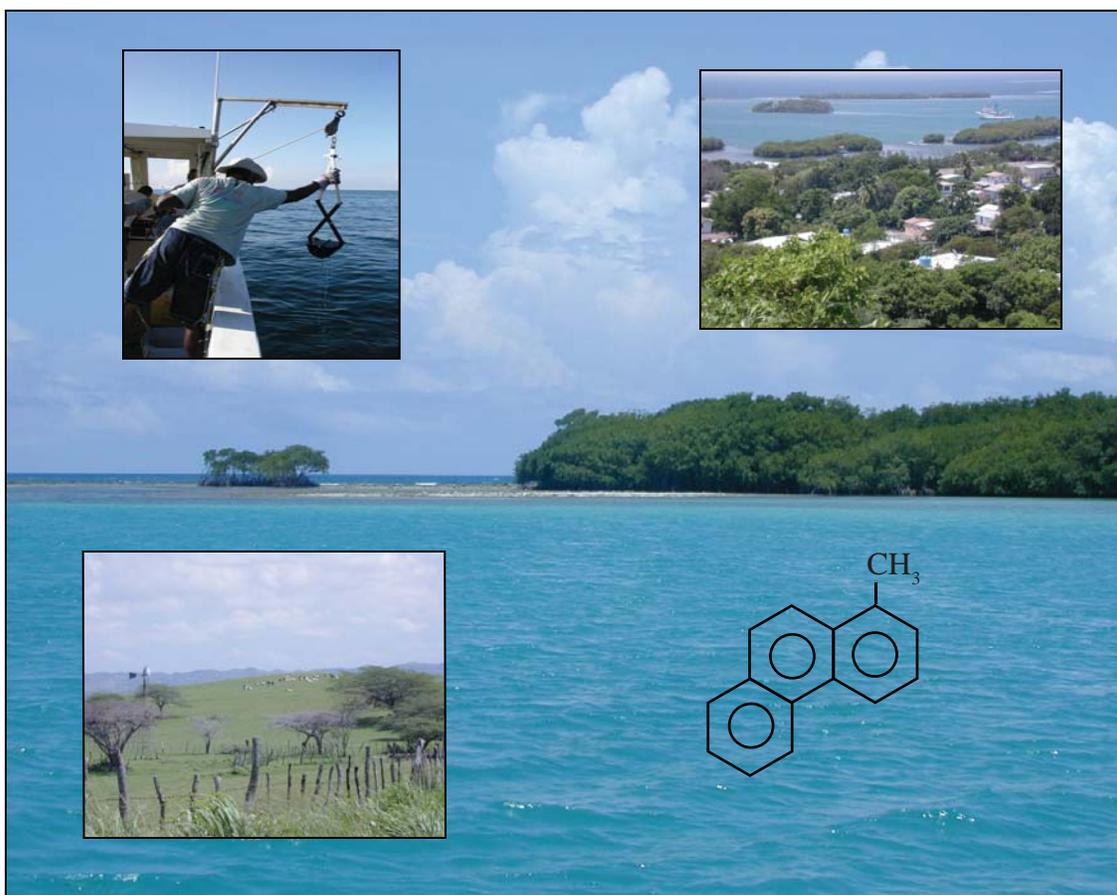


# Land-Based Sources of Pollution in Southwest Puerto Rico: an Assessment of Chemical Contaminants in Coral Reef Ecosystem Study Sediments

## DRAFT



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# Land-Based Sources of Pollution in Southwest Puerto Rico: an Assessment of Chemical Contaminants in Coral Reef Ecosystem Study Sediments

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# Land-Based Sources of Pollution in Southwest Puerto Rico: an Assessment of Chemical Contaminants in Coral Reef Ecosystem Study Sediments

*This report is the first product from a collaborative effort to implement an “ecosystem approach” to assess coral reef health. Through the concurrent development and analysis of data on chemical contaminants, reef biogeography, coral pathogens, biomarkers and land use, cause and effect linkages between stressors and coral condition can be established. The project is in direct response to the NOAA-led interagency assessment “The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States”, which calls for an integrated approach for assessing, monitoring and forecasting coral reef ecosystem condition, and highlights the need to communicate and transfer these capabilities.*

*This report summarizes the results from the first phase of the project in southwest Puerto Rico, which included a characterization of chemical contamination in sediments. Over 120 contaminants were analyzed in the sediments collected including a number of organic (e.g., hydrocarbons), inorganic (metals), and biological (bacterial) contaminants. The report also provides a preliminary analysis of the association between sediment contaminants and coral species richness. Subsequent reports will provide interpretations of other analyses being completed in this project, including chemical contaminants in corals, pathogens in coral tissues and biomarkers, all of which are important components in the approach being developed as part of this project.*



*Media Luna emergent reef in southwest Puerto Rico.*

## **Introduction**

Coral reefs are among the most productive and diverse ecosystems in the world (Bryant *et al.*, 1998). They occur in tropical and semitropical oceans and are home to thousands, perhaps millions of species of fish, corals, crustaceans and molluscs. Coral reefs provide a variety of goods and services ranging from commercial and subsistence fisheries, tourism and recreation, sources of new medicines, to natural protection against storms for communities and ports. The global value of coral reefs has been estimated at \$375 billion/year (Costanza *et al.*, 1997).

Worldwide, however, coral reefs are experiencing significant degradation, much of it thought to be related to human activities. Pollution, disease, sedimentation, overfishing, global climate change, invasive species, ship groundings (Waddell *et al.*, 2005), and possibly ocean acidification (Kleypas *et*

*al.*, 2006), are some of the threats currently faced by coral reefs worldwide.

In their report entitled “America’s Living Oceans”, the Pew Oceans Commission cited both point and nonpoint sources of pollution as major threats to the oceans (Pew Oceans Commission, 2003). Waddell *et al.* (2005) have described some of the threats posed by pollution to coral reefs of the U.S. and Freely Associated States. Bryant *et al.* (1998) have estimated that 58 percent of the world’s reefs are at risk from human disturbance. The World Resources Institute (Burke and Maidens, 2004) noted that nearly

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two-thirds of the coral reefs in the Caribbean are threatened by human activities. Gardner *et al.* (2003) estimated that coral cover in the Caribbean has been reduced by 80 percent.

In 2002, the U.S. Coral Reef Task Force (USCRTF) adopted the “Puerto Rico Resolution”, which called for the development of Local Action Strategies (LAS) to identify and implement priority actions needed to reduce key threats to valuable coral reef resources. Pollution was identified as a focus area for priority action in the LAS for Puerto Rico, the Virgin Islands and Southeast Florida. Although pollution is frequently cited as impacting coral reef health, the concentration of chemical contaminants present in coral reefs is not well characterized, and even less is known regarding linkages between contaminants and coral health.

Downs *et al.* (2005) concluded that coral decline in a section of the northern Florida Keys is likely related to chemical contaminant exposure, and noted that an analysis of contaminants present would greatly increase the power of determining the impact of this stressor. Developing an understanding of how and to what extent contaminants affect the health of corals and coral reefs also would help focus management efforts and optimize the use of finite resources (funds and personnel) to conserve and restore coral reef habitats.

*Project Goals.* To address these needs, NOAA’s National Centers for Coastal Ocean Science (NCCOS) in partnership with the University of Puerto Rico, the University of Hawaii, and Haereticus Environmental Laboratory are conducting a project to assess chemical contamination in the coral reefs in southwest Puerto Rico, and to develop a better understanding of the relationships between chemical contaminants and coral health. Objectives included:

- 1) characterize both organic (*e.g.*, petroleum hydrocarbons) and inorganic (*e.g.*, metals) contaminants in the study area;
- 2) quantify a series of parameters related to coral function (biomarkers)
- 3) map and determine coral distribution/species richness (biogeography); and
- 4) develop and implement an assessment

framework that can be applied throughout the Caribbean and elsewhere.

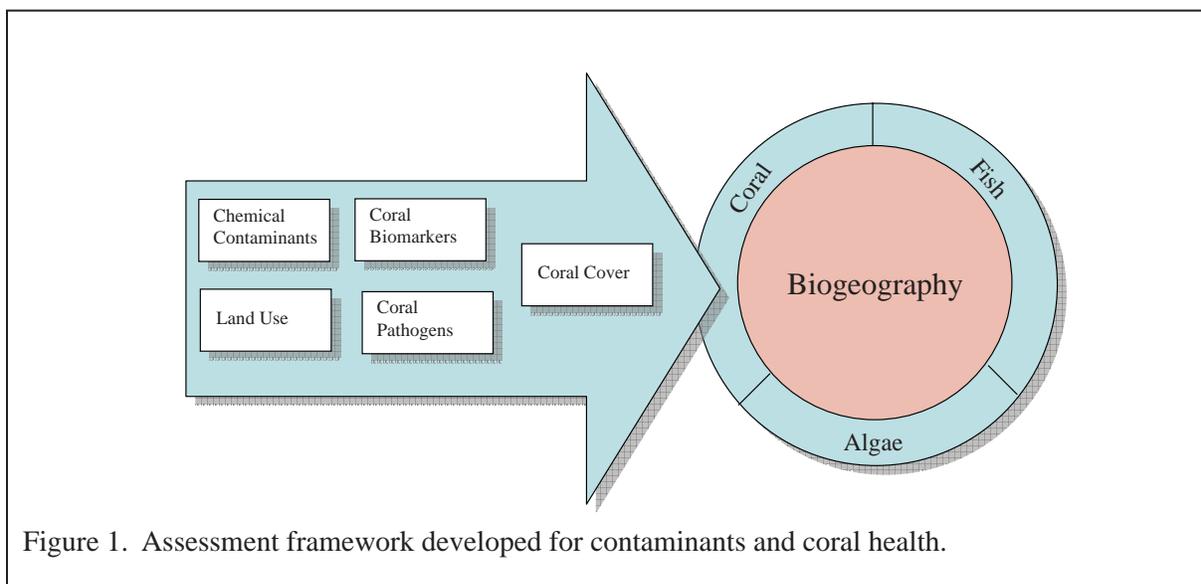
This project directly responds to the USCRTF’s call for an improved understanding of the effects of chemical contaminants on coral reefs. Because there is a lack of information available on the effects of contaminants, and even contaminant concentrations in coral reefs, management efforts may be missing an important and in some locations a critical information need for the sustained management of these valuable resources. Knowing how, where, and to what extent chemical contaminants are impacting coral reefs would provide managers and policy makers with the knowledge needed to make informed decisions regarding both land-use and coastal resource management.

### ***Assessment Framework***

The assessment framework developed as part of this project integrates a number of specialties including environmental chemistry, biogeography, molecular biology, microbiology and geographic information system (GIS) analysis (both terrestrial and marine), to better understand how anthropogenic inputs may affect coral ecosystems. The integration and concurrent analysis of these data types maximizes the likelihood of quantifying linkages between stressors (*e.g.*, chemical contaminants) and coral health. Figure 1 presents a simple schematic of the assessment framework that shows the types of information brought together.

*Chemical Contaminants.* In the framework, sediments and coral tissues are analyzed for a suite of chemical contaminants (*e.g.*, petroleum hydrocarbons, metals, and pesticides). In the next section, the compounds analyzed in sediments as part of this work will be discussed. An assessment of contaminants in the sediment and coral tissues is a core capability, and provides the means for correlating contaminants with other parameters measured in the framework.

*Coral Biomarkers.* The molecular biomarkers measured in the coral tissues provide a means for assessing coral condition or injury (Downs *et al.*, 2005). Subsequent reports will present the results of the coral biomarker analysis.



*Coral Cover.* Since 1999, NOAA’s Biogeography Team has completed extensive mapping and monitoring of the reefs in southwest Puerto Rico and elsewhere in the U.S. Caribbean. These data can be used to help determine relationships between the presence of contaminants and the distribution and abundance of coral species and in combination with the biomarkers, provides the opportunity for understanding effects from the molecular to the community levels.

*Coral Pathogens.* The presence of coral pathogens is also determined as part of the framework. In addition to providing a measure of their presence, exploring the relationship between contaminants and coral pathogens may provide a means for understanding if chemical contaminants modulate pathogen susceptibility and ultimately the onset of coral disease.

*Land Use.* The types of contaminants found in the aquatic environment are a function, in part, of the activities that occur on land. Nonpoint source runoff from agricultural areas can introduce pesticides, nutrients (*e.g.*, fertilizers) and sediments onto the reefs. Nonpoint source runoff from urban or suburban areas can also introduce a number of contaminant types, ranging from petroleum hydrocarbons to coliform bacteria. Point sources such as wastewater treatment plants or industrial

operations also discharge a variety of contaminant types.

*Project Partners.* Because of the multidisciplinary nature of this approach, a number of collaborators are part of the overall project. The Coastal Ocean Assessment Status and Trends (COAST) Team, and the Biogeography Team (BT) of NOAA’s Center for Coastal Monitoring and Assessment (CCMA) are working to characterize chemical contaminants within sediments and to document coral cover/species richness, respectively. The COAST Team operates NOAA’s National Status and Trends (NS&T) Program, which has monitored the Nation’s coastal waters for contaminants and bioeffects for over 20 years. The NS&T Program contains the Mussel Watch Project which monitors approximately 280 sites around the Nation for chemical contaminants in both bivalve tissues and sediments. NOAA’s Biogeography Program has worked to characterize and map coastal habitats for over 20 years, and for the last eight years, has worked specifically in tropical ecosystems. The concurrent analysis of data on chemical contaminants and coral cover/diversity creates a powerful tool to assess contaminant effects on habitat and species distributions. As additional projects are implemented, the partners may change, for example, as a result of adding local partners in a study area or partners with expertise related to local issues.

The University of Puerto Rico-Mayaguez is providing expertise in local coral reef ecology, and a base of operations for field work. NOAA's Center for Coastal Environmental Health and Biomolecular Research and Hollings Marine Laboratory in Charleston, South Carolina are providing laboratory space as needed, and analyzing coral tissues for pathogens associated with coral disease. The University of Hawaii/Kewalo, and Haereticus Environmental Laboratory are characterizing coral biomarkers as well as chemical contaminants in coral tissues. TDI-Brooks, International analyzed the sediment samples for contaminants.

### **Materials and Methods** *Study Area*

The study area for this project is approximately 40 km long, extending from Guanica Bay (Figure 2) in southwest Puerto Rico, west past the town of La Parguera to the Margarita reef complex. The study area was selected based on established partnerships, data availability, and designation of the area as a NOAA funded Coral Reef Ecosystem Study (CRES) site. CRES, funded by NCCOS' Center for Sponsored Coastal Ocean Research (CSCOR), is a 5-year program that began in 2002 to understand the causes and effects of reef degradation, and to provide managers with the information and tools needed to help reverse the degradation of coral reef ecosystems. CRES-Parguera is one of two CRES study sites in Puerto Rico. The Puerto Rico Planning Board has classified the area as a Zone of Special Planning, and La Parguera has also been designated as a Natural Reserve by the Puerto Rico Department of Natural and Environmental Resources (Garcia *et al.*, 1998). NOAA's Biogeography Team has completed extensive coral reef habitat mapping in this and other areas of Puerto Rico. The University of Puerto Rico-Mayaguez has also done extensive research on the reefs around La Parguera.



*View of La Parguera and Isla Maguieyes*

**Terrestrial Environment.** The southwest coast of Puerto Rico is generally a dry and warm region, and has been classified as a subtropical dry forest life zone (Garcia *et al.*, 1998). The town of La Parguera is located in the municipality of Lajas, and is home to approximately 26,000 people (U.S. Census Bureau 2006). Approximately 100,000 visitors come to La Parguera during the year for recreation, and over the

last 10 years a number of guest houses, private vacation homes and resorts have been developed (Garcia *et al.*, 1998). A wastewater treatment plant is situated between the town of La Parguera and Isla Guayacan (Figure 2). The facility discharges approximately 228,000 liters of secondary treated effluent per day into a series of percolation ponds (Garcia *et al.*, 1998).

The area around La Parguera has relatively low rainfall and subsequently low runoff. A series of coastal hills known as the Sierra Bermeja, separates the narrow coastal plain from the Lajas Valley. The valley drains primarily into Guanica Bay via a manmade canal system. Historically, the Lajas Valley was home to extensive sugarcane production, but now has significant pastureland along with the production of selected vegetable and melon crops (USDA, 2004). The municipality of Lajas has approximately 42 sq. km of pastureland (primarily for beef cattle), higher than any other in Puerto Rico, and ranks second in terms of percent land area devoted to pasture.

**Marine Environment.** The shelf along the southern coast of the island extends approximately 10 km from the shore, and then drops off at about 20 meters. In some areas this drop off is fairly abrupt (Garcia-Sais *et al.*, 2004), plunging to depths of 350 meters or more. The shelf, composed mainly of carbonates, was formed during the Cretaceous Period and then



Figure 2. Study area in southwest Puerto Rico. The text in yellow denotes some of the emergent reefs in the study area.

flooded around 5,000 - 9,000 years ago as a result of sea level rise (Garcia *et al.*, 1998). The shelf contains both emergent and submerged reefs along with extensive seagrass beds, coastal fringing mangroves and a series of mangrove islands. A number of the emergent reefs also shelter the inner parts of the shelf.

The reefs around La Parguera display a variety of reef forms from the typical spur and groove formations to extensive patch reefs, fringing reefs, and emergent island reefs or keys (Figure 2). In the La Parguera area, coral growth has been primarily responsible for the formation of these reefs (Garcia-Sais *et al.*, 2004). Many of the emergent reefs also contain stands of mangroves.

Typical corals include boulder coral (*Montastrea annularis*), brain corals (*Diploria spp.*), mustard hill coral (*Porites astreoides*), branching corals such as *Porites porites*, fire corals (*Millepora spp.*) and elkhorn and staghorn corals (*Acropora palmata* and *A. cervicornus*, respectively).

In 2006, both acroporid species were listed as threatened under the Endangered Species Act. There are also extensive areas of soft sediment in around the patch reefs (Morelock *et al.*, 1994).

#### Sampling Design

The primary sampling mission for the project took place in August 2005. During this mission, samples of sediment, water, and coral tissue were collected for the analysis of chemical contaminants. An earlier reconnaissance mission (May 2005) was used to characterize (grain size and organic carbon) the sediments in the study area and qualitatively assess land use in the watershed.

The major goal for this phase of the project was to characterize sediment contaminants in the study area. To do this, a stratified random sampling design was used to select points where sediments would be collected for chemical contaminant analysis. The

location of sampleable sediments in the study area was made possible by the extensive benthic habitat mapping completed by CCMA's Biogeography Program (Kendall *et al.*, 2001).

Using GIS (ArcGIS<sup>®</sup>), the hardbottom (coral) data layer was removed from the NOAA benthic map, leaving the sampleable soft bottom sediment data layer. The area to be sampled was then stratified by benthic zone which included mangrove, lagoon, backreef and bankshelf (Figure 3). The study area was also stratified by longshore position. The

sampling points were randomly selected using ArcGIS<sup>®</sup>. In each habitat/longshore stratum, at least three randomized sampling points were identified.

Sediments collected during the reconnaissance mission in May 2005, were analyzed for total organic carbon (TOC) and grain size. These two parameters are important in determining

where contaminants are more likely to accumulate if they are being introduced into a system, and were used to guide the selection of sampling sites for the August 2005 mission. Contaminants, particularly organics, tend to accumulate in sediments that have a higher TOC content. Grain size is also an important factor, as smaller grain size sediments have more surface area available for the adsorption of contaminants.

The sediment TOC data were analyzed for spatial structure using autocorrelation techniques. A positive test for spatial autocorrelation was found for TOC. Subsequently, Kriging techniques were used to interpolate the sediment TOC data and create a generalized map of high and low TOC (Figure 4). The contours in pink represent those areas modeled as having a high probability of elevated organic carbon, while areas in blue represent sediments with lower TOC. The map was then used to optimize the sampling for the August mission.



Pastureland in Lajas municipio.

*Sampling Protocols.* Sediments for contaminant analysis were collected in August 2005 from 43 sites, randomly selected within the high and low TOC strata, using standard NS&T Program protocols (Lauenstein and Cantillo, 1998). The 52 target sample sites are shown in Figure 5. The red half-circles indicate the higher organic carbon sites; blue are the sites identified by Kriging as having lower organic carbon.

Samples were collected aboard the vessel *Aquanauta* using a GPS programmed with the latitude/longitude coordinates of the stations. A modified Van Veen grab (see inset) was deployed to collect the sediment samples using a pulley and davit, and retrieved by hand.

Rocks or bits of seagrass were removed as needed. If a particular grab did not result in 200-300 g of sediment, a second grab was made and composited with material from the first grab. If not enough sediment had been collected after three

deployments of the grab, the site was abandoned and the boat moved on to the next location.

Because the sediments collected were to be analyzed for chemical contaminants, protocols were used to avoid contamination of samples by equipment and cross contamination between samples. All equipment was rinsed with acetone and then distilled water just prior to use, to reduce the possibility of contaminating the sediment sample. Personnel handling the samples also wore disposable gloves. The top 2 cm of sediment were collected from the sediment grab using a Kynar-coated sediment scoop.



*Sampling for sediment with the Van Veen grab.*

The sediments to be analyzed for contaminants were placed into two certified clean (I-Chem<sup>®</sup>) 250 ml labeled jars, one for organic chemical analysis the other for metal analysis, capped

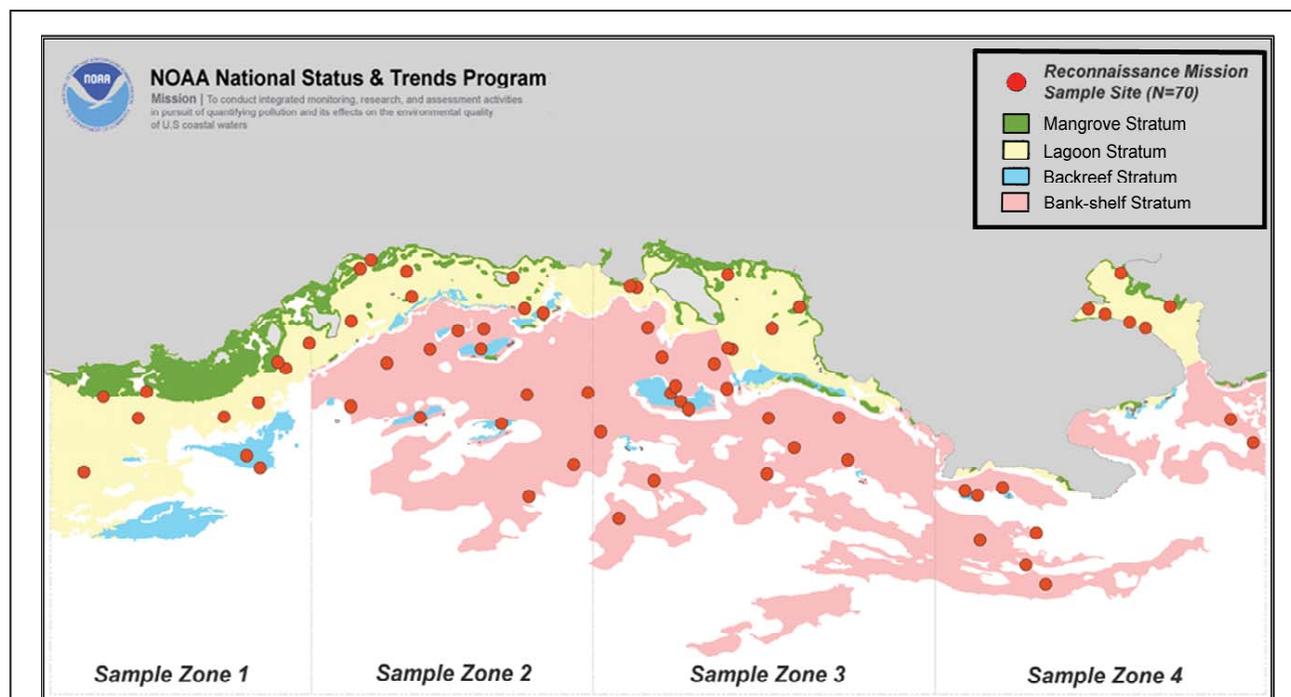


Figure 3. Stratified random sampling design used in May 2005 sampling in southwest Puerto Rico.

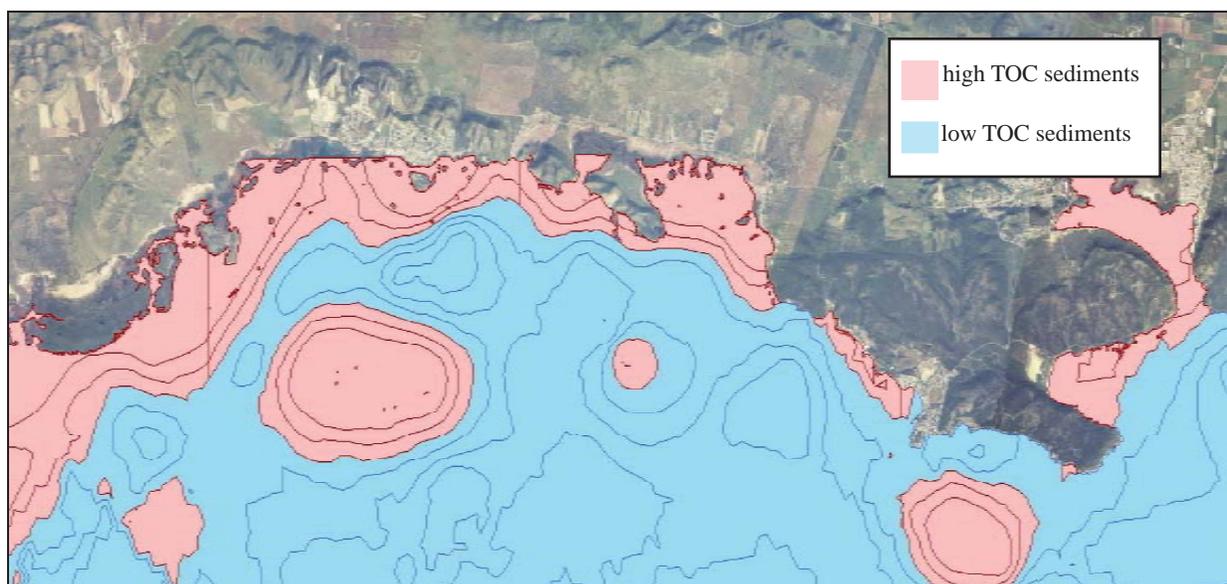


Figure 4. Modeled total organic carbon levels in the sediments.

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

A series of water quality parameters (dissolved oxygen, temperature, salinity, and conductivity) were measured at each site using a YSI<sup>®</sup> salinity/conductivity/temperature meter. The instrument probe was submerged to a depth of approximately one meter. Secchi depth was also measured at each site.

Water samples were analyzed from 47 of the sites identified in Figure 5 for total nitrogen and phosphorus analysis. Water samples were collected by submerging a labeled 125 ml HDPE (high density polyethylene bottle) beneath the water, capping it and then placing it on ice.

Water samples were also collected from seven sites for the analysis of Irgarol 1051, an antifoulant compound currently used in paint formulations for boat hulls. Water samples were collected in

precleaned 500 ml amber glass bottles at a depth of 30-40 cm by hand, the bottle was capped and then placed on ice.

Finally, coral tissues (*Porites astreoides*) were collected at selected sites. The green half-circles in Figure 5 identify those sites where *P. astreoides* and soft sediments were co-located. The protocols used and results of the coral tissue analyses will be included in later publications.

#### *Compounds Analyzed*

NOAA's NS&T Program monitors the Nation's estuarine and coastal waters for contaminants in bivalve mollusk tissues and sediments. The Program regularly quantifies over 120 organic and inorganic contaminants. The list of chemical contaminants analyzed in the sediments for this project is shown in Table 1. The compounds include 59 polycyclic aromatic hydrocarbons (PAHs), 30 organochlorine pesticides, 38 polychlorinated biphenyls (PCBs), four butyltins, 38 polybrominated diphenyl ether (PBDE) flame retardants, and 16 metals. All samples were analyzed using NS&T analytical protocols (Lauenstein and Cantillo, 1998). Each of the contaminant classes is discussed below.

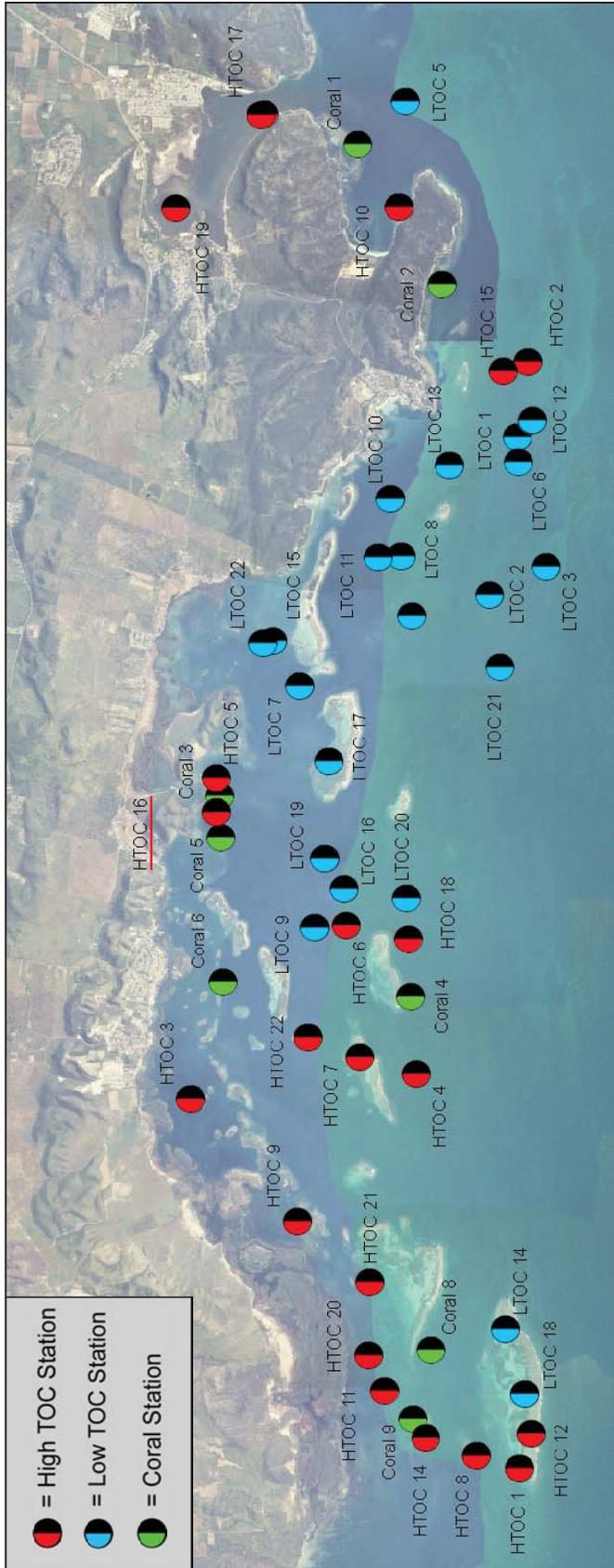


Figure 5. Sites targeted in southwest Puerto Rico during the August 2005 mission.

**PAHs.** Polycyclic aromatic hydrocarbons are associated with the use and combustion of fossil fuels (*e.g.*, oil and gas) and other materials (*e.g.*, wood). Natural sources of PAHs include forest fires and volcanoes. The PAHs analyzed are two to six ring aromatic compounds (see inset). A number of PAHs can bioaccumulate in aquatic and terrestrial organisms, are toxic and some including benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenzo[a,h]anthracene, and indeno[1,2,3-c,d]pyrene) are likely carcinogens.

**PCBs.** Polychlorinated biphenyls are a class of manmade compounds used in the past in numerous applications ranging from electrical transformers and capacitors, to hydraulic and heat transfer fluids to pesticides and paints. PCBs have a biphenyl ring structure (two benzene rings with a carbon to carbon bond) and a varying number of chlorine atoms. There are 209 PCB structures or congeners possible. PCBs can bioaccumulate, and degradation in the environment proceeds slowly. Exposure to PCBs has been linked to liver damage, reduced birth weight in infants exposed to PCBs via the mother, and decreased motor skills and short term memory.

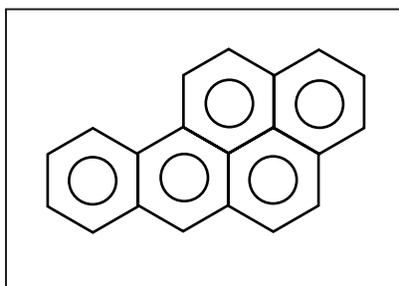
**Butyltins.** This class of compounds has a range of uses from biocides to catalysts to glass coatings. Tributyltin (TBT) in particular, used in antifoulant paint formulations on boat hulls has been associated with endocrine disruption, specifically an imposex condition in marine gastropod molluscs. Beginning in 1989, the use of TBT as an antifouling agent was banned on vessels smaller than 25 meters in length.

**PBDEs.** Polybrominated biphenyls are currently a widely used class of flame retardants whose concentrations are rising in the environment as well as in human tissues. They are used in many products, most notably in high impact polystyrene (plastics), foams, carpets and upholstery, textiles,

office furniture, electronic equipment, and electronic circuits. They are analogous to PCBs in structure, having 209 congeners, but containing bromine atoms bonded to the aromatic rings. Worldwide production of PBDEs is estimated at about 67,000 metric tons per year, with the deca-BDE congener constituting the largest fraction. The penta-BDE is still used in large quantities in the United States but its use is now severely curtailed in Europe.

Most PBDEs are released into the environment slowly, and tend to persist in sediment and soils. The fully brominated deca-BDE is not as readily bioaccumulated as the other PBDE congeners, however, it can degrade to penta-BDE through metabolic or environmental processes. The penta-

BDE is rapidly and almost completely absorbed, not eliminated from the body quickly, and tends to bioaccumulate. Recently, there has been concern regarding PBDEs because of rising concentrations in the environment and human tissues, and related effects. PBDEs have been shown to affect thyroid hormone function, along with impaired liver function and neural development.



*Benzo-a-pyrene, one of the PAHs analyzed for in the sediments from Puerto Rico.*

**Metals.** A total of 16 major and trace elements or metals were measured in the sediments for this project (Table 1). All occur naturally to some degree in the environment. Aluminum, iron, and silicon are major elements in the Earth's crust. As their name implies, trace elements occur at lower concentrations in the crustal material, however mining and manufacturing processes along with the use and disposal of materials containing trace elements result in elevated concentrations in the environment. A number of trace elements are toxic at low concentrations. Ingestion of cadmium, used in metal plating and solders, can result in liver and kidney damage, as can arsenic. Mercury is fairly volatile and can enter the atmosphere through processes including mining, manufacturing, combustion of fossil fuels (*e.g.*, coal) and volcanic eruptions. The methylated form of mercury can cause damage to the brain and

Table 1. Chemical contaminants analyzed in the sediments from southwest Puerto Rico.

PAHs - Low MW Weight	PAHs - High MW Weight	Organochlorine Pesticides	PCBs	Major and Trace Elements	PBDEs
Decalin	Fluoranthene	Aldrin	PCB8/5	Silver (Ag)	BDE 1 (2-MonoBDE)
C1-Decalins	Pyrene	Dieldrin	PCB18	Cadmium (Cd)	BDE 2 (3-MonoBDE)
C2-Decalins	C1-Fluoranthenes/Pyrenes	Endrin	PCB28	Copper (Cu)	BDE 3 (4-MonoBDE)
C3-Decalins	C2-Fluoranthenes/Pyrenes	Heptachlor	PCB29	Lead (Pb)	BDE 10 (2,6-DiBDE)
C4-Decalins	C3-Fluoranthenes/Pyrenes	Heptachlor-Epoxyde	PCB31	Antimony (Sb)	BDE 7 (2,4-DiBDE)
Naphthalene	Naphthobenzothiophene	Oxychlorane	PCB44	Tin (Sn)	BDE 8(2,4'-DiBDE)
1-Methylnaphthalene	C1-Naphthobenzothiophenes	Alpha-Chlordane	PCB45	Aluminum (Al)	BDE 11 (3,3'-DiBDE)
2-Methylnaphthalene	C2-Naphthobenzothiophenes	Gamma-Chlordane	PCB49	Arsenic (As)	BDE 12 (3,4-DiBDE)
2,6-Dimethylnaphthalene	C3-Naphthobenzothiophenes	Trans-Nonachlor	PCB52	Chromium (Cr)	BDE 13 (3,4'-DiBDE)
1,6,7-Trimethylnaphthalene	Benz(a)anthracene	Cis-Nonachlor	PCB56/60	Iron (Fe)	BDE 15 (4,4'-DiBDE)
C1-Naphthalenes	Chrysene	Alpha-HCH	PCB66	Manganese (Mn)	BDE 30 (2,4,6-TriBDE)
C2-Naphthalenes	C1-Chrysenes	Beta-HCH	PCB70	Nickel (Ni)	BDE 32 (2,4',6'-TriBDE)
C3-Naphthalenes	C2-Chrysenes	Delta-HCH	PCB74/61	Silicon (Si)	BDE 17 (2,2',4'-TriBDE)
C4-Naphthalenes	C3-Chrysenes	Gamma-HCH	PCB87/115	Zinc (Zn)	BDE 25 (2,3',4'-TriBDE)
Benzothiophene	C4-Chrysenes	2,4'-DDD	PCB95	Mercury (Hg)	BDE 33 (2',3,4'-TriBDE)
C1-Benzothiophenes	Benzo(b)fluoranthene	4,4'-DDD	PCB99	Selenium (Se)	BDE 28 (2,4,4'-TriBDE)
C2-Benzothiophenes	Benzo(k)fluoranthene	2,4'-DDE	PCB101/90		BDE 35 (3,3',4'-TriBDE)
C3-Benzothiophenes	Benzo(e)pyrene	4,4'-DDE	PCB105		BDE 37 (3,4,4'-TriBDE)
Biphenyl	Benzo(a)pyrene	2,4'-DDT	PCB110/77		BDE 49/71 (2,2',4',5'-TetraBDE/ 2,3',4',6'-TetraBDE)
Acenaphthylene	Perylene	4,4'-DDT	PCB118		BDE 47 (2,2',4,4'-TetraBDE)
Acenaphthene	Indeno(1,2,3-c,d)pyrene	1,2,3,4-Tetrachlorobenzene	PCB128		BDE 66 (2,3',4,4'-TetraBDE)
Dibenzofuran	Dibenzo(a,h)anthracene	1,2,4,5-Tetrachlorobenzene	PCB138/160		BDE 77 (3,3',4,4'-TetraBDE)
Fluorene	C1-Dibenzo(a,h)anthracenes	Hexachlorobenzene	PCB146		BDE 100 (2,2',4,4',6-PentaBDE)
C1-Fluorenes	C2-Dibenzo(a,h)anthracenes	Pentachloroanisole	PCB149/123		BDE 119 (2,3',4,4',6-PentaBDE)
C2-Fluorenes	C3-Dibenzo(a,h)anthracenes	Pentachlorobenzene	PCB151		BDE 99 (2,2',4,4',5-PentaBDE)
C3-Fluorenes	Benzo(g,h,i)perylene	Endosulfan II	PCB153/132		BDE 116 (2,3,4,5,6-PentaBDE)
Carbazole		Endosulfan I	PCB156/171/202		BDE 118 (2,3',4,4',5-PentaBDE)
Anthracene	<b>Butyltins</b>	Endosulfan Sulfate	PCB158		BDE 85 (2,2',3,4,4'-PentaBDE)
Phenanthrene	Monobutyltin	Mirex	PCB170/190		BDE 126 (3,3',4,4',5-PentaBDE)
1-Methylphenanthrene	Dibutyltin	Chlorpyrifos	PCB174		BDE 155 (2,2',4,4',6,6'-HexaBDE)
C1-Phenanthrene/Anthracenes	Tributyltin		PCB180		BDE 154 (2,2',4,4',5,6'-HexaBDE)
C2-Phenanthrene/Anthracenes	Tetraethyltin		PCB183		BDE 153 (2',2',4,4',5,5'-HexaBDE)
C3-Phenanthrene/Anthracenes			PCB187		BDE 138 (2,2',3,4,4',5'-HexaBDE)
C4-Phenanthrene/Anthracenes			PCB194		BDE 166 (2,3,4,4',5,6-HexaBDE)
Dibenzothiophene			PCB195/208		BDE 183 (2,2',3,4,4',5',6-HeptaBDE)
C1-Dibenzothiophenes			PCB201/157/173		BDE 181 (2,2',3,4,4',5,6-HeptaBDE)
C2-Dibenzothiophenes			PCB206		BDE 190 (2,3,3',4,4',5,6-HeptaBDE)
C3-Dibenzothiophenes			PCB209		

Abbreviations: MW, molecular weight; PAH, polycyclic aromatic hydrocarbons; HCH, hexachlorocyclohexane; DDT, DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; PCB, polychlorinated biphenyl ether; BDE, brominated diphenyl ether

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central nervous system. Copper has a number of uses such as in antifouling paints, wood preservatives, heat exchangers in power plants, electrical wires, coinage, and in agricultural pesticides. Although an essential element to human life, high doses of copper can cause anemia, and liver and kidney damage.

*Clostridium perfringens*. Although not a chemical contaminant, the bacterium *C. perfringens* has been used as an indicator of fecal pollution, and was analyzed in the sediment samples from southwest Puerto Rico. This bacterium occurs in the intestines of humans along with some domestic and feral animals and can cause food poisoning.

*Nitrogen and Phosphorus*. Nitrogen and phosphorus are nutrients essential for primary production in plants. Excessive loading of nutrients, from sources such as land application of fertilizers and waste water treatment plant effluent, can lead to eutrophication characterized by an overabundance of algae and reduced dissolved oxygen.

*Irgarol 1051*. This triazine herbicide is currently used in copper-based antifoulant paints on boats. While Irgarol 1051 has been detected in both salt and freshwater environments (Berard *et al.*, 2003), impacts that might occur in corals and seagrass communities are currently under investigation.

#### *Statistical and Spatial Analyses*

All contaminant data were analyzed using JMP<sup>®</sup> 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, bivariate regression analyses and Pearson Product moment correlations were run to explore relationships between parameters. If the data were not normally distributed and transformations were not effective, Spearman's nonparametric multivariate correlation was used.

Correlations between contaminant classes and sample strata (habitat type) were also investigated. ANOVAs were run when tests (O'Brien's test) revealed adequate homogeneity of variance on either the raw or transformed data. Pair-wise comparisons (Student's T or Tukey's HSD) were then run to

assess differences among the means. A Wilcoxon nonparametric test was run on data that did not meet the required homogeneity of variance condition.

Data also were analyzed using the Spatial Analyst extension in ArcGIS<sup>®</sup>. The data (*e.g.*, PAHs in sediments) were first tested for spatial autocorrelation. The correlation is used to measure the similarity of objects within an area, the degree to which a spatial phenomenon is correlated with itself, the level of interdependence between the variables, and the nature and strength of that interdependence (Childs, 2004). The significance of the spatial autocorrelation was tested using Moran's I and Geary's C test. Indicator Kriging was then used to model the concentrations of spatially autocorrelated contaminant data. In addition, correlations (*e.g.*, Spearman's Rho) between contaminant class and coral community structure were evaluated to determine the degree to which coral richness and contamination correspond in the region.

#### *Effects of Contaminants on Corals*

A number of authors have concluded that pollution can significantly impact coral reefs. Pandolfi *et al.* (2003) noted that pollution and overfishing have resulted in massive declines in abundance, diversity and habitat structure in coral reefs and associated tropical nearshore ecosystems. Edinger *et al.* (1998) found that reefs exposed to land-based pollution in Indonesia showed a 30-50 percent reduction in coral diversity at a depth of 3 meters, and a 40-60 percent reduction in coral diversity at a depth of 10 meters. This section of the report provides an overview of some of the documented effects of chemical contaminants on corals. More detailed discussions are included in the Results and Discussion section.

Understanding the effects that chemical contaminants can have on corals is important as it provides a basis for describing mechanistic linkages between contaminants and coral health, from the individual coral to the community. To date, there does not appear to be a large body of work on the effects of individual contaminants to adult corals. One likely reason for this is the difficulty in maintaining and culturing corals in the laboratory. The majority of the literature found on the effects of chemical

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contaminants on corals involves aqueous exposures (e.g., crude oil, trace elements and pesticides) to coral larvae or the direct application of contaminants (e.g., crude oil) to corals. Although most of the chemical contaminant data presented in this report are for sediments, the presence of chemical contaminants in the sediments provides an indication of what the corals are being exposed to over time, as sediments act as a reservoir for many contaminant types.

Table 2 summarizes some of the documented effects of individual contaminants and crude oil on corals. It can be seen that exposure to a number of contaminants can affect coral fertilization, settlement and metamorphosis, primary production and calcification (formation of coral skeleton). Much of the research has shown that chemical contaminant concentrations as low as ug/L (part per billion or ppb) can have significant and in some cases serious impacts on corals. Only one article involving the effects of contaminated sediments on corals was found.



An example of boulder star coral, *Montastrea annularis*.

#### *Petroleum Hydrocarbons*

A few studies were located that described the effects of individual PAHs such as anthracene, phenanthrene, pyrene and benzo[a]pyrene (Peachey and Crosby, 1996; Knap *et al.*, 1982; Gassman and Kennedy, 1992; and Kennedy *et al.*, 1992) on corals. Most of the literature found on the effects of petroleum hydrocarbons, however, were for crude or refined oils rather than individual PAHs. Crude oil is a complex mixture containing aliphatic (saturated), aromatic (including PAHs) and other compound classes. A substantial amount of the research to assess the impacts of crude oil on corals is from field studies, primarily oil spills or chronic discharges to reefs. Although this report focuses on the presence and effects of individual compounds, some of the studies of crude oil were included to supplement the available PAH data.

