

An Assessment of Chemical Contaminants, Toxicity and Benthic Infauna in Sediments from the St. Thomas East End Reserves (STEER)



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May 2013

NOAA TECHNICAL MEMORANDUM NOS NCCOS 156

NOAA NCCOS Center for Coastal Monitoring and Assessment



Citation

Pait, A.S., S.I. Hartwell, A.L. Mason, R.A. Warner, C.F.G. Jeffrey, A.M. Hoffman, D.A. Apeti, F.R. Galdo Jr., and S.J. Pittman. 2013. 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. 70 pp.

Acknowledgements

The authors wish to acknowledge the support from NOAA's Coral Reef Conservation Program (CRCP) for this project. We would also like to thank Jean-Pierre Oriol, Director of the Department of Planning and Natural Resources (DPNR) Division of Coastal Zone Management, Roy Pemberton, Director along with Renata Platenberg and Stephen Hale of DPNR Division of Fish and Wildlife, Anita Nibbs of DPNR Division of Environmental Protection, Jeanne Brown of The Nature Conservancy, Tyler Smith, Sandra Romano, Kevin Brown, and Stanley Lateski of the University of the Virgin Islands (UVI), and Rob Ferguson and Marlon Hibbert of NOAA's CRCP for help with the planning, logistics, and field work along with interpretation of results for this project. Sybille Sorrentino of Virgin Island Ecotours graciously provided a base of operations for our field work. We would also like to acknowledge the help provided by Alexandra Holecek and John Barimo, formerly of the DPNR Division of Coastal Zone Management and UVI, respectively. Finally, we would like to thank Captain Bobby Vante of the *Bright Star* for his skill and patience in getting us to the sampling sites within the St. Thomas East End Reserves.

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NOAA Technical Memorandum NOS NCCOS 156



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Abstract

This report contains a chemical and biological characterization of sediments from the St. Thomas East End Reserves (STEER) in St. Thomas, U.S. Virgin Islands (USVI). The STEER Management Plan (published in 2011) identified chemical contaminants and habitat loss as high or very high threats and called for a characterization of chemical contaminants as well as an assessment of their effects on natural resources. The baseline information contained in this report on chemical contaminants, toxicity and benthic infaunal community composition can be used to assess current conditions, as well as the efficacy of future restoration activities.

In this phase of the project, 185 chemical contaminants, including a number of organic (e.g., hydrocarbons and pesticides) and inorganic (e.g., metals) compounds, were analyzed from 24 sites in the STEER. Sediments were also analyzed using a series of toxicity bioassays, including amphipod mortality, sea urchin fertilization impairment, and the cytochrome P450 Human Reporter Gene System (HRGS), along with a characterization of the benthic infaunal community.

Higher levels of chemical contaminants were found in Mangrove Lagoon and Benner Bay in the western portion of the study area than in the eastern area.

The concentrations of polychlorinated biphenyls (PCBs), DDT (dichlorodiphenyltrichloroethane), chlordane, zinc, copper, lead and mercury were above a NOAA sediment quality guideline at one or more sites, indicating impacts may be present in more sensitive species or life stages in the benthic environment. Copper at one site in Benner Bay, however, was above a NOAA guideline indicating that effects on benthic organisms were likely. The antifoulant boat hull ingredient tributyltin, or TBT, was found at the third highest concentration in the history of NOAA's National Status and Trends (NS&T) Program, which monitors the Nation's coastal and estuarine waters for chemical contaminants and bioeffects. Unfortunately, there do not appear to be any established sediment quality guidelines

for TBT. Results of the bioassays indicated significant sediment toxicity in Mangrove Lagoon and Benner Bay using multiple tests. The benthic infaunal communities in Mangrove Lagoon and Benner Bay appeared severely diminished.

Introduction

The St. Thomas East End Reserves, or STEER, is a collection of Marine Reserves and Wildlife Sanctuaries (MRWS) located on the southeastern end of the island of St. Thomas, U.S. Virgin Islands (Figure 1). Within the STEER, there are extensive mangroves and seagrass beds, along with coral reefs, lagoons and cays. The value of the natural resources in the Reserves has long been recognized. In 1979, the area was identified by NOAA's National Marine Sanctuary Program as a "marine area of national significance, deserving of marine sanctuary designation" (NOAA, 1981). The same year, the Mangrove Lagoon/Benner Bay area, along with Vessup Bay, were designated by the USVI government

as Areas of Particular Concern, or APC, due to the abundance of important but threatened natural resources, and the desire to preserve and, as needed, restore these areas.

The STEER is made up of four MRWS, including the Inner Mangrove Lagoon, Cas Cay/Mangrove Lagoon, St. James, and Compass Point Salt Pond Marine

Reserves and Wildlife Sanctuaries (Figure

1). In 2008, the U.S. Virgin Islands Department of Planning and Natural Resources (DPNR) received a permit application for a floating bar and restaurant that would be located in the St. James MRWS. Public opposition to this proposed activity was strong, but a review of existing regulations at the time did not show the activity was specifically prohibited. As a result of this episode, along with recognition of the connectivity of the natural, cultural, and economic resources of the four Reserves, it was decided that a comprehensive management plan was needed, in order to protect and properly manage the natural resources in the area (STEER, 2011). In April 2008, DPNR along with the University of the Virgin Islands, The Nature Conservancy,



View into the St. Thomas East End Reserves (STEER).



Figure 1. Individual Reserves that comprise the STEER.

and a community group called the Friends of Christmas Cove, formed the STEER Core Planning Group and began development of a management plan for the STEER, which was completed in May 2011.

STEER Boundaries

The STEER comprises an area of approximately 9.6 km², with approximately 34 km of coastline (STEER, 2011). Boundaries for the STEER include the Mangrove Lagoon/Benner Bay MRWS with Long Point as the western border (Figure 1). The St. James MRWS forms the eastern boundary of the STEER, which includes the waters surrounding Great St. James and the north shore of Little St. James Island. To the north, the boundary of the STEER runs along the coastline, from Cabrita Point westward to Benner Bay. At Benner Bay, the boundary follows a line offshore from Cocus Rock along Roto Cay to the northeastern entrance of Mangrove Lagoon; the marina areas within Benner Bay are outside of the STEER.

Aquatic Environment

With mangroves, seagrass beds, lagoons, salt ponds, coral reefs and a number of cays, the STEER contains a multitude of habitats and natural resources. The STEER is thought to be one of the most valuable nursery areas remaining in St. Thomas, with many species of fish and shellfish spending some portion of their lives in the protected areas around the mangroves and in the extensive seagrass beds (STEER, 2011). Fishing is not allowed in most parts

of the Reserves, and where it is allowed (e.g., for baitfish), a DPNR permit is required.

The abundance of natural resources has contributed to the STEER being a popular destination for recreational activities, ranging from swimming, camping, snorkeling and SCUBA, to boating and ecotourism. These uses have recently been documented in a coastal use mapping project for the STEER funded by NOAA's CRCP (Dillard and D'lorio, 2012).

Mangroves. The largest mangrove system in St. Thomas occurs along the shores of Mangrove Lagoon/Benner Bay (IRF 1993). Mangrove species include the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*). Mangroves offer many ecological benefits. They serve as natural buffers against shore erosion, floods and hurricane waves. Mangroves also provide protection for juvenile fish and other organisms around the roots, and generate detrital material that enters the food chain, becoming a food resource for a number of marine organisms (DPNR-DFW, 2005). Sampling with fish traps along the mangrove fringe in Benner Bay/Mangrove Lagoon has yielded as many as 40 fish species (Boulon, 1992; Colletti 2011).

Seagrass Beds. There are extensive areas of seagrass in Benner and Jersey Bays. At one time, seagrasses were also abundant in Mangrove Lagoon (Grigg et al., 1971). Turtle

grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*) are two of the major seagrass species found in the STEER (DPNR-DFW, 2005). Seagrasses provide habitat for many organisms, including juvenile fish. Seagrasses are also an important food source for parrotfish, surgeonfish, and pinfish, along with turtles, birds, and sea urchins. Conch feed off the epiphytes on the seagrass leaves (DPNR-DFW, 2005). Finally, seagrasses in the Caribbean, as in other areas, help to improve water clarity and light penetration, by trapping fine sediments and allowing the sediment particles to settle out of the water column.

Coral Reefs. There are significant coral reef areas in Jersey Bay and also south of Cas and Patricia Cays. Many species of coral can be found in the STEER, including the star coral complex (*Montastraea annularis*, *M. faveolata* and *M. franksi*), mustard hill coral (*Porites astreoides*), lesser and massive starlet corals (*Siderastrea radians* and *S. siderea*), finger coral (*P. porites*), symmetrical brain coral (*Diploria strigosa*), and great star coral *M. cavernosa* (DPNR-DFW, 2005). Also within the STEER are the threatened elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals. The STEER is a relatively shallow system, supporting both patch and fringing reefs. The coral reefs provide habitat and food for many organisms.

Interconnected Habitats.

Not surprisingly, the habitats in the STEER are closely linked to one another. For example, a variety of fish and invertebrates move between the mangroves, seagrass beds and coral reefs, either during the course of their lives (e.g., juvenile fish living among the mangrove prop roots for protection, with adults moving out onto the reefs), or as part of a diurnal cycle (e.g., invertebrates and fish feeding in the seagrass beds at night and returning to the protection of the reefs during the day) (STEER, 2011).

Degraded environmental quality in any one of these habitats affects the others. Poor water and sediment quality in mangrove areas will reduce habitat quality for fish species

and their prey, particularly those sensitive to dissolved oxygen concentrations. Elevated levels of suspended sediment in the water column can lead to a reduction in the amount of light reaching seagrasses and corals, which can result in reduced growth or even die-off. Sediments that settle out of the water column can also act to smother corals. Elevated nutrient levels can result in increased algal growth in the water column and, as with sediments, can reduce the amount of light reaching corals or seagrasses. Chemical contaminants can impact a variety of organisms and life stages. Excess nutrients also promote the growth of epiphytic algae that may smother coral and seagrass.

Watersheds

There are two watersheds which drain into the STEER, the Jersey Bay and the Red Hook watersheds (Figure 2). The largest is the Jersey Bay watershed which empties into Mangrove Lagoon/Benner Bay and Jersey Bay. The

Frenchman Bay watershed drains to the west of the STEER. The area of the STEER east of Deck Point receives input from the Red Hook watershed. It has been estimated that approximately one-third of the population of the island of St. Thomas resides in the Mangrove Lagoon/Benner Bay APC or Area of Particular Concern (IRF, 1993).

There are a multitude of land uses within the watersheds that drain into the STEER, including a large ac-

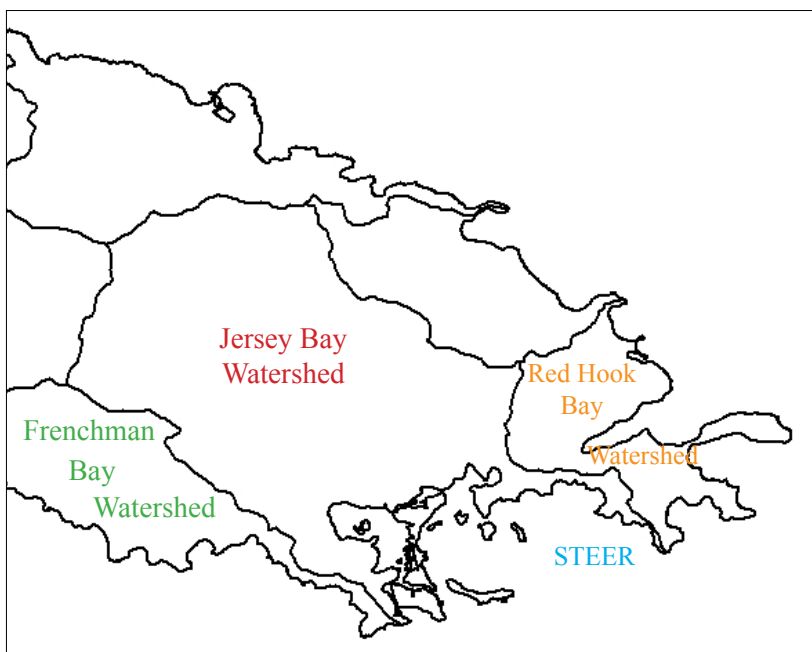


Figure 2. Primary watersheds adjacent to the STEER.

tive landfill, numerous marinas and boatyards, a number of resorts, various commercial/industrial activities, an EPA Superfund Site, a horse racetrack, and residential areas served by individual septic systems, some of which are likely failing (IRF, 1993). The EPA Superfund site (Tutu Wellfield Superfund Site) was established due to contamination of groundwater and wells in the area by chlorinated volatile organic compounds (CVOC) (EPA, 2011). All of these watershed activities have the potential to contribute both point and nonpoint source pollution to the STEER.

The area that borders the western side of Mangrove Lagoon contains the Bovoni Landfill, which serves not only all of

St. Thomas, but also receives solid waste from St. John. The landfill covers approximately 330 acres, with nearly 40 acres directly adjacent to Mangrove Lagoon (IRF, 1993). On the northern side of Mangrove Lagoon is the Clinton Phipps Racetrack. During construction of the racetrack, the mangrove delta draining Turpentine Gut, the only perennial stream on St. Thomas (Nemeth and Platenberg, 2007), was altered by filling and diverting the delta to form a single channel, resulting in additional sediment being deposited directly into Mangrove Lagoon rather than in the delta (STEER, 2011).

There are also numerous marinas in Benner Bay, serving both residents and transient boaters. There are significant residential areas in the Jersey Bay watershed and, along the north shore of Jersey and Cowpet Bays, a number of resorts/hotels, condominiums and yacht clubs.

Elevated levels of chemical contaminants have been documented in the STEER watershed (EPA, 2011). DPNR has said that the extent of chemical contamination and biological effects or bioeffects in the STEER are currently unknown, but that data on land-based sources of pollution are needed in order to make better informed decisions on coastal resource management. The quantification of sediment contaminants, toxicity, and the benthic infaunal community, along with the biological survey being conducted as part of this project, are helping to provide the data needed to optimize management of the STEER.

NOAA/NCCOS Involvement in the STEER

At the NOAA Coral Reef Ecosystem Integrated Observing System (CREIOS) Meeting in San Juan, Puerto Rico in 2009, NOAA scientists met with resource managers and local scientists from the U.S. Caribbean, including representatives from the Virgin Islands, to elicit priority information needs, and to highlight important issues of concern. At that meeting, representatives from DPNR's Divisions of Coastal Zone Management and Environmental Protection identified the STEER as a priority area, and noted that there were significant data and information gaps in terms of the chemical contaminants present, their concentrations, effects, and the overall health of the biological communities within the STEER.

With these needs in mind, NOAA's National Centers for Coastal Ocean Science (NCCOS), in partnership with the STEER Core Planning Group consisting of scientists and managers from DPNR's Divisions of Coastal Zone Management, Fish and Wildlife, and Environmental Protection, along with the University of the Virgin Islands, and The Nature Conservancy, proposed a multiyear project to

NOAA's Coral Reef Conservation Program (CRCP), to develop an integrated assessment of chemical and biological conditions within the STEER. In 2011, NCCOS scientists along with project partners collected sediments for chemical contaminant analysis, toxicity bioassays, and benthic infaunal analysis. As part of the work in Year 1, the University of the Virgin Islands also began monthly sampling for nutrients, and monthly monitoring of total suspended solids (TSS, a CRCP performance measure), and sedimentation, using sediment traps placed at five locations within the STEER. Passive water samplers, or POCIS, were also deployed in the same locations as the sediment traps. The passive water samplers are used to quantify the presence of wastewater contaminants in the water column. Activities in the second year included a biological survey of the entire STEER, along with the collection of coral and conch for chemical contaminant analysis, and the continued monthly monitoring of nutrients, TSS, and the sediment traps. The results of the Year 2 and other assessment activities (e.g., POCIS) will be included in additional project publications.

In another CRCP-funded project, the goal of which is to develop a watershed management plan for the STEER, a number of these and other watershed issues are being highlighted, along with opportunities, goals, and actions needed. Reducing the impacts from the landfill, along with the need for improving wastewater and storm water management, pollution prevention, and wetland restoration, are seen as key items for the STEER watershed restoration (Kitchell, 2012).

In addition to the chemical and biological analysis, NOAA's CRCP also funded an effort to develop a new high resolution map describing the distribution, quantity and type of seafloor habitats inside the STEER. This map is being developed from LiDAR (Light Detection and Ranging) bathymetry and reflectivity imagery collected by Fugro LADS and the U.S. Geological Survey. The new habitat map and related products will be used to update nautical charts in the area to: help fill critical information gaps about the seafloor in a priority area identified by NOAA's CRCP; support fisheries-related performance measures outlined in the USVI Jurisdictional Working Group Priority Settings document; and to support best management practices inside the STEER, related to permitting activities, restoration, fisheries, climate change and scientific research.

Sediment Quality Triad

This report covers the results of the chemical contaminant analysis in sediments, sediment bioassays, and benthic infaunal analysis from Year 1 of the project in the STEER. These three components make up what is referred to as

the Sediment Quality Triad (SQT). The SQT has been developed to assess the presence and impacts of chemical contaminants in benthic habitats (Chapman et al., 1987). Additional information on each of these three components follows.

Overview of the Chemical Contaminants. The quantification of chemical contaminants in sediments provides the opportunity for understanding what chemical stressors are present, their concentrations, how these concentrations compare to established sediment quality guidelines, along with providing input to the other two components of the triad. Each of the contaminant classes analyzed for this project are discussed below.

Polycyclic Aromatic Hydrocarbons. Also referred to as PAHs, polycyclic aromatic hydrocarbons are associated with the use and combustion of fossil fuels (e.g., oil and gas) and other organic materials (e.g., wood and trash). Natural sources of PAHs include forest fires, and the decay of vegetation. The PAHs analyzed are two to six ring aromatic compounds. An example of a three ring PAH (1-methylphenanthrene) is shown on the cover of this report. A number of PAHs bioaccumulate in aquatic and terrestrial organisms, are toxic, and some including benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenzo[a,h]anthracene, and indeno[1,2,3-c,d]pyrene, are likely carcinogens (USDHHS, 1995).

Aliphatic Hydrocarbons. In addition to the PAHs, another group of hydrocarbons, the aliphatics were analyzed in the sediments. Aliphatic hydrocarbons are straight chain or branched nonaromatic structures. Aliphatic hydrocarbons are often associated with uncombusted fuels such as gasoline, diesel or oil.

Polychlorinated Biphenyls. Commonly referred to as PCBs, polychlorinated biphenyls are synthetic compounds that have been used in numerous applications ranging from electrical transformers and capacitors, to hydraulic and heat transfer fluids, to pesticides and in paints. Approximately 60 percent of PCBs manufactured in the U.S. were used in electrical applications (EPA, 1997). PCBs have a biphenyl ring structure (two benzene rings with a carbon to carbon

bond) and a varying number of chlorine atoms. There are 209 PCB congeners possible.

PCBs were manufactured in the U.S. between 1929 and 1977. In the United States, all PCBs were produced by a single manufacturer, and the commercial products were referred to as Aroclors. Aroclors are mixtures of PCB congeners. The manufacture of PCBs in the U.S. was banned in 1979 due to their toxicity. Because PCBs bioaccumulate and degradation in the environment proceeds only slowly, they are now ubiquitous contaminants. Exposure to PCBs in fish has been linked to reduced growth, reproductive impairment and vertebral abnormalities (EPA, 1997).

Organochlorine Pesticides. Beginning in the 1950s and continuing in to the early 1970s, a series of chlorine containing hydrocarbon insecticides were used to control mosquitoes and agricultural pests. One of the best known

of the organochlorine pesticides was the insecticide DDT (dichlorodiphenyltrichloroethane).

The use of many of the organochlorine pesticides, including DDT, was banned due to their environmental persistence, potential to bioaccumulate, and especially the chronic (i.e., longer-term) effects on nontarget organisms. Organochlorine pesticides are typically neurotoxins, and DDT along with PCBs have also been shown to interfere with the endocrine system. DDT and its metabolite DDE, for example, were specifically linked to eggshell thinning in birds, particularly raptors, but also in pelicans. A number of organochlorine pesticides are toxic to nontarget aquatic life as well, including crayfish, shrimp and some species of fish. While DDT was banned by the EPA for most uses in the U.S. in 1972, it is still effectively used in some developing countries, particularly on the inside of living areas to help control mosquitos that can transmit malaria.

Most uses of the organochlorine insecticide chlordane were canceled in 1978, and all uses were canceled by 1988. A primary non-agricultural use of chlordane was in the treatment of wooden structures to prevent damage by termites.

Because of their persistence and heavy use in the past, residues of organochlorine pesticides can also be found in the environment, including in biota. The persistence of these



The Bovoni Landfill on the western end of the STEER receives solid waste from both St. Thomas and St. John.

compounds and toxicity to nontarget organisms continues to be an environmental concern.

Butyltins. This compound class has a range of uses, from biocides to catalysts to glass coatings. In the 1950s, tributyltin, or TBT, was first shown to have biocidal properties (Bennett, 1996). In the late 1960s, TBT was incorporated into an antifoulant paint system, quickly becoming one of the most effective paints ever used on boat hulls (Birch-enough et al., 2002). TBT was incorporated into a polymer paint system that released the biocide at a constant and minimal rate, to control fouling organisms such as barnacles, mussels, weeds, and algae (Bennett, 1996).

TBT was linked to endocrine disruption, specifically an imposex (females developing male characteristics) condition in marine gastropods, and in other mollusks (e.g., oysters), abnormal shell development, and poor weight gain (Batley, 1996). Beginning in 1989, the use of TBT as an antifouling agent was banned in the U.S. on non-aluminum vessels smaller than 25 meters in length (Gibbs and Bryan, 1996). In a survey of TBT in the USVI, Strand et al. (2009) found evidence of elevated levels of TBT and its degradation products in gastropod species, as well as imposex organisms at several locations, including the harbor in Charlotte Amalie Bay, St. Thomas.

In the aquatic environment, TBT is degraded by microorganisms and sunlight (Bennett, 1996). The transformation involves sequential debutylization resulting in dibutyltin, monobutyltin, and finally inorganic tin (Batley, 1996).

Major and Trace Elements. All of the major and trace elements occur naturally to some extent in the environment. Aluminum, iron, and silicon are major elements in the Earth's crust. As their name implies, trace elements occur at lower concentrations in crustal material, however, mining and manufacturing processes along with the use and disposal of products containing trace elements can lead to elevated concentrations in the environment.

A number of trace elements are toxic at low concentrations. Cadmium, used in metal plating and solders, has been shown to impair development and reproduction in several invertebrate species, and osmoregulation in herring larvae (USDHHS, 1999; Eisler, 1985). Mercury is volatile

and can enter the atmosphere through processes including mining, manufacturing, combustion of coal and volcanic eruptions (Eisler, 1987). Mercury is currently used in compact and other fluorescent light bulbs, electrical switches and relays, thermostats and in some dental amalgams. Effects of mercury on copepods include reduced growth and rates of reproduction (Eisler, 1987). Chromium has been shown to reduce survival and fecundity in the cladoceran *Daphnia magna*, and reduced growth in fingerling chinook salmon (*Oncorhynchus tshawytscha*) (Eisler, 1986). Copper has a number of uses, such as in antifouling paints for boats, wood preservatives, heat exchangers in power plants, electrical wires, coinage, and in agricultural fungicides. While an essential biological element, elevated levels of copper can impact aquatic organisms, including the functioning of gills along with reproduction and development (Eisler, 1998).

Most of the current uses of lead appear to be in lead-acid batteries, although other uses include oxides in glass and ceramics. In the past, lead was used in paints and also in gasoline, however, these uses have ended due to environmental and human health concerns. Nickel has many applications in both industrial and consumer products. Approximately 65% of the nickel in the U.S. is used to make stainless steel. Other uses include its incorporation into a series of alloys, in rechargeable batteries (Ni-Cd), catalysts, coins, plating, and in foundry products. Corrosion-resistant zinc plating of steel (hot-dip galvanization) is an important application, accounting for roughly 50% of zinc use. In the marine industry, zinc anodes are used to protect vital engine and boat parts (e.g., propellers, struts, rudders, and outboard and inboard engines), and is a component in some antifoulant paint formulations. Zinc is also used in batteries, and in alloys such as brass.

Bacterial Indicator. Although not a chemical contaminant, the bacterium *Clostridium perfringens* has been used as an indicator of fecal pollution and was analyzed in the sediment samples from the STEER. This bacterium occurs in the intestines of humans and in some domestic and feral animals, and is a common cause of food poisoning.

Sediment Toxicity Tests. NOAA's NCCOS, National Status and Trends Bioeffects Program routinely uses a suite of tests to assess sediment toxicity through different modes of contaminant exposure (bulk sediment, sediment porewater,



Marina area in Benner Bay.

and chemical extracts of contaminants from sediment) to a variety of species (invertebrates, vertebrate cells and bacteria) and different assessment end-points (i.e., mortality, impaired reproduction, physiological stress, and enzymatic response).

Since the test results are not necessarily axiomatic and biological effects of contaminants occur at different levels of biological organization, i.e., from cells to ecosystems, results from a suite of toxicity tests are used in the “weight of evidence” context to infer the incidence and severity of environmental toxicity (Chapman, 1996). The toxicity bioassays used in this project included amphipod (*Ampelisca abdita*) mortality, sea urchin (*Arbacia punctulata*) fertilization impairment, and cytochrome P450 Human Reporter Gene System (HRGS).

Benthic Infaunal Analysis. Mixtures of synthetic organic compounds (e.g., PCBs and DDT), metals, PAHs, excess nutrients, and various inorganic chemicals are released into the ocean from municipal and industrial point sources, atmospheric deposition, stormwater runoff, spills, and groundwater. These anthropogenic contaminants may accumulate in the sediment in coastal bays, estuaries, and nearshore coastal zones.

Two of the most influential parameters in the distribution of benthic communities are salinity and sediment grain size. Environmental concentrations of organic enrichment and toxicants are often confounded in space and time with gradients of salinity and grain size, making their separate and combined biological effects difficult to detect, especially at the levels of population and community. However, understanding toxic hazard due to sediment contamination by means of community assessment is valuable. Biological systems integrate the complexity of natural habitat stressors and ambient pollutant mixtures, through physical contact with sediments, ingestion of sediment, and the bioaccumulation of contaminants via food webs, along with the synergetic effects of exposure to multiple toxic chemicals.

Many examples exist in which marine benthic communities’ response to contaminant and physical stressors have been documented (Hartwell and Claflin, 2005; Hartwell and Hameedi, 2007; Hartwell et al., 2009; Oliver et al., 2011; Wlodarska-Kowalczyk et al., 2005). Impacts of contamination on marine benthos have shown that total biomass, relative proportion of deposit feeders, and abundance of species with ‘opportunistic’ life histories (e.g. high fecundity, short generation time, and rapid dispersal) increase with increasing organic enrichment. Some opportunistic taxonomic groups are known to be tolerant of

chemical toxicants. Others are capable of thriving in physically disturbed habitats (e.g. high sedimentation, dredging operations, etc), but not necessarily in contaminated areas.

In areas impacted by excessive sedimentation from terrestrial runoff, dominant organisms tend toward surface suspension feeding modes and high reproductive potential regardless of taxonomic relationship, whereas away from the sedimentation stress, feeding modes shift to species that are deep deposit feeders along with the emergence of filter feeders. Experimental manipulation of habitats have shown that polychaete worms, in specific taxonomic lines, with opportunistic life history strategies respond positively to organic enrichment (Fleeger et al., 2003). Infaunal arthropods respond negatively to toxicants and organic enrichment. The response of specific arthropod and echinoderm species to organic and toxic contamination is mediated by life history and feeding mode characteristics. These observations have direct relevance to coral reef condition assessment. Finally, the benthic community will respond to management actions that affect physical and chemical stressors in vastly shorter time frames than will coral reefs.

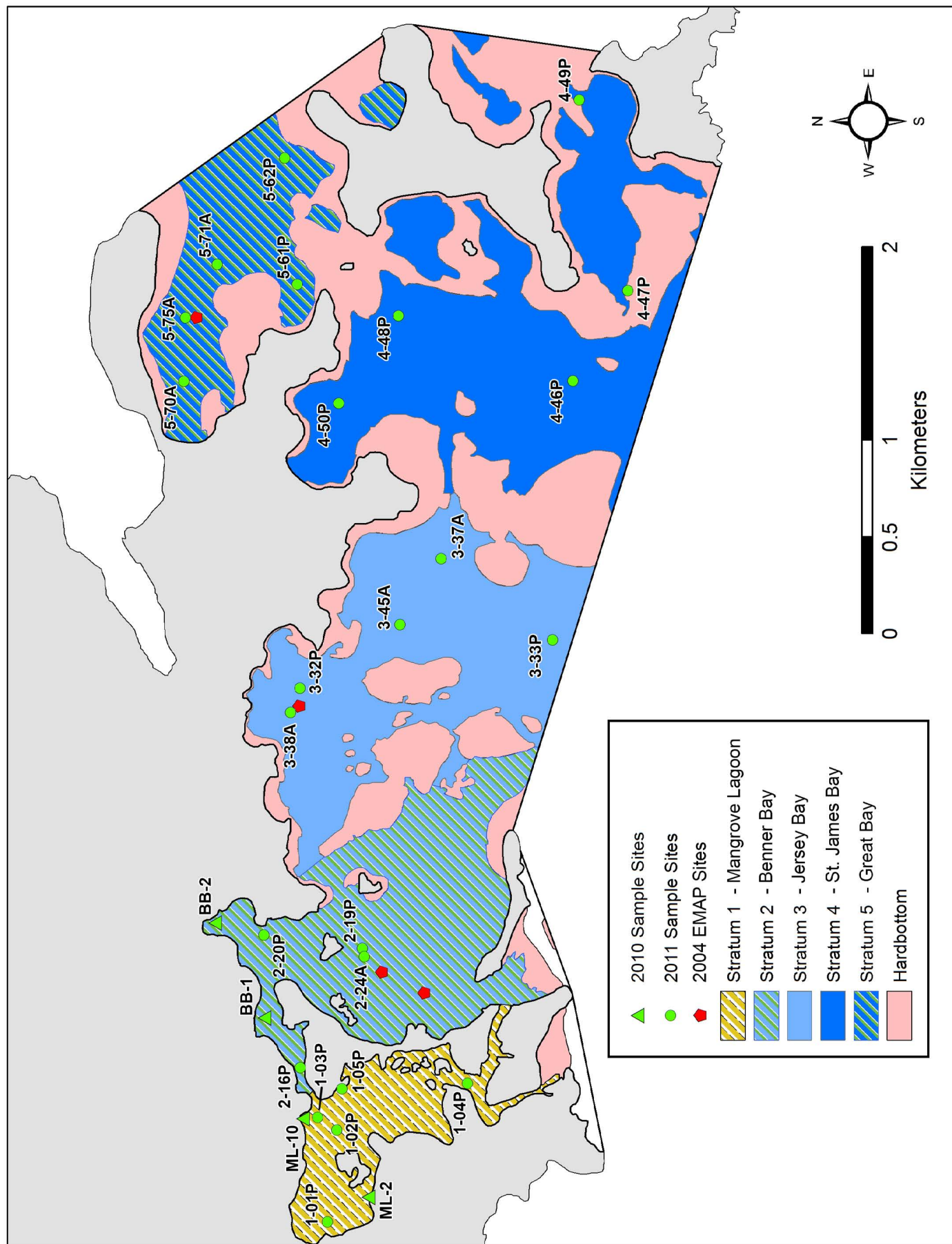
Materials and Methods

The sampling strategy for sediments was developed in meetings with the STEER Core Planning Group. A stratified random sampling design was selected, which is a standard benthic assessment technique. The STEER was first subdivided into five strata based on habitat and geography (e.g., hard bottom areas, seagrass beds, mangroves, etc) (Figure 3). Five sampling points on soft bottom sediments were then randomly selected using ArcGIS®. Both primary and alternate sites were identified throughout the STEER. Alternate sites were sampled in the event that a primary site was unsuitable due to hard bottom, obstructions, etc.

The stratified random sampling design was used in order to characterize the spatial distribution of chemical contaminants, toxicity and the benthic infaunal community throughout the STEER. Using this design, the extent and concentration of chemical contaminants and bioeffects can be compared between strata. The 2011 collection of sediment samples in the STEER occurred 14 - 17 June. The samples were collected under DPNR Permit STX-032-11.

All sediment sites were located using a GPS programmed with the site coordinates. Most of the sediment samples were collected from the charter vessel *Bright Star*. Mangrove Lagoon, however, was too shallow for the *Bright Star*. To enable the collection of samples in that stratum, personnel from the DPNR Division of Fish and Wildlife

Figure 3. Strata and sediment sites sampled in the St. Thomas East End Reserves (STEER) in June 2011.



brought in a shallow draft motor boat to help NOAA personnel collect the sediment samples in Mangrove Lagoon.

In addition to the work in 2011, preliminary field work took place in May 2010. From that effort, a total of 13 sediment samples were taken, and enough funding was available at the time to analyze four of the samples collected. The results of the analysis of these samples is also included in this report. However, as the four samples were collected from targeted sites and were not selected randomly, they could not be included in the statistical comparisons between strata, nor were they included in the calculation of the mean (average) concentration of sediment contaminants in the STEER.

Samples for Chemical Contaminant Analysis

The sediments for chemical contaminant analysis were collected using standard NOAA National Status and Trends (NS&T) protocols (Apeti et al., 2012a). The NS&T Program within NCCOS monitors the Nation's estuarine and coastal waters for contaminants in bivalve mollusk tissues and sediments, and toxicity or bioeffects in sediments.



The PONAR grab used to take sediment samples in the STEER.

Sampling Protocols. A PONAR grab (see inset) was deployed to collect the samples using a pulley and davit, and retrieved by hand. Rocks and bits of seagrass were removed. If a particular grab did not result in 200-300 g of sediment, a second grab was made and composited with material from the first. If enough sediment had not been collected after three deployments of the grab, the site was abandoned and the boat moved on to an alternate site.

A series of protocols (Apeti et al., 2012a) were used to avoid contamination of the sediment samples by equipment and cross contamination between samples and sites. All equipment was rinsed with acetone and then distilled water just prior to use at a site. Personnel handling the samples also wore disposable nitrile gloves. The top 3 cm of sediment were collected from the grab using a stainless steel sediment scoop. This top layer of sediment is referred to as surficial sediment, and is typically indicative of recent deposition.

Sediments were placed into two certified clean (I-Chem®) 250 ml labeled jars, one for organic chemical analysis, the other for major and trace element analysis, capped and then

placed on ice in a cooler. Sediments for grain size analysis were placed in a WhirlPack® bag, sealed and placed on ice in a cooler. At the end of each day, sediment samples for contaminant analysis were placed in a freezer. The WhirlPack® bags for the grain size analysis were placed in a refrigerator rather than frozen, to avoid altering the grain size structure of the sediment.

A series of water parameters (dissolved oxygen, temperature, salinity, and conductivity) were also measured at each site, using a YSI® salinity/conductivity/temperature meter. The instrument probe was submerged to a depth of approximately 0.5 meter (m) for the surface measurement, and within a meter of the sediment for the bottom measurement. Secchi depth was also measured at each site.

The sediment samples collected were analyzed for a suite of 185 organic (e.g., hydrocarbons and pesticides) and inorganic (e.g., metals) contaminants by TDI-Brooks International, using protocols established by the NS&T Program. The list of chemical contaminants analyzed in the sediments is shown in Table 1. The 59 polycyclic aromatic hydrocarbons (PAHs) were analyzed using gas chromatography/mass spectrometry in the selected ion monitoring mode. The 37 aliphatic hydrocarbons were analyzed by gas chromatography/flame ionization detection. The 31 organochlorine pesticides and 38 polychlorinated biphenyls (PCBs) were analyzed using gas chromatography/electron capture detection. The four butyltins were analyzed using gas chromatography/flame photometric detection after derivatization. A subset of the sediment samples were subsequently reanalyzed using gas chromatography/mass spectrometry for confirmation of the TBT concentrations detected at certain sites from the initial analysis. The major and trace elements were analyzed using inductively coupled plasma mass spectrometry and atomic-fluorescence spectroscopy. Detailed descriptions of the NS&T protocols, including quality assurance/quality control (QA/QC) used in the analysis of the organic contaminants, can be found in Kimbrough et al. (2006); for inorganic analyses, Kimbrough and Lauenstein (2006).

Statistical Analysis. The sediment contaminant data were analyzed using JMP® statistical software. A Shapiro-Wilk test was first run on individual parameters to see if the data were normally distributed. When data were normally distributed, an Analysis of Variance (ANOVA) was run followed by pairwise (Tukey HSD) comparisons. If the

Table 1. Compounds analyzed in sediments from the St. Thomas East End Reserves.

PAHs - Low MW	PAHs - High MW	Aliphatics	Organochlorine Pesticides	PCBs	Major and Trace Elements
Naphthalene	Fluoranthene	n-C9	Aldrin	PCB8/5	Aluminum (Al)
1-Methylnaphthalene	Pyrene	n-C10	Dieldrin	PCB18	Antimony (Sb)
2-Methylnaphthalene	C1-Fluoranthenes/Pyrenes	n-C11	Endrin	PCB28	Arsenic (As)
2,6-Dimethylnaphthalene	C2-Fluoranthenes/Pyrenes	n-C12	Heptachlor	PCB29	Cadmium (Cd)
1,6,7-Trimethylnaphthalene	C3-Fluoranthenes/Pyrenes	n-C13	Heptachlor-Epoxide	PCB31	Calcium (Ca)
C1-Naphthalenes	Naphthobenzothiophene	i-C15	Oxychlordane	PCB44	Chromium (Cr)
C2-Naphthalenes	C1-Naphthobenzothiophenes	n-C14	Alpha-Chlordane	PCB45	Copper (Cu)
C3-Naphthalenes	C2-Naphthobenzothiophenes	i-C16	Gamma-Chlordane	PCB49	Iron (Fe)
C4-Naphthalenes	C3-Naphthobenzothiophenes	n-C15	Trans-Nonachlor	PCB52	Lead (Pb)
Benzothiophene	Benz[a]anthracene	n-C16	Cis-Nonachlor	PCB56/60	Manganese (Mn)
C1-Benzothiophenes	Chrysene	i-C18	Alpha-HCH	PCB66	Mercury (Hg)
C2-Benzothiophenes	C1-Chrysenes	n-C17	Beta-HCH	PCB70	Nickel (Ni)
C3-Benzothiophenes	C2-Chrysenes	Pristane	Delta-HCH	PCB74/61	Selenium (Se)
Biphenyl	C3-Chrysenes	n-C18	Gamma-HCH	PCB87/115	Silicon (Si)
Acenaphthylene	C4-Chrysenes	Phytane	DDMU	PCB95	Silver (Ag)
Acenaphthene	Benzo[b]fluoranthene	n-C19	2,4'-DDD	PCB99	Tin (Sn)
Dibenzofuran	Benzo[k]fluoranthene	n-C20	4,4'-DDD	PCB101/90	Zinc (Zn)
Fluorene	Benzo[e]pyrene	n-C21	2,4'-DDE	PCB105	
C1-Fluorenes	Benzo[a]pyrene	n-C22	4,4'-DDE	PCB110/77	
C2-Fluorenes	Perylene	n-C23	2,4'-DDT	PCB118	
C3-Fluorenes	Indeno[1,2,3-c,d]pyrene	n-C24	4,4'-DDT	PCB128	
Carbazole	Dibenzo[a,h]anthracene	n-C25	1,2,3,4-Tetrachlorobenzene	PCB138/160	
Anthracene	C1-Dibenzo[a,h]anthracenes	n-C26	1,2,4,5-Tetrachlorobenzene	PCB146	
Phenanthrene	C2-Dibenzo[a,h]anthracenes	n-C27	Hexachlorobenzene	PCB149/123	
1-Methylphenanthrene	C3-Dibenzo[a,h]anthracenes	n-C28	Pentachloroanisole	PCB151	
C1-Phenanthrene/Anthracenes	Benzo[g,h,i]perylene	n-C29	Pentachlorobenzene	PCB153/132	
C2-Phenanthrene/Anthracenes		n-C30	Endosulfan II	PCB156/171/202	
C3-Phenanthrene/Anthracenes		n-C31	Endosulfan I	PCB158	
C4-Phenanthrene/Anthracenes		n-C32	Endosulfan Sulfate	PCB170/190	
Dibenzothiophene		n-C33	Mirex	PCB174	
C1-Dibenzothiophenes		n-C34	Chlorpyrifos	PCB180	
C2-Dibenzothiophenes		n-C35		PCB183	
C3-Dibenzothiophenes		n-C36	Butyltin	PCB187	
		n-C37	Monobutyltin	PCB194	
		n-C38	Dibutyltin	PCB195/208	
		n-C39	Tributyltin	PCB201/157/173	
		n-C40	Tetrabutyltin	PCB206	
				PCB209	

Abbreviations: MW, molecular weight; PAH, polycyclic aromatic hydrocarbon; HCH, hexachlorocyclohexane; DDMU, 1-chloro-2,2-(p-chlorophenyl)ethylene; DDT, dichlorodiphenyl-trichloroethane; DDE, dichlorodiphenyldichloroethylene; PCB, polychlorinated biphenyl

data were not normally distributed and a log₁₀ transformation was not effective, Spearman's nonparametric multivariate correlation was used. Some of the data were also subsequently ranked, followed by a Kruskal-Wallis test and pairwise comparisons. The statistical analyses were used, for example, to compare differences in contaminant levels between strata.

