CHAPTER 5: ASSESSMENT OF CHEMICAL CONTAMINANTS IN SEDIMENTS AND CORALS IN VIEQUES

Anthony S. Pait, Andrew L. Mason, David R. Whitall, John D. Christensen, and S. Ian Hartwell*

Center for Coastal Monitoring and Assessment, National Centers for Coastal Ocean Science, National Ocean Service, NOAA, 1305 East-West Highway, Silver Spring, MD 20910

**Corresponding author: tony.pait@noaa.gov*

5.1 INTRODUCTION

The goal for this component of the ecosystem characterization in Vieques was to quantify the level of chemical contaminants in sediments and coral tissues from nearshore waters, and contaminants in sediments from a series of inland lagoons, in support of the environmental restoration efforts in Vieques. Objectives were to: 1) collect and analyze sediments from sites throughout the nearshore waters and inland lagoons for organic (e.g., hydrocarbons) and inorganic (e.g., trace elements, typically metals) contaminants; 2) collect and analyze samples of mustard hill coral (*Porites astreoides*) for residues of the same organic and inorganic contaminants; and 3) collect and analyze sediments for residues of energetics (i.e., explosives).

Image 5.1. Beach at Bahia Salina del Sur.

5.2 METHODS

Sampling Design

The sediment sample sites for the current study were selected using a stratified random sampling design. Similar to the fish/habitat characterization (Chapter 3), nearshore waters around Vieques were divided into five north and five south strata (Figure 3.1). NOAA's 2001 benthic habitat map (Kendall et al. 2001) was used to generate a data layer of sampleable soft bottom sediments. A spatially-articulated random-stratified technique was then used to optimize for statistical generalization over the sediments in the study area. The sediments were collected from both nearshore waters and from a number of inland lagoons in May 2007. The 55 sites where sediments were collected and analyzed are shown in Figure 5.1. Following these collections, a request was made by NOAA's Office of Response and Restoration for an additional sampling of sediments from inland lagoons in Vieques to further characterize these areas. Sample sites within the inland lagoons were selected using a random-stratified technique. Twenty-three sediment samples were collected in October 2007 (Figure 5.1, three character site designations). Because the sites sampled in October 2007 were also selected randomly within the lagoons, the data generated could be combined with the results from the May 2007 sampling. The results of this second collection also enabled comparisons between nine inland lagoons in Vieques. Sites where *P. astreoides* were collected are shown in Figure 5.2. Some of the coral sampling sites were co-located with the Biogeography Program dive sites. Coral tissues were collected under permit 06-IC-056 issued by the Puerto Rico Department of Natural and Environmental Resources (DNER). A total of 35 coral samples collected in May 2007 were analyzed for this project. Typically, coral and sediment sites were not collocated; there were two sites, however, where both *P. astreoides* and sediments were collected.

Sampling Protocols

Sediments sampled in the former U.S. Navy property and in the civilian areas were collected by hand. Samples were collected in this manner due to the possibility of subsurface unexploded ordnance located in the former Vieques Naval Training Range (VNTR) on the eastern half of the island, and the Naval Ammunition Support

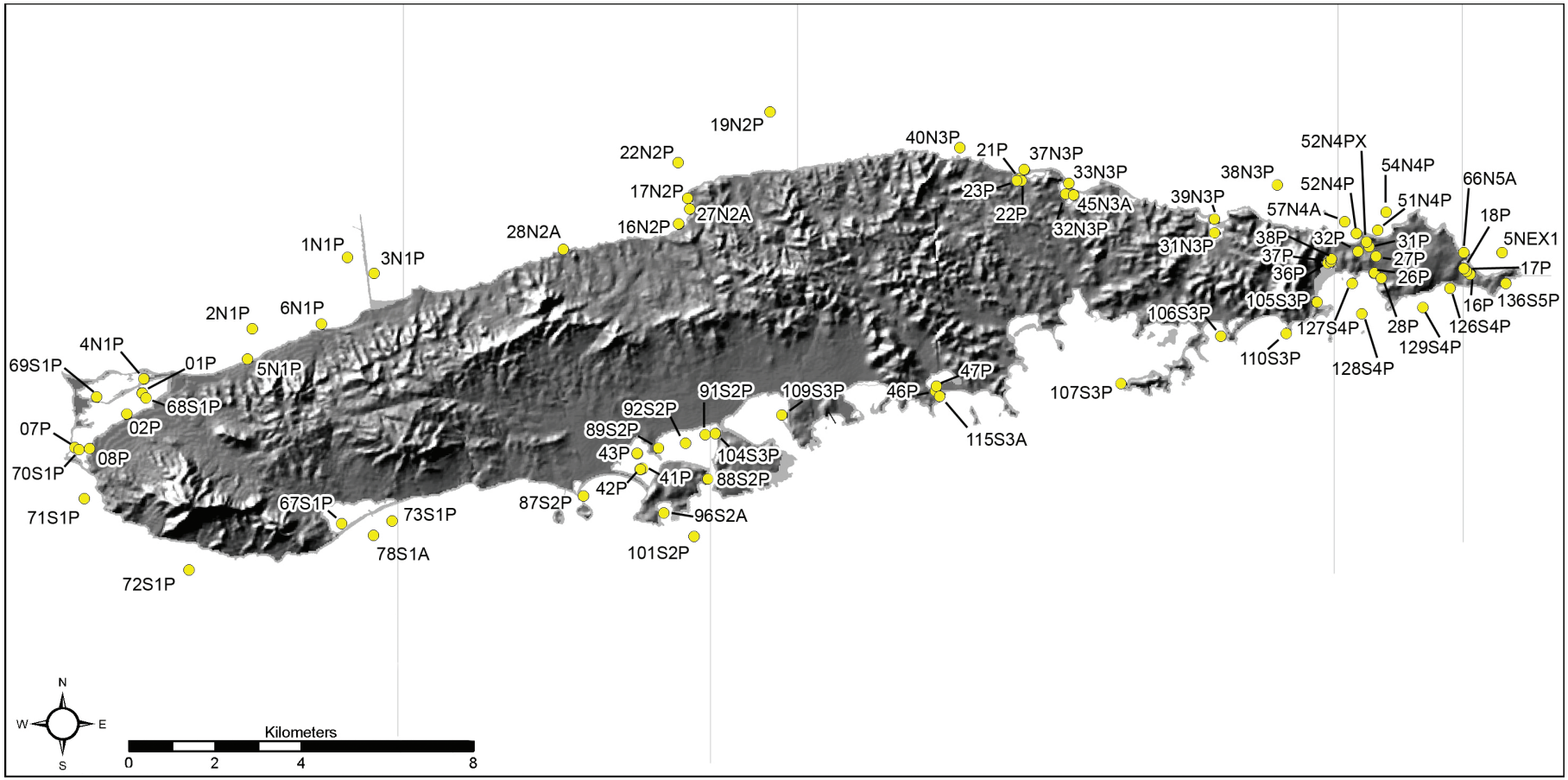


Figure 5.1. Sediment sites analyzed in Vieques (May and October 2007). Letters represent primary or alternate (P or A) sites or sites on the north or south (N or S) shore of Vieques. Three letter designations (e.g., 08P) represent October 2007 inland lagoon site designations.

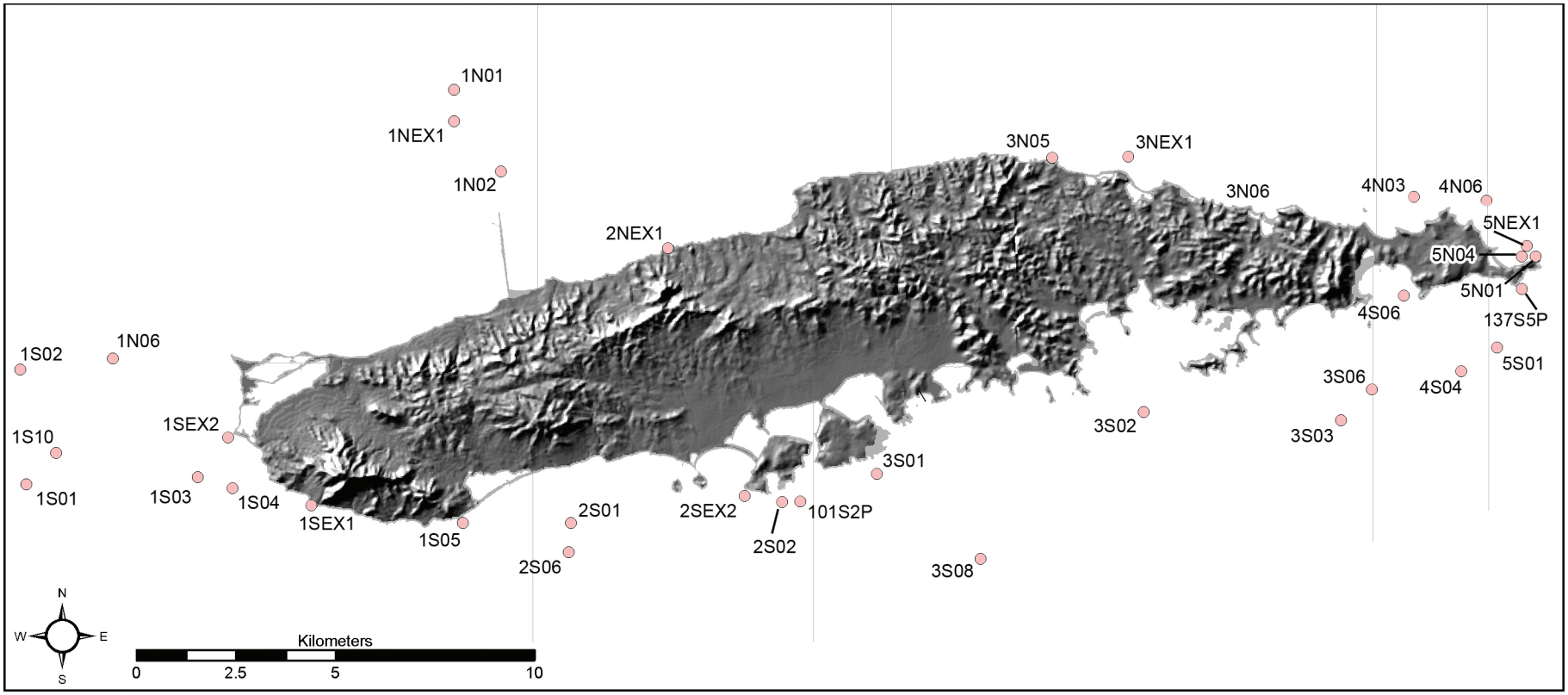


Figure 5.2. Coral sites analyzed. Letters (N or S) designate sites on the north or south shore of Vieques.

Detachment (NASD) in the western portion of Vieques. When sampling the VNTR or NASD areas, a U.S. Navy UXO (unexploded ordnance) safety contractor (e.g., PIKA International or CH2MHILL) accompanied NOAA's Center for Coastal Monitoring and Assessment (CCMA) personnel, and tested the area with a metal detector prior to sample collection, to ensure the safety of the operation. Samples were collected by scooping the top 3 cm of sediment into two certified clean IChem® 250 ml jars. CCMA personnel collecting the samples wore disposable nitrile gloves to avoid contaminating the sample. In deeper waters, sediment samples were collected by CCMA SCUBA divers from the vessel *Aquanauta*. A sediment sample was also collected for grain size. Once collected, the sediment samples were placed on ice in a cooler. At the end of each day, samples for contaminant analysis were frozen at -15°C in a freezer at the headquarters of the Vieques National Wildlife Refuge (VNWR), operated by the U.S. Fish and Wildlife Service (USFWS). The samples collected for grain size analysis were placed in a refrigerator rather than frozen, to avoid altering the grain size structure of the sediment. At the end of the mission, samples were shipped overnight to the laboratory (TDI-Brooks International in College Station, TX) for analysis. Prior to analysis, samples were stored at -20°C.

Image 5.2. CCMA diver sampling the coral *P. astreoides* in Vieques.

The coral samples were taken by NOAA SCUBA divers in May 2007 using a hammer and titanium punch (see inset). Titanium was used as it was not a target trace element for this project. As with sediment sampling, a U.S. Navy UXO safety contractor diver accompanied NOAA divers in the areas offshore of the former VNTR and NASD areas, first testing the site with a metal detector, to ensure the safety of the personnel, before the coral sample was collected. Prior to each use, the punch was rinsed with acetone to minimize cross-contamination. Divers collecting the coral samples also wore disposable nitrile gloves. The diver hammered the titanium punch into the coral head which produced a coral core with a diameter of approximately 1.5 cm and a similar core length. Approximately 20 cores were taken at each site and placed underwater in an IChem® certified clean 250 ml jar and then capped. The jar was brought to the surface, drained of water and placed on ice. At the end of each day, the samples were placed in a freezer (-15 ºC) at the VNWR. At the end of the mission, samples were shipped overnight to the laboratory for analysis. A series of water parameters (dissolved oxygen, temperature, salinity, and conductivity) were measured at each site using a YSI® salinity/conductivity/temperature meter. In nearshore waters, surface and bottom readings were taken. In the shallower inland lagoons, only surface readings were made.

Chemical Contaminants Analyzed

The list of chemical contaminants analyzed in the sediment and coral samples for this project is shown in Table 5.1. The samples were analyzed as part of NOAA's National Status and Trends (NS&T) Program within CCMA. For over 20 years, NS&T has monitored the Nation's estuarine and coastal waters for chemical contaminants in bivalve mollusk tissues and sediments. Work to characterize chemical contaminants as part of CCMA's ecological characterizations in tropical waters, represents a recent expansion of NS&T activities. NS&T regularly quantifies approximately 150 organic and inorganic contaminants. The compounds analyzed include 58 polycyclic aromatic hydrocarbons (PAHs), 31 organochlorine pesticides, 38 polychlorinated biphenyls (PCBs), four butyltins, and 16 trace and major elements. All samples were analyzed using NS&T analytical protocols. The analytical protocols for organics (Kimbrough et al. 2006) and trace and major elements (Kimbrough and Lauenstein 2006) have previously been published. Each of the contaminant classes analyzed for this project are discussed below. In addition, sediment samples were analyzed for 15 energetics (explosives) or related compounds.

PAHs

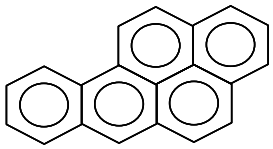
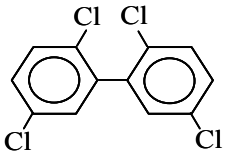
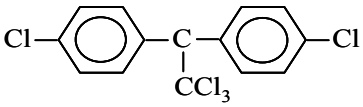
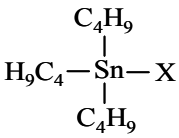
Polycyclic aromatic hydrocarbons (Table 5.1) are associated with the use and combustion of fossil fuels (e.g., oil and gas) and other organic materials (e.g., wood). Natural sources of PAHs include forest fires and volca-

Table 5.1. Chemical contaminants analyzed in the sediment and coral tissues collected in Vieques.

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

[1]The benzothiophenes and dibenzothiophenes are thio-PAHs; [2]energetics not analyzed in coral tissues.
Abbreviations: PAHs, polycyclic aromatic hydrocarbons; HCH, hexachlorocyclohexane; DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDMU, 1-chloro-2,2- (p-chlorophenyl)ethylene; PCB, polychlorinated biphenyl; HMX, cyclotetramethylene tetranitramine; RDX, cyclotrimethylene trinitramine

Table 5.2. Structure of selected organic compounds.

Compound Class	Compound	Structure	Use
Polycyclic aromatic hydrocarbon (PAH)	Benzo[a]pyrene		Byproduct of use and combustion of fossil fuels
Polychlorinated biphenyl	2,2', 5,5'-Tetra chlorinated biphenyl		Former widespread use in transformers, capacitors and hydraulic and heat transfer applications
Organochlorine pesticide	DDT		Insecticide, banned in US in 1972
Butyltin	Tributyltin (TBT) (X = anion or anionic group)		Biocide; banned on smaller vessels (<25 m) in the US in 1988

noes. The PAHs analyzed are two to six ring aromatic compounds. An example of the structure of PAHs can be seen in Table 5.2. PAHs were analyzed using gas chromatography/mass spectrometry in the selected ion monitoring (SIM) mode.

Effects of PAHs. An extensive amount of research on the accumulation and effects of PAHs has been conducted on aquatic organisms, however, very little research has been carried out to address the effects of PAHs on corals. Because of their hydrophobic nature, PAHs readily accumulate in marine organisms through the body surface, gills, or through the diet (Neff 1985). Exposure to PAHs has been associated with oxidative stress, effects on the immune system and endocrine system, and developmental abnormalities (Hylland 2006). In addition, a number of PAHs 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). The carcinogenic potential of PAHs is associated with their metabolism by Phase I P450 enzymes, generating reactive epoxides which can bind to cellular components such as DNA (Hylland 2006; Neff 1985).

In addition to the living tissues of corals, PAHs can also accumulate in the zooxanthellae, the symbiotic photosynthetic dinoflagellate algae found within coral tissues. Bioaccumulation appears to be related to the lipid content of both (Kennedy et al. 1992). While the simple accumulation of PAHs by corals is not an impact by itself, the accumulation of a chemical contaminant in an organism increases the likelihood of adverse effects. Solbakken et al. (1984) showed that both phenanthrene and naphthalene were accumulated by the brain coral *Diploria strigosa* and green cactus coral *Madracis decatis*, and that the lower molecular weight naphthalene was eliminated at a higher rate than phenanthrene (Solbakken et al. 1984). The PAHs fluoranthene and pyrene have been shown to be toxic to adult corals, particularly in the presence of increased ultraviolet radiation (phototoxicity) (Peachey and Crosby 1996; Guzman-Martinez et al. 2007).

PCBs

Polychlorinated biphenyls are a class of synthetic compounds that have been used in numerous applications ranging from electrical transformers and capacitors, to hydraulic and heat transfer fluids, to pesticides and paints. Although no longer manufactured in the U.S., environmental contamination by PCBs is widespread due to their environmental persistence and tendency to bioaccumulate. In some cases, use of PCB containing equipment (e.g., railroad locomotive transformers) is still permitted (CFR 1998). PCBs have a biphenyl ring structure (two benzene rings with a carbon to carbon bond) and a varying number of chlorine atoms (Table 5.2). There are 209 PCB congeners (structures) possible. PCBs were analyzed using gas chromatography/electron capture detection.

Effects of PCBs. Exposure to PCBs in fish has been linked to reduced growth, reproductive impairment and vertebral abnormalities (EPA 1997). Solbakken et al. (1984) investigated the bioconcentration of radiolabeled hexaPCB (2,4,5,2',4',5'-hexachlorobiphenyl) in coral. The PCB was rapidly accumulated in *Diploria strigosa* and *Madracis decatis*, however, depuration proceeded at a slow rate; after 275 days nearly 33 percent of the original radioactivity from the PCB remained in the coral.

Organochlorine Pesticides

A total of 31 organochlorine pesticides and related compounds were analyzed in the sediment and coral samples from Vieques (Table 5.1). Beginning in the 1950s and continuing 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 used during this time period was DDT. It has been estimated that during the 30 years prior to its cancellation in 1972, 1.35 billion pounds of DDT were applied in the US, with the majority applied to the cotton crop (EPA 2009). The use of many of the organochlorine pesticides, including DDT, was banned due to their environmental persistence, potential to bioaccumulate, and toxicity to nontarget organisms. From Table 5.2, it can be seen that some of the organochlorine compounds, including DDT, share structural similarities to PCBs, which are also persistent environmental contaminants (Table 5.2). Because of their persistence and heavy use in the past, residues of many organochlorine pesticides can be found in the environment, including biota.

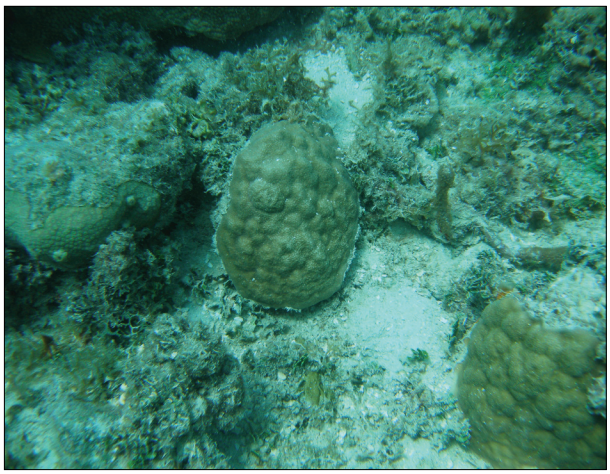


Image 5.3. Encrusting form of *Porites astreoides*, similar to the size of the colonies sampled. Diameter of colony shown is approximately 25 cm.

Effects of Organochlorine Pesticides. Organochlorine pesticides are typically neurotoxins. Both DDT and PCBs have also been shown to interfere with the endocrine system. DDT and its metabolite DDE were specifically linked to eggshell thinning in birds, particularly raptors. A number of organochlorine pesticides are also toxic to aquatic life including crayfish, shrimp and some species of fish.

Butyltins

This class of compounds 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). Beginning in the late 1960s, TBT (Table 5.2) was incorporated into a very effective antifoulant paint system, quickly becoming one of the most effective paints ever used on boat hulls (Birchenough 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). 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). 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 is considerably longer, on the order of 2 - 4 years (Batley 1996). Butyltins were analyzed using gas chromatography/flame photometric detection.

Effects of TBT. The widespread use of TBT as an antifouling agent was associated with endocrine disruption, specifically an imposex condition in marine gastropod mollusks. Beginning in 1989 in the U.S., the use of TBT as an antifouling agent was banned on vessels smaller than 25 m in length (Gibbs and Bryan 1996). Negri et al. (2002) investigated the effects of TBT in sediments from a shipwreck, on the coral *Acropora microphthalma* from the Great Barrier Reef in Australia. Sediments originally contained approximately 160 µg/g TBT. When diluted to 5 percent of the original concentration, successful settlement of coral larvae in the laboratory was prevented.

Major and Trace Elements

A total of 16 trace and major elements were measured in sediments, and 14 in coral tissues for this project (Table 5.1). Most of these elements are metals, however, antimony, arsenic and silicon are metalloids; selenium is a nonmetal. All occur naturally to some extent in the environment. Aluminum, iron, and silicon are major components of the Earth's crust. Some trace and major elements in the appropriate concentrations are biologically essential. As their name implies, trace elements such as chromium, cadmium, lead and nickel occur at lower concentrations in crustal material, however mining and manufacturing processes along with the use and disposal of products containing trace elements result in elevated concentrations in the environment. As mentioned earlier, a stratified random sampling design was used for this project in order to characterize the areas sampled. Using this approach all nearshore and lagoon areas had an equal chance of being selected for contaminant characterization. As a result, no samples were specifically collected to represent background conditions in these areas. Silver, cadmium, copper, lead, antimony, and tin were analyzed using inductively coupled plasma - mass spectrometry. Aluminum, arsenic, chromium, iron, manganese, nickel, silicon and zinc were analyzed using inductively coupled plasma - optical emission spectrometry. Mercury was analyzed using cold vapor - atomic absorption spectrometry. Selenium was analyzed using atomic fluorescence spectrometry. Total metal was analyzed for this project.

