understood. While some studies exist linking specific contaminants to deleterious effects in corals (e.g. Solbakken et al. 1984, Peachey and Crosby, 1996; Reichelt-Brushett and Harrison, 2005; Guzman-Martinez et al., 2007), further research is needed to link observed contaminants in coral tissues with sub-lethal responses in the coral. This might be accomplished by ecotoxicological studies in coral mesocosm experimental facilities, or in the field with genetic analysis of stressor genes in combination with field measurements of contamination.

The presence of contaminants in the marine environment may also be of concern from a fisheries perspective, which can be both an ecological issue as well as a seafood safety/human health issue. Chlordane, which was determined to have sediment concentrations at levels of concern in this study, bioaccumulates in marine fish (USDHSS 1994). Future studies could include fish body burden analysis in both commercial and recreational species.

With the exception of copper and chlordane, no contaminants quantified in this study exceeded published sediment quality guidelines, suggesting that the overall likelihood of toxicity to sediment infauna within the study area is low. It should be noted, however, that not all analytes have guidelines. Furthermore, these guidelines do not consider additive or synergistic effects of multiple toxicants. In order to definitively address sediment toxicity concerns, sediment toxicity assays could be conducted in the future in order to assess potential toxicity in areas where multiple pollutants are highest (e.g. Coral Harbor).

5. Conclusions

Overall, the chemical contamination of Coral and Fish Bays is fairly low. High levels of pollution are generally limited to the inner portions of bays, especially in Coral Harbor. This data set is an important baseline against which to measure change. It should be noted that watershed management activities may have unintended consequences. For example, in order to reduce erosion a number of dirt roads were paved in 2010. However, newly paved roads may cause higher PAH fluxes to the Bays in the future, from PAHs contained in the paving materials or as a result of increased vehicle miles traveled.

There are a variety of potential sources of pollution to Coral and Fish Bays but there is no one "smoking gun" which identifies any one source of primary concern. This speaks to the need for an integrated management strategy which addresses multiple sources of land based pollution.

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References

Apeti, D.A., Hartwell, S.I., Johnson, W.E ., Lauenstein, G.G., 2012a. National Status and Trends Bioeffects Progam: Field Methods. NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Asssessment. NOAA NCCOS Technical Memorandum 135. Silver Spring, MD.

Apeti, D., Whitall, D., Pait, A., Dieppa, Zitello, A. and Lauenstein, G. 2012b. Characterization of land-based sources of pollution in Jobos Bay, Puerto Rico: status of heavy metal concentration in bed sediment. Environ Monit Assess (2012) 184:811–830.

Beets, J., Friedlander, A., 1999. Evaluation of a conservation strategy: a spawning aggregation closure for red hind, Epinephelus guttatus, in the Virgin Islands. Environ. Biol. Fish. 55:91-98.

Beets, J., Rogers, C.S., 2002. Decline of fishery resources in marine protected areas in the US Virgin Islands: the need for marine reserves. Proc 9th International Coral Reef Symposium:449-454.

Brooks, G.R., Devine, B., Larson, R.A., Rood, B.P., 2007. Sedimentary Development of Coral Bay, St. John, USVI: A Shift From Natural to Anthropogenic Influences. Caribbean Journal of Science 43(2):226-243.

Dubinsky, Z., Stambler, N. 1996. Marine pollution and coral reefs. Global Change Biology 2:511-526.

Eisler, R. 1998., Copper hazards to fish, wildlife, and invertebrates: a synoptic review (Contaminant Hazard Reviews Report No. 33). US Department of the Interior and US Geological Survey.

EPA (U.S. Environmental Protection Agency)., 2000. Hazard Summary for Chlordane. http://www.epa.gov/ttnatw01/hlthef/chlordan.html Accessed July 26, 2013.

EPA (U.S. Environmental Protection Agency)., 2013. NPDES Facility Registry. Facility Detail Report for Bordeaux Mountains.

http://iaspub.epa.gov/enviro/fii_query_dtl.disp_program_facility?pgm_sys_id_in=VIGSA0034&pgm_sys_acrnm_in=NPDES Accessed July 26, 2013.

Fabricius, K. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. 2005. Mar. Poll. Bull. 50: 175-189.