NOAA numerical sediment quality guidelines (SQG) developed by Long and Morgan (1990) and Long et al. (1995), known as ERM (Effects Range-Median), and ERL (Effects Range-Low), express statistically derived levels of contamination, above which toxic effects would be expected to be observed with at least a 50% frequency (ERM), and below which effects were rarely (<10 %) expected (ERL). The ratio of the ERM value to the sediment concentration for each chemical is called the ERM quotient or ERM_q (Long et al., 1998). The quotient expresses how close measured concentrations are to the ERM level on a zero to one scale. A quotient of one or greater means the concentrations are at or above the ERM. This also normalizes the ERMs for different chemicals to a common scale. The mean ERM_q of all the contaminants averaged together expresses a measure of contamination across the entire spectrum of measured contaminants. Field research suggests that a mean ERM_q value of 0.1 is a threshold where degraded communities begin to be seen, as observed in the southeast U.S. (Hyland et al., 1999). The mean quotient of the ERMs and observed contaminant concentrations were calculated on a site by site basis.

Samples for Sediment Toxicity Bioassays

The protocols for the bioassays were based on standard methods, as outlined by the U.S. EPA (1999, 2002a) and ASTM (2008). Sediment samples for the bioassays were collected into three containers. Samples for the amphipod toxicity tests (bulk sediment) were collected in 1 liter (L) jars; for the sea urchin fertilization tests (porewater extraction), a 3.79 liter (one gallon) sample of sediment was collected; and for the P450 test, a sample of sediment was taken out of the 250 ml organics jar and extracted.

Amphipod Toxicity Test. The whole sediment toxicity bioassay test is commonly used in North America for assessing sediment quality, in part because the test integrates the effects of complex contaminant mixtures in relatively unaltered sediment, and also because amphipods are fairly common and an ecologically important species in coastal waters. The organisms are standard test species with known ranges of sensitivity and their presence or absence in a particular habitat is not relevant because they are tested under standardized conditions. Results of increased mortal-

ity, which is significantly different from controls, is considered an indicator of marginal toxicity. Results that are significantly different from controls and greater than 20% mortality is indicative of highly toxic conditions (Thursby et al., 1997).

Sea Urchin Fertilization Test. The sea urchin (*A. punctulata*) fertilization toxicity test (also known as the sperm cell test) involves exposing sea urchin sperm to sediment pore water (interstitial water), followed by the addition of eggs. This test is used extensively in assessments of ambient water quality, toxicity of industrial and municipal effluents, and sediment toxicity in coastal waters. It combines the features of testing sediment pore waters (the phase of sediments in which dissolved toxicants may be bioavailable) and exposures of gametes which often are more sensitive than adult organisms. Increased fertilization failure which is significantly different from controls is considered symptomatic of marginal toxicity. Results that are significantly different from controls and greater than 20% below control fertilization is indicative of highly toxic conditions (Carr and Bidenbach, 1999).

P450 Test. The HRGS P450 test was used to determine the presence of toxic organic compounds in the sediments. Cytochrome P450s are a family of membrane-bound enzymes that metabolize a diverse number of compounds, including natural substrates, drugs, hormones, and many toxic compounds. They are present in a wide variety of animals, plants and other organisms. P450 is shorthand for Pigment and 450 is the wavelength at which they most strongly absorb light. HRGS stands for Human Reporter Gene System. In this case, a reporter gene is a DNA sequence in a human cancer cell line that has been genetically engineered to include a gene (the reporter gene) from the firefly that produces luciferase, the chemical that produces light in the insect when presented with the proper substrate. The gene is spliced into the region of the DNA strand that is activated to produce P450 enzymes when the cell is exposed to chemicals that stimulate metabolic activity. The more stimulated the cell is to metabolize a foreign compound, the more the reporter gene produces luciferase, which can be measured by increased light output.

Different compounds stimulate P450 production to differing degrees, which can be calibrated. PCBs and PAHs stimulate certain Cytochrome P450 enzymes (e.g. CYP1A), but each individual compound exhibits its own level of stimulation. Heavy metals do not stimulate P450 at all. Under appropriate test conditions, induction of CYP1A is evidence that the cells have been exposed to one or more xenobiotic organic compounds, including dioxins, furans,

planar PCBs, and several PAHs. When run in parallel with a serial dilution of standard PAH toxicant benzo[a]pyrene (BaP), or TCDD (dioxin), test results can be expressed in terms of standard toxicant equivalents based on the relative reporter gene response. Samples that exhibited a response greater than 50% of a standard 10 nM TCDD threshold control were again tested against a B[a]P serial dilution to calculate responses normalized to the B[a]P EC50 (effective concentration for 50% of the test cells) or the B[a]P equivalents (B[a]P eq).

Anderson et al. (1999a) calculated the mean and 95% confidence interval of HRGS values from 527 sampling points in the NOAA biological effects database to be 22.7 ± 10.1 (CI=12.6-32.8) mg B[a]P Eq/kg. Hence, values less than 12.6, forming the tail of the distribution in the direction of low induction (or impact) could be interpreted as a minimal (background) level. This is consistent with data from pristine sites in Alaska and California where HRGS values did not exceed 10.4 mg B[a]P Eq/kg (Anderson et al., 1999b; Fairey et al., 1996). Fairey et al. (1996) also demonstrated that HRGS values above 60 mg B[a]P Eq/kg were highly correlated with degraded benthic communities in San Diego and Mission Bays, and with PAH concentrations above the 9,600 $\mu\text{g/kg}$ Probable Effects Level (PEL) guideline (MacDonald, 1993), which are similar to the ERLs. Based on these data, HRGS values greater than 10 and 60 mg B[a]P Eq/kg were considered to represent marginal and highly contaminated thresholds, respectively.

Differences in the ability of the P450 enzyme system to metabolize chlorinated and non-chlorinated compounds allows for differentiation between these classes of compounds in environmental samples. Since most PAHs are metabolized, they exhibit a maximum response in 6 hours, at which point the response begins to fade. Chlorinated hydrocarbons (dioxins, furans, and certain PCBs), on the other hand, are not degraded and continue to induce CYP1A, resulting in increasing responses after 24 hours following exposure.

Benthic Infaunal Analysis

A benthic community sample was taken with the PONAR grab sampler, in addition to the samples for chemical analysis and toxicity testing. The entire contents of an acceptable grab (at least 5 cm deep) was sieved on site through a 0.5 mm mesh. In coarse sediments, nested sieves of 1.0 mm and 0.5 mm were sometimes necessary to reduce clogging of the screens and damage to the organisms. All organisms were retained in plastic containers and preserved in buffered 10% formalin containing Rose Bengal stain and sodium borate buffer.

The following data and information were recorded at each site: stratum, site, alternate (if applicable), date, water depth, time, latitude, longitude, and depth of sediment in the grab. Also included was a written description of each sampling site including digital color photographs of the site, a physical description of sediment characteristics (texture, color, odor, benthos, sheen) and photographs of the undisturbed sediment.

In the laboratory, all animals were carefully segregated into major groups (e.g. worms, clams, shrimp and crabs). They were then identified to species unless the specimen was a juvenile or damaged. At a minimum, 10% of all samples were re-sorted and re-counted on a regular basis. Also, 10% of samples were randomly selected and re-identified. The minimum acceptable sorting and taxonomic efficiency was 95%. A voucher collection composed of representative individuals of each species encountered in the project was accumulated and retained.

The benthic communities were characterized by abundance (number of animals), number of species, and diversity (a type of ratio of abundance and number of species). Abundance was calculated as the total number of individuals per grab; species richness as the total number of species represented at a given site; and diversity was calculated with the Shannon-Weiner Index (Shannon and Weaver, 1949), using the following formula:

$$H' = -\sum_{i=1}^S p_i (\ln p_i)$$

where, S = is the number of species in the sample, i is the ith species in the sample, and p_i is the number of individuals of the ith species divided by the total number of individuals in the sample.

Nonparametric Spearman rank correlation coefficients were calculated for all parameters to assess relationships between the physical, chemical, toxicological and biological variables. Multivariate cluster analysis was employed to group site and species data. The objective was to produce a coherent pattern of association between sites and species (Figure 4). Cluster analysis is a two-step process including: 1) creation of a resemblance data matrix from the raw data, and 2) clustering the resemblance coefficients in the matrix. The input resemblance (similarity or dissimilarity) matrix can be created by a number of methods. Input data may or may not be standardized or transformed depending on the requirements of the method (e.g. Bray Curtis). Based on previous research (Hartwell and Claffin, 2005), the Jaccard method (Goodall, 1973) was used to generate the similarity

matrix. The Jaccard method is a binary method based only on presence/absence data, and thus ignores abundance values.

Cluster analyses were calculated from the matrices using the Unweighted Pair-Group Method Using Arithmetic Averages (UP-GMA) procedure which clusters coefficients based on arithmetic mean distance calculations (Sneath and Sokal, 1973). To optimize the cluster analysis results, several manipulations of the input data were performed to remove confounding effects and bias:

1- Epibenthic species, such as sea anemones and tunicates, were eliminated from the data set as they are not truly infauna.

2- 'Artificial species' (resulting from failure to identify some specimens all the way down to species) were identified as a data bias. For example, if specimens of two to three species were identified in genus A, and other specimens were identified only to genus A, this tends to artificially increase species richness and diversity of the sample when in fact that diversity is an artifact of imperfect taxonomic identification. In some instances, specimens were only identifiable to family, order or class. To address this problem, specimens not identified to species level were eliminated, unless they were identified to a taxonomic level below which no other specimens in the collection belonged. That is, even though they were not identified to species, they were the only representative of that taxonomic line and did represent a non-redundant taxon. In other cases,

where a specimen was identified to genus and there was only one species identified in that genus, they were combined at the genus level.

3- Rare and unique species were defined as those species that were found at no more than two sites. Although they

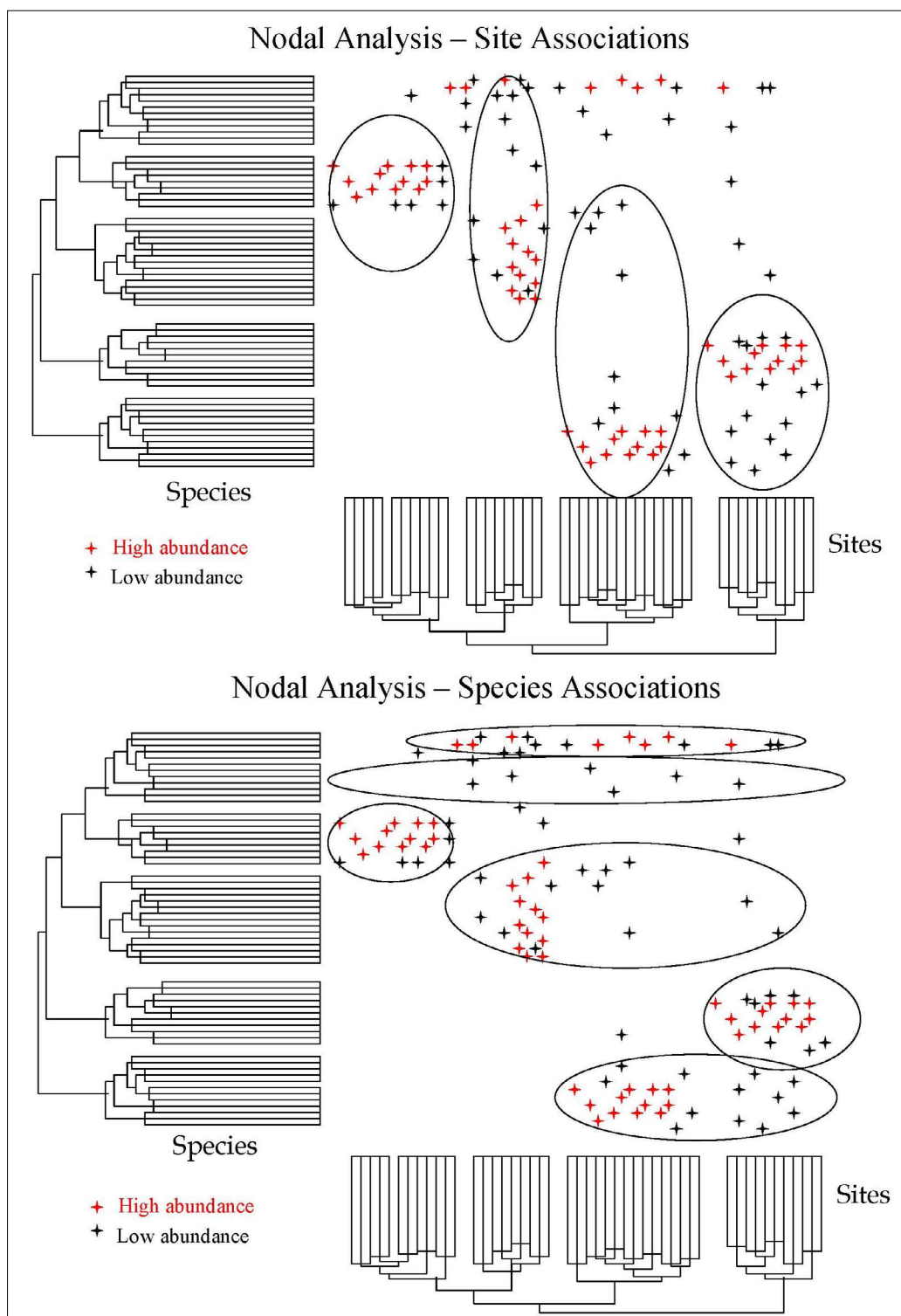


Figure 4. Combined cluster analysis overlays of species clusters and site clusters. The top figure illustrates the dominant species communities found in different site clusters. The lower figure illustrates how different species assemblages distribute themselves between different habitats.

do contribute to the overall assessment of biodiversity, they were eliminated from the cluster analysis data set. Because of their limited distribution, by definition, they do not provide information on the impact of contaminant or other stressor gradients in the environment because they do not occur across a gradient.

After the data set had been finalized, a nodal analysis routine was applied to the data (Lambert and Williams, 1962).

This consisted of combining independent cluster analyses in a graphical array. The first analysis clustered sites using species occurrence data. The second calculation clustered species together into groups. The intersection of site clusters on the abscissa and species clusters on the ordinate axis yields a pattern of species associations with site clusters, termed nodes (Figure 4). In practice, this is done on large 3ft x 4ft plots of the cluster analysis output. Reduction to normal text page size sacrifices a significant

amount of detail. The site and species clusters were also characterized by physicochemical habitat parameters, contaminant concentrations, and other site-specific data. Plotting the tabulated values in parallel to the cluster output (Figure 5), allows an empirical evaluation of similarities in habitat characteristics within and between species and site clusters (i.e., what they do or do not have in common) to guide interpretation of subsequent statistical contrasts. For each species, the parameters were normalized to their abundance at each site.

Once the nodes were defined, the species data within each node were further assessed with methods developed by Clark and Warwick (2001) to assess the relative importance of a species in characterizing a set of sites in a quantitative way, called a Similarity Index. Average similarity for a species is the contribution of the species to the Bray-Curtis

similarity within a site group (node). This value indicates how typical the species is for the group of sites and ranges from 0 to 100%.

Results and Discussion

Field Data

The collection of 25 sediment samples was planned for the June 2011 sampling mission. Twenty-nine sites were visited, however, at five sites the field team was unsuccessful

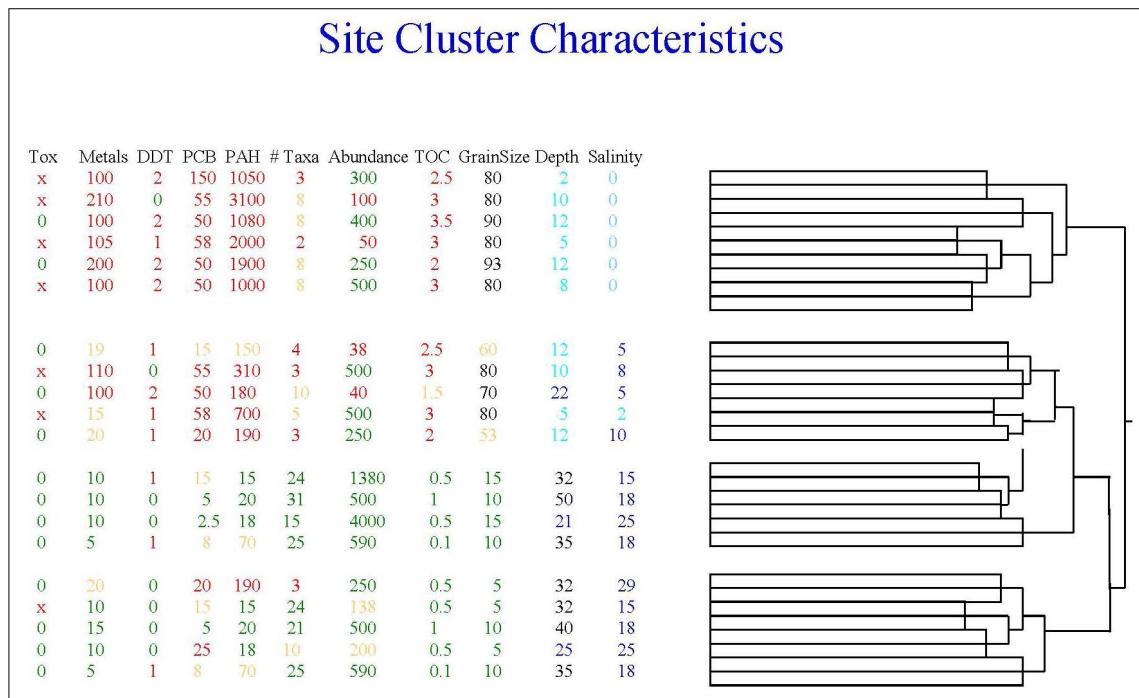


Figure 5. Hypothetical representation of the distribution of physicochemical habitat parameters, contaminant concentrations, and other site-specific data used to characterize site and species clusters.

ful in collecting sediments, resulting in sediment samples from 24 sites.

The average water depth at the sites sampled was 7.2 meters (m). As might be expected, the shallowest water depth was 0.6 m at Site 1-5P in Mangrove Lagoon. The average salinity encountered on the surface of the sites was 33.2‰, the average bottom salinity 33.7‰, indicating fairly well mixed waters. The highest salinity encountered during the mission was 34.6‰, a bottom salinity reading taken at Site 5-61P; the lowest salinity encountered (28.3‰) was in Mangrove Lagoon on the surface at Site 1-1P. Site specific data can be found in Appendix A.

The average water surface temperature at the sites in the STEER was 30.1°C, the average bottom temperature was 29.5°C. A Kruskal-Wallis test run on the ranked data indi-

cated that salinity ($p < 0.0001$) and temperature ($p < 0.0001$) varied significantly by stratum, with lower salinities and higher temperatures being found in Strata 1 and 2.

Total Organic Carbon and Grain Size

The average percent total organic carbon (TOC) in the sediments collected was 2.49%, and ranged from a low of 0.44% to a high of 5.44% (Appendix B). A Kruskal-Wallis test run on the ranked TOC values indicated no differences in percent TOC in the STEER by stratum ($p = 0.0645$).

Chemical contaminants, particularly organic (carbon-containing) contaminants, tend to accumulate in sediments with higher TOC values. Chemical contaminants also tend to accumulate in sediments that have a higher proportion of the smaller grain sizes (i.e., silt and clay). Smaller grain size sediments have more surface area per unit volume available for the adsorption of contaminants, and are typically found in depositional habitats. In addition, metals are attracted to sediments with higher clay content due to the charge structure on the surface of the clay particles.

For this report, the percent silt and percent clay fractions are combined and referred to as percent fines (sum of percent silt and percent clay sediment fractions). Figure 6 shows the percent fines in the sediments sampled in the STEER; the average content was $22.3 \pm 4.03\%$. It can be seen that areas in Mangrove Lagoon and, to a certain extent in Benner Bay, had a higher proportion of percent fines in the sediments. However, the major sediment size class in the STEER was sand ($68 \pm 4.35\%$).

Chemical Contaminants

The results from the analysis of each chemical contaminant class are discussed below. More detailed information

can be found in Appendices C-H. Each of the chemical contaminants, along with the bacterial measurement, are discussed below.

Polycyclic Aromatic Hydrocarbons. Total PAHs as used in this report refers to the sum of the 59 PAH compounds and compound classes (e.g., anthracene, C1-naphthalenes)

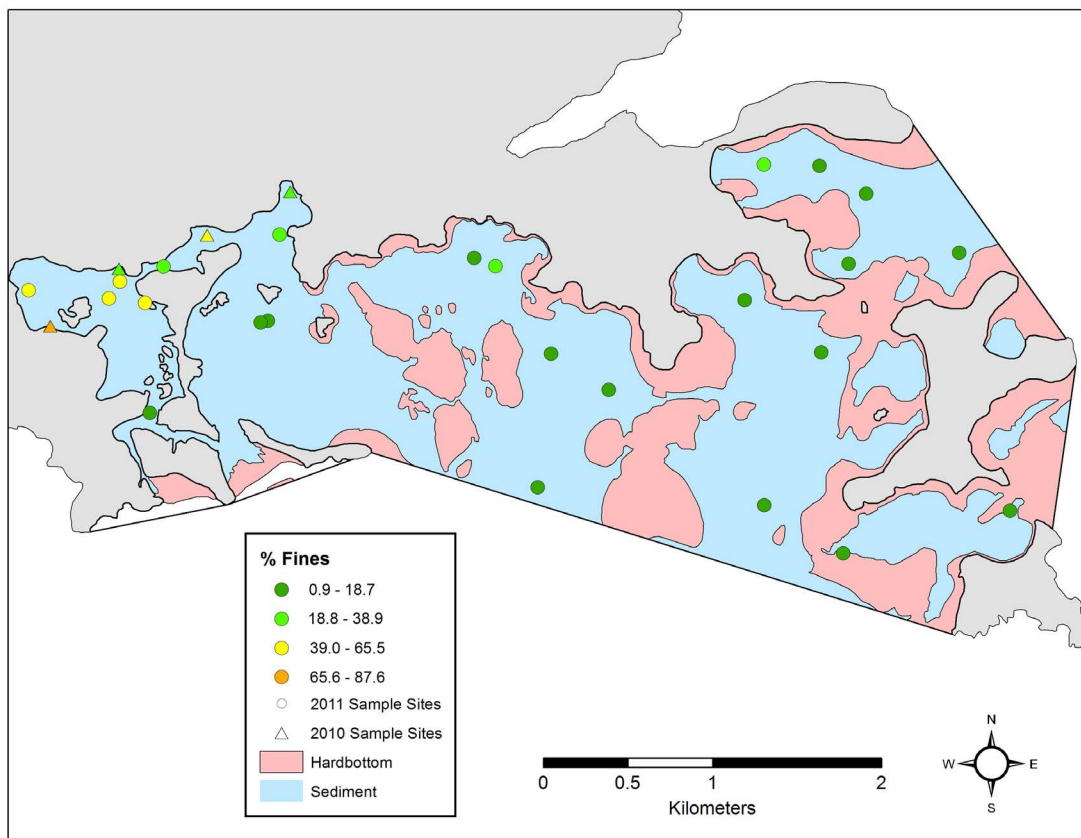


Figure 6. Percent fines (percent silt plus percent clay fractions) in sediments from the STEER.

analyzed in the STEER sediment samples. Appendix C contains detailed results of this analysis. A map summarizing total PAHs in the sediments is shown in Figure 7. It can be seen that there were a number of higher PAH concentrations, mainly in Mangrove Lagoon and Benner Bay, as opposed to the other strata and sites further offshore. As will be seen, the pattern of higher concentrations of chemical contaminants in the Mangrove Lagoon and northern Benner Bay areas was repeated for a number of the other contaminant classes analyzed.

The mean concentration in the sediment from the STEER was 142 ± 58 ng/g. The units ng/g (nanogram/gram) are also referred to as parts per billion (ppb). The median total PAH concentration was 6.02 ng/g. The highest total PAH concentration was at site 1-3P, with 1,131 ng/g. In Man-

grove Lagoon, the mean concentration of total PAHs in the sediments was 425 ± 214 ng/g, with the standard error indicating a wide range in the concentrations in this stratum (Stratum 1). The lowest concentration of total PAHs was found in Stratum 4, at site 4-49P (0.93 ng/g) near St. James Island. From the preliminary sampling for this project in 2010, the highest concentration of total PAHs was found at the ML-10 site in Mangrove Lagoon, at 951 ng/g (Appendix C).

Variation of Total PAHs Across Strata. A Kruskal-Wallis test run on the ranked data indicated a significant difference in total PAHs by stratum ($p = 0.0210$). A Tukey's HSD (Highly Significant Difference) analysis indicated that only Stratum 1 and Stratum 4 were significantly different, due in part to the large standard errors in total PAHs within each stratum. Note that the targeted samples collected in 2010 were not included in the statistical analysis by stratum.

Comparison with Other Data. EPA's Environmental Monitoring and Assessment Program (EMAP) was developed to monitor and assess the status and trends in national ecological resources (EPA, 2000). In 2004, sediment samples were collected and analyzed by EMAP at a number of locations around St. Thomas. Four of those sites were in the STEER; two sites were in Benner Bay, and one site each in Jersey Bay and Great Bay. The four EMAP sites are also included in Figure 3. A suite of 23 PAHs were analyzed in the sediments at each site. The detection limit for each PAH analyzed by EMAP was 10 ng/g. None of the sediments sampled within the STEER boundaries by EPA's EMAP had a detectable level of the PAHs analyzed.

Recent chemical contaminant studies have also been conducted in Puerto Rico and can be used to compare with the results found in the STEER. In Vieques, Puerto Rico, the mean concentration of total PAHs was 52.3 ± 8.7 ng/g,

somewhat below total PAHs found in the STEER sediments (Pait et al., 2010). In southwest Puerto Rico, Pait et al. (2008) reported a mean total PAH concentration in the sediments of 80.6 ± 25.5 ng/g, also lower than the mean found in the STEER.

Because of the national-level contaminant monitoring carried out by NOAA's NS&T Program, data from the STEER

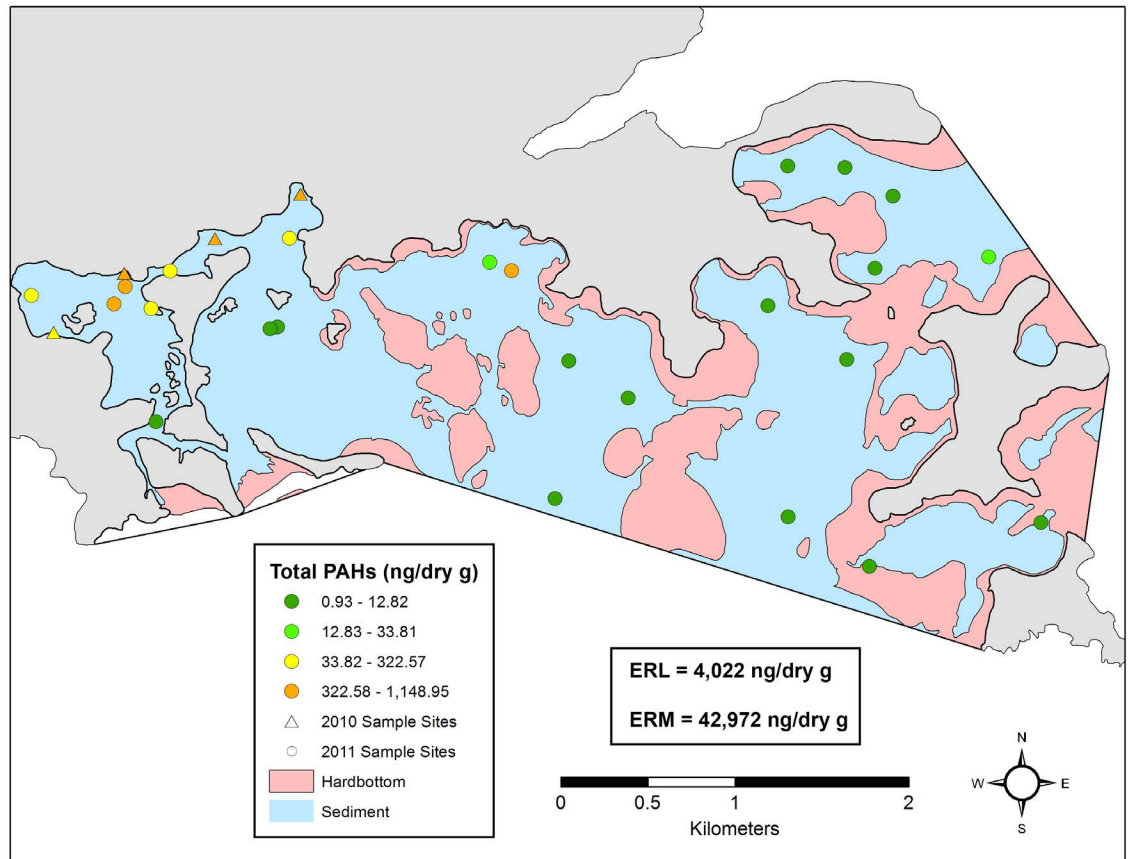


Figure 7. Total polycyclic aromatic hydrocarbons (PAHs) detected in sediments from the St. Thomas East End Reserves.

can be compared with data from the rest of the Nation's coastal waters. For this report, data from the STEER sediments are compared with the most recent (2006/2007) nationwide analysis of sediments from the NS&T Program. The most recent NS&T nationwide sediment analysis data were used, as the individual compounds in some of the chemical contaminant classes (e.g., total PAHs, total PCBs and total DDT) that NS&T analyzes, have changed over time, and the 2006/2007 NS&T sediment data contains the most comparable list of analytes.

The NS&T 2006/2007 median (NS&T median) for total PAHs is 395 ng/g. Three sites, two of which were in Mangrove Lagoon (1-3P, 1-2P, and 3-32P), were above the NS&T median for total PAHs. None of the sites sampled in

the STEER approached the NS&T 2006/2007 85th percentile (NS&T 85th percentile) of 2,883 ng/g. The median (i.e., the “middle value”) and 85th percentile values (elevated contaminant concentrations), are used to show how the results from the STEER sediments compare with NOAA’s national results.

less than 10 are more indicative of pyrogenic sources; F/P ratios greater than 1 are also thought to be associated with pyrogenic sources. Most of the sites in the STEER had P/A ratios of less than 10, and the F/P ratio close to or above 1, indicating the pyrogenic nature of the PAHs present in the sediments. At 1-3P in Mangrove Lagoon, which had the highest total PAH level in the samples analyzed from

Table 2. Comparison of higher concentrations of individual PAHs at STEER sites with NOAA NS&T data.

Compound	Sites						NS&T Statistics and Guidelines			
	1-2P	1-3P	3-32P	BB-1	BB-2	ML-10	Median	85th Percentile	ERL	ERM
Acenaphthylene	2.2	3.4	0.2	2.8	4.0	2.4	2.1	15.1	44	640
Anthracene	3.2	5.6	1.3	7.4	9.2	5.7	3.4	38.7	85.3	1,100
Napthalene	7.3	9.2	0.9	5.4	6.4	7.3	3.7	27.6	160	2,100
Benzo-a-pyrene	20.3	35.0	35.1	9.6	17.5	15.6	14.7	127	430	1,600
Dibenzo(a,h)anthracene	3.4	6.4	8.2	7.4	6.9	11.6	5.0	23.8	63.4	260

All concentrations are in ng/g.

NOAA Sediment Quality Guidelines for Total PAHs. As noted earlier, the NS&T Program developed effects-based, numeric guidelines to estimate the toxicological relevance of certain sediment chemical contaminants (Long et al., 1998). These guidelines, the Effects Range-Low (ERL) and the Effects Range-Median (ERM) define sediment contaminant concentration ranges that are rarely (<ERL), occasionally (ERL to ERM) or frequently (>ERM) associated with toxic effects in aquatic biota (NOAA, 1998). The ERL and ERM values for total PAHs are also shown in Figure 7. As can be seen, total PAHs in the sediments were below the ERM and ERL as well.

NOAA’s NS&T Program has developed ERL and ERM guidelines for a number of individual PAHs, which are shown in Table 2. None of the sediments collected in the STEER exceeded the ERL, ERM or the NS&T 85th percentile for any of the individual PAHs listed in Table 2. However, from the 2011 stratified random sampling, Sites 1-2P, 1-3P and 3-32 exceeded the NS&T median for a number of the individual PAHs listed (Table 2). From the 2010 targeted sampling, BB-1, BB-2 and ML-10 also exceeded the median for a number of the listed PAHs. As will be seen later, results from the P450 test indicated a response to PAHs in Mangrove Lagoon and northern Benner Bay.

The ratios of phenanthrene-to-anthracene (P/A) and fluoranthene-to-pyrene (F/P) have been used as a screening tool to assess the relative contributions of pyrogenic (combustion-related) versus petrogenic (uncombusted) sources of PAHs (Budzinski et al., 1997). Higher levels of uncombusted PAHs would be more indicative of the presence of spilled fuels, such as gasoline or oil. P/A ratios

the STEER, the P/A ratio was 3.24, indicating pyrogenic sources, however the F/P ratio was 0.70, indicating that petrogenic sources may also have contributed to the mix of PAHs found in the sediments at this site.

Effects of Sediment Grain Size and TOC. As noted earlier, the adsorption of organic contaminants onto sediments is strongly influenced by grain size (Hassett et al., 1980). The smaller grain sizes of the silts and clays have proportionally higher surface areas available for the adsorption of chemical contaminants and tend to have more TOC than coarse grained sediment. To assess this relationship for the samples collected in the STEER, a nonparametric regression was run between percent fines (sum of percent silt and percent clay) and the concentration of total PAHs found in the sediment samples. There was a highly significant ($P < 0.0001$) and positive correlation between the percent fines and the concentration of total PAHs. There was also a significant negative correlation ($p < 0.0001$) between the concentration of PAHs and the sand fraction of the sediments, indicating that as the percent sand concentration increased in sediments, the amount of total PAHs present was correspondingly lower. A regression run between percent gravel in the sediments and total PAHs was not significant ($p = 0.4065$).

Typically, a positive relationship also exists between sediment total organic carbon (TOC) and chemical contaminants in freshwater, estuarine and coastal waters (Shine and Wallace, 2000; Hassett et al., 1980). Because of this, organic contaminant concentrations are often normalized to the organic carbon content of sediments. However, a

nonparametric correlation between TOC and total PAHs for the STEER samples was not significant (Spearman Rho = -0.1779, $p = 0.4057$).

Interestingly, TOC also showed no significant correlation with either the silt (Spearman Rho = -0.2435, $p = 0.2515$), clay (Spearman Rho = -0.1331, $p = 0.5353$) or fines (Spearman Rho = -0.2531, $p = 0.2328$) fractions of the sediment. TOC is typically associated with the smaller size fractions, particularly the silts. It is unclear why a significant relationship between TOC and grain size also did not exist for the sediments in STEER. Perhaps the organic carbon in these sediments is in a different form or is cycled differently than in estuarine and/or temperate areas. It was noted earlier that while a number of the inshore sites had elevated TOC levels, some of the more offshore sites (e.g., 4-46P, 3-37A, 4-49P, and 4-47P) also had higher TOC levels (Appendix B). The grain size distribution in these more offshore areas, however, was primarily sand and gravel.

Work in Vieques and Jobos Bay, Puerto Rico indicated a strong relationship between PAHs and TOC (Pait et al., 2012; Pait et al., 2010). However, work in southwest Puerto Rico indicated results similar to the STEER, that is no relationship between TOC and PAHs in the sediment (Pait et al., 2008). Additional work is needed to assess the relationship between grain size and TOC in the sediments in STEER and possibly in other tropical areas.

Total Extractable Hydrocarbons. The results of the analysis of total extractable hydrocarbons, or TEH, is shown in Figure 8. TEH is not only composed of PAHs, such as those occurring from the combustion of fuels, but also of straight and branched aliphatics (nonaromatic hydrocarbons) found

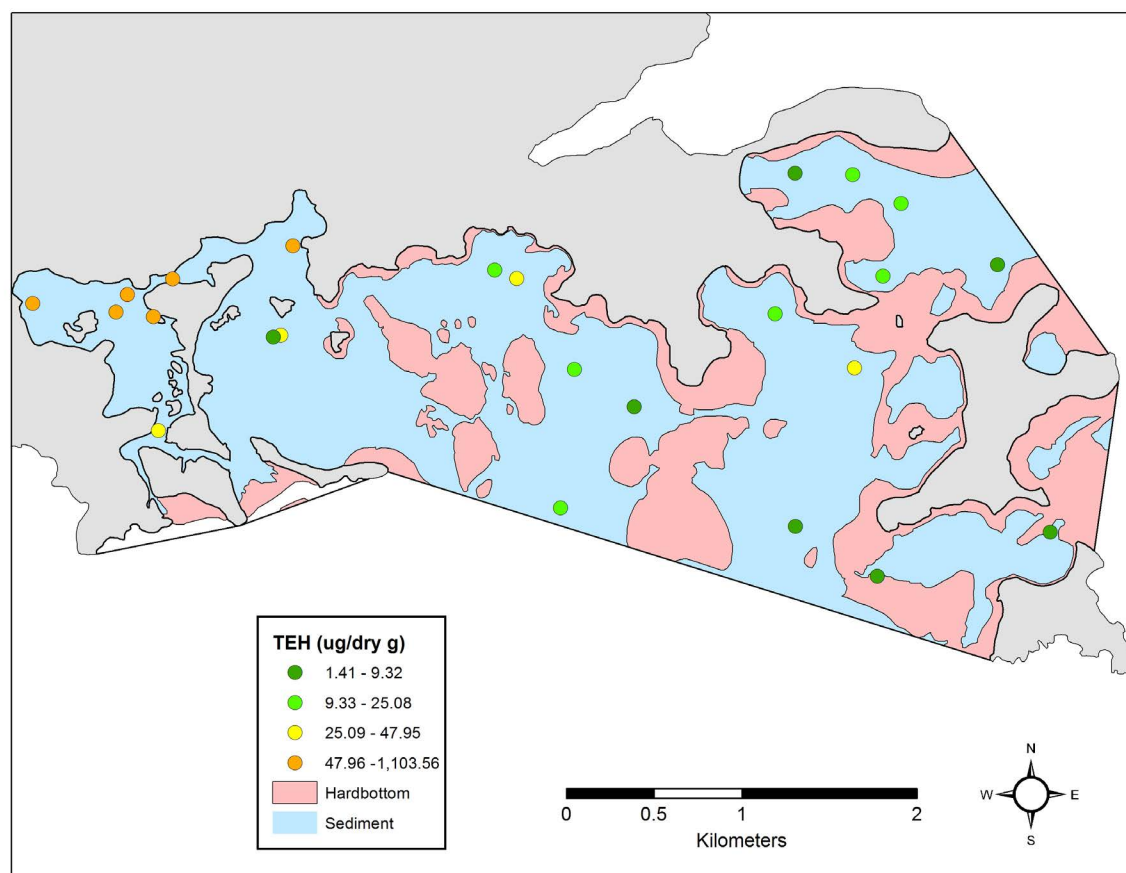


Figure 8. Total extractable hydrocarbons (TEH) detected in sediments from the St. Thomas East End Reserves.

in uncombusted fuels and in oils, and from natural sources (e.g., decaying vegetation). TEH provides a more complete assessment of the total mass of hydrocarbons present in a sediment sample.

It can be seen from Figure 8 that the relative concentration of TEH in the STEER mirrors total PAHs (Figure 7). It should be noted, however, that the units for total PAHs are in ng/g (ppb), while TEH is in $\mu\text{g/g}$ (ppm or parts per million). TEH in the sediments at a number of locations in the STEER were approximately an order of magnitude higher than total PAHs. The mean TEH concentration in the STEER was 167 $\mu\text{g/g}$. The highest TEH concentration (1,104 $\mu\text{g/g}$) was found in Mangrove Lagoon at 1-3P.

Variation of TEH Across Strata. An ANOVA run on the log10 transformed data indicated that TEH varied by stratum ($p = 0.0018$), and a Tukey-Kramer HSD test indicated that Stratum 1 was significantly different (higher) than Strata 3, 4 and 5.

Sediment Quality Guidelines and TEH. There are no NOAA sediment quality guidelines for TEH. Boehm et al. (2008) carried out a regression analysis between total

PAHs and TEH, and calculated a TEH “ERL” of 2,600 $\mu\text{g/g}$, and a TEH “ERM” of 9,760 $\mu\text{g/g}$. Using these values as rough TEH sediment quality guidelines, none of the TEH concentrations found in the STEER exceeded the lower threshold estimated by Boehm et al. (2008).