Effects of Trace Elements. A number of trace elements are toxic at low concentrations. Cadmium, used in metal plating, solders, and batteries has been shown to impair development and reproduction in several invertebrate species, and the ability to osmoregulate 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. Effects of mercury on copepods include reduced growth and reproductive rates (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, wood preservatives, heat exchangers in power plants, electrical wires, coinage, and agriculture. Although an essential element, elevated levels of copper can impact aquatic organisms, including reproduction and development in mysid shrimp (Eisler 1998). In corals, Reichelt-Brushett and Harrison (2005) found that a copper concentration of 20 µg/L significantly reduced fertilization success in brain coral *Goniastrea aspera*. At copper concentrations at or above 75 µg/L, fertilization success was one percent or less. Fertilization success was also significantly reduced in the coral *Acropora longicyathus* at 24 µg/L, similar to *G. aspera*.

Energetics

Fifteen energetics and related compounds (Table 5.1) were analyzed in the sediments collected from Vieques. There are three major classes of energetics used by the U.S. military, and include nitroaromatics such as TNT and trinitrobenzene, nitramines such as RDX and HMX, and the nitrate esters such as nitroglycerin (GlobalSecurity 2008). The energetics were analyzed in sediment samples from Vieques using high performance liquid chromatography (HPLC) with a UV (ultraviolet) detector (EPA Method 8330). Fourteen samples with energetics concentrations that appeared to be above the method detection level (MDL) were subsequently reanalyzed using EPA Method 8330, followed by LC/MS/MS (liquid chromatography/mass spectrometry/mass spectrometry) to confirm their presence.

Effects of Energetics. A number of studies have assessed the toxicity and accumulation of energetics. Rosen and Lotufo (2007) investigated the toxicity of TNT, RDX and HMX on the marine mussel *Mytilus galloprovincialis*. The effective concentration (EC50) of TNT that resulted in abnormal larval development in 50 percent of the test organisms was 750 µg/L. The highest concentrations of RDX (28,400 µg/L) and HMX (1,900 µg/L) tested failed to have any toxicological effects on the larvae. Lotufo and Lydy (2005) calculated kinetic bioconcentration factors in juvenile sheepshead minnows (*Cyprinodon variegatus*) for TNT (9.6 ml g^{-1}), RDX (1.7 ml g^{-1}) and HMX (0.5 ml g^{-1}).

Rosen and Lotufo (2005) investigated the toxicity and fate of TNT and RDX on the estuarine amphipod *Eohaustorius estuarius*. Sediments were spiked with ^{14}C-labeled TNT or nonradiolabeled RDX in ten day spiked sediment exposures. The LC_{50} for TNT ranged between 28 - 36 µg/g, depending on the sediment used in the test. The TNT critical body residues (tissue concentration associated with mortality) for *E. estuarius* ranged between 1.1 and 9.8 µg/g. Exposure to RDX did not result in significant mortality even at the highest measured sediment concentration of 2,400 µg/g dry weight, and tissue concentrations of 21 µg/g wet weight. Rosen and Lotufo (2005) noted that the lack of RDX lethal effects appeared consistent with results for other invertebrates.

TOC and Grain Size

Total organic carbon (TOC) and grain size analyses were also carried out on the sediment samples. These two characterizations are important for assessing the potential for accumulation of contaminants in sediments. Typically, a positive relationship exists between sediment TOC and chemical contaminants, particularly organic contaminants, in freshwater, estuarine and coastal waters (Shine and Wallace 2000; Hassett et al. 1980). TOC was quantified in the sediments using a sequence of steps that involves combusting the carbon in a sample at a high temperature and then quantifying the CO_2 produced. Grain size is also an important sediment characteristic as many organic contaminants and a number of metals bind to the smaller silt and clay grain size fractions of sediments, due to the larger surface areas of these fractions, and in the case of trace and major elements, the charge characteristics of clays. Grain size analysis was carried out using a series of sieving and settling techniques. Additional information on TOC and grain size analysis can be found in McDonald et al. (2006).

Radioactivity

As part of the sediment collections in the inland lagoons, a reading of radioactivity (i.e., alpha, beta, and gamma radiation) was made using a Radalert 100 ™ nuclear radiation monitor. Readings were made at each site before a sediment sample was taken, and then again by holding the radiation monitor within 5 cm of the collected sediment sample. Readings were taken in milliroentgens per hour (mR/hr).

Clostridium perfringens

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 Vieques. This bacterium occurs in the intestines of humans and in some domestic and feral animals, and ingestion of *C. perfringens* can cause food poisoning. For this analysis, sediment extracts were plated on a specialized growth medium and then incubated anaerobically for 48 hours, after which time the *C. perfringens* colonies were counted.

Statistical Analyses

All 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) and Tukey HSD were calculated to explore relationships between parameters. If the data were not normally distributed and a log10 data transformation was not effective, Wilcoxon or Spearman's nonparametric tests were used. Some contaminant data that were not normally distributed were subsequently ranked to allow ANOVAs and pair-wise comparisons. All statistical tests used an alpha value of 0.05.

5.3 PREVIOUS STUDIES

A significant amount of work has been conducted over the years to assess chemical contaminants in Vieques, primarily in the areas formerly owned by the U.S. Navy, with much of this work occurring in the terrestrial environment. A number of studies have been completed, while others are ongoing. To better understand the chemical contaminant issues that might be present in Vieques, and to put the current work into perspective, a literature survey was carried out for previous contaminant-related research in the terrestrial and nearshore environments. Previous studies of contaminants on or near the island of Vieques include assessments of metals, energetics, volatile organic compounds, pesticides, PCBs and other contaminants. The majority of these assessments characterize chemical contaminants in soil samples, but a number of studies also include the analysis of fish and shellfish, terrestrial plant materials, surface and subsurface land-based water samples, air samples and sediment samples from limited marine locations.

Studies Conducted

One of the earlier assessments was conducted in 1972 by the U.S. Geological Survey to evaluate the metallic resources of Vieques (Learned et al. 1973). In a study commissioned by the U.S. Navy, soil samples from the Eastern Maneuver Area (EMA) and Live Impact Area (LIA) were collected to characterize the presence of explosive compounds (Lai 1978; Hoffsommer and Glover 1978). In the last decade, numerous studies also commissioned by the U.S. Navy have been carried out, with the majority conducted by the Agency for Toxic

Substances and Disease Registry (ATSDR) and CH2MHILL (ATSDR 2001, 2003a, 2003b, 2003c; CH2MHILL 2000, 2001, 2004, 2007; CH2MHILL and Baker 1999). The focus of most of these studies included the former Live Impact Area (LIA), Eastern Maneuver Area (EMA), and the solid waste management units (SWMU) and areas of concern (AOCs) on the western end of the island (NASD).

Findings. Elevated levels of trace elements have been documented in both the former Vieques Naval Training Range (VNTR) and in the municipal regions of Vieques (ATSDR 2003b; NOAA and Ridolfi, 2006). The higher concentrations of trace elements were found in areas on or nearshore of the former LIA and the NASD. It should be noted, however, that most of the studies that have been conducted appear to have concentrated on the areas formerly owned by the U.S. Navy.

CH2MHILL (2007) conducted a survey of soil inorganics (e.g., trace and major elements) for East Vieques. The goal of the survey was to establish background levels within the former VNTR which could then be used to assess whether site-specific concentrations could be attributable to releases from these sites, or were more consistent with background levels. For each element, a UTL or Upper Tolerance Level was developed. Elemental concentrations at or below the UTL threshold concentration represent those levels that are indistinguishable from background concentrations. Not surprisingly, the UTLs were highest for major elements including aluminum (35,000 µg/g), iron (38,100 - 43,200 µg/g) and magnesium (3,710 - 22,200 µg/g) for various soil types on Vieques. For the trace elements, the arsenic UTLs ranged from 1.6 - 9.2 µg/g; for cadmium 2.2 to 2.4 µg/g, chromium 70-72 µg/g, lead 5.4 - 16 µg/g, copper 53-94 µg/g, nickel 22 - 41 µg/g, and mercury 0.057 - 0.31 µg/g.

The highest concentrations of trace elements were found in or nearshore of the former LIA, and are noted in Figure 5.3. The highest trace element levels detected include arsenic (42.2 µg/g in sediments), cadmium (46.8 µg/g in coral tissues), chromium (182.6 µg/g in plant organic material), lead (195 µg/g in coral tissues), manganese (1,740 µg/g in plant organic material), mercury (< 2.15 µg/g in sediments), nickel (78.3 µg/g in plant organic material), and selenium (11 µg/g in lobster tissues) (ATSDR 2006; Barton and Porter 2004; CH2MHILL 2002; Massol-Deya et al. 2005; NOAA and Ridolfi 2006). The highest concentrations for the five remaining elements were all found on the Western end of Vieques on or near the former NASD. These metals include aluminum (1,250 µg/g) in fiddler crab (*Uca sp.*) tissues, copper (203 µg/g) in fiddler crab (*Uca sp.*), iron (39,000 µg/g) in soils, magnesium (16,000 µg/g) in soils, and zinc (97 µg/g) in fiddler crab (*Uca sp.*) tissues (ATSDR 2006; Barton and Porter 2004; CH2MHILL 2002; Massol-Deya et al. 2005; NOAA and Ridolfi 2006).

The presence of 17 organochlorine pesticides in Vieques has been documented in the tissues of land crabs (*Cardisoma guanhumi*) (Lopez 2002; NOAA and Ridolfi 2006). The majority of the detections were for DDT or one of its metabolites, while chlordane was found at approximately 50% of the sites sampled (NOAA and Ridolfi 2006). Other pesticides detected include Mirex, endosulfan sulfate, methoxychlor, and aldrin. The highest concentration detected for an organochlorine pesticide was DDT in *C. guanhumi* (203.2 ng/g) from Laguna Kiani on the western end of Vieques (NOAA and Ridolfi 2006). The second highest DDT concentration (187.2 ng/g) was found near the public vehicle access bridge near Red Beach (NOAA and Ridolfi 2006).

Commercial PCB products used in the U.S. were referred to as Aroclors, and are mixtures of PCB congeners. For example, Aroclor 1242 refers to a mixture of PCBs that is 42 percent chlorine by weight. Nine PCB Aroclors (1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268) were analyzed in the tissues of fiddler crabs (*Uca sp.*) and land crabs (*C. guanhumi*) from Vieques (NOAA and Ridolfi 2006). In only one of the samples were PCBs detected. The fiddler crab sample was collected near Laguna Kiani and had an Aroclor 1254 concentration of 58 ng/g (NOAA and Ridolfi 2006), substantially below the EPA ecological screening benchmark of 23 ug/g. The ATSDR (2006) concluded that the levels of PCBs found in land crabs by NOAA and Ridolfi (2006) were lower than levels reported in the scientific literature as causing harmful human health effects.

Energetics have occasionally been detected in the terrestrial and marine environments of Vieques (ATSDR 2003a,b; Barton and Porter 2004). HMX (cyclotetramethylene tetranitramine) (0.42 µg/g), RDX (cyclotrimethylene trinitramine) (2.8 µg/g), TNT (2,4,6-trinitrotoluene) (13 µg/g), nitroglycerin (19 µg/g), and 2-amino-4,6-dinitrotoluene (degradation product of TNT) (0.62 µg/g) have been detected in soil samples from the former LIA (ATSDR 2003a). In the marine environment, Barton and Porter (2004) investigated the presence of explosives adjacent to the scuttled Navy ship *USS Killen*. TNT was detected at a concentration of 4,380 µg/g adjacent (less than 2 meters) to a 2,000 pound bomb at the site, and 19,333 µg/g TNT inside the bomb. Concentrations of TNT rapidly decreased to levels below detection at distances greater than 2 meters from the bomb (Barton and Porter 2004). TNT and RDX were not detected in the sediments at the bow or stern of the ship, suggest-

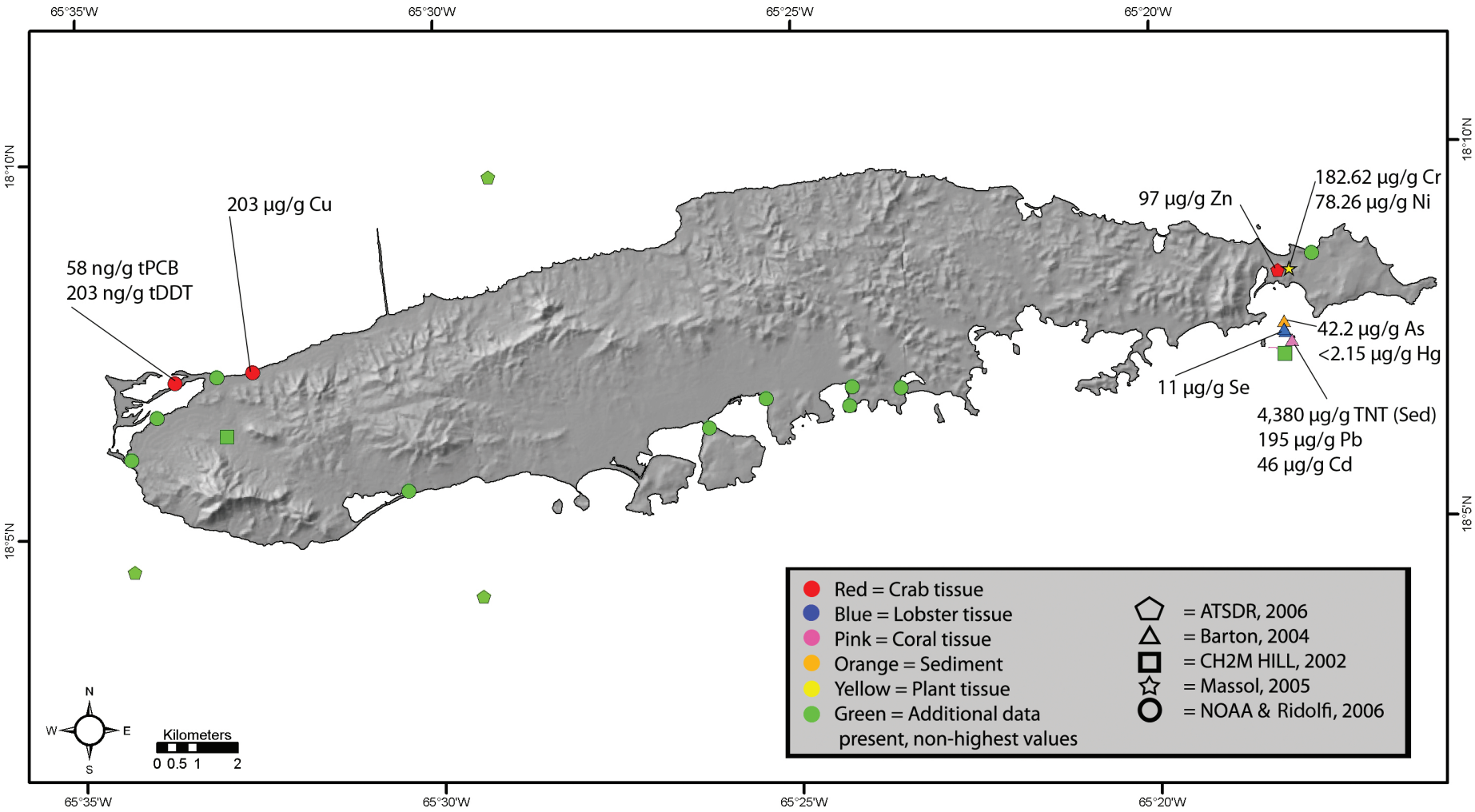


Figure 5.3. Sites of previous contaminant-related studies on Vieques.

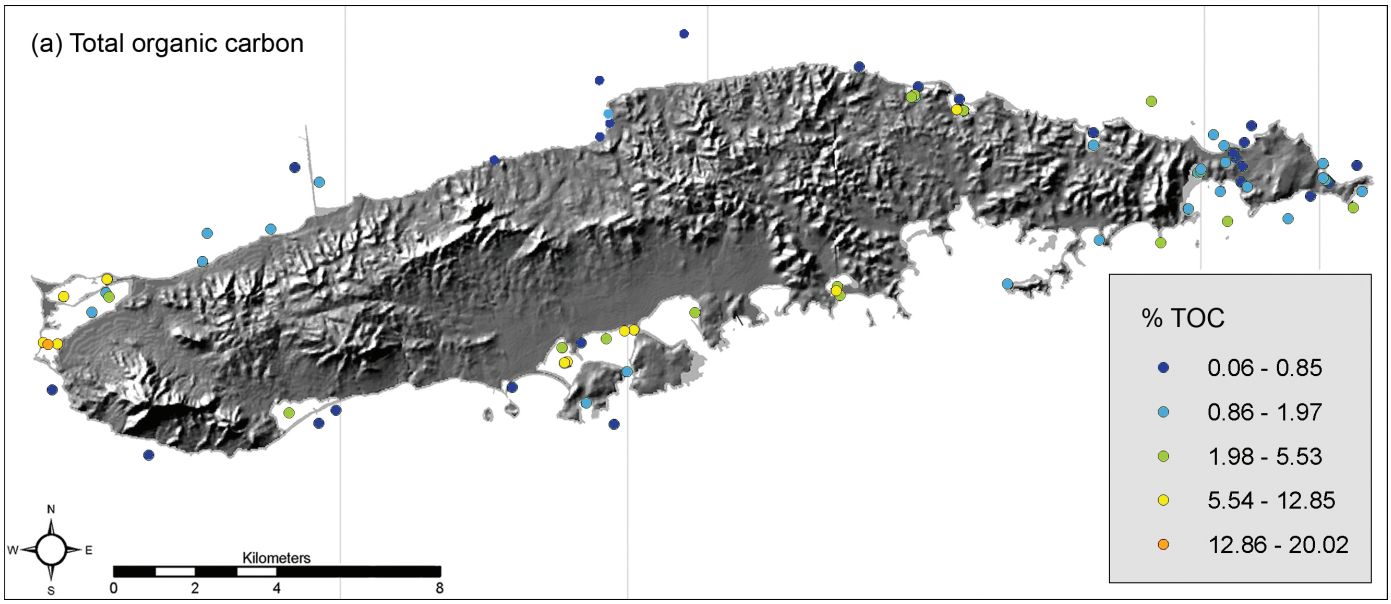
ing that the presence of higher concentrations of energetics may be a localized phenomenon (i.e., in direct proximity to unexploded ordnance). TNT was also detected at a concentration of 252 µg/g in one coral (*Diploria labyrinthiformis*) sample adjacent to the stern of the scuttled ship.

5.4 RESULTS AND DISCUSSION

All Appendices cited in this section are available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques.html.

Field Data

The average water depth of the non-inland lagoon sediment sites in Vieques was 4.5 ± 0.7 m; the average surface water temperature was 29.6 ± 0.2 ºC, and the average bottom temperature was 29.2 ± 0.1 ºC. The salinity at the non-inland lagoon sites was also fairly constant. The average surface salinity was 35.6 ± 0.5 ppt, the average bottom salinity was 35.9 ± 0.7 ppt. These data indicated no stratification for either temperature or salinity. The dissolved oxygen at the non-inland lagoon sites was 5.4 ± 0.4 mg/L near the surface; 6.3 ± 0.3



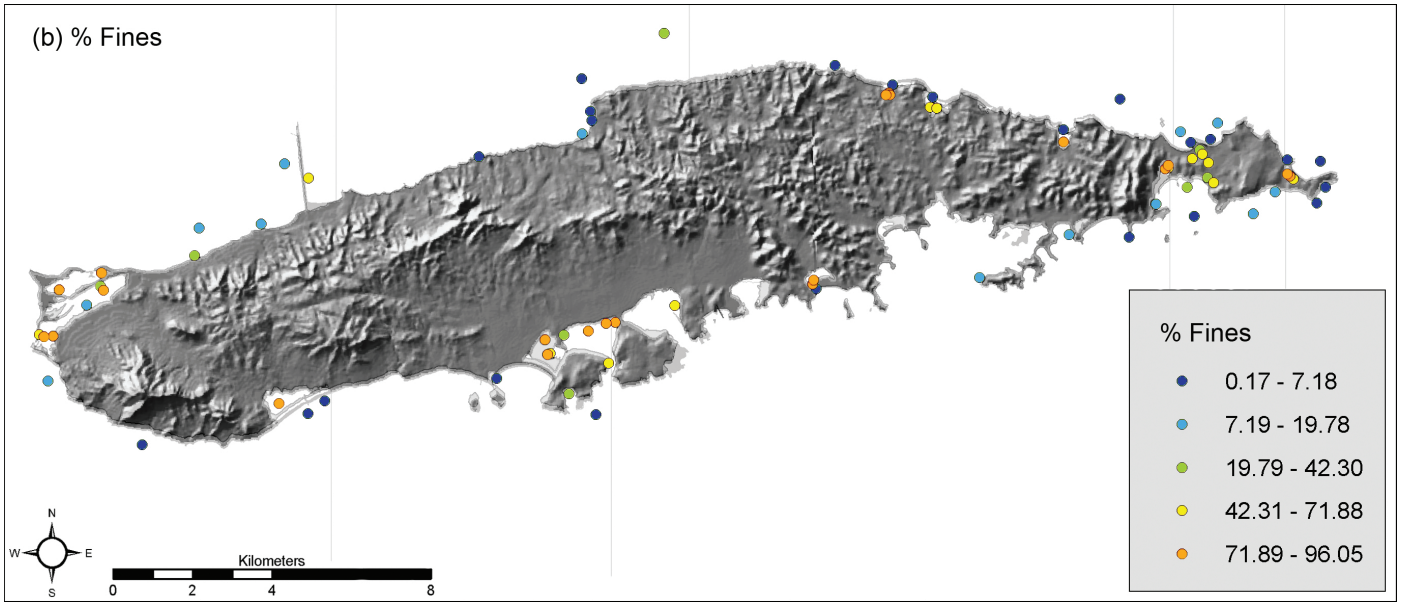


Figure 5.4. Total organic carbon (TOC) (a) and % fines (b) in sediments. Fines is the sum of the % silt and % clay fractions of the sediments.

mg/L near the bottom. It is unclear why the mean dissolved oxygen appeared higher near the bottom, as there was little evidence of stratification in terms of temperature. One possible explanation could be benthic primary production.

The inland lagoons were shallower with more variability in the water parameters measured. The average temperature at the inland lagoon sites was 33.0 ± 0.4 ºC. The salinity ranged from 4.8 to 79.2 ppt, with an average of 37.8 ± 3.2 ppt. The mean dissolved oxygen level in the inland lagoons was 4.3 ± 0.5 mg/L. The detailed field data collected during May 2007 (sediment and coral sites, and some inland lagoon sites) and October 2007 (inland lagoon sites) can be found in Appendix A and B, respectively. Equipment failure prevented the measurement of water parameters at some of the sites where sediments or coral tissues were sampled.

Sediment Total Organic Carbon (TOC)

Chemical contaminants, particularly organics (i.e., carbon-containing contaminants such as PCBs), tend to accumulate in sediments that have a higher organic carbon content, due to the binding of the contaminant to the organic carbon matrix on and within the sediment particles. The relationship between TOC and organic contaminants is fairly common and has been found in freshwater, estuarine and coastal systems. Because of this correlation, organic contaminant concentrations are sometimes normalized to the organic carbon content of sediments (Shine and Wallace 2000; Hassett et al. 1980). Figure 5.4a summarizes TOC in the sediments analyzed from Vieques. The average sediment TOC was 2.49 ± 0.38%. Not surprisingly, higher TOC levels were found in nearshore and inland lagoon areas (Figure 5.4a), which are likely subjected to greater inputs of terrestrial organic matter. The average TOC in the inland lagoon areas was 4.25 ± 0.74%, compared with 1.05 ± 0.12% for the non-inland lagoon sites, and an ANOVA run on the log10 transformed data indicated this difference was significant ($p < 0.0001$).