Friedlander, A.M., C.F.G. Jeffrey, S.D. Hile, and S.J. Pittman. 2012. Coral reef ecosystems of St. John, U.S. Virgin Islands: Spatial and temporal patterns in fish and benthic communities (2001-2009). NOAA Technical Memorandum 152. Silver Spring. MD.

Guzman-Martinez, M.D.C., Ramirez-Romero, P., Banaszak, A.T., 2007. Photoinduced toxicity of the polycyclic aromatic hydrocarbon, fluoranthene, on the coral, *Porites divaricata*. Journal of Environmental Science and Health, Part A 42: 1495-1502.

Harland AD, Brown BE., 1989. Metal tolerance in the scleractinian coral Pontes lutea. Mar Pollut Bull 20:353-357.

Hassett, J.J., Means,, J.C., Banwart, W.L., Wood, S.G., 1980. Sorption related properties of sediments and energy related pollutants. U.S. Environmental Protection Agency. EPA-600/3-8-041. 133 pp.

Kimbrough, K.L., Lauenstein, G.G., 2006. Major and trace element analytical methods of the National Status and Trends Program: 2000-2006. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 29. 19 pp.

Kimbrough, K.L., Lauenstein, G.G., Johnson, W.E., 2006. Organic contaminant analytical methods of the National Status and Trends Program: Update 2000-2006. NOAA Technical Memorandum NOS NCCOS 30. 137 pp.

Long, E.R., Morgan, L.G., 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. NOAA Tech. Memo NOS OMA 52. NOAA, Seattle, WA. 175 pp.

Long, E.R., MacDonald, D.D., Smith, S.L., Calder, F.D.,1995. Incidence of adverse biologival effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19: 81-97.

McDonald, S.J., Frank, D.S., Ramirez, J.A., Wang, B., Brooks, J.M., 2006. Ancillary methods of the National Status and Trends Program: 2000-2006 Update. Silver Springs, MD. NOAA Technical Memorandums NOS NCCOS 28. 17 pp.

Mitchelmore, C.L , Verde, E. A. , Weis, V.M., 2007. Uptake and partitioning of copper and cadmium in the coral *Pocillopora damicornis* Aquatic Toxicology 85: 48–56.

Pait, A.S., Whitall, D.R., Jeffrey, C.F.G., Caldow, C., Mason, A.L., Christensen, J.D., Monaco, M.E., Ramirez, J., 2007. An assessment of chemical contaminants in the marine sediments of southwest Puerto Rico. NOS NCCOS 52. Silver Spring, MD. NOAA/NOS/Center for Coastal Monitoring and Assessment, 116pp.

Pait, A.S., Jeffrey, C.F.G, Caldow, C., Whitall, D.R., Hartwell, S.I., Mason, A.L. , Christensen, J.D., 2009. Chemical Contaminants in the Coral *Porites astreoides* from Southwest Puerto Rico. NOS NCCOS 91. NOAA/NOS/Center for Coastal Monitoring and Assessment. Silver Spring, MD.

Pait, A.S., Mason, A.L.,Whitall, D.R., Christensen, J.D., Hartwell, S.I., 2010. Assessment of chemical contaminants in sediments and corals in Vieques In: Bauer and Kendall (eds.), An Ecological Characterization of the Marine Resources of Vieques, Puerto Rico Part II: Field Studies of Habitats, Nutrients, Contaminants, Fish, and Benthic Communities. NOAA Technical Memorandum NOS NCCOS 110. Silver Spring, MD.

Pait, A.S., Hartwell, S.I. , Mason, A.L., Warner, R.A. ,Jeffrey, C.F.G., Hoffman, A.M., Apeti, D.A., Galdo, F.R. Jr., Pittman, S.J. . In press. An assessment of chemical contaminants, toxicity and benthic infauna in sediments from the St. Thomas East End Reserves (STEER). NOAA Technical Memorandum NOS NCCOS 156. Silver Spring, MD. 62 pp.

Peachey, R.L., Crosby, D.G. Phototoxicity in tropical reef animals. *Mar. Environ. Res.* 1996, 42: 359-362.

Ramos-Scharrón, C.E. , MacDonald, L.H., 2005. Measurement and prediction of sediment production from unpaved roads, St. John, U.S. Virgin Islands. Earth Surface Processes and Landforms. 30:1283–1304.