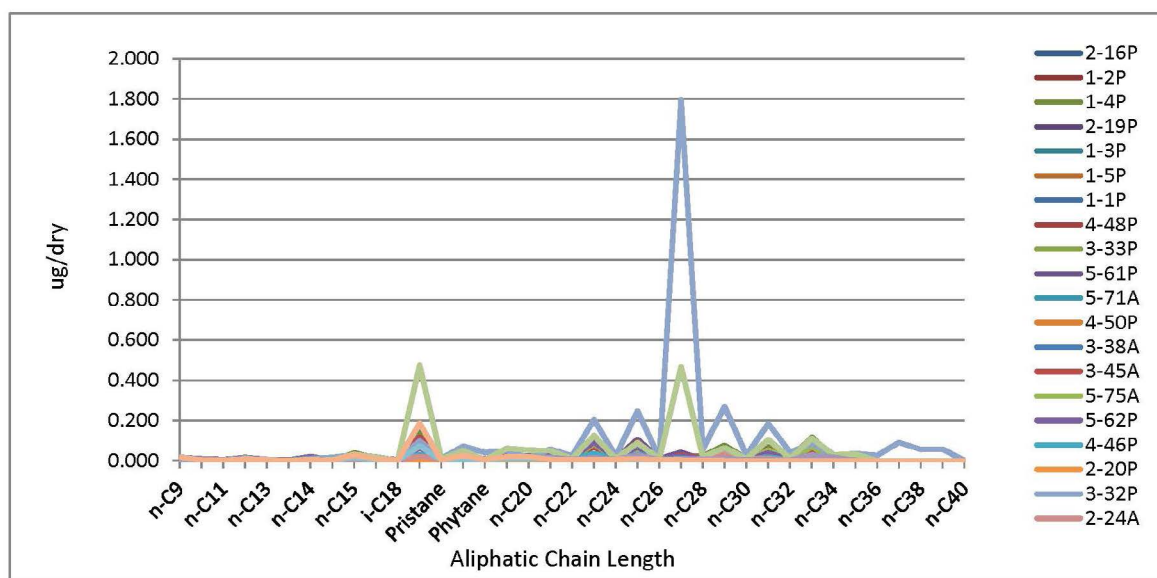


Figure 9. Straight chain and branched hydrocarbons (aliphatics) in sediments from the St. Thomas East End Reserves.

Effects of Sediment Grain Size

and TOC. A nonparametric correlation run between TEH and percent fines indicated a significant positive correlation (Spearman Rho = 0.5852, $p = 0.0027$), however, there was no significant correlation between TEH and TOC (Spearman Rho = -0.0030, $p = 0.9887$).

Polychlorinated Biphenyls. Total PCBs detected in the sediments are shown in Figure 10. Appendix E contains results of the analysis for individual PCBs. Total PCBs as included in this report represents the sum of the 38 congeners analyzed for the project.

Aliphatics. In addition to TEH, straight chain and branched aliphatics, indicative of un-combusted fuels or oil, were also analyzed in the sediment samples (Figure 9). There were a number of aliphatics in the C-19 (molecules containing 19 carbons), and the C-23 - C-31 range, with spikes at C-19 and C-27, particularly at Site 3-32P but also at Site 5-70A. The aliphatics present appear to be in the range of diesel fuel and lubricating oils (Libes, 1992), and could indicate some type of discharge in the past or perhaps low level, chronic (longer term) inputs at this site.

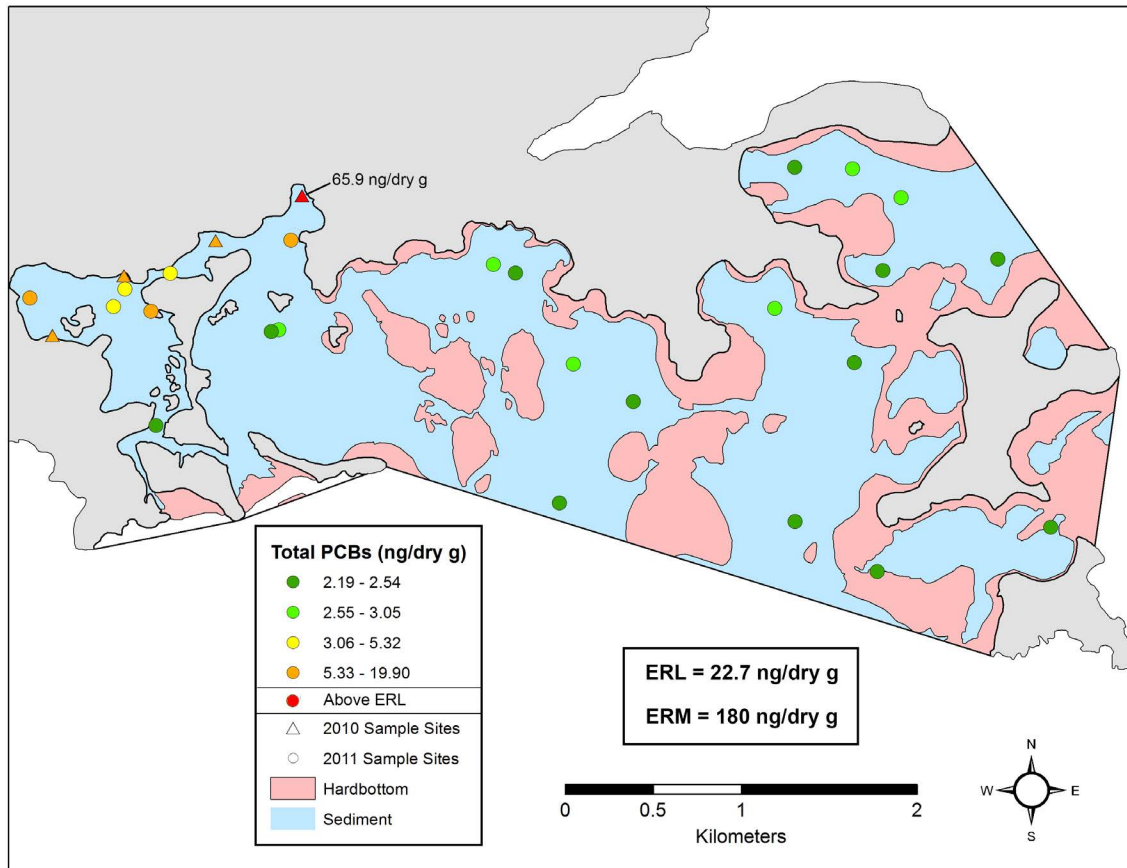


Figure 10. Total PCBs detected in sediments from the St. Thomas East End Reserves.

The mean concentration of total PCBs found in the STEER was 1.00 ± 0.32 ng/g; the median was 0.37 ng/g. As with the PAHs, there was a pattern of somewhat elevated levels of total PCBs in Mangrove Lagoon and in the northern Benner Bay areas.

The highest concentration of total PCBs from the stratified random sampling was 7.2 ng/g; from the targeted 2010 sampling, the highest concentration was 65.9 ng/g at BB-2 (Figure 10). Eighteen, or 75%, of the sites sampled in the STEER, however, had a total PCBs concentration of less than 1 ng/g.

Variation of Total PCBs Across Strata. The variation of total PCBs by stratum was assessed using an ANOVA, run on the log10 normalized concentration values. The results indicated no significant variation ($p = 0.0573$) in total PCBs concentration across the five strata established in the STEER.

Comparison with Other Data. EPA's EMAP sampled and analyzed sediments in the STEER from four locations in 2004 (Figure 3). A total of 21 congeners were analyzed in the sediment samples taken. No PCB congeners were detected in the four samples analyzed; the detection limit for each congener was 0.05 ng/g.

In a project conducted by NCCOS in Jobos Bay, the mean total PCBs concentration found in the sediments was 2.09 ± 0.50 ng/g (Pait et al., 2012). In Vieques, that value was 2.86 ± 0.14 ng/g, both higher than the STEER. In southwest Puerto Rico, the mean total PCBs concentration in sediments was 12.1 ± 2.26 ng/g not including two very high total PCBs concentrations (1,022 ng/g and 2,710 ng/g) within Guanica Bay. If the two sites in Guanica Bay are included, the mean for total PCBs in the southwest Puerto Rico study area was 74.7 ± 47.9 ng/g (Pait et al., 2008).

Four of the five sites from the stratified random sampling (in Mangrove Lagoon and northern Benner Bay) had a total PCBs concentration above the NS&T median of 2.2 ng/g. All four of the 2010 targeted sample were above the NS&T median. BB-2 (65.9 ng/g) from the targeted sampling was above the 85th percentile (23.7 ng/g) for total PCBs.

NOAA Sediment Quality Guidelines for Total PCBs. ERLs and ERM have been established for total PCBs. The concentration of total PCBs at Site BB-2 (65.9 ng/g) from the targeted sampling was higher than the PCB ERL (Figure 10). At 21.8 ng/g, ML-10 was just below the ERL. Levels below the ERL indicate that effects on benthic infauna are not as likely. Concentrations above the ERL but below the ERM indicate that more sensitive species or life stages may begin to be impacted.

Effects of Grain Size and TOC. A nonparametric analysis of the data revealed a significant positive correlation between total PCBs and the fines fractions of the sediment (Spearman Rho = 0.5452, $p = 0.0059$). No significant correlation existed between total PCBs and gravel, and there was a significant negative correlation (Spearman Rho = -0.4648, $p = 0.014$) between sand and total PCBs.



Sampling of sediments in the STEER.

An analysis of total PCBs and TOC revealed no significant correlation (Spearman Rho = 0.0322, $p = 0.8813$), similar to what was observed for PAHs. For both PAHs and PCBs in the STEER, sediment concentrations appeared to be influenced more by sediment particle size than sediment TOC.

DDT and Other Organochlorine Pesticides. Figure 11 contains the results of the analyses of total DDT in sediment samples from

the STEER. Detailed results for DDT and a number of other organochlorine pesticides analyzed for this project can be found in Appendix F. Total DDT as defined in this report is the sum of the parent isomers (4,4'-DDT and 2,4'-DDT), along with degradation products DDE, DDD and DDMU. The mean concentration of total DDT in the sediments in the STEER was 0.047 ± 0.025 ng/g; the median was 0.002 ng/g. As with a number of the other chemical contaminants, higher concentrations of total DDT were found in the Benner Bay and Mangrove Lagoon areas. The highest total DDT concentration from the stratified random samples collected in 2011 was 0.609 ng/g at 2-20P (Table 3). The highest concentration of total DDT from the 2010 targeted sampling was 3.61 ng/g at BB-2 (Figure 3) in northern Benner Bay. The second highest concentration was also in Benner Bay (1.31 ng/g) at BB-1. Currently, there does

not appear to be much agriculture on the island of St. Thomas, although in the past DDT could have been used on crops such as sugarcane, fruits and vegetables, along with use to control mosquitoes.

Variation of Total DDT Across Strata. Although there were some elevated levels of DDT in Benner Bay and Mangrove Lagoon (Table 3), an ANOVA run on log10 normalized data indicated no significant variation ($p = 0.2575$) in total DDT concentration across the five strata in the STEER. In addition, the degradation products DDD and DDE appeared to make up much of the total DDT present, indicating that the parent compound had degraded over time.

Comparison with Other Data. EPA's EMAP analyzed DDT along with a number of DDT degradation products from four sites in the STEER. The only DDT-related compound detected was the degradation product 4,4'-DDD, at a concentration of 0.26 ng/g at one site. In southwest Puerto Rico, Pait et al. (2008) detected a mean total DDT concentration of 2.10 ± 1.26 ng/g, higher than in the STEER. In Jobos Bay, the mean total DDT concentration was 0.54 ± 0.10 ng/g. In Vieques, the mean concentration of total DDT in the sediments was substantially higher, 23.6 ± 16.5 ng/g, due in part to elevated concentrations at four (78 ng/g to 1,274 ng/g total DDT) sediment sampling sites (Pait et al., 2010).

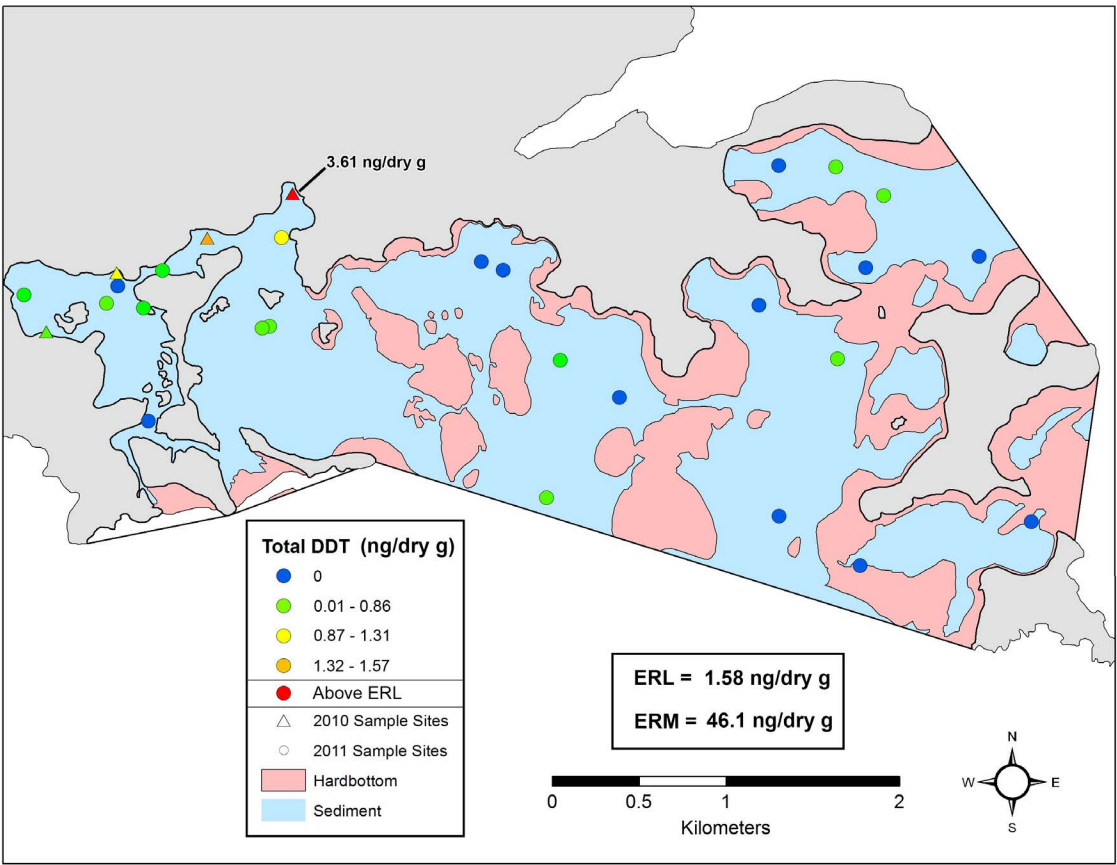


Figure 11. Total DDT detected in sediments from the St. Thomas East End Reserves.

The concentration of total DDT in the STEER exceeded the NS&T median value of 0.395 ng/g at four sites in the STEER, three of those from the 2010 targeted sampling. (Table 3). The concentration of total DDT at BB-2 was just above the NS&T 85th percentile of 3.49 ng/g.

NOAA Sediment Quality Guidelines for Total DDT. The concentration of total DDT at BB-2 (3.61 ng/g) from the 2010 targeted sampling was also above the ERL (1.58 ng/g). However, none of the sites sampled in the STEER had a concentration above the DDT ERM.

Effects of Sediment Grain Size and TOC. A nonparametric analysis of the data revealed no significant correlation

Table 3. Comparison of higher concentrations of pesticides at STEER sites with NOAA NS&T data.

Compound	Sites						NS&T Statistics and Guidelines			
	1-5P	2-16P	2-20P	BB-1	BB-2	ML-10	Median	85th Percentile	ERL	ERM
Total DDT	0.10	0.082	0.609	1.31	3.61	0.86	0.395	3.49	1.58	46.1
Chlordane	0.07	0.18	0.02	0.22	0.2	0.85	0.195	0.975	0.5	6
Total Endosulfan	0.0	0.0	0.142	0.0	1.13	0.63	0.0	0.253	N/A	N/A
Chlorpyrifos	0.0	0.253	0.0	1.33	0.13	0.62	0.01	0.328	N/A	N/A

N/A, not available

between total DDT and percent fines (Spearman Rho = 0.2993, $p = 0.1554$), or total DDT and percent TOC (Spearman Rho = -0.0060, $p = 0.9776$), however, it should be noted that 13 of the 24 stratified random samples had no detectable level of total DDT.

Additional Pesticides. A number of other pesticides were analyzed in the sediments from the STEER as part of this project. Most of the results were below detection limits. Selected results are shown in Table 3; the rest can be found in Appendix F. The highest concentration of chlordane (alpha and gamma isomers) detected in STEER sediments was 0.85 ng/g at site ML-10 at the mouth of Turpentine Gut, which empties into Mangrove Lagoon. This concentration is above the NS&T median but below the NS&T 85th percentile for chlordane (Table 3). NOAA has also established ERL and ERM values for chlordane. Chlordane was above the ERL only at ML-10. None of the sites had a chlordane concentration above the ERM.

The insecticides endosulfan and chlorpyrifos have had both agricultural and nonagricultural (e.g., homeowner) uses. Endosulfan, an organochlorine insecticide, is currently being phased out for all uses due to health risks to farmworkers and wildlife, and its persistence in the environment (EPA, 2010). Since there appears to be little commercial agriculture currently on St. Thomas, it is likely that endosulfan was used in the past, perhaps also on vegetables and fruits in gardens, prior to being phased out for homeowner use. The highest concentration of total endosulfan (sum of endosulfan I and II and endosulfan sulfate) detected in the STEER (1.13 ng/g) was at BB-2 in Benner Bay, which is above the NS&T median and 85th percentile. There are no NOAA sediment quality guidelines for endosulfan.

Although the organophosphate insecticide chlorpyrifos has had widespread use both domestically and in agriculture, virtually all homeowner uses have been eliminated (EPA, 2002b). Chlorpyrifos can still be used on certain food crops, on golf courses, for wood treatment (nonstructural), and as an adult mosquitocide. The highest concentration of chlorpyrifos (1.33 ng/g) was in Benner Bay at BB-1. This concentration was above the NS&T median and also above the 85th percentile (Table 3). The concentration of chlorpyrifos at ML-10 was also above the NS&T median and 85th

percentile. There are no NOAA sediment quality guidelines for chlorpyrifos in sediments.

Tributyltin (TBT). The results of the analysis of butyltins in STEER sediments are shown in Figure 12 and in Appendix G. Mono-, di-, tri-, and tetrabutyltins were analyzed in the sediments. Tetrabutyltin is an intermediate in the manufacture of TBT compounds. As noted earlier, TBT has had extensive use in the past as an antifoulant on boat hulls. In the environment, TBT degrades to dibutyltin, then monobutyltin, and finally to inorganic tin. Experiments have shown that the half-life of TBT, the amount of time needed to convert half of the TBT to dibutyltin in natural water samples, is on the order of days; degradation to monobutyltin takes approximately a month (Batley, 1996). Experiments with aerobic sediments have shown that the half-life of TBT is similar to that measured in solution. In deeper, anoxic sediments, however, the half life of TBT appears to be considerably longer, on the order of 2-4 years (Batley, 1996).



Sediment sample in the PONAR grab from Stratum 1 (Mangrove Lagoon).

The mean, or average, concentration of TBT in the sediments in the STEER was 1.85 ± 1.30 ng Sn/g; the median was zero. The highest concentration of TBT detected in STEER sediments collected using the stratified random sampling design was at site 2-20P in Benner Bay, with a concentration of 31 ng/g.

However, of the samples analyzed from 2010, BB-1 and BB-2 had even higher

TBT concentrations. The concentration of TBT at BB-1 was 77 ng/g; the TBT concentration at BB-2 was even higher, 248 ng/g.

Variation of TBT Across Strata. Because the targeted 2010 samples were collected nonrandomly, that data cannot be used to assess the variation of TBT in sediments across the STEER strata. An ANOVA run on the log10 transformed data for the 2011 samples collected using the stratified random design did not indicate any significant differences ($p = 0.4368$) in the concentration of TBT between strata.

Comparison with Other Data. The NS&T median concentration of TBT in sediments is 0.16 ng Sn/g. The NS&T 85th percentile for TBT is 1.38 ng Sn/g, which is lower than the mean concentration of TBT found in STEER sediments. The highest concentration of TBT detected in the

STEER (248 ng Sn/g) represents the third highest detection ever in sediments in NOAA's NS&T Program (not just the 2006/2007 nationwide sediment sampling). The only two higher TBT concentrations from NOAA's NS&T Program were from the Elizabeth River in the southern Chesapeake Bay area, and Elliot Bay in Puget Sound. Pait et al. (2008) detected a mean TBT concentration of 0.01 ± 0.01 ng Sn/g in southwest Puerto Rico. In Vieques, Puerto Rico, the mean concentration of TBT was 0.05 ± 0.02 ng Sn/g and in Jobos Bay, the mean concentration was 0.56 ± 0.28 ng Sn/g.

It should be noted, however, that 15 of the 24 sediment samples taken in the STEER had no detectable TBT. The higher concentrations of TBT tended to occur in the northern Benner Bay area. For the most part, this was also the case for the TBT degradation products dibutyltin and monobutyltin (Appendix G).

Sediment Quality Guidelines and TBT. There are no established sediment quality guidelines for TBT, due in part to the complex chemistry of this compound, including its bioavailability largely being governed by partitioning into porewater (water in between sediment particles), which is in turn is governed by a number of parameters of the sediment at a site.

One of the few attempts at establishing guidelines for TBT was reported by Weston (1996). In that document, lower

and upper screening values were established for TBT, based on a sediment organic carbon content of 2%. The intent was to establish thresholds for cleanup actions at contaminated sites. The lower and upper values are not analogous to NOAA ERL or ERM values, but rather represent a range that was to be used to determine when additional testing (e.g., additional toxicity testing) at a site would be advis-

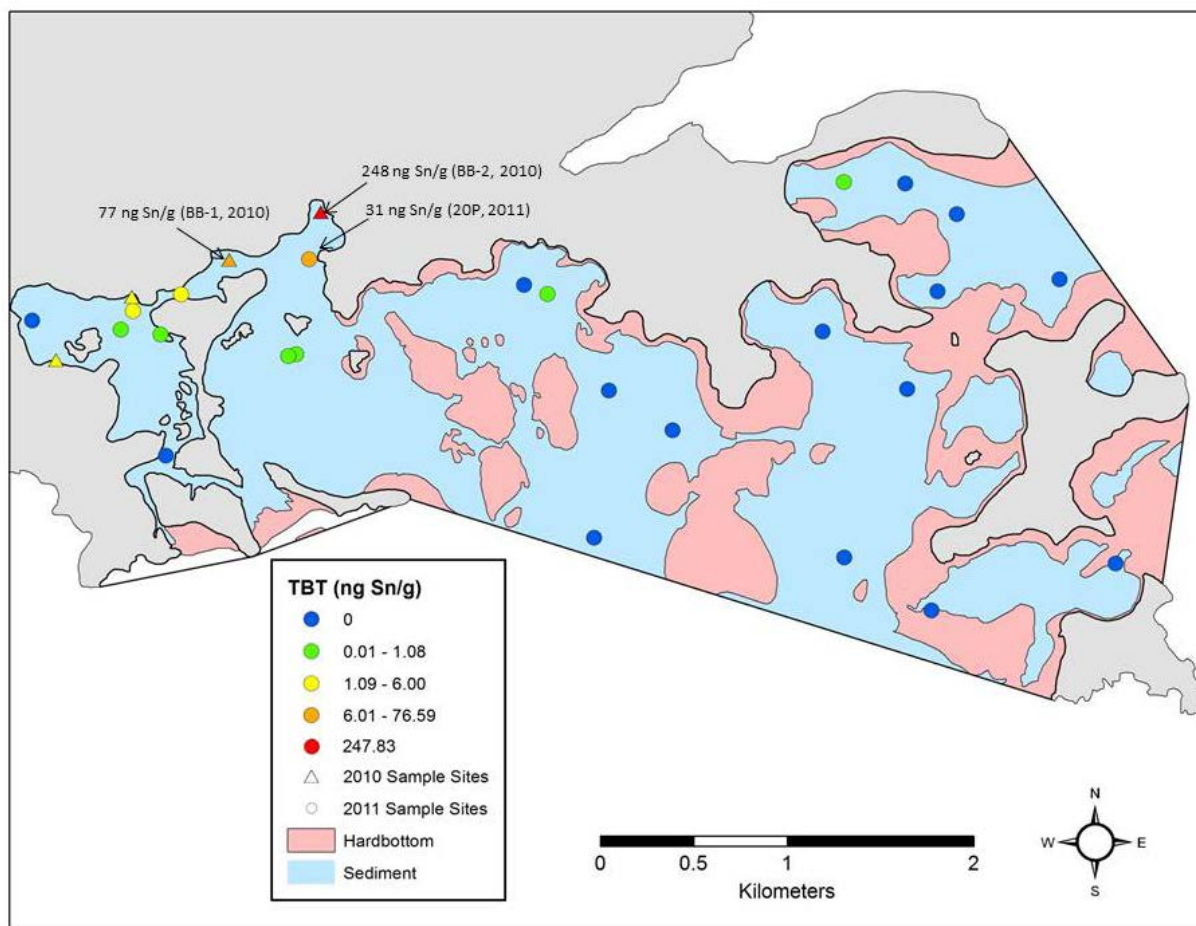
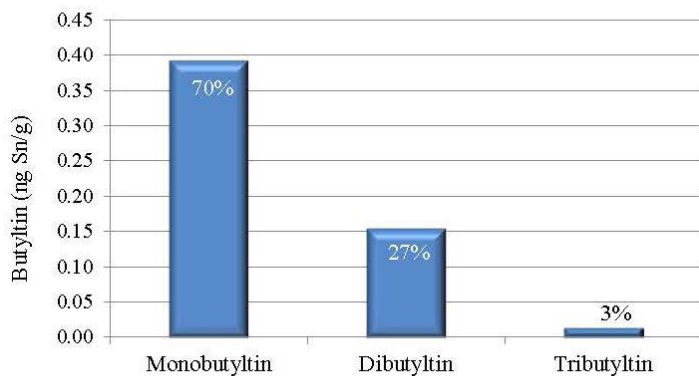


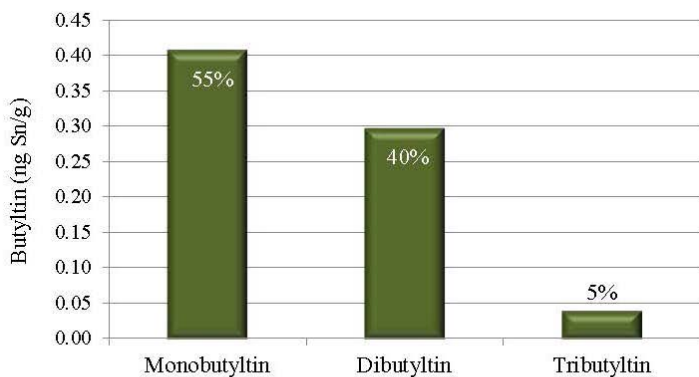
Figure 12. Tributyltin detected in sediments from the St. Thomas East End Reserves. BB-1 and BB-2 represent targeted, nonrandomized samples taken in 2010.

able. Using this approach, Weston (1996) recommended TBT values between 10 and 144 ng Sn/g as the lower and upper screening values, respectively, with the actual screening value selected being determined by an EPA site manager at the particular EPA Superfund site. If these two values are used as rough boundaries for determining when additional work (e.g., toxicity testing) would be recommended, it indicates there should be concern regarding the elevated TBT level at BB-2, especially as the concentration was above the higher screening value developed by Weston (1996). Sites BB-1 and 2-20P were above the lower screening value but below the upper screening value, but are also of concern. The results did not change even when the organic carbon content from each of these three sites

Mean butyltins in sediments from southwest Puerto Rico.



Mean butyltins in sediments from Vieques, Puerto Rico.



% indicates percent of butyltin total

Figure 13. Tributyltin detected in sediments from southwest Puerto Rico and Vieques, Puerto Rico. Values represent means.

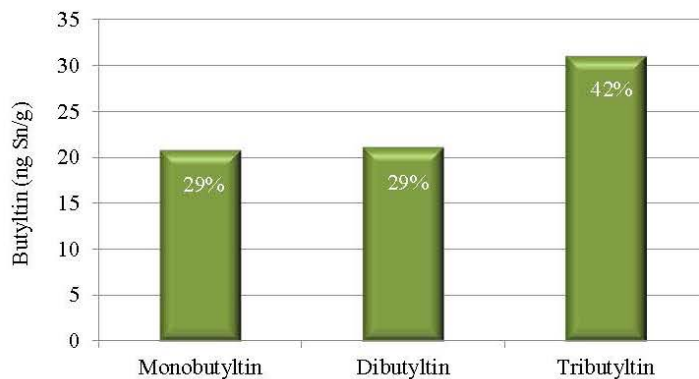
was incorporated into the equations used in Weston (1996), including BB-2, which had an organic carbon content of roughly 2% (Appendix B).

Butyltin Levels in the Sediments Northern Benner Bay.

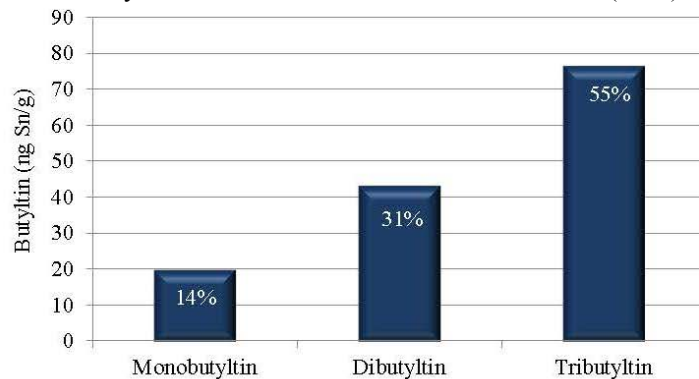
A comparison was made with butyltin data generated in northern Benner Bay and by NOAA/NCCOS in Puerto Rico. A summary of the results for TBT and its metabolites in southwest Puerto Rico (Pait et al., 2007) and Vieques, Puerto Rico (Pait et al., 2010) is shown in Figure 13. From this figure, it can be seen that the majority of the butyltin present in the sediment samples from southwest Puerto Rico, and in Vieques, were primarily in the form of monobutyltin and dibutyltin, with only a small fraction of the total as the parent or undegraded TBT.

Figure 14 shows the same type of information for the three sites in the STEER that had the highest TBT concentrations. Not only are the absolute concentrations vastly different, the ratios of TBT to monobutyltin and dibutyltin

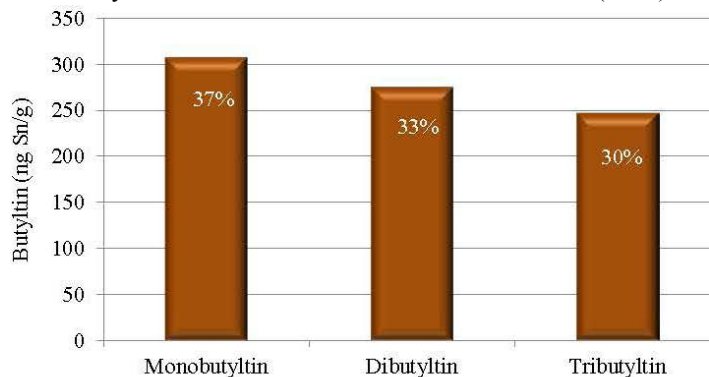
Mean butyltins in sediments from 20P in the STEER (2011).



Mean butyltins in sediments from BB-1 in the STEER (2010).



Mean butyltins in sediments from BB-2 in the STEER (2010).



% indicates percent of butyltin total

Figure 14. Tributyltin detected in sediments from three sites in the STEER.

at these three sites are different from those shown in Figure 13. The concentration of TBT at these three sites in the STEER was similar to, if not higher than, the concentration of monobutyltin and dibutyltin at these same sites. The higher concentrations of TBT relative to monobutyltin and dibutyltin, along with the overall higher concentration of TBT, may be indicative of recent deposition of TBT. For example, as a result of the mooring of boats and/or the cleaning and scraping of boat bottoms containing TBT-based paints, with subsequent input of these materials (e.g.,

paint chips or dust) through stormwater runoff into adjacent waters.

The higher levels of TBT found could also be related to past deposition. As noted, the sediment samples analyzed as part of this project were surficial or surface sediments. For the analysis, the top three cm (centimeters) of sediment were collected from the sediment grab. Given this, it is likely that the samples analyzed in the STEER represent more recently deposited sediments. However, in order to confirm this, additional studies would be useful to assess the sedimentation rate in this part of Benner Bay, along with data from sediment cores to track concentrations back in time. As part of the monthly monitoring in the STEER being conducted by UVI, six sediment traps have been installed in the STEER which include sites in Mangrove Lagoon, Benner Bay, Rotto Cay, Cowpet Bay, and adjacent to Great St. James and Little St. James. Preliminary results (January - May 2012) indicate terrestrial inputs are significant at all sites, and that deposition rates in the sediment traps using these preliminary data appear higher at the Benner Bay and Rotto Cay locations.

Regardless of whether the TBT found in the Benner Bay area is from past inputs, more recent input, or both, the elevated levels suggests the need for additional work to quantify the distribution of this contaminant in the sediments along with effects (toxicity), including possible endocrine disruption in mollusks. As noted earlier, Strand et al. (2009) found evidence of elevated levels of TBT and its degradation products in several gastropod species, as well as imposex at several locations, including Charlotte Amalie Bay in St. Thomas. As part of the current project in the STEER, samples of queen conch (*Strombus gigas*) and coral (*Porites astreoides*) are being analyzed for chemical contaminants, including butyltins, and will be reported in a later publication.

At the very least, additional work is needed to further quantify the lateral and vertical (i.e., sediment cores) distribution of TBT in the sediments in the northern part of Benner Bay. Analyzing the concentration of TBT and its metabolites in sediment cores would provide a better understanding of degradation rates and concentrations of TBT in sediments over time, along with the total amount of TBT that may be present in the area. This would be particularly important if construction or dredging operations in this part of Benner Bay were to occur in the future, so as to limit the transport and impact of contaminated sediments. As will be seen, copper was also elevated in this part of the STEER with the highest copper sediment concentration, like the highest TBT concentration, occurring at BB-2. Copper is an

important component of current and past antifouling paint formulations.

Effects of Sediment Grain Size and TOC. The correlation of TBT concentrations to grain size and TOC was examined for sediments sampled in the STEER. A nonparametric analysis of the data revealed a significant correlation between TBT and percent fines (Spearman Rho = 0.5759, $p = 0.0032$). As noted earlier, smaller grain sizes (silt and clays) of sediments have more surface area available for the adsorption of contaminants. There was no correlation, however, found between TBT and percent TOC (Spearman Rho = 0.0430, $p = 0.8419$), similar to what was seen for a number of the other organic chemical contaminants analyzed for this project.

Cadmium. Seventeen major and trace elements were analyzed in the sediment samples collected. Detailed results for all of these elements are contained in Appendix H. The discussion that follows focuses on those trace elements that have been shown to be toxic at low concentrations, and for a number of these elements that were found at elevated concentrations in the STEER sediment.

The concentration of cadmium in the sediments sampled in the STEER can be seen in Figure 15. The mean concentration in the STEER sediments was 0.03 ± 0.02 $\mu\text{g/g}$. Only three sediment samples from the stratified random sampling had a detectable level of cadmium, including 1-1P and 1-3P in Mangrove Lagoon, and 2-16P in Benner Bay. The highest concentration of cadmium in these samples was 0.264 $\mu\text{g/g}$ at site 1-3P. Of the four samples collected in 2010, the highest concentration was 0.371 $\mu\text{g/g}$ at ML-2 in Mangrove Lagoon (Appendix H). At BB-2, no cadmium was detected.

Variation of Cadmium Across Strata. Because of the low number of detections of cadmium in the STEER, no analysis by stratum was carried out.

Comparison with Other Data. EPA's EMAP analyzed cadmium in sediments from four locations in the STEER. The mean concentration of cadmium was 0.25 $\mu\text{g/g}$, higher than the mean detected in the STEER in the current project. In southwest Puerto Rico, the mean cadmium concentration in sediments was 0.01 $\mu\text{g/g}$, similar to that found in the STEER. In Vieques, the mean cadmium concentration in sediments was 0.13 $\mu\text{g/g}$ (Pait et al., 2010). In Jobos Bay, the mean cadmium concentration was 0.01 $\mu\text{g/g}$, similar to southwest Puerto Rico (Apeti et al., 2012b). The NS&T median for cadmium in sediments is 0.19 $\mu\text{g/g}$, the 85th percentile is 0.44 $\mu\text{g/g}$. All three sites in the STEER where

cadmium was detected from the stratified random sampling were at or above the NS&T median, but below the 85th percentile. Three of the four sites from the 2010 targeted sampling were also above the NS&T median, but all were below the 85th percentile.

NOAA Sediment Quality Guidelines for Cadmium. Figure 15 also contains the NOAA ERL and ERM. All cadmium levels detected in the STEER sediments, either from the stratified random sampling or from the 2010 targeted sampling, were below the ERL.

Cadmium is used in a number of applications, including nickel-cadmium (Ni-Cd) batteries, paint pigments and in electroplating (Ellor and Stelmiski, 2007). Sites 1-1P and 1-3P are both in Mangrove Lagoon, which is adjacent to the Bovoni Landfill, and could be one source for the cadmium. At this time, it is not known whether the cadmium detected is associated with runoff or subsurface flow from the landfill, or perhaps input from septic systems or runoff from residential areas. At one time, a wastewater treatment plant emptied directly into Mangrove Lagoon (Grigg et al., 1971). Additional work is needed to better assess the possible sources of cadmium to the area of Mangrove Lagoon and Benner Bay.

Effects of Sediment

Grain Size. Because of the low number of cadmium detections, an assessment of the effects of grain size and TOC was not carried out.

Chromium. The concentrations of chromium detected in the sediments collected from the STEER are shown in Figure 16. Higher concentrations were detected in the Mangrove Lagoon and Benner Bay areas, a pattern similar to a number of the organic compound classes (e.g., PAHs, PCBs) analyzed for this project.

The mean concentration of chromium in the STEER from the stratified random sampling was $14.1 \pm 1.76 \mu\text{g/g}$; the median was $11.4 \mu\text{g/g}$. The highest concentration of chromium in the sediments analyzed from the stratified random sampling was $35.7 \mu\text{g/g}$ at site 1-1P in Mangrove Lagoon. The second highest concentration, $32.3 \mu\text{g/g}$, was also in Mangrove Lagoon at site 1-3P. The three highest levels of chromium from the stratified random sampling were all from Mangrove Lagoon. The lowest level of chromium detected from the stratified random sampling was at 2-24A ($4.91 \mu\text{g/g}$).

Figure 16 also contains the results of the targeted sampling in 2010. The highest chromium concentration detected was

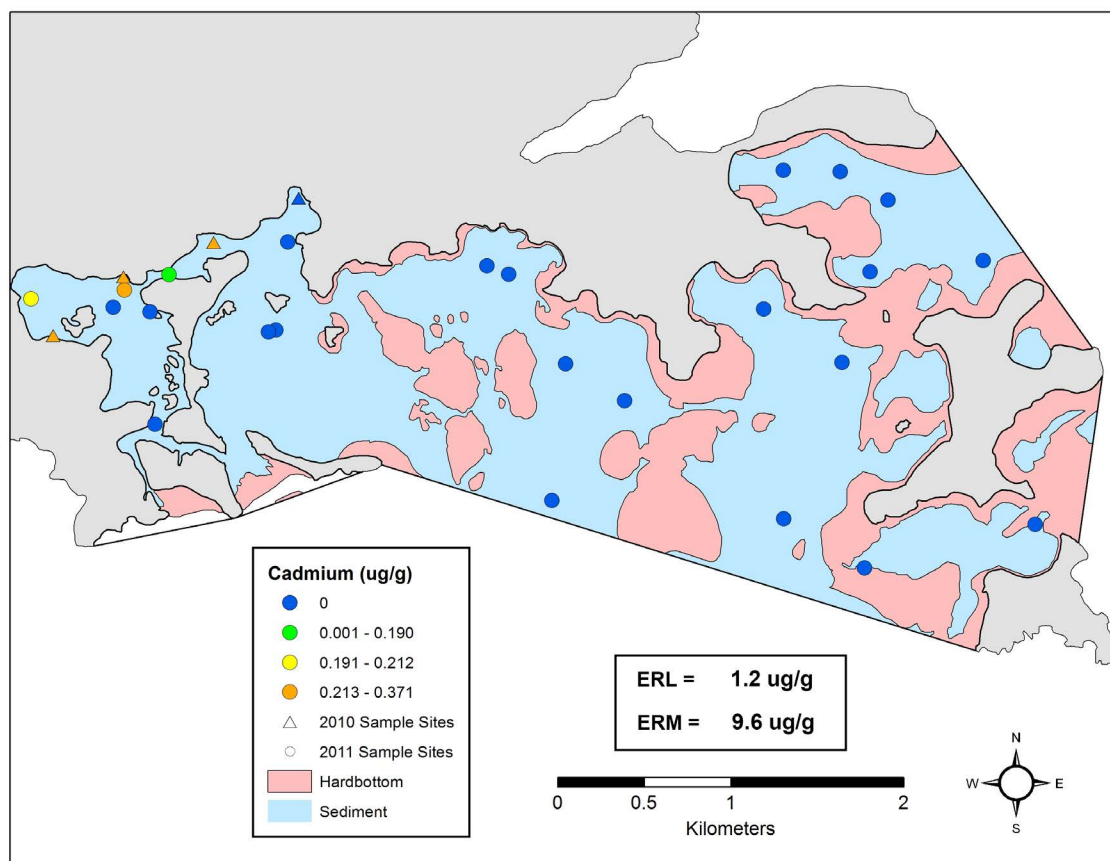


Figure 15. Cadmium detected in sediments from the St. Thomas East End Reserves.

$40.4 \mu\text{g/g}$ at BB-2, similar to the concentration of chromium at the sites in Mangrove Lagoon.