PAHs readily accumulate in the living tissues of corals and the zooxanthellae, and appears to be related to the lipid content in 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 are 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). Peachey and Crosby (1996) have shown that the toxicity (coral larval motility) of PAHs to corals was enhanced by exposure to light (phototoxicity).

PAHs have also been shown to induce microsomal degradative enzymes (Cytochrome P450 class) in corals. In higher organisms, P450 enzymes 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.

Crude and refined oils can also impact coral health. Negri and Howard (2000) found that concentrations of crude oil in water as low as 82 ug/L reduce coral larval settlement (Table 2). Peters *et al.* (1981) found that exposure to No. 2 fuel oil at concentrations as low as 70 ug/L in the rose coral (*Manicina areolata*) over a 12 week period resulted in substantial histologic changes in both the somatic and reproductive tissues, along with the loss of the zooxanthellae.

#### *Pesticides*

A few studies have focused on the effects of pesticides on corals, but none were found on the effects of organochlorine pesticides such as

Table 2. Effects of chemical contaminants on corals.

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Fungia scutaria</i> (mushroom coral)	Pyrene	PAH	Larval motility	32 ug/L	No toxicity to larvae exposed to pyrene (1-48 ug/L) in the dark; immobilization of larvae observed when exposed to pyrene in the presence of artificial sunlight (phototoxicity)	2 hours	Peachey and Crosby (1996)
<i>Montastrea annularis</i> (lobbed star coral)	Benzo[a]pyrene	PAH	Uptake and depuration	5 ug/L	Rapid uptake of radiolabeled benzo[a]pyrene in both coral tissue and zooxanthellae; low rate of depuration and metabolism	25 hours	Kennedy <i>et al.</i> (1992)
<i>Favia fragum</i> (golfball coral)	Benzo[a]pyrene	PAH	Uptake and depuration	5 ug/L	Rapid uptake of radiolabeled benzo[a]pyrene in both the coral tissue and zooxanthellae; low rate of depuration and metabolism	25 hours	Kennedy <i>et al.</i> (1992)
<i>Diploria strigosa</i> (symmetrical brain coral)	Phenanthrene	PAH	Uptake and depuration	33 ug/L	Rapid uptake of radiolabeled phenanthrene in the coral; rapid depuration during first two days, followed by much slower rate between day two and day 10	24 hours	Knap <i>et al.</i> (1982)
<i>Diploria strigosa</i> (symmetrical brain coral)	Phenanthrene	PAH	Uptake and depuration	3 ug/L	Rapid uptake of radiolabeled phenanthrene in the coral; rapid depuration during first ten days, followed by much slower release; radioactivity still detectable after one year	24 hours	Solbakken <i>et al.</i> (1984)
<i>Montastrea annularis</i> (lobbed star coral)	Phenanthrene	PAH	Uptake and depuration	3 ug/L	Rapid uptake of radiolabeled phenanthrene in the coral; roughly 10 percent of radioactivity still detectable after one month of depuration	24 hours	Solbakken <i>et al.</i> (1984)
<i>Diploria strigosa</i> (symmetrical brain coral)	Naphthalene	PAH	Uptake and depuration	16 ug/L	Rapid uptake of radiolabeled naphthalene in the coral; rapid depuration compared to phenanthrene; after 21 days less than one percent of original radioactivity present	24 hours	Solbakken <i>et al.</i> (1984)
<i>Madracis decactis</i> (green cactus coral)	Naphthalene	PAH	Uptake and depuration	16 ug/L	Rapid uptake of radiolabeled naphthalene in the coral; rapid depuration compared to phenanthrene; after 21 days less than two percent of original radioactivity present	24 hours	Solbakken <i>et al.</i> (1984)
<i>Oculina diffusa</i> (ivory bush coral)	Naphthalene	PAH	Uptake and depuration	42 ug/L	Rapid uptake of radiolabeled naphthalene in the coral; half life of the accumulated naphthalene was 24 hours; clearance of accumulated naphthalene estimated at 14 days	7 hours	Neff and Anderson (1981)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Diploria strigosa</i> (symmetrical brain coral)	2,4,5,2',4',5'-hexachlorobiphenyl	PCB	Uptake and depuration	15 ug/L	Rapid uptake of radiolabeled PCB in the coral; depuration very slow, after one year nearly a third of the original radioactivity was present	24 hours	Solbakken <i>et al.</i> (1984)
<i>Madracis decactis</i> (green cactus coral)	2,4,5,2',4',5'-hexachlorobiphenyl	PCB	Uptake and depuration	15 ug/L	Rapid uptake of radiolabeled PCB in the coral; depuration very slow, after one year nearly a third of the original radioactivity was present	24 hours	Solbakken <i>et al.</i> (1984)
<i>Acropora millepora</i> (no common name)	Water accommodated fraction	Crude oil	Fertilization success	165 ug/L	No effect of water accommodated fraction (WAF) of crude oil up to 165 ug/L	4 hours	Negri and Heyward (2000)
<i>Acropora millepora</i> (no common name)	Water accommodated fraction	Crude oil	Larval settlement	82 ug/L	Larval settlement significantly affected at 82 ug/L; no settlement at 165 ug/L	4 hours	Negri and Heyward (2000)
<i>Sylophora pistillata</i> (club foot coral)	Water soluble fraction	Crude oil	Larval settlement	0.1%	No settlement of larvae at a water soluble fraction concentration of the crude oil of 0.1%	12 hours	Epstein <i>et al.</i> (2000)
<i>Diploria strigosa</i> (symmetrical brain coral)	Water accommodated fraction	Crude oil	Coral growth	10,000 ug/L	Corals exposed to light crude oil for 24 hours and then moved back onto the reefs; no effect on growth of corals over the next year	24 hours	Dodge <i>et al.</i> (1984)
<i>Acropora formosa</i> (stony coral)	Water accommodated fraction	Crude oil	Coral survival	5,000 ug/L	Corals exposed to marine fuel oil for 12 and 24 hours expelled zooxanthellae and then died	12 hours	Harrison <i>et al.</i> (1990)
<i>Manicina areolata</i> (rose coral)	Water accommodated fraction	No. 2 fuel oil	Histologic effects	70 ug/L	Degraded reproductive tissues, degradation or loss of zooxanthellae and atrophy of mucous secretory cells in corals	12 weeks	Peters <i>et al.</i> (1981)
<i>Acropora surculosa</i> (no common name)	Copper	Trace element	Fertilization success	10 ug/L	Significantly reduced fertilization success at or above this concentration; at 200 ug/L less than 10 percent fertilization success	5 hours	Victor and Richmond (2005)
<i>Lobophytum compactum</i> (soft coral)	Copper	Trace element	Fertilization success	117 ug/L	Significantly reduced fertilization success at or above this concentration; EC <sub>50</sub> (calculated concentration that decreased fertilization by 50%) was 261 ug/L	5 hours	Reichel-Brushett and Michalek-Wagner (2005)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Goniastrea aspera</i> (brain coral)	Copper	Trace element	Fertilization success	20 ug/L	Significantly reduced fertilization at or above this concentration; at 75 ppb less than 1% fertilization success; EC <sub>50</sub> of 19 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Goniastrea retiformis</i> (no common name)	Copper	Trace element	Fertilization success	20 ug/L	Significantly reduced fertilization at or above this concentration; EC <sub>50</sub> of 25 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora tenuis</i> (finger coral)	Copper	Trace element	Fertilization success	42 ug/L	Significantly reduced fertilization rate at or above this concentration; at 67 ug/L, less than 5% fertilization success occurred; EC <sub>50</sub> of 40 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora longicyathus</i> (no common name)	Copper	Trace element	Fertilization success	24 ug/L	Significantly reduced fertilization rate at or above this concentration; at 61 ug/L, less than 3% fertilization success occurred	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora surculosa</i> (no common name)	Copper	Trace element	Development	12 ug/L	Embryo development significantly reduced at or above this concentration; at concentrations greater than 58 ug/L, no embryo development	12 hours	Victor and Richmond (2005)
<i>Acropora millepora</i> (no common name)	Copper	Trace element	Fertilization success	17 ug/L	Fertilization success EC <sub>50</sub>	4 hours	Negri and Heyward (2001)
<i>Acropora millepora</i> (no common name)	Copper	Trace element	Larval settlement	110 ug/L	Larval settlement EC <sub>50</sub> in the presence of crustos algae	24 hours	Negri and Heyward (2001)
<i>Goniastrea aspera</i> (brain coral)	Copper	Trace element	Larval motility	21 ug/L	Larval motility EC <sub>50</sub> ; a no observable effect concentration (NOEC) of 20 ug/L was determined	12 hours	Reichelt-Brushett and Harrison (2004)
<i>Montipora verrucosa</i> (rice coral)	Copper	Trace element	Zooxanthellae growth	40 ug/L	Significantly decreased growth rate in <i>Symbiodinium microadriaticum</i> , zooxanthellae cultured from the coral <i>Montipora verrucosa</i>	28 days	Goh and Chou (1997)
<i>Acropora tenuis</i> (finger coral)	Copper	Trace element	Larval settlement	42 ug/L	Larval settlement EC <sub>50</sub> of 35 ug/L; at 200 ug/L, all larvae died	48 hours	Reichelt-Brushett and Harrison (2000)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Porites cylindrica</i> (yellow finger coral)	Copper	Trace element	Primary production	11 ug/L	No effect on primary production when coral exposed only to copper; reduced primary production when corals exposed to increased temperature and copper	24 hours	Nystrom <i>et al.</i> (2001)
<i>Acropora microphthalma</i> (no common name)	Tributyltin, Copper and Zinc	Antifoulant ingredient and trace elements	Larval settlement	8 ug/g TBT, 72 ug/g Cu, 92 ug/g Zn in diluted sediments	No larval settlement on preconditioned terracotta tiles; exposure of larvae to 5% contaminated field sediments containing tributyltin (TBT), copper and zinc; most larvae died before metamorphosis at this concentration	48 hours	Negri <i>et al.</i> (2002)
<i>Goniastrea aspera</i> (brain coral)	Nickel	Trace element	Fertilization success	100 ug/L	Significantly reduced fertilization rate at or above this concentration.	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Pocillopora damicornis</i> (lace coral)	Nickel	Trace element	Larval settlement	1,000 ug/L	Significantly reduced larval settlement at 1 ppm nickel after 9 days of recovery; effects seen for all durations of exposure (12-96 hours)	12 hours	Goh (1991)
<i>Goniastrea aspera</i> (brain coral)	Zinc	Trace element	Fertilization success	500 ug/L	No significant difference in fertilization success compared to controls for any concentration tested, up to 500 ug/L.	5 hours	Reichelt-Brushett and Harrison (1999)
<i>Acropora tenuis</i> (finger coral)	Zinc	Trace element	Fertilization success	10 ug/L	Significantly reduced fertilization at or above this concentration; NOEC <10 ug/L; at 5,000 ug/L, no fertilization occurred at all	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Montipora verrucosa</i> (rice coral)	Zinc	Trace element	Zooxanthellae growth	509 ug/L	No effect on growth rate of <i>Symbiodinium microadriaticum</i> , zooxanthellae cultured from the coral <i>Montipora verrucosa</i>	28 days	Goh and Chou (1997)
<i>Goniastrea aspera</i> (brain coral)	Cadmium	Trace element	Fertilization success	200 ug/L	No significant difference in fertilization success compared to controls for any concentration tested, up to 200 ug/L	5 hours	Reichelt-Brushett and Harrison (1999)
<i>Oxyypora lacera</i> (scroll coral)	Cadmium	Trace element	Fertilization success	1,000 ug/L	No significant difference in fertilization success compared to controls for any concentration tested, up to 1,000 ug/L	5 hours	Reichelt-Brushett and Harrison (1999)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Acropora tenuis</i> (finger coral)	Cadmium	Trace element	Fertilization success	5,000 ug/L	Significantly reduced fertilization rate at or above this concentration; NOEC of 2,000 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora longicyathus</i> (no common name)	Lead	Trace element	Fertilization success	855 ug/L	Significantly reduced fertilization at or above this concentration; EC <sub>50</sub> of 1,453 ug/L; NOEC of 451 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora tenuis</i> (finger coral)	Lead	Trace element	Fertilization success	1,982 ug/L	Significantly reduced fertilization at or above this concentration; EC <sub>50</sub> of 1,801 ug/L; NOEC of 7901 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Goniastrea aspera</i> (brain coral)	Lead	Trace element	Fertilization success	6,409 ug/L	Significantly reduced fertilization at or above this concentration; NOEC of 5,455 ug/L	5 hours	Reichelt-Brushett and Harrison (2005)
<i>Acropora millepora</i> (no common name)	Tributyltin (TBT)	Antifoulant ingredient	Fertilization success	200 ug/L	Fertilization success EC <sub>50</sub>	4 hours	Negri and Heyward (2001)
<i>Acropora millepora</i> (no common name)	Tributyltin (TBT)	Antifoulant ingredient	Larval settlement	2 ug/L	Larval settlement EC <sub>50</sub> in the presence of crustos algae	24 hours	Negri and Heyward (2001)
<i>Madracis mirabilis</i> (yellow pencil coral)	Irgarol 1051	Antifoulant ingredient	Photosynthesis in intact coral	0.1 ug/L	Reduction in net photosynthesis (O <sub>2</sub> evolution); at TBT concentrations exceeding 1 ug/L, little or no photosynthesis	8 hours	Owen <i>et al.</i> (2002)
<i>Seriatopora hystrix</i> (bird's nest coral)	Irgarol 1051	Antifoulant ingredient	Chlorophyll fluorescence	0.7 ug/L	Concentration resulting in 50% decrease (EC <sub>50</sub> ) in chlorophyll fluorescence (maximum effect quantum yield)	10 hours	Jones and Kerswell (2003)
<i>Madracis mirabilis</i> (yellow pencil coral)	Irgarol 1051	Antifoulant ingredient	Photosynthesis in zooxanthellae	0.063 ug/L	Inhibition of photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	8 hours	Owen <i>et al.</i> (2002)
<i>Diploria strigosa</i> (symmetrical brain coral)	Irgarol 1051	Antifoulant ingredient	Photosynthesis in zooxanthellae	2 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Favia fragum</i> (golfball coral)	Irgarol 1051	Antifoulant ingredient	Photosynthesis in zooxanthellae	2 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)
<i>Madracis mirabilis</i> (yellow pencil coral)	Diuron	Antifoulant ingredient	Photosynthesis in intact coral	2 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2002)
<i>Diploria strigosa</i> (symmetrical brain coral)	Diuron	Antifoulant ingredient	Photosynthesis in zooxanthellae	2 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)
<i>Favia fragum</i> (golfball coral)	Diuron	Antifoulant ingredient	Photosynthesis in zooxanthellae	2 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)
<i>Acropora formosa</i> (stony coral)	Diuron	Herbicide	Chlorophyll fluorescence	2.3 ug/L	Concentration resulting in 50% decrease (EC <sub>50</sub> ) in chlorophyll fluorescence (maximum effect quantum yield)	10 hours	Jones and Kerswell (2003)
<i>Acropora formosa</i> (stony coral)	Atrazine	Antifoulant ingredient	Chlorophyll fluorescence	45 ug/L	Concentration resulting in 50% decrease (EC <sub>50</sub> ) in chlorophyll fluorescence (maximum effect quantum yield)	10 hours	Jones and Kerswell (2003)
<i>Madracis mirabilis</i> (yellow pencil coral)	Atrazine	Antifoulant ingredient	Photosynthesis in intact coral	100 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2002)
<i>Diploria strigosa</i> (symmetrical brain coral)	Atrazine	Antifoulant ingredient	Photosynthesis in zooxanthellae	100 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)
<i>Favia fragum</i> (golfball coral)	Atrazine	Antifoulant ingredient	Photosynthesis in zooxanthellae	100 ug/L	Reduction in net photosynthesis ( <sup>14</sup> C incorporation) in isolated zooxanthellae after 6 hours	6 hours	Owen <i>et al.</i> (2003)
<i>Acropora formosa</i> (stony coral)	Simazine	Antifoulant ingredient	Chlorophyll fluorescence	150 ug/L	Concentration resulting in 50% decrease (EC <sub>50</sub> ) in chlorophyll fluorescence (maximum effect quantum yield)	10 hours	Jones and Kerswell (2003)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

Table 2. Effects of chemical contaminants on corals (cont.).

Coral/Species	Contaminant	Contaminant Class	Response	Concentration	Effect	Duration of Exposure	Reference
<i>Pocillopora damicornis</i> (lace coral)	Chlorpyrifos	Insecticide	Movement	100 ug/L	Reduced swimming motion in all larvae; at a concentration of 1,000 ug/L killed 50 to 100 percent of larvae within 24 hours	24 hours	Acevedo (1991)
<i>Acropora longicyathus</i> (no common name)	Ammonium (NH <sub>4</sub> )	Nutrient	Fertilization success	18 ug/L	Mean fertilization success reduced in gametes	5 hours	Harrison and Ward (2001)
<i>Acropora longicyathus</i> (no common name)	Phosphate (PO <sub>4</sub> )	Nutrient	Fertilization success	95 ug/L	Mean fertilization success reduced in gametes	5 hours	Harrison and Ward (2001)
<i>Porites porites</i> (thick finger coral)	Nitrate (NO <sub>3</sub> )	Nutrient	Photosynthesis and calcification	310 ug/L	Increased photosynthesis (↑ zooxanthellae), but decreased calcification	40 days	Marubini and Davis (1996)
<i>Montastrea annularis</i> (boulder coral)	Nitrate (NO <sub>3</sub> )	Nutrient	Photosynthesis and calcification	310 ug/L	Increased photosynthesis (↑ zooxanthellae), but decreased calcification	30 days	Marubini and Davis (1996)
<i>Acropora digitifera</i> (staghorn coral)	Suspended sediment	Sediment	Fertilization success	50 mg/L	Reduced fertilization, post embryonic development not affected	18 hours	Gilmour (1999)

Abbreviations: ug/L, micrograms/Liter or parts per billion (ppb); mg/L, milligrams/Liter

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DDT or chlordane. A number of studies were found for Irgarol 1051. Data for diuron, another triazine herbicide used in antifoulant paints were located. Both of these herbicides have been shown to significantly affect corals, particularly the zooxanthellae, the symbiotic photosynthetic dinoflagellate algae within corals. Concentrations of Irgarol 1051 as low as 0.063 ug/L (0.063 ppb or 63 ppt) were found to significantly inhibit photosynthesis in zooxanthellae (Owen *et al.*, 2002). Diuron was found to impact photosynthesis at a concentration of 2 ug/L (Owen *et al.*, 2003). Other herbicides, more commonly used in agriculture, such as atrazine and simazine were less effective in inhibiting photosynthesis (Table 2). At a concentration of 100 ug/L, the organophosphate insecticide chlorpyrifos significantly inhibited swimming motion in the larvae of the lace coral *Pocillopora damicornis*.

#### *Trace Elements*

A number of studies were found that assessed the effects of trace elements on corals, primarily on fertilization and settlement success. Many of these studies involved copper (*e.g.*, Reichelt-Brushett and Harrison, 1999; Reichelt-Brushett and Harrison, 2000; Negri and Heyward, 2001; Nystrom *et al.*, 2001; and Victor and Richmond, 2005). Investigating the effects of copper is likely due in part, to its use in boat hull antifoulant paints, and also in agriculture and industry. Copper has been shown to impact coral fertilization success and settlement and metamorphosis in the ug/L range (Table 2). A number of studies were also located for other trace elements including nickel (Goh, 1991; and Reichelt-Brushett and Harrison, 2005), zinc (Goh and Chou, 1997; Reichelt-Brushett and Harrison, 1999), lead (Reichelt-Brushett and Harrison, 2004), and mercury (Bastidas and Garcia, 2004). Nickel and zinc can impact coral fertilization and settlement, but typically at higher concentrations.

#### *Nutrients*

In addition to promoting the growth of macroalgae which can outcompete and overgrow corals, nitrogen and phosphorus can impact corals directly. Harrison and Ward (2001) showed that phosphate (PO<sub>4</sub>) at a concentration of 95 ug/L reduced fertilization success in the coral *Acropora longicyathus*. Marubini

and Davis (1996) showed that nitrate (NO<sub>3</sub>) at a concentration of 310 ug/L significantly reduced photosynthesis in two species, and perhaps even more of a concern, reduced the calcification rate in the coral skeleton.

## **Results and Discussion**

### *Field Data*

Data collected in the field during the August 2005 mission are presented in Table 3. A total of 50 sites were visited. At seven sites, the field team was unsuccessful in collecting sediments, resulting in sediment samples being collected at 43 sites. The average depth at the sites sampled was 10.3 m. The shallowest site was a backreef site (LTOC 14), with a depth of 1.2 m; the deepest site sampled was 21 m (HTOC 22). The average salinity encountered was 34.2 ppt, average temperature was 30.2 °C. Nonparametric analysis indicated that salinity did not vary significantly (P > 0.2824) by habitat (lagoon, backreef, bankshelf and coral sites). Analysis of temperature data indicated differences between habitat types (P < 0.0001).

Secchi depth also varied between sites. At a number of sites, including all of the backreef locations, water clarity was good to the bottom (Table 3). An ANOVA run on those sites where the Secchi depth was less than the bottom depth indicated significant differences (P < 0.0001) between habitat types (*e.g.*, lagoon, coral, and bankshelf). Results of a Tukey-Kramer HSD test indicated not surprisingly, that visibility was better at the offshore (bankshelf) sites.

### *Total Organic Carbon and Grain Size*

The results of the sediment total organic carbon (TOC) and grain size analyses are included in Appendix D. The average TOC in the sediments collected was 1.17%, and ranged from a low of 0.13% to 4.99%. As noted earlier, a positive correlation between organic carbon in the sediments and levels of contaminants is often found in coastal marine and estuarine sediments (Shine and Wallace, 2000). In addition, sediments with higher organic carbon levels (>3% organic carbon) have been

Table 3. Field data from the August 2005 mission.

Site	Collection Date	Habitat	Latitude (DD)	Longitude (DD)	Water Depth (m)	Dissolved Oxygen (mg/L)	Temperature (°C)	Salinity (ppt)	Conductivity (mS)	Secchi Depth (m)
Coral 1	8/27/05	Coral	17.94219	-66.91481	9.1	4.63	30.0	33.9	56.8	3.7
Coral 2	8/27/05	Coral	17.93012	-66.93719	7.0	4.61	29.6	33.8	56.1	6.7
Coral 3	8/27/05	Coral	17.96335	-67.02396	10.7	5.32	30.1	34.4	57.5	5.8
Coral 4	8/28/05	Coral	17.93594	-67.04942	18.9	5.04	29.6	34.3	57.0	7.9
Coral 5	8/27/05	Coral	17.96351	-67.01735	9.1	5.31	30.1	34.5	52.5	bottom
Coral 6	8/27/05	Coral	17.96334	-67.04679	13.7	4.81	29.6	34.5	57.3	7.3
Coral 8	8/28/05	Coral	17.93339	-67.10513	4.3	4.89	30.1	34.5	57.7	bottom
Coral 9	8/28/05	Coral	17.9362	-67.11609	4.6	4.62	30.1	34.6	57.9	3.7
LTOC 1	8/30/05	Bank	17.91935	-66.96133	14.3	5.26	30.0	34.2	57.2	14.0
LTOC 2	8/30/05	Bank	17.92371	-66.98617	15.5	4.95	30.4	34.0	57.2	bottom
LTOC 3	8/30/05	Bank	17.91522	-66.98183	16.2	4.91	30.1	34.1	57.2	bottom
LTOC 7	8/30/05	Bank	17.95165	-67.00027	13.7	5.24	30.1	34.4	57.6	6.7
LTOC 8	8/30/05	Bank	17.93658	-66.98	14.9	5.02	30.2	34.3	57.5	11.9
LTOC 9	8/29/05	Bank	17.94982	-67.03835	18.3	4.86	29.8	34.4	57.3	7.6
LTOC 10	8/30/05	Bank	17.93802	-66.9709	11.6	5.10	30.1	34.4	57.5	9.1
LTOC 11	8/30/05	Bank	17.9399	-66.98	14.6	5.18	30.1	34.4	57.6	11.0
LTOC 12	8/30/05	Bank	17.91706	-66.95874	13.7	5.17	30.0	34.3	57.2	bottom
LTOC 13	8/30/05	Bank	17.92927	-66.9657	11.9	5.05	30.1	34.4	57.3	bottom
LTOC 14	8/29/05	Backreef	17.92256	-67.10196	1.2	3.86	30.7	34.4	57.5	bottom
LTOC 15	8/30/05	Lagoon	17.95547	-66.99307	11.6	5.04	30.2	34.5	57.8	6.1
LTOC 16	8/29/05	Bank	17.94553	-67.03236	18.6	4.95	29.7	34.5	57.3	10.7
LTOC 17	8/30/05	Backreef	17.94743	-67.01212	1.8	5.49	30.8	34.4	58.3	bottom
LTOC 18	8/29/05	Backreef	17.91975	-67.11229	1.8	4.73	31.5	34.4	58.5	bottom
LTOC 19	8/29/05	Bank	17.9482	-67.02749	15.8	4.90	29.8	34.4	57.3	9.8
LTOC 22	8/30/05	Lagoon	17.95699	-66.99334	10.7	5.12	30.2	34.4	57.7	6.7
HTOC 1	8/29/05	Lagoon	17.92071	-67.12399	4.0	6.18	30.7	34.4	58.2	bottom
HTOC 2	8/27/05	Bank	17.9177	-66.94946	13.7	5.15	30.0	34.1	56.8	7.6
HTOC 3	8/28/05	Lagoon	17.96823	-67.06515	7.6	5.43	31.0	34.2	58.3	4.9
HTOC 4	8/29/05	Bank	17.93527	-67.06151	19.5	4.85	30.0	34.4	57.4	11.9
HTOC 6	8/29/05	Bank	17.94524	-67.03802	18.3	4.85	29.9	34.5	57.4	8.2
HTOC 7	8/29/05	Backreef	17.94338	-67.05894	1.5	4.70	29.5	34.5	57.0	bottom
HTOC 8	8/29/05	Lagoon	17.92699	-67.12191	10.4	5.22	30.3	34.5	57.9	bottom
HTOC 9	8/28/05	Lagoon	17.95278	-67.08468	3.7	6.16	30.8	34.9	59.0	bottom
HTOC 10	8/27/05	Bank	17.93624	-66.92476	4.3	5.03	30.0	33.9	56.7	bottom
HTOC 12	8/29/05	Backreef	17.91879	-67.1185	1.9	4.80	30.4	34.4	57.7	bottom
HTOC 14	8/28/05	Backreef	17.93436	-67.11897	2.7	5.13	30.3	34.5	57.9	bottom
HTOC 15	8/27/05	Bank	17.92125	-66.95095	15.2	5.02	29.8	34.1	56.8	7.6
HTOC 16	8/30/05	Bank	17.96392	-67.01995	18.0	4.83	30.1	33.6	56.5	9.8
HTOC 17	8/27/05	Lagoon	17.95639	-66.91005	6.4	5.28	30.8	33.7	57.2	2.4
HTOC 19	8/27/05	Lagoon	17.96895	-66.92469	4.0	5.25	31.0	30.0	53.6	1.2
HTOC 20	8/28/05	Lagoon	17.9426	-67.10583	3.0	5.28	30.4	34.7	58.3	bottom
HTOC 21	8/28/05	Lagoon	17.94228	-67.09434	5.5	5.41	30.3	34.6	58.1	4.6
HTOC 22	8/29/05	Bank	17.95096	-67.05567	21.0	4.93	29.9	34.5	57.5	8.2

Abbreviations: DD, decimal degrees; m, meters; mg/L, milligrams/liter; ppt, parts per thousand; mS, milli-Siemans.

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associated with degraded benthic communities (U.S. EPA, 2002).

#### *Polycyclic Aromatic Hydrocarbons*

Total PAHs as used in this report refers to the sum of the 59 compounds and compound classes (*e.g.*, anthracene, C1-naphthalenes) analyzed in the sediment samples. Appendix E contains detailed results of this analysis.

A map showing total PAHs in the sediments is shown in Figure 6. Elevated concentrations of total PAHs were found in the sediments adjacent to the town of La Parguera, particularly behind the emergent reef tracts and in the embayments. Higher concentrations of PAHs were also found in Guanica Bay. This spatial pattern, higher concentrations of contaminants closer to shore and in Guanica Bay, was seen for a number of chemical contaminant classes. A plot of total PAH concentrations is shown in Figure 7. The sampling sites in this figure are organized in a west to east direction so as to be comparable to Figure 6. The pattern of elevated PAH concentrations around La Parguera and Guanica Bay is also apparent.

*Comparison with Mussel Watch Data.* Concentrations at the majority of sites sampled were below 300 ng/g (ppb). Figure 7 also contains information related to the NS&T median and 85th percentile. Because of the long-term, national-level contaminant monitoring carried out by the NS&T Program, data from southwest Puerto Rico can be compared with data from the rest of the Nation's coastal waters sampled by the NS&T Program, to see how the sites compare. Overall, the concentrations of total PAHs in the study area were low. Only two sites, HTOC 17 and HTOC 19, both in Guanica Bay, were above the national NS&T median of 388 ng/g for total PAHs. None of the sites sampled in southwest Puerto Rico approached the national NS&T 85th percentile of 2,300 ng/g.

*EPA National Coastal Assessment Data.* The U.S. Environmental Protection Agency's (EPA) National Coastal Assessment (NCA) Program provides information on the condition of the Nation's coastal resources (U.S. EPA, 2004). In 2000, sediments were sampled by the NCA in Bahia Montalva. One

of the parameters measured by the NCA Program is total PAHs. The EPA list of total PAHs includes 22 individual compounds. The concentration of total PAHs detected at the NCA Bahia Montalva site was 25.2 ng/g (U.S. EPA, 2004). Two sites (LTOC 15 and LTOC 22) in the present study were adjacent to the Bahia Montalva site. The sum of these same 22 PAHs measured by NS&T was approximately 100 ng/g, somewhat higher than the adjacent NCA site.

In March 1973, the tanker *Zoe Colocotronis* ran aground on a reef near Cabo Rojo in Bahia Sucia, just west of the study area. Following the grounding, 37,000 barrels of Venezuelan crude oil were intentionally released to refloat the vessel (Corredor *et al.*, 1990). Much of the discharged oil washed up on the shores of Cabo Rojo. To assess whether surface sediments in the western part of the study area showed evidence of that spill as would be indicated by increased PAH concentrations, an ANOVA was run on total PAH concentration by longshore position (Figure 3). Results indicated no significant difference ( $P > 0.0612$ ,  $R^2 = 0.1701$ ).

The NS&T Program has developed effects-based, numerical guidelines to estimate the toxicological relevance of certain sediment contaminants (Long *et al.*, 1998). The goal of developing these guidelines is to compare environmental concentrations of contaminants with concentrations that have been associated with effects in the laboratory. These guidelines, the Effects Range-Low (ERL) and the Effects Range-Median (ERM) define contaminant concentration ranges that are rarely (<ERL), occasionally (ERL to ERM) or frequently (>ERM) associated with toxic effects in biota (NOAA, 1998). The ERL and ERM values for total PAHs are also contained in Figure 7. As can be seen, total PAHs in the sediments were well below not only the ERM, but also the ERL.

Figure 8 shows the concentrations of a number of individual PAHs in the sediments, which have ERL and ERM values. Most of the exceedences of the NS&T median occurred at the two sites in Guanica Bay, although there were a number of sites (*i.e.*, Coral 5, LTOC 7, LTOC 22, and HTOC 16) where the NS&T median for naphthalene was exceeded, mostly



Figure 6. Map of total PAHs detected in sediments in southwest Puerto Rico. Data classified into quantiles.

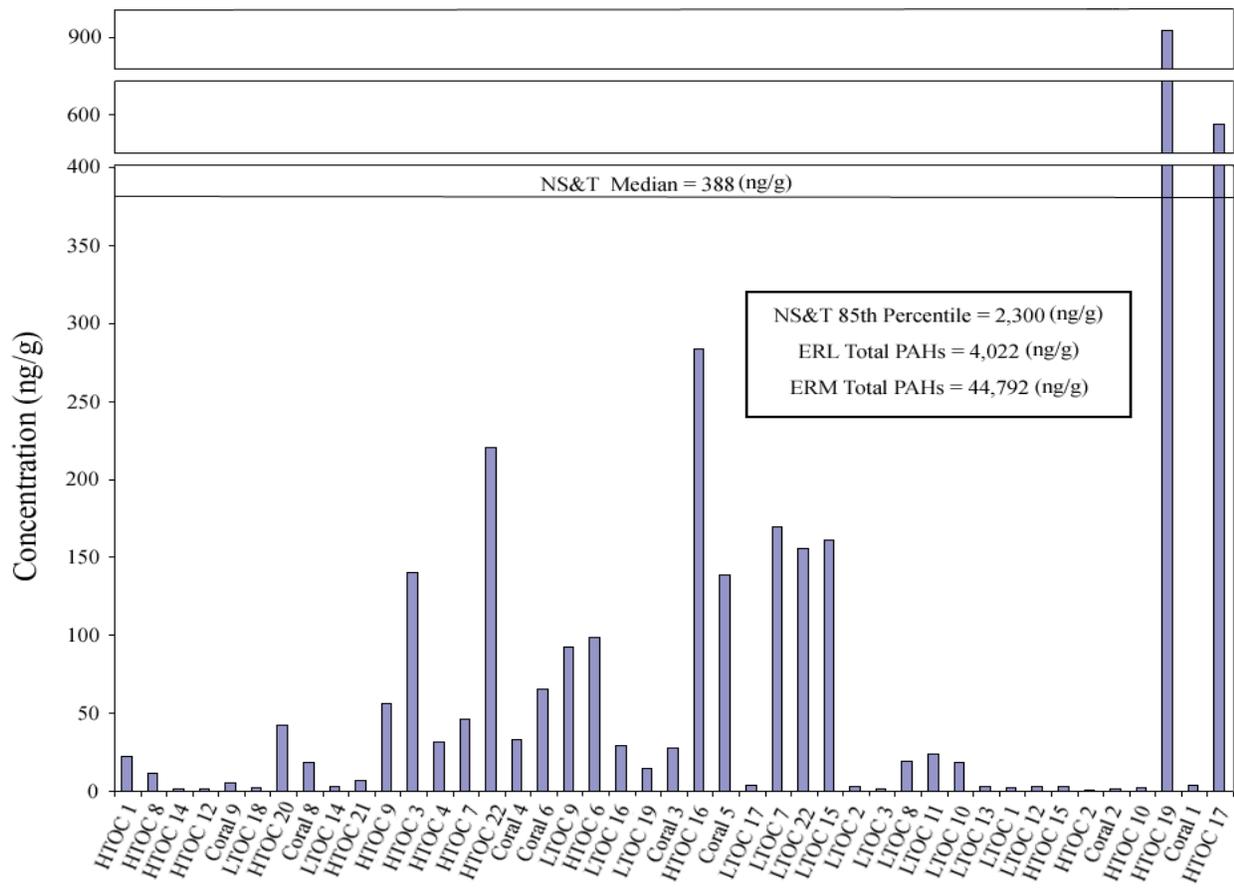


Figure 7. Total PAHs detected in sediments in southwest Puerto Rico.

nearshore sites or sites near emergent reefs (Figure 5). None of the sites approached the 85th percentile, the ERL or ERM. Elevated levels of naphthalene (above the NS&T median), a low molecular weight PAH, could be indicative of more recent PAH discharges, perhaps from boats.

**PAHs and Grain Size.** As noted, the adsorption of organic contaminants onto sediments is strongly influenced by grain size. The smaller grain sizes of the silts and clays have proportionally higher surface areas available for the adsorption of contaminants.

To assess this relationship for the samples collected in southwest Puerto Rico, a regression was run between grain size and the concentration of total PAHs found in the sediment samples. The data for grain size and PAH concentration were log<sub>10</sub> transformed. The results are shown in Figure 9. There was a highly significant ( $P < 0.0001$ ) relationship between the silt fraction of the sediment and the concentration of total PAHs ( $R^2 = 0.7944$ ). There was also a significant relationship ( $P < 0.0001$ ,  $R^2 = 0.3977$ ) between the concentration of PAHs and the clay fraction of the sediments. Nonparametric tests indicated a negative correlation ( $P < 0.0001$ , Spearman Rho -0.8162) between the sand fraction of the sediments and total PAHs, and a significant negative correlation between the gravel fraction of the sediments and total PAH ( $P > 0.0343$ , Spearman Rho -0.3236).

**PAHs and Total Organic Carbon.** Typically, a positive relationship exists between sediment total organic carbon (TOC) and chemical contaminants in freshwater, and in estuarine and coastal waters (Shine and Wallace, 2000; Hassett *et al.*, 1980). Because this phenomenon is very common in aquatic systems, organic contaminant concentrations are often normalized to the organic carbon content of sediments. A regression of TOC against the concentration of PAHs (both log<sub>10</sub> transformed) in the sediments, however, was not significant (Figure 10;  $P > 0.6531$ ,  $R^2 = 0.005$ ).

Total organic carbon, particularly in estuarine systems, is usually associated with the silt fraction of sediments. For example, a nonparametric analysis of

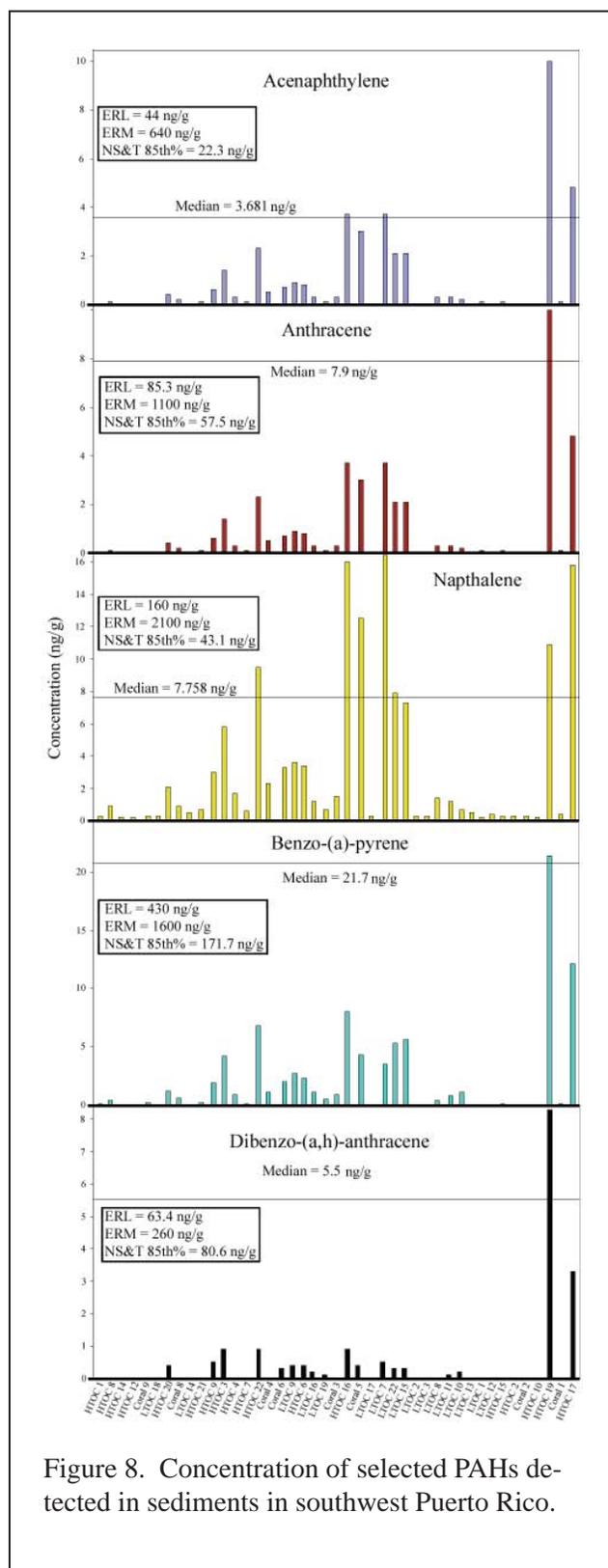
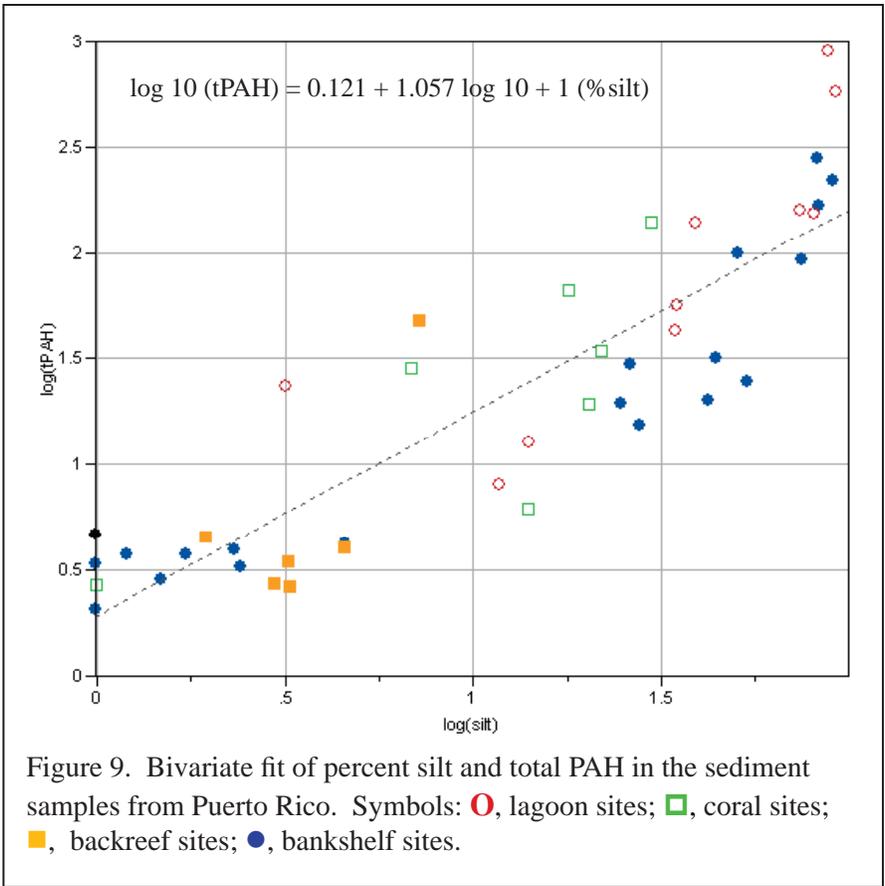


Figure 8. Concentration of selected PAHs detected in sediments in southwest Puerto Rico.



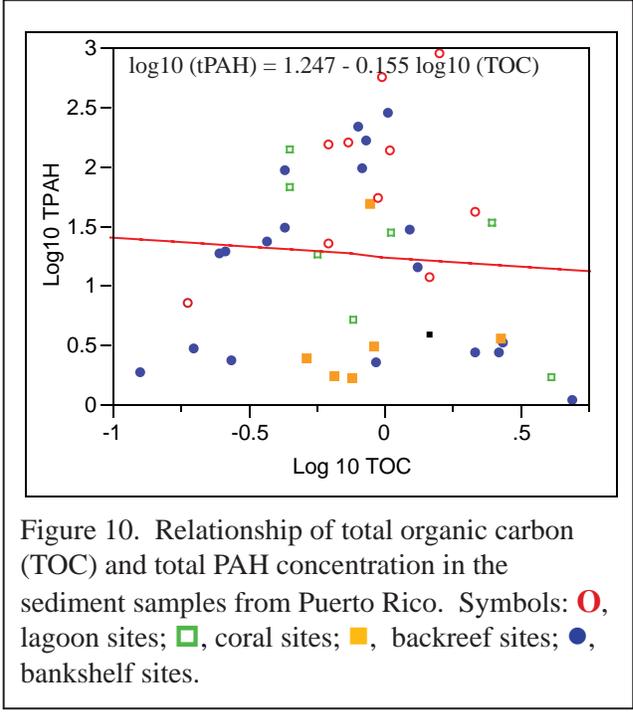
contaminants and sediment TOC could have implications in terms of the bioavailability of contaminants to coral reef organisms. Contaminants adsorbed onto sediments with lower organic carbon content could desorb from the sediments more readily and as a result, be more bioavailable to aquatic organisms.

*Low and High Molecular Weight PAHs.* The distribution of low ( $\leq 3$  rings) and high ( $\geq 4$  rings) molecular weight PAHs is shown in Figure 11. The PAHs in raw or refined petroleum products tends to be the lower molecular weight compounds. The major source of the higher molecular weight ( $\geq 4$  rings) PAHs is the combustion of petroleum products and other organic matter (Neff *et al.*, 2005). From Figure 11, it can be seen that in general, there was a fairly

nationwide data from the NS&T Program (excluding data from Hawaii, and other data from Puerto Rico) indicated a strong relationship between TOC and % silt ( $P < 0.0001$ , Spearman Rho = 0.5766). Using the Puerto Rico data from this study, however, regressions between TOC and silt ( $P > 0.2474$ ), and TOC and clay ( $P > 0.3948$ ) showed no positive correlation with either of these fractions.

It is not clear why a significant relationship between TOC and grain size did not exist for the sediments sampled in southwest Puerto Rico. Perhaps the organic carbon in these sediments is processed faster or differently than in estuarine and/or temperate areas. Additional work is needed to assess the behavior of TOC in the sediments in southwest Puerto Rico and possibly other tropical areas.