The 95th percentile for TOC was 9.03%, and all sites within this quantile were from inland lagoons. The highest TOC (20.02%) found in any of the sediments analyzed was from 70S1P (Figure 5.4 and Figure 5.2) in Laguna Boca Quebrada, which is part of the SWMU4 (solid waste management unit) area in the western part of Vieques. The second highest was found at 07P, from the same lagoon. Sediments from the south side of the island also had higher TOC levels than those collected from the north side ($p = 0.0016$). Finally, there was a significant difference ($p = 0.0105$) between strata; North 2 and South 1 had significantly lower TOC concentrations than most of the other strata on the south side of the island.

Sediment Grain Size

The adsorption of contaminants, both organic and inorganic (e.g., trace elements) is also strongly influenced by the grain size of the sediment (Hassett et al. 1980). The smaller grain sizes of the silts and clays have proportionally higher surface areas available for adsorption. The adsorption of metals is influenced not only by smaller grain sizes, but also by ionic forces (i.e., negative charge structure) within the layered structure of clays. In this report, the silt and clay fractions are combined (summed) and reported as % fines.

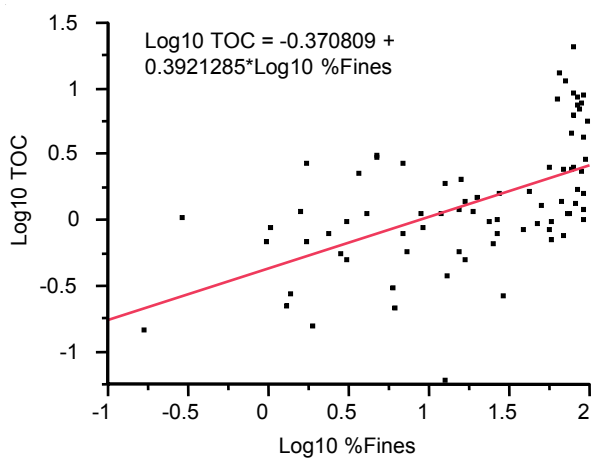


Figure 5.5. Bivariate fit of log10 normalized TOC and % fines for the sediment samples analyzed from Vieques.

The % fines in the sediments can be seen in Figure 5.4b. More detailed information on the results of the grain size analysis can be found in Appendix C. Like the TOC values, all of the sites containing fine grain sediments were from the nearshore and inland lagoon depositional areas. Areas containing finer grain sediments are important as these locations are more likely to accumulate contaminants if they are being introduced into the system. A Wilcoxon nonparametric test indicated a significant difference ($p < 0.0001$) in the % fines from inland lagoon areas versus non-lagoon areas, similar to that found for TOC. Finally, a positive relationship frequently exists between TOC and grain size. Higher TOC is usually associated with the silt fraction of sediments. Figure 5.5 shows a plot of log10 normalized concentrations of % fines and TOC content of the sediments in Vieques; the relationship was significant ($p < 0.0001$). Interestingly, although this relationship was found to be significant for the sediments collected throughout the coastal areas of the U.S. by the NS&T Program and in Vieques, this relationship did not hold for sediments collected in 2005 from southwest Puerto Rico (Pait et al. 2007).

Polycyclic Aromatic Hydrocarbons (PAHs)

The results of the PAH analysis in the sediments and corals can be seen in Figure 5.6 and also in Appendices D and F. The scale on the two graphics in Figure 5.6 is the same to better enable comparisons between sediments and corals. Total PAHs as used in this report refers to the sum of the 58 compounds and compound classes (e.g., anthracene, C1-naphthalenes, Table 5.1) analyzed.

PAHs in Sediments. The mean concentration of total PAHs in the sediments collected from Vieques was 52.3 ± 8.7 ng/g; the median was 17.9 ng/g. The higher concentrations of PAHs were found in sediments from the nearshore and inland lagoon areas (Figure 5.6a). Overall, the concentration of total PAHs in Vieques was low. Because of the long-term, national-level contaminant monitoring carried out by NOAA's NS&T Program, data from Vieques can be compared with data from the rest of the Nation's coastal waters. No sediment sites were above the national NS&T median of 395 ng/g for total PAHs, although 68S1P (370.3 ng/g) taken from Laguna Kiani in the northwestern portion of Vieques was near this value. Other higher total PAH concentrations found in the sediments in Vieques included 4N1P (287.7 ng/g) in Laguna El Pobre, 27N2A (283.9 ng/g) near the town of Isabel Segunda, 69S1P (276.5 ng/g) in Laguna Arenas, 46P (210.3 ng/g) along Blue Beach, and 70S1P (208.9 ng/g) in Laguna Boca Quebrada. Additional results can be found in Appendix D.

Comparisons Between Strata. A series of statistical tests were carried out to understand how the distribution of total PAHs in the sediments varied across the sites sampled on the island of Vieques. An ANOVA on the log10 normalized data indicated that the inland lagoons had significantly higher total PAH concentrations than nonlagoon areas ($p < 0.0001$). An ANOVA indicated no difference ($p = 0.1005$) in the concentration of sediment total PAHs between strata (e.g., North 5 versus South 1) There was also no difference in the concentration of total PAHs in the north strata versus the south strata ($p = 0.2540$). If the north and south strata are combined (e.g., North 1 and South 1), five strata (1 to 5) moving west to east across the island of Vieques result (Figure 5.7). This grouping can be used to compare contaminants in Vieques related to adjacent land use. When differences in total PAHs in sediments were assessed across these strata, an ANOVA indicated a significant difference ($p = 0.0130$), and a Tukey HSD showed that total PAHs in the far western Stratum 1 were significantly higher than in Stratum 4.

Summary for Total PAHs

- *The highest total PAH concentration in sediments was 370 ng/g and was found in Laguna Kiani in the western portion of Vieques (Stratum 1).*
- *Concentrations of total PAHs were higher in the inland lagoon areas of the island.*
- *Total PAHs in sediments were significantly higher in Lagoon 1 (Laguna Boca Quebrada); and in western Vieques.*
- *Overall, the concentrations of total PAHs in sediments were low; none of the concentrations of total PAHs exceeded the sediment quality guidelines examined.*
- *The concentration of total PAHs in coral (Porites astreoides) were not significantly different from the concentration in the sediments.*

Comparison Among Inland Lagoons. The October 2007 sediment sampling in Vieques focused on a number of inland lagoons, which enabled a comparison of contaminant concentrations between nine inland lagoons on the island (Figure 5.7). For total PAHs, an ANOVA on the log10 normalized total PAH values indicated a significant difference ($p = 0.0010$) between the nine lagoons sampled. A pairwise comparison (Tukey HSD) indicated that total PAHs in Lagoon 1 (Laguna Boca Quebrada) and 2 (Laguna Kiani) on the western side of Vieques were significantly higher than the concentration of total PAHs in sediments sampled from Lagoon 7 and 9.

Comparison with Sediment Quality Guidelines. The NS&T Program and others have developed effects-based, numeric guidelines to estimate the toxicological relevance of certain sediment contaminant concentrations (Long et al. 1998). Two of these guidelines, shown in Table 5.3, are the Effects Range-Low (ERL) and the Effects Range-Median (ERM) developed by NOAA, and define sediment contaminant concentration ranges that are rarely (< ERL), occasionally (ERL to ERM), or frequently (> ERM) associated with toxic effects in aquatic biota (typically amphipods) in the sediments (NOAA 1998). It can be seen from Table 5.3 that the concentration of total PAHs measured in the sediments in Vieques were substantially below the ERL (4,022 ng/g) and ERM (44,792 ng/g) values.

A number of other sediment quality guidelines have been developed to assess potential adverse effects from chemical contaminants in sediments. The Threshold Effects Level (TEL) and Probable Effects Level (PEL) are similar to the effects range approach (e.g., ERL), except that the TEL is the geometric mean of the 15th percentile of the effects data and 50th percentile of the no effects data (MacDonald et al. 1996). The PEL is the

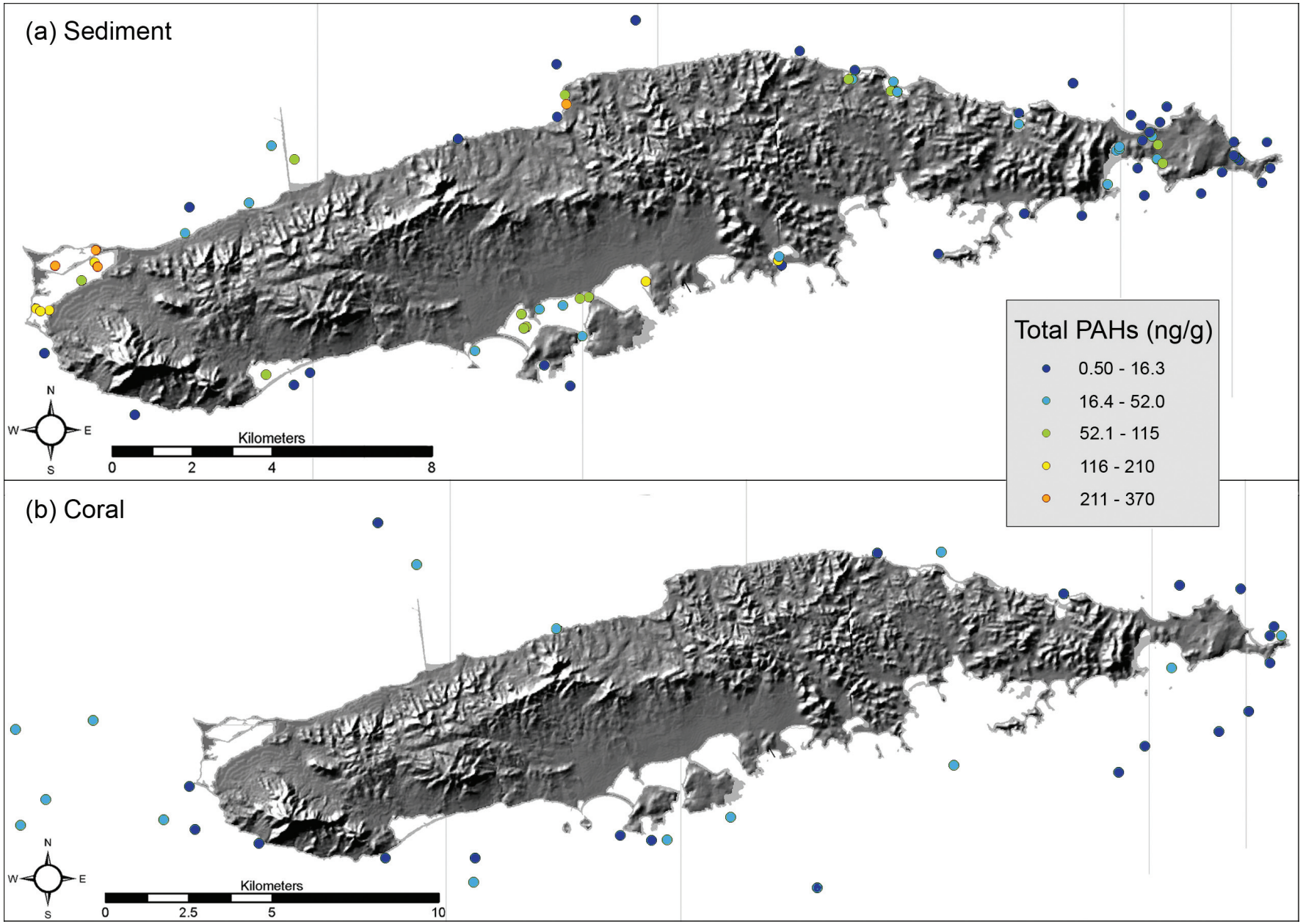


Figure 5.6. Total PAHs detected in the sediments (a) and in *Porites astreoides* (b).

geometric mean of the 50th percentile of the effects data and the 85th percentile of the no effects data. The Apparent Effects Threshold or AET, is used to help determine the concentration of a contaminant above which significant biological effects in benthic infaunal organisms could be expected (EPA 1989). AET values are determined using data on chemical contaminants and biological effects (from benthic infaunal analyses and from sediment bioassays) from contaminated and reference sites (EPA 1989).

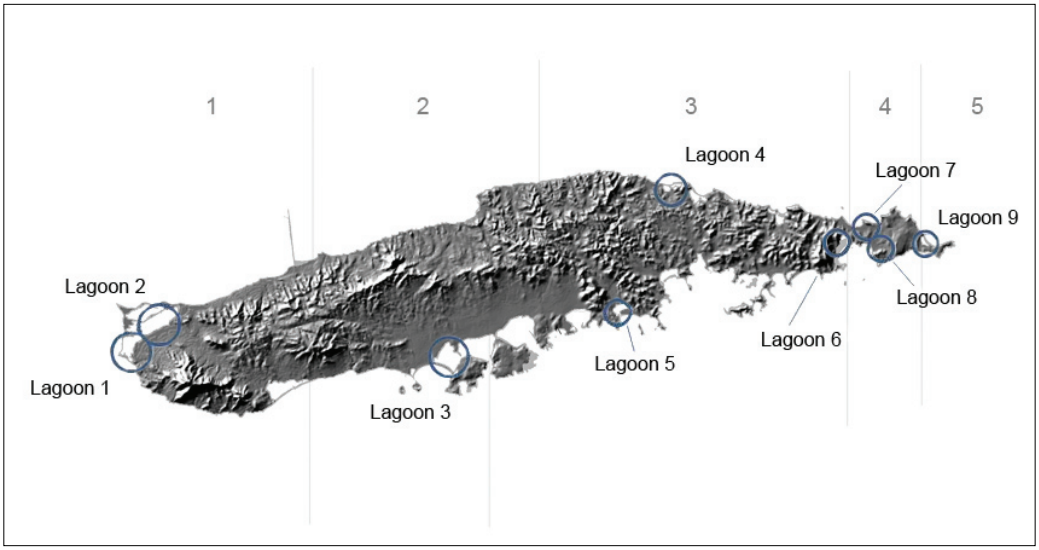


Figure 5.7. West to east strata (1 to 5) used to assess the influence of land-use patterns, and the nine inland lagoons where the sampling strategy allowed comparisons between lagoons.

Table 5.3 also contains the TEL and PEL values for total PAHs. It can be seen from this table that the mean and the highest total PAH values found in the sediments sampled were well below these guidelines. There are also a number of guidelines for individual PAHs. The only exceedance of one of the guidelines for individual PAHs was for dibenzo(a,h)anthracene. The TEL of 6.22 ng/g was exceeded at 19 sites (Appendix D). The highest dibenzo(a,h)anthracene concentration (29.3 ng/g) was found at 08P in Laguna Boca Quebrada (Figure 5.2).

The results for total PAHs found in the sediments can be compared with work recently completed in southwest Puerto Rico (Pait et al. 2007). In Vieques, the mean total PAH concentration in the sediments was 52.3 ng/g, similar to the mean total PAH concentration in southwest Puerto Rico, for sediments outside of Guanica Bay (48.1 ± 10.72 ng/g). Samples taken at the two sites in Guanica Bay for that project were somewhat elevated and if they are included, the mean total PAH concentration in sediments from the study area in southwest Puerto Rico was 80.6 ± 25.5 ng/g, higher than the mean sediment total PAHs found in Vieques.

Table 5.3. Total PAHs in Vieques sediments and guidelines.

Vieques Results	Concentration (ng/g)
Vieques sediment total PAHs minimum	0.5
Vieques sediment total PAHs maximum	370.3
Vieques sediment total PAHs mean	52.3 ± 8.7
Vieques sediment total PAHs median	17.9
NOAA NS&T	
Mean	3,390 ± 1,634
Median	395
85th Percentile	2,880
Guidelines	
Threshold Effects Limit (TEL)	1,684
Effects Range - Low (ERL)	4,022
Effects Range - Median (ERM)	44,792
Probable Effects Level (PEL)	16,770
Apparent Effects Threshold (AET)	NA

NA, not available

PAHs and TOC. The adsorption of organic contaminants onto sediments in many types of aquatic environments is strongly influenced by total organic carbon (Hassett et al. 1980; Shine and Wallace 2000). A bivariate regression (Figure 5.8a) of log10 normalized TOC against the concentration of log10 total PAHs in the sediments was significant ($p < 0.0001$).

PAHs and Grain Size. The adsorption of organic contaminants onto sediments is also 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 contaminants. A nonparametric analysis of nationwide data from the NS&T Program indicated a significant relationship between total PAH and % fines ($p < 0.001$). To assess the relationship for the samples collected in Vieques, a regression was run between % fines and the concentration of total PAHs in the sediments. The data for grain size and PAH concentration were log10 transformed. The bivariate regression (Figure 5.8b) of % fines against the concentration of total PAHs in the sediments was significant ($p < 0.0001$).

Normalization of PAHs to TOC and Fines. An exercise was carried out to normalize the concentration of total PAHs detected in the sediments to TOC (e.g., total PAH/TOC), and by % fines (e.g., total PAH/ % fines) across the study area. Normalizations of these types are used to help identify sources of contaminants (Birch 2003; Burgess et al. 2001). The normalization of nonpolar organic compounds is typically restricted to those sediments containing at least 0.2% TOC. Below 0.2%, other factors that influence the partitioning of contaminants (e.g., sorption to nonorganic mineral fractions) become relatively more important (Di Toro 1991). There were three samples (78S1A, 16N2P, and 37N3P) where the TOC was less than 0.2%. For these samples, the TOC was set at 0.2%. Because of the fairly low concentrations of total PAHs seen throughout the study area, the normalizations were not revealing, however, they are included in Appendix E.

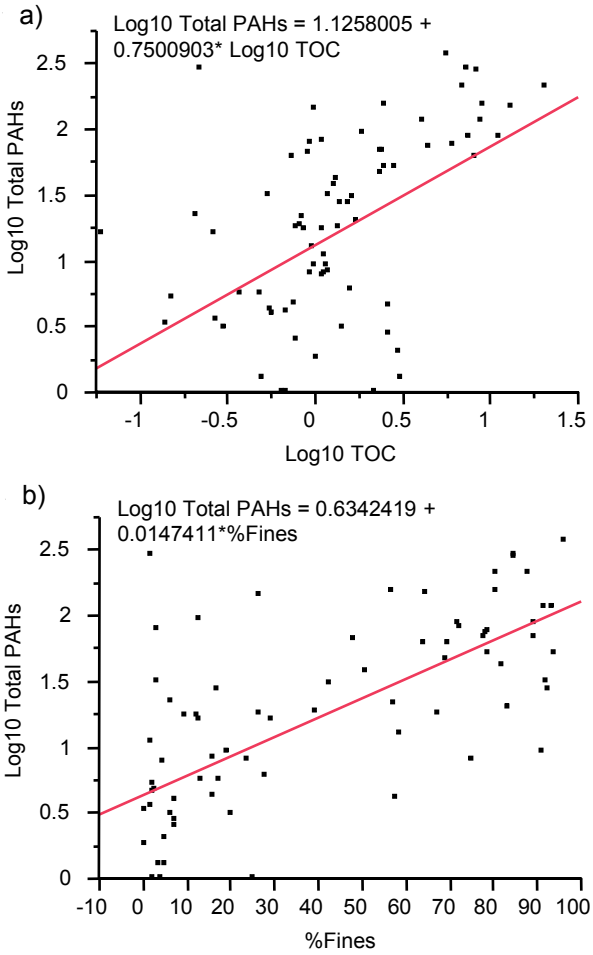


Figure 5.8. Bivariate fit of log10 total PAHs in sediments versus log10 TOC (a) and log10 % fines (b) from Vieques.

PAHs in Corals. The concentrations of total PAHs found in the coral tissues are presented in Figure 5.6b and in Appendix F. The mean concentrations of total PAHs in the tissues of *P. astreoides* (15.0 ± 0.6 ng/g) were numerically lower than that found in the sediments (52.3 ng/g), however, an ANOVA indicated that the difference was not significant (p = 0.6624). Pait et al. (in press) calculated a mean total PAH concentration of 46.9 ± 18.5 ng/g in *P. astreoides* from southwest Puerto Rico, somewhat higher than in corals from Vieques. Unfortunately, no guidelines appear to exist for any chemical contaminants in corals.

A number of ANOVAs were also carried out to assess how the distribution of total PAHs (log10 transformed) in the coral tissues varied across Vieques. The results indicate there was no difference in the concentration of total PAHs in the north strata versus the south strata (p = 0.5160), nor were there differences in the concentration of sediment total PAHs between strata (e.g., North 5 versus South 1) (p = 0.0900), or total PAHs in corals moving west to east (p = 0.1138) (Strata 1 to 5, Figure 5.7).

Normalization of Coral Tissues to Lipid Content. Just as sediments can be normalized to TOC, tissues can be normalized to lipid content, which can help identify possible sources of contaminants (Lake et al. 1990). The results of normalizing total PAHs by coral lipid content were not very revealing as concentrations of PAHs in coral tissues across Vieques were consistently low, but are included in Appendix G.

PAH Accumulation and Effects in Corals. Thomas and Li (2000) used supercritical extraction of ground and air dried samples of the coral *Porites compressa* followed by immunoaffinity chromatography, and analysis by gas chromatography and mass spectrometry to quantify PAHs present. Corals were collected at Kaneohe Bay in Oahu, Hawaii, which is impacted by industrial, military and civilian use in addition to wastewater discharges. Thomas and Li (2000) analyzed for a number of PAHs including fluorene, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo[e]pyrene, and benzo[a]pyrene. The total concentration for these PAHs in the coral (*P. compressa*) sampled from Kaneohe Bay was 220 ng/g, substantially higher than that found in *P. astreoides* in Vieques. Readman et al. (1996) analyzed for PAHs (including phenanthrene, fluoranthene, and pyrene) in the coral *Porites lutea* from Kuwait. In sections of the coral corresponding to the 1988/1989 timeframe (prior to the Gulf War), the concentration of these PAHs was approximately 0.3 ng/g. It should be noted, however, that Readman et al. (1996) sectioned and analyzed coral skeleton for PAHs.

Peachey and Crosby (1996) investigated the phototoxicity of PAHs. Phototoxicity refers to the toxic effects of chemicals caused or enhanced by light. In the laboratory, larvae of the coral *Fungia scutaria* (mushroom coral) were first exposed to nominal concentrations of pyrene ranging from 1 - 48 µg/L for a period of 2 hours. Larvae were then exposed to artificial sunlight and evaluated for changes in their mobility over a period of eight hours. A nominal pyrene concentration of 32 µg/L resulted in a significant number (40%) of immobilized larvae.