Variation of Chromium Across Strata. An ANOVA carried out on the log10 transformed data indicated that chromium varied significantly ($p = 0.0090$) by stratum. A subsequent pair wise comparison (Tukey HSD) indicated that Stratum 1 was significantly different (higher) from Strata 3, 4 and 5, however, Stratum 2 (Benner Bay) was not significantly different from Stratum 1.

Comparison with Other Data. EPA's EMAP analyzed four samples from the STEER in 2004. The mean concentration from these four samples was 3.06 µg/g, lower than the mean found in the current study in the STEER. The highest chromium concentration found in the STEER by EMAP was 4.8 µg/g.

In southwest Puerto Rico, Pait et al. (2008) calculated a mean chromium concentration of 31.2 µg/g, higher than in the STEER. In Vieques, mean chromium levels in the sediment were also somewhat higher, 22.5 µg/g (Pait et al., 2010). In Jobos Bay, the mean chromium concentration was 18.3 µg/g (Apeti et al., 2012b), similar to what was found in the STEER. The NS&T median for chromium in sediments is 66 µg/g, higher than any of the chromium levels found in sediments in the STEER in this study.

Chromium is used in a number of applications, including stainless steel production, chromium plating, and as a pigment. As with cadmium, it is not known if the chromium detected in the Mangrove Lagoon area is associated with inputs from the landfill, from septic systems, runoff from residential areas, or perhaps a combination of these sources. As noted, at one time a wastewater treatment plant emptied directly into Mangrove Lagoon (Grigg et al., 1971).

NOAA Sediment Quality Guidelines for Chromium. The ERL and ERM for chromium are also included in Figure 16. All STEER chromium values were below both of these NOAA guidelines.

Effects of Sediment Grain Size. Using the log10 normalized data, chromium was found to be correlated with the percent fines ($p = 0.0180$). A nonparametric analysis

showed this metal had a slightly higher correlation with percent clay (Spearman Rho = 0.5441, $p = 0.0060$) than the percent silt content (Spearman Rho = 0.4767, $p = 0.0185$).

Copper. The results from the analysis of copper in the sediments from the STEER can be seen in Figure 17 and in Appendix H. The mean concentration of copper found in the sediments was 21 ± 7.46 µg/g; the median was 3.75 µg/g. The highest copper concentration from the stratified

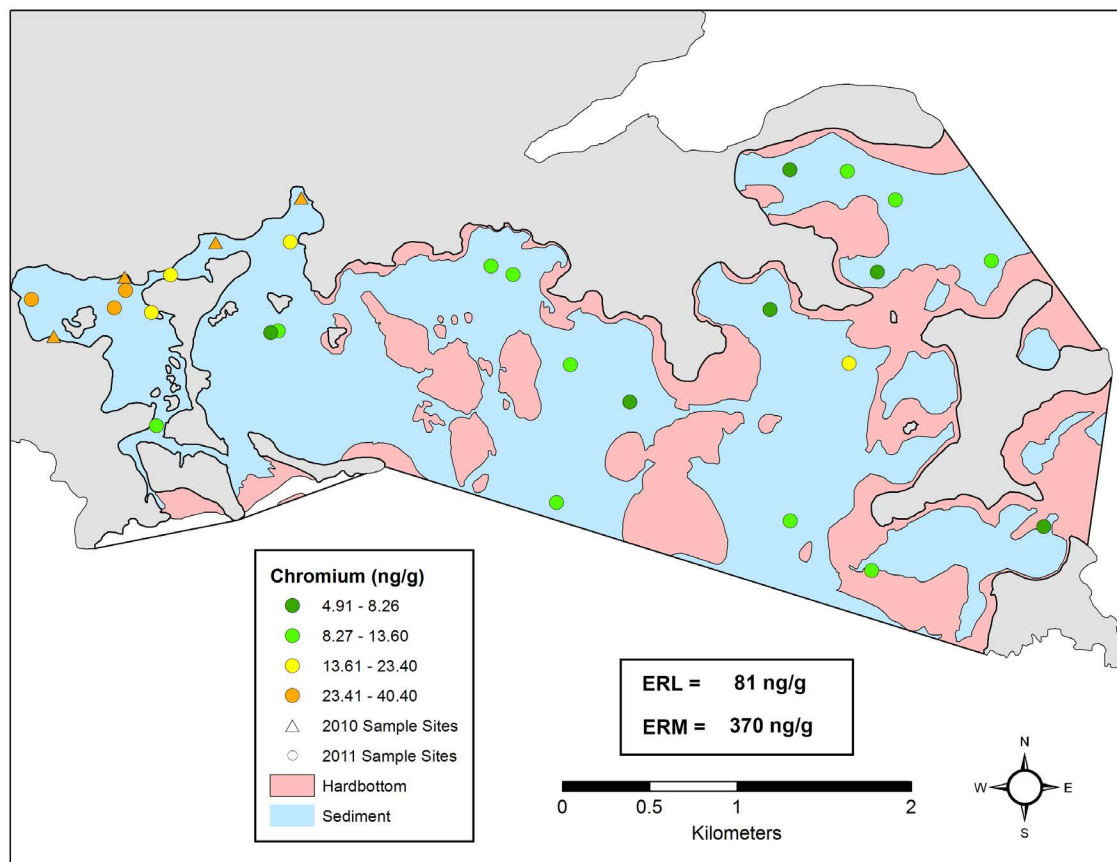


Figure 16. Chromium detected in sediments from the St. Thomas East End Reserves.

random sampling was 155 µg/g at site 2-20P, followed by 69.9 µg/g at site 1-1P in Mangrove Lagoon.

From the targeted sampling in 2010, the lowest concentration was 60.6 µg/g at ML-10. At BB-1, the concentration of copper in the sediment was 145 µg/g. At BB-2, the copper concentration was very high, 1,010 µg/g.

Copper has many applications including use in wire, electronic circuits, antifouling paints for boat hulls, copper plumbing, industrial catalysts, and in a number of alloys (e.g., brass). Copper sulfate is used in agriculture and as an anti-algal agent, although it is probably unlikely copper was used to any great extent agriculturally in the STEER watershed.

Variation of Copper Across Strata. A Kruskal-Wallis test run on the ranked values from the stratified random sampling indicated a significant difference ($p = 0.0001$) in the concentration of copper across the strata. A Tukey-Kramer HSD analysis indicated that copper did not vary significantly between Strata 1 and 2, but were different from Strata 3, 4, and 5.

Comparison with Other Data. EPA's EMAP collected and analyzed four sites within the STEER for copper in 2004. The mean concentration of copper in the sediments from the EMAP work was $3.9 \mu\text{g/g}$, substantially less than the mean concentration found in the STEER in the current study. It is unclear why the means for the stratified random sampling done in both studies were quite different, although it may be related to the greater number of samples taken in the current study, particularly in the Mangrove Lagoon area. As noted earlier, Mangrove Lagoon was not included in the EMAP work.

In southwest Puerto Rico, Pait et al. (2008) detected a mean copper concentration of $5.21 \mu\text{g/g}$, lower than the mean in the STEER. In Vieques, the mean copper concentration was $25.9 \mu\text{g/g}$, similar to the mean in the STEER sediments. In Jobos Bay, Apeti et al. (2012b) found a mean copper concentration of $34.1 \mu\text{g/g}$, somewhat higher than the mean found in the STEER.

The NS&T median for copper in sediments is $16 \mu\text{g/g}$. From the stratified random sampling in 2011, six sites (2-20P, 1-1P, 1-3P, 1-2P, 2-16P, 1-5P), all either in Mangrove Lagoon or northern Benner Bay, had copper levels above the NS&T median. The NS&T 85th percentile for copper is $38.3 \mu\text{g/g}$. Five of these sites had copper levels above the NS&T 85th percentile level. All four of the targeted samples were above the NS&T median and 85th percentile.

Finally, the concentration in the sediment at BB-2, is one of the 10 highest concentrations of copper that has been detected in NOAA's NS&T Program.

NOAA Sediment Quality Guidelines for Copper. The ERL for copper is $34 \mu\text{g/g}$ (Figure 17); the ERM is $270 \mu\text{g/g}$. From the stratified random sites, six sites (2-20P, 1-1P, 1-3P, 1-2P, 2-16P, 1-5P) exceeded the ERL, but none exceeded the ERM for copper, indicating that more sensitive life stages in these areas could be experiencing effects related to the presence of copper.

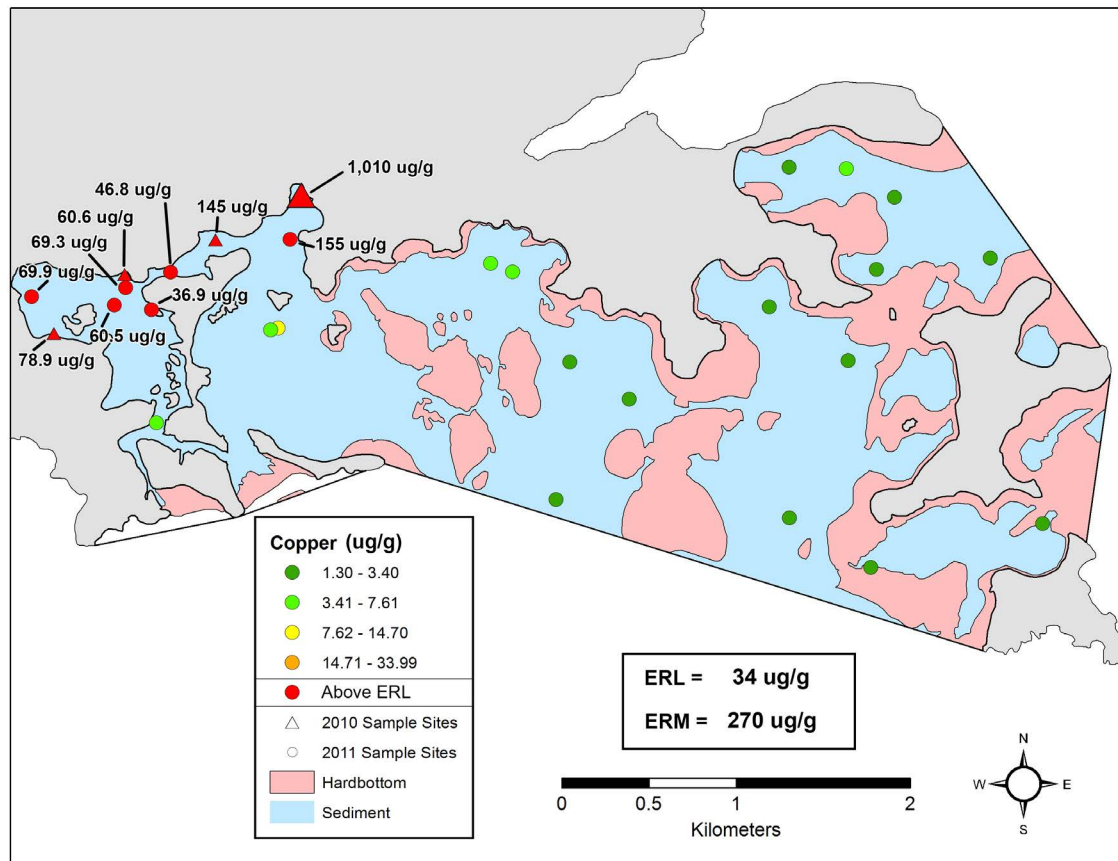


Figure 17. Copper detected in sediments from the St. Thomas East End Reserves.

All four of the 2010 targeted sites (i.e., BB-1, BB-2, ML-2 and ML-10) were above the NOAA ERL for copper. At Site BB-2 ($1,010 \mu\text{g/g}$), the level of copper substantially exceeded the copper ERM of $270 \mu\text{g/g}$, indicating that effects from this trace element on biota inhabiting the sediments are likely.

Copper in the Sediments in Northern Benner Bay and Mangrove Lagoon. The pattern of copper seen in the sediments in Mangrove Lagoon and Benner Bay, with higher concentrations in the northern part of Benner Bay, and somewhat lower concentrations in Mangrove Lagoon, suggests a pos-

sible gradient. The flow of water into and out of Mangrove Lagoon appears to have a number of driving forces, including a clockwise pattern through Cas Cay, a reversing tidal current, along with wind drift and runoff flow through both entrances (Tetra Tech, 2005). The three highest concentrations of copper were found at sites BB-1, 2-20P and BB-2, all in the northern part of Benner Bay. Given the variable direction of water currents in the area, a significant source of the higher copper concentrations in the sediments could be from the northern part of Benner Bay. However, additional work would be needed to assess this possibility.

Marinas and boat yards are a major commercial land use adjacent to the northern portion of Benner Bay. Copper has been used for years in antifoulant paint systems on boat hulls. Activities such as the mooring of vessels with hulls painted with copper-containing bottom paints, along with the cleaning, scraping and repainting of boat hulls, and subsequent runoff containing paint chips and dust, as might occur during a rainstorm, could lead to elevated concentrations of this metal in the environment. The elevated levels of TBT in the sediments in this same part of Benner Bay and lower levels of TBT

in Mangrove Lagoon support the possibility that the copper found in the sediments in the northern part of Benner Bay are related to the use of both copper and TBT over the years in boat-related activities. A nonparametric correlation analysis between copper and TBT in the STEER showed a significant positive correlation (Spearman Rho = 0.7078, $p = 0.0001$). As noted earlier, TBT has had significant use as an antifoulant on boat hulls. For copper, however, inputs of copper into Mangrove Lagoon from Turpentine Gut, runoff from residential areas, and inputs from the adjacent Bovoni Landfill could also be contributing sources.

In any case, the concentration of copper at BB-2 is indicative of levels that are likely impacting benthic organisms in this area. As with TBT, additional work is needed to assess

the extent of copper contamination both in surface sediments and in sediment cores, along with effects on biota.

Effects of Sediment Grain Size. A nonparametric analysis revealed that copper was significantly correlated with the percent fines (Spearman Rho = 0.7852, $p < 0.0001$) fraction of the sediments.

Lead. The concentrations of the trace element lead detected in the STEER sediments are shown in Figure 18. The mean

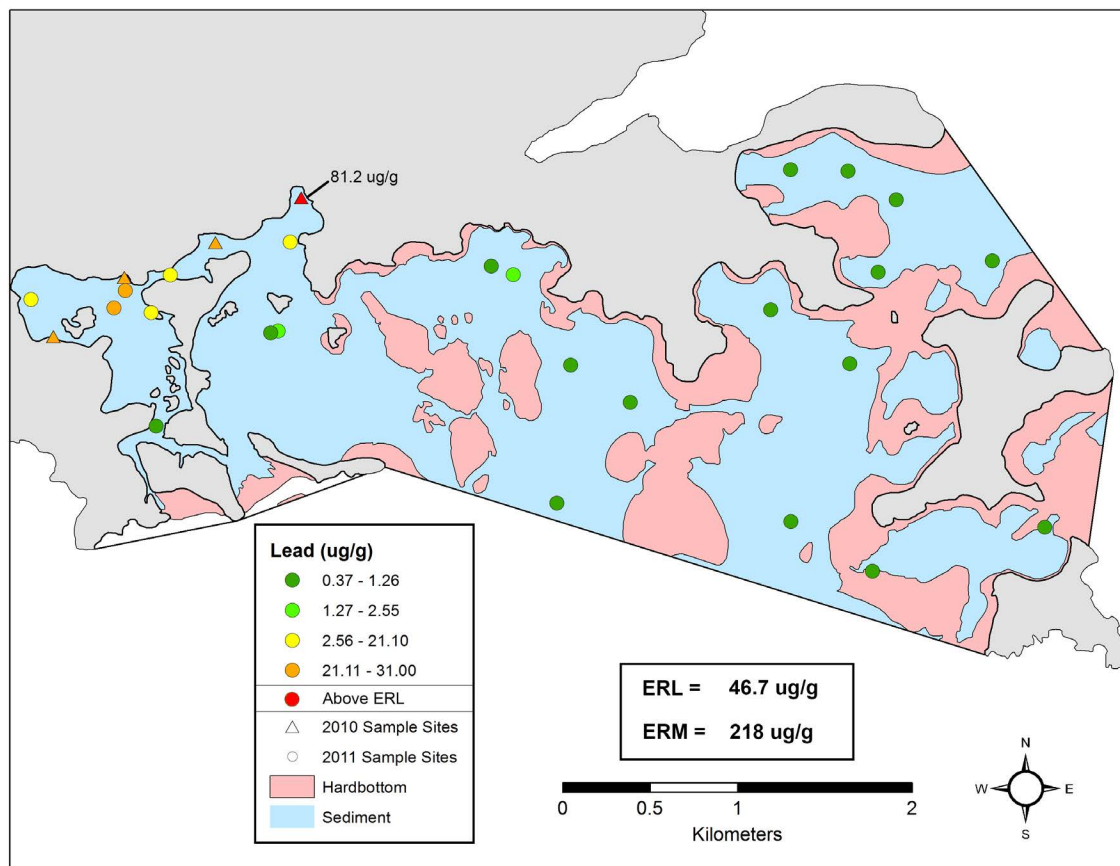


Figure 18. Lead detected in sediments from the St. Thomas East End Reserves.

concentration was $5.87 \pm 1.90 \mu\text{g/g}$; the median was $0.82 \mu\text{g/g}$. The highest concentration of lead in the sediments from the stratified random sampling was $31 \mu\text{g/g}$ at 1-2P in Mangrove Lagoon. The lowest concentration detected was $0.371 \mu\text{g/g}$ at 4-50P in Cowpet Bay. The highest concentration from the 2010 targeted sampling was $81.2 \mu\text{g/g}$ at BB-2 in Benner Bay (Figure 18, Appendix H).

Variation of Lead Across Strata. A log10 transformation of the results failed to normalize the stratified-random sampling data. The data were subsequently ranked, and a Kruskal-Wallis test on the ranked data showed a significant ($p < 0.0001$) difference in the concentration of lead across the STEER. A Tukey HSD test indicated that Stratum

1 was significantly higher than Strata 3, 4, and 5. The concentration of lead in Stratum 2 was not significantly different from Stratum 1 or Stratum 3, but was significantly higher than in Strata 4 and 5.

Comparison with

Other Data. The mean concentration of lead in the sediments in the STEER analyzed by EMAP was 1.02 µg/g, lower than the mean concentration found in the STEER in the current study. In south-west Puerto Rico, Pait et al. (2008) detected a mean lead concentration of 1.93 µg/g, less than that found in the STEER. In Vieques, the mean lead concentration was 5.42 µg/g, close to that in the STEER. In Jobos Bay, the mean concentration of lead in the sediments sampled was 7 µg/g (Apeti et al., 2012b), also similar to the STEER.

The NS&T median sediment concentration

for lead is 22.3 µg/g. Only two sites (1-2P and 1-3P) from the stratified random sampling, both in Mangrove Lagoon, had lead levels above the NS&T median. The NS&T 85th percentile for lead is 39.1 µg/g. None of the sites in the STEER from the stratified random sampling had a lead concentration in the sediments above this level. From the 2010 targeted sampling, three of the four sites were above the NS&T median, with one site (BB-2) above the NS&T 85th percentile.

NOAA Sediment Quality Guidelines for Lead. The ERL for lead is 46.7 µg/g (Figure 18); the ERM is 216 µg/g. None of the randomly chosen sites had a concentration above the ERL. However, BB-2 (81.2 µg/g) from the 2010 targeted sampling had a concentration above the ERL, but still well below the ERM of 218 µg/g.

Effects of Sediment Grain Size. A nonparametric correlation analysis between lead and percent fines in the sediment

indicated a significant positive correlation (Spearman Rho = 0.7643, $p < 0.0001$).

Mercury. The concentrations of mercury detected in the sediments in the STEER are shown in Figure 19. The

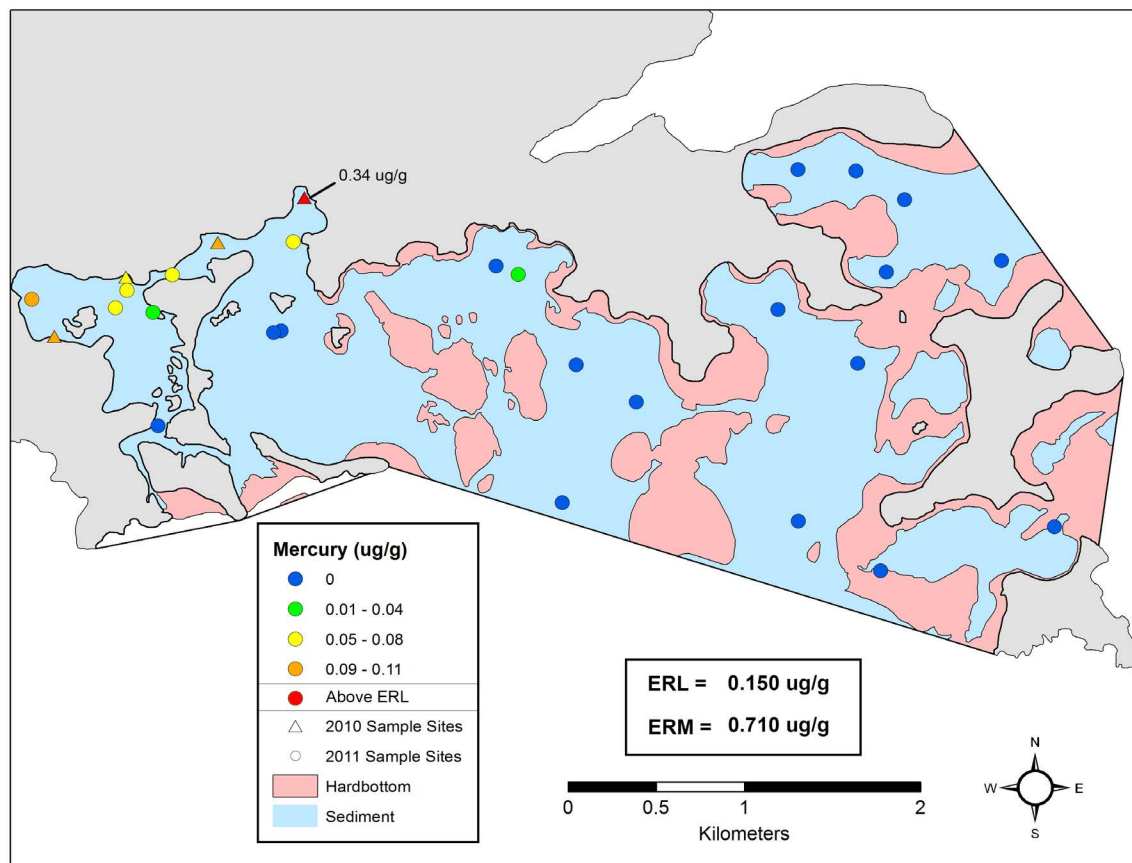


Figure 19. Mercury detected in sediments from the St. Thomas East End Reserves.

mean concentration of mercury in the sediments sampled in the STEER from the stratified random sampling was 0.019 ± 0.01 µg/g; the median was 0.002 µg/g. The highest concentration of mercury found from the stratified random sampling was in Mangrove Lagoon at site 1-1P (0.109 µg/g). The second highest mercury detection was also in Mangrove Lagoon at site 1-3P (0.081 µg/g). From the 2010 targeted sampling, the highest concentration found was at BB-2 (0.34 µg/g) in northern Benner Bay. As with a number of the other contaminants, higher concentrations of mercury were found in northern Benner Bay and in Mangrove Lagoon.

Mercury is found in crustal materials, and natural erosional processes can contribute to its presence in the marine environment, in addition to anthropogenic inputs. Coal-burning power plants are the largest human-caused source of mercury emissions to the air in the United States, accounting for over 50 percent of all domestic human-caused mercury

emissions (Eisler, 1987). As noted earlier, although many uses of mercury have been discontinued, mercury is currently used in fluorescent light bulbs and in various electrical switches.

Variation of Mercury Across Strata. A Kruskal-Wallis test run on the ranked mercury values indicated a significant difference ($p < .0001$) between strata, and a Tukey-HSD test indicated that Strata 1 and 2 were higher than Strata 3, 4, and 5.

Comparison with Other Data. Mercury was not detected by EMAP in the sediments in the STEER. The mean sediment concentration of mercury found in southwest Puerto Rico was $0.004 \mu\text{g/g}$. In Vieques, Pait et al. (2010) found a mercury concentration of $0.019 \mu\text{g/g}$, the same as in the STEER. Apeti et al. (2012b) detected a mean concentration of $0.042 \mu\text{g/g}$ mercury in sediments from Jobos Bay, higher than was found in the STEER. The NS&T median for mercury is $0.062 \mu\text{g/g}$.

There were five sites from the 2011 stratified random sampling that were above the NS&T median; all four sites from the 2010 targeted sampling were above the NS&T median. Site BB-2 ($0.34 \mu\text{g/g}$) was above the NS&T 85th percentile of $0.20 \mu\text{g/g}$.

NOAA Sediment Quality Guidelines for Mercury. NOAA has established both ERL and ERM values for mercury, which are included in Figure 19. There was one exceedence of the ERL for mercury ($0.150 \mu\text{g/g}$) at BB-2 in northern Benner Bay, with a concentration of $0.34 \mu\text{g/g}$, twice as high as the ERL, but below the ERM.

Effects of Sediment Grain Size. A nonparametric correlation between mercury and the percent fines of the sediment indicated a significant positive correlation (Spearman Rho = 0.8116 , $p < .0001$) between mercury and the smaller grain sizes of the sediments sampled in the STEER.

Nickel. The concentrations of nickel detected in the sediments in the STEER are shown in Figure 20. The mean concentration of nickel from the stratified random sampling was $6.53 \pm 0.57 \mu\text{g/g}$ and the median was $5.08 \mu\text{g/g}$. The highest concentration of nickel found from the stratified random sampling was in Mangrove Lagoon at site 1-1P ($15.1 \mu\text{g/g}$). The second highest nickel detection was also

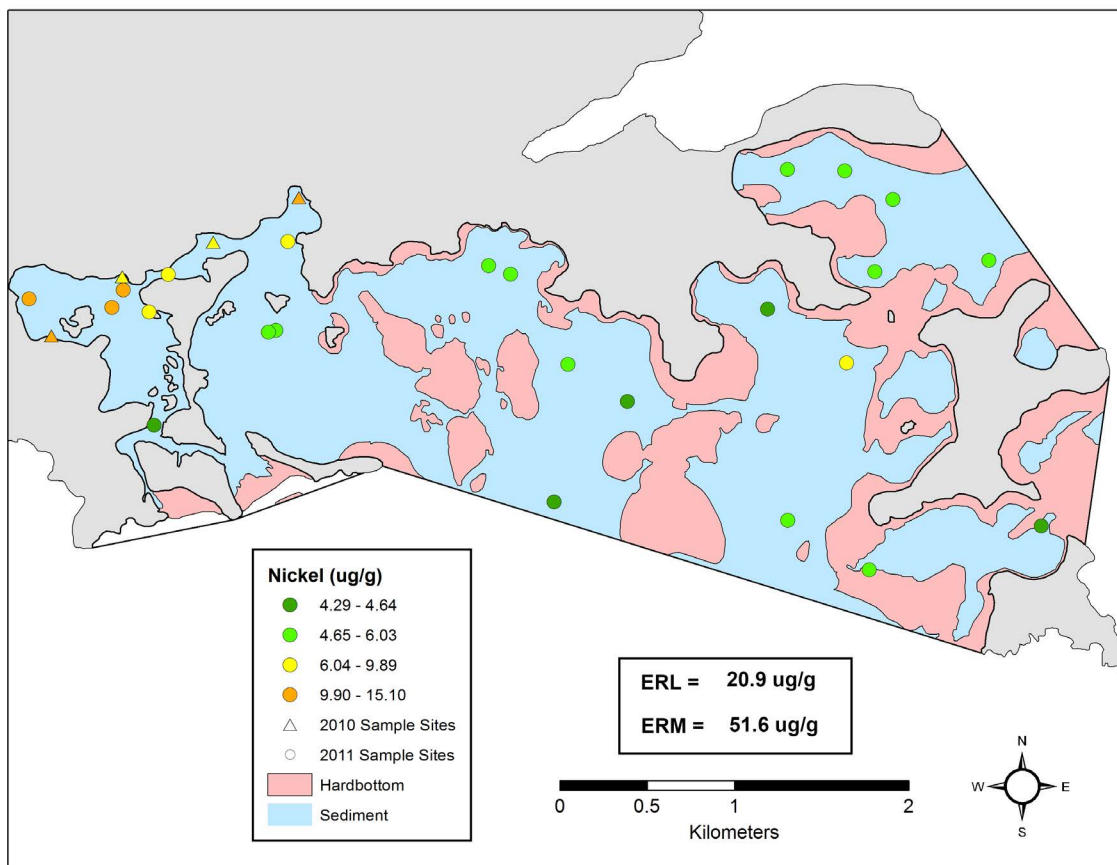


Figure 20. Nickel detected in sediments from the St. Thomas East End Reserves.

in Mangrove Lagoon at site 1-2P ($11.6 \mu\text{g/g}$). In fact, four of the highest nickel detections were in Mangrove Lagoon. From the 2010 targeted sampling, the highest concentration found was at ML-2 ($13.5 \mu\text{g/g}$) also in Mangrove Lagoon. As with other trace elements, nickel is found in crustal materials, and natural erosional processes can contribute to its presence in the marine environment, in addition to anthropogenic inputs.

Variation of Nickel Across Strata. As part of the analysis, an assessment was completed to look at the variation of nickel among strata. A Kruskal-Wallis test run on the ranked nickel values, however, indicated no significant difference ($p = 0.1395$) between strata.

Comparison with Other Data. EPA's EMAP collected sediments from four sites located within the STEER. The mean concentration of nickel in the sediments at these four sites

was 1.75 $\mu\text{g/g}$, lower than the mean found in the current study (6.53 $\mu\text{g/g}$). Even if the sites from Mangrove Lagoon are excluded, the mean concentration of nickel found in the sediments in the STEER outside of Mangrove Lagoon was 5.49 $\mu\text{g/g}$. The mean sediment concentration of nickel found in southwest Puerto Rico was 26.6 ± 14.1 , due in part to some substantially elevated levels at two sites within Guanica Bay (Pait et al., 2008). If the two sites in Guanica Bay are left out of the calculation, the mean concentration in the study area in southwest Puerto Rico was 6.48 ± 1.03 $\mu\text{g/g}$, similar to what was found in the STEER. In Vieques, Pait et al. (2010) found a nickel concentration of 7.80 ± 1.07 $\mu\text{g/g}$, again similar to the STEER. Apeti et al. (2012b) detected a mean concentration of 10.2 $\mu\text{g/g}$ nickel in sediments from Jobos Bay, higher than was found in the STEER. The NS&T median for nickel is 25.1 $\mu\text{g/g}$, higher than any concentration found in the STEER, either through the stratified random or the targeted sampling.

NOAA Sediment Quality Guidelines for Nickel. NOAA has established both ERL and ERM values for nickel, which are included on Figure 20. All of the sediment samples from the STEER were below the ERM and the ERL. However, a number of sites within Mangrove Lagoon, particularly 1-1P (15.1 $\mu\text{g/g}$), approached the ERL.

Effects of Sediment Grain Size. A non-parametric correlation between nickel and the percent fines of the sediment indicated a significant positive correlation (Spearman Rho = 0.6583, $p = 0.0005$) between nickel and the smaller grain sizes of the sediments sampled in the STEER.

Zinc. The results of the analysis of zinc in the sediments collected in the STEER are shown in Figure 21. The mean zinc concentration in the sediments from the stratified ran-

dom sampling was 37.3 ± 10.7 $\mu\text{g/g}$; the median was 11.1 $\mu\text{g/g}$. The highest concentration of zinc from these collections was found at site 1-2P, at 159 $\mu\text{g/g}$. The second highest zinc concentration from the stratified random sampling was also in Mangrove Lagoon at site 1-3P, with a concentration of 154 $\mu\text{g/g}$.

From the 2010 targeted sampling, the highest zinc concentration detected was 392 $\mu\text{g/g}$ in Benner Bay (BB-2), followed by 192 $\mu\text{g/g}$ in BB-1, also in Benner Bay. As with a number of the other contaminants included in this report, higher concentrations were found in northern Benner Bay and in Mangrove Lagoon.

Variation of Zinc Across Strata. A Kruskal-Wallis test on the ranked values from the stratified random sampling indicated zinc varied significantly ($p = 0.0006$) by stratum, and

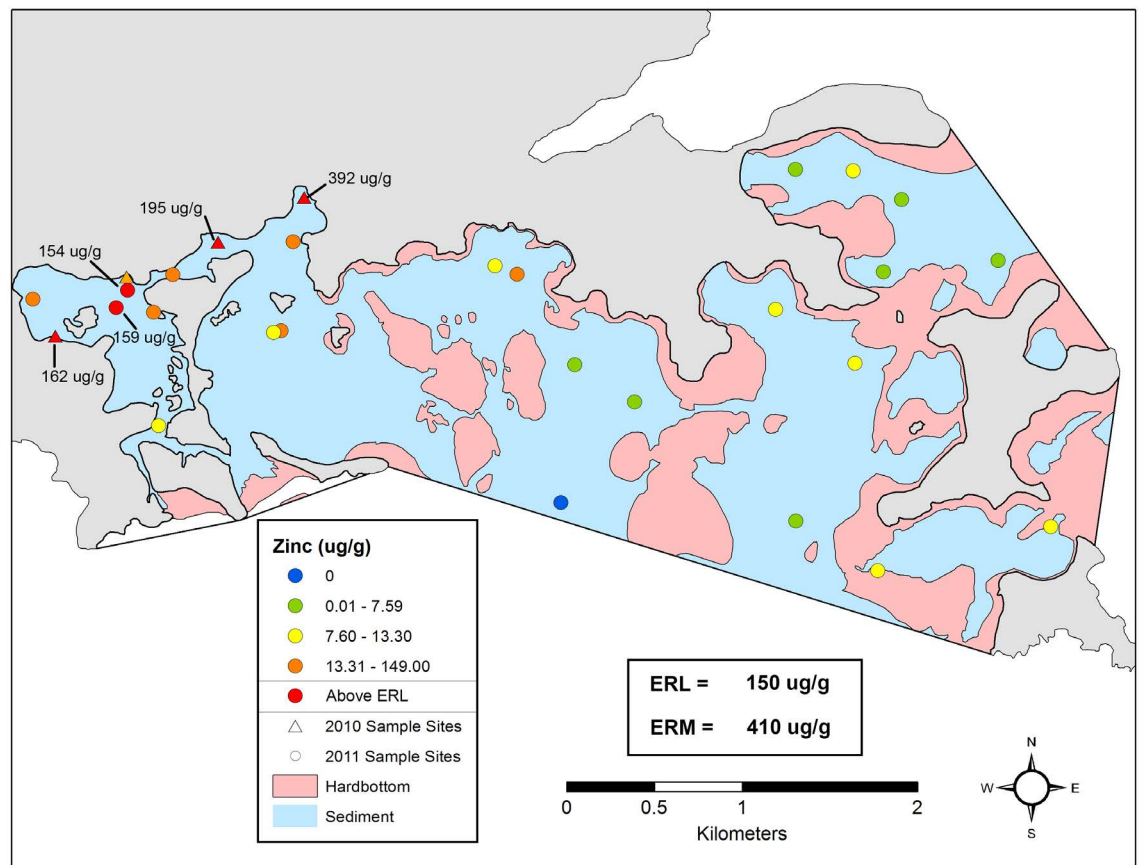


Figure 21. Zinc detected in sediments from the St. Thomas East End Reserves.

the Tukey-Kramer HSD test indicated that Stratum 1 and 2 were significantly different (higher) from Stratum 5.

Comparison with Other Data. The mean for the four samples that EPA's EMAP collected outside of Mangrove Lagoon in the STEER was 5.8 $\mu\text{g/g}$, substantially below the mean for the STEER in the current project. If the samples within Mangrove Lagoon are left out, the mean for

the STEER is 18.4, still higher than was found by EMAP.

The concentration of zinc detected in the STEER can also be compared with work completed in southwest Puerto Rico. Pait et al. (2008) detected a mean zinc concentration of 8 µg/g, below the mean found in the STEER. In Vieques, Pait et al. (2010) calculated a mean zinc concentration of 34.4 µg/g, similar to what was found in the STEER. In Jobos Bay, Apeti et al. (2012b) found a mean zinc concentration of 54.7 µg/g, somewhat higher than what was found in the STEER.

The NS&T median for zinc is 74 µg/g; the 85th percentile is 143 µg/g. From the stratified random sampling, there were six sites above the NS&T median, and two sites (1-2P and 1-3P) above the NS&T 85th percentile (Appendix H.). From the 2010 targeted sampling, three (BB-2, BB-1, and ML-2) of the four sites analyzed were above the NS&T 85th percentile.

NOAA Sediment Quality Guidelines for Zinc. The ERL for zinc is 150 µg/g. There were two sites (1-2P and 1-3P) from the stratified random sampling that exceeded the ERL. From the 2010 targeted sampling, three of the four sites (BB-2, BB-1, and ML-2) analyzed exceeded the ERL. The results of this analysis indicate that some of the more sensitive species or life stages in both Benner Bay and Mangrove Lagoon could begin to experience effects related to the elevated levels of zinc. In addition, any additive effects that may be present as a result of multiple contaminants (e.g., TBT and copper) from this area are unknown. None of the sites exceeded the ERM, however, BB-2 (392 µg/g) from the 2010 targeted sampling was fairly close to the zinc ERM of 410 µg/g.

Effects of Sediment Grain Size. Finally, the non-parametric Spearman's analysis between zinc and the sediment percent fines indicated a significant positive correlation (Spearman Rho = 0.5678, $p = 0.0038$) between zinc and the smaller grain sizes of the sediments sampled in the STEER. The correlation between zinc and percent clay (Spearman Rho = 0.7270, $p < 0.0001$) appeared somewhat higher than silt (Spearman Rho = 0.5235, $p = 0.0038$).

Normalization of Trace Elements. The range of concentrations of individual metals was highly

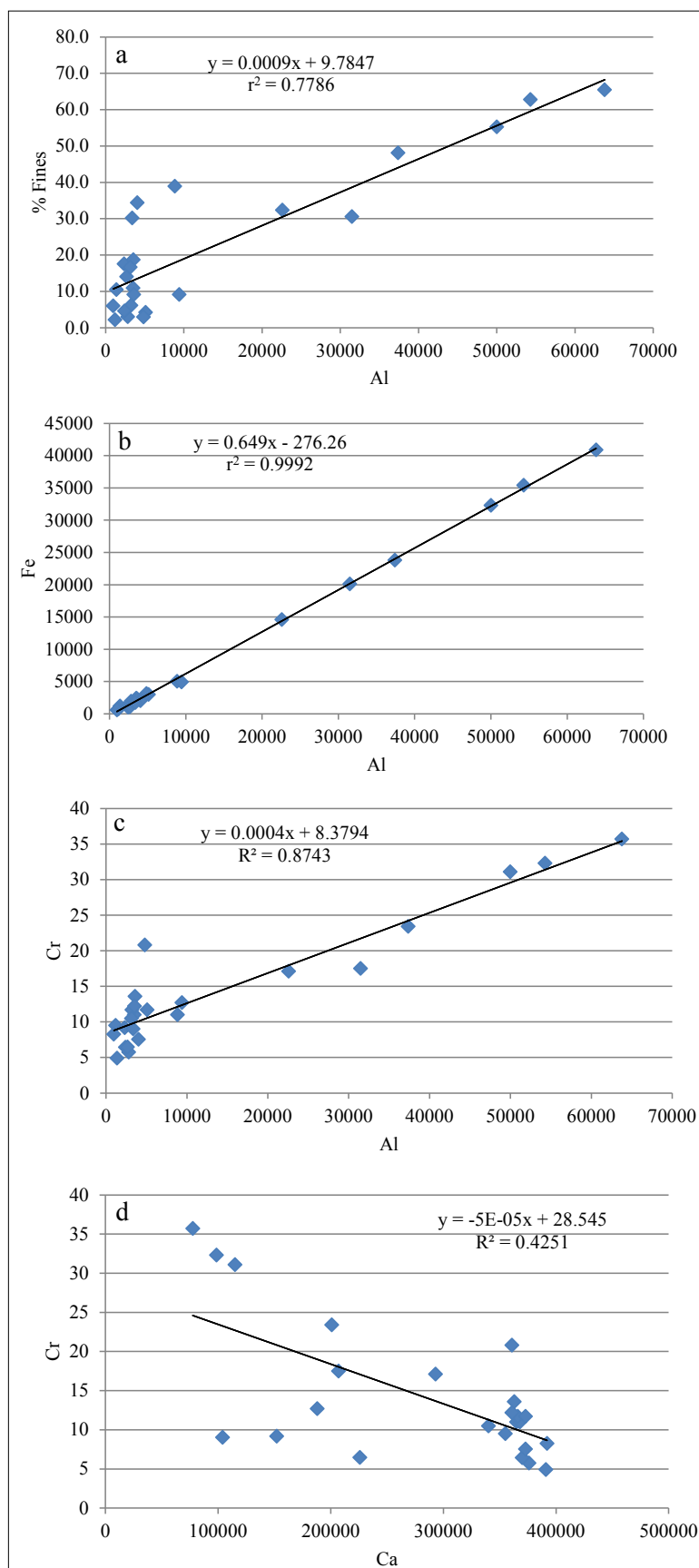


Figure 22. Normalization of aluminum to %fines (a), aluminum to iron (b), aluminum to chromium (c) and calcium to chromium (d) in sediments from the STEER.

variable across the STEER (Appendix H). Copper concentrations varied by a factor of up to 119, while nickel varied only by a factor of 3.5. Silver was not detected at any site. Cadmium, antimony, and elemental tin were above detection limits only in Mangrove Lagoon and one or two locations in Benner Bay.