Total PAH concentrations in the sediments from southwest Puerto Rico were highly correlated with sediment particle size, and not sediment organic carbon. The lack of association between



even mix of LMW and HMW PAHs (Prob > ChiSq = 0.4472) in the sediment samples, possibly indicating a mixture of both petrogenic (e.g., petroleum product from fuel spill or other discharges), and pyrogenic sources.

The presence of alkylated (i.e., containing methyl groups) PAHs has also been used to assess petrogenic versus pyrogenic sources (Colombo *et al.*, 1989). Alkylated

PAHs are more abundant in petroleum products than in combusted materials. In Appendix E, alkylated PAHs are designated with the notations C1-C4, which indicates the number of methyl groups on the molecule.

In the sediment samples from southwest Puerto Rico, the ratio of nonalkylated (sometimes termed the parent compound) to alkylated PAHs was 2.72, indicating a higher average concentration of nonalkylated compounds, those PAHs more commonly associated with pyrogenic sources. This could be due in part, however, to the limited number of alkylated PAHs analyzed in the samples.

**PAH Fingerprinting.** The pattern of individual PAHs present in environmental samples can be used to help discern their origins, and is termed “fingerprinting” (Zeng and Vista, 1997). Comparing individual PAHs from sources such as automobile exhaust and road dust, coal dust, creosote and even outboard engines,

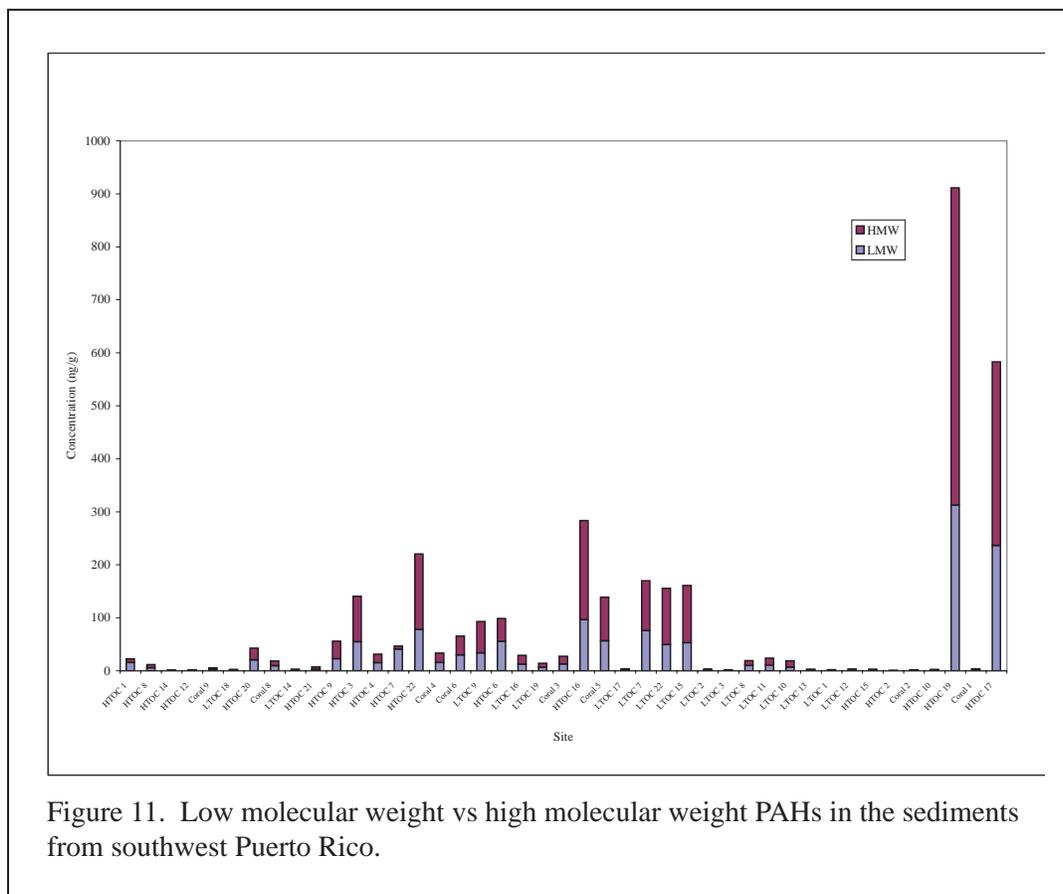


Figure 11. Low molecular weight vs high molecular weight PAHs in the sediments from southwest Puerto Rico.

with the PAHs in sediments, can assist in identifying major sources.

Kimbrough and Dickhut (2006), investigated PAH inputs to urban wetlands in relation to adjacent land use in the Elizabeth River, a sub-estuary of the Chesapeake Bay in Virginia. They analyzed a series of wetland sediments and compared the PAH profile to sources ranging from automobile exhaust to creosote to coal. Specifically, they looked at the patterns of five high molecular weight PAHs including fluoranthene, pyrene, benzo[a]anthracene, benzo[a]pyrene, and benzo[ghi]perylene. Figure 12 contains a comparison of the selected high molecular weight (HMW) PAHs in the sediment samples from southwest Puerto Rico expressed as a percent, to emissions from automobiles. From Figure 12, it can be seen that the pattern of these five HMW PAHs from the sediments is similar to the automobile engine emission signature, indicating that automobile emissions could be an important source of PAHs in the sediments.

Neff *et al.* (2005) also investigated the signature of PAHs from a variety of sources. They looked at phenanthrene:anthracene, and fluoranthene:pyrene ratios from different sources. For auto exhaust soot, a ratio of 1.79 was reported for phenanthrene:anthracene, and a ratio of 0.90 for fluoranthene:pyrene. In southwest Puerto Rico, the ratio of phenanthrene:anthracene was 2.90, and the ratio of fluoranthene:pyrene was 0.82, somewhat similar to what Neff *et al.* (2005) found in automobile exhaust.

Ballofett and Quinn (2004) assessed the relationship between boating activity and contamination from PAHs on Lake Tahoe in Nevada and California. They looked at a suite of 11 PAHs discharged in the exhaust from various types of outboard engines (four cycle, 2-cycle fuel injected, and 2 cycle carbureted). The study area in southwest Puerto Rico has a significant amount of recreational boating activity, particularly on weekends, along with some commercial fishing boats. Comparing the PAH signal from outboard engines with the pattern of PAHs detected in the sediments in southwest Puerto Rico provides another opportunity to assess possible sources. Ballofett and Quinn (2004) found that the outboard engine exhaust was enriched in acenaphthylene, fluorene and phenanthrene for all outboard engine types tested (Figure 13). The sediments collected in southwest Puerto Rico, however, had higher relative contributions (percent) of fluoranthene and pyrene (Figure 13, red striped bars). The pattern of PAHs in the sediments appears more similar to emissions from automobile engines than outboard engines, although phenanthrene is elevated in both automobile and outboard engine

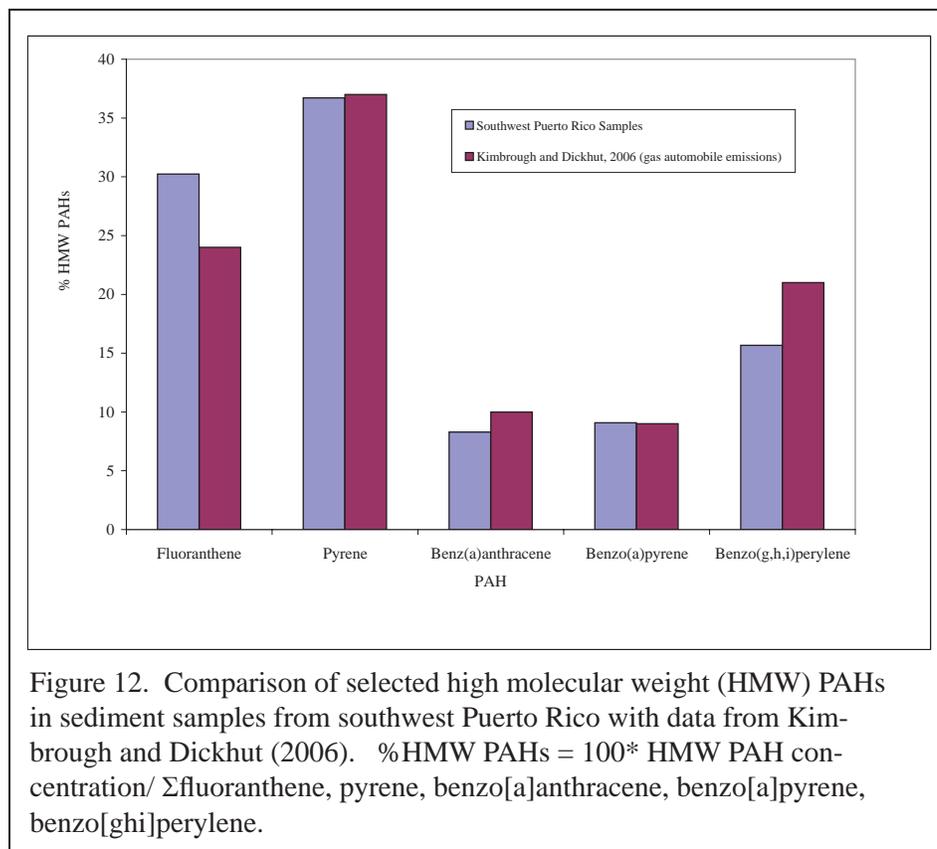


Figure 12. Comparison of selected high molecular weight (HMW) PAHs in sediment samples from southwest Puerto Rico with data from Kimbrough and Dickhut (2006). %HMW PAHs = 100\* HMW PAH concentration/  $\Sigma$ fluoranthene, pyrene, benzo[a]anthracene, benzo[a]pyrene, benzo[ghi]perylene.

discharges. Some of the boats around La Parguera have inboard engines, a number of which may be converted automobile engines which could have the same or similar exhaust discharge characteristics of automobile engines.

**PAHs and Habitat.** The habitats in the study area in southwest Puerto Rico vary from nearshore mangrove and lagoon sites to shallow areas behind the emergent reefs (backreef), to the deeper bank reefs. To assess whether total PAHs in the sediments vary by habitat, an ANOVA was run on log10 transformed data, followed by pairwise comparisons (Tukey-Kramer HSD). The results along with the 95% confidence intervals are shown in Figure 14. There was a significant difference ( $P > 0.0077$ ,  $R^2 = 0.2605$ ) in the total PAH concentration between habitats. The pairwise comparison indicated that the concentration of total PAHs in the backreef areas were significantly different (lower) than the concentrations of PAHs in the other sites.

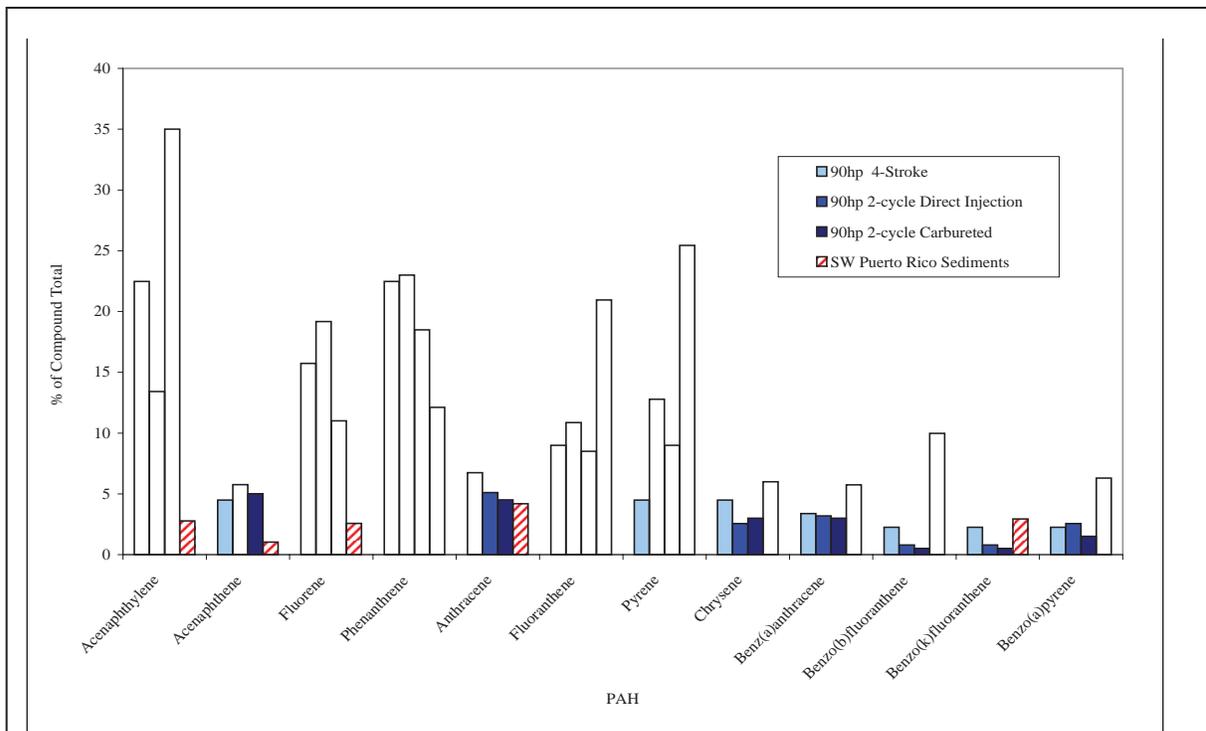


Figure 13. Comparison of signatures for selected PAHs in outboard engines with PAHs in sediments in southwest Puerto Rico. Outboard engine data from Ballofett and Quinn (2004).

*Effects of PAHs and other Petroleum Hydrocarbons on Corals.* Most of the research on the effects of hydrocarbons on corals involves the accumulation and effects of crude and refined petroleum, with only very limited data available on individual PAHs. Only five papers were located that assessed individual PAHs in corals, four of those concerned with uptake and depuration of PAHs. The remaining papers examined the effects of oil on corals. Because this project focused on individual PAHs, only a few of the studies investigating the effects of oil on corals are presented, to supplement the information presented on PAHs.

**PAHs.** Peach and Crosby (1996) carried out a study to look at the phototoxicity of PAHs. Phototoxicity refers to the toxic effects of chemicals caused or enhanced by light (Peachey and Crosby, 1996). In the laboratory, larvae of the coral *Fungia scutaria* (mushroom coral) were first exposed to nominal concentrations of pyrene ranging from 1-48 ug/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 ug/L resulted in a significant number (40%) of immobilized larvae. Changes in the mobility of the coral larvae, or their ability to find suitable substrate could impact recruitment, important in maintaining and building the reef structure. In addition, phototoxicity of PAHs could be an issue especially in tropical areas, which receive intense sunlight during much of the year.

Kennedy *et al.* (1992) investigated the uptake and metabolism of radiolabeled ( $^{14}\text{C}$ ) benzo[a]pyrene in two species of corals, *Montastrea annularis* and *Favia fragum*. Whole corals were exposed to a nominal concentration of 5 ug/L benzo[a]pyrene for a period of 25 hours. Corals were then removed to uncontaminated flowing seawater, and depuration was followed over a period of 144 hours. Uptake of benzo[a]pyrene was rapid in both species, a little higher in *M. annularis*, which Kennedy *et al.* (1992)

noted could be related to a higher lipid content in *M. annularis*. Approximately 38 and 65 percent of the accumulated radioactivity remained in *F. fragum* and *M. annularis* respectively, 144 hours after removing them from the test solution.

Kennedy *et al.* (1992) noted that the rate of

metabolism of benzo[a]pyrene in both species was low. After 144 hours, between 79 and 90 percent of the organic soluble radioactivity was in the form of unmetabolized benzo[a]pyrene. They noted that for both of these species, the low capacity to metabolize and eliminate xenobiotics compared to other marine invertebrates, indicate that corals could be very susceptible to environmental pollutants.

Knap *et al.* (1982) exposed the brain coral *Diploria strigosa* to <sup>14</sup>C labeled phenanthrene at a measured concentration of 33 ug/L for a period of 24 hours. Corals were then removed to a flow through aquarium with filtered water to observe depuration. Knap *et al.* (1982) found that the phenanthrene was readily accumulated by *D. strigosa*. When the corals were removed to an aquarium with flow-through seawater, there was a period of rapid decrease (~70 percent) in phenanthrene (and metabolite) concentration after two days as measured by the radioactivity remaining in the corals, followed by a much slower depuration rate between two and 10 days. Knap *et al.* (1982) concluded that the uptake of phenanthrene was similar to other invertebrates, and that the depuration rate was similar to that of the mussel *Modiolus modiolus*.

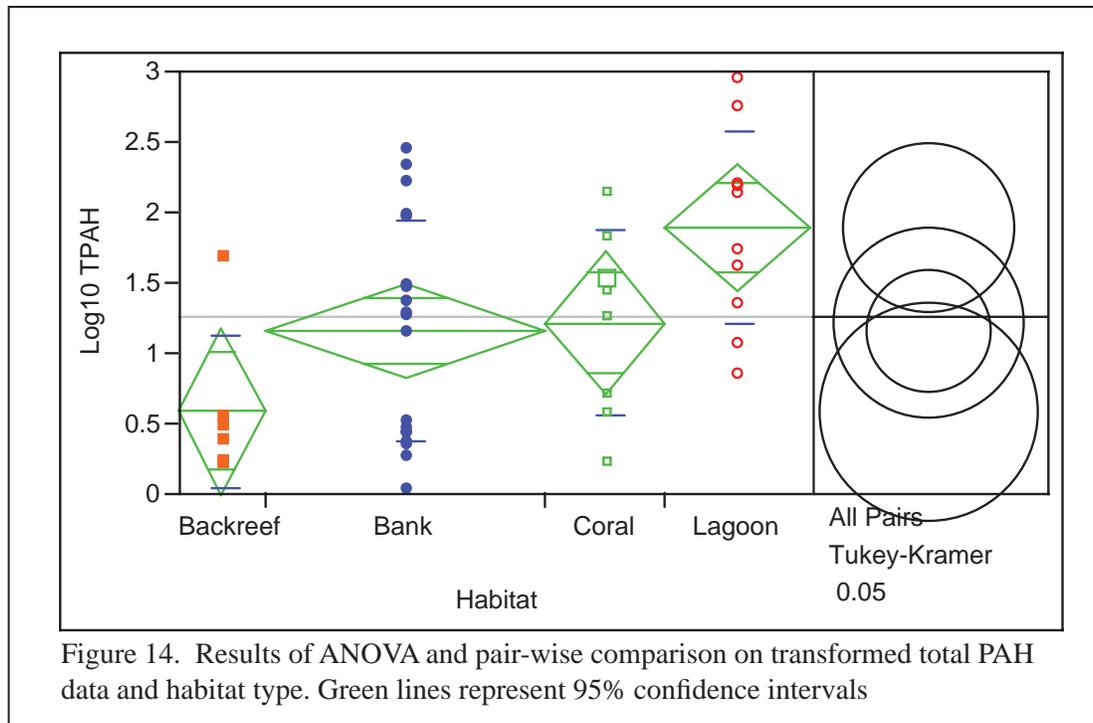


Figure 14. Results of ANOVA and pair-wise comparison on transformed total PAH data and habitat type. Green lines represent 95% confidence intervals

Solbakken *et al.* (1984) investigated the uptake of radiolabeled naphthalene and phenanthrene in *D. strigosa* and in a number of other corals. At a concentration of 3 ug/L, phenanthrene was rapidly accumulated by *F. fragum* and *M. annularis*. *D. strigosa* also accumulated the phenanthrene, but at a lower rate than the other two species. Solbakken *et al.* (1984) attributed this to taxonomic differences. While the uptake of phenanthrene was slower in *D. strigosa*, the depuration was also slower. Radioactivity, in the form of parent compound and any metabolites were still detectable in the corals one year after the exposure.

The uptake of another compound, naphthalene was also rapid, and depuration of this lower molecular weight PAH was faster than for phenanthrene in both *D. strigosa* and in the green cactus coral *Madracis decactis*. After two days, 92 percent of the naphthalene and any metabolites had been depurated (Solbakken *et al.* (1984).

Neff and Anderson (1981) exposed the coral *Oculina diffusa* to radiolabeled naphthalene. Naphthalene was added to a 10 percent solution of crude oil,

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producing a naphthalene exposure concentration of approximately 42 ug/L. Similar to what Solbakken *et al.* (1984) found, the bioconcentration of naphthalene in *O. diffusa* was rapid during the seven hour exposure period. The corals were then moved to clean flowing seawater in order to assess depuration. As with *D. strigosa*, depuration of naphthalene was rapid, and Neff and Anderson (1981) calculated a naphthalene elimination half-life of 24 hours, and estimated that the naphthalene would be cleared from the tissues after 14 days.

Crude and Refined Oil. Negril and Heyward (2000) investigated the effects of the water accommodated fraction (WAF) of heavy crude oil on the scleractinian coral *Acropora millepora*. The WAF is the amount of oil that remains in the aqueous phase after mixing and then phase separation. In WAF, the oil can be truly dissolved, or in particulate (*e.g.*, emulsions or oil droplets) forms. In these experiments, the oil and water were stirred vigorously for two hours at a ratio of 1:99, and then allowed to separate for a period of two hours. Coral gametes collected from reefs during spawning events were used in the experiments. Concentrations of total hydrocarbon (THC) up to 165 ug/L failed to significantly inhibit fertilization. However, larval settlement and metamorphosis was significantly affected by a THC concentration of 82 ug/L, and *A. millepora* larval settlement was completely inhibited at a concentration of 165 ug/L.

Epstein *et al.* (2000) investigated the effects of the water soluble fraction (WSF) of Egyptian crude oil on the settlement of coral larval *Stylophora pistillata*. The WSF is that amount of oil truly dissolved in an aqueous solution. A 0.1% WSF test solution was used. No mortality was observed during these experiments, and there were no observed alterations in swimming behavior. However, the 0.1% WSF prevented any larval settlement after 12 hours. (Epstein *et al.*, 2000).

Dodge *et al.* (1984) exposed the brain coral *D. strigosa* in a series of field and laboratory experiments to light crude oil at measured concentrations ranging from 1,000 - 50,000 ug/L. Corals were exposed for up to 24 hours, and the

corals were then moved back to or left on the reefs for a year. Dodge *et al.* (1984) found no effects of any concentration on the growth on *D. strigosa*.

Harrison *et al.* (1990) exposed whole *Acropora formosa* to the WAF of marine fuel oil for 12 to 24 hours. Measured concentrations in the water ranged from 5,000 ug/L to 10,000 ug/L. Unlike Dodge *et al.* (1984), the corals exposed by Harrison *et al.* (1990) became stressed, producing excess amounts of mucus followed by expulsion of the zooxanthellae, and then coral death. The very different results obtained by Dodge *et al.* (1984) and Harrison *et al.* (1990) point out how factors such as exposure material (*ie.*, crude oil versus marine fuel oil), and other factors (*e.g.*, species differences and experimental design) can impact results.

Peters *et al.* (1981) exposed adult rose coral (*Manicina areolata*) to the WAF of No. 2 fuel oil for 12 weeks at measured average concentrations ranging from 0.70 to 150 ug/L. Although none of the corals died during the exposures, histologic examination revealed a number of changes. Corals examined after two, four, and six weeks showed a substantial increase in secretory cell activity, and by the twelfth week, the cells had atrophied and in some cases completely disappeared (Peters *et al.*, 1981). There was also degeneration and loss of zooxanthellae in the coral, and nearly half of the corals in the higher exposure had degenerated ova.

Several studies have documented the association between the presence of oil and impacts in coral communities. Bak (1987) documented a deterioration in the reef structure adjacent to, and downstream of an abandoned oil refinery. Some coral species such as *M. annularis* and *A. palmata* were completely absent in the transects just upstream of the refinery and 5 km downstream of the site, along the coast. Interestingly, however, some corals such as *D. strigosa* were relatively abundant in the area adjacent to the abandoned refinery. Loya (1975) also documented an association between large oil refineries and low coral larval recruitment.

From these studies, it can be seen that PAHs and crude and refined petroleum products can have

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significant effects on corals. The effects of individual PAHs and crude or refined petroleum products in the environment are certain to be variable and dependant on factors including species involved, contaminants present, how the contaminants are introduced (*e.g.*, spill or chronic discharges) and environmental conditions such as depth, currents and time of year. In addition, impacts may not become apparent immediately if the contaminants have more subtle effects, for example on metabolism or reproduction, the outcome which may take longer to be manifested. Additional work is needed to better understand linkages that may exist between contaminants such as PAHs and effects at the community and species levels.

*Other Effects of PAHs.* PAHs can accumulate in the tissues of fish, aquatic plants, and marine invertebrates. Fish, however, have the ability to metabolize PAHs, and as such their tissues often do not show high levels of PAHs in known areas of contamination. Unlike fish, many marine invertebrates and mollusks are unable to efficiently metabolize PAHs.

Intake of high levels of PAHs in vertebrate test animals has been shown to have adverse health effects including bone marrow depression, hemorrhaging, increased susceptibility to infection, decreased fertility, sterility in offspring, increased liver weight, kidney toxicity, and tumors. The metabolism of PAHs in fish livers gives rise to nucleophilic compounds that can result in tumors in fish. Naphthalene, phenanthrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-c,d]pyrene, and dibenzo[a,h]anthracene are all known cancer causing PAHs (USDHHS, 1995).

#### *Polychlorinated Biphenyls*

Total PCBs detected in the sediments are shown in Figures 15 and 16. Appendix F contains results of the analysis for individual PCBs. Total PCBs as included in this report represents the sum of 18 congeners multiplied by a factor to estimate the total amount of all PCBs present in a sample.

*Comparison with NS&T Data.* As with the PAHs, there was a pattern of elevated total PCB levels adjacent to La Parguera and especially in Guanica Bay (Figure 15 and 16). A number of the sites around La Parguera had total PCB levels above the NS&T median of 8 ng/g, including HTOC 3, Coral 6, and Coral 3. Several sites around La Parguera, including HTOC 16, Coral 5, and HTOC 22 were also above the ERL for total PCBs of 22.7 ng/g. None of the sites adjacent to La Parguera, however, were above the NS&T 85th percentile of 80 ng/g, or the ERM of 180 ng/g.

In Guanica Bay (HTOC 17 and 19), however, the concentration of total PCBs at the sites sampled was not only above the NS&T 85th percentile, it was also substantially above the ERM value of 180 ng/g, indicating that PCBs are more likely impacting aquatic biota at these sites. Total PCBs at HTOC 17 in Guanica Bay (estimated at 2,700 ng/g) were over two orders of magnitude higher than the average found at the other sites in the study area. The other site sampled in Guanica Bay, HTOC 19 had an estimated total PCB sediment concentration of over 1,000 ng/g.

PCBs were manufactured in the U.S. between 1929 and 1977, and used in electrical applications including transformers and capacitors as insulators and coolants, and also in hydraulic and heat transfer systems, lubricants, paints, plasticizers, adhesives, flame retardants, brake linings, and asphalt. Approximately 60 percent of PCBs manufactured in the U.S. were used in electrical applications (U.S. EPA, 1997). In the United States, all PCBs produced in North America were made by a single manufacturer, and the commercial products were referred to as Aroclors. Aroclors are mixtures of PCB congeners. For example, Aroclor 1242 refers to a commercial mixture of PCBs that is 42 percent chlorine by weight.

The presence of substantially elevated levels of PCBs in Guanica Bay could be the result of a spill, industrial discharges, dumping of PCB contaminated equipment (*e.g.*, transformers), discharges from ships, or runoff (*e.g.*, from rainfall or cleaning activities)

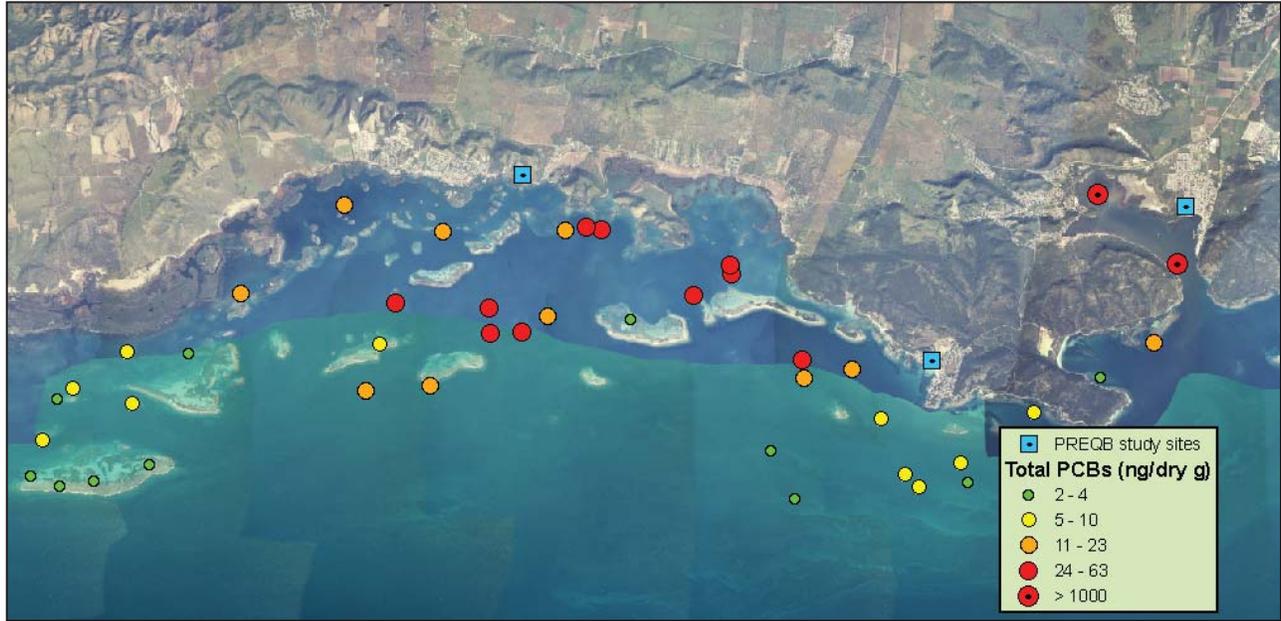


Figure 15. Map of total PCBs detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

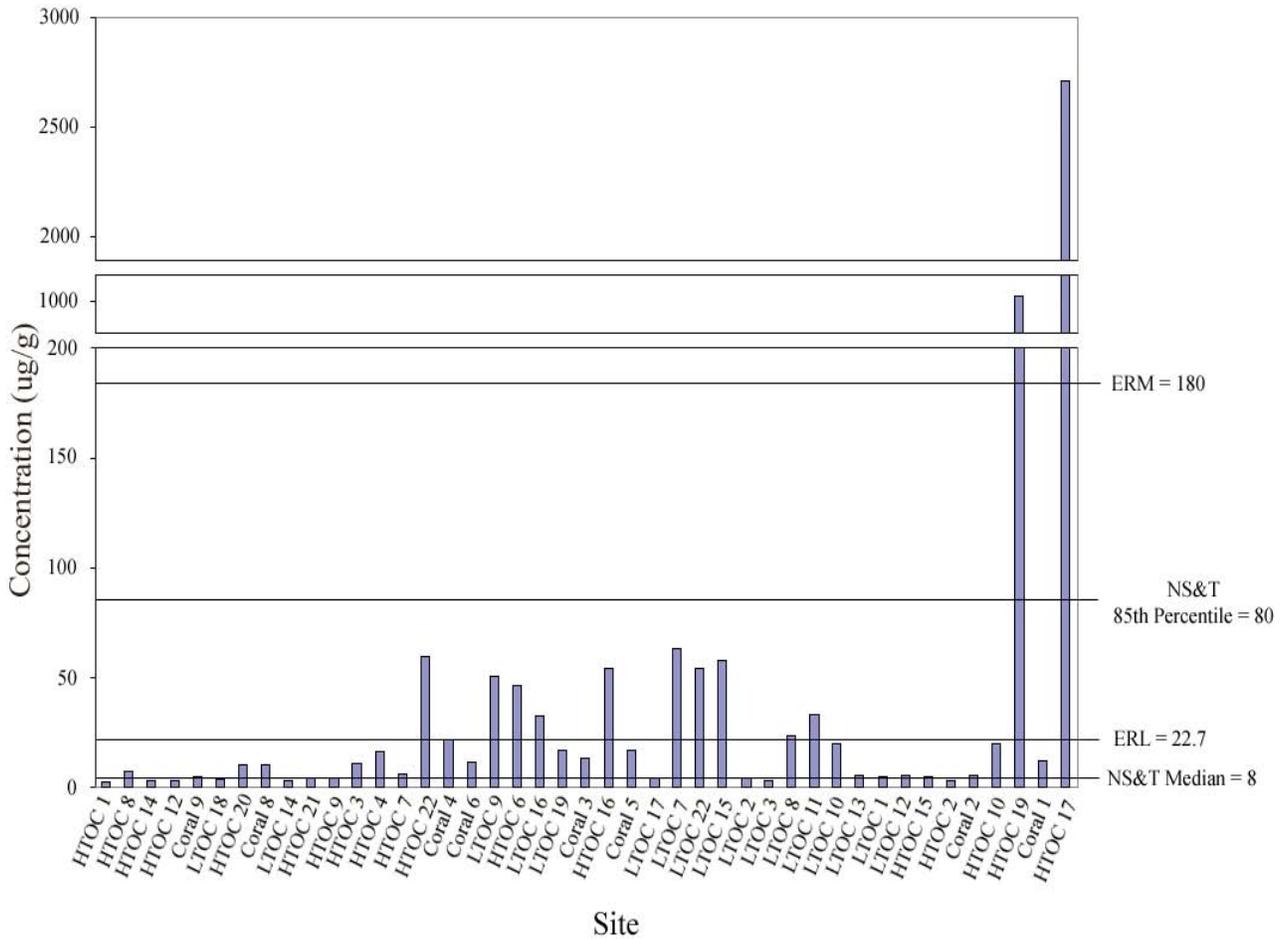


Figure 16. Total PCBs detected by site in the sediments in southwest Puerto Rico.

from industrial sites, to mention a few possibilities. There have been a number of industrial operations within Guanica Bay, ranging from sugar refining to fertilizer production to textile manufacture to electronics. It would be useful, at some point, to better characterize the spatial distribution of PCBs in Guanica Bay, including PCBs in sediment cores along with possible biological effects.

*Comparison with Other Data Sources.* Data from the Puerto Rico Environmental Quality Board (PREQB) was also accessed for this report using EPA's STORET database (U.S. EPA, 2005). The PREQB periodically monitors a variety of parameters, including a number of contaminants in water samples. Five PREQB sites are located inland or along the shore in the study area. Three of those sites are shown in Figure 15. PCBs were not detected in any of the water samples analyzed by PREQB. As part of EPA's NCA Program, total PCBs in the sediments were measured. The sum of the 10 individual congeners measured by the NCA was 3.10 ng/g. The sums of these same congeners measured at the two adjacent sites in Bahia Montalva (LTOC 15 and LTOC 22) by the NS&T Program were 8.04 and 7.09 ng/g.

*PCBs and Grain Size.* The relationship between PCBs, grain size and TOC can also be examined. Figure 17 contains a plot of total PCB (log 10 transformed) and percent silt in the sediments. A nonparametric analysis of the data revealed a significant positive correlation between the silt fraction of the sediment, and total PCB ( $P < 0.0001$ , Spearman Rho = 0.8578). An analysis of total organic carbon and TOC (Figure 18), however, revealed no significant relationship between TOC and total PCBs ( $P > 0.9242$ , Spearman Rho = 0.0150), similar to what was observed for PAHs. For both PAHs and PCBs, sediment chemical contaminant concentration appeared to be more influenced by sediment particle size than sediment TOC.

*Comparison of PCBs in the Sediments with Aroclors.* A type of fingerprinting is also possible with PCBs. The commercial Aroclor mixtures manufactured in the U.S. contained PCBs ranging in chlorination from two (DiPCBs) to the fully chlorinated PCB

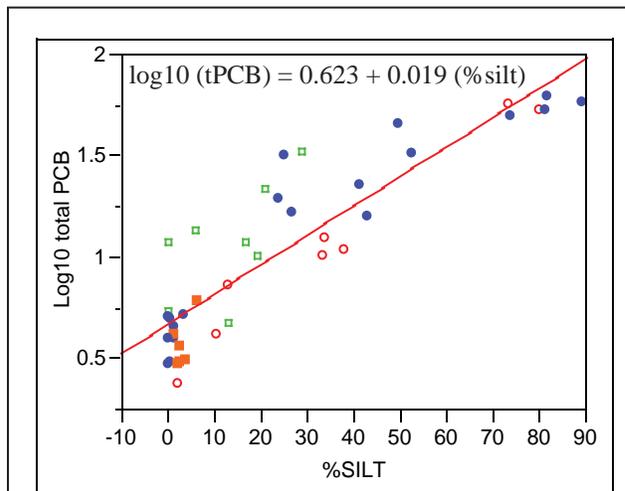


Figure 17. Bivariate fit of total PCB (log10 transformed) and percent silt in the sediments from southwest Puerto Rico. Symbols: ○, lagoon sites; □, coral sites; ■, backreef sites; ●, bankshelf sites.

containing 10 chlorine atoms, referred to as DecaPCB. By comparing the “signature” of the various Aroclor formulations to the PCBs found in the sediments in southwest Puerto Rico, a better understanding can be developed of the Aroclors that may have been used.

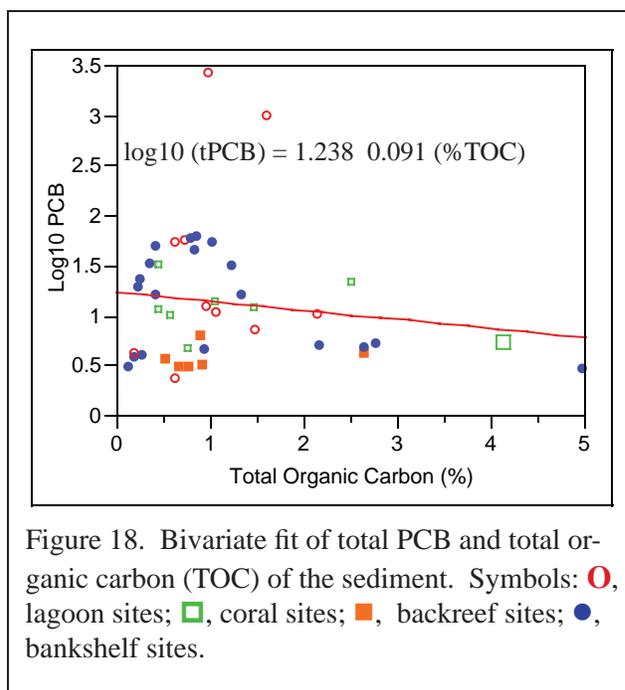


Figure 18. Bivariate fit of total PCB and total organic carbon (TOC) of the sediment. Symbols: ○, lagoon sites; □, coral sites; ■, backreef sites; ●, bankshelf sites.

Figure 19 contains the relative proportions of the different classes (e.g., TetraPCBs, PentaPCBs, etc.) of PCBs in Aroclor 1242, 1248, 1254 and 1260. These formulations consist of PCBs containing 2-7 chlorines. In Figure 20, the relative proportions of these same PCB classes found in the sediment samples from southwest Puerto Rico are presented. By comparing the two graphs, it can be seen that the pattern of PCBs in the two sediment samples from Guanica Bay shares some similarity with Aroclors 1248 and 1254.

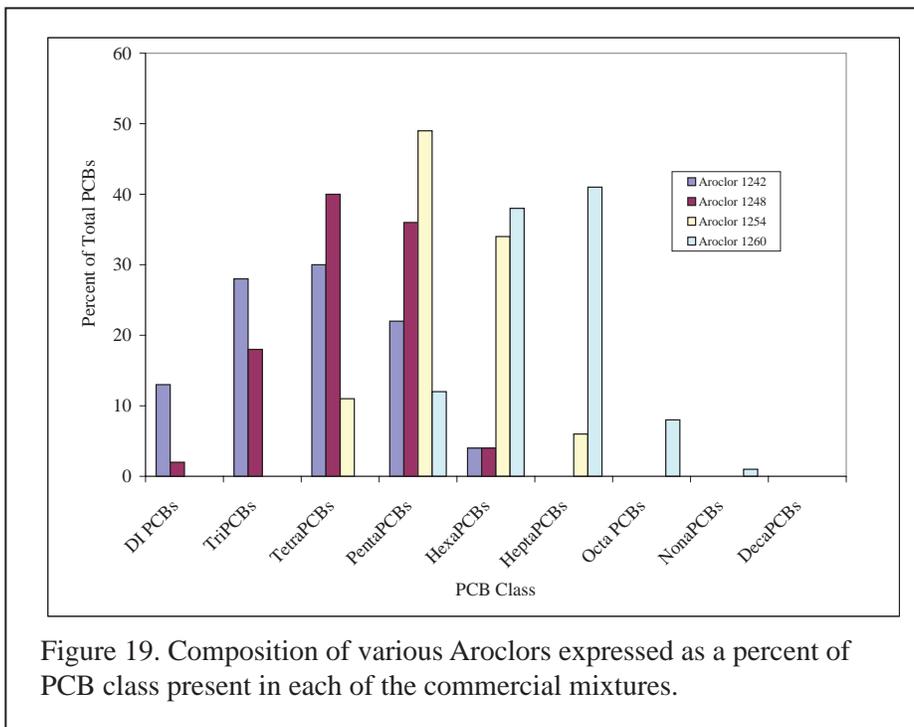


Figure 19. Composition of various Aroclors expressed as a percent of PCB class present in each of the commercial mixtures.

The mix of PCB classes found in the sediments around La Parguera is also similar to those found in the sediments in Guanica Bay. It is not known whether the PCBs detected in the sediments adjacent to La Parguera, although at much lower concentrations, might be the result of PCBs transported out of Guanica Bay. The predominant longshore flow in the study area is from east to west (CFMC, 1998). However, it is also quite possible that the PCBs detected in the sediments adjacent to La Parguera were the result of activities in that area. A nonparametric test revealed that lagoon sites (close to shore), had significantly higher concentrations of total PCBs than the backreef sites.

*Effects of PCBs on Corals.* Only one laboratory study on the uptake of PCBs in corals was located. Solbakken *et al.* (1984) assessed the bioconcentration

of radiolabeled HexaPCB (2,4,5,2',4',5'-hexachlorobiphenyl) in *D. strigosa* and *M. decatis*. The PCB was accumulated in both species, but at lower levels than Solbakken *et al.* (1984) found for phenanthrene and naphthalene. Depuration of this

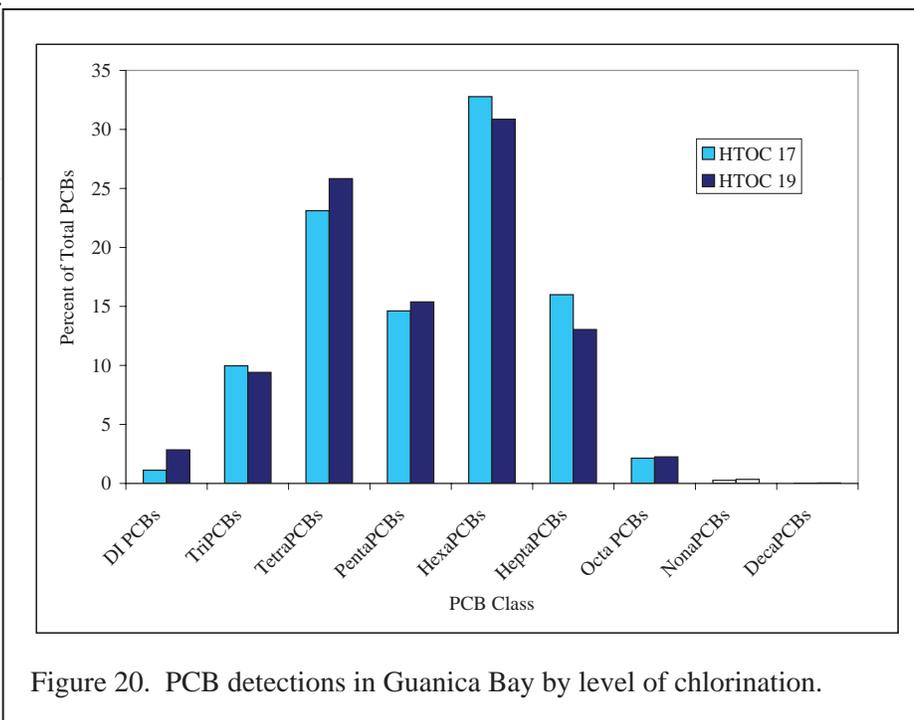


Figure 20. PCB detections in Guanica Bay by level of chlorination.

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PCB also proceeded at a slower rate than for either phenanthrene or naphthalene. After 275 days, nearly 33 percent of the original radioactivity from the PCB remained in the coral. Additional information on PCBs, particularly effects on corals would be useful as elevated concentrations of a number of the PCB congeners were found in the sediments in the study area. The slower depuration of this PCB congener, at least in the two species investigated by Solbakken *et al.* (1984) would indicate that once accumulated, PCBs would remain in the tissues, increasing the likelihood of adverse effects.

*Other Effects of PCBs.* PCBs readily accumulate in the tissues of other organisms including many marine animals such as filter feeders, fish, and marine mammals. PCBs do not readily break down in the environment and can take years to degrade in sediments. Biomagnification of PCBs occurs with higher levels found in the tissues of animals at the top of the food chain. Consumption of contaminated fish and shellfish is a common pathway for human exposure to PCBs. High levels of exposure in both humans and animals can cause adverse health effects including liver, thyroid, dermal and ocular changes, immunological alterations, neurodevelopmental changes, reduced birth weight, and reproductive toxicity (USDHHS, 2000a).