Reichelt-Brushett, A.J., Harrison, P.L., 1999. The effect of copper, zinc and cadmium on fertilization success of gametes from scleractinian reef corals. Marine Pollution Bulletin 38 (3), 182-187

Reichelt-Brushett, A.J., Harrison, P.L., 2005. The effect of selected trace elements on the fertilization success of several scleractinian coral species. *Coral Reefs* 24: 524-534.

Shine, J., Wallace, G., 2000. Chemical aspects of organic carbon and ecosystem stress in benthic ecosystems. In: Ad Hoc Benthic Indicator Group - results of initial planning meeting. IOC Technical Series No 57, UNESCO, 65pp.

Solbakken, J.E., Knap, A.H., Sleeter, T.D., Searle, C.E., Palmork, K.H., 1984. Investigation into the fate of 14C-labeled xenobiotics (napthalene, phenanthrene, 2,4,5,2',4',5'-hexachlorobiphenyl, octachlorostyrene) in Bermudian corals. Marine Ecology Progress Series 16: 149-154.

U.S. Department of Human Health and Services (USDHHS), 1994. Toxicological Profile for Chlordane. ATSDR (Agency for Toxic Substances and Disease Registry). http://www.atsdr.cdc.gov/toxprofiles/tp31.pdf Accessed July 26, 2013.

Table 1: List of analytes.

PAHs - Low Molecular Weight	**PAHs - High Molecular Weight**	**PCBs**	**Organochlorine Pesticides**
Naphthalene	Fluoranthene	PCB8/5	Aldrin
1-Methylnaphthalene	Pyrene	PCB18	Dieldrin
2-Methylnaphthalene	C1-Fluoranthenes/Pyrenes	PCB28	Endrin
2,6-Dimethylnaphthalene	C2-Fluoranthenes/Pyrenes	PCB29	Heptachlor
1,6,7-Trimethylnaphthalene	C3-Fluoranthenes/Pyrenes	PCB31	Heptachlor-Epoxide
C1-Naphthalenes	Naphthobenzothiophene	PCB44	Oxychlordane
C2-Naphthalenes	C1-Naphthobenzothiophenes	PCB45	Alpha-Chlordane
C3-Naphthalenes	C2-Naphthobenzothiophenes	PCB49	Gamma-Chlordane
C4-Naphthalenes	C3-Naphthobenzothiophenes	PCB52	Trans-Nonachlor
Benzothiophene	Benz(a)anthracene	PCB56/60	Cis-Nonachlor
C1-Benzothiophenes	Chrysene	PCB66	Alpha-HCH
C2-Benzothiophenes	C1-Chrysenes	PCB70	Beta-HCH
C3-Benzothiophenes	C2-Chrysenes	PCB74/61	Delta-HCH
Biphenyl	C3-Chrysenes	PCB87/115	Gamma-HCH
Acenaphthylene	C4-Chrysenes	PCB95	2,4'-DDT
Acenaphthene	Benzo(b)fluoranthene	PCB99	4,4'-DDT
Dibenzofuran	Benzo(k)fluoranthene	PCB101/90	2,4'-DDD
Fluorene	Benzo(e)pyrene	PCB105	4,4'-DDD
C1-Fluorenes	Benzo(a)pyrene	PCB110/77	2,4'-DDE
C2-Fluorenes	Perylene	PCB118	4,4'-DDE
C3-Fluorenes	Indeno(1,2,3-c,d)pyrene	PCB128	DDMU
Anthracene	Dibenzo(a,h)anthracene	PCB138/160	1,2,3,4-Tetrachlorobenzene
Phenanthrene	C1-Dibenzo(a,h)anthracenes	PCB146	1,2,4,5-Tetrachlorobenzene
1-Methylphenanthrene	C2-Dibenzo(a,h)anthracenes	PCB149/123	Hexachlorobenzene
C1-Phenanthrene/Anthracenes	C3-Dibenzo(a,h)anthracenes	PCB151	Pentachloroanisole
C2-Phenanthrene/Anthracenes	Benzo(g,h,i)perylene	PCB153/132	Pentachlorobenzene
C3-Phenanthrene/Anthracenes		PCB156/171/202	Endosulfan II
C4-Phenanthrene/Anthracenes	**Trace Elements (cont.)**	PCB158	Endosulfan I
Dibenzothiophene	Copper	PCB170/190	Endosulfan Sulfate
C1-Dibenzothiophenes	Iron	PCB174	Mirex
C2-Dibenzothiophenes	Lead	PCB180	Chlorpyrifos
C3-Dibenzothiophenes	Manganese	PCB183	
	Mercury	PCB187	**Butyltins**
Trace Elements	Nickel	PCB194	Monobutyltin
Aluminum	Selenium	PCB195/208	Dibutyltin
Antimony	Silver	PCB199	Tributyltin
Arsenic	Tin	PCB201/157/173	Tetrabutyltin
Cadmium	Zinc	PCB206	
Chromium		PCB209	

Table 2: Sediment Quality Guidelines (Long and Morgan 1990).