Copper and zinc were above ERLs at one or more sites, but none exceeded an ERM level at any of the randomized sites. BB-2 from the 2010 sampling did exceed the ERM level for copper. Metal concentrations are generally correlated with sediment grain size.

Concentrations of aluminum, iron, and trace metals correlate well with concentrations of the percent fines because concentrations of both aluminum and most metals are very low in coarse-grained quartz sand or carbonate shell material and much higher in fine-grained aluminosilicates (Figure 22a). Aluminum and iron in sediments are derived from terrestrial sources resulting from watershed erosion and are rarely introduced above background levels by anthropogenic activities other than metal production facilities. They are present at percent levels in most sediment as opposed to part per million levels for trace metals and exhibit a very close relationship (Figure 22b). Because the metals are primarily derived from terrestrial erosion, sediment aluminum has a much closer relationship to the trace metals such as chromium (especially in fine grained sediment) than sediment calcium because the origin of the calcareous sands is not terrestrial (Figure 22c and d).

Coarse grained sediments generally contain high levels of silica or carbonate depending on their origin. In temperate systems, silica is the predominant element in coarse sand and exhibits an inverse relationship with aluminum or iron, which predominate in fine grained sediment. In tropical island systems, sources of silicates are limited, and the dominant source of coarse grained sediments is calcium carbonate from organic sources. Aluminum and calcium thus have an inverse relationship (Figure 23a). For this study, concentrations of trace metals were normalized to Al to assess locations where unusually high concentrations of trace metals may indicate anthropogenic inputs, above that expected as background. The relationships between aluminum and copper, zinc, and mercury can be seen in

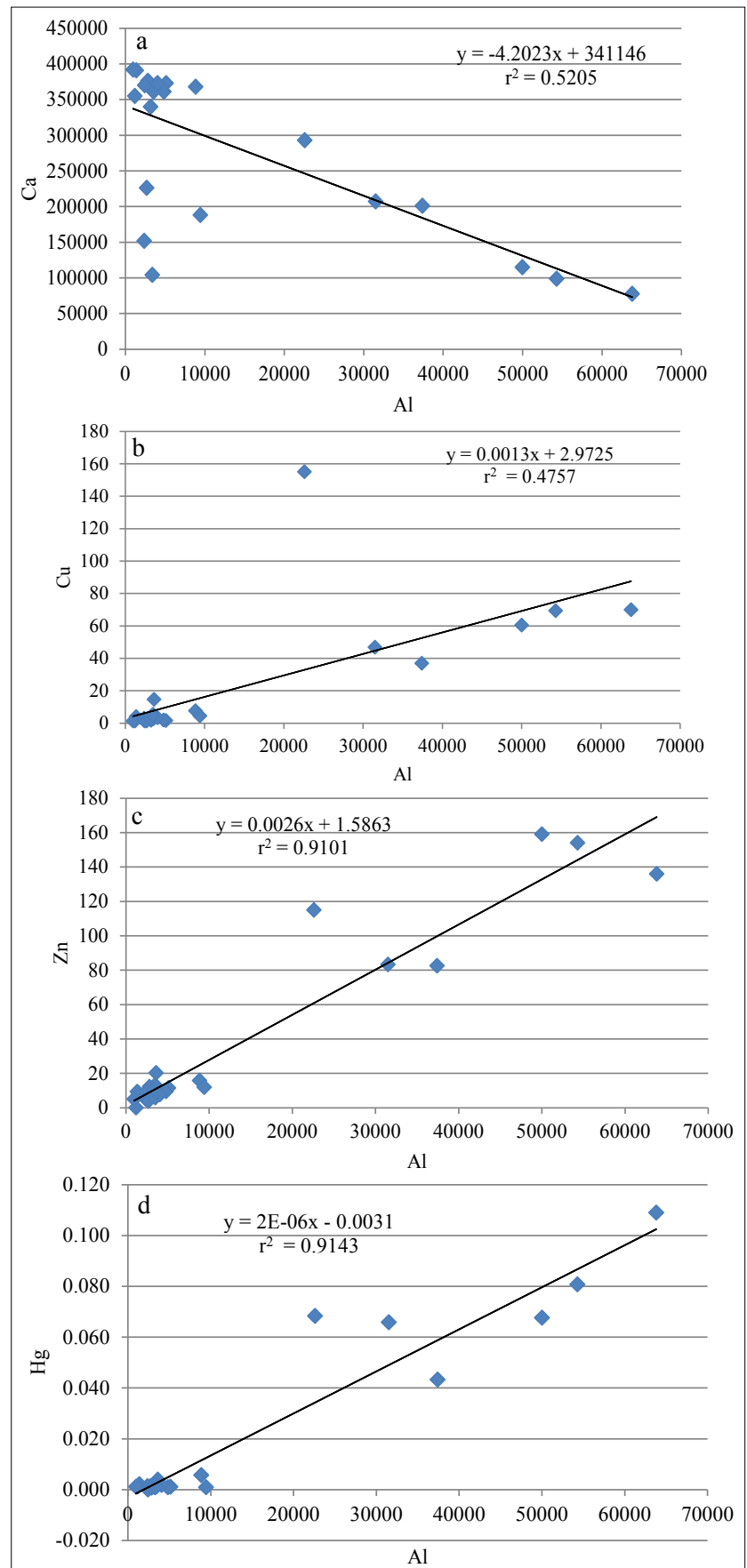


Figure 23. Normalization of aluminum to calcium (a), aluminum to copper (b), aluminum to zinc (c), and aluminum to mercury (d) in sediments from the STEER.

Figure 23 b-d, respectively. It is evident that copper, zinc, and mercury are found at a few selected sites at concentrations above that which would be predicted based upon background aluminum levels. All of these sites are in either Mangrove Lagoon or Benner Bay. It should also be noted that the concentrations of aluminum and iron are considerably higher in Mangrove Lagoon and Benner Bay than in the other strata, indicating that terrestrial sources of sediment are more dominant there than in the rest of the STEER. Additional regressions of aluminum and calcium versus the trace elements can be found in Appendix I.

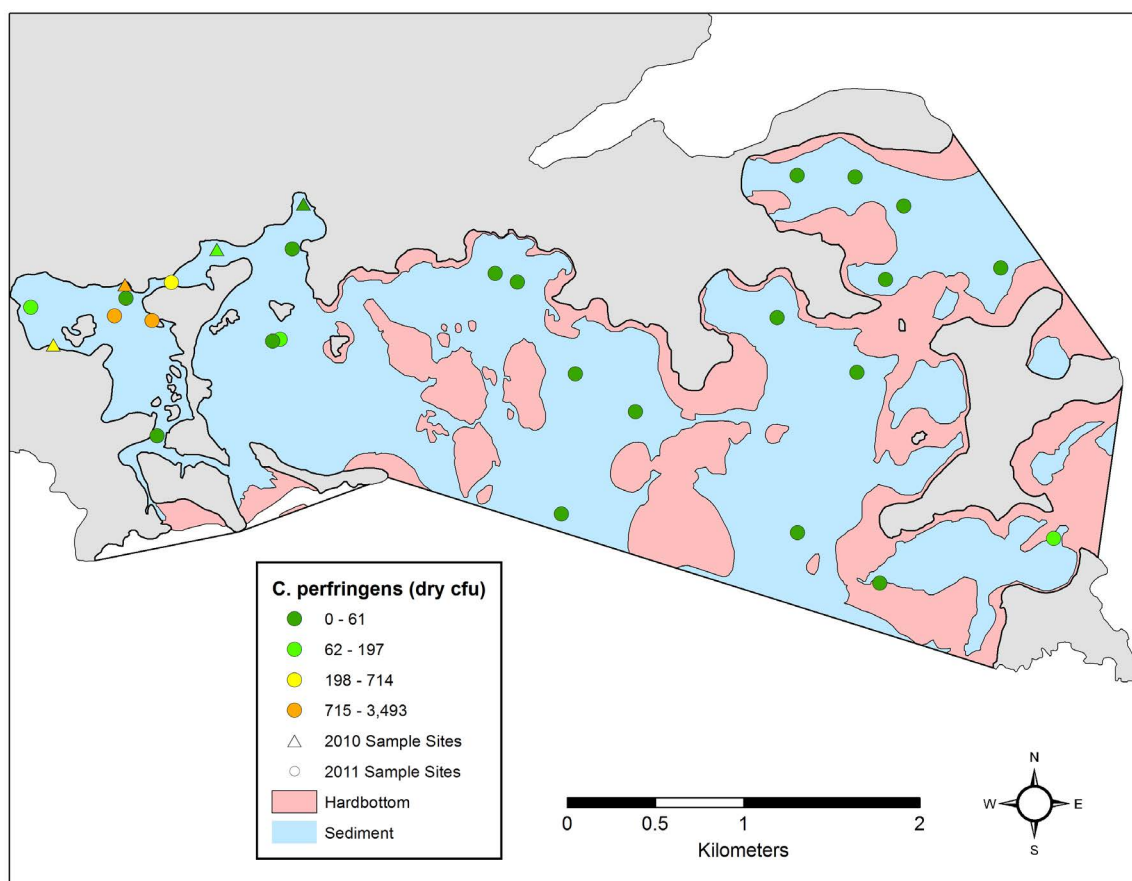


Figure 24. *Clostridium perfringens* detected in sediments from the St. Thomas East End Reserves.

the highest concentration of *C. perfringens* found was at ML-10, also at the mouth of Turpentine Gut (2,558 CFU/g).

Clostridium perfringens. Although this species bacteria is not a chemical contaminant, it is often included in the analyses done by NOAA's NS&T Program. This anaerobic, gram-positive staining rod-shaped bacteria frequently occurs in the intestines of humans, as well as in domestic and wild animals, and has been used as a sewage indicator. The results of the analysis of sediments for *C. perfringens* are shown in Figure 24 and in Appendix J. Higher levels of *C. perfringens* were found primarily in Mangrove Lagoon, with lower concentrations in most other locations.

To assess the presence of viable *C. perfringens*, sediment extracts are plated on growth medium and the number of colonies that develop are counted. The mean *C. perfringens* concentration in the sediments was 291 ± 167 CFU/g (colony forming units per gram of dry sediment). The sediment sample from 1-2P contained 3,493 CFU. Site 1-3P had a *C. perfringens* count of 2,137 CFU/g. Both 1-2P and 1-3P are near the mouth of Turpentine Gut, as it enters Mangrove Lagoon, which may be indicative of input from septic systems, domestic animals such as dogs, and from a nearby horse race track. From the 2010 targeted sampling,

Variation of C. perfringens Across Strata. A Kruskal-Wallis test run on the ranked *C. perfringens* data indicated a significant difference ($p < 0.0001$) between strata. A Tukey HSD test indicated that Strata 1 and 2 were significantly different (higher counts) from Strata 3, 4 and 5.

An analysis of *C. perfringens* and grain size was also carried out. A strong ($p = 0.0010$) correlation was found between the log10 normalized *C. perfringens* data and percent fines. A nonparametric analysis indicated a significant negative correlation between *C. perfringens* and percent sand (Spearman Rho = -0.6342 , $p = 0.0009$), and no correlation between *C. perfringens* and percent gravel (Spearman Rho = 0.1907 , $p = 0.3722$).

Sediment Quality Guidelines and C. perfringens. No NOAA or other health guidelines exist for *C. perfringens* in sediments. *C. perfringens* is a common cause of food-borne illnesses. A more severe form of the disease can be fatal and results from ingesting large numbers of the active bacteria, typically from food. *C. perfringens* also has the capability of forming spores which can persist in soils and sediments.

The high levels of *C. perfringens* within Mangrove Lagoon indicate there is a need to reduce wastewater, stormwater and various sources of inputs for this pathogen, and other pathogenic microorganisms that may be present as well. Reducing the levels of bacterial contamination would not only benefit ecological health, but human health as well.

Sediment Toxicity

The use of sediment toxicity bioassays, along with the benthic infaunal community analysis, provides important information on the impacts of the chemical contaminants found in the STEER sediments. While the NOAA ERM and ERLs provide an indication of the likelihood of effects from one chemical contaminant or chemical contaminant class, the bioassays (and the benthic community analysis) integrate the effects of all contaminants present along with other environmental parameters. For this project, the sediment toxicity bioassays included amphipod (*Ampelisca abdita*) mortality, sea urchin (*Arbacia punctulata*) fertil-

Table 4. Toxicity bioassay summary results from the STEER.

Site	Amphipod Mortality (%) Different from Control	Sig	Sea Urchin Fertilization Failure (%) Different from Control	Sig	P450 Response	BaP Eq. (ng/g)
1-1P	10.31		23.7	*	4.94	5.64
1-2P	14.43	*	14.5	*	13.79	12.98
1-3P	4.12		8.2		14.24	44.83
1-4P	7.22		6.3		9.86	0.12
1-5P	15.46		97.6	*	15.66	0.80
2-16P	12.37	*	40.4	*	11.12	8.33
2-19P	4.12		2.9		2.39	
2-20P	8.25		0.0		13.35	1.78
2-24A	13.40		5.1		2.88	
3-32P	10.31		15.5	*	15.64	8.58
3-33P	7.22		65.9	*	2.47	
3-37A	10.31		9.2		3.36	
3-38A	7.22		0.0		4.76	2.03
3-45A	47.42	*	0.0		2.49	
4-46P	29.90	*	30.5	*	2.20	
4-47P	21.65	*	13.8		2.75	
4-48P	12.37		13.3		1.23	
4-49P	10.31		18.2	*	2.73	
4-50P	37.11	*	6.8		1.49	
5-61P	9.28		0.0		1.45	
5-62P	22.68	*	3.6		1.90	
5-70A	53.61	*	0.2		5.57	
5-71A	4.12		5.8		3.14	0.97
5-75A	28.87	*	13.6		2.15	
* - statistically significant from control						

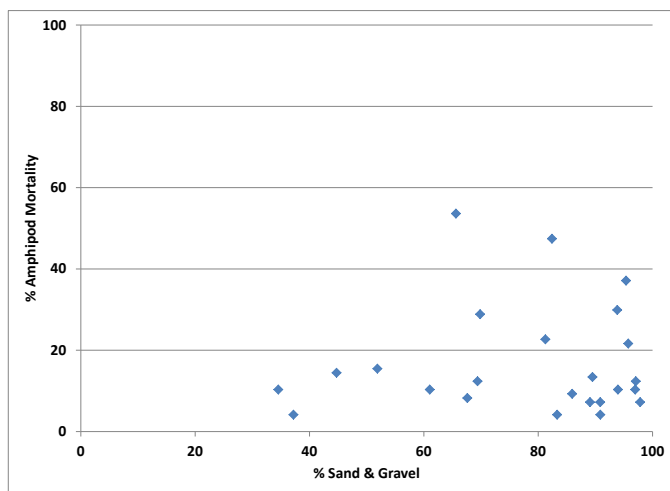


Figure 25. Amphipod mortality vs % sand and gravel in St. Thomas STEER sediments.

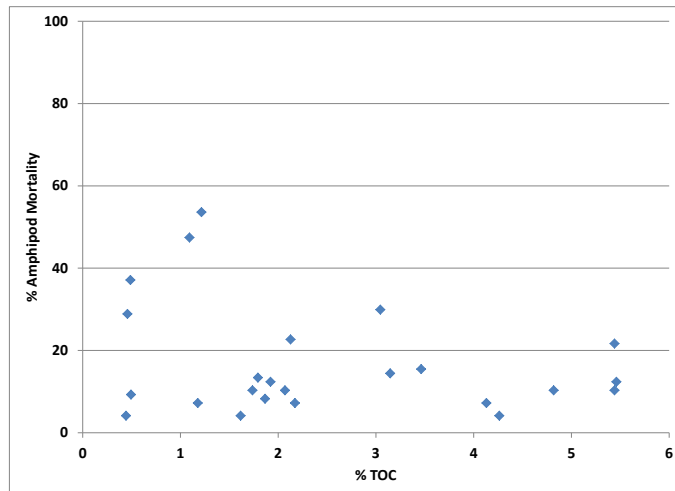


Figure 26. Amphipod mortality versus % total organic carbon in the STEER sediments.

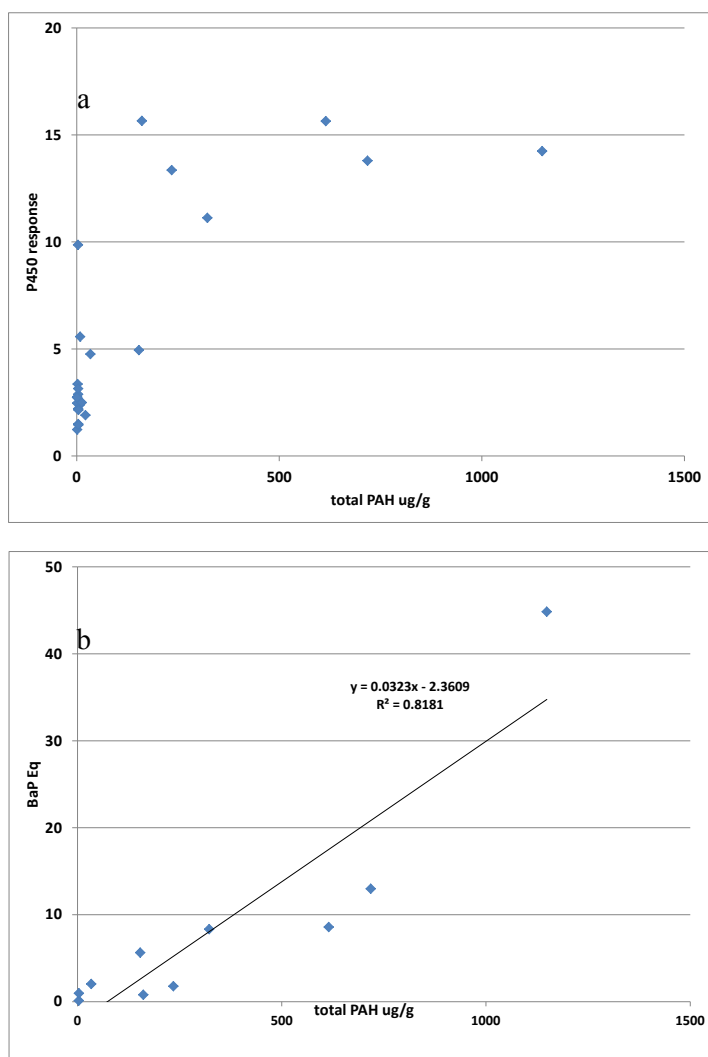


Figure 27. P450 response vs PAH concentrations (a), P450 response in terms of B[a]P eq for the subset of samples that exceeded the TCDD standard response (b).

ization impairment, and cytochrome P450 Human Reporter Gene System (HRGS) response tests.

The bioassay results for all tests are summarized in Table 4. All values are control corrected. Significant amphipod mortality occurred throughout the STEER study area. The highest mortality values observed were in the eastern strata. This may be influenced by sediment grain size. The amphipod *A. abdita* normally live in silty sand habitats and may not thrive well in coarse sand (ASTM, 2008), however, this has not been tested rigorously.

Amphipod Toxicity. All the amphipod bioassays with mortality elevated above 20% were in sediments that were greater than 60% sand and gravel (Figure 25). Other parameters (e.g. higher TOC) may ameliorate this effect. Most of the highly toxic amphipod results were in coarse sand with very low TOC (Figure 26).

Table 5. Average (n = 3) P450 bioassay response following 6 and 24 hour incubation with STEER sediment extracts.

Site	6 Hour Response	24 Hour Response
1-1P	104.9	13.3
1-2P	113.3	24.7
1-3P	117.3	35.0
1-4P	78.5	10.4
1-5P	129.8	14.1
2-16P	89.7	22.6
2-19P	12.3	3.53
2-20P	113.4	29.0
2-24A	17.3	1.37
3-32P	134.4	41.0
3-33P	39.0	3.00
3-37A	21.6	9.24
3-38A	100.0	9.44
3-45A	39.8	5.22
4-46P	11.0	3.19
4-47P	16.1	3.28
4-48P	6.12	1.74
4-49P	15.9	1.86
4-50P	13.0	2.46
5-61P	11.9	0.30
5-62P	24.0	1.42
5-70A	42.0	3.84
5-71A	57.0	5.17
5-75A	30.6	3.26
clean	4.44	0.56
blank	-1.39	0.10
spike	125.5	46.5
contam	123.2	55.9

Values are expressed as % of the 10nM TCDD standard response. QA/QC samples: blank = solvent blank; clean = uncontaminated site in the Chesapeake Bay; contam = contaminated site in Chesapeake Bay; spike = spiked solvent solution.

Sea Urchin Fertilization. Half of the significant sea urchin fertilization bioassays were in sediment from Mangrove Lagoon or the canal joining it to Benner Bay (Table 4). Jersey Bay and St. James Bay also showed significant results in two locations.

P450. Most of the significant P450 responses were in the western strata, including all of the Mangrove Lagoon sites. Further testing of those samples that exceeded 50%

of the 10 nM TCDD standard are also presented in Table 4 in terms of B[a]P eq. The P450 response in terms of B[a]P eq is strongly correlated with PAH concentrations (Figure 27).

Results of the timed exposure (6 vs 24 hrs) to test for the relative contribution of labile versus persistent contaminants are shown in Table 5. In all cases, the 6 hr incubation showed a higher response than the 24 hr incubation (Figure 28). This also indicates that the predominant chemical classes the cells were responding to were PAHs, as they are more easily degraded than the more recalcitrant PCBs. It is noteworthy that the level of response in Mangrove Lagoon and portions of Benner Bay and Cowpet Bay exhibit initial responses as high as the spiked sample and the positive control.

Taken together, the bioassay results indicate a significant gradient of effect from west to east within the STEER (Figure 29). Toxic responses occurred in all strata, but the western portion of the study area exhibited significant results from multiple bioassays. As noted above, several of the amphipod bioassay results may be an artifact of the coarse coralline sediment present in many of the eastern sites (Strata 4 and 5, Appendix B).

With the exception of TBT and copper, extremely high concentrations of individual chemical pollutants were not seen. However, the observed widespread toxicological responses indicate the interaction of a variety of factors, including multiple contaminants, physicochemical characteristics of the sediment, and likely chemical pollutants beyond the standard list of analytes that may vary from stratum to stratum. Additional statistical correlation analyses are in progress.

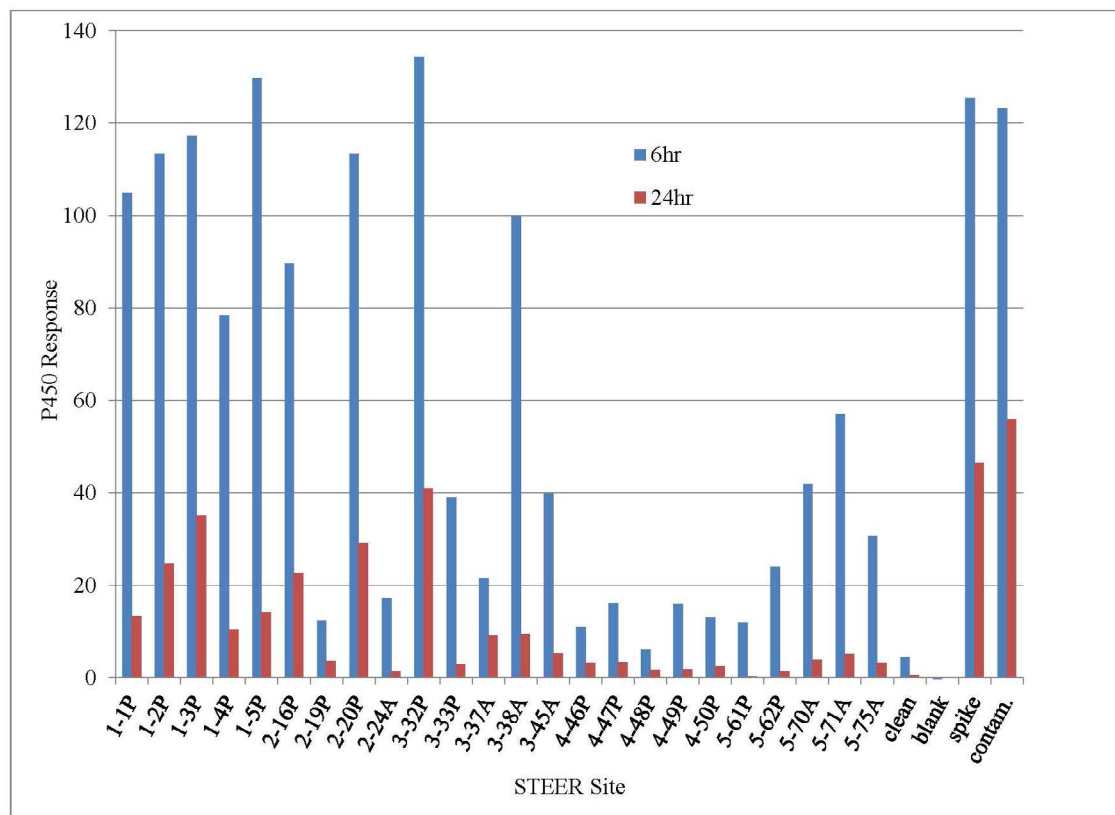


Figure 28. P450 response (normalized to standard 10nM TCDD) following 6 and 24 hour exposures to extracts from St. Thomas STEER sediment samples. (QA/QC samples; blank=solvent blank; clean=uncontaminated site in Chesapeake Bay; contam.=contaminated site in Chesapeake Bay; spiked solvent solution).

Benthic Community Analysis

A total of 10,926 organisms were enumerated, comprised of 434 taxa (species or higher taxonomic level). Following elimination of epibenthic species (dwelling on hard surfaces, not within the sediment) and 'artificial' species (see page 13), there were 333 taxa and 10,605 individuals for analysis. There were 168 rare and unique taxa. One hundred fifty seven taxa were found at only one location. Annelids were the dominant taxa, accounting for 59.2% of all the organisms. Mollusks and arthropods accounted for 19.2 and 15.7%, respectively. Less than 1% of the animals were echinoderms. Throughout the STEER, abundance was dominated by two dozen taxa that were found throughout most strata and a large number of taxa only represented by a few individuals (Figure 30).

Abundance was more uniform on average than diversity or number of species, but some locations had extremely low abundance and some sites were extremely high (Figure 31). Site 1-1P in Mangrove Lagoon only had 4 species and five organisms in total. Site 2-16P had over 1,000 organisms.

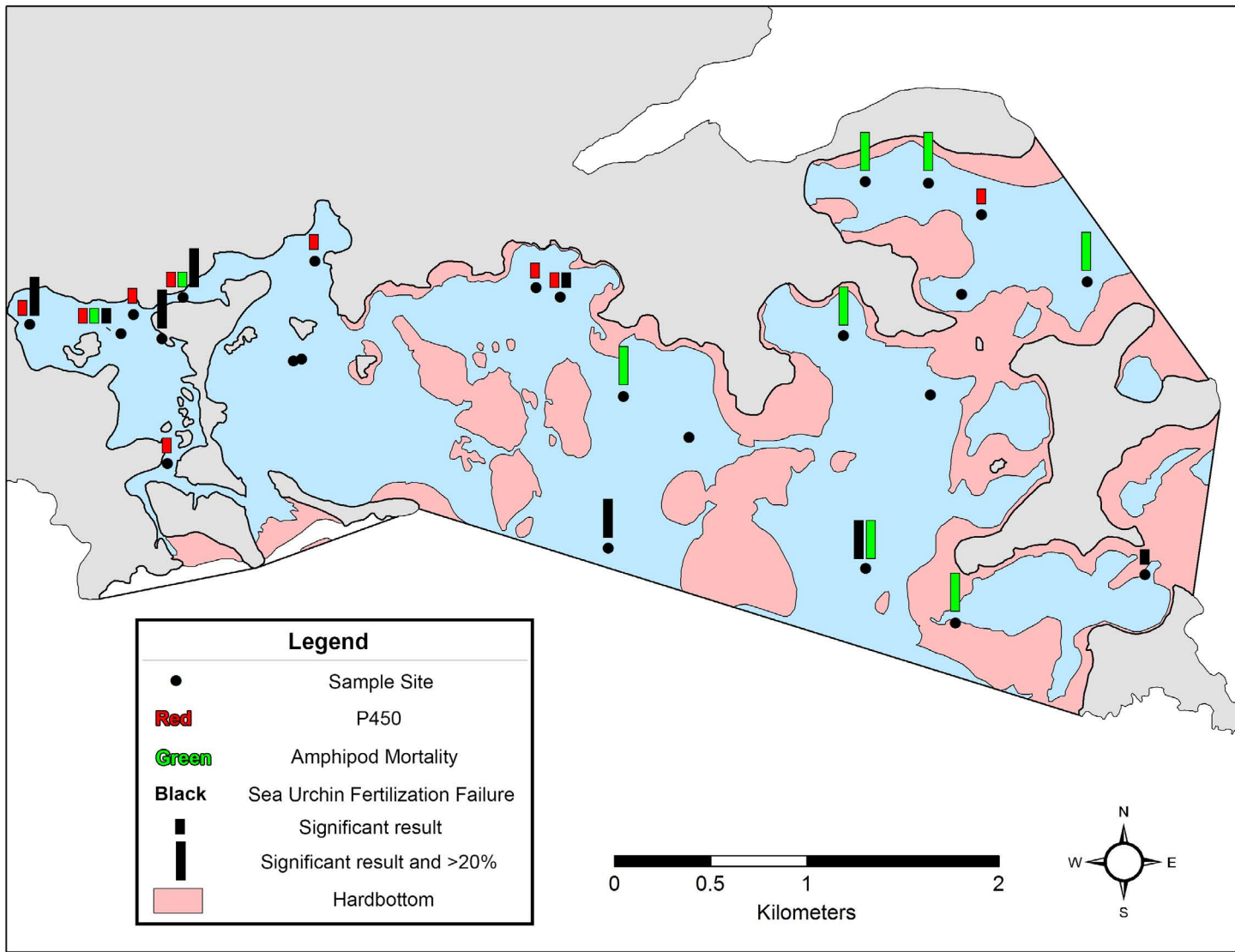


Figure 29. Distribution of bioassays showing responses that were significantly different than controls or greater than a standard threshold (P450) in St. Thomas STEER sediments.

Gradients of diversity and species richness were seen from low in the west to higher in the eastern strata (Figure 32). With two exceptions (Sites 1-4P and 2-19P), diversity was higher in the eastern strata than in Mangrove Lagoon and Benner Bay.

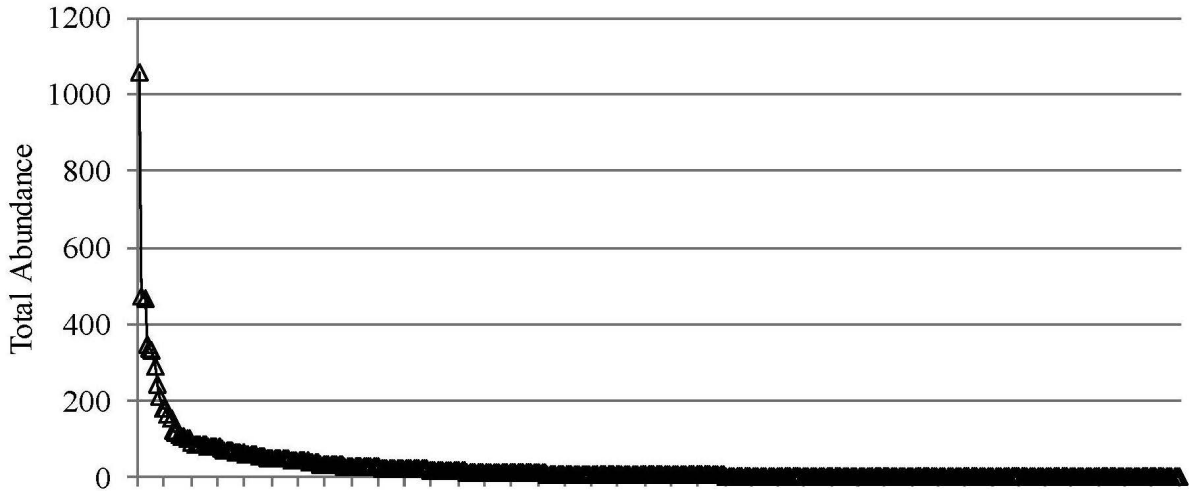


Figure 30. Plot of total abundance of each taxa used in the analyses. Each triangle represents the total abundance of each individual taxa collected in the STEER.

These are reflected in the calculated correlation coefficients. Number of species and diversity were negatively correlated with the ERMq, (Table 6). The ERMq is calculated by dividing the concentration of each contaminant analyzed in the sediment by its available ERM to produce a quotient. Number of species and diversity were positively correlated with stratum. There were no significant correlations with amphipod mortality or sea urchin fertilization failure. The number of species and diversity were significantly and negatively correlated with the PAH benzo[a]pyrene concentrations. A similar pattern was seen with respect to the percentage of fines in the sediments, and sand plus gravel showed the inverse.

Nodal Analysis. The nodal analysis revealed two site groups and three species groups. The site groups divided cleanly between

Stratum 1 and 2 (Mangrove Lagoon and Benner Bay) vs 3, 4, and 5. There was almost no overlap in species makeup between the site groups. In Mangrove Lagoon and Benner Bay, there were 25 species, versus 109 species found in the other three strata. Species that were found in Mangrove Lagoon and Benner Bay were generally rarely found or were completely absent in the other three strata, and vice versa. The three species groups corresponded to the site groups. Mangrove Lagoon and Benner Bay have a different species assemblage than the other three strata, and were dominated by polychaete worm species that are

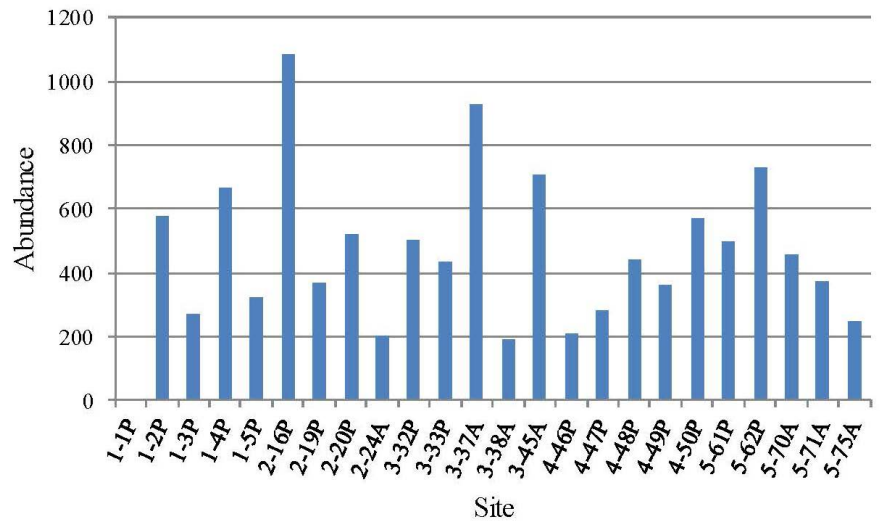


Figure 31. Total animal abundance at each station in the STEER.

neither widespread nor numerous in the rest of the STEER. Strata 3, 4 and 5 shared a common assemblage of species.

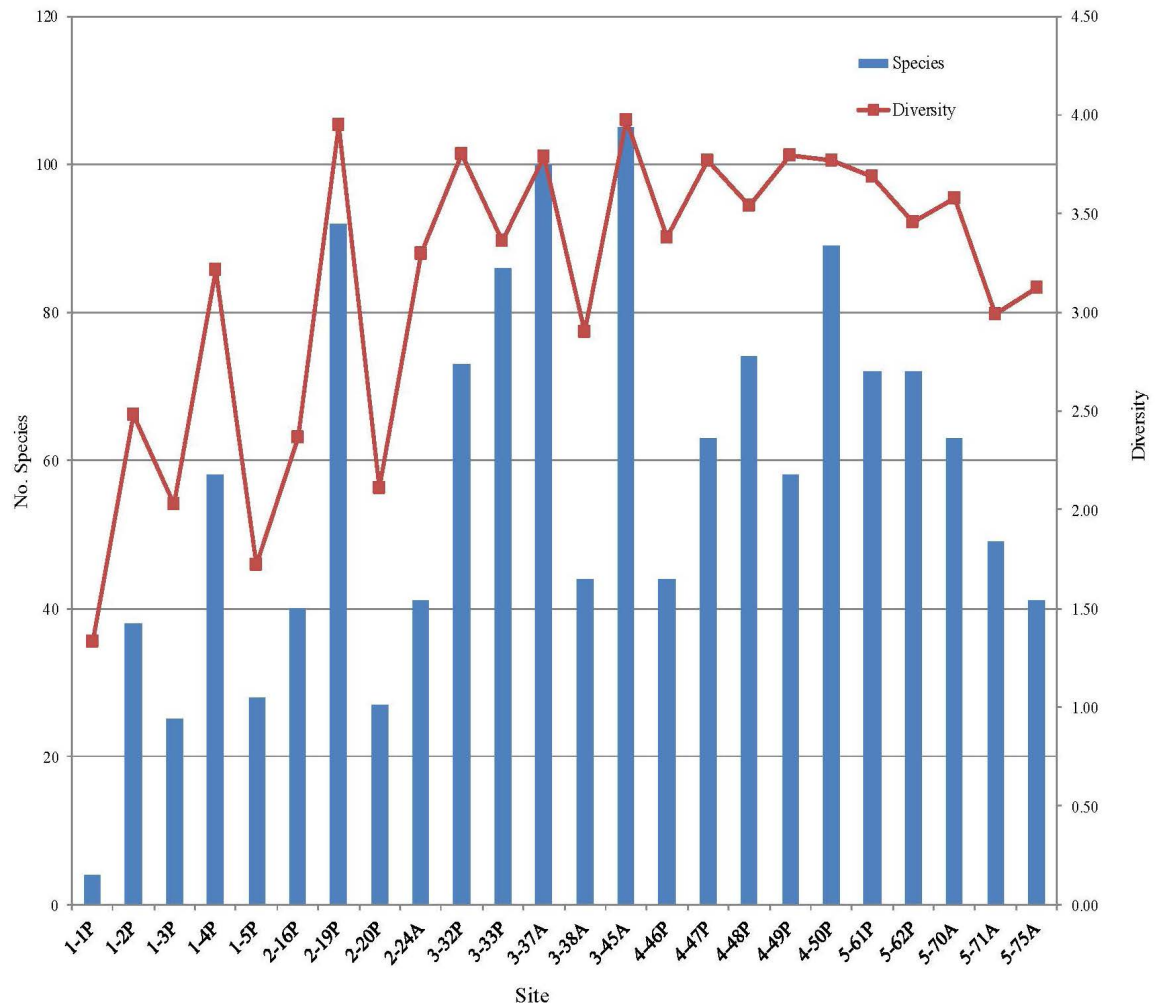


Figure 32. Total number of species (taxa) and calculated diversity at each station in the STEER.

Table 6. Spearman Rank correlation coefficients (bold) and significance level for community parameters and selected physical and chemical parameters, and toxicological results.

Parameter	Statistics	ERMq	Stratum	Amphipod Mortality	Fertilization Failure	B[a]P	%Silt and %Clay (Fines)	%Sand and %Gravel
Species	Spearman Rho	-0.65154	0.44292	0.12172	-0.25736	-0.64343	-0.62068	0.62068
	Significance	0.0006	0.0302	0.571	0.2247	0.0007	0.0012	0.0012
Abundance	Spearman Rho	0.16565	0.04081	0.13534	-0.16166	-0.01359	0.01913	-0.01913
	Significance	0.4392	0.8498	0.5283	0.4505	0.9497	0.9293	0.9293
Diversity	Spearman Rho	-0.56542	0.47125	0.22625	-0.24324	-0.65588	-0.55937	0.55937
	Significance	0.004	0.0201	0.2877	0.2521	0.0005	0.0045	0.0045

The third group of 26 species were found at sites 1-4P and 2-19P (hereinafter referred to as excluded sites). These species were rarely found elsewhere in either Mangrove Lagoon and Benner Bay, or the other three strata. These two sites had a unique species assemblage, different from the other areas. Site 1-4P in the lower part of Mangrove Lagoon away from the influence of Turpentine Gut and the landfill, and 2-19P in central Benner Bay have sediment that is predominantly sand, unlike most of the other sites in those strata. These two locations shared a number of species found within Strata 1 and 2, but also another set of species that were much more diverse and included polychaetes, crustaceans, bivalves and snails. Again, the dominant species in these two sites are unlike the dominants in Strata

1 and 2, and the other strata in the STEER (Tables 7 and 8) as well.

SIMPER Analysis.