#### *Organochlorine Pesticides*

Organochlorine pesticides like DDT and chlordane were widely used in the past to control a variety of insect pests, both in agriculture and in and around structures including houses (*e.g.*, mosquito, ant, and termite control). Most organochlorine pesticides have been banned due to their long environmental half lives, ability to bioaccumulate, and toxic effects to nontoxic organisms. DDT (dichloro-diphenyltrichloroethane), was banned by the EPA for most uses in the U.S. in 1972. DDT is still used in many developing countries to help control malaria. Most uses of chlordane were canceled in 1978, and all uses were canceled by 1988. Another chlorinated insecticide, endosulfan is still in use primarily in agriculture.

*DDT.* Figure 21 and 22 contain the results of the analyses of total DDTs in the sediments. The results

for the individual organochlorine pesticides are included in Appendix G. Total DDTs is the sum of the parent isomers (4,4'-DDT and 2,4'-DDT) and the DDE and DDD degradation products.

*Comparison with DDT with NS&T Data.* As with the PAHs and the PCBs, there were elevated levels of DDT in the sediments near the town of La Parguera, and higher concentrations at the two sites in Guanica Bay. With the exception of the two sites in Guanica Bay, all concentrations of total DDTs were below the ERL value of 1.58 ng/g, and below the NS&T median and 85th percentile. A Wilcoxon nonparametric test revealed no differences in total DDTs concentration by habitat type.

In Guanica Bay, total DDTs exceeded the NS&T 85th percentile of 18 ng/g, and in HTOC 17, total DDTs concentration of 46.93 ng/g slightly exceeded the ERM value (46.1 ng/g), indicating a greater likelihood of biological effects on biota inhabiting this area. As with total PCBs, however, elevated levels of total DDTs did not appear to be present at the sampling sites just outside of Guanica Bay.

*Comparison with Other Data Sources.* The PREQB measured DDT and its metabolites in water samples at two sites north of Guanica Bay. Both DDT and its metabolites were below the level of quantification in the water samples. EPA's NCA Program also quantified total DDTs in the sediments in Bahia Montalva in 2000. Total DDTs in the sediment was 0.072 ng/g. Total DDTs measured in the sediments at LTOC 15 and LTOC 22 were 1.45 and 1.28 ng/g, respectively, somewhat higher than that found by the NCA Program.

*DDT and % Silt.* A regression of total DDTs (log<sub>10</sub> normalized) and % silt is shown in Figure 23a. A nonparametric analysis of the data indicated a significant positive correlation between total DDTs and the silt fraction of the sediment ( $P < 0.0001$ , Spearman Rho = 0.8381). A similar analysis to look at the association between total DDTs and sediment TOC, however, revealed no significant association ( $P > 0.7755$ , Spearman Rho = 0.0448).

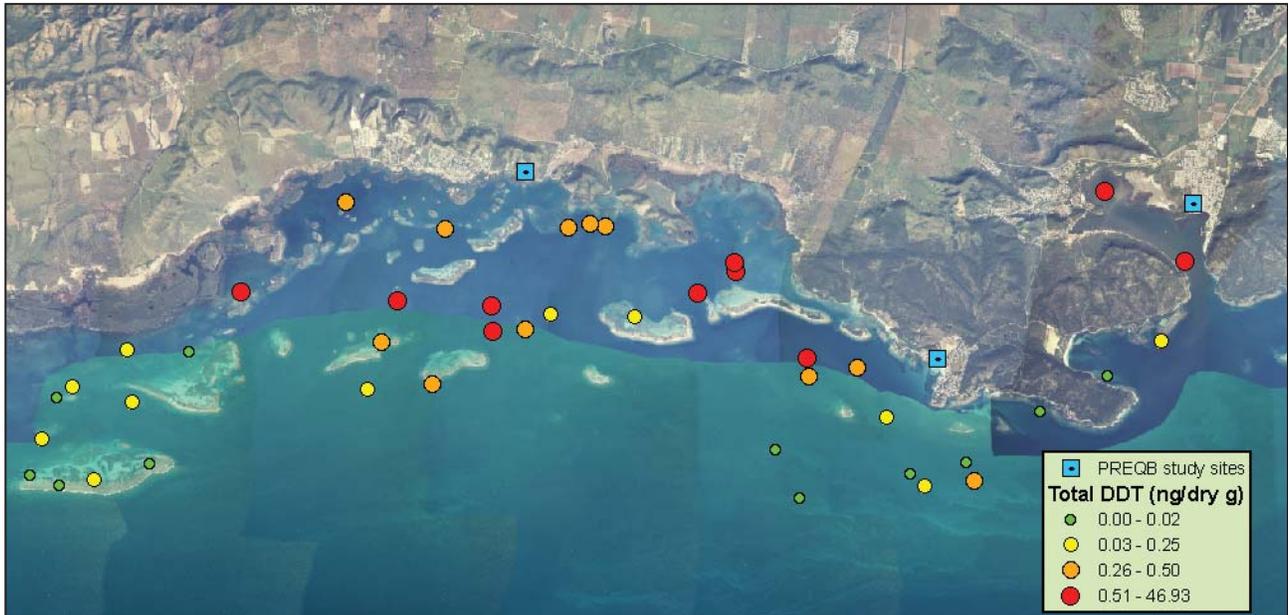


Figure 21. Map of total DDT detected by site in the sediments in southwest Puerto Rico. Data classified into quantiles.

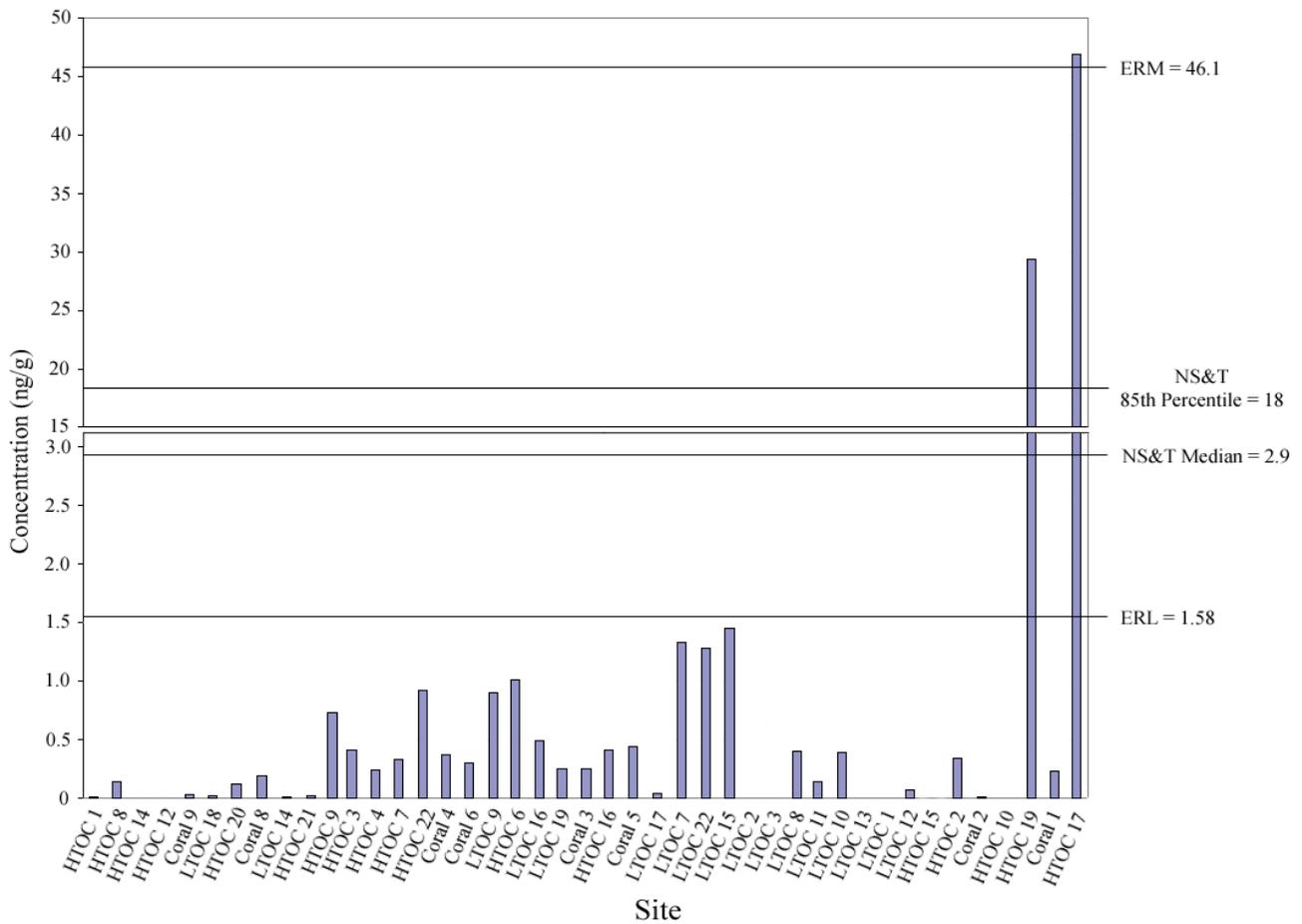


Figure 22. Total DDT detected by site in the sediments in southwest Puerto Rico.

The elevated levels of DDT and its metabolites (Appendix G) in Guanica Bay could be related to past agricultural activity. Much of the Lajas Valley drains to Guanica Bay through a series of manmade canals. The area has had extensive agricultural activity over the years, including sugarcane and pineapple production. DDT was likely applied to both of these crops to control insects on the foliage and in the soil.

*Effects of DDT on Corals.* No information was located on the effects of DDT in corals.

*Other Effects of DDT.* DDT readily accumulates in the tissues of marine organisms, especially in the adipose tissues of fish, shellfish, whales, and seals. DDT is also bioaccumulated by terrestrial organisms, including humans. Exposure of humans and lab animals to large quantities of DDT (grams) over a short period of time has been known to cause seizures, tremors, headache, nausea, vomiting, dizziness, liver damage, weight loss, reproductive harm, developmental effects, immunological effects, and multiple neurological effects. Currently, exposure to DDT and its metabolites is not considered to increase the risk of developing cancer (USDHHS, 2002a).

*Other Organochlorine Pesticides.* A number of other organochlorine pesticides included in this study were also detected in the sediments in southwest Puerto Rico (Table 4, Appendix G), including total dieldrin (sum of dieldrin and aldrin), endrin, and

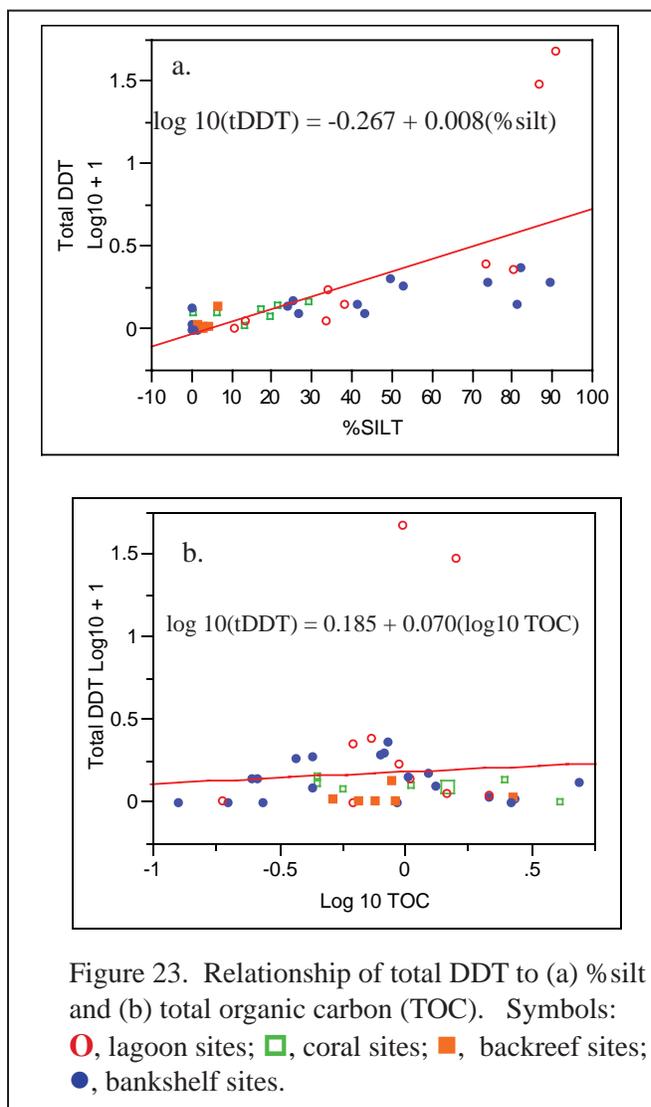


Table 4. Concentrations of other selected organochlorine pesticides found in the sediments in southwest Puerto Rico.

Compound(s)	Sites	Concentration (ng/g)	NS&T Median (ng/g)	NS&T 85th Percentile (ng/g)
Total dieldrin	HTOC 17	0.41	0.30	1.90
	HTOC 19	0.42		
	HTOC 22	0.14		
Endrin	Coral 4	0.06	0.00	0.06
	Coral 6	0.16		
	HTOC 6	0.27		
	HTOC 8	0.06		
	HTOC 9	0.13		
Total chlordane	HTOC 17	2.54	0.51	3.10
	HTOC 19	1.08		
Lindane ( $\gamma$ -HCH)	Coral 8	0.69	0.00	0.82

total chlordane (alpha-chlordane, gamma-chlordane, heptachlor, heptachlorepoide, oxychlordane, *trans*-nonachlor, and *cis*-nonachlor). None of these compounds or compound classes currently have ERL or ERM values. Most concentrations were below the NS&T median (Table 4). A few sites, particularly the two in Guanica

Bay (HTOC 17 and HTOC 19) had sediment concentrations above the median for total dieldrin, endrin, and total chlordane. Three sites, (Coral 6, HTOC 6 and HTOC 9) had endrin concentrations above the NS&T 85th percentile.

Concentrations of these same pesticides in almost all of the water samples collected by the PREQB were below the detection limit or not detected. Dieldrin was detected once by the PREQB at a site upstream of Guanica Bay at a concentration of 0.6 ng/L.

The chlorinated insecticide endosulfan is currently used in agriculture on a variety of vegetable and fruit crops. Endosulfan is a restricted use pesticide, meaning that it can only be applied by certified applicators. In the past, endosulfan was classified as a general use pesticide, and could also be used by homeowners to control insect pests. A map of endosulfan detections is shown in Figure 24. It is interesting to note that while there were detections of endosulfan adjacent to La Parguera, there were no endosulfan detections in Guanica Bay. Although there were only two sites sampled in Guanica Bay, the results may indicate that endosulfan was not a pesticide commonly applied agriculturally in the Lajas Valley.

The NCA Program measured a sediment concentration of 0.43 ng/g total endosulfan at Bahia Montalva. The sediment concentration of total endosulfan in the sediment sample at LTOC 15 was 1.32 ng/g, and at LTOC 22 endosulfan was not detected. Another currently used pesticide, the

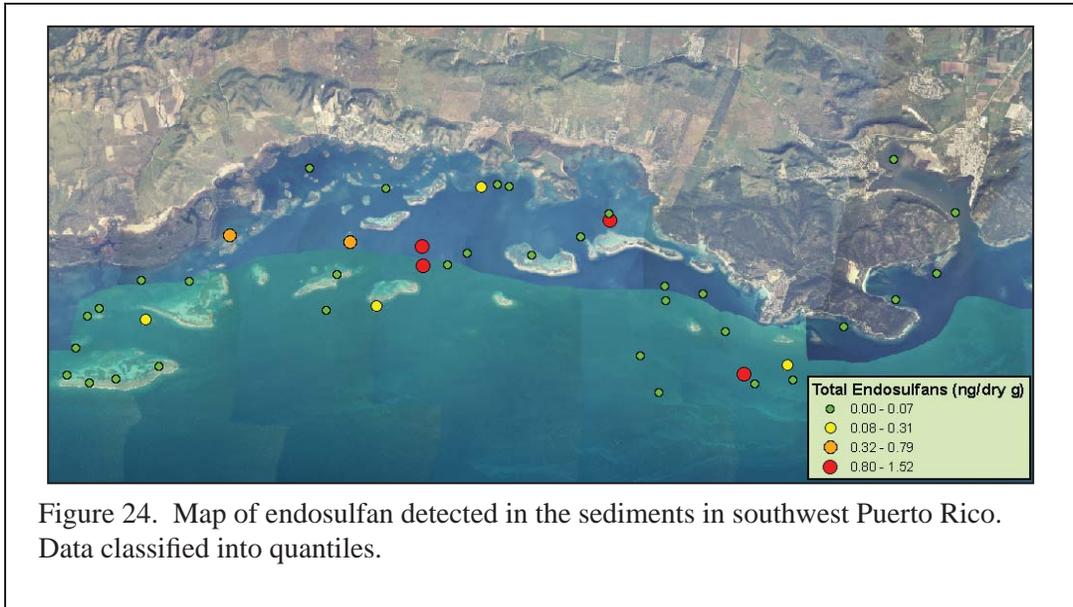


Figure 24. Map of endosulfan detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

chlorinated organophosphate insecticide chlorpyrifos was detected at one site in Guanica Bay (HTOC 19), at a concentration of 0.60 ng/g.

#### *Effects of Other Chlorinated Pesticides on Corals.*

The only data located on the effects of other chlorinated pesticides analyzed in this project was for chlorpyrifos. Acevedo (1991) exposed larvae of the coral *Pocillopora damicornis* to concentrations of chlorpyrifos ranging from 10 to 10,000 ug/L for up to 96 hours. Chlorpyrifos concentrations of 10 ug/L had no noticeable adverse effects on the coral larvae. A chlorpyrifos concentration of 100 ug/L slowed the swimming of larvae. A concentration of 1,000 ug/L killed 50 to 100 percent of the larvae within 24 hours. At 10,000 ug/L, all larvae were killed within 12 hours. Acevedo (1991) also tested two other compounds, the insecticide carbaryl, and 1-naphtho, a degradation product of carbaryl. Both compounds were found to have no noticeable effects on the larvae of *P. damicornis* after 24 hours at concentrations up to 10,000 ug/L (Acevedo, 1991).

*Other Effects of Chlorinated Pesticides.* Most chlorinated pesticides have the ability to bioaccumulate in aquatic and terrestrial animals including humans. Accumulation typically occurs in the adipose tissues. Many of the organochlorine pesticides affect the central nervous system. Negative

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health effects include seizures, respiratory disease, nausea, vomiting, developmental and reproductive effects, liver damage, and musculoskeletal effects. A number of chlorinated pesticides such as chlordane and dieldrin have been labeled as potential carcinogens (USDHHS, 2002b).

#### *Polybrominated Biphenyl Ethers*

Polybrominated diphenyl ethers or PBDEs belong to a group of flame retardants used in products ranging from foam cushions in furniture to the plastics in televisions and computers. The use of PBDEs results in a slower ignition time and rate of fire growth, providing additional time to escape or extinguish the fire. PBDEs have recently come under scrutiny, however, because of increasing concentrations of these compounds in the environment and evidence of immunological, endocrine and hepatic effects (U.S. EPA, 2006).

*PBDE Concentrations.* The concentration of total PBDEs (sum of 38 congeners) found in the sediments in southwest Puerto Rico is shown in Figure 25 and 26, and in Appendix H. The analysis of PBDEs within the NS&T Program is a new activity. As a result, NS&T median and 85th percentile values have not been established for PBDEs in sediments. In addition, ERL and ERM values have not been developed for either total PBDEs or for any of the congeners.

The concentrations of total PBDEs found in the sediment samples were low, the average concentration was 0.54 ng/g. Total PBDEs were fairly evenly distributed across the study area (Figure 25), with a spike in Guanica Bay at HTOC 17 (7.2 ng/g). It is interesting to note that around La Parguera, slightly higher concentrations of total PBDEs were found offshore, in the areas around the emergent reefs as opposed to higher concentrations nearshore, the pattern found for a number of other contaminant classes.

In the U.S. there is one manufacturer of PBDEs. The commercial PBDE products, analogous to the Aroclors, contain mixtures of various congeners. Theoretically, 209 congeners could be

included, but a much smaller number are actually found in the PBDE-containing products sold in the U.S. Three formulations of commercial PBDE products are produced in the U.S., and are referred to as pentabromodiphenyl ether (pentaBDE), octabromodiphenyl ether (octaBDE), and decabromodiphenyl ether (decaBDE). Each commercial product contains a mixture of the various congeners. For example, the pentaBDE is actually composed of tetraBDEs (24-38%), pentaBDEs (50-62%), hexaBDEs (4-12%) and triBDEs (0-1%) (U.S. EPA, 2006).

Figure 27 presents the results of the analysis by class of PBDE (*i.e.*, mono to hepta PBDEs). It can be seen that the diBDEs contributed significantly to the PBDEs detected, followed by the tetra- and pentaBDEs. The highest diBDE detected in a sample was BDE 11 (3,3'-DiBDE), detected at a concentration of 7 ppb at HTOC 17 in Guanica Bay (Appendix H). A number of other sites also had detections of this congener, but at lower concentrations. Most of the remaining PBDEs found in the sediment samples were the tetra and penta congeners. The penta- and octaBDE commercial products are made up primarily of the tetra, penta, and hepta congeners. The diBDE congener is not a component of the mixtures produced and used in the U.S. The presence of this congener in the samples could be the result of the breakdown of some of the higher brominated PBDEs, or perhaps diBDE is used in the area.

No other data sources were located for concentrations of PBDEs in the study area. In the U.S., the majority (74%) of the commercial PBDE product used in 2001 was actually the decaBDE mixture (U.S. EPA, 2006). The decaBDE formulation contains deca congeners (10 bromines) almost exclusively. Unfortunately, the sediment analysis for this project did not include the decaBDEs.

*Effects of PBDEs on Corals.* No data on the effects of PBDEs on corals was located. PBDEs have the ability to bioaccumulate, and have been found in aquatic and terrestrial organisms, and in humans. As a result, PBDEs may also be present in coral tissues.

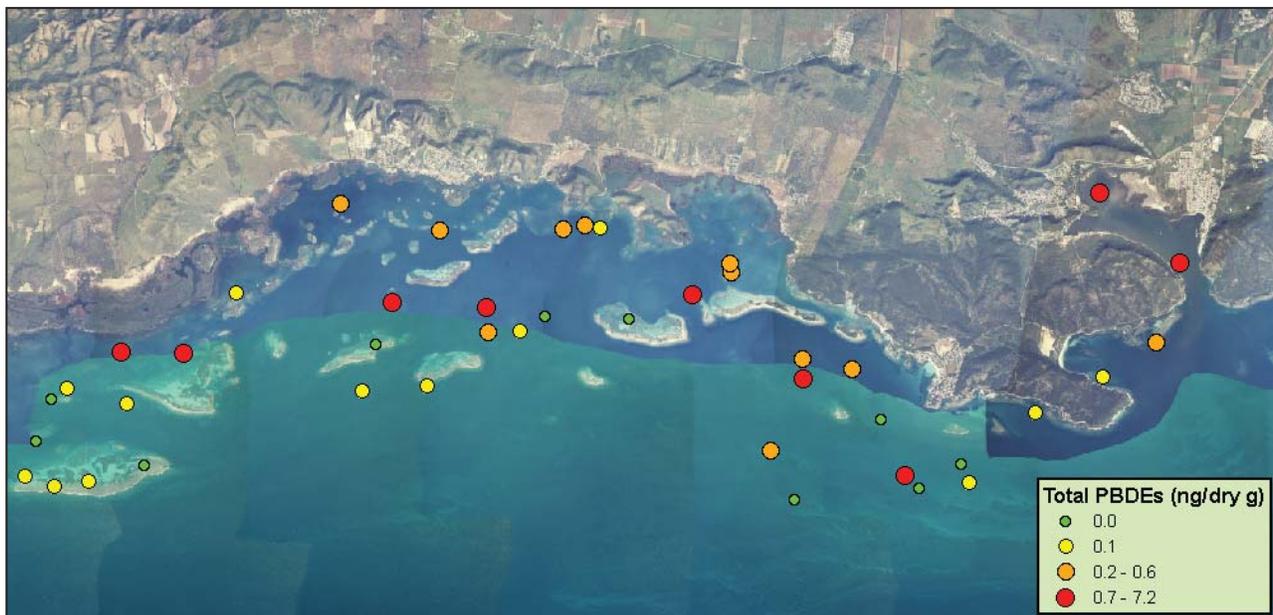


Figure 25. Map of total PBDEs detected by site in the sediments in southwest Puerto Rico. Data classified into quantiles.

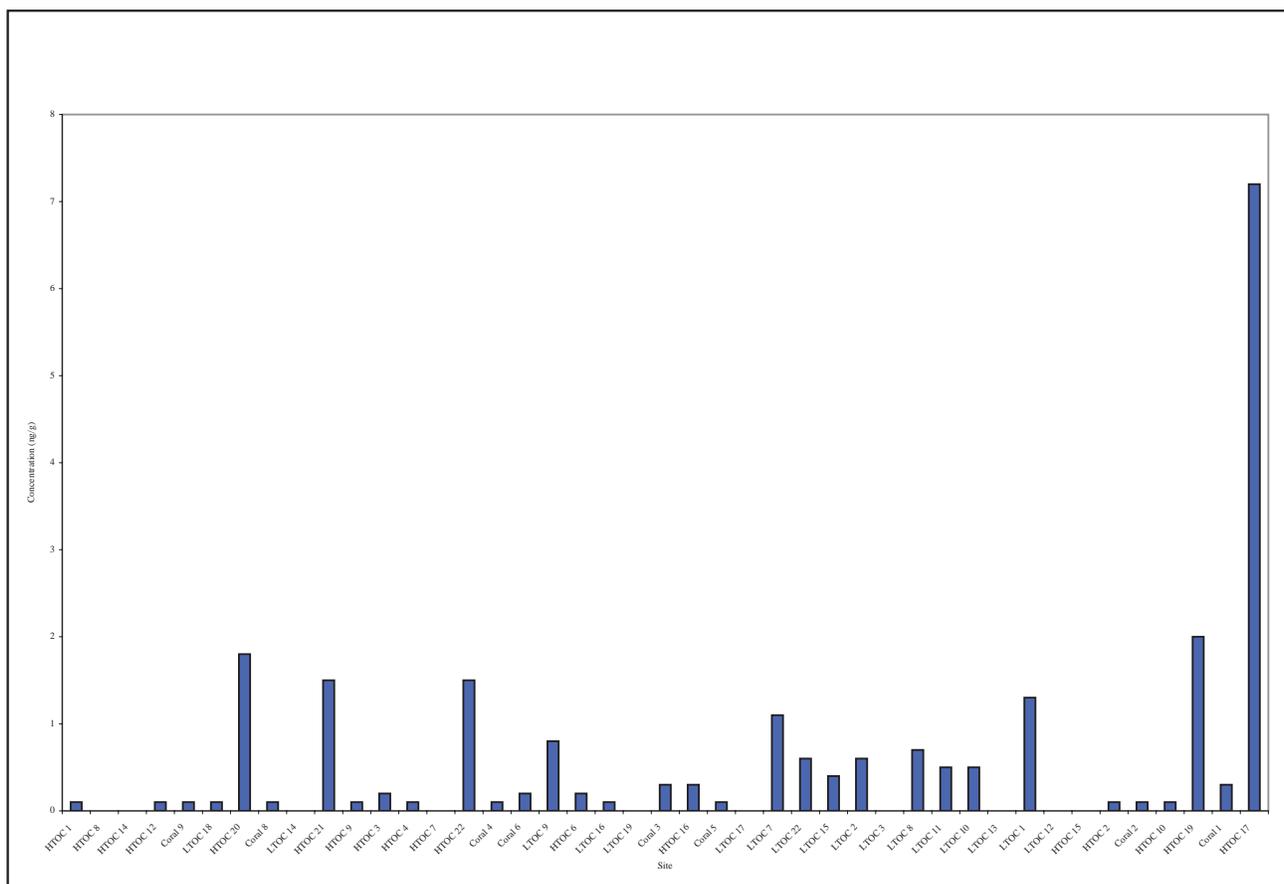


Figure 26. Total PBDEs detected by site in the sediments in southwest Puerto Rico.

*Other Effects of PBDEs.* There is a significant and growing body of work on the effects of PBDEs, primarily for vertebrates. The increasing concentrations of PBDEs in human breast milk, from nearly zero in 1985 to over 200 ng/g lipid weight recently, is seen as an alarming trend and a cause for more effective control of their manufacture and use.

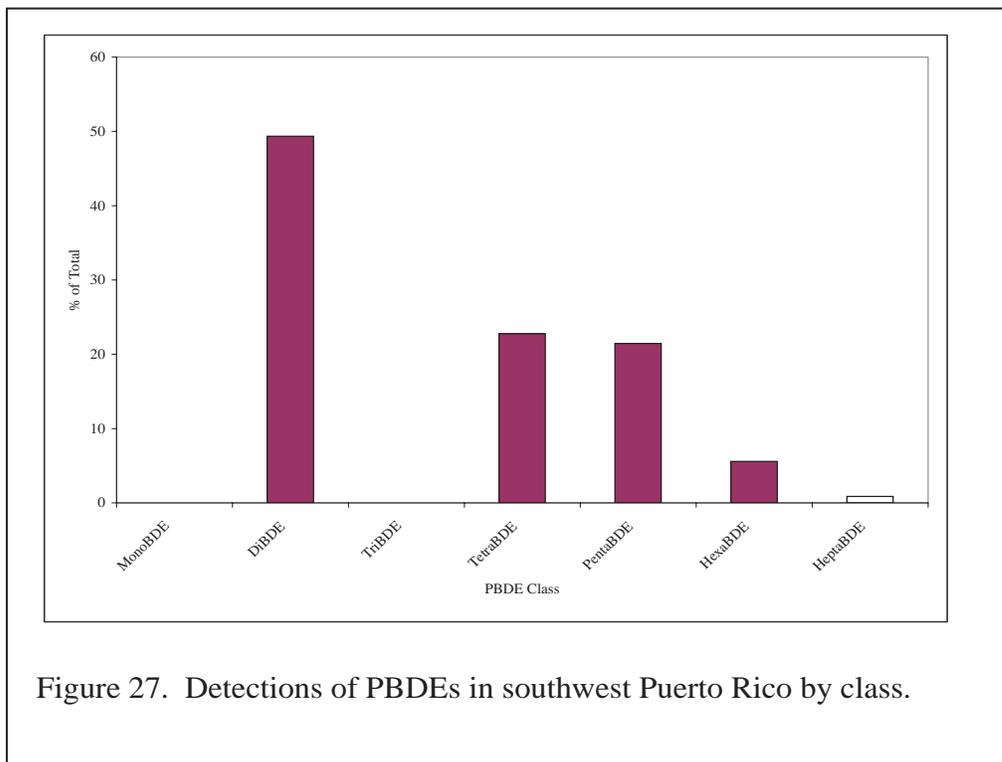


Figure 27. Detections of PBDEs in southwest Puerto Rico by class.

Much of the work to date on the effects of PBDEs has focused on the penta congeners. Fowles *et al.* (1994) found that pentaBDE mixtures resulted in suppressed antibody production, and Thuvander and Darnerud (1999) found decreased immunoglobulin production in mice. Developmental effects have also been found in mice exposed in the laboratory to PBDEs (Branchi *et al.*, 2002).

It is also now fairly well established that due to their structural similarity to the hormone thyroxine, PBDEs have the ability to mimic thyroid hormones, and PBDES have been associated with a number of health consequences including goiter, benign and neoplastic thyroid diseases, and impaired neural development. Zhou *et al.* (2001) found effects on the thyroid system, mainly reduced serum levels of thyroxine in rats, following exposure to pentaBDE. Meerts *et al.* (2001) found evidence of estrogenic effects for 11 PBDE congeners and 2 hydroxylated metabolites. Stoker *et al.* (2004) found evidence of anti-androgenic activity in rats. There are also limited data to suggest that PBDEs can cause liver defects.

#### *Butyltins*

The results of the analyses of butyltins are shown in Figure 28 and in Appendix I. Mono-, di-, tri-, and tetrabutyltins were analyzed in the sediments. In the 1950s, tributyltin or TBT was first shown to have biocidal properties (Bennett, 1996). Beginning in the late 1960s, TBT 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 shell, weed 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 is approximately a month (Batley, 1996). Experiments with oxid

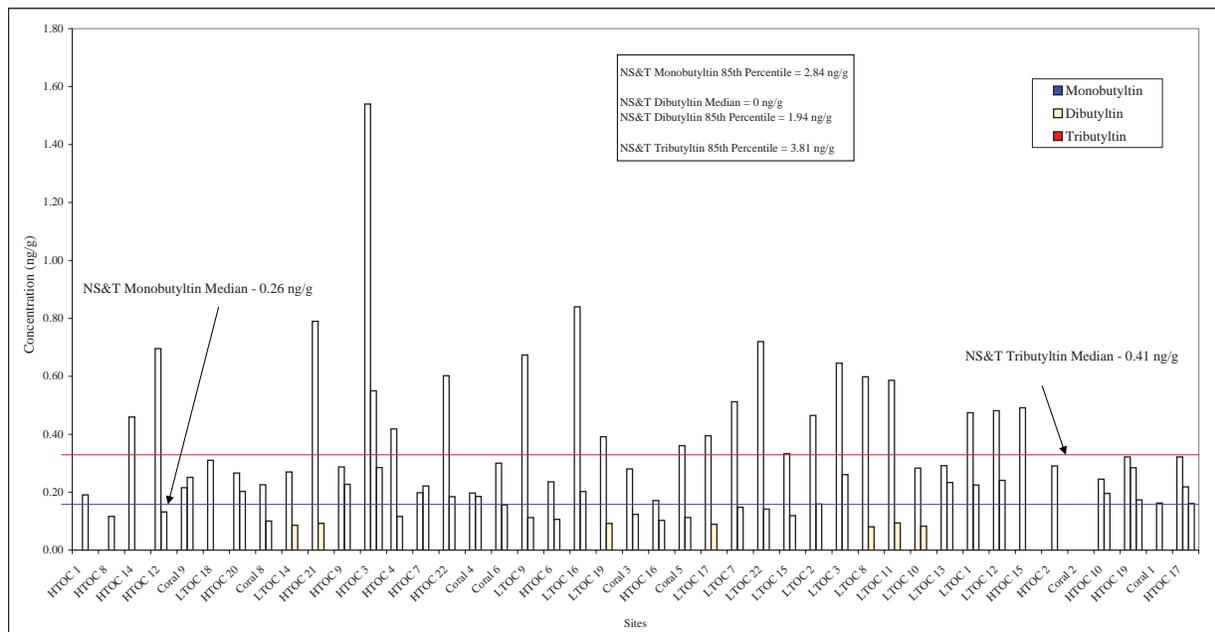


Figure 28. Butyltins detected in the sediments in southwest Puerto Rico.

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 appear to be considerably slower, on the order of 2-4 years (Batley, 1996).

There were few detections of TBT in the sediments sampled in southwest Puerto Rico (Figure 28). Detectable TBT was only found at three sites, two of which were in Guanica Bay. At all three sites, TBT concentrations were below the NS&T median. In the sediment samples, monobutyltin was the dominant butyltin found, and is likely the result of TBT debutylization. No samples in the study area had concentrations of dibutyltin or monobutyltin above the NS&T 85th percentile. Several sites, however, had sediment concentrations above the NS&T median for monobutyltin (0.26 ng/g). Tetrabutyltin, an impurity in the manufacture of tributyltin oxide, was not detected in any of the sediments. No other data sources for TBT in study area were located.

*Effects of TBT on Corals.* 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 ( $EC_{50}$ ) of fertilization after four hours was 200 ug/L. A second set of experiments was carried out to assess the successful settlement and metamorphosis of larval *A. millepora*. The calculated concentration needed to inhibit 50 percent larval metamorphosis was low, only 2 ug/L.

Negri *et al.* (2002) investigated the effects of contaminants in sediments on the coral *Acropora microphthalma*. This was the only work located that assessed the effects of contaminants in sediments on corals. 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 ug/g, copper concentrations of 1,180 ug/g, and zinc concentrations of 1,570 ug/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 on preconditioned terracotta tiles in the laboratory. The tiles were preconditioned by placing the tiles on control reefs for three months.

*Other Effects of TBT.* Beginning in the 1970s, a number of effects related to TBT exposure became apparent in the environment, particularly in gastropods and bivalves. In 1971, the term “imposex” was first used to describe the superimposition of male characteristics in the intertidal snail *Ilyanassa obsoleta* (Gibbs and Bryan, 1996). In the 1980s, TBT was implicated in the near collapse of oyster farming in western France and southern England, and in the dogwhelk *Nucella lapillus* in areas of high shipping and boating activity in southwest England. In North America, sterilization of the gastropods *Nucella emarginata*, *Nucella lamellosa* (northwest coast) and *I. obsoleta* (northeast coast) were found. TBT has also been shown to cause shell deformation in the Pacific oyster *Crassostrea gigas* in the U.S., along with abnormal development of larvae (Peachey, 2003).

France enacted a ban on TBT in 1982. In the U.S., the Organotin Antifouling Paint Control Act of 1988 called for a ban on the use of tributyltin-based paints on vessels 25 meters in length or less (except for aluminum vessels). A number of other countries, primarily in Europe and in Australia adopted regulations prohibiting the use of TBT shortly thereafter.

The physiological and biochemical mechanisms of TBT are poorly understood, but in gastropods the mode of action appears to be related to effects on the endocrine system. Observations with *N. lapillus* have suggested that TBT elevates levels of testosterone, which may result from an inhibition of the Cytochrome P-450 dependant enzyme aromatase, responsible for the conversion of testosterone to estradiol (Gibbs and Bryans, 1996).

#### *Trace Elements*

Sixteen major and trace elements were analyzed in the sediment samples collected. The results of the

analyses are contained in Appendix J. An assessment of arsenic, chromium, nickel and copper follows.

*Arsenic.* The results of the sediment analysis are shown in Figures 29 and 30. Arsenic concentrations were low. Only one site, Coral 1 (Figure 30), just outside of Guanica Bay, had a concentration above the NS&T median of 6.8 ug/g. The concentration of arsenic in sediments at Coral 1 (10.3 ug/g) was also somewhat higher than the ERL value of 8.2, but appreciably below the ERM value. A nonparametric analysis indicated no significant relationship between arsenic concentration and habitat, and unlike a number of other chemical contaminants, there was no relationship between arsenic and grain size.

No data were located from the PREQB for arsenic. In 2000, EPA’s NCA Program sampled sediments in Bahia Montalva. The concentration of arsenic at this site was 5 ug/g, similar to the 7.7 ug/g and 5.84 ug/g found at LTOC 22 and LTOC 15, respectively, the two sites adjacent to Bahia Montalva.



*An image of symmetrical brain coral, Diploria strigosa.*

In Figure 29, it can be seen that the spatial pattern for arsenic in the sediments was somewhat different from that of the organic compounds and as will be seen, for a number of the other trace elements. In this study, elevated levels of chemical contaminants were typically found nearshore, adjacent to the town of La Parguera, and in Guanica Bay. This pattern suggests, at least for the organic compounds, that the contamination is associated with anthropogenic activities (*e.g.*, land-based or nearshore marine). Figure 29 shows that elevated concentrations of arsenic, however, were outside of Guanica Bay and to the east of La Parguera.

Because trace elements occur naturally in the Earth’s crust, their presence in the environment can be the result of both natural and anthropogenic inputs. Valette-Silver *et al.* (1999) hypothesized that arsenic contained in phosphatic rock was a significant source



Figure 29. Map of arsenic detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

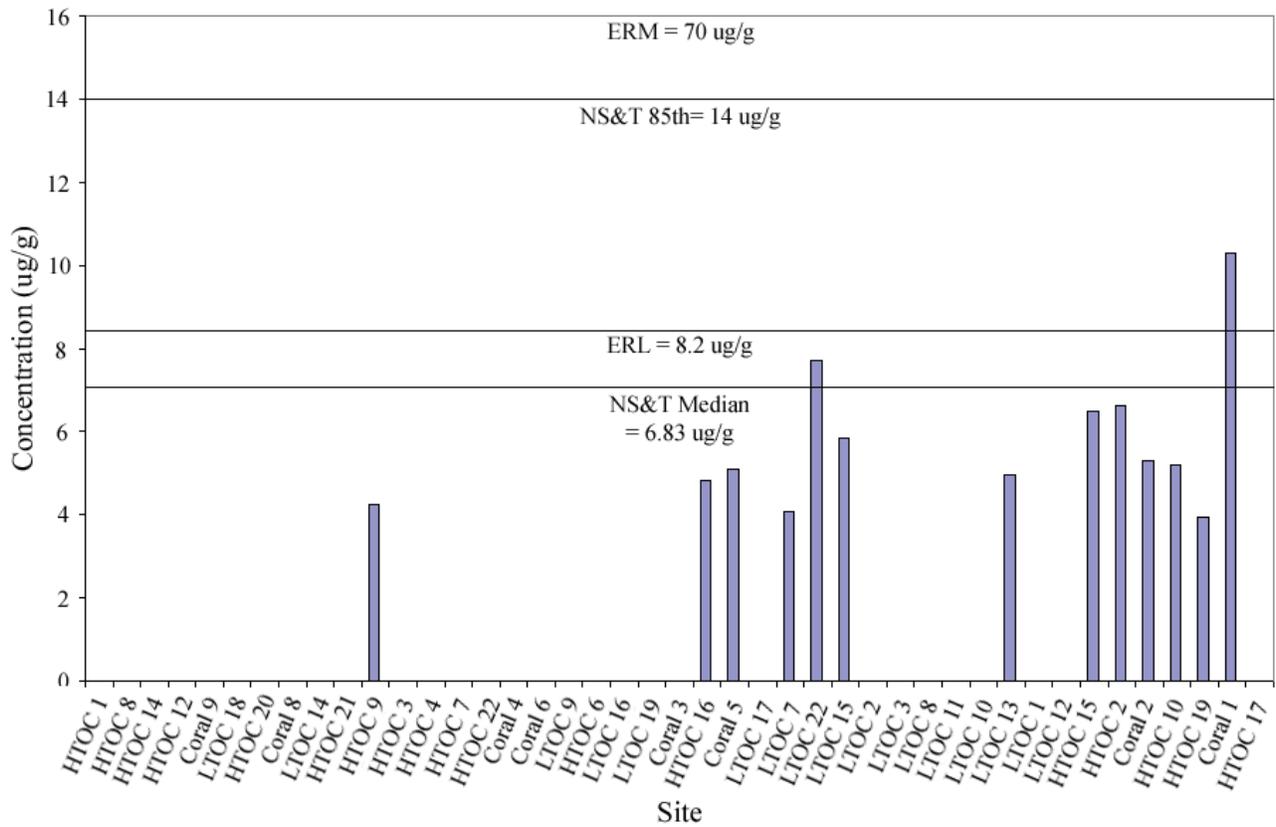


Figure 30. Arsenic detected by site in the sediments in southwest Puerto Rico.

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contributing to elevated arsenic concentrations in both sediments and bivalve tissues in the southeast U.S.

The results presented here for southwest Puerto Rico do not appear to indicate a large anthropogenic source for arsenic, either around the town of La Parguera or in Guanica Bay. The presence of slightly higher arsenic concentrations outside of these populated areas could be the result in part, of natural processes. Additional work would be needed to assess this possibility.

*Effects of Arsenic on Corals.* No literature on the effects of arsenic on corals was found.

*Other Effects of Arsenic.* Arsenic is a widely distributed element occurring most commonly in the environment as inorganic and organic combinations in soil, sediments, water and the air. Arsenic has the potential for accumulation in the tissues of fish and shellfish, but usually in the less harmful arsenobetaine form. Arsenobetaine, containing three methyl groups bonded to the arsenic atom, results from the reduction and methylation of arsenic.

Inorganic arsenic, however, has been shown to affect the skin, liver, and to a lesser extent the endocrine system in humans and test animals. Arsenic also has documented neurological effects in humans including headache, lethargy, mental confusion, hallucination, seizures, and coma (USDHHS, 2005).

The U.S. Department of Human Health and Services (DHHS), the International Agency for Research on Cancer (IARC) and EPA have all classified inorganic arsenic as a carcinogen. The most common forms of cancer caused by inorganic arsenic are lung and skin cancer, resulting from long term exposure to higher than normal levels of arsenic.

*Chromium.* Concentrations of chromium detected in the sediments are shown in Figures 31 and 32. The spatial pattern found for chromium in the sediments, elevated levels adjacent to the town of La Parguera and at the two sites in Guanica Bay, is similar to the pattern for a number of the organic compound classes analyzed in this project.

With the exception of Guanica Bay, chromium levels in the sediments were below the NS&T national median of 55 ug/g, and also below the ERL value of 81 ug/g. The PREQB detected a concentration of 11 ug/L in a water sample north of Guanica Bay. EPA's NCA Program detected a concentration of 23 ug/g in the sediments in Bahia Montalva, similar to the 31 ug/g and 30.4 ug/g concentrations detected at LTOC 15 and LTOC 22 (Appendix J), respectively. In Guanica Bay, however, the chromium levels were not only above the ERL value, but also above the ERM value of 370 ug/g, indicating that effects as a result of chromium contamination at these sites were likely. The ERM is the median value of the laboratory effects data.

A nonparametric analysis (Wilcoxon Test) indicated a significant association between habitat and chromium concentrations ( $P < 0.0005$ , ChiSquare = 17.8641). Similar to a number of organic chemical contaminants, metals are often associated with the silt and clay fractions of the sediments. Figure 33 shows the relationship between chromium levels and the silt and clay fractions of the sediment. A nonparametric analysis of the data indicated that both the silt ( $P < 0.0001$ , Spearman Rho = 0.7259) and the clay ( $P < 0.0001$ , Spearman Rho = 0.6354) fractions were positively correlated with chromium in the sediments. Rieuwertts *et al.* (1998) noted that metal accumulation in these size fractions is a function of the high relative surface areas for adsorption. In addition, metal ions are also absorbed through both ion exchange and specific adsorption processes (Rieuwertts *et al.*, 1998).