Guzman-Martinez et al. (2007) showed that the PAH fluoranthene at a concentration of 60 µg/L reduced photochemical efficiency in the coral *Porites divaricata* when combined with ultraviolet radiation at levels to simulate natural solar radiation, similar to the results found by Peachey and Crosby (1996). PAHs have also been shown to induce microsomal degradative enzymes (Cytochrome P450 class) in corals. As noted earlier P450 enzymes, particularly in higher organisms, can metabolize contaminants such as PAHs, often making them more water soluble, and enhancing their rate of excretion. Gassman and Kennedy (1992) were among the first researchers to show that at least some corals possess Cytochrome P450 enzymes. From these articles, it can be seen that PAHs can accumulate and impact corals. However, it should be noted that most of the contaminant effects data for corals are from dissolved concentrations in water. The concentration of contaminants in water (e.g., µg/L) having an effect cannot be directly compared with concentration in sediments (e.g., ng/g).

Polychlorinated Biphenyls (PCBs)

The results of the PCB analysis in sediments and coral tissues can be seen in Figure 5.9 and in Appendices H and J. The scale on the two graphics in Figure 5.9 is the same to make comparisons between sediments and corals easier. Total PCBs as used in this report was calculated using the following equation:

$$\text{Total PCBs} = (\text{sum of 18 PCB congeners} \times 2.19) + 2.19$$

The congeners used in the equation include: PCB8, PCB18, PCB28, PCB44, PCB52, PCB66, PCB101, PCB105, PCB118, PCB128, PCB138, PCB153, PCB170, PCB180, PCB187, PCB195, PCB206, and PCB209. The equation is used within the NS&T Program to estimate the total concentration of PCB congeners present in a sample (NOAA 1993).

PCBs in Sediments. The mean concentration of total PCBs in the sediments sampled in Vieques was 2.86 ± 0.14 ng/g; the median 2.38 ng/g (Table 5.4). The mean for total PCBs in sediments for 2006 and 2007 from the NS&T Program (most recent year of NS&T sediment data) is somewhat higher, 13.7 ± 2.70 ng/g. The higher concentrations of PCBs in Vieques tended to be found in sediments from the nearshore and inland lagoon areas (Figure 5.9a). The highest concentration of total PCBs (9.82 ng/g) in the sediments was from 38P (Figure 5.1) in Lagoon 6 in the North 4 stratum.

Summary for Total PCBs

- *The highest total PCB concentration in sediments was 9.82 ng/g and was found in Lagoon 6 adjacent to the former Live Impact Area (LIA).*
- *Concentrations of total PCBs were higher in the inland lagoons.*
- *There were no differences in total PCB concentrations in sediments between any of the strata.*
- *Overall, the concentrations of total PCBs in sediments were low; none of the concentrations of total PCBs exceeded the sediment quality guidelines examined.*
- *The concentration of total PCBs in coral (Porites astreoides) were not significantly different from the concentration in the sediments.*

The results for total PCBs found in the sediments can be compared with work recently completed in southwest Puerto Rico (Pait et al. 2007). The mean total PCB concentration in the sediments for those sites in southwest Puerto Rico outside of Guanica Bay was 18.1 ± 2.96 ng/g, higher than in Vieques. Samples taken at the two sites within Guanica Bay were elevated for a number of contaminants, including PCBs. If the two sites in Guanica Bay are included, the mean total PCBs concentration in sediments from the study area in southwest Puerto Rico was 104.1 ± 66.3 ng/g.

Comparisons Between Strata. As with the PAHs, a series of statistical analyses were carried out to understand how the distribution of total PCBs in sediments from nearshore waters and inland lagoons varied across Vieques. In general, the inland lagoons had a significantly higher total PCB concentration ($p < 0.0001$) than non-inland lagoon areas. A nonparametric (Wilcoxon) analysis indicated no difference in the concentration of sediment total PCBs between strata (e.g., North 5 versus South 1) ($p = 0.4140$). There was no difference in the concentration of total PCBs in the north strata versus the south strata ($p = 0.2207$). Finally, if the north and south strata are combined (e.g., North 1 and South 1) to create five strata moving west to east (Figure 5.7), there were no significant differences in total PCBs ($p = 0.3158$) between these strata.

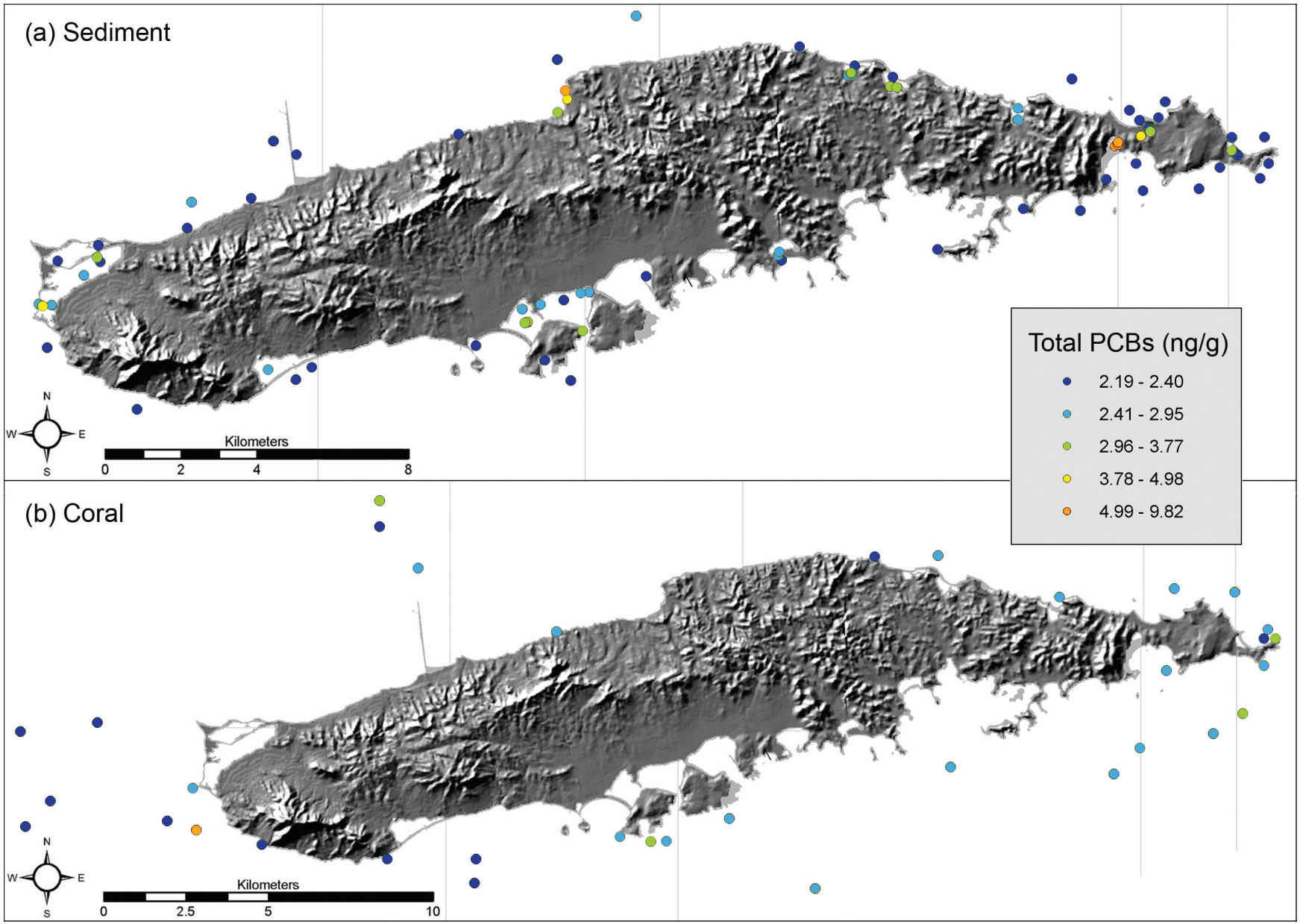


Figure 5.9. Total PCBs detected in the sediments (a) and in *Porites astreoides* (b).

Comparison Among Inland Lagoons. The sampling conducted in Vieques not only enabled comparisons between strata, but also comparisons in contaminant levels between nine inland lagoons (Figure 5.7) on the island. A Wilcoxon test indicated, however, there were no significant differences ($p = 0.1038$) between the nine lagoons for total PCBs in sediments.

Comparison with Sediment Quality Guidelines. Table 5.4 contains additional information on the levels of total PCBs detected in the sediments, along with sediment quality guidelines. The mean and median levels for total PCBs found in the sediments sampled in Vieques were well below all the guidelines shown in Table 5.4, as was the maximum total PCBs concentration (9.82 ng/g).

Table 5.4. Total PCBs in Vieques sediments and guidelines.

Vieques Results	Concentration (ng/g)
Vieques sediment total PCBs minimum	2.19
Vieques sediment total PCBs maximum	9.82
Vieques sediment total PCBs mean	2.86 ± 0.14
Vieques sediment total PCBs median	2.38
NOAA NS&T	
Mean	13.7 ± 2.70
Median	2.16
85th Percentile	23.7
Guidelines	
Threshold Effects Limit (TEL)	21.6
Effects Range - Low (ERL)	22.7
Effects Range - Median (ERM)	180
Probable Effects Level (PEL)	189
Apparent Effects Threshold (AET)	130

PCBs and TOC. Because the concentration of total PCBs was not normally distributed, nonparametric correlations (Spearman's) were run. There was no correlation between sediment PCBs and TOC in the samples taken in Vieques. One possibility for the lack of significant correlation could be the consistently low levels of PCBs seen in the sediments throughout the study area.

PCBs and Grain Size. A nonparametric analysis of % fines and total PCBs in the sediments, however, did reveal a significant ($p < 0.0001$) correlation. As noted, finer grain size sediments provide binding sites for contaminants including organics, however, it is not clear why there would be a correlation between total PCBs and % fines, but not for TOC.

Normalization of Total PCBs to TOC and Fines. The results of the normalization of total PCBs in the sediments to TOC (total PCBs/%TOC) and to % fines (total PCBs/% fines) for each site sampled is shown in Appendix I. As with the PAHs, because of the fairly low concentrations of total PCBs in the sediments seen throughout the study area, the normalizations were not revealing in terms of sources for the PCBs detected.

PCBs in Corals. The concentration of total PCBs found in the coral tissues are presented in Figure 5.9b. The mean concentration of total PCBs was 2.63 ± 0.11 ng/g; the median was 2.57 ng/g. The concentration of total PCBs in coral tissues was not significantly different from total PCBs found in the sediments ($p > 0.05$, Chi-Square = 0.3763). In southwest Puerto Rico, Pait et al. (in press) calculated a mean total PCBs concentration of 4.01 ± 1.03 ng/g in *P. astreoides* from southwest Puerto Rico, similar to what was found in *P. astreoides* in Vieques. A number of Wilcoxon tests were carried out to assess how the distribution of total PCBs in the coral tissues varied around Vieques. The results indicated there were no differences in the concentration of total PCBs in the north strata versus the south strata ($p = 0.4775$), nor were there differences in the concentration of coral total PCBs between strata (e.g., North 5 versus South 1) ($p = 0.8151$), or total PCBs in corals moving west to east ($p = 0.4049$) (Strata 1 to 5, Figure 5.7).

Normalization of Coral Tissues to Lipid Content. Appendix K contains the results of normalizing total PCBs in *P. astreoides* to lipid content. Because of the low concentrations of total PCBs seen throughout the study area, the normalization of total PCBs to lipid content was not very revealing.

PCB Accumulation in Corals. There are few articles on the accumulation of PCBs in corals. El Nemr et al. (2004) analyzed *Acropora sp*. tissues from a number of sites along the Egyptian Red Sea Coast. The average concentration of seven PCB congeners in the coral tissues was 18 ng/g (El Nemr et al. 2004), higher than was found in Vieques. Miao et al. (2000) analyzed coral (*Porites lobata*) samples for a number of PCB congeners from four sites in the French Frigate Shoals in the Pacific Ocean. Seventeen of the congeners analyzed by Miao et al. (2000) were also analyzed in the coral samples from Vieques. The approximate mean concentration for these congeners in *P. lobata* was 110 ng/g, substantially higher than the mean for total PCBs in *P. astreoides* from Vieques.

Comparison with Other Work in Vieques. NOAA and Ridolfi (2006) found 7.6 ng/g of total PCBs, representing nine Aroclors, in the tissues of the land crab *C. guanhumi* in Vieques, similar to the maximum total PCBs found in the sediments in the current study. The land crab where PCBs were detected was collected in Laguna Kiani. Comparison of data from different sources (i.e., crab tissue vs. coral tissue or sediments) can describe possible bioaccumulation (not obvious from the results present here) as well as contamination in a different matrix.

Total DDT

Thirty-one organochlorine pesticides and related compounds and degradation products were analyzed in the sediments and coral tissues collected in Vieques. The results for the individual organochlorine pesticides can be found in Appendix L and M. A more detailed discussion of the results for DDT, chlordane and endosulfan follow. These organochlorine pesticides were chosen as they had more of the detectable, and in the case of DDT, higher concentrations in the samples collected in Vieques.

DDT in Sediments. Figure 5.10a shows the distribution of total DDT in the sediments collected in Vieques. Total DDT is the sum of the parent isomers (4,4'-DDT and 2,4'-DDT) and degradation products DDE, DDD and DDMU. The mean concentration of total DDT in the sediments was 23.6 ±16.5 ng/g, higher than the NS&T mean (3.11 ng/g) (Table 5.5). The higher mean and large standard error of the mean for Vieques were due to elevated DDT levels in some of the inland lagoon sites. The NS&T Program median for total DDT is 0.40 ng/g, higher than the total DDT median (0.10 ng/g) found in the sediments in Vieques.

The highest concentration of total DDT found in the sediments from Vieques (1,274 ng/g) was from an inland lagoon site (46P) adjacent to Blue Beach, in the former Eastern Maneuver Area of the VNTR (Figure 5.1 and Figure 5.10a). The second highest total DDT concentration (178 ng/g) was also found in a sediment sample (21P) from the Eastern Maneuver Area, from a lagoon adjacent to Puerto Negro on the northeastern part of the island. The higher concentrations of total DDT were found in the inland lagoon areas, as can be seen in Figure 5.10a. This is perhaps not surprising as the use of DDT in the past likely occurred in the inland areas where mosquitoes and other pests were a problem. The application of DDT in this part of Vieques was more likely for non-agricultural uses as military training exercises were conducted in these areas. It should also be noted, however, that of the 78 sediment samples collected in Vieques for this project, approximately 70% contained less than 1 ppb total DDT; 22% of the sites contained no detectable DDT at all.

Summary for Total DDT

- *The highest total DDT concentration in the sediments was 1,274 ng/g and was found in Lagoon 10 adjacent to Blue Beach in the former Eastern Maneuver Area (EMA).*
- *Concentrations of total DDT were higher in the inland lagoon areas of the island.*
- *The stratum containing the EMA had significantly higher total DDT in the sediments than the other strata.*
- *The concentration of total DDTs in the sediments exceeded the Effects Range Median value of 46.1 ng/g at four locations in Vieques, indicating likely impacts (toxicity) in sediment-dwelling organisms in these areas.*
- *Overall, the concentration of total DDT in coral (Porites astreoides) was not significantly different from the concentration in the sediments.*

The results for total DDT in the sediments can be compared with work recently completed in southwest Puerto Rico (Pait et al. 2007). The mean total DDT concentration in the sediments from southwest Puerto Rico was 2.10 ± 1.26 ng/g, lower than the mean found in Vieques. Even if the value for total DDT from 46P is removed from the calculation, the mean total DDT for Vieques would be 7.38 ±2.81 ng/g.

Comparison Between Strata. As with the other contaminant classes, a series of statistical analyses were carried out to understand how the distribution of total DDT quantified in the sediments varied across the island of Vieques. Not surprisingly, a nonparametric Wilcoxon test indicated that the concentration of total DDT from the inland lagoons was significantly higher ($p < 0.0001$) than the nonlagoon areas. A nonparametric (Wilcoxon) analysis indicated a significant difference ($p = 0.0279$) in the concentration of sediment total DDT between strata (e.g., North 5 versus South 1), however, a comparison (Tukey HSD) of ranked values did not reveal any significant differences between individual strata. There were no differences ($p = 0.3767$) in the north strata versus the south strata. If the strata (e.g., North 1 and South 1) are combined to form five strata moving in a west

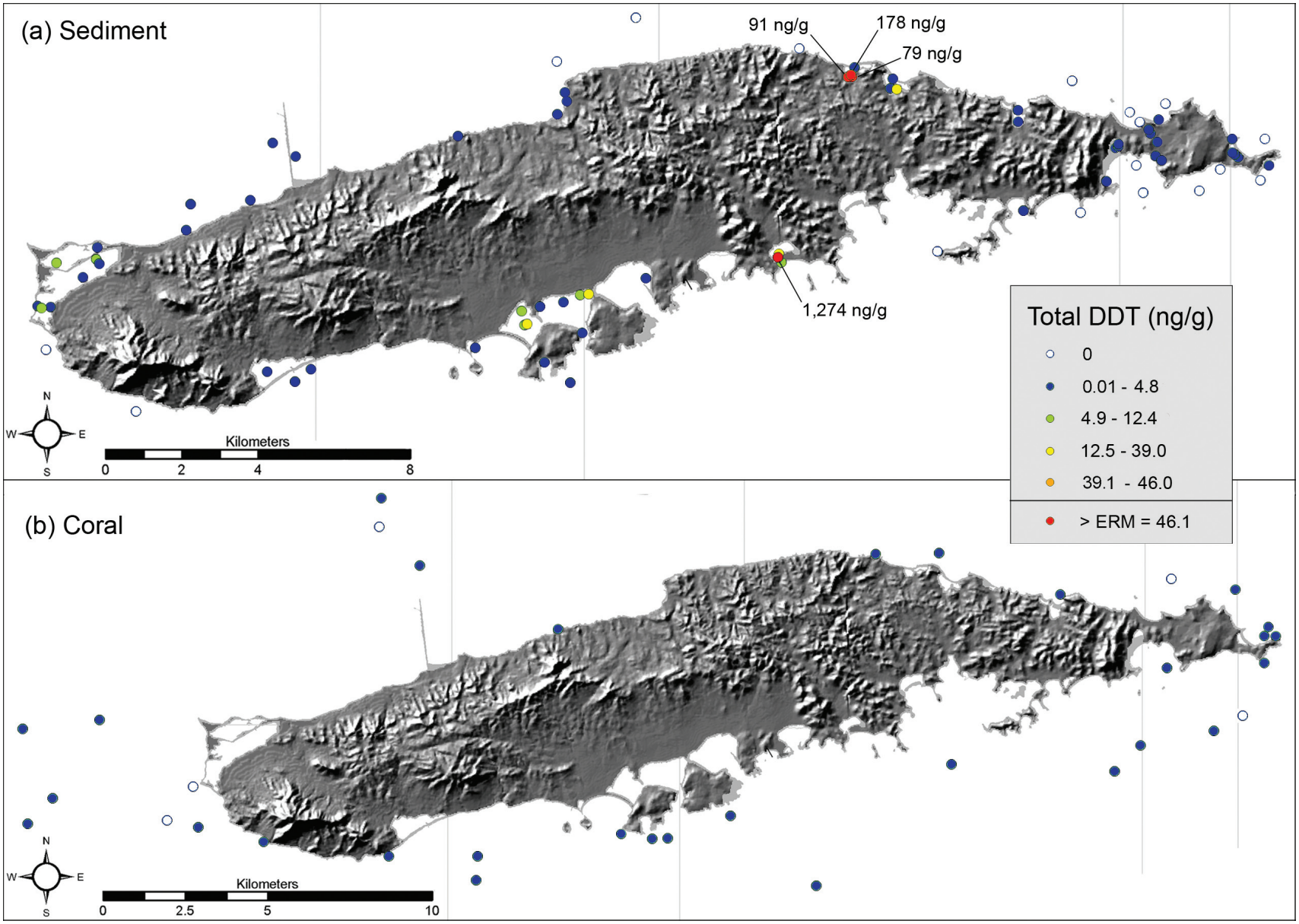


Figure 5.10. Total DDT detected in the sediments (a) and in *Porites astreoides* (b).

to east direction (Figure 5.7), Stratum 3 which contains the Eastern Maneuver Area where the higher concentrations of total DDT were found, was significantly different ($p = 0.0082$, Tukey HSD on the ranked data).

Comparison Among Inland Lagoons. The October 2007 sediment sampling in Vieques concentrated on a number of inland lagoons, and along with the results from the May 2007 sampling, enable a comparison of contaminant concentrations between nine inland lagoons (Figure 5.7) on the island. For total DDT, a Wilcoxon test indicated a significant difference ($p = 0.0027$) between the nine lagoons sampled. A pairwise comparison (Tukey HSD) of the ranked data indicated that total DDT in the sediments in Lagoon 4 (Laguna Algodones) on the north shore, Lagoon 5 near Blue Beach (which contains 46P) and Lagoon 3 near Ensenada Sombe had significantly different (higher) total DDT concentrations than Lagoons 6 through 9.

Comparison with Sediment Quality Guidelines. Table 5.5 contains additional information on the levels of total DDT detected in the sediments, along with a number of established sediment quality guidelines. Four sediment samples, including 46P, and all the samples taken from the lagoon adjacent to Puerto Negro (21P (178 ng/g), 22P (79 ng/g) and 23P (91 ng/g)) were not only above the ERL, but also above the ERM value of 46.1 ng/g, indicating that benthic organisms inhabiting these lagoons may be impacted by the concentration of DDT. These same sites also exceeded the PEL or probable effects level (51.7 ng/g). The Apparent Effects Threshold or AET, was developed by the State of Washington and represents the concentration above which significant biological effects (toxicity) in benthic infaunal organisms may be expected. The AET for total DDT is 11 ng/g, lower than the ERM. In Vieques, there were 10 sites above the AET for total DDT, including the four listed above; all were located in the inland lagoon areas.

Table 5.5. Total DDT in Vieques sediments and guidelines.

Vieques Results	Concentration (ng/g)
Vieques sediment total DDT minimum	0
Vieques sediment total DDT maximum	1,274
Vieques sediment total DDT mean	23.6 ± 16.5
Vieques sediment total DDT median	0.10
NOAA NS&T	
Mean	3.11 ± 0.896
Median	0.395
85th Percentile	3.49
Guidelines	
Threshold Effects Limit (TEL)	3.89
Effects Range - Low (ERL)	1.58
Effects Range - Median (ERM)	46.1
Probable Effects Level (PEL)	51.7
Apparent Effects Threshold (AET)	11

Parent and Degradation Products of DDT. Because the measurement of total DDT is made up of both the parent isomers and degradation products, the ratio of parent compounds to degradation products can provide some insight into the relative age or "freshness" of the DDT present. Total DDT concentrations containing higher ratios of the parent compound are more likely to be recently introduced into the environment. For sites 21P, 22P and 23P, the DDT degradation products accounted for approximately 97% of the total, indicating that the DDT present had degraded over time. At 46P, which had a total DDT concentration of 1,274 ng/g, approximately 68% of the total DDT present consisted of the parent compounds, which could indicate more recent introduction of the pesticide into the environment. The source of the DDT at this site is currently unknown, however, the high concentration along with the higher levels of the parent compounds could indicate a more recent spill or dumping of DDT at or near the site sampled. According to the U.S. Navy, the area around Blue Beach once served as a fuel offloading site (Hood, personal communication). It is possible that containers of DDT may have been spilled at this site, or perhaps DDT was over applied to control insect pests in the area.