The difference in dominant species between strata is also illustrated in the results from the SIMPER analysis. Figure 33 shows the similarity index values for Strata 1 and 2 (Mangrove Lagoon and Benner Bay, respectively), and the values for the excluded sites (excluded from

the Stratum 1 and 2 lists), ranked from highest to lowest. Only a small number of species have high scores in Strata 1 and 2. That is, only a few are dominant. In contrast, none of the species in the two excluded sites have high scores. They are all equally important in defining the community make-up. The top 15 species in each group are listed in Table 7. Species highlighted in yellow were found in both Strata 1 and 2 (the colors are arbitrary). The strata have very similar dominant species makeup (there are many overlapping species that have high index values in both strata). Only two of the top species found in the excluded sites were present in both Strata 1 and 2. Thus, the species that are considered 'typical' in Strata 1 and 2 were generally not 'typical' in the

Table 7. Results of SIMPER analysis. Taxa highlighted in green were cosmopolitan and were found in all strata. Taxa highlighted in yellow were found in strata 1 and 2.

Stratum 1		Stratum 2		Excluded Sites	
Index Value	Species	Index Value	Species	Index Value	Species
23.8	<i>Tubificidae (lpil)</i>	15.3	<i>Tubificidae (lpil)</i>	6.11	<i>Tubificidae (lpil)</i>
13.07	<i>Macoma brevifrons</i>	14.83	<i>Mediomastus (lpil)</i>	5.32	<i>Prionospio heterobranchia</i>
6.23	<i>Prionospio heterobranchia</i>	14.01	<i>Prionospio heterobranchia</i>	4.65	<i>Schistomeringos pectinata</i>
5.98	<i>Podarkeopsis levifuscina</i>	11.95	<i>Nemertea (lpil)</i>	4.65	<i>Branchiomma nigromaculata</i>
5.56	<i>Caecum pulchellum</i>	11.64	<i>Cirrophorus lyra</i>	4.65	<i>Maldanidae (lpil)</i>
4.71	<i>Exogone verugera</i>	7.19	<i>Podarkeopsis levifuscina</i>	4.47	<i>Podarkeopsis levifuscina</i>
4.01	<i>Nemertea (lpil)</i>	3.68	<i>Schistomeringos pectinata</i>	4.47	<i>Sabellidae (lpil)</i>
3.99	<i>Mediomastus (lpil)</i>	3.66	<i>Pseudopolydora (lpil)</i>	4.27	<i>Cumella (lpil)</i>
3.94	<i>Naineris setosa</i>	3.08	<i>Scoletoma verrilli</i>	4.27	<i>Leptochelia forrestii</i>
3.89	<i>Pseudopolydora (lpil)</i>	2.87	<i>Syllis cornuta</i>	4.27	<i>Nemertea (lpil)</i>
3.83	<i>Caulleriella cf. alata</i>	2.6	<i>Aoridae (lpil)</i>	4.27	<i>Syllis cornuta</i>
3.67	<i>Podarke obscura</i>	2.59	<i>Capitella capitata</i>	3.76	<i>Chione cancellata</i>
3.58	<i>Sphaerosyllis piriferopsis</i>	2.41	<i>Exogone verugera</i>	3.76	<i>Mesanthura bivittata</i>
1.89	<i>Sabellidae (lpil)</i>	2.18	<i>Nereis acuminata</i>	3.76	<i>Cirratulidae (lpil)</i>
1.81	<i>Grandidierella bonnieroides</i>	2.03	<i>Schistomeringos rudolphi</i>	3.76	<i>Terebellidae (lpil)</i>

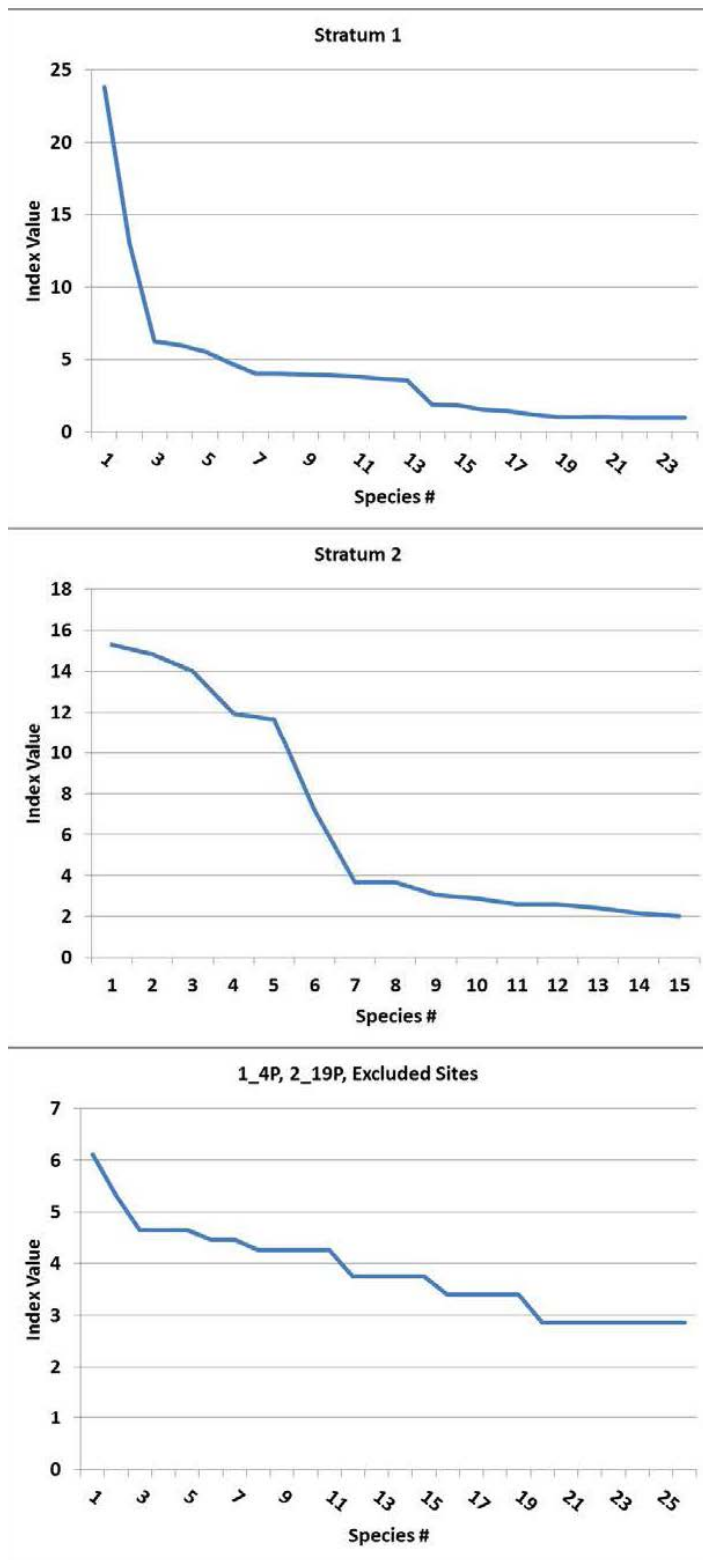


Figure 33. Results of the SIMPER analysis for Strata 1-2.

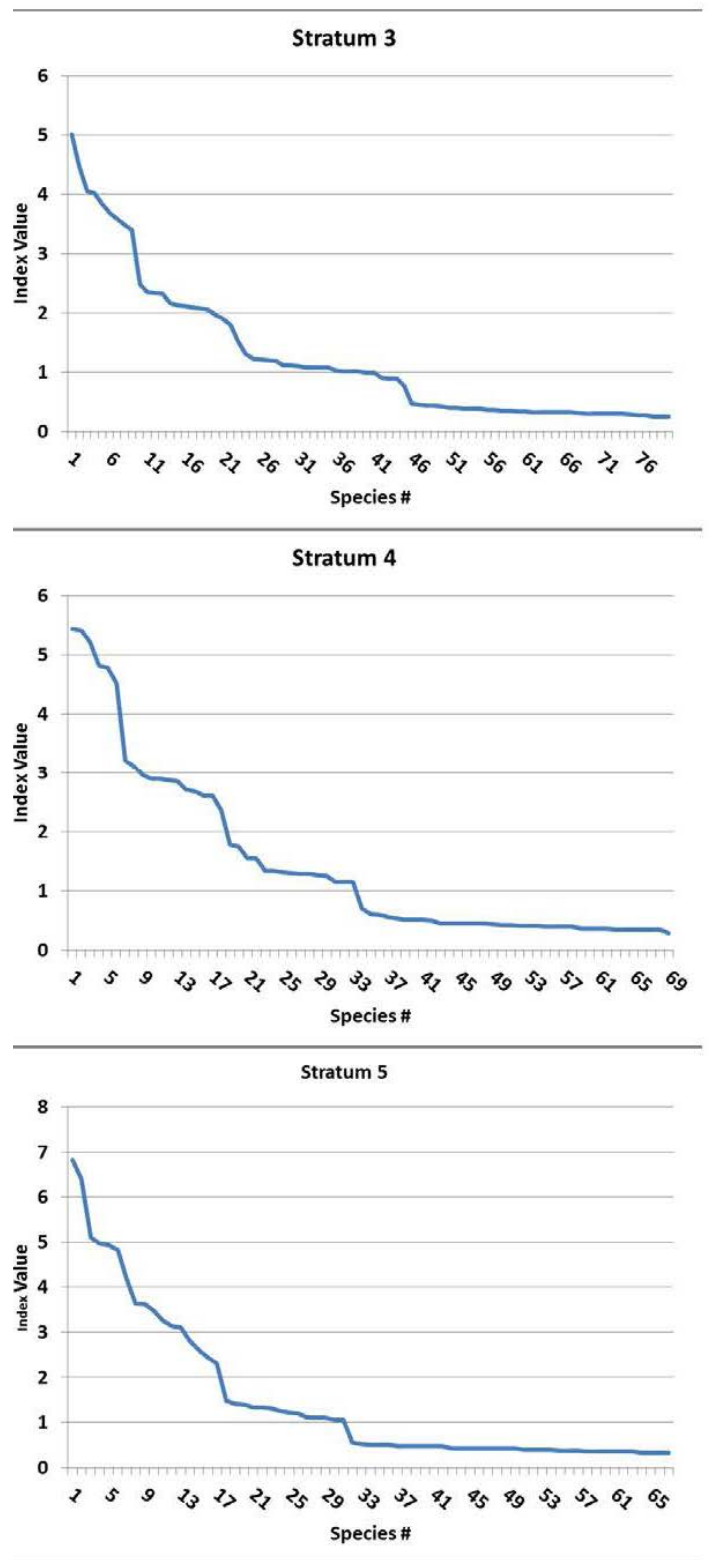


Figure 34. Results of the SIMPER analysis for Strata 3-5.

Table 8. Top species in each stratum. Taxa highlighted in green were cosmopolitan and were found in all strata. Taxa highlighted in blue were found in strata 3, 4, and 5.

Stratum 3		Stratum 4		Stratum 5		Excluded Sites	
Index Value	Species	Index Value	Species	Index Value	Species	Index Value	Species
5.01	<i>Nemertea (lpil)</i>	5.44	<i>Nemertea (lpil)</i>	6.83	<i>Nemertea (lpil)</i>	6.11	<i>Tubificidae (lpil)</i>
4.47	<i>Galathowenia oculata</i>	5.42	<i>Exogone lourei</i>	6.4	<i>Lucinidae (lpil)</i>	5.32	<i>Prionospio heterobranchia</i>
4.05	<i>Exogone lourei</i>	5.22	<i>Tubificidae (lpil)</i>	5.1	<i>Tubificidae (lpil)</i>	4.65	<i>Schistomeringos pectinata</i>
4.02	<i>Prionospio (lpil)</i>	4.82	<i>Lucinidae (lpil)</i>	4.97	<i>Prionospio steenstrupi</i>	4.65	<i>Branchiomma nigromaculata</i>
3.84	<i>Armandia maculata</i>	4.79	<i>Heteropodarke formalis</i>	4.94	<i>Galathowenia oculata</i>	4.65	<i>Maldanidae (lpil)</i>
3.69	<i>Lucinidae (lpil)</i>	4.52	<i>Armandia maculata</i>	4.82	<i>Exogone rolani</i>	4.47	<i>Podarkeopsis levifuscina</i>
3.59	<i>Maldanidae (lpil)</i>	3.21	<i>Pionosyllis gesae</i>	4.18	<i>Cumella (lpil)</i>	4.47	<i>Sabellidae (lpil)</i>
3.49	<i>Ischyroceridae (lpil)</i>	3.11	<i>Pseudoleptochelia (lpil)</i>	3.64	<i>Aricidea taylori</i>	4.27	<i>Cumella (lpil)</i>
3.4	<i>Sipuncula (lpil)</i>	2.96	<i>Terebellidae (lpil)</i>	3.62	<i>Codakia (lpil)</i>	4.27	<i>Leptochelia forresti</i>
2.48	<i>Aspidosiphon (lpil)</i>	2.89	<i>Fabricinuda trilobata</i>	3.47	<i>Leptochelia (lpil)</i>	4.27	<i>Nemertea (lpil)</i>
2.35	<i>Fabricinuda trilobata</i>	2.89	<i>Caulleriella cf. alata</i>	3.26	<i>Xenanthura brevitelson</i>	4.27	<i>Syllis cornuta</i>
2.34	<i>Sphaerosyllis piriferopsis</i>	2.87	<i>Saltipedis (lpil)</i>	3.13	<i>Exogone lourei</i>	3.76	<i>Chione cancellata</i>
2.33	<i>Exogone dispar</i>	2.85	<i>Tellinidae (lpil)</i>	3.1	<i>Sipuncula (lpil)</i>	3.76	<i>Mesanthura bivittata</i>
2.16	<i>Ophiuroidea (lpil)</i>	2.71	<i>Protodorvillea kefersteini</i>	2.81	<i>Pitar simpsoni</i>	3.76	<i>Cirratulidae (lpil)</i>
2.13	<i>Ampharetidae (lpil)</i>	2.68	<i>Magelona sp. c</i>	2.6	<i>Armandia maculata</i>	3.76	<i>Terebellidae (lpil)</i>

two excluded sites (1-4P and 2-19P). The taxa highlighted in green were found in all five strata. Tubificids are a family of oligochaete worms. Nemerteans, also called proboscis worms, constitute an entire phylum. Both are difficult to identify to species without highly specialized expertise. Thus, these taxa actually represent potentially hundreds of species and are not particularly informative. *Syllis cornuta* is a polychaete worm with a worldwide distribution. Thus, outside of these cosmopolitan taxa, the excluded sites had very little in common with the species makeup of Strata 1 and 2.

Figure 34 shows the indices for the species found in Strata 3-5. The numbers of species in these strata are much higher than in Strata 1 and 2. All the scores are relatively low because of the much higher diversity than in Strata 1 and 2, but the inflection of the curves shows that the top 15-20 species are the most important. Table 8 shows the top 15 species in each stratum, plus the excluded sites (1-4P and 2-19P) for comparison. Species names highlighted in blue were found in all three strata. Again, the taxa highlighted in green were cosmopolitan and are not informative. The species makeup of Strata 3, 4 and 5 is very similar. That is, the species highlighted in blue are typical in all three strata. The dominant species found in the excluded sites has almost no overlap with these strata. Thus there are three distinct species assemblages in the STEER. One in Mangrove Lagoon and Benner Bay, which are relatively depauperate. The two excluded sites that share some of the species found in Strata 1 or 2, but also another group of species not com-

mon anywhere else. The third assemblage is a much more diverse group, and occupies the bulk of the STEER area.

Overall Patterns in the STEER Benthic Community. The average diversity and species richness is lower in Mangrove Lagoon and Benner Bay than the other strata, but abundance varies throughout the study area. Diversity and species richness are better indicators of stress than abundance, however. Extremely depressed abundance is indicative of highly stressed habitats, but marginally stressed areas may have as high or higher an abundance of organisms as healthy habitats, because those species that can thrive in stressed habitats may be released from competitive and predation pressure. Species in stressed environments also tend to have opportunistic and mobile life styles.

The composition of species present in various locations is also an indicator of stressed habitats. Many authors consider amphipods and echinoderms to be relatively sensitive to contaminant stress (Long et al., 2001, Llanso et al., 2002). Similarly, several types of polychaetes, such as Spionids and Capitellids, and oligochaete tubificids, are considered to be tolerant of contamination and/or other stressful conditions, such as hypoxia (Lenihan and Micheli, 2001; Llanso et al., 2002).

The community makeup of specific taxonomic groups in the different strata is shown in Table 9. Average total abundance of the large taxonomic groups was not informative. However, pollution tolerant species of annelids make up a much larger proportion of the organisms in Mangrove

Lagoon and Benner Bay than in the two excluded sites or any other strata. The number of amphipods show the opposite pattern.

Influence of Chemical Contamination on the Benthic Infaunal Community. Both species richness and diversity declined with ERMq (Figure 35). Likewise, species richness and diversity declined with increasing percent fines (percent silt+clay) in the sediment (Figure 36). The relationship between contaminants and muddy sediment is clear (Figure 37), but which is the causative factor for reduced species community condition cannot be determined from the data. Resident communities found in muddy areas are inherently different from the areas with coarser grained sediments. However, it is clear that the occurrence of significant toxicity and the variety of significant end-

Table 9. Average per-station abundance of selected taxonomic groups in Mangrove Lagoon and Benner Bay without stations 1-4P and 2-19P, stations 1-4P and 2-19P together, and the remaining strata in 3 (Nazareth Bay), 4 (Cowpet/St. James Bay), and 5 (Great Bay).

Organism	Species	Mangrove Lagoon Benner Bay	Stations 1-4P and 2-19P	Stratum 3	Stratum 4	Stratum 5
Annelids		331.1	298	298.2	147.6	246.4
	<i>Tubificidae</i>	106.1	48	18	7.2	16.8
	<i>Capitellidae</i>	28.1	6.5	6	2.8	7.6
	<i>Spionidae</i>	77.4	28	27.2	8.4	38.4
Malacostraca		7.6	78	141.2	57.6	100
	<i>Amphipoda</i>	5.3	43	39.8	23.2	14.8
Echinoderms		0	17	8.8	1.2	1.6
Molluscs		73.4	84	77	41.8	172
	<i>Bivalva</i>	16.9	24.5	60.6	31.4	144.4
	<i>Gastropoda</i>	56.6	58	12.6	8	26
Miscellaneous		13.9	38.5	24.6	7.6	53.2
Total		426	515.5	552	257	573.6

points is highest in Mangrove Lagoon (Figure 29). Many of the significant results from the amphipod bioassays are likely due to the coarse grain size of the sediments in the eastern strata. Consequently, amphipod mortality appears to be more widespread than the other toxicity endpoints. Abundance did not decline as sharply as species richness with increasing contamination, suggesting that pollution tolerant species are able to grow and reproduce in contaminated areas in the absence of competitors, predators, and/or indirect effects on the habitat. The weight of evidence between the toxicity, diversity, community makeup, and chemical contamination indicate pollution impacts in Benner Bay and, especially, in Mangrove Lagoon.

Summary and Conclusions

The degradation of coral reef ecosystems worldwide has led to intensive efforts to understand and mitigate the stressors responsible for the declines of these ecosystems. The role of pollution is often cited as a major factor, but the degree to which pollution, and more specifically, chemical contaminants, impact coral reef and associated habitats is largely unknown. Because of this, coral reef managers may be missing an important, and in some locations, a critical piece

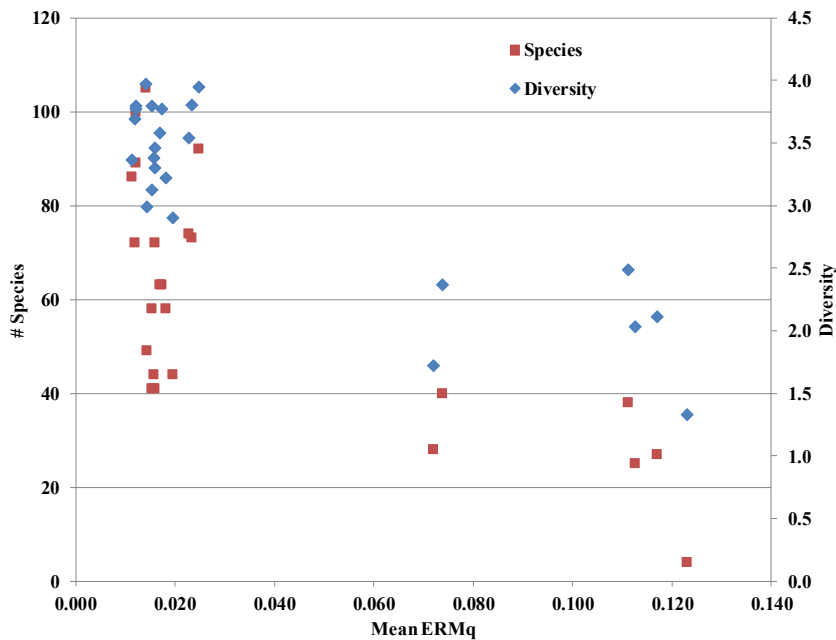


Figure 35. Relationship between number of species and species diversity and the ERMq.

of information required to effectively manage and, where needed, initiate restoration efforts.

For this project, a stratified random sampling design was utilized to characterize the distribution and concentrations of chemical contaminants, toxicity, and the benthic infaunal community on an areal basis. This allows for a quantitative analysis of habitat condition between strata. The Sediment Quality Triad, or SQT approach, which combines three types of analyses, was used to provide a means for more holistically assessing the presence and impacts of anthropogenic stressors. Sediment samples for the analysis of both organic contaminants (e.g., polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and pesticides), and inorganic contaminants (trace elements such as chromium, nickel and copper) were collected during a mission in June 2011. In 2010, a preliminary targeted sampling exercise resulted in the analysis of four of the sediment samples collected.

Elevated levels of chemical contaminants were primarily found in Mangrove Lagoon and in northern Benner Bay. There is a large landfill adjacent to Mangrove Lagoon, that likely contributes a variety of contaminants through runoff,

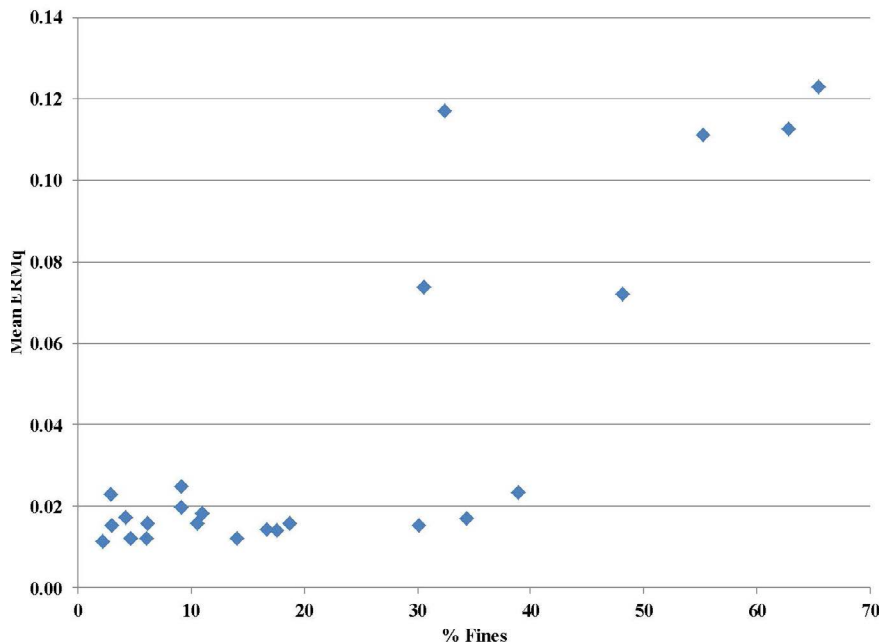


Figure 37. Relationship between mean ERMq and percent fines.

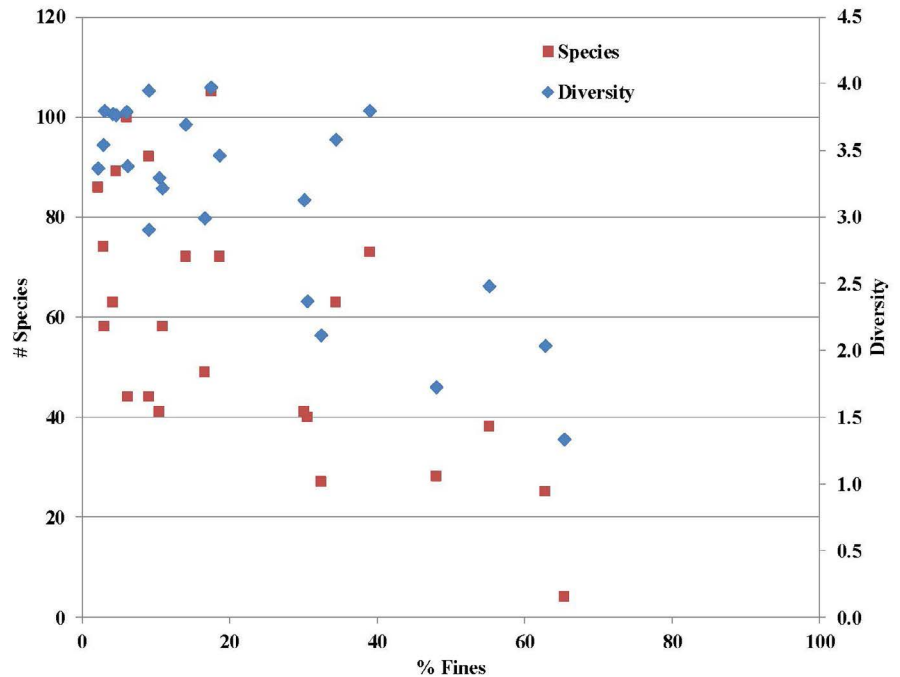


Figure 36. Relationship between number of species and species diversity and percent fines.

groundwater seeps, and perhaps from atmospheric deposition (e.g., from tire/trash fires). Mangrove Lagoon also receives input from various commercial/industrial sources, as well as from adjacent residential/urbanized areas in the watershed via Turpentine Gut. Land use around northern Benner Bay appears dominated by marina-related activities, including the mooring, maintenance, and repair of boats, which is likely a source of chemical contaminants to the STEER.

Tributyltin, or TBT, was found at very high levels at three sites in the northern Benner Bay area (two from the targeted 2010 sampling). The level of TBT detected at one site in Benner Bay was the third highest quantified in NOAA's NS&T Program. The presence of high concentrations of TBT likely represents the results of past application of TBT, mooring of vessels that contain TBT, along with the cleaning and scraping of hulls that may have had TBT applied at some point. Unfortunately, there are no established guidelines for TBT in sediment. A site specific numerical upper guideline established for an EPA Superfund site in the state of Washington was exceeded in northern Benner Bay. The purpose of the guideline developed was to inform EPA site manag-

ers when additional testing (e.g., toxicity testing) would be recommended.

At the very least, additional analysis should be conducted in this area to better understand the distribution of TBT in surficial and deeper (cores) sediments, along with additional toxicity testing in the area. This is particularly needed if any of these areas are dredged in the future to deepen navigation channels to the marinas.

Copper and zinc were elevated at several locations in Benner Bay and Mangrove Lagoon. The elevated copper level was above the NOAA ERM at one site from the 2010 targeted sampling, indicating that impacts to benthic organisms and within the broader food web are likely. This also appears to be associated with marina activities, including the mooring of vessels, along with the cleaning, and scraping of the hulls and subsequent transport of these materials into northern Benner Bay. The locations where the three highest copper concentrations were found was also the location of the three highest TBT concentrations.

A number of other chemical contaminants analyzed for this project, including zinc, lead, copper, mercury, total PCBs, and total DDT, were above ERLs at one or more sites in the STEER, indicating that impacts may be occurring in some of the more sensitive species or life stages that may be present. Additive effects of these levels of contaminants on biota in the STEER are possible. *Clostridium perfringens*, a pathogenic bacteria used as sewage indicator, was found at high levels in Mangrove Lagoon.

The elevated levels of chemical contaminants in the Mangrove Lagoon and northern Benner Bay areas were reflected in the results of a number of the toxicity tests. Overall, the bioassays indicated a significant gradient (high to low) of effects from west to east in the STEER. The widespread toxicological responses likely indicate the interaction of multiple chemicals, including those beyond the standard suite of NS&T analytes, along with other physicochemical characteristics which also vary between strata.

Half of the significant sea urchin fertilization failure bioassays in the STEER were in sediments from Mangrove Lagoon or the canal that joins it to Benner Bay. In addition, most of the significant P450 responses were in the western strata in the STEER, including all of the Mangrove Lagoon sites. The predominant class of contaminants to which the cells were responding to appeared to be the PAHs or polycyclic aromatic hydrocarbons, which were elevated in this part of the STEER, as opposed to PCBs.

The benthic infaunal analysis also correlated with the chemical contaminant and bioassay data, indicating gradients of diversity and species richness, with lower values in the western strata, especially in Mangrove Lagoon, and higher values towards the east. Similar to the results of the P450 analysis, the number of species and diversity were significantly and negatively correlated with benzo[a]pyrene concentrations, indicating the likely impacts of this PAH and other chemicals present.

Finally, the nodal analysis showed that the community composition of animals in the sediments of Mangrove Lagoon and Benner Bay were distinct in terms of the species found from the other three strata in the STEER. Furthermore, the species found in Mangrove Lagoon and Benner Bay were for the most part absent from the other strata and vice versa, likely due in part to natural and anthropogenic stressors found in Mangrove Lagoon and Benner Bay.

The ecological health and condition of the interconnected mangroves, seagrass beds, and coral reefs within the STEER are a significant management concern for many, including the USVI DPNR and NOAA's CRCP. The proximity of the Reserves to the Bovoni Landfill, marinas, and other commercial and industrial activities, combined with likely inputs from residential sewer systems, has prompted concerns about negative impacts of chemical pollutants on natural resources of the STEER. Until this current study, very little was known about the types and concentrations of chemical contaminants present, or their spatial distribution patterns within these Reserves. The information generated from this assessment of chemical contaminants, along with the bioeffects, establishes a baseline of conditions so that managers can understand not only the status, but also the challenges that exist to improve the ecological functioning of the STEER.

Anthropogenic stressors, concentrated in Benner Bay and Mangrove Lagoon, are most likely impacting the ecology of the STEER, including the health of juvenile and adult species, and likely the spawning of fish and invertebrates. Loss of suitable habitat further impacts the ability of the STEER to be a source of new recruits of marine resource species for St. Thomas and beyond. Finally, the STEER has so many natural amenities and ecological services to offer, it is imperative that they be protected, enhanced, and where needed, restored, not only to improve the ecological functioning and productivity of the Reserves, but also to provide both recreational and economic benefits for residents and visitors alike.

Literature Cited

- Anderson, J.W., J.M. Jones, S. Steinert, B. Sanders, J. Means, D. McMillin, T. Vu, and R. Tukey. 1999a. Correlation of CYP1A1 induction, as measured by the P450 RGS biomarker assay, with high molecular weight PAHs in mussels deployed at various sites in San Diego Bay in 1993 and 1995. *Marine Environmental Research* 48:389-405.
- Anderson, J.W., J.M. Jones, J. Hameedi, E. Long, and R.H. Tukey. 1999b. Comparative analysis of sediment extracts from NOAA's bioeffects studies by the biomarker, P450 HRGS. *Marine Environmental Research* 48:407-425.
- Apeti, D.A., S.I. Hartwell, W.E. Johnson and G.G. Lauenstein. 2012a. National Status and Trends Bioeffects Program: Field Methods. NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment. NOAA NCCOS Technical Memorandum 135. Silver Spring, MD. 52pp.
- Apeti, D.A., D.R. Whitall, A.S. Pait, A. Dieppa, A.G. Zitello, and G.G. Lauenstein. 2012b. Characterization of land based sources of pollution in Jobos Bay, Puerto Rico: status of heavy metal concentration in bed sediments. *Environmental Monitoring and Assessment* 184:811-830.
- ASTM. 2008. Method E1367 – 03, Standard test method for measuring the toxicity of sediment-associated contaminants with estuarine and marine invertebrates. ASTM, Philadelphia, PA. 62pp.
- Batley, G. 1996. Distribution and fate of tributyltin. In: S. J. de Mora, editor, *Tributyltin: a case study of an environmental contaminant*. Cambridge University Press. Cambridge, England. 301pp.
- Bennett, R.F. 1996. Industrial manufacture and applications of tributyltin compounds. In: S. J. de Mora, editor, *Tributyltin: a case study of an environmental contaminant*. Cambridge University Press. Cambridge, England. 301pp.
- Birchenough, A.C., N. Barnes, S.M. Evans, H. Hinz, I. Kronke, and C. Moss. 2002. A review and assessment of tributyltin contamination in the North Sea, based on surveys of butyltin tissue burdens and imposex/intersex in four species of neogastropods. *Marine Pollution Bulletin* 44:534-543.
- Boehm, P.D., D.S. Page, J.S. Brown, J.M. Neff, J.R. Bragg, and R.M. Atlas. 2008. Distribution and weathering of crude oil residues on shorelines 18 years after the Exxon Valdez spill. *Environmental Science and Technology* 42:9210-9216.
- Boulon, R.H. 1992. Use of mangrove prop root habitats by fish in the northern U.S. Virgin Islands. *Proceedings, Gulf and Caribbean Fishery Institute* 41:189-204.
- Budzinski, H., I. Jones, J. Bellocq, C. PiCrard, and P. Garrigues. 1997. Evaluation of sediment contamination by polycyclic aromatic hydrocarbons in the Gironde estuary. *Marine Chemistry* 58:85-97.
- Carr, R.S. and J.M. Biedenbach. 1999. Use of power analysis to develop detectable significance criteria for sea urchin toxicity tests. *Aquatic Ecosystem Health and Management* 2:413-418.
- Chapman, P.M., R.N. Dexter, and E.R. Long. 1987. Synoptic measures of sediment contamination, toxicity and infaunal community structure (the sediment quality triad). *Marine Ecology Progress Series* 37:75-96.
- Chapman, P.M. 1996. Presentation and interpretation of sediment quality triad data. *Ecotoxicology* 5:327-339.
- Clark, K.R., and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation. Primer-E Ltd., Plymouth, UK.
- Colletti, C.M. 2011. The effect of seascape structure on the spatial distribution of juvenile fish within Benner Bay Mangrove Lagoon, St. Thomas, United States Virgin Islands (USVI). MS Thesis. Masters of Marine and Environmental Sciences. University of the Virgin Islands. 118pp.
- Dillard, M., and M. D'lorio. 2012. St. Thomas East End Reserves (STEER) Coastal Use Mapping Project: Ocean Uses Map Book. 32pp.
- DPNR-DFW (Department of Planning and Natural Resources, Division of Fish and Wildlife). 2005. Marine resources and fisheries strategic and comprehensive conservation plan. Division of Fish and Wildlife, Department of Planning and Natural Resources, U.S. Virgin Islands. 554pp.
- Eisler, R. 1985. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85. 46pp.

- Eisler, R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85. 60pp.
- Eisler, R. 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85. 63pp.
- Eisler, R. 1998. Copper hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Geological Survey, Biological Resources Division, Biological Science Report 1998-0002. 98pp.
- Ellor, J.A., and P. Stelmiski. 2007. Sustainable practices concerning the use of cadmium and hexavalent chromium as corrosion control products. Tri-Service Corrosion Conference 2007, Denver, CO. 8pp.
- EPA (U.S. Environmental Protection Agency). 1997. Management of polychlorinated biphenyls in the United States. Available at: <http://www.chem.unep.ch/pops>. Office of Pollution Prevention and Toxics U.S. Environmental Protection Agency. 6pp.
- EPA (U.S. Environmental Protection Agency). 1999. Method 4425: screening extracts of environmental samples for planar organic compounds (PAHS, PCBS, PCDDS/PCDFS) by a reporter gene on a human cell line. EPA Office of Solid Waste, SW 846 Methods, Update IVB. EPA. Washington, DC. 36pp.
- EPA (U.S. Environmental Protection Agency). 2000. Coastal communications: National coastal assessment - coastal 2000. EPA/620/R-00/005b. 2pp.
- EPA (U.S. Environmental Protection Agency). 2002a. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to marine and estuarine organisms, 3rd Ed. EPA-821-R-02-014, US EPA, Wash., DC. 464pp.
- EPA (U.S. Environmental Protection Agency). 2002b. Chlorpyrifos facts. Accessed on the internet 9/2012 at: http://www.epa.gov/oppsrrd1/REDs/factsheets/chlorpyrifos_fs.htm.
- EPA (U.S. Environmental Protection Agency). 2010. Endosulfan phase-out. Accessed on the internet 9/2012 at: <http://www.epa.gov/pesticides/reregistration/endosulfan/endosulfan-agreement.html>.
- EPA (U.S. Environmental Protection Agency). 2011. Remediation system evaluation. Tutu Wellfield Superfund Site, St. Thomas, U.S. Virgin Islands. Office of Solid Waste and Emergency Response (5102G). Final Report. EPA-542-R-11-008. 37pp.
- Fairey, R., C. Bretz, S. Lamerdin, J. Hunt, B. Anderson, S. Tudor, C.J. Wilson, F. LaCaro, M. Stephenson, M. Puckett, and E. R. Long. 1996. Chemistry, toxicity and benthic community conditions in sediments of the San Diego Bay Region. State of California Water Resources Control Board Final Report to NOAA. 169pp. plus appendices.
- Fleeger, J.W., K.R. Carman, and R.M. Nisbet. 2003. Indirect effects of contaminants in aquatic ecosystems. *Science of the Total Environment* 317:207-233.
- Gibbs, P.E., and G.W. Bryan. 1996. TBT-induced imposex in neogastropod snails: masculinization to mass extinction. In: S. J. de Mora, editor, Tributyltin: a case study of an environmental contaminant. Cambridge University Press. Cambridge, England. 301pp.
- Goodall, D.W. 1973. Sample similarity and species correlation. pp 105-156. In: R.H. Whittaker (ed.) *Ordination and classification of communities*. W. Junk, New York, NY. 737pp.
- Grigg, D.I., R.E. vanEepoel, and R.W. Brody. 1971. Water pollution report no. 10. water quality and environmental status of Benner Bay-Mangrove Lagoon St. Thomas. 42pp plus appendices.
- Hartwell, S.I. and L.W. Clafin. 2005. Cluster analysis of contaminated sediment data - nodal analysis. *Environmental Toxicology and Chemistry* 24:1816-1834.
- Hartwell, S.I. and J. Hameedi. 2007. Magnitude and extent of contaminated sediment and toxicity in Chesapeake Bay. NOAA Technical Memorandum NOS/NCCOS/CCMA 47. NOAA, NOS, Silver Spring, MD. 234pp.
- Hartwell, S.I., D.A. Apeti, L.W. Clafin, W.E. Johnson, and K. Kimbrough. 2009. Sediment quality triad assessment in Kachemak Bay: characterization of soft bottom benthic habitats and contaminant bioeffects assessment. North Pacific Research Board Final Report 726. 138pp.
- Hassett, J.J., J.C. Means, W.L. Banwart, and S.G. Wood. 1980. Sorption related properties of sediments and energy related pollutants. U.S. Environmental Protection Agency. EPA-600/3-8-041. 133pp.
- Hyland, J.L., R.F. Van Dolah, and T.R. Snoots. 1999. Predicting stress in benthic communities of southeast-

- ern U.S. estuaries in relation to chemical contamination of sediments. *Environmental Toxicology and Chemistry* 18(11):2557–2564.
- IRF (Island Resources Foundation). 1993. Mangrove Lagoon/Benner Bay area of particular concern (APC) and area for preservation and restoration (APR) management plan: a comprehensive analytic study. Prepared by Island Resources Foundation, St. Thomas, Virgin Islands, for USVI DPNR/CZM Program. 32pp.
- Kimbrough, K. L., and G. G. Lauenstein (Eds). 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. 19pp.
- Kimbrough, K. L., G. G. Lauenstein and W. E. Johnson (Eds). 2006. Organic contaminant analytical methods of the National Status and Trends Program: Update 2000-2006. NOAA Technical Memorandum NOS NCCOS 30. 137pp.
- Kitchell, A. 2012. STEER Watershed Management Plan: 12/6/2012. Presentation made at Ivanna Eudora Kean High School, Red Hook, St. Thomas, USVI.
- Lambert J.M, and W.T. Williams. 1962. Multivariate methods in plant ecology. VI nodal analysis. *Journal of Ecology* 50:775-802.
- Lenihan, H.S. and F. Micheli. 2001. Soft sediment communities. In: *Marine Community Ecology*. M.D. Bertness, S.D. Gaines and M.E. Hay (Eds). Sinauer Assoc. Inc. Sunderland Mass. 550pp.
- Libes, S.M. 1992. An introduction to marine biogeochemistry. Wiley, New York, NY. 734pp.
- Llansó, R. J., L.C. Scott, J.L. Hyland D.M. Dauer, D.E. Russell, and F.W. Kutz. 2002. An estuarine benthic index of biological integrity for the mid-Atlantic region of the United States. II. index development. *Estuaries* 25(6A):1231-1242.
- Long, E.R., L. J. Field, and D.D. MacDonald. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environmental Toxicology and Chemistry* 17(4):714-727.
- Long, E.R., C.B. Hong, and C.G. Severn. 2001. Relationships between acute sediment toxicity in laboratory tests and abundance and diversity of benthic infauna in marine sediments: a review. *Environmental Toxicology and Chemistry*. 20(1):46-60.
- Long, E. R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environment & Management* 19:81–97.
- Long, E. R., and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52, Seattle, WA 175pp.
- MacDonald, D.D. 1993. Development of an Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Report to Florida Department of the Environment by MacDonald Environmental Science Ltd., Ladysmith, B.C., Canada. 1, 128pp.
- Nemeth, D. and R. Platenberg. 2007. Diversity of freshwater fish and crustaceans of St. Thomas: watersheds and its relationship to water quality as affected by residential and commercial development. WRRP Project 2006VI73B. Division of Fish and Wildlife, Department of Planning and Natural Resources, St. Thomas. 28pp.
- NOAA. (National Oceanic and Atmospheric Administration). 1981. Proposed St. Thomas national marine sanctuary. Draft environmental impact statement. 59pp and appendices.
- NOAA. (National Oceanic and Atmospheric Administration). 1998. NS&T Program: National Status and Trends Program for Marine Environmental Quality. NOAA/National Ocean Service. 32pp.
- Oliver, J., K. Hammerstrom, E. McPhee-Shaw, P. Slattery, J. Oakden, S. Kim, S. I. Hartwell, and S. Foss. 2011. High species density patterns in macrofaunal invertebrate communities in the marine benthos. *Marine Ecology*. 32(3):278-288.
- Pait, A. S., D.R. Whitall, C.F.G. Jeffrey, C. Caldwell, A.L. Mason, G.G. Lauenstein, G. G., and J.D. Christensen. 2008. Chemical contamination in southwest Puerto Rico: an assessment of organic contaminants in nearshore sediments. *Marine Pollution Bulletin* 56:580–606.
- Pait, A. S., A.L. Mason, D.R. Whitall, J.D. Christensen, and S.I. Hartwell. 2010. Assessment of chemical contaminants in sediments and corals in Vieques. In: Bauer and Ken-

- dall (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. 174pp.
- Pait, A.S., D. R. Whitall, A. Dieppa, S. E. Newton, L. Brune, C. Caldow, A. L. Mason, D. A. Apeti, and J. D. Christensen. 2012. Characterization of organic chemical contaminants in sediments from Jobos Bay, Puerto Rico. *Environmental Monitoring and Assessment*. 184(8):5065-5075.
- Shannon, L.C. and W. Weaver. 1949. *The mathematical theory of communication*. University of Illinois Press. Urbana, IL. 117pp.
- Shine, J. and G. Wallace. 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.
- Sneath, P.H. and R.R. Sokal. 1973. *Numerical taxonomy - the principles and practice of numerical classification*. W.H. Freeman. San Francisco, CA. 588pp.
- STEER. 2011. *St. Thomas East End Reserves Management Plan*. Edited by J. Brown, A. Holecek, J. Murray, L. Noori, J.P. Oriol, J. Pierce, R. Platenberg, S. Romano, D. Russo, and C. Settar. 99pp.
- Strand, J., A. Jørgensen, and Z. Tairova. 2009. TBT pollution and effects in molluscs at US Virgin Islands, Caribbean Sea. *Environment International* 35:707-711.
- Tetra Tech. 2005. *Fecal coliform total maximum daily load, Mangrove Lagoon and Benner Bay, St. Thomas, United States Virgin Islands*. Final draft prepared for: U.S. Environmental Protection Agency, Region 2, and United States Virgin Islands Department of Environmental Protection. 42pp.
- Thursby, G. B., J. Heltshe, and K.J. Scott. 1997. Revised approach to toxicity test acceptability criteria using a statistical performance assessment. *Environmental Toxicity and Chemistry* 16:1322-1329.
- USDHHS (U.S. Department of Human Health and Services). 1995. *Polycyclic aromatic hydrocarbons toxicology profile*. Agency for Toxic Substance and Disease Registry (ASTDR). Atlanta, GA. 487pp.
- USDHHS (U.S. Department of Human Health and Services). 1999. *Toxicological profile for cadmium*. Agency for Toxic Substance and Disease Registry (ASTDR). Atlanta, GA. 439pp.
- Weston. 1996. *Recommendations for screening values for tributyltins in sediments at Superfund sites in Puget Sound, Washington*. Roy F. Weston, Inc. Contract 68-W9-0046. 65pp.
- Wlodarska-Kowalczyk, M., T.H. Pearson, and M.A. Kendall. 2005. Benthic response to chronic natural physical disturbance by glacial sedimentation in an Arctic fjord. *Marine Ecology Progress Series* 303:31-41.