Chromium has a number of uses in industry, such as in stainless steel, chrome plating, and as a catalyst. In Guanica Bay, there have been various industrial activities over the years, ranging from the production of sugar to fertilizer mixing to textile manufacture. Inorganic fertilizers can contain certain trace elements including cadmium, arsenic, copper, chromium and lead (Mortvedt, 1996). Elevated levels of cadmium in phosphatic rock, used in the manufacture of inorganic fertilizers have been cited as a concern due to potential effects on human health (Smil, 1999; Mortvedt, 1996). At the two sites sampled in Guanica Bay, however, cadmium levels

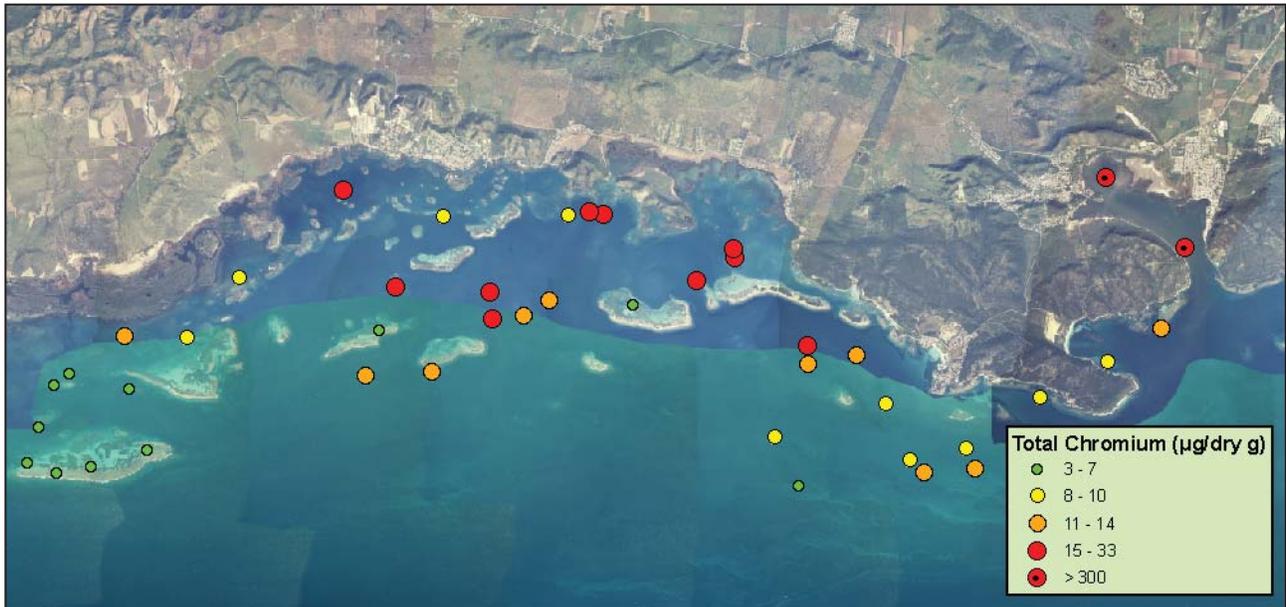


Figure 31. Map of chromium detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

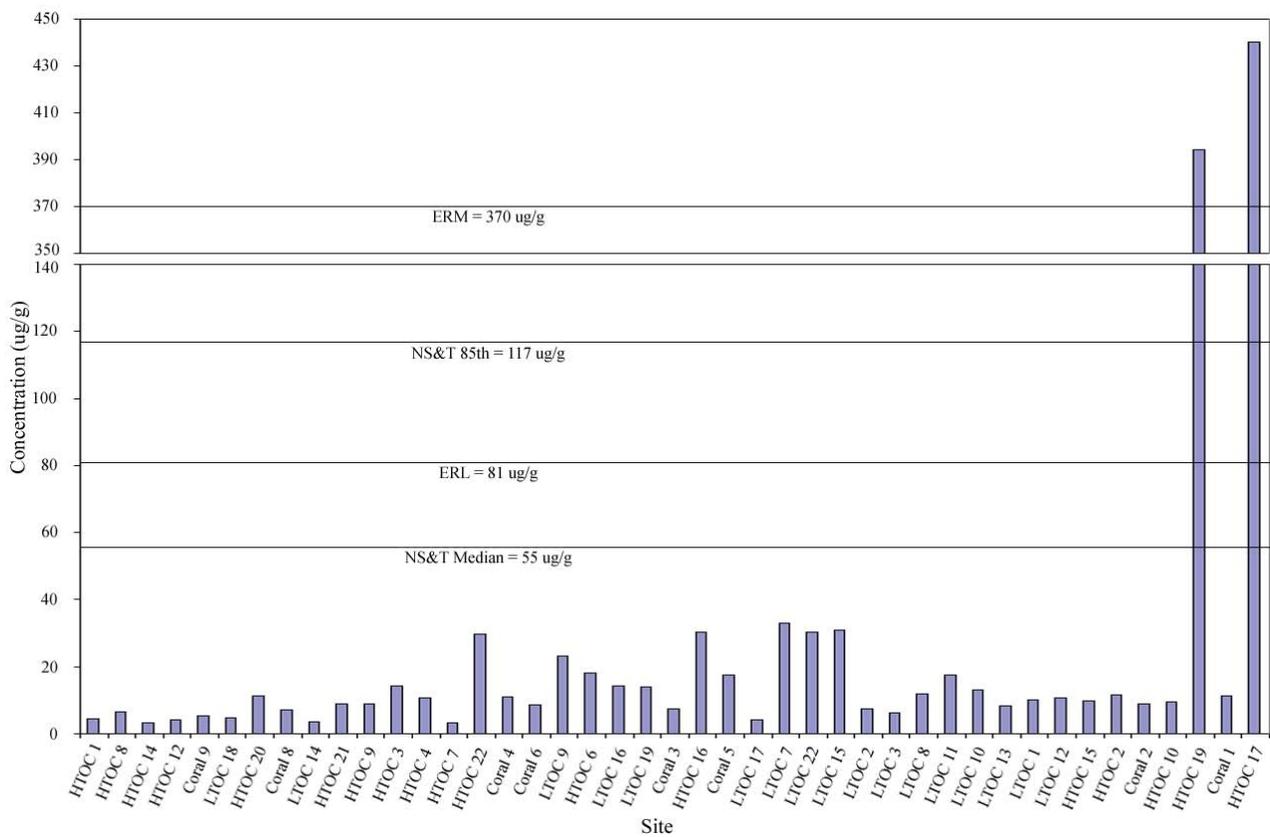


Figure 32. Chromium detected by site in the sediments in southwest Puerto Rico.

were low (Appendix J) in comparison to the amount of chromium in the sediments (Figure 32).

Chromium is frequently used along with nickel and sometimes manganese in the production of stainless steel. Chromium can constitute up to 18 percent of the chemical composition of stainless steel (Wallinder *et al.*, 2004). Although only two sediment samples were analyzed from Guanica Bay, the levels of chromium, and nickel (next section) at both of these sites were over an order of magnitude higher than at any of the other sites sampled in this study. Manganese, which is also a fairly common component in stainless steel formulations, was elevated at the two sites in Guanica Bay as well (Appendix J).

Stainless steel was first manufactured and used in the early part of the 20th century. Chromium and nickel have both been shown to leach out of stainless steel as a result of industrial use or environmental (*e.g.*, weathering) processes (Wallinder *et al.*, 2004). One of the common industrial uses of stainless steel is in the production of sugar. The elevated levels of chromium, nickel, manganese, and also iron in the sediments sampled in Guanica Bay (Appendix J), could be related to the use of stainless steel in the production of sugar, or other industrial activities that have occurred in the area around Guanica Bay. The production of sugar in Guanica Bay area ceased in the early 1950s.

*Effects of Chromium on Corals.* No information was located on the effects of chromium on coral. This type of information would be useful for this study, and in other coral reef areas where chromium may be present at elevated levels.

*Other Effects of Chromium.* Chromium has a low bioaccumulation potential in the tissues of fish and shellfish. Intake of high levels of chromium in the mg/kg range has been shown to have severe health effects including dehydration, caustic burns, convulsions, irregular respiration, hemorrhaging, shock, liver damage, acute renal failure, and death. Male rats exposed to 42 mg chromium(VI)/kg/day as potassium dichromate in the drinking water

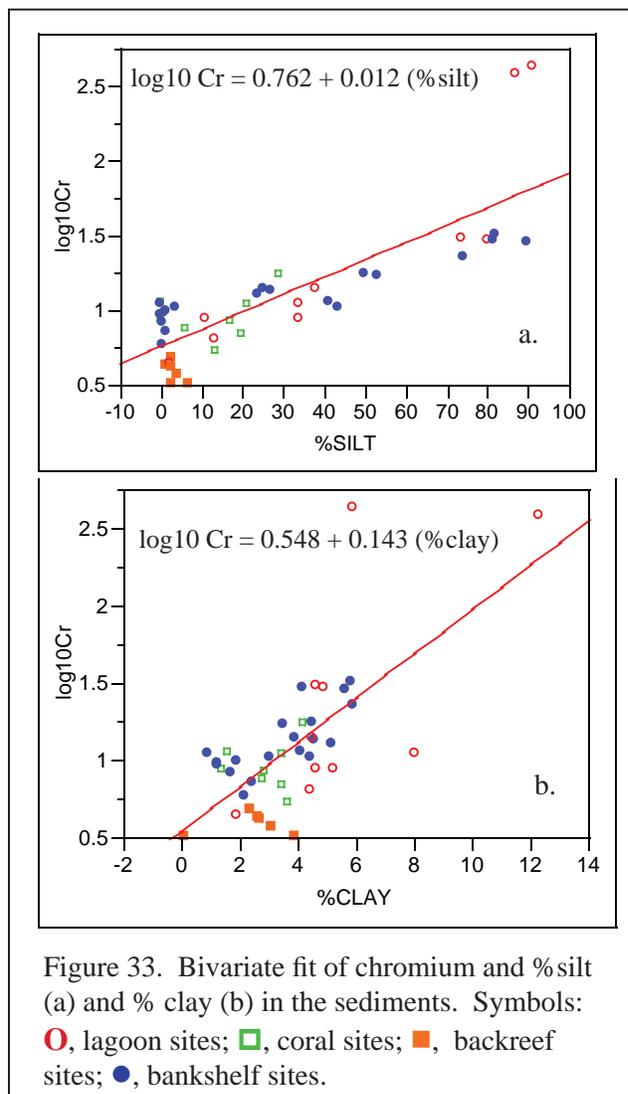


Figure 33. Bivariate fit of chromium and % silt (a) and % clay (b) in the sediments. Symbols: **○**, lagoon sites; **□**, coral sites; **■**, backreef sites; **●**, bankshelf sites.

demonstrated highly aggressive behavior and significant alterations in sexual behavior. Female rats exhibited significantly reduced fertility at the same exposure rate. Chromium is considered a carcinogen both through oral and inhalation sources. However, these are long term effects that usually arise from occupational exposure (USDHHS, 2000b).

*Nickel.* The concentrations of nickel detected in the sediments are shown in Figures 34 and 35. Other than Guanica Bay, there were few detections above the NS&T national median. Four sites outside of Guanica Bay (LTOC 15, LTOC 22, HTOC 16, and HTOC 22) were very close but slightly below the ERL value of 21 ug/g. In Guanica Bay, both sites were substantially above the ERM value of 52 ug/g,

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indicating that impacts on biota were likely. EPA's NCA Program detected a concentration of 33 ug/g nickel in a sediment sample from Bahia Montalva, similar to the 20.9 and 20.3 ug/g values detected at LTOC 15 and LTOC 22 sites, respectively.

The bivariate fit of nickel with the silt and the clay fractions of the sediments is shown in Figure 36. Because the concentrations of nickel were not normally distributed, nonparametric analyses were run to assess the relationship between nickel and sediment particle size. As with chromium, the concentration of nickel was associated with both the silt ( $P < 0.0001$ , Spearman Rho = 0.8393) and clay ( $P < 0.0001$ , Spearman Rho = 0.7326) fractions of the sediments. These associations remained very significant even when the data from the two sites in Guanica Bay were excluded.

As noted, the association of metals with these sediment fractions are due to high surface areas and ionic forces for the clay fraction. The silt and particularly the clay fractions have higher total surface areas providing sites for the adsorption of contaminants. The clays also have inherently negative charges within their layered structures allowing for cation exchange with various metals such as nickels. For clays, both the surface area and ionic forces are important factors for the association with metals. There was a significant negative correlation between the sand fraction of the sediment and nickel, an no correlation existed between percent gravel and nickel.

Nickel has many applications in both industrial and consumer products. Approximately 65 % of the nickel in the U.S. is used to make stainless steel. Other uses of nickel include its incorporation into a series of alloys, and also use in rechargeable batteries, in catalysts and other chemicals, in coins, plating, and in foundry products.

Nickel and chromium were elevated along with iron at the two sites sampled in Guanica Bay (Appendix J). All three metals are components of stainless steel, and the higher concentrations in Guanica Bay could be indicative of the use, particularly the industrial use, of stainless steel.

*Effects of Nickel on Corals.* Two articles were found on the effects of nickel in corals. Reichelt-Brushett and Harrison (2005) exposed the gametes of *Goniastrea aspera* to nickel concentrations ranging from 5 to 2,000 ug/L. Concentrations of nickel at or above 100 ug/L resulted in decreased fertilization success. In another study, Goh (1991) exposed larvae of the coral *P. damicornis* to nickel. The larvae were exposed to concentrations ranging from 1 to 25 mg/L (ppm) for durations of 12 to 96 hours. After the exposure, the larvae were placed in natural filtered seawater, and settlement success was followed over a period of days. Goh (1991) found significantly lower settlement success of the larvae nine days after the recovery period in all concentrations, regardless of the duration of the treatment.

*Other Effects of Nickel.* Nickel in the environment can come from a variety of sources including the use and disposal of the products mentioned above, the combustion of fuels in power plants, and waste material in incinerators. Nickel has a low potential for bioaccumulation in the tissues of fish and most mollusks. Nickel can, however be adsorbed to sediments and other particles. Filter feeders tend to accumulate more nickel as a result of it binding to suspended sediments, especially those containing iron or manganese.

Humans come into contact with nickel through the use of items containing this trace element, through foodstuffs, inhalation in areas where the combustion of fossil fuels containing nickel occurs and also from cigarettes. Adverse effects from the ingestion of high levels (~10 - 570 mg Ni/kg/day) of nickel in humans and test animals include hepatic, gastrointestinal, and renal effects, as well as rashes, dizziness, headache, and death by cardiac arrest. Negative reproductive effects, such as decreased sperm motility and count, have been observed in mice. Exposure of rats to nickel causes decreased fertility and birth defects.

Sulfidic and oxidic nickel is considered a carcinogen by the U.S. Department of Human Health and Services (DHHS) however, these forms are not easily soluble in water and are not common in the aquatic environment (USDHHS, 2005b).

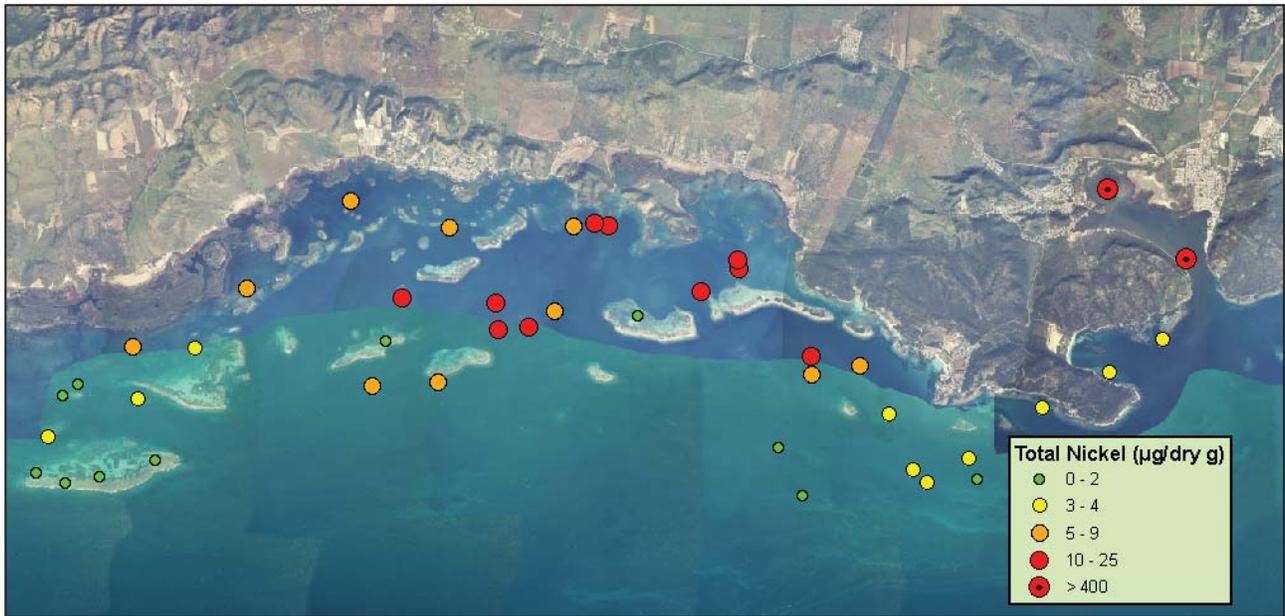


Figure 34. Map of nickel detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

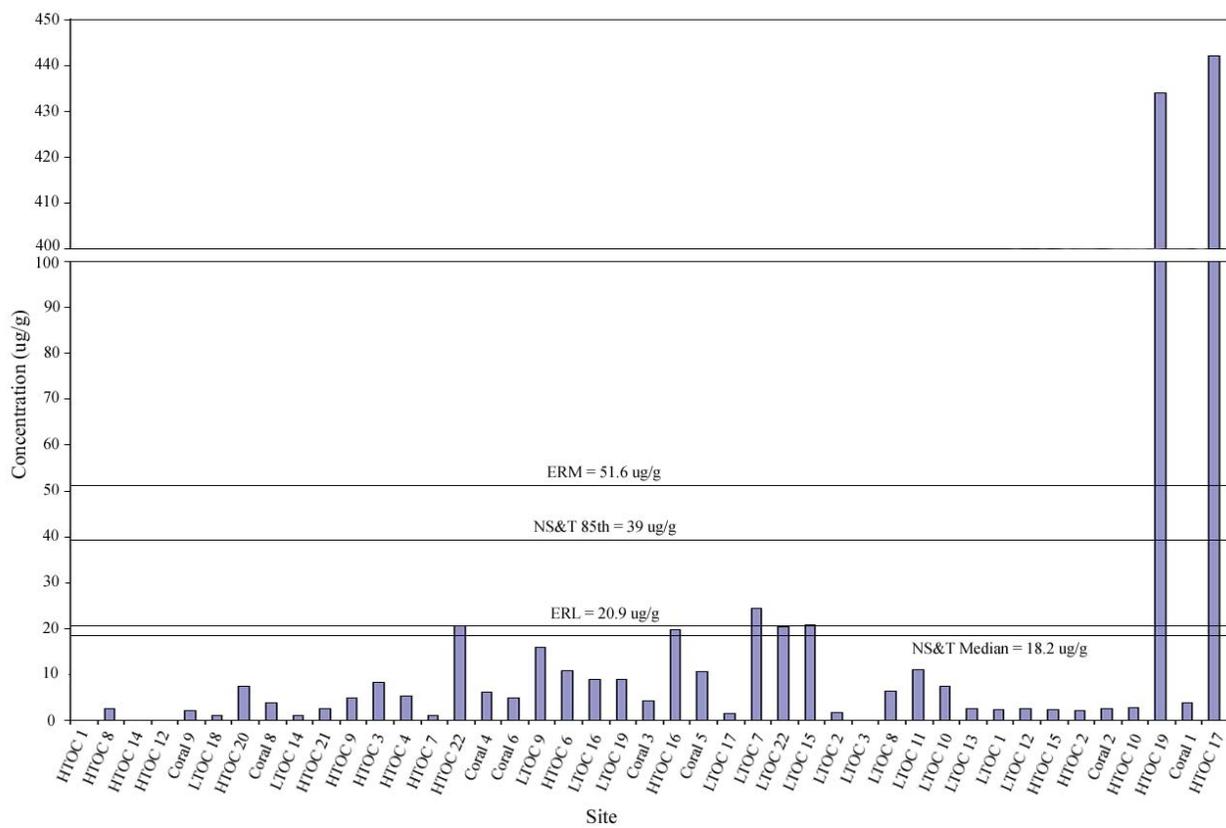


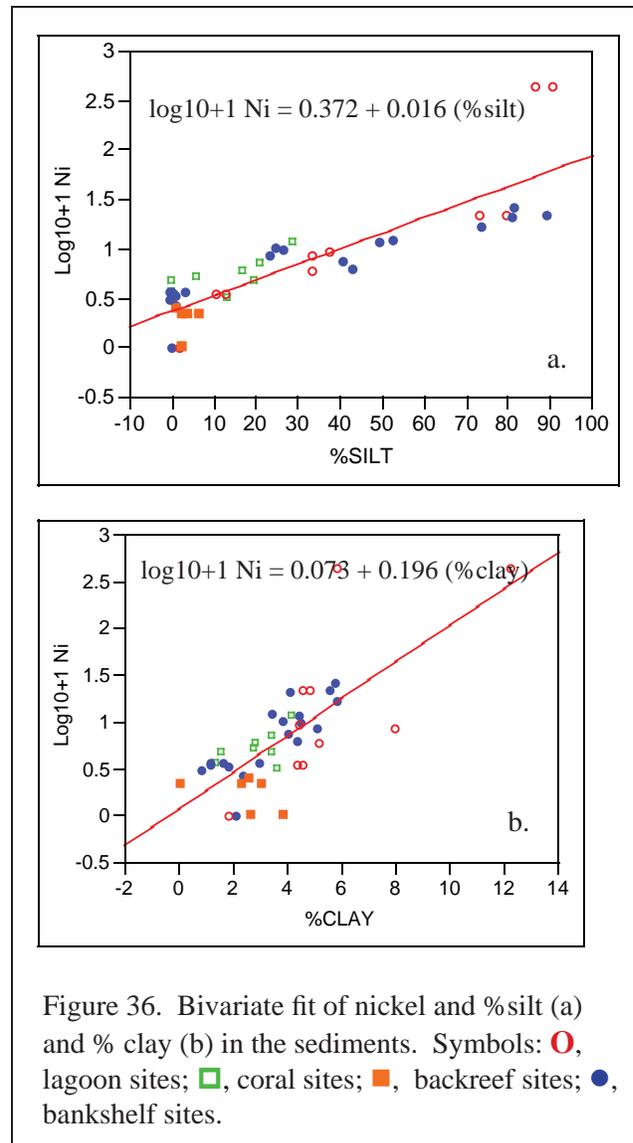
Figure 35. Nickel detected by site in the sediments in southwest Puerto Rico.

**Copper.** The results of the analysis of copper are shown in Figures 37 and 38, and in Appendix J. The highest copper concentrations were found in the sediments at the two sites in Guanica Bay. There were some elevated levels of copper around La Parguera, but all were below the NS&T median of 15 ug/g. In Guanica Bay, copper in the sediment samples from HTOC 17 was above the ERL of 34 ug/g. At HTOC 19, copper (80.6 ug/g), was above the NS&T 85th percentile, but below the ERM value of 270 ug/g. No data were located from the PREQB for copper, however, EPA's NCA Program detected copper at a concentration of 9 ug/g in the sediments at Bahia Montalva, similar to the 7.83 and 7.4 ug/g copper detected at LTOC 15 and LTOC 22, respectively.

In Figure 39, copper is plotted against the silt and clay fractions of the sediment. Nonparametric analyses indicated a strong positive relationship between copper and the silt ( $P < 0.0001$ , Spearman Rho = 0.8835) and clay ( $P < 0.0001$ , Spearman Rho = 0.7879) fractions of the sediment, similar to chromium and nickel.

Copper has many applications including its use as an antifoulant on boat hulls and in many industrial and consumer applications, including copper wire, electronic circuits, copper plumbing, cookware, coins and as industrial catalysts. Copper is also commonly used in agriculture as a fungicide on citrus crops. The higher levels of copper in the sediments in Guanica Bay may be the result of a combination of uses in industry, agriculture and as an antifoulant on boat hulls.

**Effects of Copper on Corals.** Copper appears to be 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 ug/L and greater significantly affected fertilization in the reef building coral *Acropora surculosa* in the laboratory after five hours. In a second experiment, Victor and Richmond (2005) found that embryo development was affected when gametes were exposed to copper at concentrations of 12 ug/L and higher. At



concentrations of 58 ug/L and greater, no embryo development was observed.

Reichelt-Brushett and Harrison (2005) exposed the gametes from a number of coral species to copper. Eggs and sperm were first dosed separately with the appropriate copper concentrations and then the gametes were mixed and allowed to incubate in sealed vials on the reef for five hours. A copper concentration of 20 ug/L and higher significantly reduced the fertilization success in *G. aspera*. At copper concentrations at or above 75 ug/L, fertilization success was one percent or less. Reichelt-Brushett and Harrison (2005) also found that copper at or above 20 ug/L significantly



Figure 37. Map of copper detected in the sediments in southwest Puerto Rico. Data classified into quantiles.

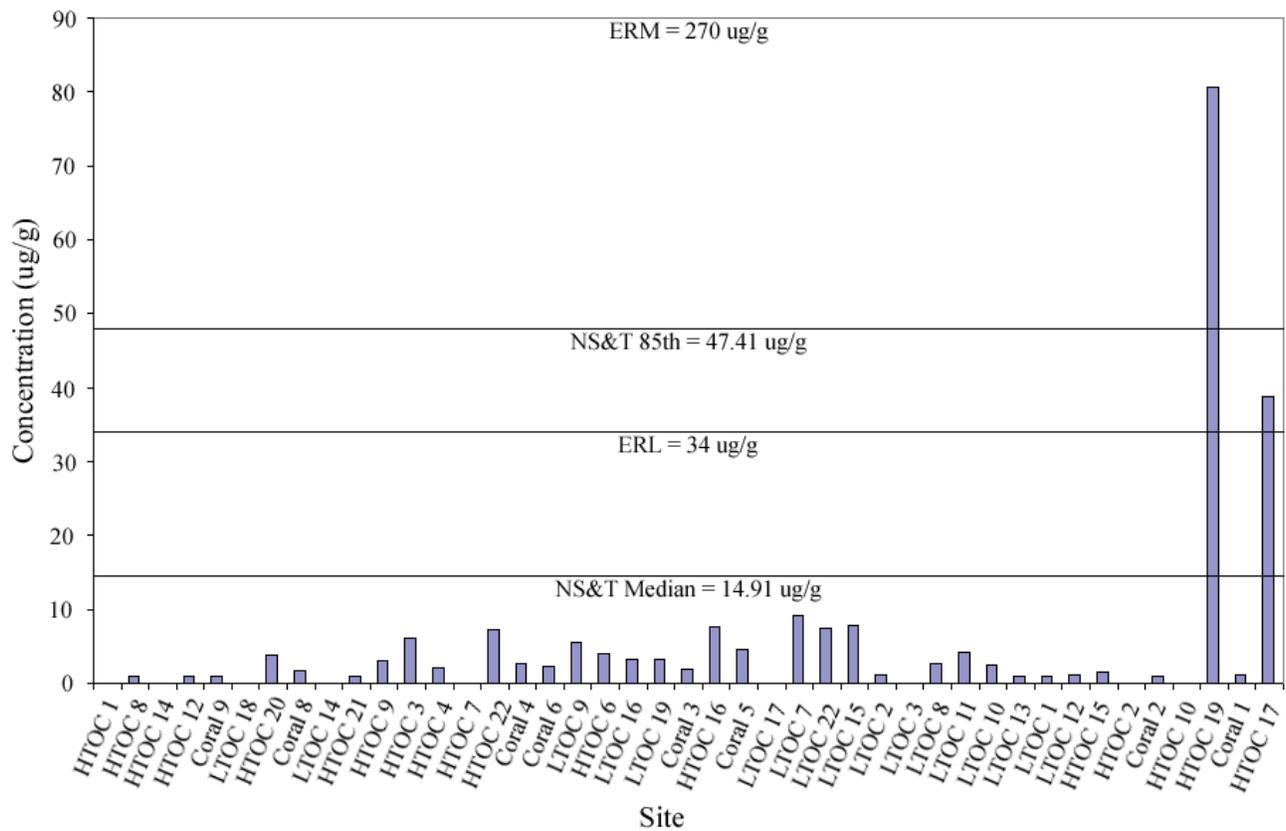


Figure 38. Copper detected by site in the sediments in southwest Puerto Rico.

decreased fertilization success in the coral *Goniastrea retiformis*, the same as for *G. aspera*. Fertilization success was also significantly reduced in *Acropora longicyathus* at 24 ug/L, similar to *G. retiformis*, however, in the finger coral *Acropora tenuis*, a significant effect on fertilization was only seen at concentrations of 42 ug/L and greater. At 67 ug/L and higher, fertilization success was 5 percent or less.

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 ug/L and above, higher than that found for a number of other coral species. The  $EC_{50}$  value, that which decreased fertilization by 50% was 261 ug/L. Reichelt-Brushett and Michalek-Wagner (2005) speculated the higher copper concentrations needed to affect fertilization could be a function of the longer gametogenic cycle for this species (nearly two years), leading the authors to suggest that *L. compactum* may have developed some type of biochemical copper detoxification mechanism.

Negri and Heyward (2001) calculated an  $EC_{50}$  of 17.4 ug/L copper for fertilization in *A. millepora* (4 hour exposure). They also found there was a 50 percent inhibition of larval metamorphosis in the presence of coralline algae at a copper concentration of 110 ug/L.

Reichelt-Brushett and Harrison (2004) exposed 4-6 day old larvae of *G. aspera* to varying concentrations of copper for 12 hours and calculated an  $EC_{50}$  for larval motility of 21 ug/L. They also noted that the  $EC_{50}$  was much lower than the 24 hour  $LC_{50}$  (137 ug/L).

Reichelt-Brushett and Harrison (2000) investigated the settlement of larval *A. tenuis* on biologically preconditioned terracotta ceramic tiles. A copper concentration of 42 ug/L was found to significantly reduce settlement success of the larvae after 48 hours. The 48 hour  $EC_{50}$  was 35 ug/L, and the calculated no observed effect concentration (NOEC) was 20 ug/L.

Goh and Chou (1997) investigated the effects of copper on the zooxanthellae *Symbiodinium*

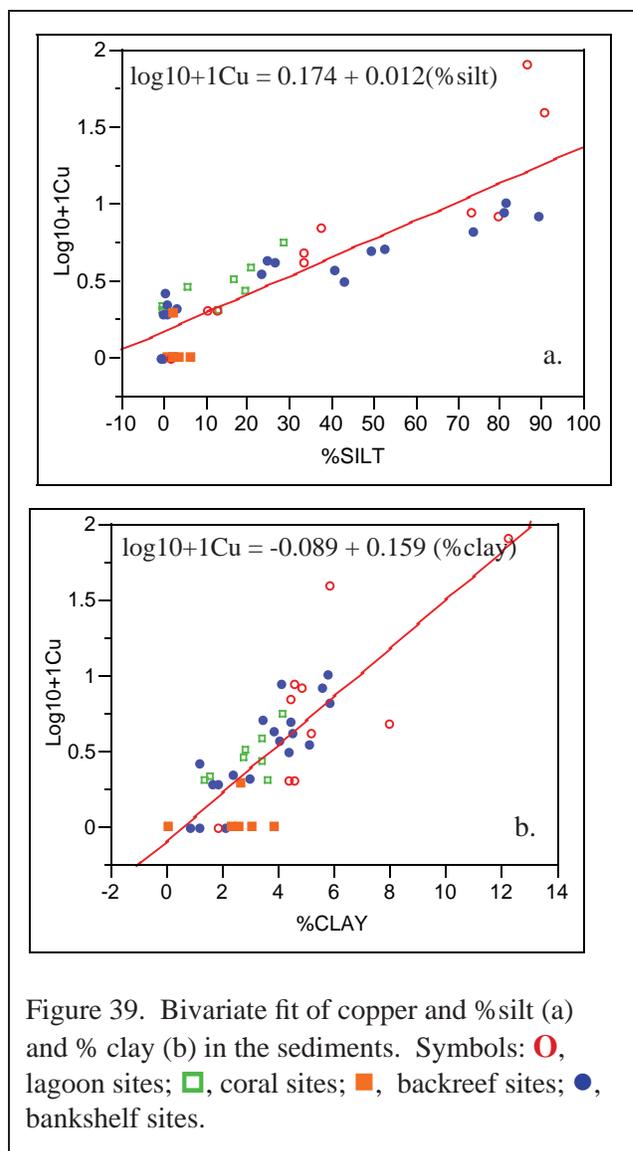


Figure 39. Bivariate fit of copper and % silt (a) and % clay (b) in the sediments. Symbols: O, lagoon sites; □, coral sites; ■, backreef sites; ●, bankshelf sites.

*microadriaticum*, isolated from the coral *Montipora verrucosa*. A concentration of 40 ug/L copper resulted in growth inhibition in the symbiotic dinoflagellate. Goh and Chou (1997) also conducted a series of experiments where the zooxanthellae were exposed to both copper and zinc, and noted there was an apparent synergistic effect when the metals were combined.

Nystrom *et al.* (2001) investigated the effects of copper on *Porites cylindrica*. There was no change in primary production, (oxygen production/mg chlorophyll *a*) when adult corals were exposed to 11 ug/L copper for 24 hours. However, in corals that were preexposed to elevated temperatures (4°C



Figure 40. Map of *Clostridium perfringens* detected in the sediments in southwest Puerto Rico.

higher than ambient) for five days and then exposed to the copper, there was a significantly decreased primary production rate. From these articles, it appears that copper could be of concern in some locations, particularly in areas of high boat traffic.

*Other Effects of Copper.* Bioaccumulation of copper is generally low in aquatic animals, with the exception of oysters and squid. Intake of high levels of copper has been shown to have adverse health effects including liver and kidney damage, anemia, immunotoxicity, and developmental toxicity in humans and test animals (USDHHS, 2004). Ingestion of  $\geq 100$  ml of copper sulfate solution has been known to cause death in humans, usually through central nervous system depression or hepatic and renal failure. Animal studies have also demonstrated that copper can cause decreased fetal growth, and delayed growth and development of juvenile test animals as well (USDHHS, 2004). The EPA does not classify copper as a carcinogen.

#### *Other Contaminants*

As part of this project, a number of other contaminants, both biological and chemical were measured. The bacteria *Clostridium perfringens*, often used as an indicator of sewage was analyzed in the sediments collected. Total nitrogen and total

phosphorus were measured in water samples. Finally, water samples were collected from selected sites and analyzed for Irgarol 1051, a herbicide currently used in copper-based antifoulant paints for boat hulls. Water samples were collected in May and then again in August 2005. The results of each these analyses are discussed below.

*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 Figure 40 and in Appendix K.

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 concentrations of *C. perfringens* were found, similar to a number of the other contaminant classes, in Guanica Bay. The sediment sample from HTOC 17 had over 180 colony forming units (CFU) per gram of sediment. Sediment collected from HTOC 19 contained over 1,700 CFUs per gram of sample. Sources of the elevated levels of *C. perfringens* would include wastewater treatment plants or septic systems that discharge to Guanica Bay, along with inputs from the pastures in the Lajas Valley.

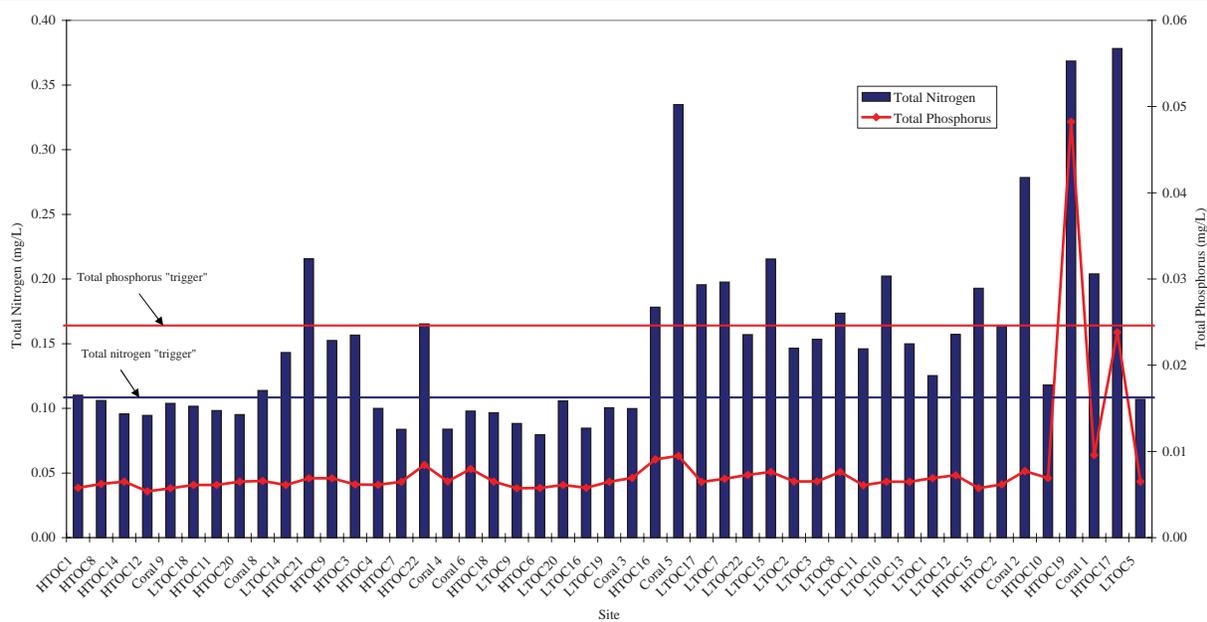


Figure 41. Total nitrogen and phosphorus in water samples from southwest Puerto Rico. Blue horizontal line represents the Southeast Australia trigger value for total nitrogen (0.120 mg/L); red horizontal line represents the trigger value for total phosphorus (0.025 mg/L) (Trigger values from ANZECC and ARMCANZ, 2000).

No health guidelines were located for concentrations of *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, and is characterized by infection and necrosis of the intestines. *C. perfringens* also has the capability of forming spores which can persist in soils and sediments in areas subject to human and animal fecal pollution.

**Nutrients.** Water samples were collected and analyzed for both total nitrogen and total phosphorus from 47 sites. The samples were taken at the same sites where the sediment samples were taken, plus at an additional four sites where sediments were not available.

The results of the analysis of total nitrogen and phosphorus in the water samples collected are shown in Figure 41. Total nitrogen and total phosphorus are the sums of the organic and inorganic forms for each nutrient. It can be seen that there were a number

of areas, for example, around La Parguera (HTOC 16 and Coral 5), and especially in Guanica Bay that had elevated levels of nitrogen and phosphorus. A Wilcoxon Test run on the nutrient concentrations indicated no significant relationship between habitat and nitrogen, but that habitat type was correlated with phosphorus concentration. The NS&T Program does not regularly analyze for nutrients, so no median or 85th percentile values are available.

No recommended guidelines for total nitrogen or total phosphorus were found for marine waters in the U.S. Instead, guidelines for marine waters in Australia and New Zealand were used. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000) contain a series of “trigger values” used to assess the risk of adverse effects from a variety of stressors, including nutrients. For southeast Australia, the trigger value for total nitrogen is 0.120 mg/L, and for phosphorus, 0.025 mg/L. These values are superimposed on Figure 41. It can be seen that total nitrogen levels in water samples from Guanica Bay and to some extent

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east of the bay had total nitrogen levels above the guidelines.

In the area from La Parguera to Guanica Bay, there was evidence of elevated concentrations of total nitrogen. A nonparametric analysis of the data indicated that total nitrogen was significantly correlated ( $P < 0.0001$ , Spearman Rho = 0.6037) with longshore position. In southwest Puerto Rico, currents flow from east to west, parallel to the coast (CFMC, 1998). The elevated levels of total nitrogen in the area from Guanica Bay to La Parguera were likely due to a combination of anthropogenic and natural factors in these areas.

The concentration of total phosphorus in the water samples for most of the sites was below the trigger value of 0.025 mg/L. The concentration of total phosphorus in the water samples was over twice the trigger value at the two sites in Guanica Bay, but at the remaining sites in the study area the concentrations were fairly stable, and below the trigger value. As with total nitrogen, a nonparametric analysis of total phosphorus indicated a significant correlation ( $P < 0.0012$ , Spearman Rho = 0.4773) between phosphorus and longshore position, that remained significant, even if the higher values from Guanica Bay were removed from the analysis.

*Effects of Nutrients on Corals.* A number of studies have found that elevated nitrogen and phosphorus levels can affect corals, both directly and indirectly. In the laboratory, Harrison and Ward (2001) found that mean coral fertilization rates were significantly reduced in the branching coral *Acropora longicyathus*, when gametes were exposed to ammonium ( $\text{NH}_4$ ) concentrations equal or greater than 18  $\mu\text{g/L}$ . Similarly, mean fertilization was also reduced in gametes from *A. longicyathus* exposed to phosphate ( $\text{PO}_4$ ) concentrations equal to or greater than 95  $\mu\text{g/L}$ . In addition, the mean percentage of embryos that developed normally was significantly reduced.

Marubini and Davies (1996) investigated the effects of nitrate ( $\text{NO}_3$ ) on two species of coral, *Porites porites* and the massive coral *M. annularis*. At nitrate concentrations of 310  $\mu\text{g/L}$  or greater, the population

density of zooxanthellae within the corals increased significantly. The amount of chlorophyll *a* and algal protein increased as well. The most dramatic change found in this study, however, was that the rate of calcification or skeletogenesis of the coral decreased by approximately 50 percent in both species when exposed to the nitrate enrichment. Lower calcification rates are of concern as they could result in the corals becoming more fragile and thus more susceptible to damage.

In the field, Hunte and Wittenberg (1992) found that the number of coral recruits decreased with increasing eutrophication along the fringing reefs on the west coast of Barbados. In addition, coral settlement rates on artificial plates were lower on reefs in the more eutrophic areas, and non-coralline settlement was heavier on the plates located in eutrophic areas. Also in the field, Abelson *et al.* (2005) found the lowest coral recruitment on ceramic tiles closest to a major eutrophication source in the Red Sea. Indirectly, increased nutrient levels can also result in macroalgal species outcompeting corals and forming dense mats that overgrow coral areas (Fabricius, 2005). As development pressures increase in areas adjacent to coral reefs, the risk of eutrophication and subsequent algal growth overwhelming corals becomes a greater concern and more likely phenomenon.

*Other Effects of Nutrients.* Nitrogen and phosphorus are essential elements for both plants and animals. Nitrogen, for example, is a component of proteins, RNA and DNA. Phosphorus is found in nucleic acids and also in certain types of lipids, essential for example, in the structure of cell membranes. Although essential for plant and animal life, elevated levels of these nutrients can lead to eutrophication characterized by an overabundance of algae and depressed dissolved oxygen levels, in a river, bay or coral reef. Eutrophication is an overproduction of organic matter, particularly algae, and is commonly caused by an increase in the amount of nutrients coming into a waterbody (Bricker *et al.*, 1999). The additional algae shade out the light needed by native plants. As the algae produced dies, additional oxygen is needed for its decay, leading to low levels of oxygen in the water. These low oxygen or



Figure 42. Detection of the antifoulant compound Irgarol 1051 in water samples from Puerto Rico in May 2005 (circles) and August 2005 (squares). Data classified into quantiles.

hypoxic conditions make it difficult for other aquatic organisms to survive.

*Irgarol 1051.* As part of the collaborative effort for this project, water samples from selected sites around La Parguera were analyzed by NOAA's Center for Coastal Environmental Health and Biomolecular Research in Charleston, South Carolina for Irgarol 1051. Water samples were collected and analyzed during the May and August 2005 missions. The results of the analyses are shown in Figure 42. The highest concentration of Irgarol 1051 was found adjacent to a marina (15.4 ng/L) in La Parguera in August 2005, followed by a concentration of 6.3 ng/L adjacent to a dry dock. Water samples from several sites where corals were sampled, or from reference sites had very low (0.1-0.2 ng/L) or nondetectable levels of Irgarol 1051 (Figure 42).

Since the ban on the use of tributyltin as an antifoulant on smaller vessels in the late 1980s, a number of "TBT-free" formulations containing copper combined with organic boosters have been used (Konstantinou and Albanis, 2004). One of the more frequently used compounds is Irgarol 1051 (2-methylthio-4-*tert*-butylamino-6-cyclopropylamino-*s*-triazine), similar in structure to atrazine, another

triazine herbicide which is used in agriculture. Irgarol 1051 is highly phototoxic, inhibiting the electron transport chain in Photosystem II within the chloroplasts of algal cells (Carbery *et al.*, 2006).

*Effects of Irgarol 1051 on Corals.* Several papers were located on the effects of Irgarol 1051 on corals, specifically related to primary production. Owen *et al.* (2002) investigated the effects of Irgarol 1051 on the yellow pencil coral *Madracis mirabilis*. Experiments were carried out on both the isolated zooxanthellae and the intact coral. For the isolated zooxanthellae, changes in photosynthesis were measured by assessing the uptake of  $^{14}\text{C}$  bicarbonate from the exposure medium, using a suite of irradiances over a period of 8 hours. Concentrations of Irgarol 1051 as low as 0.063 ug/L resulted in no  $^{14}\text{C}$  being incorporated in the zooxanthellae after 6 hours of exposure. Incorporation of  $^{14}\text{C}$  provides an estimate of photosynthetic primary production. Whole coral respiration over an 8 hour period was also investigated. Irgarol 1051 concentrations as low as 0.1 ug/L resulted in reduced photosynthesis in *M. mirabilis* as measured by the generation of oxygen after four hours. At 1 ug/L, little or no photosynthesis occurred.