Contaminant	**ERL**	**ERM**
Total PAHs (ng/g)	4,022	44,792
Total PCBs (ng/g)	22.7	180
Total DDT (ng/g)	1.58	46.1
Total Chlordane	0.05	6
Ag (μg/g)	1	3.7
As (μg/g)	8.2	70
Cd (μg/g)	1.2	9.6
Cr (μg/g)	81	370
Cu (μg/g)	34	270
Hg (μg/g)	0.15	0.71
Ni (μg/g)	20.9	51.6
Pb (μg/g)	46.7	NA
Zn (μg/g)	150	410

Sediment quality guideline have not been developed for all analytes monitored by the NOAA's National Status and Trends Program

Table 3: Summary statistics of surficial sediment organic contaminant concentrations (expressed as ng/g, except for butyltins which are expressed as ng Sn/g) for Coral and Fish Bays (random and targeted sites).

	Min	Max	Mean	Median
Total PAHs	2.94	199.08	31.65	12.99
Total PCBs	0.16	1.95	0.68	0.62
Total DDT	0	0.64	0.03	0.00
Total Chlordane	0	0.06	0.01	0.01
Total HCH	0	0	0	0
Monobutyltin	0	10.39	1.38	0
Dibutyltin	0	8.62	0.88	0
Tributyltin	0	10.47	1.01	0
Tetrabutyltin	0	0.22	0.01	0

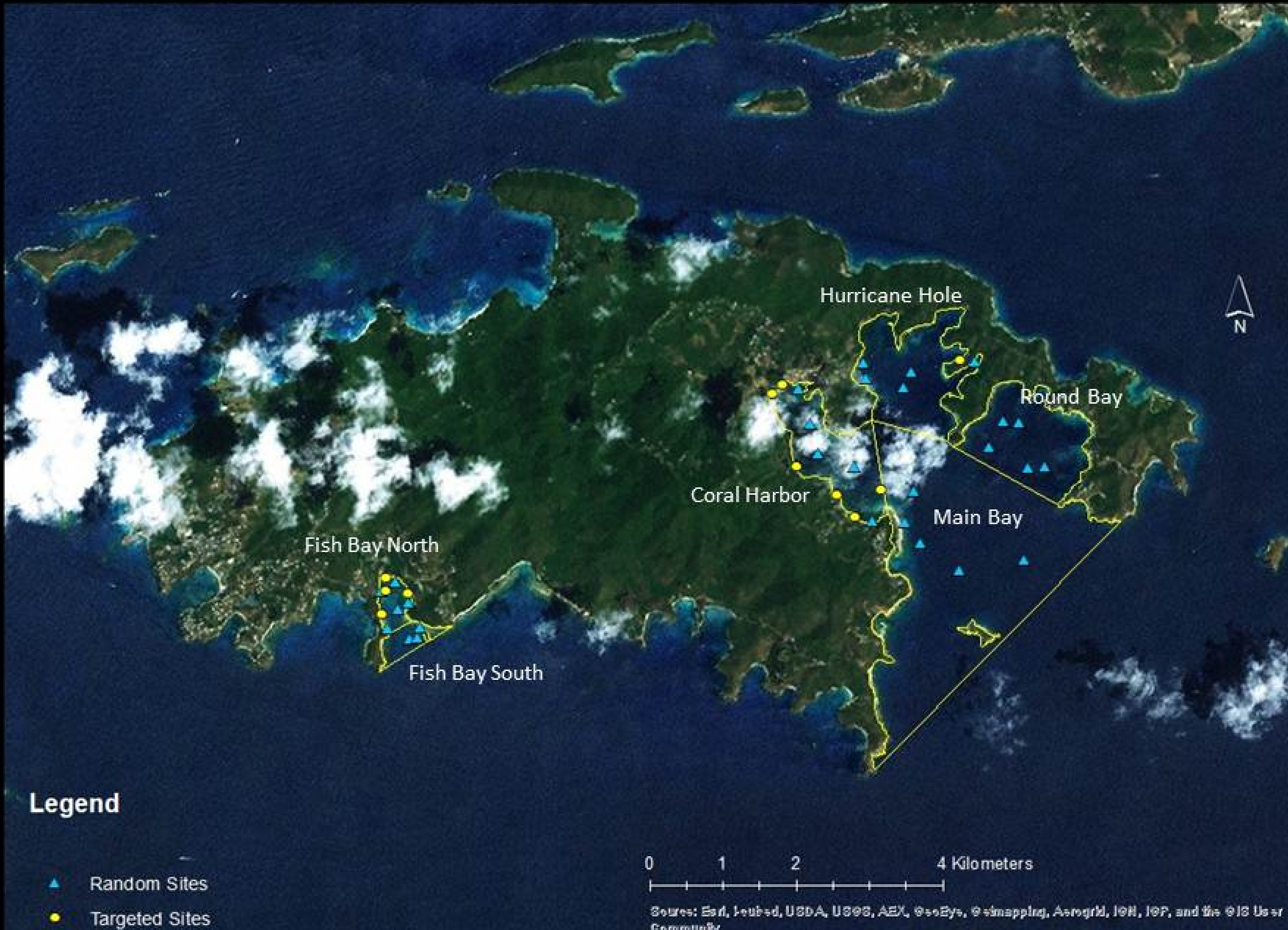
Table 4: Summary statistics of surficial sediment inorganic contaminant data for Coral and Fish Bays (random and targeted sites). Units are μg/g.