Appendix A. Field data collected from the STEER 2011 mission.

Stratum	Site	Site Type	Date	Depth (m)	Measured Latitude (DD)	Measured Longitude (DD)	Surface Temp. (°C)	Bottom Temp. (°C)	Surface Salinity (‰)	Bottom Salinity (‰)	Surface DO (mg/L)	Bottom DO (mg/L)	Secchi Depth (m)
1	1	P	6/15/2011	1.2	18.31538	-64.88128	31.4	31.4	28.32	28.33	7.22	6.31	1.1
1	2	P	6/15/2011	0.9	18.31499	-64.81677	31.8	N/A	31.46	N/A	6.22	N/A	0.9
1	3	P	6/15/2011	0.9	18.3159	-64.87617	32.1	32.1	29.15	30.9	6.41	6.74	0.9
1	4	P	6/15/2011	1.2	18.3089	-64.87443	29.4	28.8	33.14	34.32	5.2	5.27	1.2
1	5	P	6/15/2011	0.6	18.31477	-64.87476	32.8	N/A	31.62	N/A	8.85	N/A	0.6
2	16	P	6/14/2011	1.5	18.31672	-64.87375	32.8	32.9	29.11	29.83	5.62	6.49	0.8
2	19	P	6/14/2011	1.5	18.31389	-64.86786	31.5	30.8	32.91	33.42	5.34	6.15	1.8
2	20	P	6/14/2011	1.5	18.31849	-64.86726	33.1	N/A	31.05	N/A	5.13	N/A	1.2
2	24	A	6/14/2011	1.4	18.31379	-64.86827	32.2	31.2	33.03	33.54	6.77	6.55	1.4
3	32	P	6/14/2011	6.7	18.31693	-64.85516	30.4	29.4	34.38	34.45	5.83	6.56	6.7
3	33	P	6/16/2011	17.7	18.30513	-64.85267	28.9	28.9	34.35	34.36	5.74	5.75	9.8
3	37	A	6/17/2011	12.8	18.31039	-64.84875	28.9	28.9	34.46	34.46	5.75	5.76	12.8
3	38	A	6/17/2011	6.6	18.31735	-64.85635	29.4	29.2	34.44	34.43	5.94	6.18	6.4
3	45	A	6/17/2011	11.3	18.31228	-64.85199	29.1	29	34.46	34.46	5.82	5.8	11.3
4	46	P	6/16/2011	16.5	18.30429	-64.83998	28.9	28.8	34.39	34.46	5.66	5.65	9.1
4	47	P	6/17/2011	9.4	18.30177	-64.83553	28.8	28.7	34.44	34.47	5.77	5.63	9.4
4	48	P	6/15-16/2011	10.4	18.3125	-64.83687	28.7	28.7	34.46	34.46	5.65	5.61	11.0
4	49	P	6/17/2011	4.6	18.30413	-64.82621	28.6	28.6	34.5	34.5	5.45	5.53	4.6
4	50	P	6/15/2011	6.1	18.31525	-64.84118	29.5	29.3	34.47	34.44	5.89	6.1	6.1
5	61	P	6/16/2011	12.2	18.31725	-64.83537	28.6	28.5	34.52	34.61	5.62	5.42	12.2
5	62	P	6/16/2011	12.8	18.3179	-64.82919	28.7	28.5	34.49	34.55	5.52	5.56	9.4
5	70	A	6/16/2011	7.9	18.3225	-64.84019	28.6	28.7	34.41	34.51	4.98	5.42	6.1
5	71	A	6/16/2011	17.4	18.32100	-64.83443	28.7	28.6	34.47	34.53	5.86	5.64	9.8
5	75	A	6/16/2011	10.2	18.32246	-64.83707	28.8	28.7	34.49	34.5	5.57	5.58	10.2

Note: DO, dissolved oxygen; lat, latitude; long, longitude; N/A, reading not taken.

Appendix B. Grain size and organic carbon of sediments from St. Thomas East End Reserves.

Site	Total Organic Carbon (%TOC)	Total Inorganic Carbon (%TIC)	%Gravel	%Sand	%Silt	%Clay
1-1P	2.07	1.33	0.00	34.55	35.55	29.90
1-2P	3.15	8.16	18.95	25.79	31.17	24.09
1-3P	4.26	7.84	8.56	28.64	38.58	24.22
1-4P	1.18	3.91	4.97	84.09	6.25	4.69
1-5P	3.46	7.23	12.41	39.46	29.45	18.68
2-16P	1.92	9.38	17.20	52.21	15.13	15.46
2-19P	1.62	2.64	6.56	84.32	3.58	5.54
2-20P	1.87	7.24	13.14	54.48	23.87	8.51
2-24A	1.79	9.63	15.64	73.87	3.19	7.30
3-32P	1.74	9.19	2.49	58.56	29.76	9.19
3-33P	4.13	7.94	7.23	90.61	2.16	0.00
3-37A	5.44	6.61	9.21	84.76	2.41	3.62
3-38A	2.17	9.28	8.23	82.64	3.18	5.95
3-45A	1.09	9.99	7.58	74.85	13.10	4.47
4-46P	3.05	4.24	2.73	91.11	5.34	0.82
4-47P	5.44	5.74	10.36	85.41	1.32	2.91
4-48P	5.46	6.52	0.00	97.08	0.61	2.31
4-49P	4.82	6.33	32.20	64.79	1.00	2.01
4-50P	0.49	10.16	0.00	95.37	0.93	3.70
5-61P	0.49	10.72	1.05	84.90	9.91	4.14
5-62P	2.13	4.33	8.18	73.08	11.50	7.24
5-70A	1.22	10.54	12.23	53.39	29.34	5.04
5-71A	0.44	10.05	7.12	76.20	13.52	3.16
5-75A	0.46	11.23	7.91	61.93	22.41	7.75
BB-1	3.48	3.54	8.81	34.56	49.02	7.61
BB-2	2.04	2.96	23.97	34.62	35.06	6.35
ML-2	5.18	2.45	0.00	12.36	36.75	50.89
ML-10	3.74	3.35	14.78	49.51	26.55	9.16

TOC, total organic carbon; TIC, total inorganic carbon

Appendix C. PAHs detected in sediments from the St. Thomas East End Reserves (ng/ dry g).

Compound	1-1P	1-2P	1-3P	1-4P	1-5P	2-16P	2-19P	2-20P	2-24A	3-32P	3-33P	3-37A
Naphthalene	7.3	7.3	9.2	0.3	5.3	2.3	0.5	2.0	0.6	0.9	0.3	0.2
C1-Naphthalenes	5.4	5.3	6.0	0.2 J	4.0	1.8	0.3 J	1.3	0.4	0.4	0.1 J	0.1 J
C2-Naphthalenes	11.3	11.0	11.9	0.6	8.4	2.8	0.8	2.3	0.6	0.7	0.0 U	0.3 J
C3-Naphthalenes	6.6	8.1	9.9	0.0 U	5.7	1.9	0.0 U	2.7	0.0 U	0.8	0.0 U	0.0 U
C4-Naphthalenes	0.0 U	10.9	14.9	0.0 U	6.1	2.5	0.0 U	3.3	0.0 U	1.2	0.0 U	0.0 U
Benzothiophene	0.1 J	0.2	0.2	0.0 U	0.1 J	0.0 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C1-Benzothiophenes	0.0 U	0.6	2.4	0.0 U	0.6	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Benzothiophenes	0.0 U	1.8	2.5	0.0 U	0.9	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Benzothiophenes	0.0 U	3.8	2.2	0.0 U	0.4	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Biphenyl	2.4	2.3	3.6	0.2	1.4	1.3	0.3	0.6	0.2	1.7 I	0.2	0.1 J
Acenaphthylene	0.8	2.2	3.4	0.0 U	0.8	0.9	0.0 J	0.9	0.0 U	0.2 J	0.0 U	0.0 U
Acenaphthene	0.5	0.5	0.7	0.0 U	0.3	0.1 J	0.1 J	0.3	0.0 U	0.2	0.0 U	0.0 U
Dibenzofuran	3.2	3.3	3.2	0.2	2.5	0.9	0.4	0.7	0.3	0.8	0.2 J	0.2 J
Fluorene	2.8	3.3	3.3	0.1 J	2.6	0.8	0.3	0.8	0.2	0.4	0.1 J	0.1 J
C1-Fluorenes	0.0 U	4.4	5.3	0.0 U	2.5	1.5	0.2 J	0.0 U	0.0 U	0.5	0.0 U	0.0 U
C2-Fluorenes	0.0 U	13.1	19.3	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.3	0.0 U	0.0 U
C3-Fluorenes	0.0 U	16.5	22.1	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	2.0	0.0 U	0.0 U
Anthracene	1.5	3.2	5.6	0.0 J	1.1	1.5	0.1 J	1.7	0.0 U	1.3	0.0 U	0.0 U
Phenanthrene	8.6	13.7	18.2	0.4	9.5	4.3	1.0	4.4	0.7	11.2	0.3	0.3
C1-Phenanthrenes/Anthracenes	7.3	15.2	23.8	0.1 J	6.5	5.1	0.0 U	4.9	0.0 U	4.4	0.0 U	0.0 U
C2-Phenanthrenes/Anthracenes	0.0 U	26.4	45.2	0.0 U	9.3	11.2	0.0 U	10.6	0.0 U	4.7	0.0 U	0.0 U
C3-Phenanthrenes/Anthracenes	0.0 U	33.0	55.1	0.0 U	0.0 U	12.2	0.0 U	11.5	0.0 U	1.9	0.0 U	0.0 U
C4-Phenanthrenes/Anthracenes	0.0 U	25.3	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.7	0.0 U	0.0 U
Dibenzothiophene	1.6	1.9	2.6	0.1 J	1.3	0.6	0.1 J	0.6	0.1 J	0.6	0.0 U	0.0 U
C1-Dibenzothiophenes	1.6	2.6	3.7	0.0 U	1.4	0.8	0.1 J	0.6	0.1 J	0.4	0.0 U	0.0 U
C2-Dibenzothiophenes	3.3	7.4	11.9	0.0 U	2.7	2.3	0.0 U	1.8	0.0 U	0.6	0.0 U	0.0 U
C3-Dibenzothiophenes	0.0 U	16.4	25.5	0.0 U	0.0 U	5.1	0.0 U	2.9	0.0 U	0.4	0.0 U	0.0 U
Fluoranthene	4.7	17.4	23.6	0.2 J	5.1	6.2	0.3	9.5	0.2	90.0	0.1 J	0.1 J
Pyrene	4.9	20.9	33.8	0.1 J	5.4	7.7	0.3	10.4	0.1 J	70.2	0.1 J	0.1 J
C1-Fluoranthenes/Pyrenes	6.3	17.4	34.9	0.0 U	4.9	13.2	0.4	9.1	0.0 U	17.5	0.0 U	0.0 U
C2-Fluoranthenes/Pyrenes	0.0 U	28.5	53.3	0.0 U	0.0 U	23.4	0.5	11.9	0.0 U	15.7	0.0 U	0.0 U
C3-Fluoranthenes/Pyrenes	0.0 U	22.6	38.6	0.0 U	0.0 U	12.0	0.0 U	4.5	0.0 U	5.3	0.0 U	0.0 U
Naphthobenzothiophene	0.0 U	12.5	41.7	0.0 U	0.0 U	11.7	0.0 U	4.1	0.0 U	19.0	0.0 U	0.0 U
C1-Naphthobenzothiophenes	0.0 U	24.6	48.0	0.0 U	0.0 U	14.6	0.0 U	4.1	0.0 U	6.0	0.0 U	0.0 U
C2-Naphthobenzothiophenes	0.0 U	36.4	53.1	0.0 U	0.0 U	19.2	0.0 U	4.6	0.0 U	3.2	0.0 U	0.0 U
C3-Naphthobenzothiophenes	0.0 U	30.1	40.7	0.0 U	0.0 U	16.5	0.0 U	4.7	0.0 U	2.3	0.0 U	0.0 U
Benz(a)anthracene	3.9	11.4	20.2	0.0 U	2.2	6.2	0.1 J	7.7	0.0 U	49.8	0.0 U	0.0 J
Chrysene/Triphenylene	5.7	20.5	33.0	0.0 U	5.2	6.5	0.2	8.1	0.0 U	52.0	0.0 U	0.1 J
C1-Chrysenes	0.0 U	26.9	50.1	0.0 U	0.0 U	14.3	0.0 U	6.5	0.0 U	13.7	0.0 U	0.0 U
C2-Chrysenes	0.0 U	27.4	40.3	0.0 U	0.0 U	14.5	0.0 U	5.2	0.0 U	5.3	0.0 U	0.0 U
C3-Chrysenes	0.0 U	17.6	25.0	0.0 U	0.0 U	9.8	0.0 U	3.7	0.0 U	1.9	0.0 U	0.0 U
C4-Chrysenes	0.0 U	8.6	10.5	0.0 U	0.0 U	8.5	0.0 U	0.0 U	0.0 U	2.3	0.0 U	0.0 U
Benzo(b)fluoranthene	13.2	43.0	79.1	0.2 J	13.9	19.1	0.4	21.5	0.0 U	54.9	0.0 U	0.1 J
Benzo(k,j)fluoranthene	5.1	9.3	21.0	0.0 J	4.6	6.9	0.1 J	8.1	0.0 U	18.8	0.0 U	0.0 J
Benzo(e)pyrene	7.3	30.1	62.9	0.1 J	9.7	14.1	0.2 J	13.3	0.0 U	26.4	0.0 U	0.1 J
Benzo(a)pyrene	6.9	20.3	34.9	0.1 J	7.0	8.5	0.2 J	10.6	0.0 U	35.1	0.0 U	0.1 J
Perylene	2.0	7.0	13.4	0.1 J	1.9	3.1	0.1 J	2.7	0.0 U	12.4	0.0 U	0.1 J
Indeno(1,2,3-c,d)pyrene	3.7	10.0	18.0	0.1 J	4.8	7.0	0.3 J	9.4	0.0 U	31.8	0.0 U	0.1 J
Dibenzo(a,h)anthracene	1.3	3.4	6.4	0.0 U	1.6	2.1	0.0 J	2.4	0.0 U	8.2	0.0 U	0.0 U
Benzo(g,h,i)perylene	5.8	19.6	36.9	0.2	9.3	14.4	0.5	13.9	0.2	30.7	0.0 U	0.1 J
Total PAHs	135	705	1131	3.2	149	319	7.7	230	3.7	611	1.3	2.3
Individual Alkyl Isomers and Hopanes*												
2-Methylnaphthalene	5.4	5.3	6.2	0.1 J	4.0	1.9	0.3 J	1.4	0.4	0.5	0.1 J	0.1 J
1-Methylnaphthalene	2.6	2.5	2.7	0.1 J	2.0	0.7	0.2 J	0.5	0.2 J	0.2 J	0.1 J	0.1 J
2,6-Dimethylnaphthalene	5.5	5.9	6.6	0.5	4.9	1.7	0.6	1.3	0.4	0.6	0.0 U	0.2 J
1,6,7-Trimethylnaphthalene	0.8	1.0	1.2	0.0 U	0.7	0.2 J	0.0 U	0.0 U	0.0 U	0.1 J	0.0 U	0.0 U
1-Methylphenanthrene	1.6	2.8	4.4	0.0 U	0.7	0.6	0.0 U	0.7	0.0 U	1.2	0.0 U	0.0 U
C29-Hopane	805	733	1304	10.3	692	552	26.4	474	9	15	0.0 U	1.3
18a-Oleanane	87.2	96.4	147	0.0 U	83.1	68.3	0.0 U	55.3	0.0 U	3.3	0.0 U	0.0 U
C30-Hopane	652	562	979	12.9	560	466	27.8	426	9.6	17.1	0.0 U	1.6

Notes: J, below method detection level, MDL; U, not detected

*Individual isomers contained in alkylated (C1-C4 sums)

Appendix C. PAHs detected in sediments from the St. Thomas East End Reserves (ng/ dry g) (continued).

Compound	3-38A	3-45A	4-46P	4-47P	4-48P	4-49P	4-50P	5-61P	5-62P	5-70A	5-71A	5-75A
Naphthalene	0.3	0.5	0.4	0.2	0.2	0.2 J	0.2	0.4	0.4	0.5	0.2	0.4
C1-Naphthalenes	0.0 U	0.2 J	0.2 J	0.1 J	0.1 J	0.1 J	0.1 J	0.2 J	0.2 J	0.3 J	0.2 J	0.2 J
C2-Naphthalenes	0.0 U	0.6	0.5	0.0 U	0.0 U	0.0 U	0.0 U	0.5	0.6	1.0	0.4	0.4
C3-Naphthalenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Naphthalenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benzothiophene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C1-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Biphenyl	0.2	0.2	0.2	0.1 J	0.2	0.1 J	0.1 J	0.2	0.2	0.2	0.2	0.2
Acenaphthylene	0.0 U	0.0 J	0.0 J	0.0 U	0.0 U	0.0 U	0.1 J	0.0 J	0.0 U	0.0 U	0.0 U	0.0 U
Acenaphthene	0.0 U	0.1 J	0.0 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Dibenzofuran	0.2	0.2	0.3	0.2 J	0.2	0.1 J	0.1 J	0.3	0.3	0.3	0.2 J	0.2
Fluorene	0.1 J	0.2 J	0.2 J	0.1 J	0.1 J	0.1 J	0.1 J	0.2 J	0.3	0.2	0.1 J	0.2 J
C1-Fluorenes	0.0 U	0.2 J	0.2 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Fluorenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Fluorenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Anthracene	0.1 J	0.1 J	0.0 J	0.0 U	0.0 U	0.0 J	0.1 J	0.0 U	0.2	0.1 J	0.0 J	0.1 J
Phenanthrene	0.8	0.7	0.5	0.2	0.2	0.2	0.3	0.6	1.3	0.9	0.3	0.6
C1-Phenanthrenes/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.1	1.1	0.0 U	0.0 U
C2-Phenanthrenes/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Phenanthrenes/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Phenanthrenes/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Dibenzothiophene	0.0 U	0.1 J	0.1 J	0.0 U	0.0 J	0.0 U	0.0 U	0.1 J	0.1 J	0.1 J	0.1 J	0.0 U
C1-Dibenzothiophenes	0.0 U	0.0 U	0.1 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.1 J	0.0 U	0.0 U	0.0 U
C2-Dibenzothiophenes	0.0 U	0.0 U	0.1 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Dibenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Fluoranthene	4.5	1.2	0.1 J	0.0 J	0.1 J	0.1 J	0.2	0.3	1.9	0.5	0.3	0.2
Pyrene	3.3	0.9	0.1 J	0.0 J	0.0 J	0.0 J	0.2	0.2	1.6	0.3	0.2	0.2 J
C1-Fluoranthenes/Pyrenes	1.0	0.4 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.7	0.3 J	0.0 U	0.0 U
C2-Fluoranthenes/Pyrenes	0.9	0.4	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.3 J	0.0 U	0.0 U	0.0 U
C3-Fluoranthenes/Pyrenes	0.2 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.2 J	0.0 U	0.0 U	0.0 U
Naphthobenzothiophene	0.0 U	0.2	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.4	0.0 U	0.0 U	0.0 U
C1-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benz(a)anthracene	2.1	0.5	0.0 J	0.0 U	0.0 U	0.0 U	0.2	0.1	1.4	0.2	0.1 J	0.1 J
Chrysene/Triphenylene	3.2	0.8	0.1 J	0.0 U	0.0 J	0.0 U	0.2	0.2	1.5	0.3	0.1 J	0.2 J
C1-Chrysenes	0.8	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.4	0.0 U	0.0 U	0.0 U
C2-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benzo(b)fluoranthene	4.3	1.3	0.1 J	0.0 U	0.0 U	0.0 U	0.4	0.4	2.2	0.4	0.3 J	0.3 J
Benzo(k,j)fluoranthene	1.5	0.4	0.0 J	0.0 U	0.0 U	0.0 U	0.4	0.1 J	0.5	0.1 J	0.1 J	0.1 J
Benzo(e)pyrene	2.4	0.7	0.1 J	0.0 U	0.0 U	0.0 U	0.2 J	0.2 J	1.1	0.3 J	0.1 J	0.1 J
Benzo(a)pyrene	2.5	0.8	0.1 J	0.0 U	0.0 U	0.0 U	0.3	0.2 J	1.8	0.3	0.2 J	0.2 J
Perylene	0.8 J	0.4 J	0.2 J	0.0 U	0.0 U	0.0 U	0.1 J	0.1 J	0.6 J	0.2 J	0.1 J	0.1 J
Indeno(1,2,3-c,d)pyrene	2.1	0.7	0.1 J	0.0 U	0.0 U	0.0 U	0.2 J	0.2 J	1.0	0.3	0.2 J	0.2 J
Dibenzo(a,h)anthracene	0.6	0.2	0.0 U	0.0 U	0.0 U	0.0 U	0.1 J	0.0 U	0.3	0.1 J	0.0 U	0.0 U
Benzo(g,h,i)perylene	2.1	0.7	0.1 J	0.0 U	0.0 U	0.0 U	0.2	0.0 U	1.1	0.5	0.3	0.2
Total PAHs	33.8	12.8	3.6	1.0	1.2	0.9	3.8	4.3	21.5	8.5	3.7	4.2
Individual Alkyl Isomers and Hopanes*												
2-Methylnaphthalene	0.0 U	0.2 J	0.2 J	0.1 J	0.1 J	0.1 J	0.1 J	0.2 J	0.2 J	0.3 J	0.2 J	0.2 J
1-Methylnaphthalene	0.0 U	0.1 J	0.1 J	0.1 J	0.1 J	0.0 J	0.1 J	0.1 J	0.1 J	0.1 J	0.1 J	0.1 J
2,6-Dimethylnaphthalene	0.0 U	0.3 J	0.3 J	0.0 U	0.0 U	0.0 U	0.0 U	0.2 J	0.2 J	0.8	0.3 J	0.3 J
1,6,7-Trimethylnaphthalene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 J	0.0 U
1-Methylphenanthrene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.1 J	0.2 J	0.0 U	0.0 U
C29-Hopane	3.4	4.8	2.6	0 U	0.0 U	0.0 U	2.4	3.5	4.7	11	5.1	7.8
18a-Oleanane	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C30-Hopane	4.2	5.7	2.9	0 U	0.0 U	0.0 U	2.7	5.4	6.1	13.8	6.9	9.7

Notes: J, below method detection level, MDL; U, not detected

*Individual isomers contained in alkylated (C1-C4 sums)

Appendix C. PAHs detected in sediments from the St. Thomas East End Reserves (ng)

Compound	BB-1	BB-2	ML-2	ML10
Naphthalene	5.4	6.4	1.9	7.3
C1-Naphthalenes	3.7	4.7	1.4	4.6
C2-Naphthalenes	8.1	8.0	5.1	9.2
C3-Naphthalenes	9.3	8.0	3.4	7.4
C4-Naphthalenes	15.1	6.9	6.3	11.4
Benzothiophene	0.0 U	0.0 U	0.0 U	0.2
C1-Benzothiophenes	0.0 U	0.0 U	0.0 U	5.3
C2-Benzothiophenes	0.0 U	0.0 U	0.0 U	6.6
C3-Benzothiophenes	0.0 U	0.0 U	0.0 U	6.6
Biphenyl	2.5	2.3	1.0	2.1
Acenaphthylene	2.8	4.0	0.8	2.4
Acenaphthene	1.1	1.0	1.1	1.2
Dibenzofuran	3.4	4.2	0.8	3.6
Fluorene	9.1	9.1	5.3	7.4
C1-Fluorenes	4.5	6.0	0.0 U	3.4
C2-Fluorenes	15.7	0.0 U	0.0 U	13.3
C3-Fluorenes	26.4	0.0 U	0.0 U	24.2
Anthracene	7.4	9.2	1.7	5.7
Phenanthrene	33.9	31.7	5.0	30.6
C1-Phenanthrenes/Anthracenes	17.1	16.9	6.1	19.0
C2-Phenanthrenes/Anthracenes	46.1	36.9	19.4	46.8
C3-Phenanthrenes/Anthracenes	49.4	30.1	0.0 U	56.0
C4-Phenanthrenes/Anthracenes	0.0 U	0.0 U	0.0 U	30.0
Dibenzothiophene	2.7	2.6	0.8	3.1
C1-Dibenzothiophenes	2.5	2.2	1.7	2.2
C2-Dibenzothiophenes	6.8	7.5	0.0 U	9.3
C3-Dibenzothiophenes	10.0	12.3	0.0 U	24.9
Fluoranthene	17.3	19.3	6.8	33.7
Pyrene	19.3	22.7	6.8	38.8
C1-Fluoranthenes/Pyrenes	23.1	25.3	9.8	37.4
C2-Fluoranthenes/Pyrenes	52.0	28.8	113.0	121.0
C3-Fluoranthenes/Pyrenes	28.9	14.4	17.3	80.8
Naphthobenzothiophene	0.0 U	0.0 U	0.0 U	0.0 U
C1-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U
C2-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U
C3-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U
Benz(a)anthracene	12.0	16.0	5.6	33.9
Chrysene/Triphenylene	10.9	14.5	6.3	27.5
C1-Chrysenes	15.1	18.3	7.9	30.8
C2-Chrysenes	20.1	20.1	15.4	53.1
C3-Chrysenes	8.6	9.0	7.8	41.1
C4-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U
Benzo(b)fluoranthene	17.9	39.0	6.1	24.6
Benzo(k,j)fluoranthene	5.4	7.3	2.0	7.1
Benzo(e)pyrene	9.3	16.0	2.9	15.5
Benzo(a)pyrene	9.6	17.5	3.3	15.6
Perylene	5.7	5.0	3.9	9.5
Indeno(1,2,3-c,d)pyrene	8.4	16.6	3.1	9.6
Dibenzo(a,h)anthracene	7.4	6.9	6.8	11.6
Benzo(g,h,i)perylene	11.8	24.5	3.7	15.1
Total PAHs	566	531	290	951
Individual Alkyl Isomers and Hopanes*				
2-Methylnaphthalene	3.9	5.0	1.4	4.9
1-Methylnaphthalene	1.8	2.2	0.7	2.2
2,6-Dimethylnaphthalene	4.1	4.2	3.6	5.1
1,6,7-Trimethylnaphthalene	0.9	0.8	0.4	0.7
1-Methylphenanthrene	3.5	7.6	1.4	3.8
C29-Hopane	337	493	365	364
18a-Oleanane	0.0 U	0.0 U	0.0 U	0.0 U
C30-Hopane	106	428	315	289

Notes: J, below method detection level, MDL; U, not detected

*Individual isomers contained in alkylated (C1-C4 sums)

Appendix D. Aliphatics and total extractable hydrocarbons from the St. Thomas East End Reserves.

Compound	1-1P		1-2P		1-3P		1-4P		1-5P		2-16P		2-19P		2-20P		2-24A		3-32P	
n-C9	0.000	U	0.000	U	0.000	U	0.010	J	0.000	U	0.000	U	0.012	J	0.000	U	0.016		0.000	U
n-C10	0.000	U	0.000	U	0.000	U	0.006	J	0.000	U	0.000	U	0.008	J	0.000	U	0.005	J	0.000	U
n-C11	0.000	U	0.000	U	0.000	U	0.002	J	0.000	U	0.000	U	0.004	J	0.000	U	0.005	J	0.000	U
n-C12	0.000	U	0.000	U	0.000	U	0.015	J	0.000	U	0.000	U	0.014	J	0.000	U	0.007	J	0.012	J
n-C13	0.000	U	0.000	U	0.000	U	0.005	J	0.000	U	0.000	U	0.005	J	0.000	U	0.004	J	0.002	J
i-C15	0.000	U	0.000	U	0.000	U	0.002	J	0.000	U	0.000	U	0.001	J	0.000	U	0.000	U	0.000	U
n-C14	0.000	U	0.000	U	0.000	U	0.014		0.000	U	0.000	U	0.016		0.000	U	0.005	J	0.009	J
i-C16	0.000	U	0.000	U	0.000	U	0.002	J	0.000	U	0.000	U	0.002	J	0.000	U	0.002	J	0.015	
n-C15	0.000	U	0.000	U	0.000	U	0.038		0.000	U	0.000	U	0.017		0.000	U	0.007	J	0.029	
n-C16	0.000	U	0.000	U	0.000	U	0.010		0.000	U	0.000	U	0.011		0.000	U	0.007		0.018	
i-C18	0.000	U	0.000	U	0.000	U	0.004		0.000	U	0.000	U	0.002	J	0.000	U	0.000	U	0.000	U
n-C17	0.000	U	0.000	U	0.000	U	0.141		0.000	U	0.000	U	0.108		0.000	U	0.021		0.097	
Pristane	0.000	U	0.000	U	0.000	U	0.006		0.000	U	0.000	U	0.012		0.000	U	0.005		0.010	
n-C18	0.000	U	0.000	U	0.000	U	0.023		0.000	U	0.000	U	0.032		0.000	U	0.030		0.071	
Phytane	0.000	U	0.000	U	0.000	U	0.006		0.000	U	0.000	U	0.006		0.000	U	0.005	J	0.040	
n-C19	0.000	U	0.000	U	0.000	U	0.021		0.000	U	0.000	U	0.023		0.000	U	0.013		0.050	
n-C20	0.000	U	0.000	U	0.000	U	0.013		0.000	U	0.000	U	0.023		0.000	U	0.011	J	0.014	
n-C21	0.000	U	0.000	U	0.000	U	0.015		0.000	U	0.000	U	0.019		0.000	U	0.007		0.057	
n-C22	0.000	U	0.000	U	0.000	U	0.009		0.000	U	0.000	U	0.008		0.000	U	0.004		0.024	
n-C23	0.000	U	0.000	U	0.000	U	0.011		0.000	U	0.000	U	0.014		0.000	U	0.009		0.203	
n-C24	0.000	U	0.000	U	0.000	U	0.005		0.000	U	0.000	U	0.004	J	0.000	U	0.005		0.021	
n-C25	0.000	U	0.000	U	0.000	U	0.032		0.000	U	0.000	U	0.023		0.000	U	0.015		0.247	
n-C26	0.000	U	0.000	U	0.000	U	0.011		0.000	U	0.000	U	0.005	J	0.000	U	0.005	J	0.011	
n-C27	0.000	U	0.000	U	0.000	U	0.023		0.000	U	0.000	U	0.012		0.000	U	0.006	J	1.793	
n-C28	0.000	U	0.000	U	0.000	U	0.021		0.000	U	0.000	U	0.011	J	0.000	U	0.009	J	0.056	
n-C29	0.000	U	0.000	U	0.000	U	0.075		0.000	U	0.000	U	0.036		0.000	U	0.031		0.268	
n-C30	0.000	U	0.000	U	0.000	U	0.009	J	0.000	U	0.000	U	0.007	J	0.000	U	0.008	J	0.027	
n-C31	0.000	U	0.000	U	0.000	U	0.069		0.000	U	0.000	U	0.052		0.000	U	0.010	J	0.183	
n-C32	0.000	U	0.000	U	0.000	U	0.010	J	0.000	U	0.000	U	0.003	J	0.000	U	0.000	U	0.041	
n-C33	0.000	U	0.000	U	0.000	U	0.116		0.000	U	0.000	U	0.044		0.000	U	0.000	U	0.085	
n-C34	0.000	U	0.000	U	0.000	U	0.013	J	0.000	U	0.000	U	0.005	J	0.000	U	0.000	U	0.027	
n-C35	0.000	U	0.000	U	0.000	U	0.034		0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.035	
n-C36	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.026	
n-C37	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.090	
n-C38	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.055	
n-C39	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.057	
n-C40	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
TEH	753		733		1,104		48.0		482		309		30.7		300		1.41		41.5	

Notes: J, below method detection level, MDL; U, not detected

Appendix D. Aliphatics and total extractable hydrocarbons from the St. Thomas East End Reserves. (continued)

Compound	3-33P		3-37A		3-38A		3-45A		4-46P		4-47P		4-48P		4-49P		4-50P		5-61P	
n-C9	0.000	U	0.015		0.000	U	0.016		0.015		0.017		0.000	U	0.014		0.011	J	0.013	
n-C10	0.000	U	0.003	J	0.000	U	0.007	J	0.006	J	0.003	J	0.000	U	0.003	J	0.004	J	0.005	J
n-C11	0.000	U	0.002	J	0.000	U	0.002	J	0.003	J	0.002	J	0.000	U	0.001	J	0.002	J	0.001	J
n-C12	0.000	U	0.006	J	0.000	U	0.015	J	0.009	J	0.008	J	0.000	U	0.007	J	0.010	J	0.010	J
n-C13	0.000	U	0.005	J	0.000	U	0.005	J	0.005	J	0.005	J	0.000	U	0.004	J	0.004	J	0.006	J
i-C15	0.000	U	0.000	U	0.000	U	0.001	J	0.001	J	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C14	0.000	U	0.004	J	0.000	U	0.016		0.010	J	0.007	J	0.000	U	0.005	J	0.009	J	0.010	J
i-C16	0.000	U	0.000	U	0.000	U	0.002	J	0.001	J	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C15	0.000	U	0.012	J	0.000	U	0.027		0.012	J	0.016	J	0.000	U	0.028		0.011	J	0.010	J
n-C16	0.000	U	0.004	J	0.000	U	0.011		0.007		0.008		0.000	U	0.009		0.006		0.008	
i-C18	0.000	U	0.000	U	0.000	U	0.005		0.002	J	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C17	0.000	U	0.072		0.000	U	0.116		0.029		0.073		0.000	U	0.186		0.027		0.022	
Pristane	0.000	U	0.003		0.000	U	0.009		0.002	J	0.001	J	0.000	U	0.002	J	0.001	J	0.002	J
n-C18	0.000	U	0.004		0.000	U	0.032		0.003	J	0.017		0.000	U	0.025		0.012		0.019	
Phytane	0.000	U	0.002	J	0.000	U	0.008		0.002	J	0.004	J	0.000	U	0.004	J	0.004	J	0.006	
n-C19	0.000	U	0.008		0.000	U	0.034		0.015		0.015		0.000	U	0.018		0.011		0.017	
n-C20	0.000	U	0.009	J	0.000	U	0.008	J	0.006	J	0.013		0.000	U	0.019		0.003	J	0.007	J
n-C21	0.000	U	0.007		0.000	U	0.026		0.017		0.016		0.000	U	0.005		0.016		0.023	
n-C22	0.000	U	0.000	U	0.000	U	0.013		0.005		0.005		0.000	U	0.003	J	0.006		0.008	
n-C23	0.000	U	0.000	U	0.000	U	0.070		0.035		0.014		0.000	U	0.006	J	0.030		0.072	
n-C24	0.000	U	0.000	U	0.000	U	0.007		0.005	J	0.005		0.000	U	0.006		0.006		0.008	
n-C25	0.000	U	0.000	U	0.000	U	0.092		0.030		0.026		0.000	U	0.008		0.037		0.105	
n-C26	0.000	U	0.000	U	0.000	U	0.004	J	0.007	J	0.004	J	0.000	U	0.004	J	0.004	J	0.008	
n-C27	0.000	U	0.000	U	0.000	U	0.028		0.009	J	0.006	J	0.000	U	0.003	J	0.016		0.041	
n-C28	0.000	U	0.000	U	0.000	U	0.009	J	0.006	J	0.005	J	0.000	U	0.003	J	0.004	J	0.006	J
n-C29	0.000	U	0.000	U	0.000	U	0.049		0.012	J	0.009	J	0.000	U	0.000	U	0.013	J	0.046	
n-C30	0.000	U	0.000	U	0.000	U	0.011	J	0.005	J	0.003	J	0.000	U	0.000	U	0.004	J	0.004	J
n-C31	0.000	U	0.000	U	0.000	U	0.055		0.017		0.004	J	0.000	U	0.000	U	0.014	J	0.036	
n-C32	0.000	U	0.000	U	0.000	U	0.004	J	0.001	J	0.002	J	0.000	U	0.000	U	0.001	J	0.001	J
n-C33	0.000	U	0.000	U	0.000	U	0.055		0.007	J	0.028		0.000	U	0.000	U	0.022		0.022	
n-C34	0.000	U	0.000	U	0.000	U	0.005	J	0.000	U	0.016	J	0.000	U	0.000	U	0.000	U	0.001	J
n-C35	0.000	U	0.000	U	0.000	U	0.018		0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C36	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C37	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C38	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C39	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
n-C40	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U	0.000	U
TEH	24.0		3.21		22.2		16.4		6.36		2.57		31.6		2.06		23.0		16.8	

Notes: J, below method detection level, MDL; U, not detected

Appendix D. Aliphatics and total extractable hydrocarbons from the St. Thomas East End Reserves. (continued).