DDT and TOC. Because the concentration of total DDT was not normally distributed, nonparametric correlations (Spearman's) were run. There was a significant ($p < 0.0001$) positive correlation between sediment total DDT and TOC in the samples taken in Vieques. As noted, organics typically bind to sediment TOC, and the areas with elevated levels of total DDT (inland lagoons) were associated with sediments containing higher levels of TOC.

DDT and Grain Size. A nonparametric analysis of % fines and total DDT in the sediments, also revealed a significant ($p < 0.0001$) correlation. Finer grain size sediments provide binding sites for contaminants including DDT.

Normalization of Total DDT to TOC and Fines. The results of the normalization of total DDT found in the sediment to TOC (total DDT/%TOC) and to % fines (total DDT/% fines) for each site sampled is shown in Figure

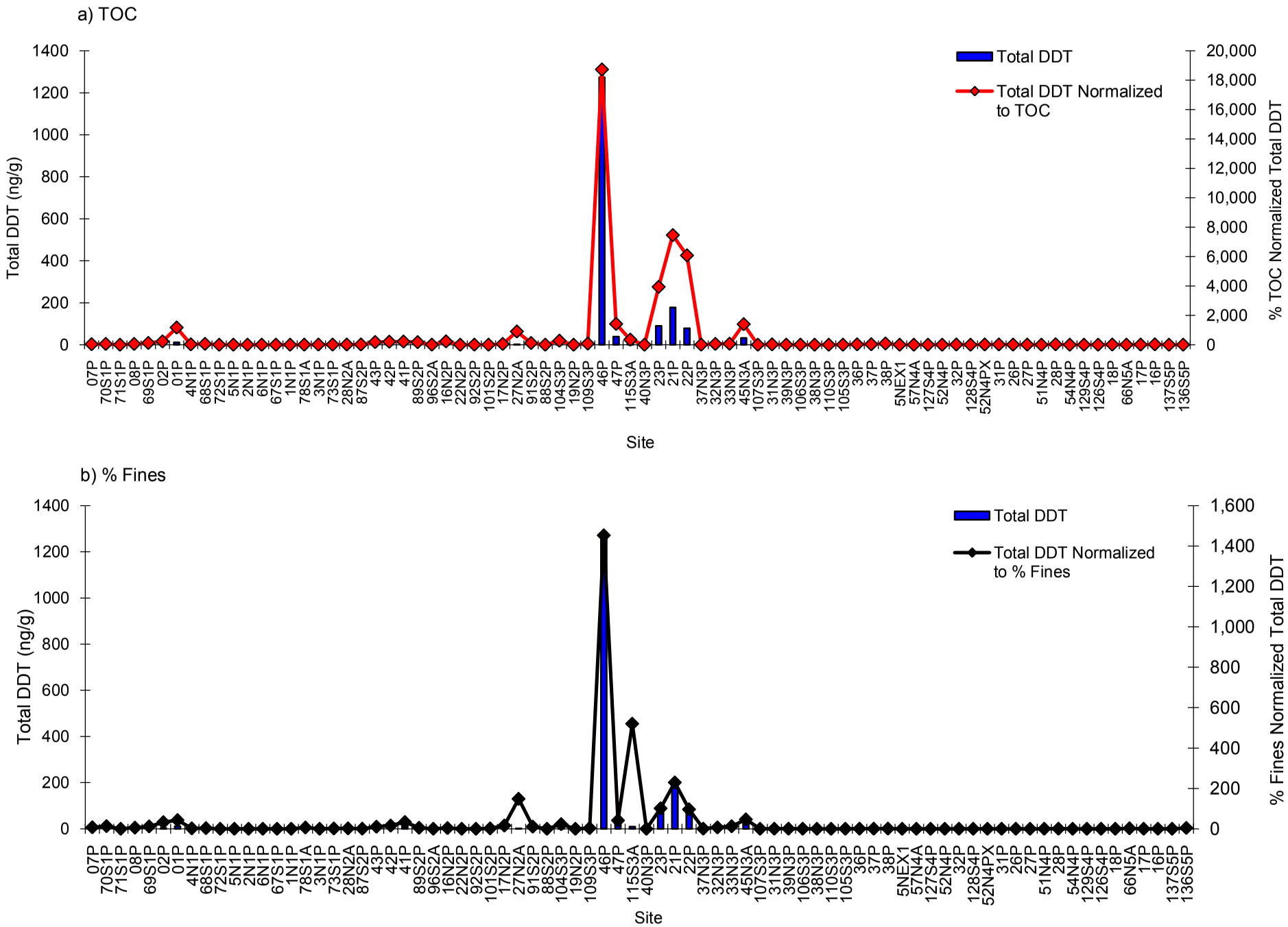


Figure 5.11. Total DDT in sediments normalized to TOC (a) and % fines (b).

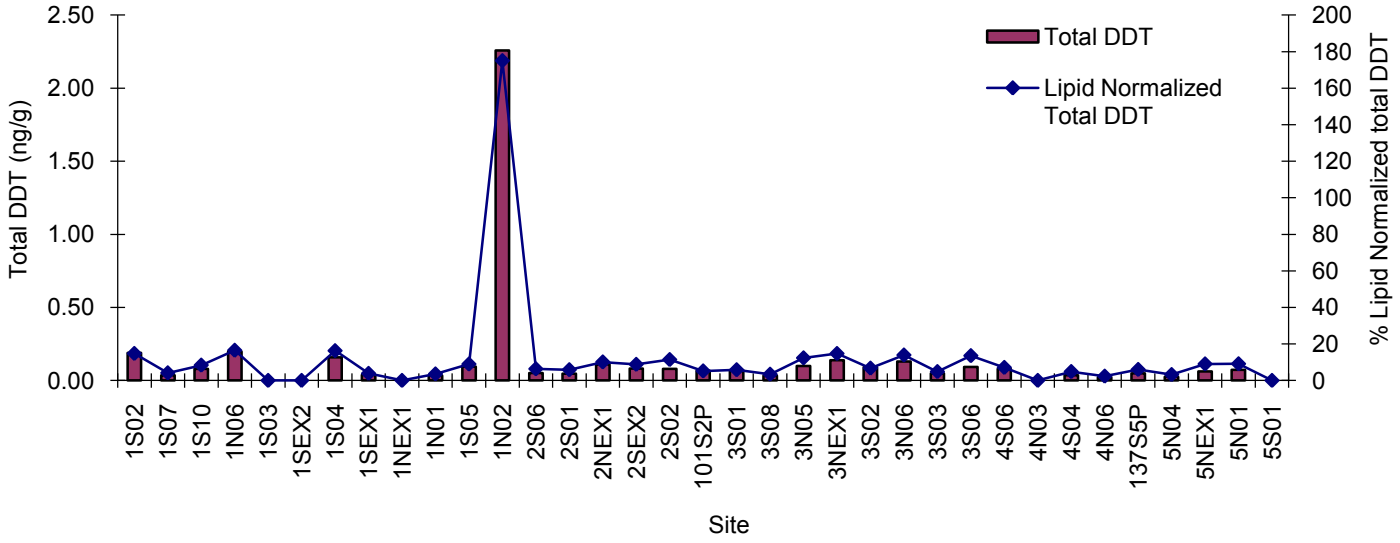


Figure 5.12. Total DDT in *P. astreoides* tissues normalized to lipid content.

5.11. The concentrations of total DDT in the sediments are plotted on both graphs in addition to the normalized values, and the sites are oriented in a west to east direction to make them comparable to the information presented in Figure 5.10. Normalizations of this type are sometimes useful for identifying sources of contaminants (Birch 2003; Burgess et al. 2001). Figure 5.11 also provides a second opportunity to compare total DDT detected in the sediments between sites. As can be seen from the blue bars in Figure 5.11, the higher concentrations of total DDT found in the inland lagoons at 46P along with 21P, 22P, and 23P are apparent. It can be also be seen from this graphic and from Appendix L, that a large number of sediments sampled in Vieques had a total DDT concentration of 1 ng/g or less.

In Figure 5.11a, total DDT normalized to TOC is displayed by the red line in the graph. There was a large spike in the TOC-normalized total DDT concentration at 46P near Blue Beach, indicating this area is a likely source for the DDT in this area. A higher total DDT normalized concentration was also visible at 21P, 22P, and 23P on the north side of Vieques in the Eastern Maneuver Area near Puerto Negro. In Figure 5.11b a similar pattern was found when total DDT concentration was normalized to % fines (i.e., higher normalized concentrations at 46P and at 21P, 22P, and 23P). A smaller spike was also apparent at 115S3A which had a lower (1.71%) concentration of fines and a total DDT concentration of 8.92 ng/g (Appendix L).

DDT in Corals. The concentration of total DDT found in the coral tissues are presented in Figure 5.10b. The mean concentration was 0.13 ± 0.07 ng/g; the median was 0.06 ng/g. A Wilcoxon test indicated that the concentration of total DDT in the coral tissues, however, was not significantly different from total DDT found in the sediments ($p = 0.1397$). In southwest Puerto Rico, Pait et al. (in press) calculated a mean total DDT concentration of 0.09 ± 0.08 ng/g in *P. astreoides*, similar to what was found in *P. astreoides* in Vieques.

A number of Wilcoxon tests were carried out to assess how the distribution of total DDT in the coral tissues varied across Vieques. The results indicate there were no differences in the concentration of total DDT in the corals in the north strata waters versus the south strata ($p = 0.5229$), nor were there differences in the concentration of coral total DDT between strata (e.g., North 5 versus South 1) ($p = 0.3306$), or total DDT in corals moving west to east ($p = 0.2634$) (Strata 1 to 5, Figure 5.7).

<u>Normalization of Coral Tissues to Lipid Content</u>. Figure 5.12 shows the results of normalizing total DDT in *P. astreoides* to lipid content. From Figure 5.12, it can be seen that the normalized concentration of total DDT closely followed the pattern of actual concentrations. There was one larger normalized total DDT peak. The coral sample with the higher normalized total DDT concentration (1N02), however, was on the northern side of Vieques, near Mosquito Pier. The sediment sample with the higher total DDT was located on the south side of the island, near Blue Beach.

<u>DDT Accumulation in Corals</u>. A few studies were found that quantified DDT and its metabolites in coral tissues. Glynn et al. (1995) collected and analyzed sediment and *P. astreoides* for residues of total DDT from the Florida Keys National Marine Sanctuary, in the area near Key Largo. The highest concentration detected was 0.01 ng/g. Glynn et al. (1989) also looked at total DDT in *P. astreoides* further north, in Biscayne National

Park, in an area known as Alina's Reef, and detected higher concentrations, ranging from 3.41 - 43.56 ng/g. In the current study, the highest total DDT concentration in *P. astreoides* was 2.26 ng/g. El Nemr et al. (2004) detected a mean total DDT concentration of 5.7 ± 0.8 ng/g (dry weight) in coral tissues from the Egyptian Red Sea Coast.

Comparison with Other Work in Vieques. NOAA and Ridolfi (2006) and ATSDR (2006) found concentrations of total DDT in Vieques, ranging from 0.47 – 283.8 ng/g. Detections were in the tissues of the land crab *C. guanhumi* and in the fiddler crab *(Uca sp)*. The highest DDT detections from these studies in increasing order were land crab from Red Beach (187.2 ng/g), land crab from Laguna Kiani (203.2 ng/g) and fiddler crab from Red Beach (283.8 ng/g). The highest total DDT concentration at Blue Beach from either of these studies was 103.3 ng/g in the fiddler crab. The concentration of total DDT in the sediments from the inland lagoon adjacent to Blue Beach (1,274 ng/g) from the current study appears to be the highest DDT level detected in any matrix in Vieques to date. Comparison of data from different sources (i.e., crab tissue vs. coral tissue or sediments) can describe bioaccumulation as well as contamination patterns in different matrices.

Other Pesticides

A number of other chlorinated pesticides were detected in the sediments and coral tissues in Vieques (Appendix L and M), including total chlordane (alpha-chlordane, gamma-chlordane, heptachlor, heptachlorepoxide, oxychlordane, trans-nonachlor, and cis-nonachlor) total endosulfan (endosulfan I and II and endosulfan sulfate), dieldrin, aldrin, endrin, gamma-HCH (lindane), and chlorpyrifos. All of these compounds, however, were at concentrations of less than 1 ng/g in both sediments and tissues. Maps of total chlordane and total endosulfan in sediments are shown in Figures 5.13 and 5.14, respectively.

Many currently used agricultural pesticides are not included in the NS&T list of core analytes, as they are water soluble and therefore less likely to accumulate in sediments and coral tissues, to the level where they could be detected. However, there appears to be little agriculture on Vieques, and so it would be unlikely that a water soluble herbicide such as atrazine would have been detected in the samples collected for this project.

Chlordane was used in the past as an insecticide. A primary non-agricultural use of chlordane was the treatment of wooden structures to prevent damage by termites. The mean total chlordane concentration in the sediments was 0.04 ±0.01 ng/g. The ERL for chlordane is 0.5 ng/g; the TEL is 2.26 ng/g. The highest total chlordane detected in the sediments in Vieques (0.67 ng/g) was at 28P (Figure 5.13) in the Live Impact Area, and was slightly above the ERL. In *P. astreoides*, the mean total chlordane was 0.12 ±0.03 ng/g. In Southwest Puerto Rico (Pait et al. 2007), the mean total chlordane concentration in the sediments was 0.15 ±0.06 ng/g.

Total endosulfan in the sediments is shown in Figure 5.14. The mean total endosulfan concentration in the sediments from Vieques was 0.02 ±0.01 ng/g. The highest concentration of total endosulfan in the sediments was 0.36 ng/g. No ERL, TEL or AET exist for this pesticide. Only one coral sample (1N01) had a detectable

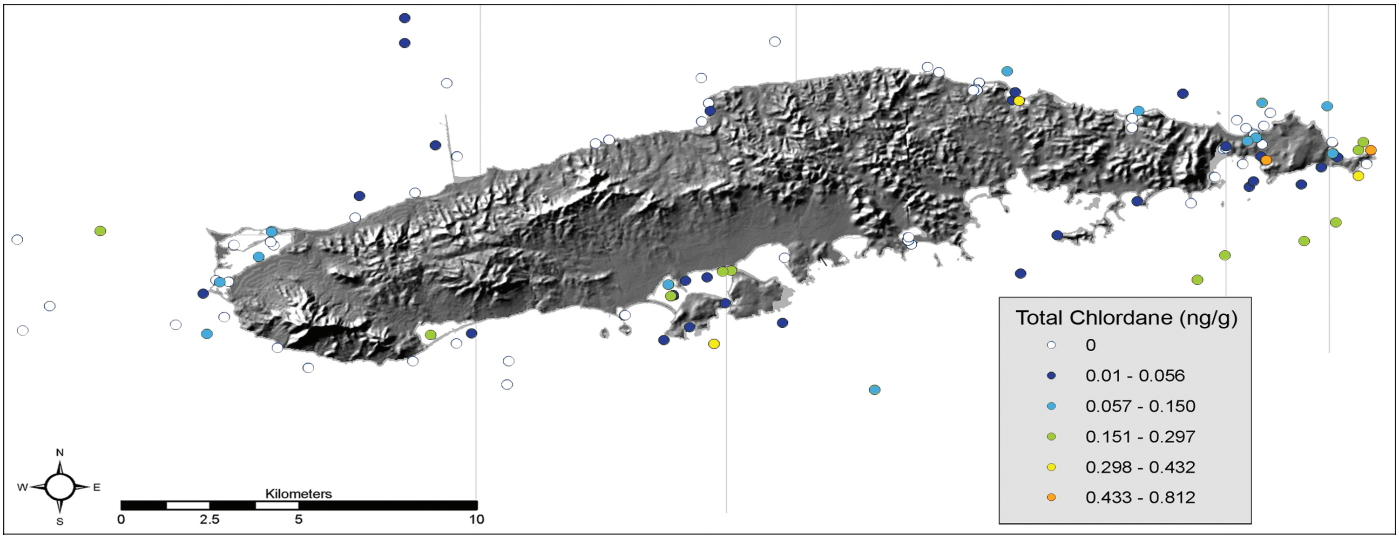


Figure 5.13. Total chlordane detected in the sediments.

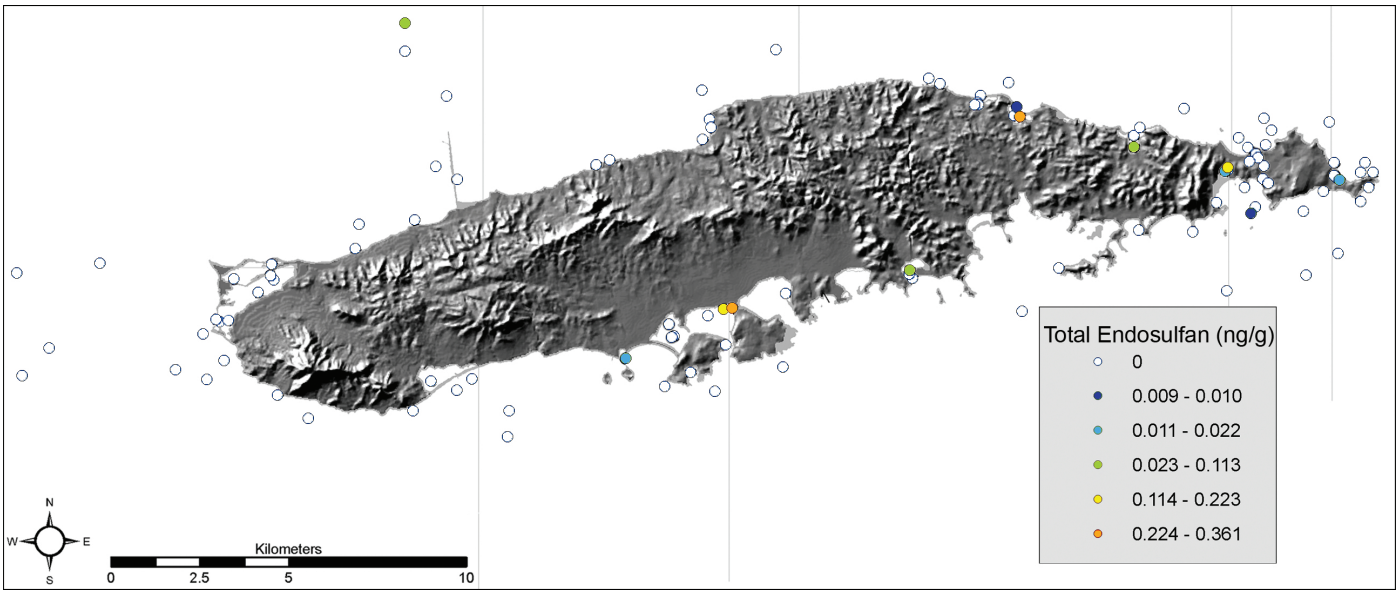


Figure 5.14. Total endosulfan detected in the sediments.

level of total endosulfan (0.09 ng/g). In southwest Puerto Rico, the mean concentration of total endosulfan in *P. astreoides* was 0.18 ±0.06 ng/g (Pait et al. 2007).

Energetics

For this project, a total of 15 energetics (explosives) and related compounds were analyzed in the sediment samples, and are shown in Table 5.1. The assessment of energetics in the sediment samples collected from Vieques was carried out because of their use as part of the naval training activities that occurred on parts of Vieques over the years. Perchlorate, used in solid rocket fuels was analyzed in selected sediment samples. The compounds 2,4,6-trinitrotoluene (TNT), HMX (High Melting Explosive), RDX (Royal Demolition Explosive) and Tetryl (2,4,6-trinitrophenyl-n-methylnitramine) are the parent energetics. Thermal degradation products include 1,3,5-trinitrobenzene, 2,4-dinitrotoluene, and 2,6-dinitrotoluene. The other energetic-related compounds listed in Table 5.1 are either impurities or microbial degradation products (Becker 1995). The analysis of energetics represents an expansion of the chemicals analyzed within NOAA's NS&T Program.

The results of the analysis for energetics is shown in Appendix N. For this project, the 78 sediment samples were initially analyzed using EPA Method 8330. From that analysis, 14 sites showed possible detections. To confirm the presence of the energetics, the 14 sediment samples were reanalyzed using Method 8330 followed by liquid chromatography/mass spectrometry/mass spectrometry (LC/MS/MS). The sites included in the reanalysis are indicated in Appendix N. Samples remained frozen at -20°C prior to reanalysis. The LC/MS/MS analysis was used to confirm the identity and concentration of any energetics. The results of the reanalysis indicated that the energetic compounds were either not found in the sediment samples analyzed, or because of matrix interferences coupled with very low concentrations, could not be quantified. Interpretation of the results of the analyses provided by TDI-Brooks International is also included in Appendix N.

Summary for Energetics

- *A total of 78 sediment samples were analyzed for 15 energetics (explosives) and related compounds.*
- *From the original analysis, there were 14 samples with possible detections of energetics.*
- *These samples were reanalyzed using liquid chromatography/mass spectrometry (LC/MS/MS) in an effort to confirm the presence of any energetics.*
- *The results of the reanalysis indicated that the energetic compounds were either not present in these samples, or because of matrix interferences coupled with very low concentrations, could not be quantified.*

The results from this study can be compared with those from other areas. In New Jersey, a study was conducted in the former Raritan Arsenal to determine whether contaminated soils and sediments within the former arsenal posed an ecological risk (USACOE 2008). As part of the baseline ecological risk assessment, estuarine sediment samples were analyzed for a number of energetics. None of the estuarine sediment samples analyzed contained energetics above the reporting limit. In Bremerton, WA, an ecological risk assessment Tier 1 screening was carried out in an area known as the Jackson Park Housing Complex (JPHC). Historically, the area had served as the U.S. Naval Ammunition Depot (NAD), Puget Sound. Activities included storage, production, demilitarization and burning of ordnance. The facility was decommissioned in 1959 (NAVFAC, 2007), and subsequently the site was converted to a residential complex for military personnel. As part of remedial actions at the site, sediments were collected in Ostrich Bay, and analyzed for a variety of contaminants including energetics. Maximum concentrations of the energetics detected included: 2,6-dinitrotoluene (0.68 µg/g), RDX (0.29 µg/g), Tetryl (0.03 µg/g), and nitrobenzene (0.008 µg/g). Decarlo et al. (2007) collected and analyzed 96 sediment and 46 fish samples in an area off Oahu, Hawaii known locally as Ordnance Reef, as part of a project to assess the extent of discarded military munitions and the presence of munitions constituents (energetics and metals). Decarlo et al. (2007) did not detect RDX, TNT or Tetryl, however, dinitrotoluene was detected at four sediment samples; no energetics or related compounds were detected in the fish sampled as part of that project.

Image 5.4. Semi-dry lagoon in the LIA, with bomb craters in the background, and ordnance in the foreground.

Comparison with Other Work in Vieques. A number of other documents have been published on the analysis of energetics in Vieques. CH2MHILL (2007) detected no energetics in 79 soil samples collected in the VNTR. NOAA and Ridolfi (2006) detected no energetics in crab tissue samples in 12 locations across Vieques. ATSDR (2006) found 0.97 µg/g of HMX in fiddler crab (*Uca sp.*) tissues taken in the former LIA. Barton and Porter (2004), however, detected TNT in sediment samples as high as 4,380 µg/g adjacent to an unexploded 2,000 pound bomb on the ocean floor, and in a brain coral (*Diploria labyrinthiformis*) tissue sample (252 µg/g) adjacent to the *USS Killen* stern.