	Min	Max	Mean	Median
Ag	0	0.0814	0.012435	0
Al	493	49300	12215.7	6535
As	0.921	7.1	2.82565	2.28
Cd	0	0.65	0.023328	0
Cr	2.7	35.4	10.90725	9.005
Cu	0	38.7	8.7885	3.18
Fe	461	25700	6260.7	3490
Hg	0	0.0308	0.006808	0.0039
Mn	20.3	437	101.5825	56.5
Ni	0	6.09	0.4245	0
Pb	0.382	12.6	2.08485	1.18
Sb	0	0.615	0.09535	0.05835
Se	0	0.961	0.1996	0.213
Si	1910	321000	62729.75	27550
Sn	0	1.33	0.1961	0
Zn	0	145	17.94025	5.865

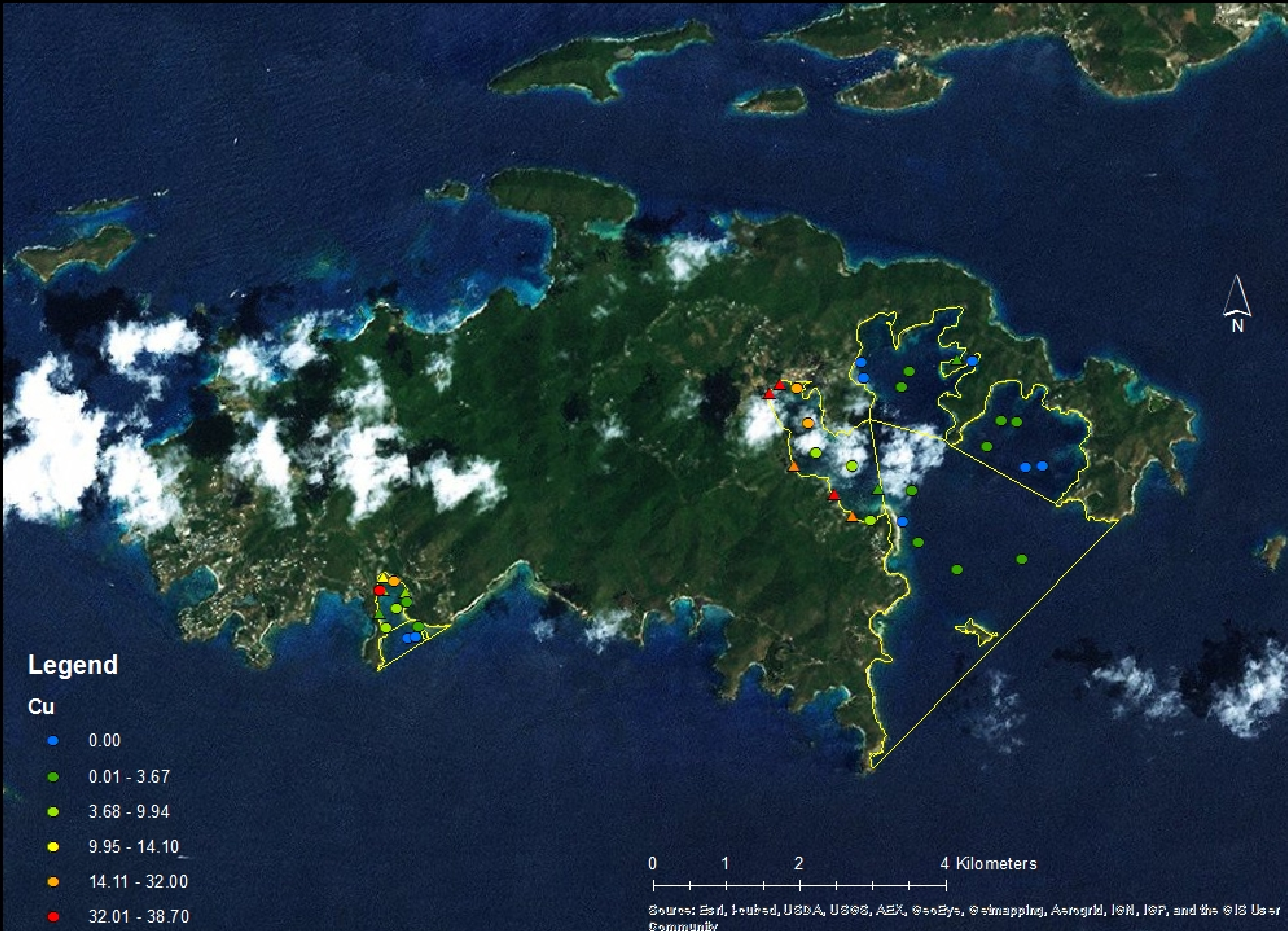
Table 5: Comparison of St. John, USVI (this study) with a previous study in St. Thomas, USVI (Pait et al. in press). Unless otherwise noted, units are μg/g.