Compound	5-62P	5-70A	5-71A	5-75A
n-C9	0.015	0.017	0.010 J	0.015
n-C10	0.009 J	0.003 J	0.005 J	0.005 J
n-C11	0.003 J	0.002 J	0.002 J	0.002 J
n-C12	0.015 J	0.009 J	0.009 J	0.011 J
n-C13	0.004 J	0.006 J	0.006 J	0.004 J
i-C15	0.003 J	0.000 U	0.000 U	0.001 J
n-C14	0.019	0.007 J	0.009 J	0.012 J
i-C16	0.003 J	0.003 J	0.000 U	0.002 J
n-C15	0.019	0.031	0.013 J	0.019
n-C16	0.010	0.017	0.007	0.009
i-C18	0.003 J	0.000 U	0.000 U	0.002 J
n-C17	0.064	0.474	0.182	0.071
Pristane	0.005	0.007	0.003	0.002 J
n-C18	0.005	0.050	0.016	0.005
Phytane	0.003 J	0.004 J	0.005 J	0.007
n-C19	0.023	0.061	0.018	0.028
n-C20	0.006 J	0.052	0.003 J	0.003 J
n-C21	0.041	0.049	0.010	0.033
n-C22	0.010	0.009	0.005	0.009
n-C23	0.093	0.124	0.012	0.085
n-C24	0.009	0.008	0.005 J	0.008
n-C25	0.068	0.088	0.037	0.052
n-C26	0.012	0.007 J	0.005 J	0.011
n-C27	0.022	0.466	0.008 J	0.010 J
n-C28	0.009 J	0.018	0.006 J	0.011 J
n-C29	0.027	0.064	0.015 J	0.022
n-C30	0.005 J	0.008 J	0.005 J	0.004 J
n-C31	0.037	0.104	0.017	0.052
n-C32	0.005 J	0.010 J	0.007 J	0.004 J
n-C33	0.027	0.110	0.029	0.069
n-C34	0.000 U	0.029	0.000 U	0.008 J
n-C35	0.000 U	0.033	0.000 U	0.021
n-C36	0.000 U	0.000 U	0.000 U	0.000 U
n-C37	0.000 U	0.000 U	0.000 U	0.000 U
n-C38	0.000 U	0.000 U	0.000 U	0.000 U
n-C39	0.000 U	0.000 U	0.000 U	0.000 U
n-C40	0.000 U	0.000 U	0.000 U	0.000 U
TEH	9.33	4.16	25.1	15.8

Notes: J, below method detection level, MDL; U, not detected

Appendix E. PCBs detected in the sediments from the St. Thomas East End Reserves.

Compound	1-1P		1-2P		1-3P		1-4P		1-5P		2-16P		2-19P		2-20P		2-24A		3-32P	
PCB8/5	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB18	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.04	J	0.00	U	0.00	U	0.00	U	0.00	U
PCB28	0.00	U	0.95		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB29	0.00	U	0.00	U	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	J	0.00	U
PCB31	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB44	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB45	0.00	U	0.00	U	0.00	U	0.02	J	0.00	U	0.06	J	0.01	J	0.04	J	0.00	U	0.00	U
PCB49	0.14		0.14		0.00	U	0.00	U	0.16		0.32		0.00	U	0.34		0.00	U	0.00	U
PCB52	0.00	U	0.00	U	0.00	U	0.03	J	0.00	U	0.00	U	0.02	J	0.33		0.00	U	0.00	U
PCB56/60	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.14		0.08		0.24		0.00	U	0.00	U
PCB66	0.00	U	0.16		0.00	U	0.00	U	0.14		0.30		0.00	U	0.43		0.01	J	0.00	U
PCB70	0.00	U	0.19		0.00	U	0.00	U	0.16		0.21		0.09		0.46		0.02	J	0.00	U
PCB74/61	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.08		0.00	U	0.00	U	0.00	U	0.00	U
PCB87/115	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.10		0.00	U	0.00	U
PCB95	0.00	U	0.00	U	0.00	U	0.02	J	0.00	U	0.16		0.08		0.22		0.01	J	0.00	U
PCB99	0.00	U	0.00	U	0.00	U	0.00	U	0.07		0.38		0.00	U	0.82		0.00	U	0.00	U
PCB101/90	0.00	U	0.00	U	0.00	U	0.04	J	0.00	U	0.25		0.06		0.84		0.07		0.00	U
PCB105	0.00	U	0.00	U	0.56		0.00	U	0.00	U	0.10		0.00	U	0.21		0.00	U	0.00	U
PCB110/77	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.12		0.00	U	0.43		0.00	U	0.00	U
PCB118	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.62		0.00	U	0.00	U
PCB128	0.11		0.22		0.35		0.00	U	0.21		0.00	U	0.00	U	0.13		0.00	U	0.00	U
PCB138/160	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.08	J	0.94		0.00	U	0.00	U
PCB146	0.00	U	0.00	U	0.00	U	0.06	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB149/123	0.00	U	0.00	U	0.00	U	0.00	U	0.10		0.20		0.00	U	0.40		0.00	U	0.00	U
PCB151	0.11		0.00	U	0.00	U	0.00	U	0.08	J	0.05	J	0.00	U	0.25		0.00	U	0.00	U
PCB153/132	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U
PCB156/171/202	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U
PCB158	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.05	J	0.00	U	0.00	U
PCB170/190	2.08		0.00	U	0.00	U	0.00	U	1.89		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB174	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.06		0.00	U	0.00	U
PCB180	0.11		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.05		0.00	U	0.02	J	0.00	U
PCB183	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.17		0.00	U	0.00	U
PCB187	0.02	J	0.11		0.18		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB194	0.00	U	0.05		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB195/208	0.00	U	0.08		0.00	U	0.00	U	0.00	U	0.00	U	0.03	J	0.00	U	0.00	U	0.00	U
PCB199	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB201/157/173	0.06		0.13		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB206	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB209	0.06		0.00	U	0.00	U	0.00	U	0.07		0.11		0.05	J	0.17		0.00	U	0.00	U
Total PCBs	2.69		2.01		1.09		0.19		2.88		2.50		0.58		7.23		0.14		0.00	

Notes: PCB, polychlorinated biphenyl; J, below method detection level, MDL; U, not detected

Appendix E. PCBs detected in the sediments from the St. Thomas East End Reserves. (continued)

Compound	3-33P		3-37A		3-38A		3-45A		4-46P		4-47P		4-48P		4-49P		4-50P		5-61P	
PCB8/5	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB18	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.10		0.00	U
PCB28	0.00	U	0.00	U	0.08		0.00	U	0.00	U	0.08		0.00	U	0.00	U	0.04	J	0.00	U
PCB29	0.01	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB31	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.13		0.00	U	0.00	U	0.00	U	0.00	U
PCB44	0.00	U	0.00	U	0.14		0.00	U	0.15		0.15		0.16		0.00	U	0.00	U	0.17	
PCB45	0.00	J	0.00	U	0.01	J	0.02	J	0.01	J	0.05	J	0.00	U	0.00	U	0.00	U	0.00	U
PCB49	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB52	0.00	J	0.01	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U
PCB56/60	0.00	U	0.00	U	0.08		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB66	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U	0.00	U
PCB70	0.00	U	0.00	U	0.00	U	0.07		0.00	U	0.00	U	0.05	J	0.00	U	0.00	U	0.00	U
PCB74/61	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB87/115	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J
PCB95	0.01	J	0.00	U	0.03	J	0.00	U	0.00	U	0.02	J	0.02	J	0.00	U	0.01	J	0.02	J
PCB99	0.00	U	0.00	U	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U
PCB101/90	0.04	J	0.08		0.14		0.11		0.03	J	0.02	J	0.05		0.03	J	0.00	U	0.00	U
PCB105	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB110/77	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB118	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB128	0.00	U	0.01	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB138/160	0.00	U	0.00	U	0.14		0.03	J	0.04	J	0.00	U	0.05	J	0.00	U	0.05	J	0.00	U
PCB146	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB149/123	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB151	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB153/132	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB156/171/202	0.01	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U	0.00	U	0.00	U
PCB158	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB170/190	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB174	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB180	0.02	J	0.03	J	0.04	J	0.10		0.00	U	0.00	U	0.01	J	0.00	U	0.01	J	0.03	J
PCB183	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB187	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB194	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB195/208	0.00	U	0.00	U	0.02	J	0.00	U	0.00	U	0.00	U	0.00	J	0.05		0.00	U	0.00	U
PCB199	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB201/157/173	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB206	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
PCB209	0.05	J	0.00	U	0.00	U	0.00	U	0.07		0.00	U	0.00	U	0.00	U	0.11		0.03	J
Total PCBs	0.13		0.15		0.66		0.35		0.30		0.46		0.34		0.08		0.33		0.25	

Notes: PCB, polychlorinated biphenyl; J, below method detection level, MDL; U, not detected

Appendix E. PCBs detected in the sediments from the St. Thomas East End Reserves. (continued)

Compound	5-62P	5-70A	5-71A	5-75A	BB-1	BB-2	ML-2	ML-10
PCB8/5	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.46	0.00 U	0.20
PCB18	0.00 U	0.00 U	0.12	0.00 U	0.00 U	0.26	0.00 U	0.08
PCB28	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	3.71	0.85
PCB29	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U	0.00 U	0.06 J	0.00 U
PCB31	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB44	0.15	0.13	0.17	0.00 U	0.28	0.71	0.18	0.28
PCB45	0.01 J	0.00 U	0.00 J	0.00 U	0.00 U	0.07 J	0.09	0.00 U
PCB49	0.00 U	0.00 U	0.00 U	0.00 U	0.89	1.86	0.09	0.13
PCB52	0.00 U	0.01 J	0.00 U	0.00 U	0.93	1.77	0.22	3.03
PCB56/60	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.69	0.00 U	0.17
PCB66	0.00 U	0.00 U	0.00 U	0.00 U	0.41	2.27	0.13	0.22
PCB70	0.00 U	0.12	0.05 J	0.00 U	0.51	1.27	0.05 J	0.16
PCB74/61	0.00 U	0.00 U	0.00 U	0.00 U	0.17	0.56	0.05 J	0.45
PCB87/115	0.05 J	0.00 U	0.00 U	0.00 U	0.21	0.84	0.00 U	0.11
PCB95	0.04 J	0.00 U	0.03 J	0.07	0.36	1.64	0.08	0.18
PCB99	0.02 J	0.00 U	0.00 U	0.00 U	0.70	3.06	0.14	0.26
PCB101/90	0.00 U	0.04 J	0.02 J	0.04 J	0.77	3.63	0.12	0.34
PCB105	0.00 U	0.00 U	0.00 U	0.00 U	0.18	0.90	0.05	0.08
PCB110/77	0.00 U	0.00 U	0.00 U	0.00 U	0.52	3.11	0.11	0.42
PCB118	0.00 U	0.00 U	0.00 U	0.00 U	0.67	3.11	0.20	0.29
PCB128	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	1.18	0.03 J	0.08
PCB138/160	0.04 J	0.00 U	0.06 J	0.13	0.98	5.89	0.36	0.49
PCB146	0.00 U	0.00 U	0.00 U	0.03 J	0.00 U	0.79	0.04 J	0.13
PCB149/123	0.00 U	0.00 U	0.00 U	0.00 U	0.69	2.44	0.21	0.24
PCB151	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.59	0.00 U	0.15
PCB153/132	0.00 U	0.02 J	0.01 J	0.00 U	1.59	7.78	0.42	0.63
PCB156/171/202	0.00 U	0.00 U	0.00 U	0.00 U	0.14	0.60	0.02 J	0.35
PCB158	0.00 U	0.00 U	0.00 U	0.00 U	0.06 J	0.42	0.05 J	0.04 J
PCB170/190	0.00 U	0.00 U	0.00 U	0.00 U	7.39 I	12.59 I	1.88 I	10.04 I
PCB174	0.00 U	0.00 U	0.00 U	0.00 U	0.13	0.68	0.03 J	0.00 U
PCB180	0.00 U	0.00 U	0.02 J	0.04 J	0.82	2.46	0.22	0.70
PCB183	0.00 U	0.00 U	0.00 U	0.00 U	0.11	0.57	0.05	0.04 J
PCB187	0.02 J	0.00 U	0.00 U	0.00 U	0.57	1.65	0.20	0.21
PCB194	0.00 U	0.00 U	0.00 U	0.00 U	0.17	0.88	0.10	0.30
PCB195/208	0.03 J	0.00 U	0.00 U	0.00 U	0.00 U	0.21	0.01 J	0.16
PCB199	0.00 U	0.00 U	0.00 U	0.00 U	0.17	0.49	0.00 U	0.00 U
PCB201/157/173	0.00 U	0.00 U	0.00 U	0.00 U	0.11	0.19	0.04 J	0.29
PCB206	0.00 U	0.00 U	0.00 U	0.00 U	0.08	0.00 U	0.04 J	0.09
PCB209	0.06	0.00 U	0.04 J	0.09	0.27	0.35	0.03 J	0.57
Total PCBs	0.40	0.32	0.53	0.39	19.89	65.94	8.97	21.78

Notes: PCB, polychlorinated biphenyl; J, below method detection level, MDL; U, not detected

Appendix F. Organochlorine compounds detected in sediments from the St. Thomas East End Reserves (ng/dry g).

Compound	1-1P		1-2P		1-3P		1-4P		1-5P		2-16P		2-19P		2-20P		2-24A		3-32P	
Aldrin	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Dieldrin	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Endrin	0.00	U	0.00	U	0.00	U	0.00	U	0.18		0.13		0.00	U	0.28		0.00	U	0.00	U
Heptachlor	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Heptachlor-Epoxide	0.00	U	0.04	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Oxychlordane	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Alpha-Chlordane	0.00	U	0.00	U	0.00	U	0.03	J	0.07		0.13		0.00	U	0.00	U	0.00	J	0.00	U
Gamma-Chlordane	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.05	J	0.00	U	0.02	J	0.00	U	0.00	U
Trans-Nonachlor	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.09		0.00	U	0.00	U	0.00	U	0.00	U
Cis-Nonachlor	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.06		0.00	U	0.05		0.00	U	0.00	U
Alpha-HCH	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Beta-HCH	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Delta-HCH	0.00	U	0.00	U	0.00	U	0.01	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Gamma-HCH	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
DDMU	0.00	U	0.00	U	0.00	U	0.00	U	0.04	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
2,4'-DDD	0.09		0.00	U	0.00	U	0.00	U	0.00	U	0.08		0.00	U	0.26		0.01	J	0.00	U
4,4'-DDD	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.01	J	0.09		0.01	J	0.00	U
2,4'-DDE	0.00	U	0.04	J	0.00	U	0.00	U	0.06		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
4,4'-DDE	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.08		0.00	U	0.00	U
2,4'-DDT	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
4,4'-DDT	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.18		0.00	U	0.00	U
1,2,3,4-Tetrachlorobenzene	0.00	U	0.11		0.00	U	0.00	U	0.00	U	0.00	U	0.03	J	0.11		0.00	U	0.00	U
1,2,4,5-Tetrachlorobenzene	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Hexachlorobenzene	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.16		0.00	U	0.00	U	0.00	U	0.00	U
Pentachloroanisole	0.35		0.37		0.46		0.02	J	0.24		0.00	U	0.02	J	0.14		0.00	U	0.00	U
Pentachlorobenzene	0.05	J	0.09		0.22		0.00	U	0.07	J	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Endosulfan II	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Endosulfan I	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Endosulfan Sulfate	0.06		0.04		0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.14		0.00	U	0.00	U
Mirex	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U	0.00	U
Chlorpyrifos	0.00	U	0.35		0.00	U	0.22		0.00	U	0.25		0.00	U	0.00	U	0.00	U	0.00	U
Total DDT	0.09		0.04		0.00		0.00		0.10		0.08		0.01		0.61		0.02		0.00	

Notes: J, below method detection level, MDL; U, not detected

Appendix F. Organochlorine compounds detected in sediments from the St. Thomas East End Reserves (ng/dry g). (continued)

Compound	3-33P	3-37A	3-38A	3-45A	4-46P	4-47P	4-48P	4-49P	4-50P	5-61P
Aldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Dieldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.10	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Heptachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Heptachlor-Epoxyde	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Oxychlordane	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Alpha-Chlordane	0.01 J	0.00 U	0.01 J	0.07	0.00 U	0.01 J	0.01 J	0.01 J	0.01 J	0.02 J
Gamma-Chlordane	0.00 U	0.00 U	0.03 J	0.02 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Trans-Nonachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Cis-Nonachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Alpha-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Beta-HCH	0.00 U	0.03 J	0.00 U	0.12	0.00 U	0.01 J	0.03 J	0.00 U	0.00 U	0.02 J
Delta-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Gamma-HCH	0.00 U	0.02 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U
DDMU	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDD	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDD	0.00 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 J	0.00 U	0.00 U	0.00 U
2,4'-DDE	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDE	0.00 U	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDT	0.00 U	0.00 U	0.00 U	0.08	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDT	0.02 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.04 J	0.00 U	0.00 U	0.00 U
1,2,3,4-Tetrachlorobenzene	0.00 U	0.02 J	0.00 U	0.00 U	0.02 J	0.03 J	0.03 J	0.01 J	0.00 U	0.00 U
1,2,4,5-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Hexachlorobenzene	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U	0.44	0.12	0.00 U	0.00 U	0.00 U
Pentachloroanisole	0.00 U	0.00 U	0.02 J	0.02 J	0.02 J	0.00 U	0.01 J	0.00 U	0.02 J	0.00 U
Pentachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endosulfan II	0.00 U	0.00 U	0.01 J	0.00 U	0.01 J	0.00 U	0.00 J	0.00 U	0.00 U	0.01 J
Endosulfan I	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endosulfan Sulfate	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U
Mirex	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Chlorpyrifos	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Total DDT	0.03	0.00	0.00	0.09	0.00	0.00	0.04	0.00	0.00	0.00

Notes: J, below method detection level, MDL; U, not detected

Appendix F. Organochlorine compounds detected in sediments from the St. Thomas East End Reserves (ng/dry g). (continued)

Compound	5-62P	5-70A	5-71A	5-75A	BB-1	BB-2	ML-2	ML-10
Aldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.96	0.20	0.64
Dieldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.08	0.08	0.05 J	0.07
Endrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.38	0.33
Heptachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.20	0.00 U	0.00 U
Heptachlor-Epoxide	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Oxychlordane	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Alpha-Chlordane	0.04 J	0.03 J	0.01 J	0.02 J	0.22	0.09	0.09	0.54
Gamma-Chlordane	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.11	0.01 J	0.31
Trans-Nonachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.09	0.09	0.02 J	0.43
Cis-Nonachlor	0.00 U	0.00 U	0.00 J	0.00 U	0.00 U	0.21	0.08	0.26
Alpha-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.11
Beta-HCH	0.02 J	0.00 U	0.03 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Delta-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Gamma-HCH	0.00 U	0.05	0.00 U	0.00 U	0.00 U	0.16	0.60	0.31
DDMU	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	1.19	0.06 J	0.42
2,4'-DDD	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.88	0.00 U	0.00 U
4,4'-DDD	0.00 U	0.00 U	0.00 U	0.01 J	0.00 U	0.78	0.05 J	0.12
2,4'-DDE	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDE	0.00 U	0.00 U	0.00 J	0.00 U	0.30	0.31	0.12	0.26
2,4'-DDT	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.17	0.16	0.00 U
4,4'-DDT	0.00 U	0.00 U	0.00 U	0.00 U	1.01	0.29	0.10	0.07
1,2,3,4-Tetrachlorobenzene	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
1,2,4,5-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Hexachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.10	0.14	0.00 U	0.08
Pentachloroanisole	0.00 U	0.00 U	0.02 J	0.03 J	0.25	0.16	0.12	0.16
Pentachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.05 J	0.00 U	0.10
Endosulfan II	0.01 J	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U	0.05	0.19
Endosulfan I	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.04	0.15
Endosulfan Sulfate	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U	1.13	0.03 J	0.29
Mirex	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Chlorpyrifos	0.00 U	0.00 U	0.00 U	0.00 U	1.33	0.13	0.08	0.62
Total DDT	0.00	0.00	0.00	0.01	1.31	3.61	0.50	0.86

Notes: J, below method detection level, MDL; U, not detected

Appendix G. Butyltins detected in sediments from the St. Thomas East End Reserves (ng Sn/dry g).

Compound	1-1P	1-2P	1-3P	1-4P	1-5P	2-16P
Monobutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	5.57
Dibutyltin	0.00 U	1.54	0.00 U	0.26 J	1.67	5.37
Tributyltin	0.00 U	1.08	3.27	0.00 U	0.90	6.00
Tetrabutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U

Compound	2-19P	2-20P	2-24A	3-32P	3-33P	3-37A
Monobutyltin	1.14	20.88	0.99	0.61	0.00 U	0.00 U
Dibutyltin	0.56	21.20	1.30	0.58	0.00 U	0.00 U
Tributyltin	0.36	31.14	1.01	0.58	0.00 U	0.00 U
Tetrabutyltin	0.00 U	0.95 U	0.00 U	0.00 U	0.00 U	0.00 U

Compound	3-38A	3-45A	4-46P	4-47P	4-48P	4-49P
Monobutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Dibutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Tributyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Tetrabutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U

Compound	4-50P	5-61P	5-62P	5-70A	5-71A	5-75A
Monobutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	2.37
Dibutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	2.28
Tributyltin	0.00 U	0.00 U	0.00 U	0.15 J	0.00 U	0.00 U
Tetrabutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U

Compound	BB-1	BB-2	ML-2	ML-10
Monobutyltin	20.01	308.33	1.36	5.55
Dibutyltin	43.32	276.20	2.58	4.11
Tributyltin	76.59	247.83	1.91	2.0
Tetrabutyltin	0.35 J	1.86	0.00 U	0.00 U

Appendix H. Major and trace elements detected in sediments from St. Thomas East End Reserves (µg/dry g).

Element	Name	1-1P	1-2P	1-3P	1-4P	1-5P	2-16P	2-19P
Ag	Silver	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Al	Aluminum	63,800	50,000	54,300	3,520	37,400	31,500	3,620
As	Arsenic	12.4	9.12	7.18	1.82	6.66	8.14	1.89
Ca	Calcium	77,600	115,000	98,700	365,000	201,000	20,700	363,000
Cd	Cadmium	0.212	0 U	0.264	0 U	0 U	0.19	0 U
Cr	Chromium	35.7	31.1	32.3	11	23.4	17.5	13.6
Cu	Copper	69.9	60.5	69.3	5.55	36.9	46.8	14.7
Fe	Iron	40,900	32,300	35,400	2,420	23,800	20,100	2,310
Hg	Mercury	0.109	0.0676	0.0808	0.0028	0.0433	0.0658	0.0039
Mn	Manganese	317	299	338	45.2	190	182	45.4
Ni	Nickel	15.1	11.6	11.4	4.46	9.89	7.44	5.04
Pb	Lead	21.1	31	25.3	1.26	14.9	12.9	2.34
Sb	Antimony	0.487	0.632	0.819	0 U	0.426	0.482	0 U
Se	Selenium	0.926	0.585	0.632	0.129	0.53	0.474	0.121
Si	Silicon	181,000 B	147,000	174,000	18,400	106,000 B	126,000	27,700
Sn	Tin	3.95	2.33	2.65	0 U	1.71	1.36	0 U
Zn	Zinc	136	159	154	13.3	82.6	83.3	20.3

Element	Name	2-20P	2-24A	3-32P	3-33P	3-37A	3-38A	3-45A
Ag	Silver	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Al	Aluminum	22,600	1,380	8,860	1,210	979	9,430	2,360
As	Arsenic	6.16	1.34	1.58	0 U	0 U	1.16	0 U
Ca	Calcium	293,000	391,000	368,000	355,000	392,000	188,000	152,000
Cd	Cadmium	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Cr	Chromium	17.1	4.91	11	9.5	8.26	12.7	9.17
Cu	Copper	155	4.1	7.61	1.39	1.33	4.51	3.08
Fe	Iron	14,600	1,200	5,010	761	582	4,910	1,230
Hg	Mercury	0.0683	0.0021	0.0057	0.0012	0.0011	0.0009	0.0013
Mn	Manganese	113	19.8	73.7	18.3	12.9	82.7	26.3
Ni	Nickel	8.01	5.15	5.95	4.48	4.57	5.9	5.01
Pb	Lead	19.2	0.782	2.55	0.785	0.615	1.12	0.824
Sb	Antimony	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Se	Selenium	0.298	0.247	0.181	0.132	0.127	0.0913	0.163
Si	Silicon	70,700 B	10,500 B	44,100 B	6,480 B	5,680 B	48,000 B	12,000 B
Sn	Tin	2.52	0 U	0 U	0 U	0 U	0 U	0 U
Zn	Zinc	115	9.42	15.8	0 U	5.04	12	5.22

Notes: U, analyte not detected; B, analyte detected in the procedural blank greater than 2X MDL. NA, not analyzed

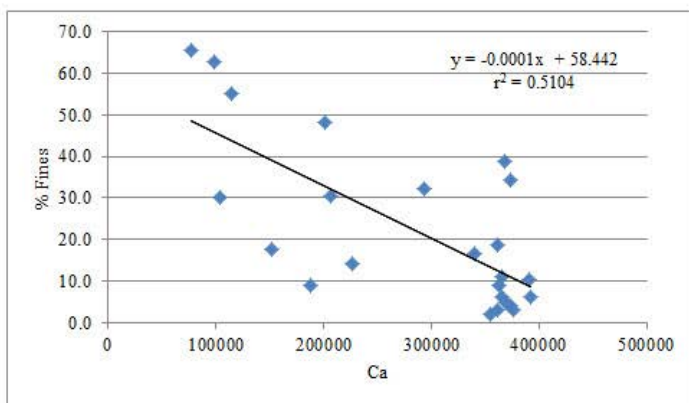
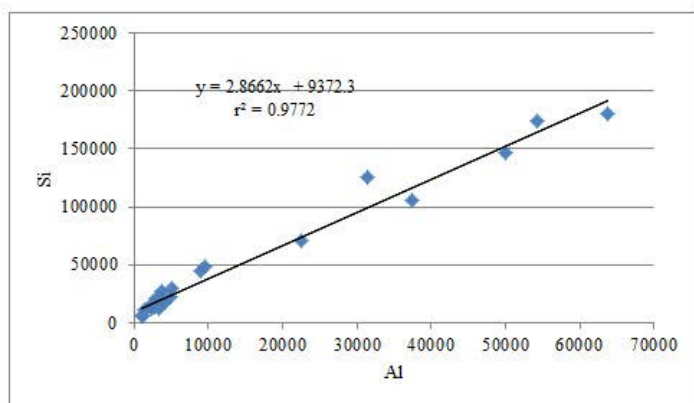
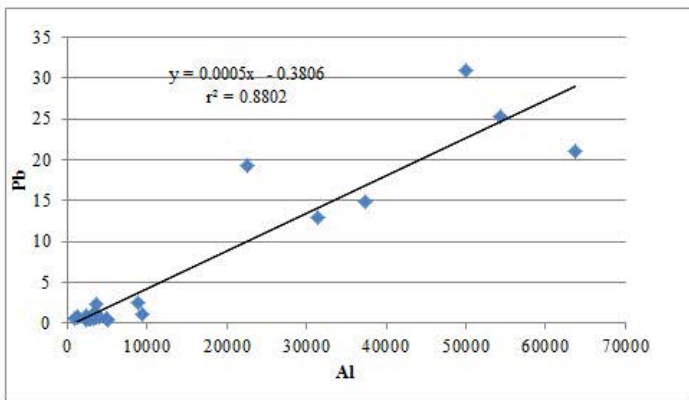
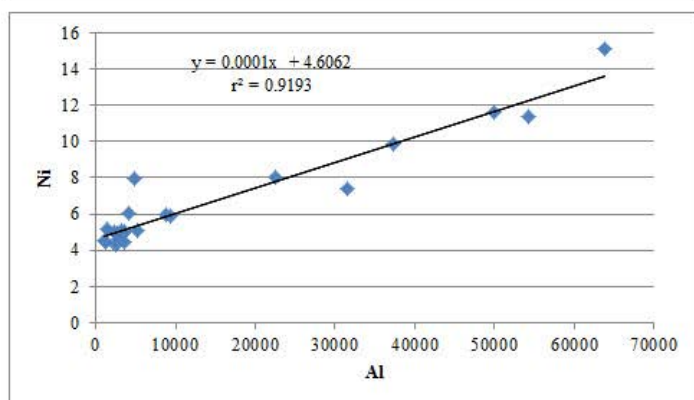
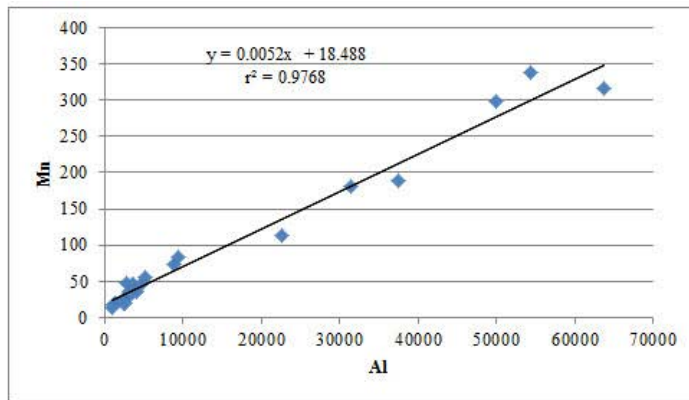
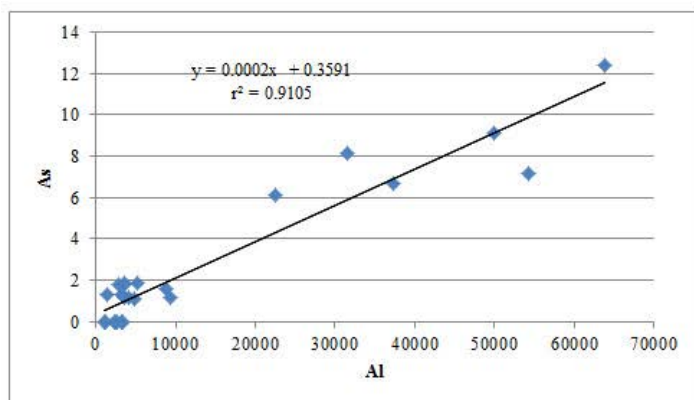
Appendix H. Major and trace elements detected in sediments from St. Thomas East End Reserves (µg/dry g). (continued)

Element	Name	4-46P	4-47P	4-48P	4-49P	4-50P	5-61P	5-62P
Ag	Silver	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Al	Aluminum	3,250	5,130	4,840	2,840	2,430	2,680	3,550
As	Arsenic	1.33	1.86	1.08	1.79	0 U	0 U	1.2
Ca	Calcium	366,000	373,000	361,000	376,000	370,000	226,000	361,000
Cd	Cadmium	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Cr	Chromium	11.7	11.7	20.8	5.75	6.43	6.46	12.2
Cu	Copper	1.8	1.63	1.87	2.21	1.3	1.35	2.64
Fe	Iron	1,850	2,980	3,110	1,940	996	1,090	2,110
Hg	Mercury	0.0009	0.0011	0.0009	0.0007	0 U	0.0012	0.0016
Mn	Manganese	37.4	54.7	47.1	47.1	19.8	19.3	43.7
Ni	Nickel	5.05	5.11	7.93	4.64	4.29	4.9	4.97
Pb	Lead	0.579	0.402	0.605	0.548	0.371	0.547	0.771
Sb	Antimony	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Se	Selenium	0.152	0.0842	0.14	0.0698	0.0948	0.0946	0.14
Si	Silicon	20,300 B	30,200 B	22,000 B	20,400 B	15,500 B	13,400 B	16,400 B
Sn	Tin	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Zn	Zinc	6.5	11.5	9.46	12.2	9.39	3.88	5.86

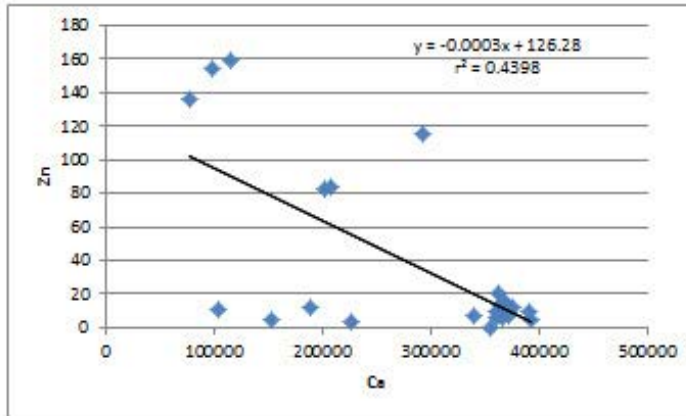
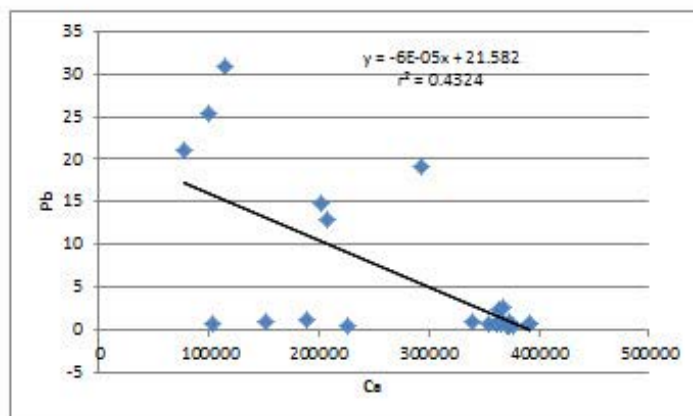
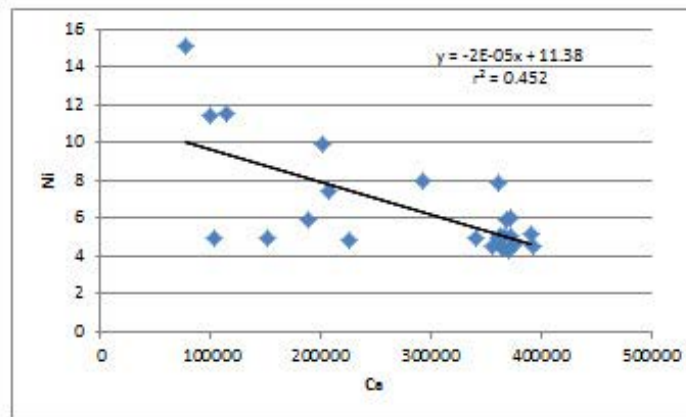
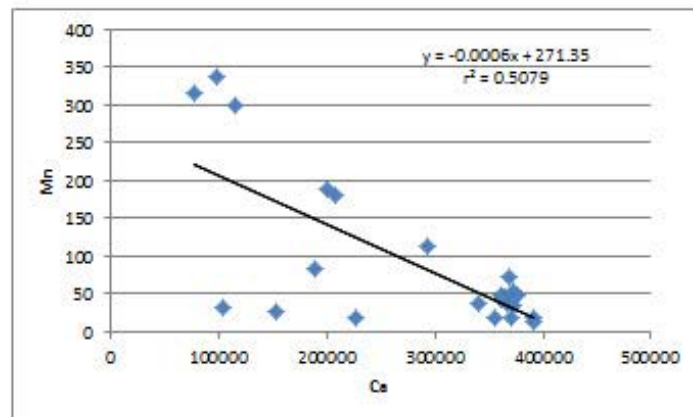
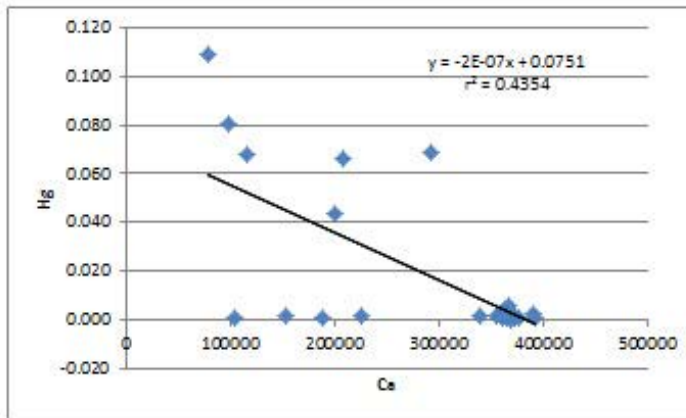
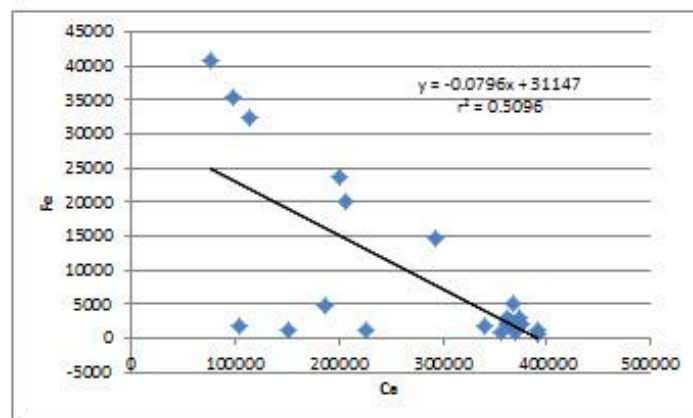
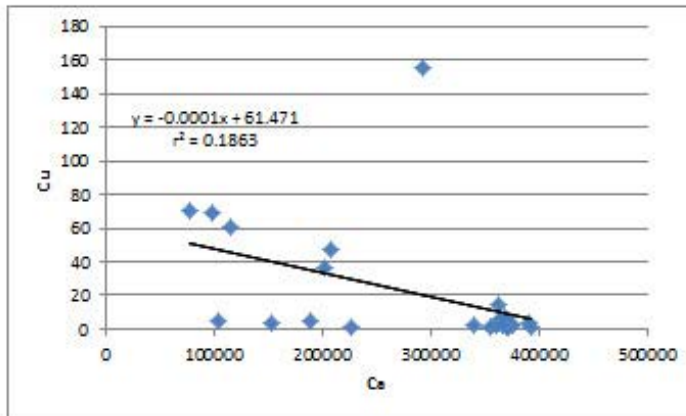
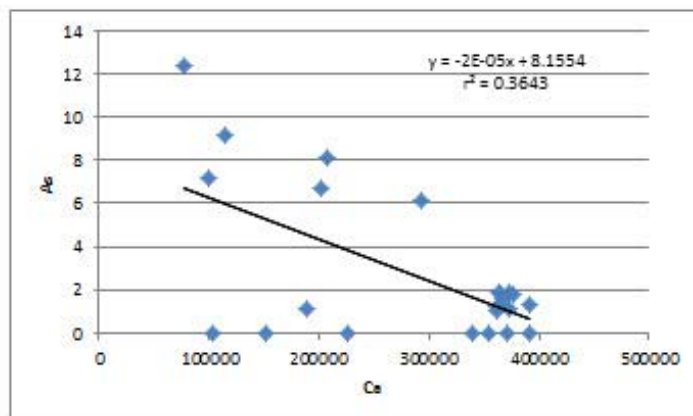
Element	Name	5-70A	5-71A	5-75A	BB-1	BB-2	ML-2	ML-10
Ag	Silver	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Al	Aluminum	4,060	3,170	3,390	41,700	52,700	53,200	45,100
As	Arsenic	1.15	0 U	0 U	9.99	13.7	12	6.81
Ca	Calcium	373,000	340,000	104,000	NA	NA	NA	NA
Cd	Cadmium	0 U	0 U	0 U	0.285	0 U	0.371	0.297
Cr	Chromium	7.54	10.5	9.03	29.5	40.4	35.3	28.8
Cu	Copper	3.4	2.48	4.74	145	1,010	78.9	60.6
Fe	Iron	2,020	1,770	1,740	26,900	29,600	36,400	29,900
Hg	Mercury	0.0018	0.0017	0.0011	0.11	0.34	0.123	0.0763
Mn	Manganese	35.5	36.4	31.7	213	220	270	379
Ni	Nickel	6.03	4.96	4.92	8.89	10.1	13.5	8.76
Pb	Lead	0.815	0.875	0.69	24.8	81.2	27.9	20
Sb	Antimony	0 U	0 U	0 U	0.393	0.687	0.743	0.669
Se	Selenium	0.113	0.105	0.129	0.55	0.438	1.12	0.577
Si	Silicon	17,200 B	14,600 B	12,600 B	130,000	169,000	120,000	191,000
Sn	Tin	0 U	0 U	0 U	3.48	13.6	5.49	2.5
Zn	Zinc	7.59	6.72	10.7	195	392	162	139

Notes: U, analyte not detected; B, analyte detected in the procedural blank greater than 2X MDL. NA, not analyzed

Appendix I. Trace elements plotted against aluminum and calcium.



Appendix I. Trace elements plotted against aluminum and calcium (continued).



Appendix J. *Clostridium perfringens* in sediments from the St. Thomas East End Reserves.

Site	Sample composition	% water	% sediment	Cperf dry (CFU/g)
1-1P	muddy shells	70.83	29.17	197
1-2P	watery shells	66.67	33.33	3,493
1-3P	muddy shells	62.12	37.88	2,137
1-4P	sandy shells	45.16	54.84	33
1-5P	muddy shells	64.71	35.29	714
2-16P	watery shells	33.33	66.67	127
2-19P	sandy shells	34.38	65.63	25
2-20P	watery shells	51.43	48.57	159
2-24A	shells	47.62	52.38	24
3-32P	sandy	40.68	59.32	61
3-33P	shells and sand	37.50	62.50	6
3-37A	shells sandy	26.47	73.53	0
3-38A	sandy	31.67	68.33	0
3-45A	shells watery	37.88	62.12	0
4-46P	sandy	26.39	73.61	0
4-47P	sandy	23.29	76.71	0
4-48P	shells and sand	23.53	76.47	0
4-49P	shells sandy	30.95	69.05	0
4-50P	sandy	28.57	71.43	0
5-61P	sandy	28.33	71.67	5
5-62P	sandy	28.77	71.23	0
5-70A	rocky sandy	34.38	65.63	0
5-71A	sandy	30.65	69.35	0
5-75A	sandy	36.99	63.01	0
BB-1	watery mud	59.62	40.38	63
BB-2	rocky mud	37.74	62.26	31
ML-2	hairy mud	85.25	14.75	234
ML-10	black mud	56.86	43.14	2,558

Notes: CFU, colony forming units



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