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An investigation by Owen *et al.* (2003) examined the effects of Irgarol 1051 on a number of other coral species. Incorporation of  $^{14}\text{C}$  was used to measure changes in net photosynthesis. Concentrations of 2 ug/l Irgarol 1051 were found to significantly inhibit photosynthesis in the symmetrical brain coral *D. strigosa* and in the golfball coral *F. fragum*. A concentration of 2 ug/L diuron in these species produced similar results, while a concentration of at least 100 ug/L of the herbicides atrazine or simazine were needed to decrease photosynthesis in these species (Owen *et al.*, 2003).

Jones and Kerswell (2003) examined the effect of Irgarol 1051 and other herbicides on two species of corals from Australia. Intact *Seriatopora hystrix* or bird's nest coral were exposed in the laboratory to five test concentrations of Irgarol 1051 along with a control. Changes in chlorophyll fluorescence (maximum effective yield) in coral fragments containing zooxanthellae were determined to assess the effects of the herbicide. In *S. hystrix*, an  $\text{EC}_{50}$  (concentration needed to reduce maximum fluorescence by 50 percent) of 0.7 ug/L was calculated for a 10 hour exposure. The effect of Irgarol 1051 on chlorophyll fluorescence was also tested in the stony coral *A. formosa*. Results indicated an  $\text{LC}_{50}$  for this species of 1.3 ug/L. After the exposures, Jones and Kerswell (2003) moved the coral fragments of *S. hystrix* to fresh running seawater. The amount of time needed to recover the preexposure fluorescence levels was measured. While the level of fluorescence returned to normal in a matter of minutes or hours in coral exposed to herbicides such as diuron, atrazine, and simazine, *S. hystrix* exposed to Irgarol 1051 recovered more slowly, on the order of hours to days.

*Other Effects of Irgarol 1051.* Much of the work done to assess the other effects of Irgarol 1051 has focused on algae, with some work done on invertebrates. Okamura *et al.* (2000) calculated an  $\text{EC}_{50}$  of 2 ug/L for the growth of germlings from the marine brown macroalga *Eisenia bicyclis* after 7 days. Okamura *et al.* (2000) also investigated the effects of Irgarol 1051 on growth in the freshwater duckweed *Lemna gibba*, and calculated a 7-day  $\text{EC}_{50}$

of 11 ug/L. These values are similar to those found for coral zooxanthellae.

There have also been investigations into invertebrate toxicity. Bellas (2006) investigated the toxicity of five antifouling biocides including Irgarol 1051 to larvae of the mussel *Mytilus edulis*, the sea-urchin *Paracentrotus lividus* and the tunicate *Ciona intestinalis*. Toxicity was measured in terms of embryonic development, larval growth and larval settlement. All tests ran for 48 hours. Irgarol 1051 was the least toxic compound tested. The  $\text{EC}_{50}$  for embryonic development in *M. edulis* was 1,540 ug/L, in *P. lividus*, 4,021 ug/L, and *C. intestinalis*, the  $\text{EC}_{50}$  was 2,115 ug/L. In *P. lividus*, the larval growth  $\text{EC}_{50}$  was 6,032 ug/L. An  $\text{EC}_{50}$  for larval settlement in *C. intestinalis* could not be calculated, as Irgarol 1051 showed no toxicity at concentrations approaching 6,500 ug/L. Irgarol 1051 is an effective inhibitor of the photosynthetic electron transport chain in chloroplasts (Konstantinou and Alabanis, 2004), and so it is perhaps not unexpected that nonphotosynthetic organisms would be less sensitive to this compound.

#### *Correlations Between Sediment Contaminants.*

A nonparametric analysis was run to look for correlations between some of the sediment contaminant classes described in this report. The results indicated that the sediment organic contaminant classes (total PAHs, total PCBs, and total DDTs) were highly correlated ( $P < 0.0001$ ). The trace elements chromium, nickel, copper, zinc, and lead were likewise highly correlated with each other. In addition, the organic contaminant classes were also highly correlated ( $P < 0.0001$ ) with the trace elements listed above. Because elevated levels of most of these contaminant classes in the environment are typically the result of anthropogenic activities, the correlations found are not surprising. The only contaminant in this exercise that did not correlate well with the other contaminants was arsenic. As mentioned previously, the presence of arsenic in the study area did not have the same geographic distribution as the other contaminants, and the low concentrations and distribution of this trace element in the study area was suggestive of natural sources rather than anthropogenic activities.

### ***Contaminants and Coral Species Richness***

One of the goals of this project and the framework being developed is to examine linkages between chemical contaminants and coral health. Because of the detailed mapping of coral reefs that has been completed in this part of Puerto Rico, it is possible to begin assessing relationships that may exist between the spatial distribution of corals in the study area and chemical contaminants. For this report, an initial analysis was made to look at correlations between concentrations of total PAHs in the sediments and coral species richness.

### ***Contaminant Modeling***

An analysis of the total PAH data using Geary's C test indicated a significant spatial autocorrelation ( $P < 0.0001$ ). The graph showing the relationship between the modeled and observed total PAH concentration ( $P < 0.0001$ ,  $R^2 = 0.78$ ) is shown in Figure 43. Subsequently, a geospatial model was developed using indicator Kriging. The lag size was 2.1 km and the lag was 7. Figure 44 shows the total PAH isopleths (red shading) and includes the relative PAH concentrations (dots) detected in the sediments. From the map, it can be seen that there is an area of higher modeled concentrations of total PAHs in the sediments that begins in the nearshore areas around the town of La Parguera. There are also higher modeled concentrations east of La Parguera

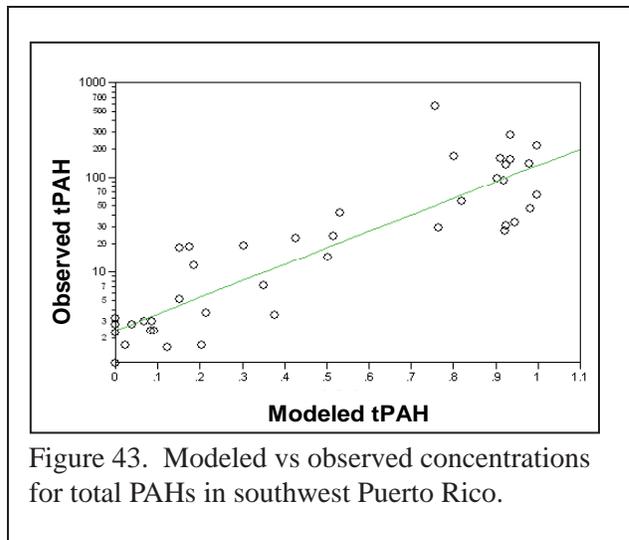


Figure 43. Modeled vs observed concentrations for total PAHs in southwest Puerto Rico.

and in Guanica Bay. Moving offshore, the modeled concentrations decrease.

Figure 45 contains the results of some additional modeling, for total PCBs, total DDTs, and copper. It can be seen that the concentrations of contaminants in the sediments result in somewhat different geospatial models, however all show an area of higher modeled contaminant concentrations in and around La Parguera and to the east. Although contaminant concentrations detected in Guanica Bay were higher for most contaminant classes, because only two sediment samples were taken there, the model was not reflective of the higher concentrations.

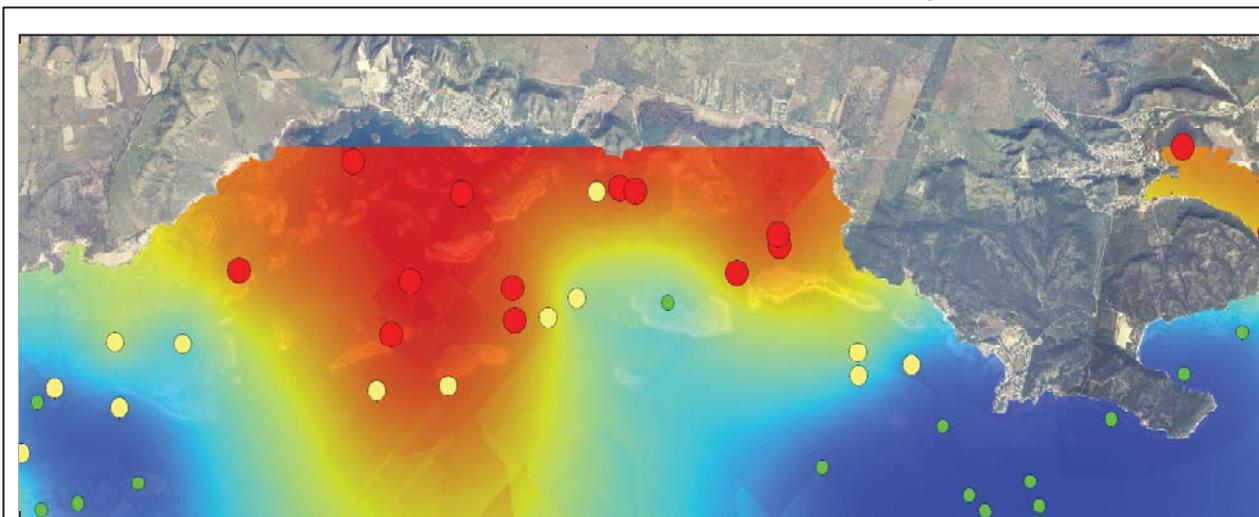


Figure 44. Indicator Kriging and measured concentrations of total PAH in the sediments in southwest Puerto Rico. Colored dots represent sediment contaminant quantiles (●, low; ●, medium; ●, high).

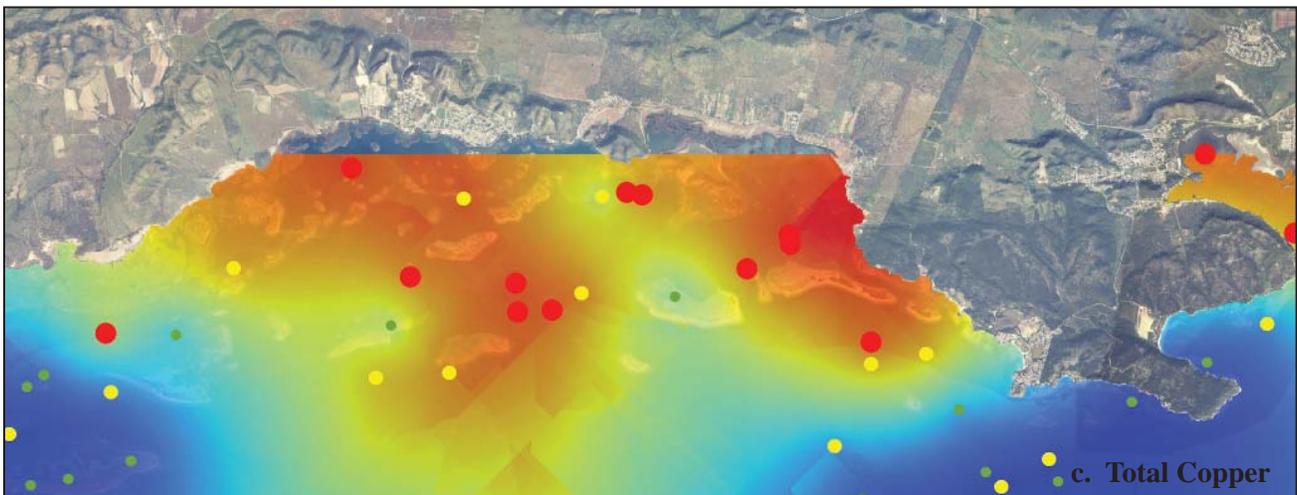
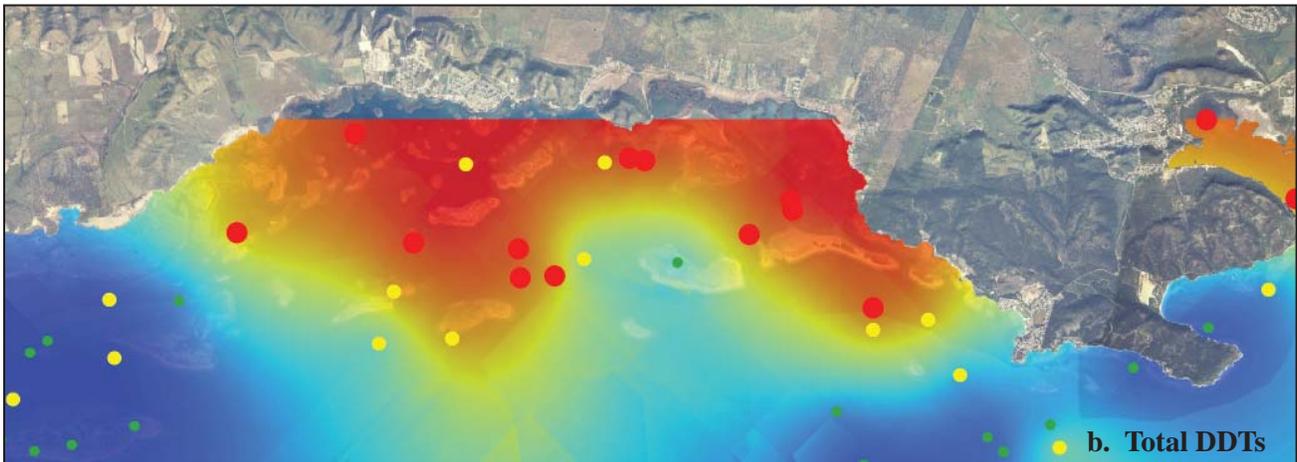
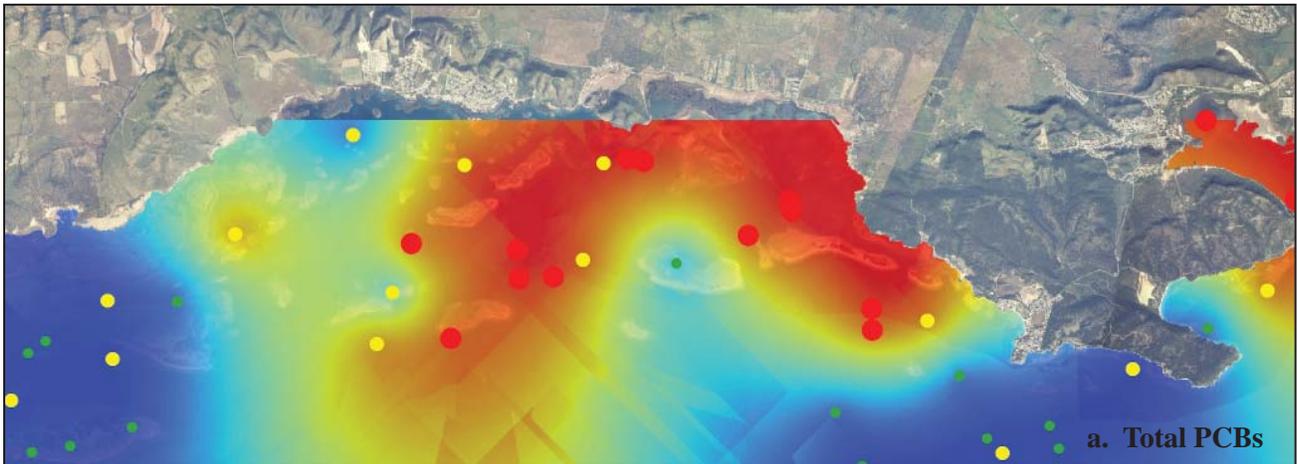


Figure 45. Indicator Kriging and measured concentrations of a) total PCBs, b) total DDTs, and c) copper. Colored dots represent sediment contaminant quantiles (●, low; ●, medium; ●, high).

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The modeled patterns of PAHs in Figure 44 could be the result of a number of processes. As noted by Garcia *et al.* (1998), improvements to transportation and infrastructure has transformed the village of La Parguera from a “mostly undeveloped and quiet fishing village” to a center of tourism. That transition has been reflected in the increase of resorts, guest houses and vacation homes, and proliferation of the transient population over the last 10 years from approximately 35,000 to over 100,000 per year. (Garcia *et al.*, 1998). Atmospheric deposition and surface runoff related to motor vehicle traffic are likely to introduce PAHs into the surrounding waters. These fluxes would be highest particularly on weekends, when automobile traffic is at its peak. The area around La Parguera also has a substantial number of boats, both for recreational and commercial fishing. Between 1996 and 2003, the total number of boats registered in Puerto Rico increased by 28% to over 60,000 (Garcia-Sais *et al.*, 2004). The use of outboard and inboard engines on boats in the area also likely contributes to the PAH load in the study area.

A number of emergent reefs in the area (*e.g.*, Enrique, Media Luna, and Corral) have shallow areas on the leeward side, that serve as gathering areas for recreational boaters, particularly on weekends and holidays. It has been reported that over 200 boats can be anchored on a small reef in La Parguera (Garcia-Sais *et al.*, 2004). The presence of boats, either moored or idling on the backsides of the emergent reefs could also be sources of the PAHs found in the sediments. However, the concentrations of total PAHs at the backreef sites did not appear to be elevated.

#### *Total PAHs and Coral Species Richness*

A goal of this project and the framework is to assess relationships between chemical contaminants (both organic and inorganic), and measurable effects in corals. Chemical contaminants, ranging from PAHs to metals to pesticides can be toxic to corals and other organisms living on the reef (Negri and Heyward, 2001; Owen *et al.*, 2003; Peachey and Crosby, 1996). Chemical contaminants can impact a number of vital life processes in corals including fertilization,

settlement and metamorphosis, development and growth. These effects can be manifested at the molecular (*e.g.*, biomarker) to the community levels. At the community level, toxic contaminants could impact the ability of various coral species to survive in an area. Developing correlations between the presence of chemical contaminants and coral species richness (number of species in an area), can help establish linkages between contaminants and coral distribution.

In Figure 46, coral reef survey data is overlaid on the total PAH isopleths. Each point represents a survey point by NOAA's Biogeography Team to characterize coral cover in the study area. Green dots represent those areas that had the highest coral species diversity (top 25th percent), while the remaining dots indicate survey sites where the coral species richness was below the 75th percentile. In order to assess whether a correlation existed between the modeled concentrations of total PAHs and species richness, a nonparametric Spearman's Rho test was carried out.

There was a strong negative correlation ( $P > 0.0425$ ; Spearman's Rho = -0.6485) between the modeled PAH concentrations and coral species richness. The corals used in the analysis included the major reef building species such as boulder corals (*Montastrea annularis*), brain corals (*Diploria spp.*), and branching corals (*e.g.*, *Porites porites*, *Acropora palmata* and *A. cervicornus*).

Rees *et al.* (1999) and Edinger *et al.* (1998) both found negative correlations between coral cover and anthropogenic inputs in Indonesia. At this point, however, the results presented in Figure 46 do not represent a cause and effect, but only an indication of a negative association between sediment PAHs and coral species richness for this area. Many factors could be responsible for the observed pattern, ranging from physical processes (currents, freshwater runoff), damage to corals caused by boat traffic coming in an out of the La Parguera area, to sedimentation resulting from natural or anthropogenic activities and, the presence of chemical contaminants such as PAHs. The data could also simply be indicative of areas of fine grain sediments which are less suitable for coral settlement and development. Future work to assess

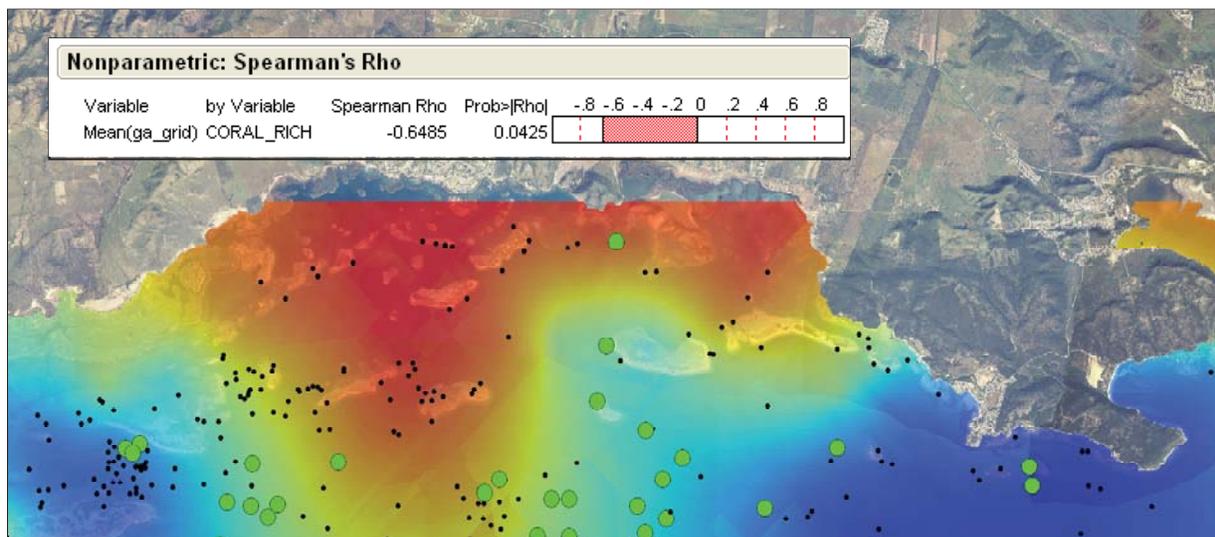


Figure 46. Kriging of total PAHs and coral species richness. Dots indicate survey points for NOAA's Biogeography Program. Green dots indicate those locations where coral species richness was in the top 25th percentile for brain, branching, pillar, encrusting, mound and boulder corals. Black dots are the remaining locations at the reef sites.

contaminants in corals and biomarkers will provide a better understanding of the factors influencing the patterns observed.

The results presented here do, however, provide an opportunity to develop testable hypotheses to better assess how contaminants may be impacting the corals in the study area. Additional results, including the coral biomarker and the coral contaminant data will be used to better understand associations between contaminants and corals from the molecular to the community levels.

### **Conclusions and Next Steps**

The degradation of coral reef ecosystems worldwide has led to intensive efforts to understand and mitigate the stressors responsible for the declines of these valued and fragile ecosystems. The role of pollution is often cited as a major factor but the degree to which pollution, and more specifically chemical contaminants impact coral reefs is in most cases unknown. Because of this, coral reef managers may be missing an important and in some locations, a critical piece of information needed to effectively manage the reefs. The impacts of chemical contaminants on corals at the community (species

diversity and distributions) and individual (*e.g.*, metabolism and reproduction) levels are both needed for a complete assessment of contaminant impacts.

### **Project and Framework**

This project and the framework that has been developed is in direct response to the need to assess the effects of pollution on coral reefs as called for by the U.S. Coral Reef Task Force, the "State of the Reefs" report (Waddell *et al.*, 2005), the Pew Oceans Commission (Pew Oceans Commission, 2003), and the World Resources Institute (Burke and Maidens, 2004), among others.

NOAA and its partners initiated this project to characterize chemical contaminants in southwest Puerto Rico and to provide a mechanism for assessing linkages between chemical contaminants and coral health (function and coral species distribution/richness). The assessment framework established as part of this project brings together various specialties ranging from environmental chemistry to biogeography to molecular and microbiology. By bringing these specialties and the resulting data types together, it is more likely that linkages between contaminants and coral health can be established.

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There are four main goals of the project and framework:

- 1) characterize both organic (*e.g.*, petroleum hydrocarbons) and inorganic (*e.g.*, trace elements) contaminants in the study area;
- 2) quantify a series of parameters related to coral function (biomarkers)
- 3) map and determine coral distribution/species richness (biogeography); and
- 4) develop and implement an assessment framework that can be applied throughout the Caribbean and elsewhere.

This report is the first product of this collaborative effort, and contains the results of the analysis of chemical contaminants in the sediments in southwest Puerto Rico. The study area, from Guanica Bay west past the town of La Parguera was chosen because of established partnerships, data availability, and designation of the area as a Coral Reef Ecosystem Study (CRES) site, the 5-year program funded by NOAA's Center for Sponsored Coastal Ocean Research. Partners in the project include two centers within NOAA's National Centers for Coastal Ocean Science (Center for Coastal Monitoring and Assessment, and the Center for Coastal Environmental Health and Biomolecular Research), the University of Puerto Rico-Mayaguez, the University of Hawaii, and Haereticus Environmental Laboratory.

A stratified random sampling design was developed for the study area to characterize the distribution and concentrations of chemical contaminants in the study area. Sediment samples for the analysis of both organic contaminants (*e.g.*, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and pesticides), and inorganic (trace elements such as chromium, nickel and copper) were collected during

a mission in August 2005. The data were analyzed using a series of statistical and geospatial tools.

#### *Chemical Contaminant Concentrations*

Overall, the levels of chemical contaminants in the sediments in the study area were fairly low. Most of the time, sediment contaminant concentrations were less than the median values in NOAA's National Status and Trends (NS&T) Program, which monitors contamination in coastal waters of the U.S. A pattern seen in the study area for a number of the contaminant classes included higher concentrations of contaminants in the embayments and behind the emergent reefs, while offshore sites tended to have lower concentrations.



*Elkhorn coral (Acropora palmata), recently listed as threatened under the U.S. Endangered Species Act (ESA).*

In this phase of the project, chemical contamination was measured in the sediments. The concentration of chemical contaminants in the sediments

are not the concentration the corals are exposed to, however, the sediments do provide a record of what has entered the coral reef environment, and therefore the chemicals the corals have been exposed to over time.

Polycyclic aromatic hydrocarbons or PAHs are associated with the use and combustion of petroleum hydrocarbons. Sediments nearer the shore (*e.g.*, embayments) and adjacent to La Parguera tended to have higher PAH concentrations. As was seen for a number of the contaminant classes, sediment concentrations of total PAHs were above NOAA's National Status and Trends (NS&T) Program median at both sites in Guanica Bay. Corals, however, are typically not found in Guanica Bay.

Polychlorinated biphenyls or PCBs, were used in the past in transformers and capacitors, and are persistent in the environment. The results from the analysis of sediments indicated that PCBs were above the NS&T median at a number of sites in nearshore areas, adja-

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cent to the town of La Parguera. The NS&T Program has developed a series of sediment contaminant concentrations associated with toxic effects. The ERL or Effects Range-Low is the concentration of a contaminant below which toxicity (10th percentile) is rarely observed. The ERM or the Effects Range-Median is the concentration above which toxicity in test organisms is more frequently (50th percentile) observed and therefore effects at this concentration or greater are more likely. In Guanica Bay, the concentration of total PCBs at the two sites was not only above the ERL, it was also substantially above the ERM value, indicating that PCBs at least at the two sites sampled in Guanica Bay may be impacting the biota there.

Levels of the organochlorine pesticide DDT in the sediments were all below the NS&T median in the sediments around La Parguera. Elevated levels of DDT were detected in Guanica Bay. Sediments from both Guanica sites were above the ERL level for DDT, and at one site in Guanica Bay, total DDTs were above the ERM, indicating the DDT in the sediment may have an impact on biota there. The drainage from the Lajas Valley flows into Guanica Bay. The Lajas Valley has had extensive agricultural activity over the years. The elevated levels of DDT found in the sediments at the two sites in Guanica Bay may be related to the past agricultural use of this insecticide.

Sediment concentrations of chromium, nickel and copper were below the NS&T median in most of the sediment samples taken in the study area. At the two sites sampled in Guanica Bay, levels of both chromium and nickel were above the ERM value for these trace elements, indicating these two metals may be having adverse impacts on the biota in these areas. Both chromium and nickel are common components of stainless steel, which is frequently used in industrial operations, and their presence in the sediments at the two sites in Guanica Bay could be an indication of their use over the years in industrial activities around this embayment.

#### *Contaminants and Corals*

One of the major goals of this project and the framework are to assess linkages between chemical contaminants and coral health. To begin to address this goal, an exercise was carried out for this report

to assess correlations between PAH concentrations in the sediments and coral species richness. A geospatial model of total PAHs in the sediments was developed using the spatially autocorrelated PAH data. Existing mapped data on coral species richness for the study area was then overlaid on the modeled PAH concentrations. A nonparametric analysis of the modeled PAH data and coral species richness for the major reef building species, indicated a strong negative correlation between modeled PAH concentrations and coral species richness. That is, higher total PAHs in the sediments were associated with lower coral species richness.

An assessment of the effects of chemical contaminants on corals was also included in this report. A number of organic and inorganic contaminants have been shown to inhibit coral fertilization and larval settlement in the ug/L or parts per billion (ppb) range. Both fertilization and settlement are critical steps in the coral recruitment process, needed for building and maintaining coral reefs. Chemical contaminants in the water column at the appropriate concentration could inhibit fertilization and coral settlement. The presence of contaminants might also result in a delay in coral larval settlement/metamorphosis until the larvae were transported to more appropriate habitat. Larvae that did settle in an area with elevated contaminants concentrations might not develop appropriately or at all. Either way, recruitment would be affected. The continuous input of contaminants could also affect adult corals over time, particularly if the contaminants being introduced were bioaccumulative.

The cause for the negative correlation between sediment PAHs and coral species richness is unknown. As mentioned, there could be many other physical (*e.g.*, currents, sedimentation), chemical (*e.g.*, temperature, salinity) and biological (substrate preference) factors that could be responsible for the observed pattern. The results from this analysis, however, will help direct additional data analysis and the development and testing of hypotheses.

#### *Next Steps*

Additional products will be developed as the data from this project are received and analyzed. In the short term, additional data analyses will be carried

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out to look at correlations between other contaminant classes and coral species diversity, including individual species distributions. If contaminants are in fact impacting corals in the study area in southwest Puerto Rico, it is likely that certain contaminants will have a greater effect than others, and it is also likely that certain species of corals would have a greater sensitivity to one or more contaminants or contaminant classes.

As part of this project, an analysis of contaminants in the coral tissue collected, along with an analysis of a series of molecular biomarkers is scheduled for the *Porites astreoides* coral tissues collected. Pathogens in the corals will also be included. The analysis of contaminants in the corals provides a better idea of not only what the corals have been exposed to, but what they have accumulated, making it easier to correlate the presence of contaminants in the corals with effects.

The molecular biomarkers scheduled to be analyzed in the coral tissues collected provides an indication of coral function and integrity. For example, elevated levels of Cytochrome P450 and glutathione-S-transferases are indicative of the metabolism of contaminant classes such as PAHs. The presence of elevated levels of certain heat shock proteins can be an indication that an organism is dealing with damage to proteins, which can occur with exposure to chemical contaminants. The accumulation of ubiquitin, which marks proteins for degradation, is an indicator of increased protein turnover, as can happen when there is damage to cellular integrity.

The additional data types to be included in this project will add to the power of the analysis and interpretation of the information. Combining the chemical contaminant data with coral biomarkers, along with information on coral species distributions, creates a powerful tool that can be used to better assess effects at different levels of organization. As an example, chemical contaminants can have a toxicological impact on individual corals, affecting metabolism and reproduction. If these effects are severe enough over time, they would be manifested at the community level, in terms of coral species distribution and diversity. Generating data that

can be indicative of effects at the individual and community levels provides the opportunity for understanding the broader effects that chemical contaminants may have on corals and coral reefs.

The inclusion in this project of pathogens associated with coral disease is another important data type. A number of bacterial and fungal pathogens have been associated with coral disease. It is possible that the presence of chemical contaminants could cause corals to put more energy into metabolizing or responding to the chemical's toxic effects stressing the coral, and making it more susceptible to disease-causing pathogens.

The results from this project would also be used to drive additional assessments. These might be in the form of applying the framework developed to other areas in the Caribbean or possibly in the Pacific. Additional assessments could also be carried out to pose additional hypotheses in the current study area in southwest Puerto Rico.

At the present time, chemical contaminants are analyzed in sediments and coral tissues, and biomarkers are analyzed in coral tissues. In the future, additional organisms, both invertebrates and vertebrates could be assessed in terms of chemical contaminants and biomarkers. This additional information, combined with biogeographic data would further increase the power of the approach.

Maintaining the various specialties (*e.g.*, environmental chemistry, biogeography, molecular and microbiology) would be a goal for any additional studies. Combining these specialties into a standardized ecosystem approach for assessing coral reefs would greatly enhance the characterization of coral reefs, and is an approach that will evolve over time, and could be transferred to other institutions. The approach would greatly increase our ability to understand not only which stressors are present in corals reefs, but also the extent to which the stressors are impacting these valuable ecosystems.

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Appendix A. Sample sites from May 2005 mission.



Abbreviations: PRBR, backreef sites; PRBS, bankshelf sites; PRMG, mangrove sites; PRLG, lagoon sites.

Appendix B. Field data from May 2005 mission.

Site	Collection Date	Habitat	Latitude (DD)	Longitude (DD)	Water Depth (m)	Dissolved Oxygen (mg/L)	Temperature (°C)	Salinity (ppt)	Conductivity (mS)	Secchi Depth (m)
PRMG1	5/26/2005	Mangrove	N17.947490	W067.115060	0.6	4.44	31.3	34.2	58.5	bottom
PRMG2	5/26/2005	Mangrove	N17.946600	W067.123610	0.6	3.40	31.4	34.4	59.0	bottom
PRMG3	5/26/2005	Mangrove	N17.953350	W067.089000	0.3	5.34	31.9	34.1	59.0	bottom
PRMG7	5/25/2005	Mangrove	N17.971420	W067.072660	2.7	5.35	31.9	33.7	58.2	bottom
PRMG8	5/23/2005	Mangrove	N17.969690	W067.042400	1.5	3.89	31.0	32	55.5	bottom
PRMG9	5/25/2005	Mangrove	N17.973070	W067.070590	0.9	4.82	31.9	33.8	58.7	bottom
PRMG13	5/23/2005	Mangrove	N17.970200	W066.999830	1.2	5.29	31.1	33.3	57.0	bottom
PRMG14	5/26/2005	Mangrove	N17.964000	W066.985630	0.9	3.16	30.3	34.7	58.2	bottom
PRMG15	5/26/2005	Mangrove	N17.968040	W067.019200	0.6	3.95	30.4	34.6	52.7	bottom
PRMG19	5/24/2005	Mangrove	N17.963620	W066.928380	1.5	4.77	30.3	14.4	35.2	2.5
PRMG21	5/24/2005	Mangrove	N17.970560	W066.921920	1.5	4.12	30.2	24.2	41.9	3
PRMG24	5/24/2005	Mangrove	N17.964090	W066.912160	1.8	5.29	31.1	32.1	54.4	5
PRLG1	5/25/2005	Lagoon	N17.942687	W067.099647	4.9	5.12	30.2	34.1	57.2	bottom
PRLG3	5/26/2005	Lagoon	N17.952112	W067.087452	1.2	5.20	30.5	34.1	57.5	bottom
PRLG4	5/25/2005	Lagoon	N17.956989	W067.082784	1.8	5.81	32.2	33.6	58.5	bottom
PRLG6	5/25/2005	Lagoon	N17.931980	W067.127456	8.5	5.30	30.3	34.1	57.3	bottom
PRLG7	5/25/2005	Lagoon	N17.945519	W067.092832	6.7	5.06	30.4	34.1	57.3	bottom
PRLG8	5/25/2005	Lagoon	N17.942424	W067.116750	5.2	4.92	31.6	33.6	51.0	bottom
PRLG17	5/25/2005	Lagoon	N17.961227	W067.074486	5.8	6.01	31.9	33.5	58.0	bottom
PRLG18	5/25/2005	Lagoon	N17.970818	W067.063506	6.1	6.81	30.9	33.8	57.4	19
PRLG19	5/23/2005	Lagoon	N17.963663	W067.040107	5.5	5.40	30.2	33.6	56.4	bottom
PRLG20	5/25/2005	Lagoon	N17.965985	W067.062499	7.0	5.24	31.5	33.8	51.5	bottom
PRLG27	5/23/2005	Lagoon	N17.959831	W066.991050	7.9	5.54	30.0	33.3	55.9	16
PRLG28	5/23/2005	Lagoon	N17.956087	W066.999836	13.4	5.39	29.9	33.4	55.2	25
PRLG29	5/23/2005	Lagoon	N17.967738	W067.017806	3.0	5.83	30.9	33.6	56.9	10
PRLG30	5/25/2005	Lagoon	N17.955862	W066.998984	13.1	5.08	29.3	34.5	57.0	23
PRLG37	5/24/2005	Lagoon	N17.962632	W066.925094	3.0	4.24	29.5	32.3	55.0	4
PRLG38	5/24/2005	Lagoon	N17.959960	W066.917055	2.7	5.06	30.1	32.4	54.7	5
PRLG39	5/24/2005	Lagoon	N17.961028	W066.920218	3.0	4.37	29.9	32.9	55.1	3
PRBR1	5/25/2005	Back Reef	N17.923550	W067.114357	2.7	5.53	30.6	34.2	57.4	bottom
PRBR2	5/25/2005	Back Reef	N17.935098	W067.095237	1.2	5.37	30.5	34.3	57.9	bottom
PRBR3	5/25/2005	Back Reef	N17.932738	W067.092546	1.2	5.39	31.4	34.1	58.3	bottom
PRBR7	5/24/2005	Back Reef	N17.942606	W067.060851	1.8	6.85	30.7	34.2	58.2	bottom
PRBR8	5/23/2005	Back Reef	N17.962857	W067.036395	0.9	7.13	30.8	33.6	51.3	bottom
PRBR9	5/24/2005	Back Reef	N17.941396	W067.044688	2.1	6.18	30.3	34.5	57.9	bottom

Abbreviations: DD, decimal degrees; m, meters; mg/L, milligrams/liter; °C, degrees Celcius; ppt, parts per thousand; mS, milli-Siemens

Appendix B. Field data from May 2005 mission (cont.).

Site	Collection Date	Habitat	Latitude (DD)	Longitude (DD)	Water Depth (m)	Dissolved Oxygen (mg/L)	Temperature (°C)	Salinity (ppt)	Conductivity (mS)	Secchi Depth (m)
PRBR12	5/25/2005	Back Reef	N17.955912	W067.048727	1.5	5.21	30.4	34.4	52.3	bottom
PRBR13	5/24/2005	Back Reef	N17.945716	W067.009205	1.2	5.66	30.9	34.2	58.0	bottom
PRBR14	5/24/2005	Back Reef	N17.944234	W067.007594	0.9	6.13	31.0	34.5	58.6	bottom
PRBR15	5/24/2005	Back Reef	N17.947177	W067.011145	1.5	5.57	30.6	33.9	51.5	bottom
PRBR25	5/24/2005	Back Reef	N17.928947	W066.945380	2.1	5.68	30.1	33.9	56.8	bottom
PRBR26	5/24/2005	Back Reef	N17.927524	W066.950354	4.6	6.58	30.6	33.9	51.6	bottom
PRBR27	5/24/2005	Back Reef	N17.928358	W066.952837	4.0	6.62	30.4	34	58.0	bottom
PRBS1	5/23/2005	Bank Shelf	N17.953140	W067.067396	18.6	5.33	30.5	32.6	55.0	29
PRBS2	5/23/2005	Bank Shelf	N17.927291	W067.039238	17.4	5.49	29.4	33.9	56.3	48
PRBS3	5/23/2005	Bank Shelf	N17.944686	W067.074537	18.6	5.79	30.0	33.4	55.9	32
PRBS4	5/24/2005	Bank Shelf	N17.958692	W067.028657	12.2	5.51	30.1	34.1	57.2	27
PRBS5	5/25/2005	Bank Shelf	N17.933401	W067.030351	18.9	5.30	29.3	34.5	56.9	37
PRBS7	5/24/2005	Bank Shelf	N17.947373	W067.027537	16.8	5.50	29.6	34.6	57.3	25
PRBS8	5/24/2005	Bank Shelf	N17.946996	W067.039631	17.7	5.63	29.5	34.5	57.2	31
PRBS9	5/25/2005	Bank Shelf	N17.955879	W067.058907	15.2	5.21	29.9	34.2	57.0	31
PRBS16	5/25/2005	Bank Shelf	N17.959484	W067.053296	18.3	5.13	30.9	34.2	58.1	31
PRBS20	5/25/2005	Bank Shelf	N17.959799	W067.048179	16.8	5.20	30.3	34.3	57.6	28
PRBS24	5/24/2005	Bank Shelf	N17.941551	W067.031722	12.2	5.65	29.7	33.9	56.5	37
PRBS29	5/23/2005	Bank Shelf	N17.942431	W066.991808	15.8	5.18	29.7	33.4	55.8	25
PRBS30	5/23/2005	Bank Shelf	N17.930319	W067.014447	18.9	5.36	29.7	33.8	56.1	35
PRBS31	5/23/2005	Bank Shelf	N17.942497	W066.977832	13.7	5.19	29.6	33.7	51.5	29
PRBS32	5/25/2005	Bank Shelf	N17.939746	W067.025056	17.4	5.31	28.3	34.5	56.9	27
PRBS33	5/24/2005	Bank Shelf	N17.948607	W067.010185	12.2	5.39	30.0	34.5	57.4	26
PRBS34	5/25/2005	Bank Shelf	N17.923034	W067.021467	22.6	5.39	28.2	34.5	56.7	47
PRBS35	5/24/2005	Bank Shelf	N17.960042	W067.015735	15.8	5.86	30.2	34.2	57.3	25
PRBS36	5/24/2005	Bank Shelf	N17.952984	W067.002496	12.2	5.60	31.2	33.7	52.2	27
PRBS40	5/24/2005	Bank Shelf	N17.934368	W066.976107	12.2	5.44	29.6	34.5	57.2	36
PRBS41	5/25/2005	Bank Shelf	N17.948125	W067.000005	15.8	4.99	29.4	34.3	56.9	31
PRBS43	5/25/2005	Bank Shelf	N17.931560	W066.992106	16.5	5.11	28.1	33.9	55.8	20
PRBS60	5/25/2005	Bank Shelf	N17.936707	W066.986643	16.8	5.18	29.2	34.4	56.7	31
PRBS62	5/25/2005	Bank Shelf	N17.954316	W067.012856	17.7	5.15	30.2	34.2	57.3	26
PRBS63	5/24/2005	Bank Shelf	N17.918851	W066.949879	13.7	5.10	28.9	34	55.8	31
PRBS65	5/24/2005	Bank Shelf	N17.910291	W066.936851	14.3	5.32	28.9	34.2	56.0	32
PRBS67	5/24/2005	Bank Shelf	N17.937626	W066.895727	18.3	5.17	29.1	33.5	55.3	27
PRBS69	5/24/2005	Bank Shelf	N17.942199	W066.900213	11.6	5.03	29.5	33.6	55.7	24
PRBS73	5/24/2005	Bank Shelf	N17.920198	W066.938717	14.0	5.60	29.8	33.4	55.9	28

Abbreviations: DD, decimal degrees; m, meters; mg/L, milligrams/liter; °C, degrees Celcius; ppt, parts per thousand; mS, milli Siemens

Appendix C. Total organic carbon and grain size distribution in sediment samples from southwest Puerto Rico, May 2005 mission.

Site	TOC %	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Site	TOC %	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
PRMG-8	3.74	0.75	37.62	48.02	13.61	PRMG-3	2.89	32.82	34.42	2.58	30.18
PRMG-13	3.02	2.72	44.16	41.46	11.65	PRMG-7	2.54	4.75	54.98	28.30	11.96
PRMG-19	4.16	6.16	48.74	38.24	6.86	PRMG-9	2.70	1.87	27.91	54.96	15.25
PRMG-21	2.69	1.09	39.94	48.26	10.71	PRMG-14	3.31	3.64	43.86	41.33	11.16
PRMG-24	1.91	0.04	22.35	69.56	8.06	PRMG-15	1.61	12.88	71.73	7.87	7.51
PRBS-3	0.64	3.77	64.81	29.03	2.39	PRBS-35	0.57	0.07	7.55	88.63	3.75
PRBS-5	0.97	1.58	60.08	37.01	1.33	PRBS-36	0.87	0.22	5.77	89.40	4.61
PRBS-9	0.60	3.20	39.22	54.93	2.66	PRBS-40	0.50	17.34	70.50	10.25	1.91
PRBS-10	0.37	3.32	93.45	1.10	2.13	PRBS-63	2.90	n/a	n/a	n/a	n/a
PRBS-16	1.34	0.00	7.32	89.09	3.59	PRBS-65	0.50	n/a	n/a	n/a	n/a
PRBS-20	0.78	0.00	5.16	91.61	3.23	PRBS-66	2.29	n/a	n/a	n/a	n/a
PRBS-29	1.03	34.43	35.09	28.33	2.15	PRBS-67	0.40	2.29	59.82	35.73	2.16
PRBS-31	0.29	0.02	34.90	64.44	1.65	PRBS-69	0.29	0.77	58.99	37.72	2.51
PRBS-32	0.52	1.69	46.65	46.88	4.77	PRBS-73	1.39	14.48	82.08	1.27	2.18
PRBS-34	0.23	0.16	53.03	43.16	1.65	PRLG-19	0.66	4.76	65.03	26.95	3.26
PRBS-41	0.92	0.00	4.50	90.64	4.86	PRLG-27	0.96	3.09	48.59	44.25	4.08
PRBS-43	0.80	29.28	65.91	3.51	1.30	PRLG-28	0.81	0.05	4.57	90.75	4.62
PRBS-60	0.28	0.50	64.72	33.24	1.54	PRLG-37	2.14	0.00	12.29	74.84	12.87
PRBS-62	0.90	0.07	5.79	90.57	3.57	PRLG-38	2.01	39.31	40.95	16.66	3.08
PRBR-2	0.72	0.11	98.56	1.31	0.02	PRLG-39	1.86	49.87	35.03	12.91	2.19
PRBR-3	0.50	3.38	88.66	6.56	1.40	PRBR-7	3.41	4.20	90.06	4.04	1.70
PRBR-8	0.29	n/a	n/a	n/a	n/a	PRBR-9	3.08	6.46	87.49	4.63	1.42
PRBR-12	0.34	0.89	93.38	3.59	2.15	PRBR-13	1.56	0.08	93.48	6.22	0.22
PRLG-1	1.06	1.46	51.71	41.85	4.98	PRBR-14	1.89	3.19	91.00	4.61	1.20
PRLG-3	2.24	10.26	28.96	43.63	17.14	PRBR-15	0.36	0.18	82.97	15.68	1.17
PRLG-4	2.77	23.63	27.94	37.32	11.11	PRBR-25	0.54	0.09	97.42	1.43	1.07
PRLG-6	0.74	14.39	55.87	24.71	5.02	PRBR-26	1.57	26.58	69.46	2.66	1.30
PRLG-7	1.80	33.94	47.97	14.58	3.51	PRBR-27	0.55	11.36	85.18	2.42	1.04
PRLG-8	2.08	17.07	27.74	42.81	12.38	PRBS-1	0.63	2.46	16.93	77.49	3.12
PRLG-17	1.97	16.37	35.19	40.95	7.50	PRBS-2	0.23	0.21	78.17	20.33	1.29
PRLG-18	1.18	8.52	44.93	40.65	5.90	PRBS-4	NA	13.14	56.86	28.30	1.70
PRLG-20	1.25	5.86	50.96	36.37	6.82	PRBS-7	0.93	22.50	30.90	44.41	2.19
PRLG-29	2.48	0.12	24.84	63.17	11.87	PRBS-8	1.03	1.21	32.45	63.70	2.64
PRLG-30	0.80	0.02	4.79	89.23	5.96	PRBS-30	0.48	0.30	76.30	21.66	1.74
PRMG-1	3.47	7.91	67.71	16.79	7.58	PRBS-33	0.51	3.48	46.92	47.54	2.06
PRMG-2	6.45	15.75	38.57	22.47	23.21						

Appendix D. Total organic carbon and grain size distribution in sediment samples from southwest Puerto Rico, August 2005 mission.