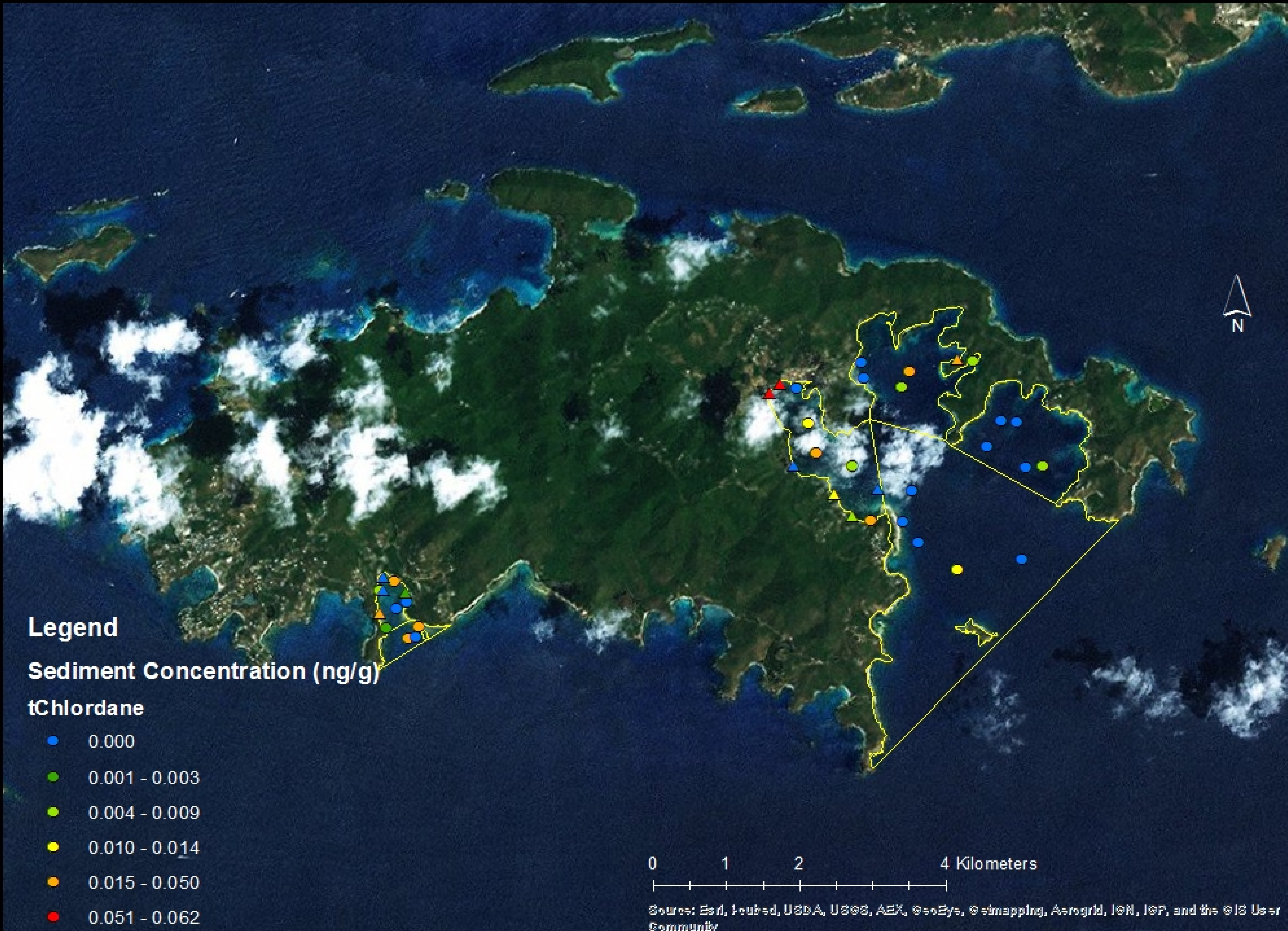
	St. Thomas			St. John		
	Mean	Maximum	Std Dev	Mean	Maximum	Std Dev
Total PAHs (ng/g)	142	1131	285	31.65	199.08	46.22
Total Chlordane (ng/g)	0.04	0.33	0.07	0.01	0.06	0.02
Total DDT (ng/g)	0.05	0.61	0.12	0.03	0.64	0.11
Total PCBs (ng/g)	1.00	7.2	1.58	0.68	1.95	0.36
Tributyltin (ng Sn/g)	1.85	31.1	6.38	1.01	10.47	2.34
Ag	0.00	0.00	0.00	0.01	0.08	0.03
Al	13596	63800	19019	12215.7	49300	13553.07
As	2.74	12.4	3.50	2.83	7.1	1.67
Cd	0.03	0.26	0.08	0.02	0.65	0.10
Cr	14.1	35.7	8.62	10.91	35.4	6.51
Cu	21.0	155.0	36.6	8.79	38.7	11.74
Fe	8547	40900	12347	6260.7	25700	6583.85
Hg	0.02	0.11	0.03	0.01	0.03	0.01
Mn	89.0	338	99.8	101.58	437	99.91
Ni	6.53	15.1	2.81	0.42	6.09	1.37
Pb	5.87	31.0	9.32	2.08	12.6	2.39
Sb	0.12	0.82	0.25	0.10	0.615	0.15
Se	0.24	0.93	0.22	0.20	0.961	0.24
Si	48340	181000	55143	62729.75	321000	77208.15
Sn	0.61	3.95	1.15	0.20	1.33	0.35

Zn	37.3	159	52.3	17.94	145	27.68



Hurricane Hole
N
Round Bay
Coral Harbor
Main Bay
Fish Bay North
Fish Bay South
Legend
Random Sites
Targeted Sites
0
1
2
4 Kilometers


N
Legend
Cu
0.00
0.01 - 3.67
3.68 - 9.94
9.95 - 14.10
14.11 - 32.00
32.01 - 38.70
0
1
2
4 Kilometers
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community


N
Legend
Sediment Concentration (ng/g)
tChlordane
0.000
0.001 - 0.003
0.004 - 0.009
0.010 - 0.014
0.015 - 0.050
0.051 - 0.062
0 1 2 4 Kilometers
Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