Butyltins

The results of the analyses of butyltins is shown in Appendix O and P. As noted, tributyltin or TBT was used in the past as an antifouling agent, primarily on boat hulls. The degradation of tributyltin results in di- and then monobutyltin, which are also included in the appendices. Tetrabutyltin is an impurity produced in the manufacture of TBT.

Summary for Tributyltin (TBT)

- *There were 10 detections of TBT in the sediments in Vieques.*
- *The highest concentration of TBT was 1.23 ng/g and was found in Punta Arenas in the northwest portion of Vieques.*
- *There were no differences in the concentration of TBT in the sediments between inland lagoon and non-inland lagoon areas..*
- *There were no differences in TBT concentrations in sediments between any of the strata.*
- *The concentration of TBT in coral (Porites astreoides) was not significantly different from the concentration in the sediments.*

TBT in Sediments. There were 10 detections of TBT in the sediments sampled in Vieques (Figure 5.15a and Appendix O). The highest detection of TBT was 1.23 ng/g at 89S2P, located in Bahia Mosquito. The mean concentration of TBT in Vieques sediments was 0.04 ± 0.02 ng/g. The mean for TBT from NOAA's NS&T Program is 1.43 ng/g. The Vieques mean for dibutyltin was 0.30 ± 0.03 ng/g and for monobutyltin 0.41 ± 0.09 ng/g. Monobutyltin had the highest concentration of any of the butyltins found in Vieques, however dibutyltin was found more frequently. Eight sediment samples exceeded the NS&T 85th

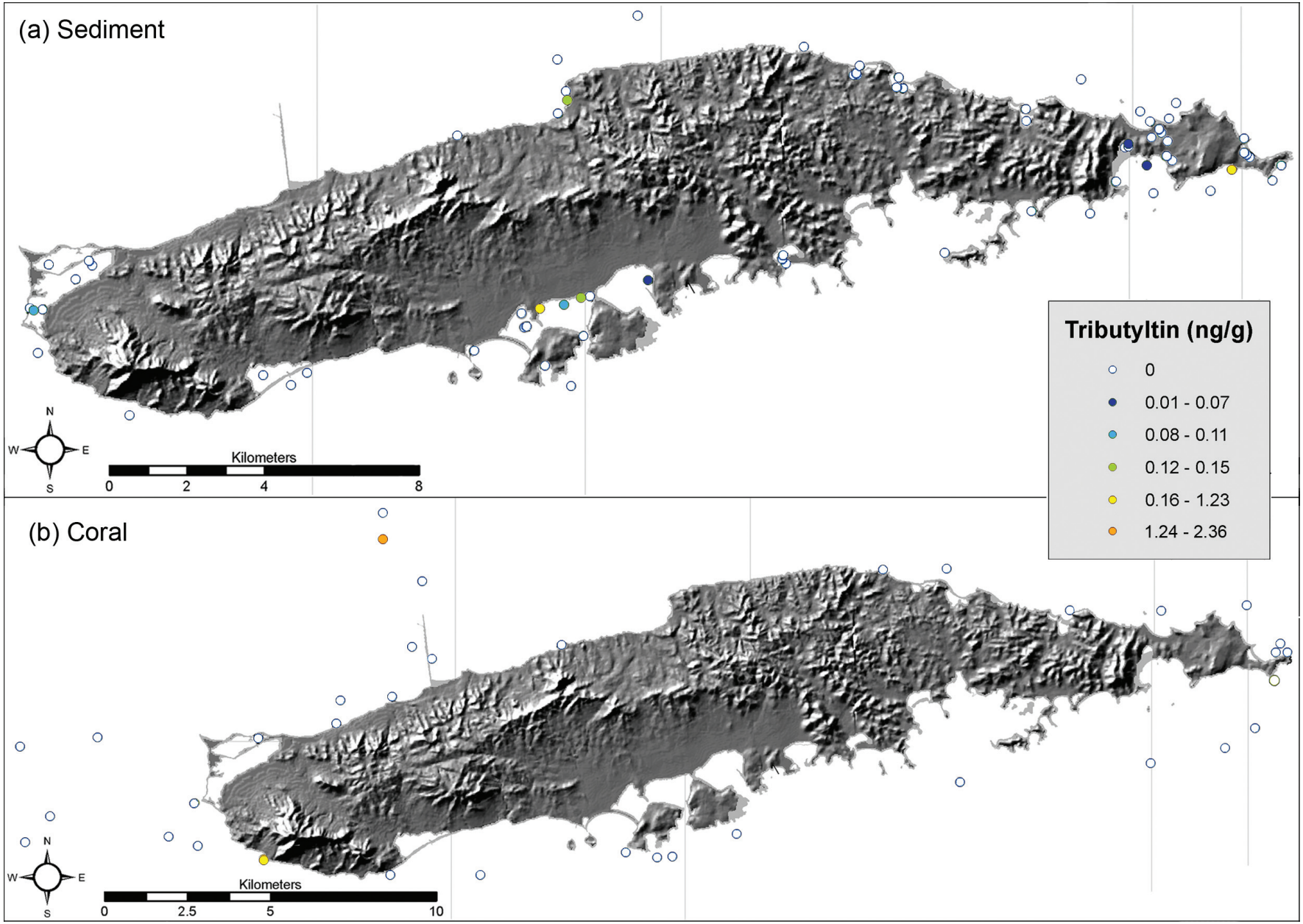


Figure 5.15. Tributyltin in sediments (a) and in *Porites astreoides* (b).

percentile for monobutyltin (1.28 ng/g). Tetrabutyltin was detected once in the sediments of Bahia Mosquito (0.22 ng/g) above the NS&T 85th percentile of 0.16 ng/g. The results for TBT found in the sediments in Vieques can be compared with work recently completed in southwest Puerto Rico (Pait et al. 2007). The mean concentration of TBT in the sediments in southwest Puerto Rico was 0.01 ± 0.01 ng/g, lower than the mean TBT concentration found in Vieques.

Comparisons Between Strata. A series of statistical analyses were carried out to assess how the distribution of TBT in the sediments varied across Vieques. In contrast to most of the other contaminants discussed, there were no significant differences between inland lagoon and non-inland lagoon areas ($p = 0.2954$). A nonparametric (Wilcoxon) analysis indicated no difference in the concentration of sediment TBT between strata ($p = 0.5474$). There was no difference in the concentration of TBT in the north strata versus the south strata on Vieques ($p = 0.1769$). Finally, if the north and south strata are combined (e.g., North 1 and South 1) to create five strata moving west to east, there were no significant differences in TBT ($p = 0.2498$) between the strata.

Comparison with Sediment Quality Guidelines. No sediment quality guidelines were located for TBT or its metabolites.

TBT in Corals. The mean concentration of TBT in *P. astreoides* (Figure 5.15b) was 0.08 ± 0.07 ng/g. The concentration of TBT in the coral tissues was not significantly different ($p = 0.3221$) from the concentration in the sediments. An analysis of variance using Wilcoxon's nonparametric test showed a significant difference between mono- and dibutyltin concentrations in coral tissues and sediments, with coral tissues having higher concentrations of both at the 95% confidence level. In the coral samples, monobutyltin was the dominant butyltin found, and is likely the result of TBT debutylization. Additional information on the butyltins detected in *P. astreoides* can be found in Appendix P.

Effects of TBT on Corals. Negri et al. (2002) investigated the effects of TBT in sediments on the coral *Acropora microphthalma*. Sediments were collected from an area where a cargo ship had grounded on the Great Barrier Reef in Australia. The grounding of the ship and subsequent wave action resulted in TBT sediment concentrations of 160 µg/g, copper concentrations of 1,180 µg/g, and zinc concentrations of 1,570 µg/g. Negri et al. (2002) diluted the sediments taken at the site of the grounding with sediments from a control site. Sediments diluted to 5 percent of the original concentration prevented successful settlement of coral larvae in the laboratory on preconditioned terracotta tiles. The tiles were preconditioned by placing them on control reefs for three months. Negri and Heyward (2001) investigated the effects of tributyltin on fertilization and larval settling of *A. millepora*. Gametes were collected from reefs in Western Australia, and brought back to the laboratory. The effective concentration of TBT which caused 50 percent inhibition (EC50) of fertilization after four hours was 200 µg/L. A second set of experiments was carried out to assess the effects of TBT on settlement and metamorphosis of larval *A. millepora*. The calculated concentration needed to inhibit 50 percent larval metamorphosis was only 2 µg/L.

Trace and Major Elements

A total of 16 trace and major elements were analyzed in the sediments; 14 elements were analyzed in coral tissues. An assessment of trace and major elements in the sediments and coral tissues collected in Vieques is of interest in part due to the previous military activities, which could be reflected in elevated concentrations of these elements in the samples collected.

A summary of the means and standard errors for the elements in sediments and coral tissues is shown in Table 5.6. Except for cadmium, the concentration of trace and major elements were lower, in some cases orders of magnitude lower, in the coral tissues. The highest mean concentration of any trace or major element analyzed in the sediments was aluminum at over 35,500 µg/g, or 35.5 parts per thousand. Silicon (18,240 µg/g) and iron (17,610 µg/g) had the second and third highest concen-

Table 5.6. Trace and major elements in sediments and coral tissues (*P. astreoides*).

Element	Sediment Mean (µg/g) ±SE	Coral Mean (µg/g) ±SE
Aluminum	35,530 ±3,530	30.75 ±4.33
Antimony	0.225 ±0.032	NA
Arsenic	4.37 ±0.33	0.241 ±0.137
Cadmium	0.133 ±0.031	0.194 ±0.018
Chromium	22.5 ±2.98	0.183 ±0.060
Copper	25.9 ±3.15	0.757 ±0.264
Iron	17,610 ±1920	51.2 ±15.0
Lead	5.42 ±0.55	0.074 ±0.001
Manganese	301 ±31.8	2.66 ±0.32
Mercury	0.019 ±0.003	<0.001
Nickel	7.80 ±1.07	0.896 ±0.290
Selenium	0.261 ±0.035	0.096 ±0.017
Silicon	18,240 ±10,750	NA
Silver	0.103 ±0.01	0.013 ±0.001
Tin	0.660 ±0.222	0.246 ± 0.012
Zinc	34.3 ±3.91	3.43 ±0.49

NA, not analyzed

trations in the sediments, respectively. Aluminum, iron, and silicon are major elements in the Earth's crust, so it is not surprising that there were higher concentrations of these elements relative to the others analyzed. Both trace and major elements are found naturally in the Earth's crust, however, the use and disposal of products containing these elements can result in elevated environmental concentrations, particularly for trace elements. In the coral tissues, the highest elemental concentration found was iron at 51 µg/g, followed by aluminum (31 µg/g) and zinc (3 µg/g).

A discussion of four elements, cadmium, chromium, copper, and lead in sediments and coral tissues follows. Brief summaries for sediments are subsequently provided for aluminum, arsenic, iron, manganese, mercury, nickel and zinc. These elements were chosen based on the pattens observed in the samples collected, likely use patterns, and reported toxicity for a number of the elements (e.g., cadmium, chromium and mercury). Detailed data for all the trace and major elements analyzed for this project can be found in Appendix Q and R.

Cadmium. The concentration of cadmium in the sediments and tissues of *P. astreoides* collected in Vieques is shown in Figure 5.16a and b, respectively. The scale on both maps is the same in order to make comparisons of cadmium between sediments and corals easier.

Cadmium in Sediments. The mean concentration of cadmium found in the sediments in Vieques was 0.13 ±0.03 µg/g. Roughly 60 percent of the sediment samples in Vieques contained no detectable cadmium. The mean concentration of cadmium found in the sediments in Vieques can be compared with what has been found nationwide in NOAA's NS&T Program. The mean concentration of cadmium in sediments sampled as part of the NS&T Program for 2006 and 2007 was 0.23 µg/g, somewhat higher than that found in Vieques.

Summary for Cadmium

- *The highest cadmium concentration in the sediments was 1.92 µg/g in Lagoon 8, inland of Bahia Salina del Sur in the former Live Impact Area (LIA).*
- *Concentrations of cadmium were higher in the inland lagoon areas of the island.*
- *The stratum containing the LIA had significantly higher cadmium in the sediments than one of the more western strata.*
- *The concentration of cadmium in the sediments exceeded the threshold Effects Range Low (ERL) and Threshold Effects Level (TEL) values at three sites in Lagoon 8 in the former LIA.*
- *Values around the threshold levels indicate the concentrations at which adverse effects may begin among sensitive life stages or species.*
- *The concentration of cadmium in coral (Porites astreoides) was significantly higher than in sediments.*

The highest concentration of cadmium found in the sediment samples was 1.92 µg/g (Table 5.7) at 28P, an inland lagoon site located on the eastern end of Vieques near Bahia Salina del Sur, in the former LIA. The second highest sediment cadmium concentration (0.813 µg/g) was in the same inland lagoon, at 27P (Figure 5.1). The top five (28P, 27P, 26P, 36P, 31P) detections of cadmium were all inland lagoon sites in or adjacent to the LIA (Figure 5.16a). Seven sediment samples (28P, 27P, 26P, 36P, 31P, 32P, and 23P) collected from Vieques exceeded the NS&T 85th percentile (0.44 µg/g) for cadmium. In southwest Puerto Rico, Pait et al. (2007) detected a mean sediment cadmium concentration of approximately 0.01 µg/g, lower than that found in Vieques. Cadmium is used in a number of applications, including nickel-cadmium (Ni-Cd) batteries. Cadmium pigments are also used in paints and in corrosion control treatments for steel and aluminum products, including those used by the military (Ellor and Stemniski 2007). The somewhat elevated concentrations of cadmium in the LIA could be related to the military activities that have occurred there in the past.

Comparison Between Strata. A series of statistical tests were carried out to see how the concentration of cadmium varied across Vieques, and how the concentration of cadmium varied with sediment grain size. Nonparametric (e.g., Wilcoxon), and then parametric analysis of the ranked values were used in the analysis. The concentration of cadmium was significantly higher in the inland lagoon areas ($p < 0.0001$). This may not be too surprising as cadmium and other trace and major elements tend to accumulate in sediments with smaller (e.g., clay) grain sizes (Manahan 1993). From Appendix C, it can be seen that most of the sediments from the inland lagoon areas contain higher levels of fines (% clay + % silt). A Wilcoxon nonparametric analysis indicated, however, that cadmium in the sediments did not vary ($p = 0.0517$) by stratum (e.g., North 5 versus South 1). A Wilcoxon test run to assess differences in the concentration of cadmium in the north versus the south strata, also indicated no significant difference ($p = 0.0849$). If the north and south strata are combined (e.g., North 1 and South 1) to create five strata moving west to east (Figure 5.7), there was a significant difference in the concentration of cadmium ($p = 0.0278$) between the strata. A pairwise comparison (Tukey HSD) of the ranked

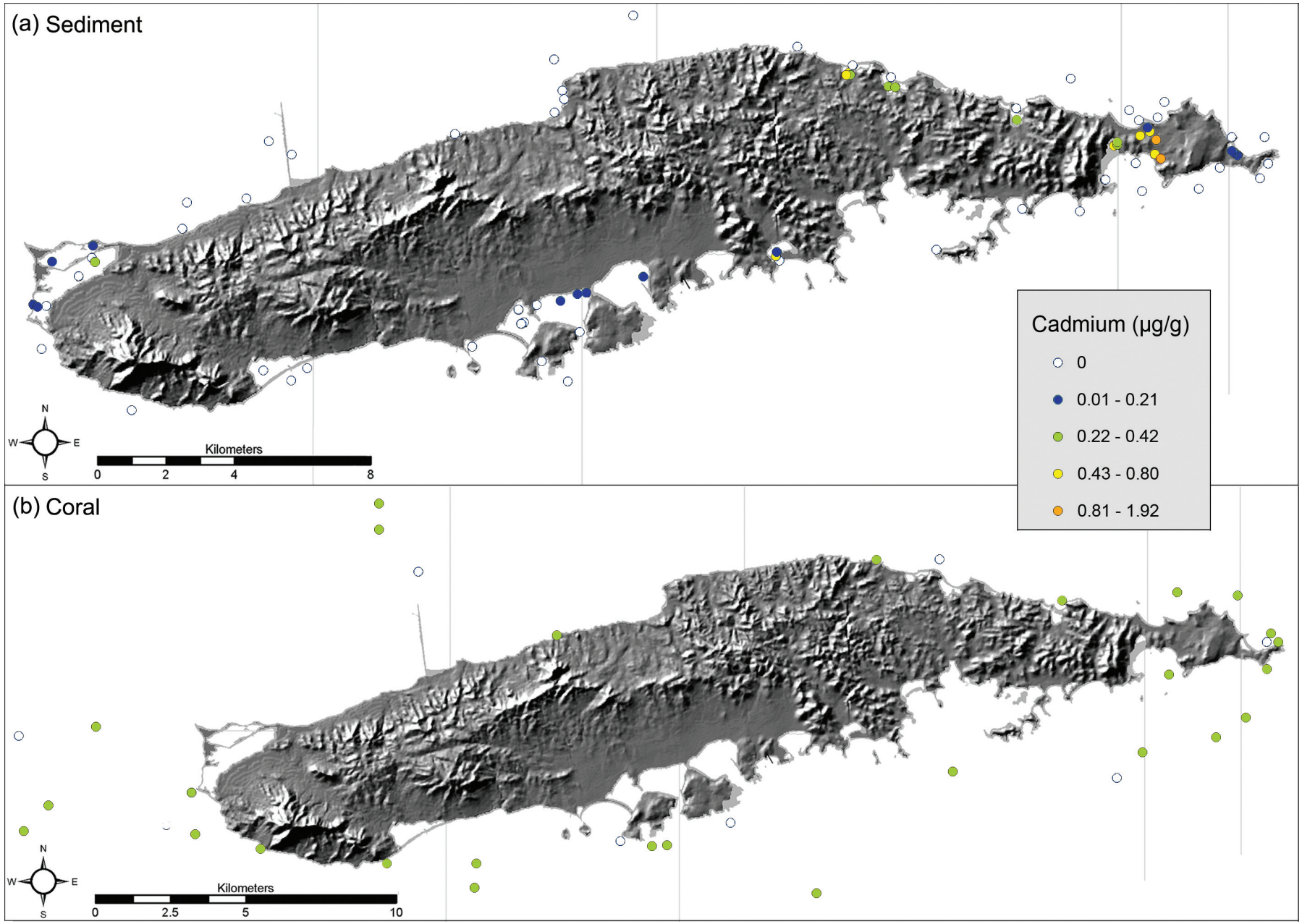


Figure 5.16. Cadmium in sediments (a) and in *Porites astreoides* (b).

values indicated that Stratum 4 (LIA) had significantly higher cadmium concentrations in the sediments than Stratum 2. A nonparametric analysis also indicated that cadmium in the sediment was correlated with the % fines ($p < 0.0001$).

Comparison Among Inland Lagoons. A Wilcoxon test indicated there were significant ($p = 0.0088$) differences in the concentration of cadmium between the nine inland lagoons included in the analysis. An analysis of the ranked data indicated that Lagoon 8 (Laguna Anones) was higher than a number of the other lagoons, particularly those on the west side of Vieques.

Table 5.7. Cadmium (Cd) in Vieques sediments and guidelines.

Vieques Results	Concentration (µg/g)
Vieques sediment Cd minimum	0
Vieques sediment Cd maximum	1.92
Vieques sediment Cd mean	0.15 ± 0.023
Vieques sediment Cd median	0
NOAA NS&T	
Mean	0.13 ± 0.03
Median	0.19
85th Percentile	0.44
Guidelines	
Threshold Effects Limit (TEL)	0.68
Effects Range - Low (ERL)	1.2
Effects Range - Median (ERM)	9.6
Probable Effects Level (PEL)	4.21
Apparent Effects Threshold (AET)	3

Comparison with Sediment Quality Guidelines. Some of the sediment quality guidelines established for cadmium are shown in Table 5.7. The concentration of cadmium at sites 28P, 27P, and 26P exceeded the Threshold Effects Limit or TEL, and 28P also exceeded the Effects Range-Low or ERL. Both the TEL and ERL represent threshold effects concentrations, meaning that concentrations below these values are unlikely to have biological impacts on sediment-inhabiting biota. Values between the ERL and ERM, could indicate that more sensitive species or life stages are beginning to experience some degree of toxic effects. No sediment concentrations, however, were above the PEL or ERM concentrations which would have indicated that effects were likely in sediment-inhabiting organisms.

Cadmium in Corals. The concentration of cadmium detected in the corals is shown in Figure 5.16b. The mean concentration was 0.19 ±0.02 µg/g. The mean concentration in *P. astreoides* was higher than in the sediments (0.15 µg/g), and a Wilcoxon test indicated that this difference was significant ($p = 0.0003$). This was the only trace element found to be higher in coral tissues than in sediments.

Effects of Cadmium on Corals. Cadmium in the aqueous phase has been shown to impact corals, but typically at higher concentrations. Reichelt-Brushett and Harrison (1999) looked at fertilization success in the brain coral *Goniastrea aspera* at concentrations up to 200 µg/L, and in the scroll coral *Oxypora lacera* up to 1,000 µg/L and found no effects. Reichelt-Brushett and Harrison (2005) did find a significant effect in finger coral (*Acropora tenuis*), but at concentrations at or above 5,000 µg/L.

Comparison with Other Work in Vieques. Cadmium has been documented in Vieques by numerous studies (ATSDR 2006; Barton and Porter 2004; Massol-Deya et al. 2005; NOAA and Ridolfi 2006; CH2MHILL 2007). The highest level of cadmium found in the sediments in the current study was below the UTL calculated by CH2MHILL (2007). Cadmium detected by NOAA and Ridolfi (2006) in land crab tissues (*C. guanhumi*) across the island ranged from 0.01 – 0.52 µg/g. CH2MHILL (2002) found no cadmium in the sediments of Laguna Kiani or Laguna Playa Grande. The highest concentration of cadmium observed by Barton and Porter (2004) was in brain coral tissues (*Diploria labyrinthiformis*) (46.8 µg/g) and was adjacent to underwater unexploded ordnance.

Chromium. The concentration of chromium detected in the sediments and in *P. astreoides* from Vieques is shown in Figure 5.17a and b, respectively. The scale is the same on both maps in order to make comparisons between sediments and coral tissues easier.