Site	TOC %	TIC %	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Coral 1	1.47	10.06	1.48	97.13	0.00	1.55
Coral 2	4.13	7.36	0.67	98.23	0.00	1.35
Coral 3	1.05	10.35	9.37	82.02	5.86	2.76
Coral 4	2.51	8.78	16.74	58.88	20.94	3.44
Coral 5	0.45	10.46	1.06	65.93	28.84	4.17
Coral 6	0.45	10.82	7.63	72.63	16.91	2.83
Coral 8	0.57	10.89	12.73	64.49	19.38	3.40
Coral 9	0.76	10.76	6.65	76.83	12.92	3.60
LTOC1	0.94	10.84	28.96	67.70	1.41	1.93
LTOC2	0.20	11.62	0.70	95.57	1.33	2.40
LTOC3	0.13	11.76	0.03	97.30	0.49	2.18
LTOC7	0.86	9.66	0.05	12.04	82.04	5.86
LTOC8	0.26	10.87	0.15	54.45	41.33	4.07
LTOC9	0.43	10.35	0.53	19.67	73.93	5.87
LTOC10	0.25	11.07	0.95	70.07	23.79	5.19
LTOC11	0.37	10.74	0.14	43.52	52.83	3.51
LTOC12	2.78	8.99	7.21	86.17	3.58	3.04
LTOC13	2.17	9.59	13.40	84.67	0.21	1.72
LTOC14	0.91	10.73	3.12	90.31	3.53	3.03
LTOC15	0.75	9.63	0.12	21.76	73.51	4.61
LTOC16	1.25	9.70	34.07	36.76	25.25	3.92
LTOC17	2.64	8.90	0.08	96.39	0.94	2.59
LTOC18	0.51	11.26	2.20	93.29	2.22	2.29
LTOC19	1.35	9.82	18.26	50.40	26.77	4.57
LTOC22	0.63	9.70	0.13	14.81	80.13	4.93
HTOC1	0.63	11.04	0.07	95.79	2.20	1.93
HTOC2	4.99	6.73	11.43	87.93	0.00	0.92
HTOC3	1.06	10.43	6.72	50.82	38.00	4.47
HTOC4	0.44	10.97	2.01	50.23	43.32	4.45
HTOC6	0.84	10.01	4.26	41.55	49.72	4.47
HTOC7	0.88	10.85	2.98	91.49	6.17	0.00
HTOC8	1.49	10.23	0.70	81.71	13.18	4.41
HTOC9	0.96	10.86	6.18	54.75	33.80	5.26
HTOC10	0.28	11.35	0.44	98.76	0.00	1.22
HTOC12	0.65	11.37	2.45	92.98	1.96	2.60
HTOC14	0.76	11.03	5.16	88.76	2.26	3.82
HTOC15	2.65	9.18	20.15	77.89	0.74	1.22
HTOC16	1.04	9.40	0.04	14.49	81.30	4.18
HTOC17	0.99	4.46	0.41	2.64	91.06	5.89
HTOC19	1.61	1.22	0.00	0.78	86.92	12.30
HTOC20	2.16	10.14	11.84	46.54	33.61	8.01
HTOC21	0.19	11.49	1.24	83.33	10.80	4.63
HTOC22	0.80	9.86	0.06	4.76	89.57	5.61

Abbreviations: TOC, total organic carbon; TIC, total inorganic carbon

Appendix E. Polycyclic aromatic hydrocarbons (PAHs) in sediment samples from southwest Puerto Rico (ng/ dry g).

Compound	Coral 1	Coral 2	Coral 3	Coral 4	Coral 5	Coral 6	Coral 8	Coral 9	LTOC1	LTOC2
Decalin	0.0 U	0.0 U	0.0 U							
C1-Decalins	0.0 U	0.0 U	0.0 U							
C2-Decalins	0.0 U	0.0 U	0.0 U							
C3-Decalins	0.0 U	0.0 U	0.0 U							
C4-Decalins	0.0 U	0.0 U	0.0 U							
Naphthalene	0.4	0.3	1.5	2.3	12.5	3.3	0.9	0.3	0.2	0.3
C1-Naphthalenes	0.2 J	0.1 J	0.3 J	0.5	1.3	0.6	0.3 J	0.2 J	0.1 J	0.1 J
C2-Naphthalenes	0.0 U	0.2 J	0.7	1.0	1.9	1.1	0.8	0.3 J	0.3 J	0.3 J
C3-Naphthalenes	0.0 U	0.0 U	0.0 U	0.0 U	1.0	0.8	0.0 U	0.0 U	0.0 U	0.0 U
C4-Naphthalenes	0.0 U	0.0 U	0.0 U	0.0 U	1.3	1.4	0.0 U	0.0 U	0.0 U	0.0 U
Benzothiophene	0.0 U	0.0 U	0.0 U							
C1-Benzothiophenes	0.0 U	0.0 U	0.0 U							
C2-Benzothiophenes	0.0 U	0.0 U	0.0 U							
C3-Benzothiophenes	0.0 U	0.0 U	0.0 U							
Biphenyl	0.2	0.2	0.5	0.6	2.0	0.8	0.3	0.2	0.2	0.2
Acenaphthylene	0.1 J	0.0 U	0.3	0.5	3.0	0.7	0.2	0.0 U	0.1 J	0.0 U
Acenaphthene	0.1 J	0.0 U	0.3	0.2	1.0	0.3	0.0 U	0.0 U	0.1 J	0.1 J
Dibenzofuran	0.1 J	0.1 J	0.4	0.5	2.0	0.8	0.3	0.1 J	0.2 J	0.2 J
Fluorene	0.2	0.0 U	1.1	0.6	1.3	1.7	0.7	0.1 J	0.2	0.3
C1-Fluorenes	0.0 U	0.0 U	0.5	0.5	0.7	0.9	0.5	0.0 U	0.0 U	0.0 U
C2-Fluorenes	0.0 U	0.0 U	1.8	1.6	1.8	2.5	1.9	0.0 U	0.0 U	0.0 U
C3-Fluorenes	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0
Carbazole	0.0 U	0.0 U	0.0 U	0.0 U	0.3 J	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Anthracene	0.0 U	0.0 U	0.4	0.6	2.9	1.0	0.2	0.1 J	0.0 U	0.0 U
Phenanthrene	0.3	0.2	2.5	3.0	14.2	5.2	1.5	0.5	0.3	0.5
C1-Phenanthrene/Anthracenes	0.3	0.1 J	0.8	0.8	3.1	1.6	0.7	0.3	0.2 J	0.3
C2-Phenanthrene/Anthracenes	0.4	0.4	1.1	1.3	2.3	1.8	0.9	0.7	0.0 U	0.0 U
C3-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U	0.8	1.5	1.1	0.0 U	0.0 U	0.0 U	0.0 U
C4-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U							
Dibenzothiophene	0.0 U	0.0 U	0.1 J	0.1 J	0.3	0.1 J	0.1 J	0.0 U	0.0 U	0.0 U
C1-Dibenzothiophenes	0.0 U	0.0 U	0.2 J	0.2 J	0.5	0.3 J	0.2 J	0.0 U	0.0 U	0.0 U
C2-Dibenzothiophenes	0.0 U	0.0 U	0.4	0.5	0.8	0.5	0.0 U	0.0 U	0.0 U	0.0 U
C3-Dibenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.8	0.5	0.0 U	0.0 U	0.0 U	0.0 U
Fluoranthene	0.3	0.1 J	2.5	3.4	19	6.7	1.6	0.4	0.2 J	0.2 J
Pyrene	0.2	0.0 U	3.1	4.1	24	7.9	1.7	0.4	0.2	0.2
C1-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.4	0.7	2.1	1.1	0.3 J	0.0 U	0.0 U	0.0 U
C2-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.6	0.4	1.4	1.9	0.0 U	0.0 U	0.0 U	0.0 U
C3-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.0 U	0.0 U	0.4	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Naphthobenzothiophene	0.0 U	0.0 U	0.0 U							
C1-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U							
C2-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U							
C3-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U							
Benz(a)anthracene	0.1 J	0.0 U	0.4	0.6	2.0	1.0	0.3	0.1 J	0.0 U	0.1 J
Chrysene	0.1 J	0.0 U	0.6	0.8	2.8	1.4	0.4	0.1 J	0.0 U	0.1 J
C1-Chrysenes	0.0 U	0.0 U	0.2 J	0.4	0.9	0.6	0.0 U	0.0 U	0.0 U	0.0 U
C2-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	1.0	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Chrysenes	0.0 U	0.0 U	0.0 U							
C4-Chrysenes	0.0 U	0.0 U	0.0 U							
Benzo(b)fluoranthene	0.2 J	0.0 U	1.2	1.4	4.8	2.8	0.9	0.3	0.0 U	0.0 U
Benzo(k)fluoranthene	0.1 J	0.0 U	0.4	0.4	1.5	0.8	0.2 J	0.1 J	0.0 U	0.0 U
Benzo(e)pyrene	0.1 J	0.0 U	0.7	0.8	3.4	1.7	0.5	0.1 J	0.0 U	0.0 U
Benzo(a)pyrene	0.1 J	0.0 U	0.9	1.1	4.3	2.0	0.6	0.2 J	0.0 U	0.0 U
Perylene	0 U	0.0 U	0.3 J	0.1 J	1.2 J	0.5 J	0.1 J	0.0 U	0.0 U	0.0 U
Indeno(1,2,3-c,d)pyrene	0.1 J	0.0 U	1.1	1.2	4.3	2.3	0.8	0.2 J	0.0 U	0.0 U
Dibenzo(a,h)anthracene	0.0 U	0.0 U	0.0 U	0.0 U	0.4	0.3	0.0 U	0.0 U	0.0 U	0.0 U
C1-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U							
C2-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U							
C3-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U							
Benzo(g,h,i)perylene	0.1 J	0.0 U	2.1	2.3	9.2	4.9	1.5	0.5	0.0 U	0.1 J
Total PAHs	3.7	1.7	27.4	33.3	139	65.7	18.4	5.2	2.3	3.0
Individual Isomers*										
2-Methylnaphthalene	0.2 J	0.1 J	0.3	0.5	1.4	0.7	0.3	0.2 J	0.1 J	0.1 J
1-Methylnaphthalene	0.1 J	0.1 J	0.2	0.3	0.7	0.3	0.2	0.1 J	0.1 J	0.1 J
2,6-Dimethylnaphthalene	0.0 U	0.1 J	0.7	1.0	2.2	1.0	0.9	0.1 J	0.2 J	0.1 J
1,6,7-Trimethylnaphthalene	0.0 U	0.0 U	0.0 U	0.0 U	0.1	0.1	0.0 U	0.0 U	0.0 U	0.0 U
1-Methylphenanthrene	0.1 J	0.0 U	0.2 J	0.2 J	0.5	0.4	0.2 J	0.1 J	0.1 J	0.1 J

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

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

Appendix E. Polycyclic aromatic hydrocarbons (PAHs) in sediment samples from southwest Puerto Rico (ng/ dry g) (continued).

Compound	LTOC3	LTOC7	LTOC8	LTOC9	LTOC10	LTOC11	LTOC12	LTOC13	LTOC14	LTOC15	LTOC16
Decalin	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C1-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C2-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C3-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C4-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
Naphthalene	0.3	16.4	1.4	3.6	0.7	1.2	0.4	0.5	0.5	7.3	1.2
C1-Naphthalenes	0.1 J	1.8	0.4	0.6	0.3 J	0.3 J	0.2 J	0.2 J	0.2 J	1.1	0.5
C2-Naphthalenes	0.3 J	2.9	0.8	1.5	0.4	0.5	0.3 J	0.3 J	0.3 J	1.7	0.7
C3-Naphthalenes	0.0 U	1.6	0.0 U	1.3	0.0 U	0.7	0.0 U	0.0 U	0.0 U	1.4	0.8
C4-Naphthalenes	0.0 U	2.2	0.0 U	2.0	0.0 U	1.7	0.0 U				
Benzothiophene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C1-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C2-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C3-Benzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
Biphenyl	0.2	2.7	0.4	0.9	0.3	0.4	0.2	0.3	0.3	1.5	0.4
Acenaphthylene	0.0 U	3.7	0.3	0.9	0.2	0.3	0.0 U	0.0 U	0.0 U	2.1	0.3
Acenaphthene	0.0 U	1.5	0.1 J	0.3	0.0 U	0.0 U	0.0 U	0.1 J	0.0 U	0.7	0.2
Dibenzofuran	0.2 J	2.1	0.4	0.7	0.0 U	0.2 J	0.1 J	0.2 J	0.0 U	1.2	0.3
Fluorene	0.1 J	1.4	0.9	1.7	0.3	0.3	0.1 J	0.1 J	0.2	1.2	0.6
C1-Fluorenes	0.0 U	1.3	0.7	1.1	0.4	0.4	0.2 J	0.3 J	0.0 U	1.0	0.7
C2-Fluorenes	0.0 U	1.8	0.0 U	1.9	0.0 U	1.0	0.7	0.0 U	0.0 U	2.4	1.7
C3-Fluorenes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0
Carbazole	0.0 U	0.4	0.0 U	0.1 J	0.1 J	0.1 J	0.1 J	0.0 U	0.0 U	0.2 J	0.1 J
Anthracene	0.0 U	3.3	0.3	1.4	0.2	0.3	0.0 U	0.0 U	0.0 U	2.6	0.4
Phenanthrene	0.3	15.7	1.6	5.9	1.1	1.5	0.2	0.3	0.3	10.2	1.8
C1-Phenanthrene/Anthracenes	0.2 J	4.5	0.8	2.4	0.7	1.0	0.2 J	0.3	0.2 J	4.6	1.0
C2-Phenanthrene/Anthracenes	0.0 U	3.9	1.2	2.7	1.5	1.4	0.0 U	0.0 U	0.6	3.2	1.3
C3-Phenanthrene/Anthracenes	0.0 U	3.0	0.0 U	2.2	0.0 U	2.6	0.0 U				
C4-Phenanthrene/Anthracenes	0.0 U	1.1	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Dibenzothiophene	0.0 U	0.4	0.1 J	0.2	0.1 J	0.1 J	0.0 U	0.0 U	0.0 U	0.3	0.0 U
C1-Dibenzothiophenes	0.0 U	0.9	0.2 J	0.5	0.2 J	0.2 J	0.0 U	0.0 U	0.0 U	0.6	0.2 J
C2-Dibenzothiophenes	0.0 U	1.5	0.4	1.0	0.2 J	0.4	0.0 U	0.0 U	0.0 U	1.1	0.4
C3-Dibenzothiophenes	0.0 U	1.6	0.0 U	1.0	0.0 U	1.1	0.0 U				
Fluoranthene	0 J	21.2	2	11	1.4	1.9	0.1 J	0.1 J	0.1 J	20	2.6
Pyrene	0 J	27.0	2	12	1.3	2.3	0.2	0.1 J	0.1 J	26	2.9
C1-Fluoranthenes/Pyrenes	0.0 U	3.7	1	2.2	0.5	0.8	0.0 U	0.0 U	0.1 J	3.2	0.7
C2-Fluoranthenes/Pyrenes	0.0 U	2.6	0.6	1.7	0.6	0.6	0.0 U	0.0 U	0.0 U	2.2	0.0 U
C3-Fluoranthenes/Pyrenes	0.0 U	1.5	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.9	0.0 U
Naphthobenzothiophene	0.0 U	0.8	0.0 U	0.5	0.0 U	0.8	0.0 U				
C1-Naphthobenzothiophenes	0.0 U	1.4	0.0 U	1.0	0.0 U	1.3	0.0 U				
C2-Naphthobenzothiophenes	0.0 U	2.1	0.0 U	1.5	0.0 U	1.9	0.0 U				
C3-Naphthobenzothiophenes	0.0 U	1.5	0.0 U	1.1	0.0 U						
Benz(a)anthracene	0.0 U	2.9	0	2.1	0.6	0.5	0.0 U	0.0 U	0.0 U	2.6	0.5
Chrysene	0 U	2.9	0	2	0.6	0.7	0.1 J	0.0 U	0.0 U	4.0	0.7
C1-Chrysenes	0.0 U	1.6	0	1.4	0.4	0.6	0.0 U	0.0 U	0.0 U	1.8	0.5
C2-Chrysenes	0.0 U	1.8	0.0 U	1.6	0.0 U	0.7	0.0 U	0.0 U	0.0 U	1.9	0.8
C3-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C4-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
Benzo(b)fluoranthene	0 U	4.5	1	4	1.4	1.2	0.0 U	0 U	0.0 U	6.8	1.4
Benzo(k)fluoranthene	0.0 U	1.1	0.2 J	1.0	0.5	0.4	0.0 U	0.0 U	0.0 U	2.2	0.4
Benzo(e)pyrene	0.0 U	2.9	0.4	2.4	0.8	0.7	0.0 U	0.0 U	0.0 U	4.8	0.8
Benzo(a)pyrene	0.0 U	3.5	0.4	2.7	1.1	0.8	0.0 U	0.0 U	0.0 U	5.6	1.1
Perylene	0.0 U	1.1 J	0.2 J	1 J	0 J	0.4 J	0.0 U	0.0 U	0.0 U	2.1	0.5 J
Indeno(1,2,3-c,d)pyrene	0.0 U	3.4	0.6	3.4	1.0	0.8	0.1 J	0.0 U	0.0 U	6.3	1.3
Dibenzo(a,h)anthracene	0.0 U	0.5	0.0 U	0.4	0.2	0.1 J	0.0 U	0.0 U	0.0 U	0.3	0.2
C1-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C2-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
C3-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U				
Benzo(g,h,i)perylene	0.0 U	6.1	0.9	5.6	1.2	1.2	0.1 J	0.0 U	0.1 J	13.5	2.3
Total PAHs	2	170	19	93	18.7	24.0	3.3	2.8	3.0	161	29.3
Individual Isomers*											
2-Methylnaphthalene	0.1 J	1.8	0.4	0.7	0.3	0.3	0.2 J	0.2 J	0.2 J	1.2	0.5
1-Methylnaphthalene	0.1 J	1.1	0.2	0.3	0.2	0.2	0.1 J	0.1 J	0.1 J	0.6	0.3
2,6-Dimethylnaphthalene	0.1 J	3.0	0.5	1.4	0.2 J	0.3	0.1 J	0.1 J	0.1 J	1.7	0.5
1,6,7-Trimethylnaphthalene	0.0 U	0.1	0.0 U	0.1	0.0 U	0.1	0.0 U	0.0 U	0.0 U	0.2	0.1
1-Methylphenanthrene	0.1 J	0.7	0.2 J	0.4	0.2 J	0.2 J	0.1 J	0.1 J	0.1 J	0.6	0.2 J

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

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

Appendix E. Polycyclic aromatic hydrocarbons (PAHs) in sediment samples from southwest Puerto Rico (ng/ dry g) (continued).

Compound	LTOC19	LTOC18	LTOC19	LTOC22	HTOC1	HTOC2	HTOC3	HTOC4	HTOC6	HTOC7	HTOC8
Decalin	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C1-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Naphthalene	0.3	0.3	0.7	7.9	0.3	0.3	5.8	1.7	3.4	0.6	0.9
C1-Naphthalenes	0.2 J	0.1 J	0.3 J	1.2	0.4	0.1 J	1.1	0.5	0.9	0.5	0.3 J
C2-Naphthalenes	0.2 J	0.2 J	0.4	1.5	0.7	0.2 J	2.2	1.0	2.1	1.3	0.5
C3-Naphthalenes	0.0 U	0.0 U	0.0 U	1.2	1.5	0.0 U	1.8	0.6	3.2	5.0	0.0 U
C4-Naphthalenes	0.0 U	0.0 U	0.0 U	1.6	1.4	0.0 U	2.8	1.1	5.9	12.9	0.0 U
Benzo(b)thiophene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C1-Benzo(b)thiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Benzo(b)thiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Benzo(b)thiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Biphenyl	0.2	0.2	0.3	1.5	0.2	0.2	1.3	0.4	0.8	0.3	0.2
Acenaphthylene	0.0 U	0.0 U	0.1 J	2.1	0.0 U	0.0 U	1.4	0.3	0.8	0.1 J	0.1 J
Acenaphthene	0.1 J	0.1 J	0.2	0.6	0.0 U	0.0 U	0.4	0.1 J	0.3	0.1 J	0.1 J
Dibenzofuran	0.1 J	0.1 J	0.2 J	1.2	0.1 J	0.1 J	1.2	0.4	0.8	0.3	0.2 J
Fluorene	0.1 J	0.1 J	0.3	1.2	0.1 J	0.1 J	3.1	0.8	2.0	0.4	0.3
C1-Fluorenes	0.2 J	0.2 J	0.5	1.0	0.5	0.0 U	1.6	0.7	2.0	2.5	0.3 J
C2-Fluorenes	0.5	0.0 U	0.0 U	2.1	1.3	0.0 U	5.0	1.4	4.6	5.4	0.7
C3-Fluorenes	0.0	0.0	0.0	0.0	1.2	0.0	3.6	0.0	3.9	0.0	0.0
Carbazole	0.0 U	0.0 U	0.0 U	0.2 J	0.0 U	0.0 U	0.3 J	0.0 U	0.3 J	0.0 U	0.0 U
Anthracene	0.0 U	0.0 U	0.2	2.6	0.1 J	0.0 U	2.7	0.5	1.3	0.2	0.2
Phenanthrene	0.3	0.2	0.9	9.2	0.5	0.1 J	9.0	2.7	6.7	2.8	1.0
C1-Phenanthrene/Anthracenes	0.2 J	0.2 J	0.7	4.7	1.8	0.0 U	4.3	1.0	3.6	4.0	0.4
C2-Phenanthrene/Anthracenes	0.5	0.5	0.9	2.9	2.8	0.0 U	4.1	1.3	4.2	3.9	0.5
C3-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U	3.2	1.6	0.0 U	0.0 U	0.0 U	4.0	0.0 U	0.0 U
C4-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U	0.8	0.6	0.0 U					
Dibenzothiophene	0.0 U	0.0 U	0.1 J	0.2	0.0 U	0.0 U	0.3	0.1 J	0.5	0.6	0.0 U
C1-Dibenzothiophenes	0.0 U	0.0 U	0.2 J	0.6	0.2 J	0.0 U	0.6	0.3 J	1.5	0.0 U	0.0 U
C2-Dibenzothiophenes	0.0 U	0.0 U	0.3 J	1.0	0.3 J	0.0 U	1.1	0.5	1.6	0.0 U	0.0 U
C3-Dibenzothiophenes	0.0 U	0.0 U	0.0 U	1.1	0.0 U	0.0 U	1.2	0.0 U	1.3	0.0 U	0.0 U
Fluoranthene	0.2 J	0.1 J	1.2	20	0.2 J	0.0 U	15	2.8	7	0.8	1
Pyrene	0.2	0.1 J	1.6	29	0.2	0.0 U	16	3.3	9	0.7	1
C1-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.3 J	3.0	0.8	0.0 U	3.5	0.6	2.4	2.3	0 J
C2-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.0 U	1.7	1.1	0.0 U	2.9	0.5	1.5	0.8	0.2 J
C3-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.0 U	0.8	0.9	0.0 U	1.7	0.0 U	0.7	0.0 U	0.0 U
Naphthobenzothiophene	0.0 U	0.0 U	0.0 U	0.6	0.2 J	0.0 U					
C1-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	1.2	0.4 J	0.0 U					
C2-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	1.8	0.4 J	0.0 U					
C3-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benz(a)anthracene	0.0 U	0.0 U	0.2	2.6	0.2	0.0 U	2.9	0.5	1.2	0.1 J	0
Chrysene	0.0 U	0.0 U	0.3	3.6	0.3	0.0 U	3.6	0.6	2	0.2	0
C1-Chrysenes	0.0 U	0.0 U	0.3 J	1.7	0.8	0.0 U	2.1	0.4	1.0	0.0 U	0 U
C2-Chrysenes	0.0 U	0.0 U	0.4	2.2	0.8	0.0 U	2.1	0.8	1.4	0.0 U	0.0 U
C3-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benzo(b)fluoranthene	0.0 U	0.0 U	0.7	6.4	0.2 J	0.0 U	8.1	1.3	4	0.1 J	1
Benzo(k)fluoranthene	0.0 U	0.0 U	0.2 J	1.9	0.0 U	0.0 U	2.2	0.1 J	0.9	0.0 U	0.2 J
Benzo(e)pyrene	0.0 U	0.0 U	0.4	4.4	0.2 J	0.0 U	4.5	0.7	2.0	0.1 J	0.3 J
Benzo(a)pyrene	0.0 U	0.0 U	0.5	5.3	0.1 J	0.0 U	4.2	0.9	2.3	0.1 J	0.4
Perylene	0.0 U	0.0 U	0.2 J	2.3	0.0 U	0.0 U	1.3 J	0.3 J	0.7 J	0.2 J	0.1 J
Indeno(1,2,3-c,d)pyrene	0.0 U	0.0 U	0.6	5.6	0.0 U	0.0 U	5.6	1.1	2.8	0.1 J	0.5
Dibenzo(a,h)anthracene	0.0 U	0.0 U	0.1 J	0.3	0.0 U	0.0 U	0.9	0.0 U	0.4	0.0 U	0.0 U
C1-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benzo(g,h,i)perylene	0.2	0.0 U	1.1	11.9	0.2	0.0 U	9.5	2.1	5.0	0.2	0.9
Total PAHs	3.5	2.4	14.4	156	22.6	1.1	141	31.4	99	47	12
Individual Isomers*											
2-Methylnaphthalene	0.2 J	0.2 J	0.3	1.2	0.4	0.2 J	1.3	0.6	1.0	0.5	0.3
1-Methylnaphthalene	0.1 J	0.1 J	0.2	0.6	0.2	0.0 U	0.6	0.3	0.5	0.3	0.1 J
2,6-Dimethylnaphthalene	0.1 J	0.1 J	0.3	1.5	0.3	0.1 J	1.7	0.7	1.7	0.4	0.3
1,6,7-Trimethylnaphthalene	0.0 U	0.0 U	0.0 U	0.1	0.2	0.0 U	0.2	0.1	0.6	1.4	0.0 U
1-Methylphenanthrene	0.0 U	0.0 U	0.2 J	0.5	0.6	0.0 U	1.0	0.3	1.2	1.5	0.1 J

Notes: J, below method detection level, MDL; U, not detected  
\*Individual isomers contained in alkylated (C1-C4 sums)

Appendix E. Polycyclic aromatic hydrocarbons (PAHs) in sediment samples from southwest Puerto Rico (ng/ dry g) (continued).

Compound	HTOC9	HTOC10	HTOC12	HTOC14	HTOC15	HTOC16	HTOC17	HTOC19	HTOC20	HTOC21	HTOC22
Decalin	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C1-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C4-Decalins	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Naphthalene	3.0	0.2	0.2	0.2	0.3	16.0	15.8	10.9	2.1	0.7	9.5
C1-Naphthalenes	0.6	0.1 J	0.1 J	0.1 J	0.1 J	1.8	6.1	6.9	0.5	0.2 J	1.7
C2-Naphthalenes	0.9	0.4	0.0 U	0.0 U	0.2 J	3.1	10.9	12.9	1.8	0.3 J	3.0
C3-Naphthalenes	0.6	0.0 U	0.0 U	0.0 U	0.0 U	2.0	9.7	11.4	1.2	0.0 U	2.4
C4-Naphthalenes	1.2	0.0 U	0.0 U	0.0 U	0.0 U	2.8	8.0	9.0	2.2	0.0 U	3.1
Benzo[thiophene]	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.2	0.0 U	0.0 U	0.0 U	0.0 U
C1-Benzo[thiophenes]	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Benzo[thiophenes]	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Benzo[thiophenes]	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Biphenyl	0.6	0.2	0.2	0.2	0.3	2.9	3.5	2.7	0.6	0.3	2.2
Acenaphthylene	0.6	0.0 U	0.0 U	0.0 U	0.1 J	3.7	4.8	10.0	0.4	0.1 J	2.3
Acenaphthene	0.3	0.2	0.1 J	0.1 J	0.1 J	1.3	2.0	1.7	1.1	0.0 U	0.8
Dibenzofuran	0.6	0.1 J	0.1 J	0.2 J	0.2 J	2.6	3.4	3.3	0.6	0.2 J	1.9
Fluorene	1.2	0.0 U	0.3	0.0 U	0.0 U	2.8	3.4	3.7	2.3	0.0 U	1.4
C1-Fluorenes	0.8	0.0 U	0.0 U	0.0 U	0.0 U	1.7	5.5	6.6	0.0 U	0.0 U	2.4
C2-Fluorenes	2.2	0.0 U	0.0 U	0.0 U	0.0 U	3.4	10.8	12.2	0.0 U	0.0 U	3.5
C3-Fluorenes	0.0	0.0	0.0	0.0	0.0	5.8	12.0	18.1	0.0	0.0	5.7
Carbazole	0.2 J	0.0 U	0.0 U	0.0 U	0.0 U	0.5	1.4	3.1	0.2 J	0.0 U	0.3 J
Anthracene	1.2	0.0 U	0.0 U	0.0 U	0.0 U	5.5	9.0	17.9	0.7	0.2	3.8
Phenanthrene	4.7	0.3	0.3	0.3	0.2	19.7	13.6	16.5	2.5	0.7	13.9
C1-Phenanthrene/Anthracenes	1.9	0.2 J	0.2 J	0.0 U	0.2 J	7.0	18.4	31.2	2.0	0.3	5.9
C2-Phenanthrene/Anthracenes	1.7	0.5	0.0 U	0.0 U	0.0 U	4.6	26.5	42.2	1.8	0.0 U	4.5
C3-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	3.7	32.4	41.0	0.0 U	0.0 U	3.5
C4-Phenanthrene/Anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.9	10.9	14.8	0.0 U	0.0 U	1.1
Dibenzothiophene	0.2	0.0 U	0.0 U	0.0 U	0.0 U	0.5	1.9	2.4	0.1 J	0.0 U	0.4
C1-Dibenzothiophenes	0.4	0.0 U	0.0 U	0.0 U	0.0 U	1.0	5.1	6.8	0.4	0.0 U	0.9
C2-Dibenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.6	10.0	13.0	0.3 J	0.0 U	1.8
C3-Dibenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.7	11.3	14.4	0.0 U	0.0 U	1.9
Fluoranthene	6	0.1 J	0.1 J	0.2 J	0.1 J	40.9	29.6	46.6	4.1	1.0	27
Pyrene	7	0.1 J	0.1 J	0.2	0.2	54.6	38.9	45.3	4.8	1.2	35
C1-Fluoranthenes/Pyrenes	1.1	0.0 U	0.0 U	0.0 U	0.0 U	5.6	20.9	33.0	0.9	0.0 U	5.0
C2-Fluoranthenes/Pyrenes	1.2	0.0 U	0.0 U	0.0 U	0.0 U	3.5	17.7	34.6	0.7	0.0 U	3.2
C3-Fluoranthenes/Pyrenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.4	8.9	15.6	0.0 U	0.0 U	1.7
Naphthobenzothiophene	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.9	6.0	9.5	0.0 U	0.0 U	0.9
C1-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.6	8.4	13.9	0.0 U	0.0 U	1.9
C2-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	2.7	13.5	23.1	0.0 U	0.0 U	2.7
C3-Naphthobenzothiophenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	1.6	13.0	22.7	0.0 U	0.0 U	2.1
Benz(a)anthracene	0.9	0.0 U	0.0 U	0.0 U	0.1 J	8.4	15.9	30.1	0.7	0.1 J	3.8
Chrysene	1	0.0 U	0.0 U	0.0 U	0.1 J	4.4	17.5	28.0	1.0	0.1 J	5.2
C1-Chrysenes	0.6	0.0 U	0.0 U	0.0 U	0.0 U	2.8	18.9	32.5	0.0 U	0.0 U	2.9
C2-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	2.7	15.8	27.2	0.0 U	0.0 U	2.6
C3-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	10.1	17.0	0.0 U	0.0 U	0.0 U
C4-Chrysenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	3.9	7.2	0.0 U	0.0 U	0.0 U
Benzo(b)fluoranthene	3	0.0 U	0.0 U	0.0 U	0.1 J	9.8	25.8	40.7	1.7	0.4	9.2
Benzo(k)fluoranthene	0.7	0.0 U	0.0 U	0.0 U	0.0 U	1.9	6.8	15.3	0.5	0.1 J	1.8
Benzo(e)pyrene	1.5	0.0 U	0.0 U	0.0 U	0.1 J	6.5	14.4	23.0	0.8	0.2 J	5.7
Benzo(a)pyrene	1.9	0.0 U	0.0 U	0.0 U	0.1 J	8.0	12.1	21.4	1.2	0.2 J	6.8
Perylene	0 J	0.0 U	0.0 U	0.0 U	0.1 J	3.0	22.2	68.0	0.3 J	0.1 J	1.8
Indeno(1,2,3-c,d)pyrene	2.5	0.0 U	0.0 U	0.0 U	0.1 J	8.6	8.7	17.1	1.8	0.3	8.0
Dibenzo(a,h)anthracene	0.5	0.0 U	0.0 U	0.0 U	0.0 U	0.9	3.3	8.3	0.4	0.0 U	0.9
C1-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C2-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
C3-Dibenzo(a,h)anthracenes	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Benzo(g,h,i)perylene	4.9	0.0 U	0.0 U	0.1 J	0.1 J	17.2	14.2	18.4	2.9	0.5	14.0
Total PAHs	56	2.4	1.7	1.6	2.8	284	583	911	42.6	7.2	220
Individual Isomers*											
2-Methylnaphthalene	0.7	0.1 J	0.1 J	0.1 J	0.1 J	1.8	6.7	7.6	0.6	0.2 J	1.8
1-Methylnaphthalene	0.3	0.1 J	0.1 J	0.1 J	0.1 J	1.0	2.9	3.2	0.3	0.1 J	0.9
2,6-Dimethylnaphthalene	0.8	0.2 J	0.0 U	0.0 U	0.1 J	3.1	8.4	10.3	1.9	0.2 J	2.8
1,6,7-Trimethylnaphthalene	0.1	0.0 U	0.0 U	0.0 U	0.0 U	0.3	1.0	1.2	0.1	0.0 U	0.2
1-Methylphenanthrene	0.4	0.0 U	0.1 J	0.0 U	0.0 U	0.8	3.0	4.6	0.3	0.1 J	0.9

Notes: J, below method detection level, MDL; U, not detected  
 \*Individual isomers contained in alkylated (C1-C4 sums)

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g).

Compound	Coral 1	Coral 2	Coral 3	Coral 4	Coral 5	Coral 6
PCB8/5	0.00 U					
PCB18	0.00 U	0.00 U	0.00 U	0.31	0.00 U	0.00 U
PCB28	0.14	0.08 J	0.25	0.48	0.60	0.11
PCB29	0.00 U					
PCB31	0.00 U	0.00 U	0.25	0.55	0.59	0.10
PCB44	0.00 U	0.00 U	0.00 U	0.02 J	0.04 J	0.00 U
PCB45	0.00 U	0.00 U	1.35	0.00 U	0.00 U	0.00 U
PCB49	1.27	0.00 U	0.94	1.67	2.62	0.83
PCB52	0.52	0.00 U	0.56	1.21	1.51	0.44
PCB56/60	0.00 U					
PCB66	0.07	0.34	0.30	0.27	0.39	0.05 J
PCB70	0.07 J	0.00 U	0.30	0.32	0.00 U	0.00 U
PCB74/61	0.00 U					
PCB87/115	0.01 J	0.00 U	0.00 U	0.04 J	0.00 U	0.02 J
PCB95	0.21	0.00 U	0.00 U	0.44	0.65	0.14
PCB99	0.26	0.00 U	0.30	0.60	1.00	0.26
PCB101/90	0.51	0.12	0.45	0.77	1.53	0.52
PCB105	0.02 J	0.01 J	0.04 J	0.05	0.05	0.05 J
PCB110/77	0.12	0.00 U	0.11	0.22	0.30	0.17
PCB118	0.17	0.02 J	0.21	0.29	0.59	0.20
PCB128	0.00 U	0.00 U	0.00 U	0.00 U	0.08 J	0.00 U
PCB138/160	0.48	0.26	0.61	1.02	1.56	0.57
PCB146	0.10 J	0.02 J	0.20	0.27	0.54	0.17
PCB149/123	0.39	0.08 J	0.49	1.04	1.03	0.44
PCB151	0.15	0.00 U	0.18	0.32	0.30	0.00 U
PCB153/132	1.30	0.31	1.49	2.55	4.46	1.57
PCB156/171/202	0.10 J	0.01 J	0.04 J	0.04 J	0.04 J	0.00 U
PCB158	0.08 J	0.00 U	0.10 J	0.14	0.20	0.05 J
PCB170/190	0.30	0.08	0.49	0.20	0.73	0.20
PCB174	0.19	0.04 J	0.10	0.29	0.34	0.02 J
PCB180	0.48	0.14	0.53	1.11	1.45	0.46
PCB183	0.10	0.02 J	0.12	0.24	0.41	0.11
PCB187	0.38	0.06 J	0.24	0.60	0.97	0.16
PCB194	0.13	0.02 J	0.09	0.17	0.17	0.00 U
PCB195/208	0.05	0.00 U	0.00 U	0.11	0.00 U	0.00 U
PCB201/157/173	0.00 U	0.00 U	0.00 U	0.02 J	0.03 J	0.00 U
PCB206	0.01 J	0.00 U	0.00 U	0.02 J	0.01 J	0.00 U
PCB209	0.00 U					
Total PCB	11.83	5.33	13.51	21.73	32.68	11.69

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	Coral 8	Coral 9	LTOC 1	LTOC 2	LTOC 3	LTOC 7
PCB8/5	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	1.16
PCB18	0.00 U	0.03 J	0.00 U	0.00 U	0.00 U	0.33
PCB28	0.21	0.00 U	0.10	0.00 U	0.00 U	1.24
PCB29	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB31	0.19	0.00 U	0.06	0.00 U	0.00 U	1.57
PCB44	0.00 U	0.03 J	0.00 U	0.00 U	0.00 U	0.11
PCB45	0.02 J	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB49	0.57	0.19	0.21	0.14	0.05 J	6.17
PCB52	0.39	0.16	0.18	0.11	0.03 J	3.77
PCB56/60	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB66	0.03 J	0.00 U	0.00 U	0.00 U	0.00 U	0.58
PCB70	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.34
PCB74/61	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB87/115	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.11
PCB95	0.17	0.00 U	0.00 U	0.00 U	0.00 U	0.88
PCB99	0.20	0.05	0.09	0.07	0.00 U	1.91
PCB101/90	0.42	0.14	0.11	0.11	0.10	2.77
PCB105	0.03 J	0.02 J	0.00 U	0.00 U	0.00 U	0.08
PCB110/77	0.10	0.00 U	0.02 J	0.02 J	0.00 U	0.68
PCB118	0.12	0.03 J	0.03 J	0.01 J	0.00 U	0.88
PCB128	0.00 U	0.06 J	0.00 U	0.00 U	0.00 U	0.13
PCB138/160	0.44	0.22	0.15	0.13	0.11 J	3.04
PCB146	0.11 J	0.04 J	0.02 J	0.00 U	0.00 U	0.78
PCB149/123	0.40	0.12 J	0.11 J	0.07 J	0.02 J	1.63
PCB151	0.00 U	0.00 U	0.04 J	0.00 U	0.00 U	1.02
PCB153/132	1.10	0.29	0.28	0.23	0.09	7.73
PCB156/171/202	0.04 J	0.00 U	0.01 J	0.00 U	0.00 U	0.29
PCB158	0.06 J	0.00 U	0.00 U	0.00 U	0.00 U	0.28
PCB170/190	0.13	0.06 J	0.07 J	0.03 J	0.02 J	1.02
PCB174	0.12	0.03 J	0.03 J	0.02 J	0.01 J	0.72
PCB180	0.48	0.12	0.14	0.12	0.05	3.13
PCB183	0.10	0.00 U	0.01 J	0.00 U	0.00 U	0.53
PCB187	0.28	0.00 U	0.05 J	0.07	0.02 J	1.69
PCB194	0.07	0.00 U	0.00 U	0.00 U	0.00 U	0.56
PCB195/208	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U	0.26
PCB201/157/173	0.02 J	0.00 U	0.00 U	0.00 U	0.00 U	0.04 J
PCB206	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.10
PCB209	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.12
Total PCB	10.15	4.68	4.61	4.00	3.11	63.27

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 8	LTOC 9	LTOC 10	LTOC 11	LTOC 12	LTOC 13
PCB8/5	0.13	0.40	0.00 U	0.00 U	0.00 U	0.00 U
PCB18	0.13	0.21	0.10	0.00 U	0.00 U	0.00 U
PCB28	0.43	0.80	0.39	0.69	0.19	0.09 J
PCB29	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB31	0.65	1.07	0.79	1.11	0.10	0.07
PCB44	0.04 J	0.08 J	0.03 J	0.05 J	0.00 U	0.00 U
PCB45	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.02 J
PCB49	2.00	4.12	1.69	2.97	0.27	0.22
PCB52	1.35	3.06	1.19	2.10	0.22	0.17
PCB56/60	0.00 U	0.00 U	0.04 J	0.00 U	0.00 U	0.00 U
PCB66	0.14	0.34	0.10	0.22	0.00 U	0.00 U
PCB70	0.07 J	0.20	0.00 U	0.05 J	0.00 U	0.09
PCB74/61	0.07	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB87/115	0.04 J	0.14	0.00 U	0.00 U	0.00 U	0.00 U
PCB95	0.25	0.69	0.30	0.53	0.00 U	0.00 U
PCB99	0.59	1.40	0.39	0.92	0.08	0.06
PCB101/90	1.10	2.13	0.68	1.57	0.22	0.14
PCB105	0.07	0.10	0.04 J	0.04 J	0.00 U	0.00 U
PCB110/77	0.23	0.56	0.18	0.32	0.00 U	0.02 J
PCB118	0.32	0.67	0.24	0.43	0.02 J	0.04 J
PCB128	0.00 U	0.10 J	0.00 U	0.00 U	0.00 U	0.00 U
PCB138/160	0.96	2.43	0.97	1.72	0.10 J	0.18
PCB146	0.20	0.59	0.22	0.37	0.03 J	0.03 J
PCB149/123	0.64	1.35	0.70	1.21	0.08 J	0.15
PCB151	0.20	0.71	0.29	0.55	0.02 J	0.04 J
PCB153/132	2.69	6.32	2.28	3.99	0.39	0.37
PCB156/171/202	0.11 J	0.09 J	0.10 J	0.21	0.00 U	0.02 J
PCB158	0.12	0.25	0.09 J	0.18	0.01 J	0.00 U
PCB170/190	0.48	1.09	0.56	0.58	0.00 U	0.09
PCB174	0.32	0.67	0.26	0.50	0.04 J	0.05
PCB180	1.15	2.51	0.86	1.83	0.19	0.19
PCB183	0.20	0.38	0.20	0.40	0.04 J	0.03 J
PCB187	0.64	1.50	0.56	1.01	0.10	0.10
PCB194	0.24	0.42	0.22	0.39	0.06	0.04
PCB195/208	0.10	0.21	0.07	0.15	0.07	0.03 J
PCB201/157/173	0.00 U	0.03 J	0.00 U	0.05 J	0.01 J	0.00 U
PCB206	0.00 U	0.08	0.00 U	0.00 U	0.00 U	0.00 U
PCB209	0.00 U	0.06 J	0.00 U	0.00 U	0.00 U	0.00 U
Total PCB	23.24	50.23	19.67	33.23	5.32	5.17