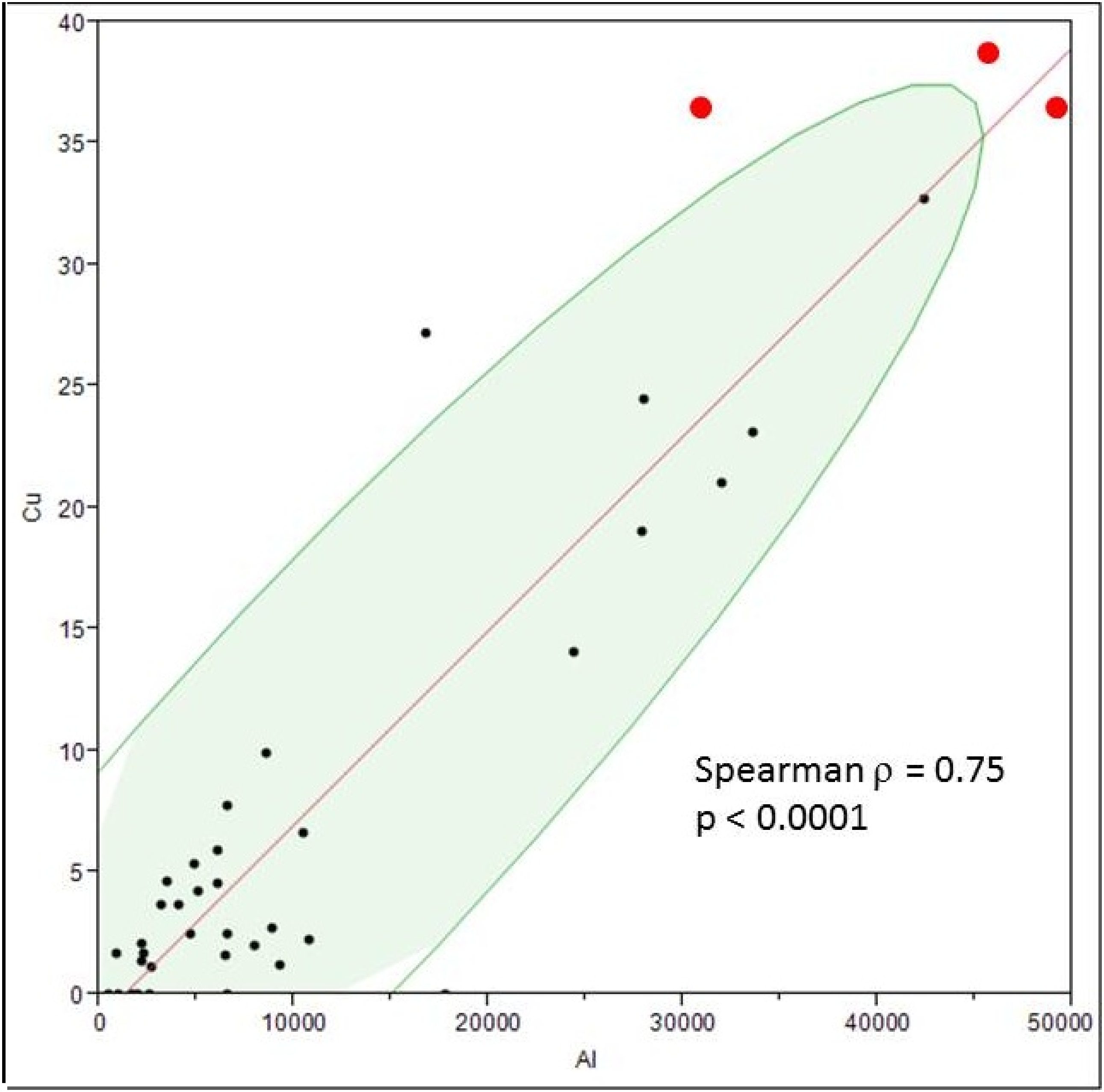

40
35
30
25
20
15
10
5
0
Cu
0
10000
20000
30000
40000
50000
Al
Spearman ρ = 0.75
p < 0.0001

Figure Captions

Figure 1: Sampling strata (yellow lines) and sediment sampling sites for Coral and Fish Bays (St. John, USVI)

Figure 2: Surficial sediment copper concentrations.

Figure 3: Surficial sediment total chlordane concentrations.

Figure 4: Aluminum concentrations versus copper concentration for surficial sediments. Shaded area is 95% density ellipse. Red dots indicate values about the Effects Range Low sediment quality guideline.