Chromium in Sediments. The mean concentration of chromium found in the sediments in Vieques was 22.5 ±2.98 µg/g. The NS&T mean for chromium in sediments is 79.7 ±5.33 µg/g (Table 5.8) for the collection year 2006 and 2007, higher than the mean found in the sediments from Vieques. The highest concentration of chromium found in the sediments sampled in Vieques was 178 µg/g at 52N4PX (Figure 5.1), an inland lagoon site (Lagoon 7) located in the eastern end of Vieques near Bahia Icacos on the northern shore, and in the former LIA. The second highest sediment concentration was found in another inland lagoon, at 38P adjacent to the LIA, at a concentration of 85.2 µg/g. Four of the top five (52N4PX, 38P, 36P, 31P, 37P) detections of chromium

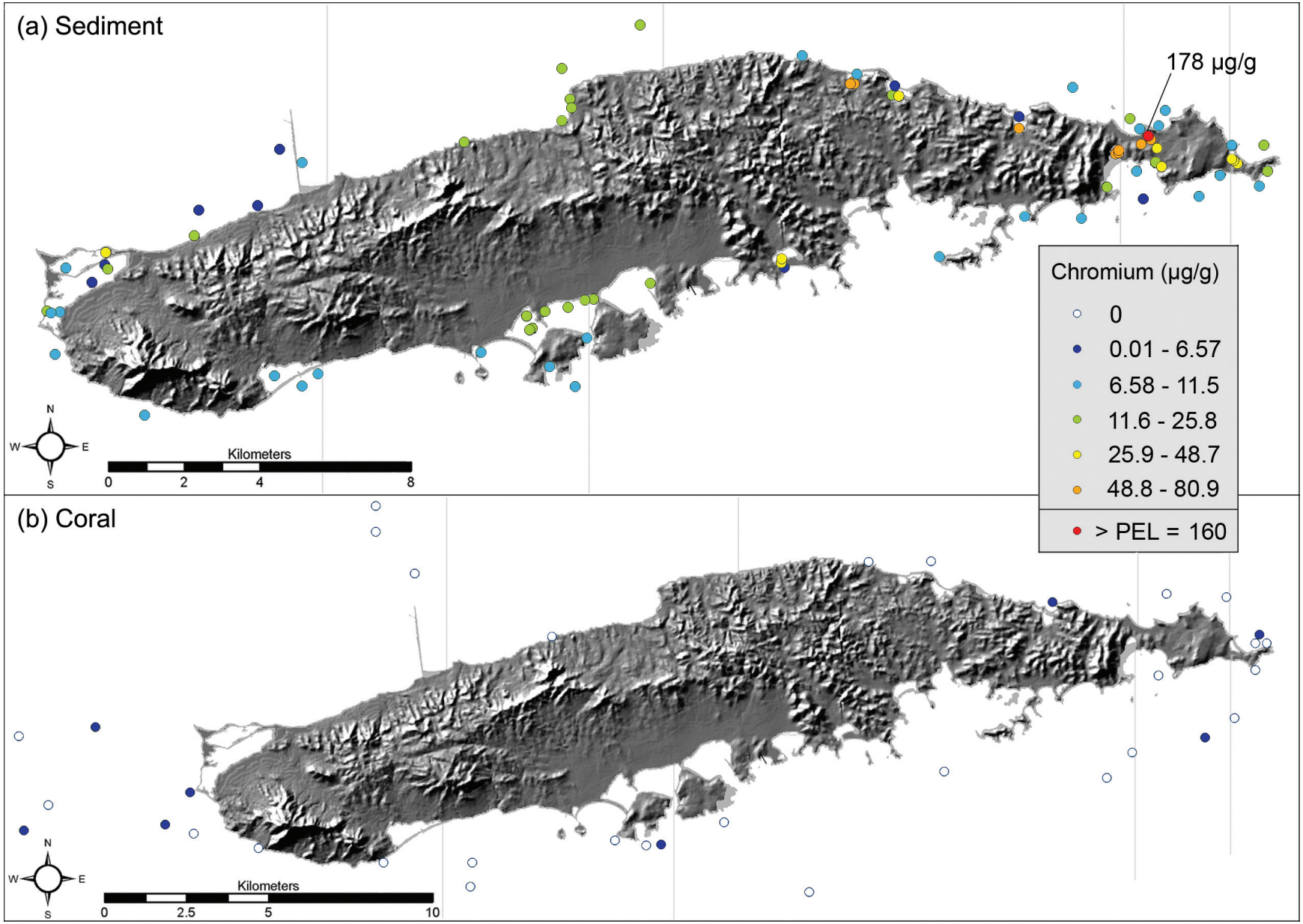


Figure 5.17. Chromium in sediments (a) and in *Porites astreoides* (b).

all occurred in or adjacent to the LIA (Figure 5.17a). The fifth location 22P, was an inland lagoon site on the north shore near Purple Beach (Figure 5.1).

Two sites in Vieques (52N4PX and 38P) exceeded the NS&T mean chromium concentration of 79.7 µg/g. The NS&T 85th percentile for chromium is 116 µg/g, and the only site sampled in Vieques to exceed this value was 52N4PX. Chromium is used to harden steel, is a component in a number of alloys, has widespread use in chrome plating, and has been a key metal used by the military and the aerospace industry in order to prevent corrosion and resist wear. Pait et al. (2007) detected a mean chromium concentration in the sediments in southwest Puerto Rico of approximately 31 µg/g, which included two sites within Guanica Bay that had fairly high (394 and 440 µg/g) chromium sediment values. If these two sites are removed in the calculation for southwest Puerto Rico, the mean is approximately 12 µg/g.

Summary for Chromium

- *The highest chromium concentration in the sediments was 178 µg/g and was found in Lagoon 7 in the former LIA.*
- *Concentrations of chromium were higher in the inland lagoon areas of the island.*
- *Sites in the northern half of Vieques had significantly higher chromium levels than those in the southern half of Vieques.*
- *The concentration of chromium in the sediments exceeded the ERL, TEL or AET threshold values at 11 sites. The threshold values indicate levels above which impacts may begin among sensitive life stages or species.*
- *The concentration of chromium in the sediments exceeded the Probable Effects Level or PEL at one site in Lagoon 7.*
- *The concentration of chromium in coral (Porites astreoides) was over two orders of magnitude lower than in sediments.*

Comparison Between Strata. A series of statistical tests were carried out to see how the concentration of chromium varied in the sediments across Vieques and if grain size was correlated with this trace element. As with cadmium, the concentration of chromium in the sediments was significantly higher in the inland lagoon areas ($p < 0.0001$). The inland lagoon sediments have a higher mean proportion (73%) of the finer grain sizes (silt and clays) compared with the nonlagoon sites (14%). As noted, metals are attracted to smaller grain sizes due to surface area and clay particle charge characteristics. A Wilcoxon nonparametric analysis indicated that chromium in the sediments did not vary ($p = 0.0591$) by stratum. A Wilcoxon test run to assess the differences in the concentration of chromium in the north versus the south strata, however, indicated a significant difference ($p = 0.0120$), with sites in the northern strata having higher concentrations of chromium. When the north and south strata were combined to make five strata in a west to east direction (Figure 5.7), a Wilcoxon test indicated no significant difference ($p = 0.0529$). Finally, a Spearman's ρ correlation coefficient was calculated to look at the association between chromium and % fines (clay + silt). The concentration of chromium was significantly correlated with the % fines ($p < 0.0001$).

Comparison Among Inland Lagoons. A nonparametric assessment of the nine inland lagoons indicated a significant difference ($p = 0.0041$) in the concentration of chromium in the sediments sampled. Pairwise comparisons of the ranked data indicated that Lagoon 6 and 7 adjacent to the LIA were significantly different (higher) from a number of the other lagoons (e.g., 1, 2, 3, 5, and 8).

Table 5.8. Chromium (Cr) in Vieques sediments and guidelines.

Vieques Results	Concentration (µg/g)
Vieques sediment Cr minimum	0
Vieques sediment Cr maximum	178
Vieques sediment Cr mean	22.5 ± 2.98
Vieques sediment Cr median	12.7
NOAA NS&T	
Mean	79.7 ±5.33
Median	66
85th Percentile	116.1
Guidelines	
Threshold Effects Limit (TEL)	52.3
Effects Range - Low (ERL)	81
Effects Range - Median (ERM)	370
Probable Effects Level (PEL)	160
Apparent Effects Threshold (AET)	62

Comparison with Sediment Quality Guidelines. A number of the sediment quality guidelines that have been established for chromium are shown in Table 5.8. There were eleven sites that exceeded the ERL, TEL or the AET. All three of these guidelines are threshold values below which effects are not expected

in benthic infaunal organisms. Concentrations between the ERL and ERM indicate that toxic effects could begin to appear in more sensitive species or life stages. Concentrations above the PEL or the ERM, however, indicate that effects are likely. The PEL is the geometric mean of the 50th percentile of the effects data and the 85th percentile of the no effects data used by MacDonald et al. (1996). The ERM is the 50th percentile concentration of the effects data used by Long et al. (1998). No sediments analyzed in this study exceeded the ERM for chromium. However, one sediment sample (52N4PX) exceeded the chromium PEL of 160 µg/g, indicating that this concentration was more likely to be impacting benthic infauna at this site.

Chromium in Corals. The concentration of chromium detected in the corals is shown in Figure 5.17b. The mean concentration was 0.18 ±0.06 µg/g, substantially below the mean sediment concentration of 22.5 µg/g (Table 5.6). Pait et al. (in press) did not detect chromium in any of the *P. astreoides* samples collected in southwest Puerto Rico, even though this trace element was found in all of the sediment samples. Additional work is needed to assess the relationship between chromium in sediments and uptake in corals. Also, no information was located on the effects of chromium in coral. This type of information would be useful not only for this study, but in other coral reef areas as well.

Comparison with Other Work in Vieques. Chromium has been documented in Vieques in other studies (ATSDR 2006; Barton and Porter 2004; CH2MHILL 2002; Massol-Deya et al. 2005; NOAA and Ridolfi 2006; CH2MHILL 2007). The chromium mean (22.5 µg/g) was below the threshold UTL range (70-72 µg/g) developed by CH2MHILL (2007), however, the chromium concentration at 52N4PX was above the UTL. Chromium observed by NOAA and Ridolfi (2006) in land crab (*C. guanhumi*) tissues across the island ranged from 1.15 – 5.71 µg/g. Barton and Porter (2004) observed chromium concentrations of 6.43 µg/g and 34.2 µg/g respectively in marine sediments adjacent to the scuttled *USS Killen* and inside a 55 gallon drum also adjacent to the scuttled ship. Neither of these concentrations exceed the sediment threshold guidelines in Table 5.8. The highest concentration of chromium detected was 182.6 µg/g by Massol-Deya et al. (2005) in plant organic material from the former LIA. This is similar to the highest observed sediment concentration (178 µg/g at 52N4PX) in the current study.

Copper. The concentration of copper quantified in the sediments and in coral tissues collected from Vieques is shown in Figure 5.18a and b, respectively.

Copper in Sediments. The mean concentration of copper found in the sediments was 25.9 ±3.15 µg/g (Table 5.9). The NS&T mean for sediment copper is 22.7 ±2.4 µg/g for the collection year 2006 and 2007, similar to the mean copper concentration found in the Vieques sediments.

Summary for Copper

- *The highest copper concentration in the sediments was 103 µg/g and was found in Lagoon 6, adjacent to the former LIA.*
- *Concentrations of copper were higher in the inland lagoon areas of the island.*
- *There were no differences in the concentration of copper in sediments between any of the strata.*
- *The concentration of copper in the sediments exceeded the threshold effects level (TEL) at 37 sites, and 28 sites where the ERL was exceeded. The threshold values indicate levels above which impacts may begin among more sensitive life stages or species.*
- *The mean concentration of copper in coral (Porites astreoides) was over an order of magnitude lower than in sediments.*

The highest concentration of copper found in the sediments in Vieques was 103 µg/g at 37P (Figure 5.1), an inland lagoon site located in the eastern end of Vieques near Bahia Salina del Sur on the southern shore, and adjacent to the former LIA. The second highest sediment concentration of copper (97.4 µg/g) was found in the same inland lagoon. The 10 highest concentrations of copper (Figure 5.18a and Appendix Q) were all located in inland lagoons, and were in either the former LIA or the Secondary Impact Area (SIA).

A total of 34 sediment samples taken in Vieques were above the NS&T Program mean for copper. Twenty-five sites were above the NS&T 85th percentile for copper of 38.3 µg/g. Twenty-one of these sites were in areas formerly controlled by the Navy. Four sites were in civilian areas. Copper has many applications including its 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 in this way in Vieques. Copper has also been used by the military in ordnance and in ammunition. The concentration of copper in the sediments collected from

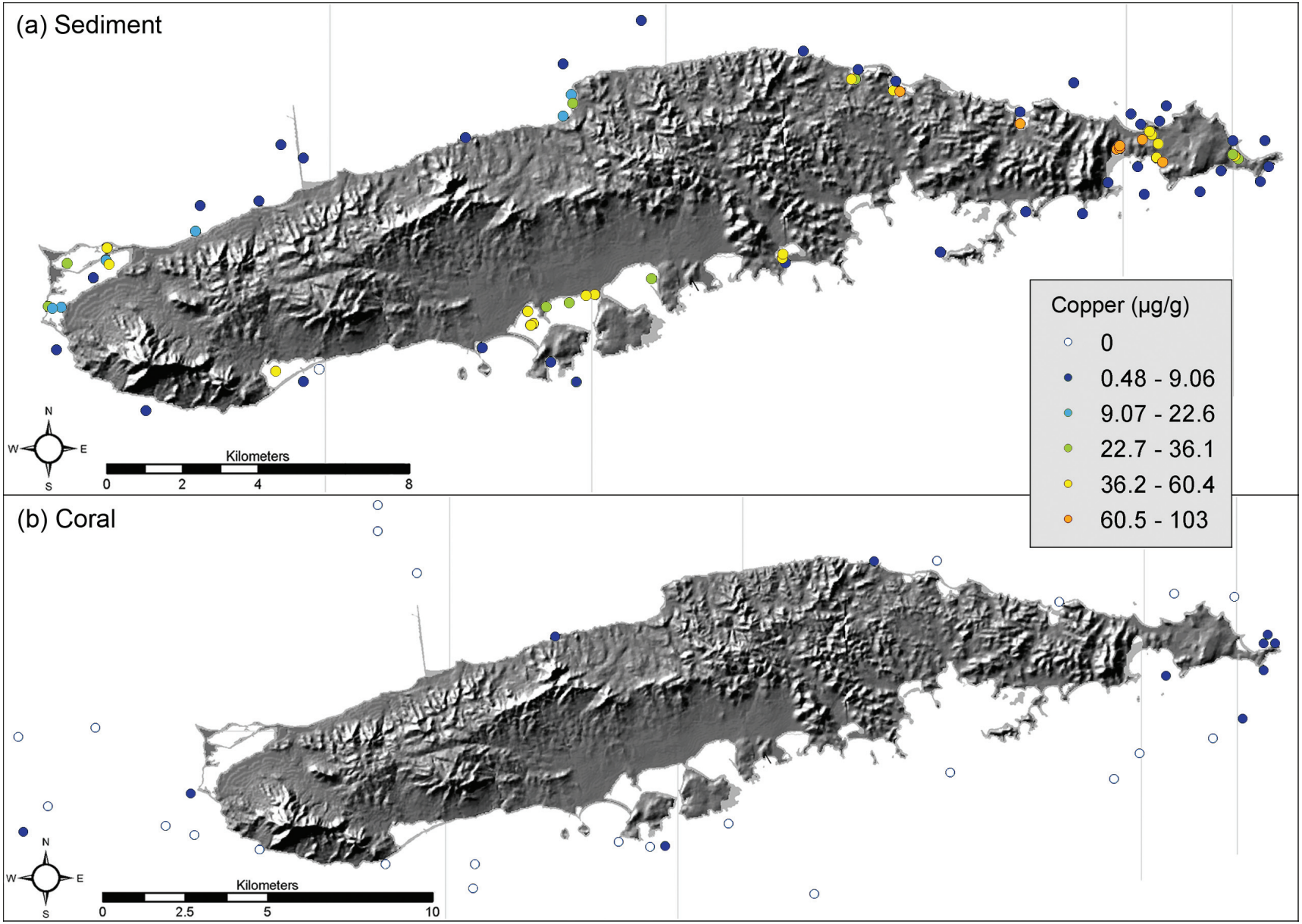


Figure 5.18. Copper in sediments (a) and in *Porites astreoides* (b).

Vieques can be compared with recent work in southwest Puerto Rico. Pait et al. (2007) found a mean copper concentration in the sediments of 5.21 µg/g, somewhat lower than the copper mean found in the sediments of Vieques.

Comparisons Between Strata. Nonparametric statistical tests (e.g., Wilcoxon) were used to assess how copper varied across the sites sampled in Vieques, and the relationship of copper to sediment grain size. As with the other trace elements, the concentration of copper in the sediments was significantly higher in the inland lagoon areas ($p < 0.0001$), which have a higher proportion of fine grained sediments than the nonlagoon areas. However, a Wilcoxon nonparametric analysis indicated that copper in the sediments did not vary ($p = 0.5260$) by stratum. Likewise, a Wilcoxon test run to assess the differences in the concentration of copper in the north versus the south strata, indicated no significant difference ($p = 0.7758$). Learned et al. (1973) noted anomalous concentrations of certain metallic elements including copper along the north coast of the island due to geologic processes, but those differences were not reflected statistically in the current study. In addition, a Wilcoxon test indicated no significant difference ($p = 0.2993$) in the concentration of copper in the sediments when the strata were combined to make a series of five strata in a west to east direction (Figure 5.7). A Spearman's ρ correlation coefficient did indicate that copper was significantly correlated with the % fines ($p < 0.0001$).

Comparison Among Inland Lagoons. A Wilcoxon nonparametric test indicated a significant difference ($p = 0.0192$) in the concentration of copper between the nine inland lagoons. A pairwise comparison (Tukey HSD) of the ranked data indicated that Lagoon 6 (Figure 5.7), located adjacent to the LIA had significantly higher copper concentrations than Lagoons 1, 2, and 9.

Comparison with Sediment Quality Guidelines. A number of sediment quality guidelines have been established for copper and are shown in Table 5.9. There were 37 sites that exceeded the TEL, and 28 sites that exceeded the ERL. There were no sites, however, where the sediment concentration exceeded the PEL, ERM, or AET. However, a copper concentration of 103 µg/g at 37P was just below the copper PEL.

Table 5.9. Copper (Cu) in Vieques sediments and guidelines.

Vieques Results	Concentration (µg/g)
Vieques sediment Cu minimum	0
Vieques sediment Cu maximum	103
Vieques sediment Cu mean	25.9 ± 3.15
Vieques sediment Cu median	12.2
NOAA NS&T	
Mean	22.7 ±2.4
Median	16
85th Percentile	38.3
Guidelines	
Threshold Effects Limit (TEL)	18.7
Effects Range - Low (ERL)	34
Effects Range - Median (ERM)	270
Probable Effects Level (PEL)	108
Apparent Effects Threshold (AET)	390

Copper in Corals. The concentration of copper found in the tissues of *P. astreoides* is shown in Figure 5.18b. The mean concentration was 0.76 ±0.26 µg/g, again substantially below the mean sediment concentration (Table 5.9). This lower detection of copper in the coral tissues can also be seen in Figure 5.18b. The highest copper concentration found in *P. astreoides* (6.5 µg/g) was at 5NEX1 (Figure 5.2) adjacent to the Eastern Conservation Area.

Effects of Copper on Corals. Copper is the trace element most commonly used in toxicity tests in corals. A number of studies have investigated the effects of this trace element on coral fertilization and development. Victor and Richmond (2005) found that a copper concentration of 10 µg/L and greater significantly affected fertilization in the reef building coral *Acropora surculosa* in the laboratory after five hours. They also found that embryo development was affected when gametes were exposed to copper at a concentration of 12 µg/L. At concentrations of 58 µg/L and higher, no embryo development was observed. Reichelt-Brushett and Michalek-Wagner (2005) investigated the effects of copper on the soft coral *Lobophytum compactum*. A significant difference in fertilization success was found at copper concentrations of 117 µg/L and above. Goh and Chou (1997) found that a copper concentration of 40 µg/L in the zooxanthellae *Symbiodinium microadriaticum*, isolated from the rice coral *Montipora verrucosa* inhibited growth in the symbiotic dinoflagellate. Goh and Chou (1997) also noted a synergistic effect when the zooxanthellae were exposed to both copper and zinc.

It should be understood that the concentrations of contaminants found in sediments cannot be directly compared with aqueous concentrations found to affect corals. The corresponding concentration of copper and many other contaminants in the water column is different, typically much less than the adjacent sediment con-

centration, however, these results indicate that when present in the aqueous phase at relatively low concentrations, copper can impact fertilization and development in corals.

Comparison with Other Work in Vieques. Copper has been documented in Vieques by numerous studies (ATSDR 2006; CH2MHILL 2002; Massol-Deya et al. 2005; NOAA and Ridolfi 2006; CH2MHILL 2007). CH2MHILL calculated a UTL for copper between 53 and 94 µg/g which is above the mean copper concentration found in the current study. The highest concentration of copper found in the sediments in the current study (103 µg/g), however, was above the UTL range. Copper observed by NOAA and Ridolfi (2006) in land crab tissues (*C. guanhumi*) across the island ranged from 26 – 179 µg/g. The highest concentration of copper was 203 µg/g, observed by ATSDR (2006) in fiddler crab tissues (*Uca sp.*) collected west of Laguna Kiani. ATSDR also found copper in fiddler crab tissue in the former LIA at a concentration of 180 µg/g. Both of these concentrations were higher than the copper detected in the sediments in this study. Comparison of data from different sources (i.e., crab tissue vs. sediments) can describe possible bioaccumulation effects as well as possible contamination in a different matrix.

Summary for Lead

- *The highest concentration of lead in the sediments was 17.6 µg/g at a site adjacent to the town of Isabel Segunda.*
- *Concentrations of lead were higher in the inland lagoon areas of the island.*
- *There was a difference in the concentration of lead in the sediments by strata, however, pairwise comparisons of the data failed to indicate differences between individual strata (e.g., North 5 versus South 1).*
- *None of the sediment lead concentrations exceeded any of the guidelines examined.*
- *The mean concentration of lead in coral (Porites astreoides) was nearly two orders of magnitude lower than in sediments.*

Lead. The concentration of lead in the sediments and in coral tissues collected in Vieques is shown in Figure 5.19 a and b, respectively.

Lead in Sediments. The mean concentration of lead found in the sediments in Vieques was 5.42 ±0.55 µg/g. The higher concentrations of lead appeared in a number of locations on the island, including sites within civilian areas, and sites within the former VNTR and NASD. The mean concentration of lead found in the sediments in Vieques can be compared with the rest of the Nation's coastal areas as sampled by the NS&T Program (Table 5.10). The NS&T mean for lead in sediments is 26.1 ±1.8 µg/g for the collection year 2006 and 2007, higher than the mean lead concentration found in the Vieques sediments.

Table 5.10. Lead (Pb) in Vieques sediments and guidelines.

Vieques Results	Concentration (µg/g)
Vieques sediment Pb minimum	0
Vieques sediment Pb maximum	17.6
Vieques sediment Pb mean	5.42 ± 0.55
Vieques sediment Pb median	1.29
NOAA NS&T	
Mean	26.1 ± 1.81
Median	22.3
85th Percentile	39.1
Guidelines	
Threshold Effects Limit (TEL)	30.24
Effects Range - Low (ERL)	46.7
Effects Range - Median (ERM)	218
Probable Effects Level (PEL)	112
Apparent Effects Threshold (AET)	400

The highest concentration of lead quantified in the sediments from Vieques was 17.6 µg/g at 16N2P, a site adjacent to the town of Isabel Segunda (Figure 5.1). The second highest lead sediment concentration (16.4 µg/g) was found at 45N3A, in Laguna Monte Largo. The NS&T 85th percentile for lead (39.1 µg/g) was more than two times greater than the highest lead concentration found in the sediments in Vieques.

Lead has many applications including lead-acid storage batteries, solder, bearings, electronics, various paints and primers, and in ammunition. Tetraethyl lead was used in the past as an anti-knock compound in gasoline. Pait et al. (2007) found a mean lead concentration in the sediments in southwest Puerto Rico of 1.93 µg/g, somewhat lower than the lead mean found in the sediments of Vieques.

Comparisons Between Strata. The nonparametric Wilcoxon test was used to assess how lead varied across the sites sampled in Vieques. The concentration of lead in the sediments was significantly higher in the inland

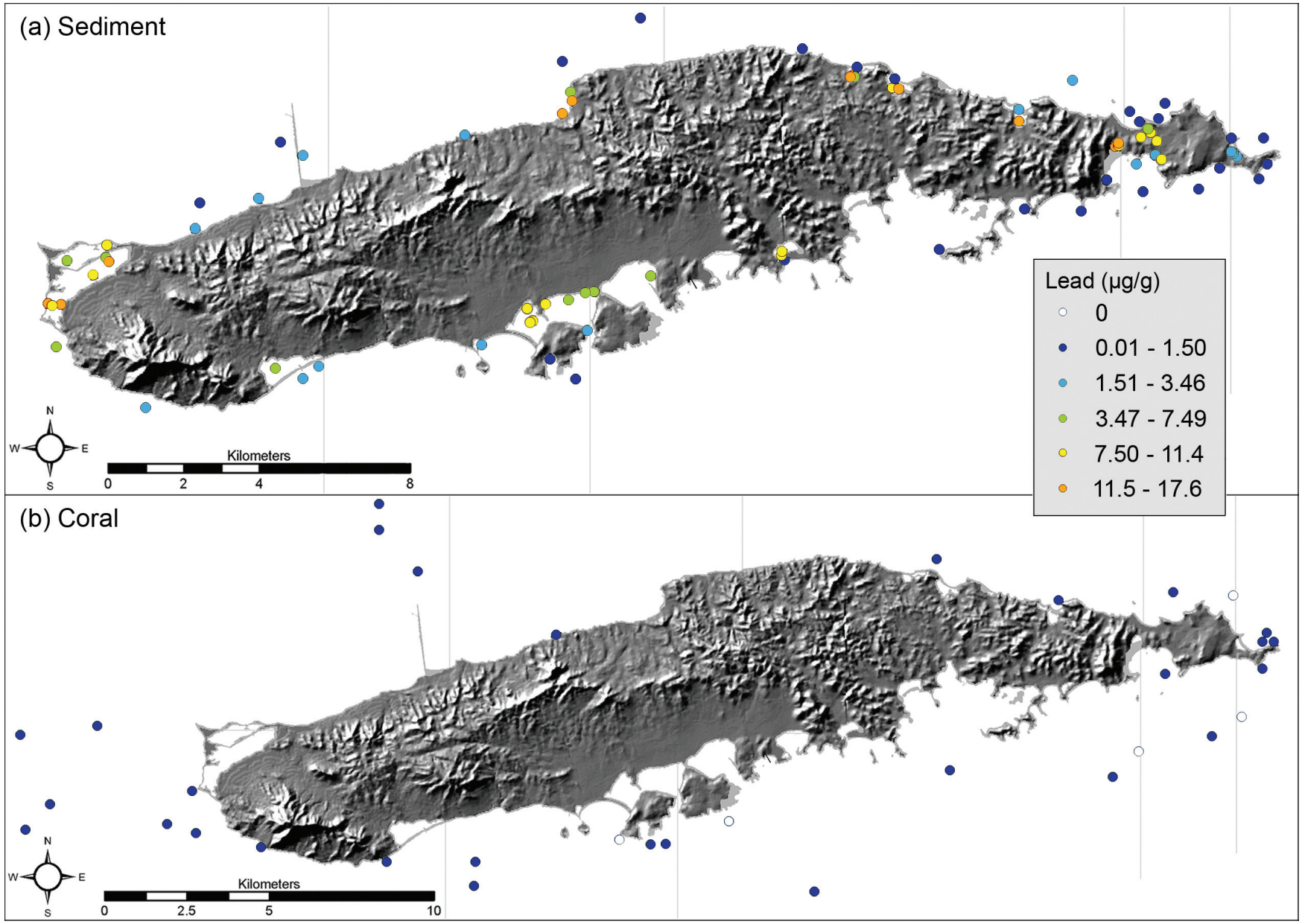


Figure 5.19. Lead in sediments (a) and in *Porites astreoides* (b).

lagoon areas ($p < 0.0001$), which have a higher proportion of fine grained sediments. Lead in the sediments also varied significantly ($p = 0.0465$) by stratum. A pairwise comparison of the ranked values, however, was not able to reveal any significant differences between individual strata. A Wilcoxon test run to assess the differences in the concentration of lead in the north versus the south strata indicated no significant difference ($p = 0.7989$). A Wilcoxon test indicated a significant difference ($p = 0.0496$) in the concentration of lead in the sediments when the strata were combined to make a series of five strata in a west to east direction (Figure 5.7). A pairwise comparison of the ranked data, however, did not reveal any significant differences. Finally, Spearman's ρ correlation coefficients were calculated to look at the association between lead and the % fines (clay + silt). The concentration of lead was significantly correlated with the % fines ($p < 0.0001$), indicating this trace element is associated with sediments containing higher levels of fine grained materials, including clays.

Comparison Among Inland Lagoons. A Wilcoxon nonparametric test indicated no significant difference ($p = 0.0754$) in the concentration of lead between the nine inland lagoons where the sampling strategy for the project enabled a comparison.

Comparison with Sediment Quality Guidelines. Some of the sediment quality guidelines that have been established for lead are shown in Table 5.10. None of the lead concentrations in the sediment samples from Vieques exceeded any of the guidelines examined.

Lead in Corals. The concentrations of lead found in the tissues of *P. astreoides* is shown in Figure 5.19b. The mean concentration was 0.07 ±0.01 µg/g, substantially below the mean sediment concentration (Table 5.10). The lower mean concentration of lead in coral tissues compared to the sediments can be seen in Figure 5.19 as well. The highest lead concentration found in *P. astreoides* (0.174 µg/g) was at 3N05 (Figure 5.2) near Punta Brigadier.

Effects of Lead on Corals. Reichelt-Brushett and Harrison (2005) looked at the effects of lead on a number of species of coral. The authors found that a lead concentration of 1,982 µg/L or above resulted in significantly reduced fertilization success in the finger coral *Acropora tennuis*. In *Acropora longicyathus*, lead concentrations of 855 µg/L or higher resulted in significantly reduced fertilization success.

Comparison with Other Work in Vieques. Lead has been documented in Vieques by a number of studies (ATSDR 2006; Barton and Porter 2004; CH2MHILL 2002; Massol-Deya et al. 2005; NOAA and Ridolfi 2006; CH2MHILL 2007). The UTL range for lead developed by CH2MHILL (2007) was 5.4 - 16 µg/g, and the mean lead concentration found in the sediments in the current study is at the low end of this range. Lead quantified by NOAA and Ridolfi (2006) in land crab tissues (*C. guanhumi*) across the island ranged from 0.02 – 2.55 µg/g, lower than the highest observed lead concentration in the current study. The highest concentration of lead observed in any matrix in Vieques (195 µg/g) was by Barton and Porter (2004) in brain coral tissues (*Diploria labyrinthiformis*) adjacent to underwater unexploded ordnance.

Other Trace and Major Elements in Sediments. A number of other trace and major elements were analyzed as part of the project in Vieques. Some of the results for sediments are briefly summarized below. With the exception of higher concentrations from inland lagoon sediments, few spatial differences were apparent. Aluminum, manganese, nickel and zinc were occasionally found at concentrations above threshold (e.g., AET and ERL) values.

Aluminum. The highest concentration of aluminum found in the sediments sampled in Vieques (118,000 µg/g) was from 45N3A, located in Laguna Monte Largo on the northern coast within the former VNTR. The mean concentration of aluminum in the sediments in Vieques (35,530 ±3,530 µg/g), was close to the UTL developed by CH2MHILL (2007), and below the NS&T mean aluminum value of 56,000 µg/g. As noted earlier, aluminum is a major crustal element, and so it is not surprising that concentrations are higher than a number of the other elements analyzed as part of this project. A Wilcoxon test indicated that aluminum was higher in the inland lagoon areas ($p < 0.0001$), but that the concentration of this major element was not significantly different between strata ($p = 0.0754$). There was also no significant difference in the concentration of aluminum in the north versus the south strata. When the strata were combined to create five west to east strata (Figure 5.7), a Wilcoxon test indicated a significant difference ($p = 0.0299$). Although the mean aluminum concentration in Stratum 3 was numerically higher, a pairwise comparison of the ranked values using a Tukey HSD test failed to reveal any significant differences for individual strata. An AET sediment guideline of 1.8% has been established for aluminum. The highest concentration of aluminum found in the sediments in Vieques was approximately 12%.

Arsenic. The mean concentration of arsenic in the sediments (4.37 ±0.33 µg/g) was below the NS&T mean value of 8.90 µg/g. The highest concentration of arsenic in the sediment samples from Vieques (15.4 µg/g) was from 27P in Lagoon 8 (Laguna Anones), located in the former LIA. A Wilcoxon test indicated that arsenic, however, was not higher in the inland lagoon areas ($p = 0.6003$), and that the concentration of arsenic was not significantly different between strata ($p = 0.1532$). There was also no significant difference in the concentration of arsenic in the north versus the south strata ($p = 0.1445$). When the strata were combined to create five west to east strata, a Wilcoxon test indicated no significant difference ($p = 0.2926$). The highest concentration of arsenic was below all the sediment quality guidelines examined.

Iron. Observations during visits to the former LIA revealed what appeared to be a significant amount of iron-containing fragments in the area. As a result, an analysis of data for this major element was carried out. The mean concentration of iron in the sediments for Vieques (17,610 ±1,920 µg/g), was below the NS&T mean value for iron of 24,600 µg/g. The highest concentration of iron in the sediments from Vieques (50,700 µg/g) was from 31N3P in Laguna Puerto Diablo. A Wilcoxon test indicated that iron was higher in the inland lagoon areas ($p < 0.0001$), but that the concentration was not significantly different between strata ($p = 0.4338$). There was also no significant difference in the concentration of iron in the north versus the south strata ($p = 0.5929$). When the strata were combined to create five strata in a west to east direction, a Wilcoxon test indicated no significant difference ($p = 0.3051$). An AET sediment guideline of 22% has been established for iron. The highest concentration of iron found in the sediments in Vieques was approximately 5%.

Manganese. The mean concentration of manganese in the sediments (301 ±31.8 µg/g), was below the NS&T mean manganese value of 608 µg/g. The highest concentration of manganese found in the sediments from Vieques (967 µg/g) was from 23P in Lagoon 4 (Laguna Algodones), located just west of Punta Brigadier. A Wilcoxon test indicated that manganese was higher in the inland lagoon areas ($p < 0.0001$), but that the concentration of manganese was not significantly different between strata ($p = 0.3695$). There was also no significant difference in the concentration of manganese in the north versus the south strata ($p = 0.3738$). When the strata were combined to create five west to east strata, a Wilcoxon test indicated no significant difference ($p = 0.5707$). The highest concentration of manganese in the sediments in Vieques was above the AET value of 260 µg/g.

Mercury. The mean concentration of mercury in the sediments (0.019 ±0.003 µg/g), was below the NS&T mean mercury value of 0.10 µg/g. The highest level of mercury (total) found in the sediments from Vieques (0.112 µg/g) was from 70S1P in Lagoon 1 (Laguna Boca Quebrada), located on the western end of Vieques. A Wilcoxon test indicated that mercury was higher in the inland lagoon areas ($p < 0.0001$), but that the concentration of mercury was not significantly different between strata ($p = 0.2797$). There was also no significant difference in the concentration of mercury in the north versus the south strata ($p = 0.3781$) or when the strata were combined to form five west to east strata ($p = 0.3545$). The highest concentration of mercury found in the sediments was less than the sediment quality guidelines examined.

Nickel. The mean concentration of nickel in the sediments (7.80 ±1.07 µg/g) was below the NS&T mean nickel value of 33 µg/g. The highest concentration of nickel (38.3 µg/g) was found at 52N4PX in Lagoon 7, located in the former LIA. A Wilcoxon test indicated that nickel was higher in the inland lagoon areas ($p < 0.0001$), but that the concentration of nickel was not significantly different between strata ($p = 0.2270$). There was also no significant difference in the concentration of nickel in the north versus the south strata ($p = 0.1790$), or when the strata were combined to form five west to east strata ($p = 0.5006$). The highest concentration of nickel found in the sediments was above the TEL (15.9 µg/g) and ERL (20.9 µg/g) threshold values.

Zinc. The mean concentration of zinc in the sediments (34.4 ±3.91 µg/g), was below the NS&T mean zinc value of 91 µg/g. The highest zinc concentration quantified in the sediments sampled in Vieques (130 µg/g) was from 36P in Lagoon 6 located in the area directly adjacent to the former LIA. As with a number of the other elements, A Wilcoxon test indicated that zinc was higher in the inland lagoon areas ($p < 0.0001$), however, the concentration of zinc was not significantly different between strata ($p = 0.2821$). There was also no significant difference in the north versus the south strata ($p = 0.4328$), or in the concentration of zinc when the strata were combined to form five west to east strata ($p = 0.2720$). The highest concentration of zinc found in the sediments was slightly above the threshold TEL (124 µg/g) value.

Radioactivity

At each inland lagoon site, two measurements of radioactivity were made. The first reading was made upon arrival at the site. The second reading was made of the sediment sample taken at the site. The results of the readings are included in Appendix S. The highest value recorded was 0.041 mR/hr at 02P; most of the readings ranged from 0 to 0.02 mR/hr. Background radiation at ground level is considered to be 0.021 mR/hr, and the upper limit for non-occupational exposure (including exposure of minors) is 0.063 mR/hr (CFR 2009). All inland lagoon sites and sediment samples were within the established background levels for radiation, or below the limit for non-occupational exposure.

Clostridium perfringens

This anaerobic, gram-positive staining rod-shaped bacteria frequently occurs in the intestines of humans as well as in domestic and wild animals. The results of the analysis of sediments for *C. perfringens* are shown in Appendix T. 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 highest concentration of *C. perfringens* (2,196 CFU/g) was found in 104S3P, an inland lagoon site adjacent to Bahia Mosquito. The second highest concentration was found at 46P also an inland lagoon site, adjacent to Blue Beach in the former Eastern Maneuver Area (Figure 5.1). Eight of the top 10 detections of *C. perfringens* occurred in inland lagoon areas. Sources of the elevated levels of *C. perfringens* include fecal material from humans, and from other animals including dogs, along with horses and cattle. Nonparametric analysis revealed that *C. perfringens* counts were higher in the inland lagoon areas than in nonlagoon areas ($p = 0.0131$). No other significant spatial differences were found. No health guidelines were located for *C. perfringens* in sediments. *C. perfringens* is a common cause of foodborne illnesses. A more severe form of the disease is often fatal and results from ingesting large numbers of the active bacteria. *C. perfringens* also has the capability of forming spores which can persist in soils and sediments.

Image 5.5. Rocky outcropping near a sampling site in the southern portion of the VNTR.

5.5 SUMMARY AND CONCLUSIONS

For this component of the Vieques ecosystem characterization, a total of 78 sediments and 35 coral (*Porites astreoides*) samples were collected in May and October 2007 using a stratified random sampling design. The island was divided into five north and five south strata. All samples were analyzed using protocols established by NOAA's National Status and Trends (NS&T) Program. Sediment samples were collected in waters from around the island, and also from a number of inland lagoons. Sediment and coral samples were analyzed for a suite of chemical contaminants including 58 polycyclic aromatic hydrocarbons (PAHs), 31 organochlorine pesticides, 38 polychlorinated biphenyls (PCBs), four butyltins, and 16 trace and major elements. The sediments were also analyzed for a suite of 15 energetics (explosives) and related compounds.

Overall, the concentrations of chemical contaminants found in the sediments and coral (*Porites astreoides*) tissues sampled from Vieques were low. Most sediment samples had contaminant concentrations below established effects guidelines. Contaminant concentrations in sediments from the inland lagoon areas were higher than in nonlagoon areas.

The sediment samples collected were also analyzed for a series of 15 energetics and related compounds. The initial analysis of the samples using EPA Method 8330, indicated possible detections at 14 sites. Subsequent reanalysis of the samples by EPA Method 8330 followed by LC/MS/MS (liquid chromatography/mass spectrometry/mass spectrometry) to confirm the presence and concentration of energetics in the 14 samples, however, revealed that none had detectable concentrations of the energetics analyzed.

As part of the data analysis, a series of statistical tests were run to assess how contaminants varied across the sites sampled on Vieques. Included were analyses to assess how the concentration of contaminants varied by strata, and comparisons between lagoon versus non-inland lagoon areas, north versus south strata, and when the north and south strata were combined, how the concentration of contaminants varied from west to east across the island in terms of former and current land use. The west to east strata corresponded to the Naval Ammunition Support Detachment (NASD) (1), the Civilian Area (2), the Eastern Maneuver Area/Secondary Impact Area (3), Live Impact Area (4), and the Eastern Conservation Area (5).

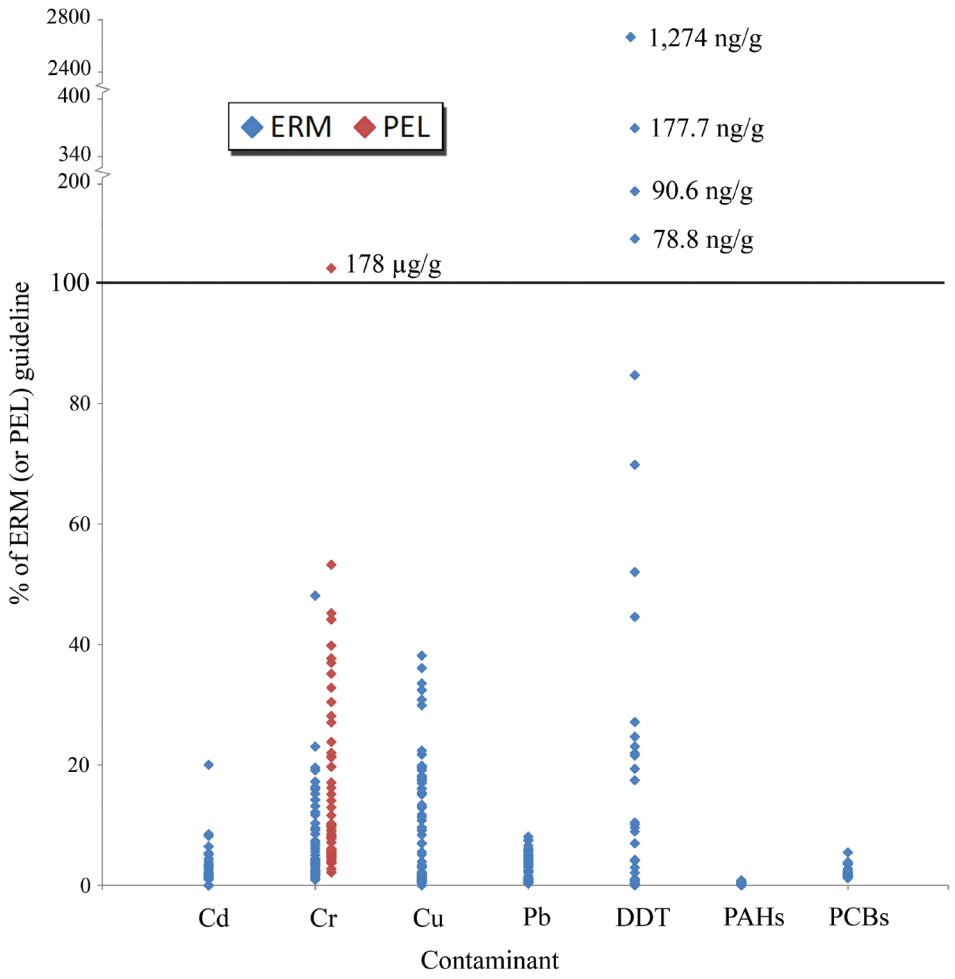


Figure 5.20. Summary of contaminants as a percent of the ERM (or the PEL) in sediments from Vieques.

There were only a few indications that concentrations of the sediment contaminants measured at some sites were likely to be toxic to sediment-inhabiting organisms. Only two contaminants in sediments appeared to be above concentrations that would indicate likely impacts to sediment-inhabiting organisms: total DDT and chromium. Using the NOAA Effects-Range Median (ERM) guideline (Figure 5.20), there were four sites that were above the DDT concentration that would indicate that toxicity to sediment-dwelling organisms was likely. The highest concentration of total DDT (1,274 ng/g) was found in a sediment sample taken from an inland lagoon site adjacent to Blue Beach, and was over an order of magnitude higher than the NOAA ERM guideline (46.1 ng/g) for total DDT. There were three other sediment samples above the ERM. Chromium exceeded (Figure 5.20) the Probable Effects Level (PEL) of 160 µg/g at an inland lagoon site located on the eastern end of Vieques near Bahia Icacos on the northern shore, in the former LIA. The concentration of chromium in the sediment sample was 178 µg/g, higher than the PEL, but below the NOAA ERM value of 370 µg/g.

Total DDT and lead varied by strata, but a pairwise comparison of the ranked data failed to show any differences between individual strata. No significant differences were found between the north and south strata, or the five strata moving west to east for total PCBs, butyltins, copper, arsenic, iron, manganese, mercury, nickel, or zinc. For total PAHs, higher concentrations were found in Stratum 1, corresponding to the NASD. For total DDT, sediment concentrations were higher in Stratum 3 which contains the site adjacent to Blue Beach (1,274 ng/g) that had the highest total DDT concentration measured in this study. For cadmium, Stratum 4, corresponding to the LIA had an overall higher sediment concentration. For chromium, the north strata had higher concentrations of this trace element, while the west to east strata (1 - 5) were not significantly different. A non-parametric test revealed differences in the lead concentration in the west to east strata, however, a comparison of the ranked values failed to reveal any statistical differences. For aluminum, Stratum 3 had significantly higher concentrations in the sediment.

The experimental design used in this study also allowed comparisons of contaminants between nine inland lagoons. Total PAHs were found to be significantly higher in Lagoon 1 (Laguna Boca Quebrada) than in some of the lagoons on the eastern part of the island. There were no differences in total PCBs between the nine

inland lagoons. For total DDT, Lagoon 4 (Laguna Algodones), Lagoon 5 near Blue Beach, and Lagoon 3 near Ensenada Sombe were higher than some of the inland lagoons further east on the island. Cadmium was higher in Lagoon 8 (Laguna Anones) in the LIA than in a number of the inland lagoons sampled on the west side of Vieques. Chromium was higher in Lagoons 6 and 7, in or adjacent to the former LIA. Copper was higher in Lagoon 6. There were no significant differences in the concentration of lead between the inland lagoons tested.

For corals, the concentration of total PAHs, total PCBs, total DDT, and butyltins were not significantly different from the sediments. For the trace and major elements, however, the concentration in coral tissues was usually lower than in sediments. The only element with significantly higher concentrations in coral tissues than in sediments was cadmium.

The results of this along with other characterizations can be used to assess the distribution and concentrations of chemical contaminants in sediments and coral tissues from around Vieques, and identify areas with possible contaminant-related issues. The information generated from this project can also be used to support and help guide the cleanup efforts on Vieques. Finally, the information presented here can serve as a baseline to document changes that may occur over time as restoration efforts proceed, and as some of the former U.S. Navy-owned areas undergo residential and commercial development.

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