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 14	LTOC 15	LTOC 16	LTOC 17	LTOC 18	LTOC 19
PCB8/5	0.00 U	0.24	0.00 U	0.00 U	0.00 U	0.00 U
PCB18	0.00 U	0.25	0.18	0.00 U	0.00 U	0.00 U
PCB28	0.00 U	0.98	0.55	0.00 U	0.00 U	0.33
PCB29	0.00 U					
PCB31	0.00 U	1.59	0.84	0.00 U	0.00 U	0.29
PCB44	0.00 U	0.11	0.03 J	0.02 J	0.00 U	0.00 U
PCB45	0.00 U					
PCB49	0.05 J	5.23	2.85	0.17	0.06 J	1.27
PCB52	0.04 J	3.21	1.86	0.09	0.04 J	0.85
PCB56/60	0.00 U	0.41	0.15	0.00 U	0.00 U	0.07 J
PCB66	0.04 J	0.38	0.15	0.00 U	0.02 J	0.00 U
PCB70	0.00 U	0.26	0.07 J	0.00 U	0.00 U	0.00 U
PCB74/61	0.00 U	0.30	0.00 U	0.00 U	0.00 U	0.00 U
PCB87/115	0.00 U	0.13	0.07 J	0.00 U	0.00 U	0.03 J
PCB95	0.00 U	0.96	0.36	0.00 U	0.00 U	0.00 U
PCB99	0.00 U	1.78	0.93	0.04 J	0.02 J	0.47
PCB101/90	0.15	2.73	1.59	0.14	0.17	0.65
PCB105	0.00 U	0.11	0.04 J	0.00 U	0.00 U	0.03 J
PCB110/77	0.02 J	0.63	0.32	0.07	0.02 J	0.14
PCB118	0.00 U	0.91	0.41	0.02 J	0.01 J	0.21
PCB128	0.00 U					
PCB138/160	0.00 U	3.18	1.69	0.16	0.21	0.88
PCB146	0.00 U	0.84	0.36	0.02 J	0.00 U	0.19
PCB149/123	0.02 J	2.23	1.20	0.08 J	0.03 J	0.65
PCB151	0.02 J	1.00	0.50	0.03 J	0.01 J	0.23
PCB153/132	0.11	7.51	3.89	0.27	0.10	1.96
PCB156/171/202	0.00 U	0.27	0.10 J	0.01 J	0.00 U	0.03 J
PCB158	0.00 U	0.29	0.17	0.01 J	0.00 U	0.09 J
PCB170/190	0.00 U	1.19 I	0.77	0.04 J	0.02 J	0.31
PCB174	0.00 U	0.68	0.49	0.00 U	0.00 U	0.20
PCB180	0.05	2.91	1.70	0.12	0.05	0.90
PCB183	0.01 J	0.64	0.32	0.00 U	0.00 U	0.18
PCB187	0.02 J	1.64	0.94	0.04 J	0.02 J	0.48
PCB194	0.00 U	0.55	0.30	0.02 J	0.00 U	0.17
PCB195/208	0.00 U	0.28	0.15	0.00 U	0.00 U	0.08
PCB201/157/173	0.00 U	0.06 J	0.00 U	0.00 U	0.00 U	0.00 U
PCB206	0.00 U	0.09	0.00 U	0.00 U	0.00 U	0.00 U
PCB209	0.00 U					
Total PCB	3.09	57.89	32.51	4.13	3.61	16.69

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 22	HTOC 1	HTOC 2	HTOC 3	HTOC 4	HTOC 6
PCB8/5	0.34	0.00 U				
PCB18	0.16	0.00 U	0.00 U	0.00 U	0.22	0.00 U
PCB28	0.82	0.00 U	0.01 J	0.26	0.31	0.93
PCB29	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB31	1.30	0.00 U	0.00 U	0.15	0.50	1.39
PCB44	0.10	0.00 U	0.00 U	0.00 U	0.04 J	0.10 J
PCB45	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB49	4.61	0.00 U	0.05 J	0.62	1.26	3.84
PCB52	2.78	0.00 U	0.05 J	0.34	0.86	2.69
PCB56/60	0.41	0.00 U	0.00 U	0.00 U	0.00 U	0.71
PCB66	0.38	0.00 U	0.00 U	0.11	0.00 U	0.39
PCB70	0.29	0.00 U				
PCB74/61	0.34	0.00 U				
PCB87/115	0.11	0.00 U	0.00 U	0.00 U	0.00 U	0.14
PCB95	0.89	0.00 U	0.00 U	0.21	0.00 U	0.72
PCB99	1.66	0.00 U	0.00 U	0.31	0.47	1.26
PCB101/90	2.08	0.00 U	0.00 U	0.33	0.75	2.05
PCB105	0.10	0.00 U	0.00 U	0.08	0.04 J	0.12
PCB110/77	0.62	0.00 U	0.19	0.00 U	0.19	0.59
PCB118	0.88	0.00 U	0.01 J	0.20	0.28	0.73
PCB128	0.09 J	0.00 U				
PCB138/160	3.05	0.07 J	0.14	0.73	0.73	2.08
PCB146	0.80	0.00 U	0.00 U	0.14	0.20	0.73
PCB149/123	2.02	0.00 U	0.03 J	0.38	0.62	1.63
PCB151	0.91	0.00 U	0.00 U	0.00 U	0.29	0.86
PCB153/132	7.11	0.00 U	0.08	1.21	1.96	5.84
PCB156/171/202	0.28	0.00 U	0.00 U	0.00 U	0.00 U	0.11 J
PCB158	0.25	0.00 U	0.00 U	0.00 U	0.09 J	0.31
PCB170/190	1.40	0.00 U	0.04 J	0.27	0.13	0.77
PCB174	0.64	0.00 U	0.00 U	0.00 U	0.22	0.73
PCB180	2.68	0.03 J	0.04 J	0.49	0.73	2.87
PCB183	0.64	0.00 U	0.00 U	0.00 U	0.16	0.58
PCB187	1.51	0.00 U	0.00 U	0.00 U	0.33	1.55
PCB194	0.56	0.00 U	0.00 U	0.00 U	0.14	0.44
PCB195/208	0.26	0.00 U	0.00 U	0.00 U	0.07	0.27
PCB201/157/173	0.04 J	0.00 U	0.00 U	0.00 U	0.00 U	0.09
PCB206	0.08	0.00 U	0.00 U	0.00 U	0.00 U	0.08
PCB209	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Total PCB	53.84	2.41	2.99	11.01	16.11	46.53

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	HTOC 7	HTOC 8	HTOC 9	HTOC 10	HTOC 12	HTOC 14
PCB8/5	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB18	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB28	0.02 J	0.03 J	0.12	0.00 U	0.00 U	0.00 U
PCB29	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB31	0.00 U	0.18	0.00 U	0.00 U	0.00 U	0.00 U
PCB44	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB45	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB49	0.23	0.52	0.21	0.12	0.07 J	0.07 J
PCB52	0.13	0.35	0.13	0.08	0.04 J	0.06 J
PCB56/60	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB66	0.07	0.02 J	0.06	0.00 U	0.00 U	0.00 U
PCB70	0.13	0.00 U	0.14	0.00 U	0.00 U	0.00 U
PCB74/61	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB87/115	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB95	0.09	0.16	0.08	0.00 U	0.00 U	0.00 U
PCB99	0.02 J	0.13	0.07	0.00 U	0.00 U	0.00 U
PCB101/90	0.19	0.28	0.12	0.00 U	0.00 U	0.00 U
PCB105	0.06	0.03 J	0.03 J	0.00 U	0.00 U	0.00 U
PCB110/77	0.03 J	0.08	0.00 U	0.03 J	0.00 U	0.00 U
PCB118	0.02 J	0.10	0.04 J	0.03 J	0.00 U	0.02 J
PCB128	0.07 J	0.00 U	0.85	0.00 U	0.00 U	0.00 U
PCB138/160	0.28	0.34	0.79	0.15	0.10 J	0.16
PCB146	0.00 U	0.09 J	0.00 U	0.00 U	0.00 U	0.00 U
PCB149/123	0.11 J	0.24	0.37	0.00 U	0.00 U	0.04 J
PCB151	0.00 U	0.11 J	0.00 U	0.06 J	0.00 U	0.00 U
PCB153/132	0.19	0.72	0.46	0.28	0.12	0.12
PCB156/171/202	0.00 U	0.00 U	0.20	0.00 U	0.00 U	0.00 U
PCB158	0.01 J	0.03 J	0.22	0.00 U	0.00 U	0.00 U
PCB170/190	0.47	0.07 J	1.25	0.09	0.00 U	0.00 U
PCB174	0.00 U	0.05	0.00 U	0.03 J	0.00 U	0.00 U
PCB180	0.19	0.20	0.58	0.12	0.05	0.00 U
PCB183	0.06	0.06	0.28	0.00 U	0.00 U	0.00 U
PCB187	0.07	0.17	0.23	0.11	0.04 J	0.00 U
PCB194	0.01 J	0.00 U	0.51	0.00 U	0.00 U	0.00 U
PCB195/208	0.00 U	0.00 U	1.05	0.00 U	0.00 U	0.00 U
PCB201/157/173	0.13	0.00 U	0.30	0.00 U	0.00 U	0.00 U
PCB206	0.00 U	0.00 U	0.16	0.00 U	0.00 U	0.00 U
PCB209	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Total PCB	6.05	7.29	12.69	4.06	2.95	2.98

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix F. Polychlorinated biphenyls (PCBs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	HTOC 15	HTOC 16	HTOC 17	HTOC 19	HTOC 20	HTOC 21	HTOC 22
PCB8/5	0.00 U	0.00 U	21.86 D	23.90 D	0.00 U	0.00 U	0.00 U
PCB18	0.00 U	0.21	22.93 D	9.20	0.16	0.00 U	0.25
PCB28	0.00 U	0.84	55.86 D	24.05 D	0.00 U	0.00 U	0.82
PCB29	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
PCB31	0.00 U	1.16	115.04 D	39.18 D	2.91	0.00 U	1.20
PCB44	0.00 U	0.10 J	3.27	1.45	0.00 U	0.00 U	0.13
PCB45	0.00 U	0.00 U	0.34	0.00 U	0.00 U	0.00 U	0.00 U
PCB49	0.30	4.47	198.52 D	88.10 D	0.66	0.14	4.65
PCB52	0.24	2.49	202.91 D	89.43 D	0.45	0.09	3.48
PCB56/60	0.00 U	0.49	6.29	2.75	0.09	0.00 U	0.40
PCB66	0.00 U	0.29	21.39 D	9.10	0.00 U	0.00 U	0.35
PCB70	0.00 U	0.18	10.81	5.00	0.16	0.02 J	0.21
PCB74/61	0.00 U	0.23	5.98	2.94	0.00 U	0.00 U	0.18
PCB87/115	0.00 U	0.12	5.21	2.39	0.00 U	0.00 U	0.00 U
PCB95	0.00 U	1.13	30.07 D	13.89 D	0.00 U	0.00 U	0.75
PCB99	0.13	1.61	86.48 D	36.50 D	0.31	0.10	1.70
PCB101/90	0.00 U	2.47	100.50 D	43.47 D	0.37	0.26	2.60
PCB105	0.00 U	0.18	4.00	1.53	0.00 U	0.00 U	0.13
PCB110/77	0.04 J	0.60	26.77 D	7.14 D	0.10	0.03 J	0.69
PCB118	0.05 J	0.86	31.29 D	13.45 D	0.13	0.02 J	0.91
PCB128	0.00 U	0.06 J	5.58	2.48	0.00 U	0.00 U	0.10 J
PCB138/160	0.16	3.40	98.69 D	48.79 D	0.56	0.16	3.61
PCB146	0.03 J	0.77	26.42 D	11.92	0.00 U	0.03 J	0.78
PCB149/123	0.11 J	2.01	64.34 D	29.84 D	0.50	0.09 J	2.14
PCB151	0.00 U	0.86	39.38 D	15.89 D	0.11 J	0.03 J	0.92
PCB153/132	0.44	7.12	377.58 D	117.16 D	1.07	0.25	7.50
PCB156/171/202	0.02 J	0.24	15.08 D	7.25	0.00 U	0.00 U	0.23
PCB158	0.00 U	0.26	10.28	4.28	0.03 J	0.00 U	0.25
PCB170/190	0.08	1.02	61.72 D	17.79 D	0.35	0.00 U	1.44
PCB174	0.00 U	0.59	0.00 U	10.77 D	0.08	0.02 J	0.64
PCB180	0.20	2.78	138.80 D	39.17 D	0.43	0.10	3.16
PCB183	0.00 U	0.53	27.61 D	11.94	0.09	0.00 U	0.58
PCB187	0.10	1.51	82.92 D	20.71 D	0.25	0.05 J	1.67
PCB194	0.00 U	0.54	30.01 D	11.75 D	0.08	0.00 U	0.60
PCB195/208	0.00 U	0.42	8.65	4.07	0.00 U	0.00 U	0.32
PCB201/157/173	0.00 U	0.05 J	2.96	1.50	0.00 U	0.00 U	0.06 J
PCB206	0.00 U	0.06	5.10	2.67	0.00 U	0.00 U	0.10
PCB209	0.00 U	0.20	0.07 J	0.29	0.00 U	0.00 U	0.14
Total PCB	4.98	53.89	2709.90	1021.78	10.41	4.23	59.67

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g).

Compound	Coral 1	Coral 2	Coral 3	Coral 4	Coral 5
Aldrin	0.00 U				
Dieldrin	0.07	0.00 U	0.00 U	0.00 U	0.00 U
Endrin	0.00 U	0.00 U	0.00 U	0.06 J	0.00 U
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlordan	0.00 U				
Alpha-Chlordane	0.00 U				
Gamma-Chlordane	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U
Trans-Nonachlor	0.00 U				
Cis-Nonachlor	0.01 J	0.00 U	0.01 J	0.02 J	0.05
Alpha-HCH	0.00 U				
Beta-HCH	0.00 U				
Delta-HCH	0.00 U				
Gamma-HCH	0.00 U				
2,4'-DDD	0.13	0.00 U	0.13	0.22	0.28
4,4'-DDD	0.00 U	0.00 U	0.00 U	0.00 U	0.01 J
2,4'-DDE	0.02 J	0.00 U	0.00 U	0.05 J	0.08
4,4'-DDE	0.06	0.00 U	0.04 J	0.00 U	0.02 J
2,4'-DDT	0.01 J	0.00 U	0.00 U	0.00 U	0.02 J
4,4'-DDT	0.01 J	0.01 J	0.08	0.10	0.03 J
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U				
Pentachloroanisole	0.00 U	0.00 U	0.08	0.00 U	0.09
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U	0.00 U	0.12 J	0.00 U	0.00 U
Endosulfan I	0.00 U				
Endosulfan Sulfate	0.00 U	0.05 J	0.00 U	0.31	0.00 U
Mirex	0.00 U	0.00 U	0.12	0.03 J	0.00 U
Chlorpyrifos	0.00 U	0.00 U	0.00 U	0.36	0.00 U
Total HCH	0.00	0.00	0.00	0.00	0.00
Total Chlordane	0.01	0.00	0.03	0.02	0.05
Total DDT	0.23	0.01	0.25	0.37	0.44

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	Coral 6	Coral 8	Coral 9	LTOC 1	LTOC 2
Aldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Dieldrin	0.00 U	0.00 U	0.00 U	0.03 J	0.00 U
Endrin	0.16 J	0.02 J	0.00 U	0.00 U	0.00 U
Heptachlor	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Heptachlor-Epoxyde	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Oxychlorane	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Alpha-Chlordane	0.09	0.14	0.01 J	0.00 U	0.00 U
Gamma-Chlordane	0.03 J	0.03 J	0.09	0.01 J	0.01 J
Trans-Nonachlor	0.00 U	0.00 U	0.02 J	0.00 U	0.00 U
Cis-Nonachlor	0.01 J	0.01 J	0.00 U	0.00 U	0.00 U
Alpha-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Beta-HCH	0.00 U	0.00 U	0.19	0.07	0.06 J
Delta-HCH	0.00 U	0.00 U	0.00 U	0.01 J	0.02 J
Gamma-HCH	0.00 U	0.69	0.00 U	0.01 J	0.01 J
2,4'-DDD	0.15	0.09	0.00 U	0.00 U	0.00 U
4,4'-DDD	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDE	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDE	0.02 J	0.03 J	0.00 U	0.00 U	0.00 U
2,4'-DDT	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDT	0.10	0.07	0.03 J	0.00 U	0.00 U
1,2,3,4-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
1,2,4,5-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Hexachlorobenzene	0.00 U	0.00 U	0.00 U	0.01 J	0.01 J
Pentachloroanisole	0.25	0.14	0.04 J	0.01 J	0.02 J
Pentachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endosulfan II	0.00 U	0.07 J	0.00 U	0.00 U	0.00 U
Endosulfan I	0.00 U	0.00 U	0.00 U	1.44	0.00 U
Endosulfan Sulfate	0.00 U	0.10	0.00 U	0.00 U	0.00 U
Mirex	0.00 U	0.03 J	0.00 U	0.00 U	0.00 U
Chlorpyrifos	0.15	0.00 U	0.06 J	0.00 U	0.00 U
Total HCH	0.00	0.69	0.19	0.10	0.09
Total Chlordane	0.14	0.19	0.13	0.01	0.01
Total DDT	0.30	0.19	0.03	0.00	0.00

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	LTOC 3	LTOC 7	LTOC 8	LTOC 9	LTOC 10
Aldrin	0.00 U	0.00 U	0.06	0.00 U	0.00 U
Dieldrin	0.00 U	0.00 U	0.00 U	0.05 J	0.00 U
Endrin	0.00 U				
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlordan	0.00 U				
Alpha-Chlordane	0.00 U				
Gamma-Chlordane	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U
Trans-Nonachlor	0.00 U				
Cis-Nonachlor	0.00 U	0.08	0.03 J	0.06	0.02 J
Alpha-HCH	0.00 U				
Beta-HCH	0.00 U	0.06 J	0.00 U	0.12	0.00 U
Delta-HCH	0.00 U	0.00 U	0.02 J	0.02 J	0.00 U
Gamma-HCH	0.00 U				
2,4'-DDD	0.00 U	0.56	0.18	0.41	0.16
4,4'-DDD	0.00 U	0.04 J	0.00 U	0.00 U	0.00 U
2,4'-DDE	0.00 U	0.15	0.07	0.26	0.13
4,4'-DDE	0.00 U	0.41	0.15	0.00 U	0.06
2,4'-DDT	0.00 U	0.18	0.00 U	0.24	0.04
4,4'-DDT	0.00 U				
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U				
Pentachloroanisole	0.00 U	0.04 J	0.04 J	0.08	0.01 J
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U	0.00 U	0.00 U	0.53	0.00 U
Endosulfan I	0.00 U	0.00 U	0.00 U	0.23	0.00 U
Endosulfan Sulfate	0.00 U	0.00 U	0.00 U	0.76	0.00 U
Mirex	0.00 U				
Chlorpyrifos	0.00 U				
Total HCH	0.00	0.06	0.02	0.14	0.00
Total Chlordane	0.01	0.08	0.03	0.06	0.02
Total DDT	0.00	1.33	0.40	0.91	0.39

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	LTOC 11	LTOC 12	LTOC 13	LTOC 14	LTOC 15
Aldrin	0.00 U				
Dieldrin	0.00 U				
Endrin	0.00 U				
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlordan	0.00 U				
Alpha-Chlordane	0.00 U				
Gamma-Chlordane	0.00 U				
Trans-Nonachlor	0.00 U				
Cis-Nonachlor	0.03 J	0.00 U	0.00 U	0.00 U	0.07
Alpha-HCH	0.00 U	0.00 U	0.05 J	0.00 U	0.00 U
Beta-HCH	0.00 U				
Delta-HCH	0.00 U	0.00 U	0.00 U	0.02 J	0.00 U
Gamma-HCH	0.00 U				
2,4'-DDD	0.31	0.04 J	0.03 J	0.01 J	0.51
4,4'-DDD	0.01 J	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDE	0.23	0.00 U	0.02 J	0.00 U	0.30
4,4'-DDE	0.20	0.00 U	0.02 J	0.00 U	0.37
2,4'-DDT	0.08	0.00 U	0.00 U	0.00 U	0.22
4,4'-DDT	0.00 U	0.00 U	0.00 U	0.00 U	0.05 J
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U				
Pentachloroanisole	0.02 J	0.01 J	0.00 U	0.01 J	0.11
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U				
Endosulfan I	0.00 U				
Endosulfan Sulfate	0.00 U	0.00 U	0.00 U	0.00 U	1.32
Mirex	0.00 U				
Chlorpyrifos	0.00 U				
Total HCH	0.00	0.00	0.05	0.02	0.00
Total Chlordane	0.03	0.00	0.00	0.00	0.07
Total DDT	0.83	0.04	0.07	0.01	1.45

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	LTOC 16	LTOC 17	LTOC 18	LTOC 19	LTOC 22
Aldrin	0.00 U				
Dieldrin	0.00 U				
Endrin	0.00 U				
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlordane	0.00 U				
Alpha-Chlordane	0.00 U				
Gamma-Chlordane	0.04 J	0.00 U	0.00 U	0.00 U	0.00 U
Trans-Nonachlor	0.00 U				
Cis-Nonachlor	0.03 J	0.00 U	0.00 U	0.00 U	0.07
Alpha-HCH	0.04 J	0.00 U	0.00 U	0.04 J	0.00 U
Beta-HCH	0.00 U				
Delta-HCH	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U
Gamma-HCH	0.00 U				
2,4'-DDD	0.29	0.04 J	0.02 J	0.17	0.51
4,4'-DDD	0.00 U				
2,4'-DDE	0.00 U	0.00 U	0.00 U	0.00 U	0.21
4,4'-DDE	0.13	0.00 U	0.00 U	0.08	0.36
2,4'-DDT	0.07	0.00 U	0.00 U	0.00 U	0.21
4,4'-DDT	0.00 U				
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U	0.00 U	0.00 U	0.08	0.00 U
Pentachloroanisole	0.05 J	0.00 U	0.01 J	0.00 U	0.05 J
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U				
Endosulfan I	0.00 U				
Endosulfan Sulfate	0.00 U				
Mirex	0.00 U				
Chlorpyrifos	0.00 U				
Total HCH	0.04	0.00	0.01	0.04	0.00
Total Chlordane	0.07	0.00	0.00	0.00	0.07
Total DDT	0.50	0.04	0.02	0.25	1.28

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	HTOC 1	HTOC 2	HTOC 3	HTOC 4	HTOC 6
Aldrin	0.00 U				
Dieldrin	0.00 U				
Endrin	0.00 U	0.00 U	0.00 U	0.00 U	0.27
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlorthane	0.00 U	0.00 U	0.00 U	0.00 U	0.05 J
Alpha-Chlordane	0.00 U	0.00 U	0.26	0.00 U	0.16
Gamma-Chlordane	0.00 U	0.00 U	0.09	0.00 U	0.00 U
Trans-Nonachlor	0.00 U	0.00 U	0.04 J	0.00 U	0.00 U
Cis-Nonachlor	0.00 U	0.00 U	0.00 U	0.01 J	0.05
Alpha-HCH	0.00 U				
Beta-HCH	0.00 U				
Delta-HCH	0.00 U				
Gamma-HCH	0.00 U				
2,4'-DDD	0.00 U	0.01 J	0.07	0.18	0.68
4,4'-DDD	0.00 U	0.00 U	0.08	0.00 U	0.00 U
2,4'-DDE	0.00 U				
4,4'-DDE	0.00 U	0.00 U	0.05	0.00 U	0.00 U
2,4'-DDT	0.00 U	0.32	0.00 U	0.00 U	0.11
4,4'-DDT	0.01 J	0.01 J	0.21	0.06	0.22
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U				
Pentachloroanisole	0.00 U	0.00 U	0.22	0.20	0.38
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U	0.05 J	0.00 U	0.00 U	0.59
Endosulfan I	0.00 U				
Endosulfan Sulfate	0.00 U	0.00 U	0.00 U	0.00 U	0.47
Mirex	0.00 U	0.00 U	0.00 U	0.00 U	0.04 J
Chlorpyrifos	0.00 U	0.00 U	0.45	0.00 U	0.54
Total HCH	0.00	0.00	0.00	0.00	0.00
Total Chlordane	0.00	0.00	0.39	0.01	0.27
Total DDT	0.01	0.34	0.41	0.24	1.01

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	HTOC 7	HTOC 8	HTOC 9	HTOC 10	HTOC 12
Aldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Dieldrin	0.00 U	0.00 U	0.00 U	0.00 U	0.05 J
Endrin	0.00 U	0.06 J	0.13 J	0.00 U	0.00 U
Heptachlor	0.00 U	0.02 J	0.00 U	0.00 U	0.00 U
Heptachlor-Epoxide	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Oxychlorane	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Alpha-Chlordane	0.09	0.07	0.08	0.00 U	0.00 U
Gamma-Chlordane	0.07	0.09	0.00 U	0.01 J	0.04 J
Trans-Nonachlor	0.03 J	0.03 J	0.00 U	0.00 U	0.00 U
Cis-Nonachlor	0.00 U	0.01 J	0.02 J	0.00 U	0.00 U
Alpha-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Beta-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Delta-HCH	0.00 U	0.00 U	0.00 U	0.03 J	0.02 J
Gamma-HCH	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDD	0.18	0.08	0.03 J	0.00 U	0.00 U
4,4'-DDD	0.03 J	0.00 U	0.00 U	0.00 U	0.00 U
2,4'-DDE	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDE	0.00 U	0.03 J	0.00 U	0.00 U	0.00 U
2,4'-DDT	0.03 J	0.00 U	0.00 U	0.00 U	0.00 U
4,4'-DDT	0.08	0.02 J	0.70	0.00 U	0.00 U
1,2,3,4-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
1,2,4,5-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Hexachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Pentachloroanisole	0.09	0.06 J	0.15	0.01 J	0.01 J
Pentachlorobenzene	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endosulfan II	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Endosulfan I	0.00 U	0.00 U	0.00 U	0.06 J	0.04 J
Endosulfan Sulfate	0.00 U	0.00 U	0.47	0.00 U	0.00 U
Mirex	0.06 J	0.00 U	0.92	0.00 U	0.00 U
Chlorpyrifos	0.11 J	0.00 U	0.29	0.00 U	0.00 U
Total HCH	0.00	0.00	0.00	0.03	0.02
Total Chlordane	0.19	0.23	0.10	0.01	0.04
Total DDT	0.33	0.14	0.73	0.00	0.00

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	HTOC 14	HTOC 15	HTOC 16	HTOC 17	HTOC 19
Aldrin	0.00 U				
Dieldrin	0.00 U	0.00 U	0.00 U	0.41	0.42
Endrin	0.00 U				
Heptachlor	0.00 U				
Heptachlor-Epoxide	0.00 U				
Oxychlordane	0.00 U				
Alpha-Chlordane	0.00 U				
Gamma-Chlordane	0.01 J	0.01 J	0.03 J	0.03 J	0.02 J
Trans-Nonachlor	0.00 U				
Cis-Nonachlor	0.00 U	0.00 U	0.08	2.51	1.05
Alpha-HCH	0.00 U				
Beta-HCH	0.04 J	0.00 U	0.00 U	0.00 U	0.00 U
Delta-HCH	0.04 J	0.00 U	0.00 U	0.00 U	0.00 U
Gamma-HCH	0.00 U				
2,4'-DDD	0.00 U	0.00 U	0.00 U	28.85 D	13.46 D
4,4'-DDD	0.00 U	0.00 U	0.02 J	0.97	1.08
2,4'-DDE	0.00 U				
4,4'-DDE	0.00 U	0.00 U	0.39	10.26	9.48
2,4'-DDT	0.00 U	0.00 U	0.00 U	5.29	3.16
4,4'-DDT	0.00 U	0.00 U	0.00 U	1.56	2.17
1,2,3,4-Tetrachlorobenzene	0.00 U				
1,2,4,5-Tetrachlorobenzene	0.00 U				
Hexachlorobenzene	0.00 U	0.00 U	0.01 J	0.00 U	0.00 U
Pentachloroanisole	0.00 U	0.00 U	0.15	0.00 U	0.00 U
Pentachlorobenzene	0.00 U				
Endosulfan II	0.00 U				
Endosulfan I	0.04 J	0.17	0.00 U	0.00 U	0.00 U
Endosulfan Sulfate	0.00 U				
Mirex	0.00 U				
Chlorpyrifos	0.00 U	0.00 U	0.00 U	0.00 U	0.60
Total HCH	0.08	0.00	0.00	0.00	0.00
Total Chlordane	0.01	0.01	0.11	2.54	1.08
Total DDT	0.00	0.00	0.41	46.93	29.33

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix G. Organochlorine pesticides in sediment samples from southwest Puerto Rico (ng/dry g)  
(continued).

Compound	HTOC 20	HTOC 21	HTOC 22
Aldrin	0.00 U	0.00 U	0.00 U
Dieldrin	0.07	0.00 U	0.14
Endrin	0.00 U	0.00 U	0.00 U
Heptachlor	0.00 U	0.00 U	0.00 U
Heptachlor-Epoxyde	0.00 U	0.00 U	0.00 U
Oxychlordane	0.00 U	0.00 U	0.00 U
Alpha-Chlordane	0.00 U	0.12	0.00 U
Gamma-Chlordane	0.00 U	0.06	0.04 J
Trans-Nonachlor	0.00 U	0.02 J	0.00 U
Cis-Nonachlor	0.02 J	0.00 U	0.07
Alpha-HCH	0.00 U	0.00 U	0.00 U
Beta-HCH	0.10	0.06 J	0.11
Delta-HCH	0.00 U	0.02 J	0.00 U
Gamma-HCH	0.00 U	0.00 U	0.00 U
2,4'-DDD	0.07	0.02 J	0.50
4,4'-DDD	0.00 U	0.00 U	0.04 J
2,4'-DDE	0.00 U	0.00 U	0.00 U
4,4'-DDE	0.00 U	0.00 U	0.39
2,4'-DDT	0.05	0.00 U	0.00 U
4,4'-DDT	0.00 U	0.00 U	0.00 U
1,2,3,4-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U
1,2,4,5-Tetrachlorobenzene	0.00 U	0.00 U	0.00 U
Hexachlorobenzene	0.00 U	0.00 U	0.01 J
Pentachloroanisole	0.32	0.00 U	0.16
Pentachlorobenzene	0.00 U	0.00 U	0.00 U
Endosulfan II	0.00 U	0.00 U	0.66
Endosulfan I	0.07 J	0.00 U	0.13
Endosulfan Sulfate	0.00 U	0.00 U	0.00 U
Mirex	0.00 U	0.00 U	0.00 U
Chlorpyrifos	0.00 U	0.00 U	0.00 U
Total HCH	0.10	0.08	0.11
Total Chlordane	0.02	0.20	0.11
Total DDT	0.12	0.02	0.92

Qualifiers (Q): J=Below the MDL, U=Not detected

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g).

Compound	Coral 1		Coral 2		Coral 3		Coral 4		Coral 5		Coral 6	
BDE 1	0.0	U										
BDE 2	0.0	U										
BDE 3	0.0	U										
BDE 10	0.0	U										
BDE 7	0.0	U										
BDE 8	0.0	U										
BDE 11	0.1	J	0.0	U	0.0	U	0.0	U	0.1	J	0.0	U
BDE 12	0.0	U										
BDE 13	0.0	U										
BDE 15	0.0	U										
BDE 30	0.0	U										
BDE 32	0.0	U										
BDE 17	0.0	U										
BDE 25	0.0	U										
BDE 33	0.0	U										
BDE 28	0.0	U										
BDE 35	0.0	U										
BDE 37	0.0	U										
BDE 75	0.0	U										
BDE 49/71	0.0	U										
BDE 47	0.2	J	0.1	J	0.1	J	0.1	J	0.0	U	0.2	J
BDE 66	0.0	U										
BDE 77	0.0	U										
BDE 100	0.0	U										
BDE 119	0.0	U										
BDE 99	0.0	U	0.0	U	0.2	J	0.0	U	0.0	U	0.0	U
BDE 116	0.0	U										
BDE 118	0.0	U										
BDE 85	0.0	U										
BDE 126	0.0	U										
BDE 155	0.0	U										
BDE 154	0.0	U										
BDE 153	0.0	U										
BDE 138	0.0	U										
BDE 166	0.0	U										
BDE 183	0.0	U										
BDE 181	0.0	U										
BDE 190	0.0	U										
Total PBDE	0.3		0.1		0.3		0.1		0.1		0.2	

Qualifiers (Q): J=Below the MDL; U=Not detected; I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	Coral 8		Coral 9		LTOC 1		LTOC 2		LTOC 3		LTOC 7	
BDE 1	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 2	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 3	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 10	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 7	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 8	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 11	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.2	J
BDE 12	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 13	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 15	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 30	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 32	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 17	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 25	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 33	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 28	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 35	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 37	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 75	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 49/71	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 47	0.1	J	0.1	J	0.0	U	0.0	U	0.0	U	0.1	J
BDE 66	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 77	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 100	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 119	0.0	U	0.0	U	0.0	U	0.6	JI	0.0	U	0.8	I
BDE 99	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 116	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 118	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 85	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 126	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 155	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 154	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 153	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 138	0.0	U	0.0	U	1.3		0.0	U	0.0	U	0.0	U
BDE 166	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 183	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 181	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 190	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
Total PBDE	0.1		0.1		1.3		0.6		0.0		1.1	

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 8		LTOC 9		LTOC 10		LTOC 11		LTOC 12		LTOC 13	
BDE 1	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 2	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 3	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 10	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 7	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 8	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 11	0.0	U	0.1	J	0.0	U	0.0	U	0.0	U	0.0	U
BDE 12	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 13	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 15	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 30	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 32	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 17	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 25	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 33	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 28	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 35	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 37	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 75	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 49/71	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 47	0.1	J	0.1	J	0.1	J	0.1	J	0.0	U	0.0	U
BDE 66	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 77	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 100	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 119	0.6	JI	0.6	JI	0.4	JI	0.4	JI	0.0	U	0.0	U
BDE 99	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 116	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 118	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 85	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 126	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 155	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 154	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 153	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 138	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 166	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 183	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 181	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 190	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
Total PBDE	0.7		0.8		0.5		0.5		0.0		0.0	

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 14	LTOC 15	LTOC 16	LTOC 17	LTOC 18	LTOC 19
BDE 1	0.0 U					
BDE 2	0.0 U					
BDE 3	0.0 U					
BDE 10	0.0 U					
BDE 7	0.0 U					
BDE 8	0.0 U					
BDE 11	0.0 U	0.1 J	0.0 U	0.0 U	0.0 U	0.0 U
BDE 12	0.0 U					
BDE 13	0.0 U					
BDE 15	0.0 U					
BDE 30	0.0 U					
BDE 32	0.0 U					
BDE 17	0.0 U					
BDE 25	0.0 U					
BDE 33	0.0 U					
BDE 28	0.0 U					
BDE 35	0.0 U					
BDE 37	0.0 U					
BDE 75	0.0 U					
BDE 49/71	0.0 U					
BDE 47	0.0 U	0.3 J	0.1 J	0.0 U	0.1 J	0.0 U
BDE 66	0.0 U					
BDE 77	0.0 U					
BDE 100	0.0 U					
BDE 119	0.0 U					
BDE 99	0.0 U					
BDE 116	0.0 U					
BDE 118	0.0 U					
BDE 85	0.0 U					
BDE 126	0.0 U					
BDE 155	0.0 U					
BDE 154	0.0 U					
BDE 153	0.0 U					
BDE 138	0.0 U					
BDE 166	0.0 U					
BDE 183	0.0 U					
BDE 181	0.0 U					
BDE 190	0.0 U					
Total PBDE	0.0	0.4	0.1	0.0	0.1	0.0

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	LTOC 22	HTOC 1	HTOC 2	HTOC 3	HTOC 4	HTOC 6
BDE 1	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 2	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 3	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 10	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 7	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 8	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 11	0.2 J	0.0 U	0.0 U	0.0 U	0.0 U	0.1 J
BDE 12	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 13	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 15	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 30	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 32	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 17	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 25	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 33	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 28	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 35	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 37	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 75	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 49/71	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 47	0.1 J	0.1 J	0.1 J	0.2 J	0.1 J	0.1 J
BDE 66	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 77	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 100	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 119	0.3 J	0.0 U				
BDE 99	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 116	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 118	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 85	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 126	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 155	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 154	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 153	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 138	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 166	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 183	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 181	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
BDE 190	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U	0.0 U
Total PBDE	0.6	0.1	0.1	0.2	0.1	0.2

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	HTOC 7		HTOC 8		HTOC 9		HTOC 10		HTOC 12		HTOC 14	
BDE 1	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 2	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 3	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 10	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 7	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 8	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 11	0.0	U	0.0	U	0.0	U	0.0	U	0.1	J	0.0	U
BDE 12	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 13	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 15	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 30	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 32	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 17	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 25	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 33	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 28	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 35	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 37	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 75	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 49/71	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 47	0.0	U	0.0	U	0.1	J	0.1	J	0.0	U	0.0	U
BDE 66	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 77	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 100	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 119	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 99	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 116	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 118	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 85	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 126	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 155	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 154	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 153	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 138	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 166	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 183	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 181	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
BDE 190	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U	0.0	U
Total PBDE	0.0		0.0		0.1		0.1		0.1		0.0	

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix H. Polybrominated biphenyl ethers (PBDEs) in sediment samples from southwest Puerto Rico (ng/dry g) (continued).

Compound	HTOC 15	HTOC 16	HTOC 17	HTOC 19	HTOC 20	HTOC 21	HTOC 22
BDE 1	0.0 U						
BDE 2	0.0 U						
BDE 3	0.0 U						
BDE 10	0.0 U						
BDE 7	0.0 U						
BDE 8	0.0 U						
BDE 11	0.0 U	0.2 J	7.0	1.8	0.0 U	1.4	0.1 J
BDE 12	0.0 U						
BDE 13	0.0 U						
BDE 15	0.0 U						
BDE 30	0.0 U						
BDE 32	0.0 U						
BDE 17	0.0 U						
BDE 25	0.0 U						
BDE 33	0.0 U						
BDE 28	0.0 U						
BDE 35	0.0 U						
BDE 37	0.0 U						
BDE 75	0.0 U						
BDE 49/71	0.0 U						
BDE 47	0.0 U	0.1 J	0.2 J	0.2 J	1.8 J	0.1 J	0.1 J
BDE 66	0.0 U						
BDE 77	0.0 U						
BDE 100	0.0 U						
BDE 119	0.0 U	1.1 I					
BDE 99	0.0 U						
BDE 116	0.0 U						
BDE 118	0.0 U						
BDE 85	0.0 U						
BDE 126	0.0 U						
BDE 155	0.0 U						
BDE 154	0.0 U						
BDE 153	0.0 U						
BDE 138	0.0 U						
BDE 166	0.0 U						
BDE 183	0.0 U						
BDE 181	0.0 U	0.2 J					
BDE 190	0.0 U	0.0 U	0.0 U	0.0 U	0.5 U	0.0 U	0.0 U
Total PBDE	0.0	0.3	7.2	2.0	1.8	1.5	1.5

Qualifiers (Q): J=Below the MDL, U=Not detected, I=Interference

Appendix I. Butyltins in sediment samples from southwest Puerto Rico (ng Sn/dry g).

Site	Coral 1	Coral 2	Coral 3	Coral 4	Coral 5	Coral 6	Coral 8
Monobutyltin	0.00 U	0.00 U	0.28 J	0.20 J	0.36 J	0.30 J	0.23 J
Dibutyltin	0.16 J	0.00 U	0.12 J	0.19 J	0.11 J	0.16 J	0.10 J
Tributyltin	0.00 U						
Tetrabutyltin	0.00 U						

Site	Coral 9	LTOC1	LTOC2	LTOC3	LTOC7	LTOC8	LTOC9
Monobutyltin	0.22 J	0.47 J	0.46 J	0.65 J	0.51 J	0.60 J	0.67 J
Dibutyltin	0.25 J	0.22 J	0.16 J	0.26 J	0.15 J	0.08 J	0.11 J
Tributyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U
Tetrabutyltin	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U	0.00 U

Site	LTOC10	LTOC11	LTOC12	LTOC13	LTOC14	LTOC15	LTOC16
Monobutyltin	0.28 J	0.59 J	0.48 J	0.29 J	0.27 J	0.33 J	0.84
Dibutyltin	0.08 J	0.09 J	0.24 J	0.23 J	0.09 J	0.12 J	0.20 J
Tributyltin	0.00 U						
Tetrabutyltin	0.00 U						

Site	LTOC17	LTOC18	LTOC19	LTOC22	HTOC1	HTOC2	HTOC3
Monobutyltin	0.39 J	0.31 J	0.39 J	0.72	0.00 U	0.00 U	1.54
Dibutyltin	0.09 J	0.00 U	0.09 J	0.14 J	0.19 J	0.29 J	0.55
Tributyltin	0.00 U	0.29 J					
Tetrabutyltin	0.00 U						

Site	HTOC4	HTOC6	HTOC7	HTOC8	HTOC9	HTOC10	HTOC12
Monobutyltin	0.42 J	0.24 J	0.20 J	0.00 U	0.29 J	0.24 J	0.70 J
Dibutyltin	0.12 J	0.11 J	0.22 J	0.12 J	0.23 J	0.20 J	0.13 J
Tributyltin	0.00 U						
Tetrabutyltin	0.00 U						

Site	HTOC14	HTOC15	HTOC16	HTOC17	HTOC19	HTOC20	HTOC21
Monobutyltin	0.46 J	0.49 J	0.17 J	0.32 J	0.32 J	0.27 J	0.79
Dibutyltin	0.00 U	0.00 U	0.10 J	0.22 J	0.28 J	0.20 J	0.09 J
Tributyltin	0.00 U	0.00 U	0.00 U	0.16 J	0.17 J	0.00 U	0.00 U
Tetrabutyltin	0.00 U						

Site	HTOC22
Monobutyltin	0.60 J
Dibutyltin	0.18 J
Tributyltin	0.00 U
Tetrabutyltin	0.00 U

Qualifiers (Q): J=Below the MDL; U=Not detected

Appendix J. Trace and major elements in sediment samples from southwest Puerto Rico ( $\mu\text{g}/\text{dry g}$ ).

Compound	Coral 1	Coral 2	Coral 3	Coral 4	Coral 5	Coral 6
Ag	0 U	0 U	0 U	0 U	0 U	0 U
Al	1,060	1,020	2,460	3,350	6,660	2,840
As	10.3	5.3	0 U	0 U	5.11	0 U
Cd	0 U	0 U	0 U	0 U	0 U	0 U
Cr	11.3	8.88	7.57	11.1	17.4	8.64
Cu	1.13	1	1.89	2.77	4.51	2.24
Fe	2,700	1,440	1,950	2,870	5,580	2,050
Hg	0 U	0 U	0 U	0 U	0 U	0 U
Mn	191	83.2	63.5	86.5	111	56
Ni	3.85	2.63	4.26	6.08	10.6	4.92
Pb	1.03	0.852	0.817	1.25	1.68	1.01
Sb	0.196	0.111	0.055	0.101	0.085	0.0597
Se	0.144	0.09186	0.16	0.147	0.254	0.147
Si	4,500	3,670	8,350	11,500	20,900	10,200
Sn	0 U	0 U	0 U	0 U	0 U	0 U
Zn	1.67	1.55	3.34	4.48	8.63	4.18

Compound	Coral 8	Coral 9	LTOC1	LTOC2	LTOC3	LTOC7
Ag	0 U	0 U	0 U	0 U	0 U	0 U
Al	2,100	1,310	1,250	931	617	13,000
As	0 U	0 U	0 U	0 U	0 U	4.06
Cd	0 U	0 U	0 U	0 U	0 U	0 U
Cr	7.04	5.36	10.2	7.48	6.1	32.9
Cu	1.73	1.01	0.906	1.19	0 U	9.08
Fe	1,420	900	1,650	924	559	8,620
Hg	0 U	0 U	0 U	0 U	0 U	0 U
Mn	65.7	29	58.5	48.1	30	197
Ni	3.75	2.15	2.32	1.69	0 U	24.5
Pb	0.692	2.48	0.821	0.482	0.35	3.19
Sb	0.0513	0.055	0.133	0.0773	0.0434	0.0867
Se	0.16	0.158	0.09315	0.1	0.09964	0.28
Si	7,440	8,440	3,480	2,710	1,830	38,300
Sn	0 U	0 U	0 U	0 U	0 U	0.351
Zn	2.71	1.88	1.68	1.13	0 U	16.2

Qualifiers (Q): J=Below the MDL; U=Not detected

Appendix J. Trace and major elements in sediment samples from southwest Puerto Rico ( $\mu\text{g}/\text{dry g}$ )  
(continued).

Compound	LTOC8	LTOC9	LTOC10	LTOC11	LTOC12	LTOC13
Ag	0 U	0 U	0 U	0 U	0 U	0 U
Al	3,250	8,450	2,920	5,050	1,300	1,090
As	0 U	0 U	0 U	0 U	0 U	4.95
Cd	0 U	0 U	0 U	0 U	0 U	0 U
Cr	11.8	23.2	13.2	17.6	10.8	8.45
Cu	2.7	5.59	2.52	4.13	1.06	0.905
Fe	2,690	6,180	2,720	4,010	1,410	1,970
Hg	0 U	0 U	0 U	0 U	0 U	0 U
Mn	100	166	108	129	59.3	82.6
Ni	6.44	15.9	7.51	11	2.61	2.62
Pb	1.15	2.51	0.973	1.52	0.77	1.01
Sb	0.0507	0.0798	0.0534	0.0538	0.0891	0.171
Se	0.135	0.231	0.177	0.145	0.118	0.117
Si	10,900	27,100	9,980	16,800	3,820	3,020
Sn	0 U	0.302	0 U	0 U	0 U	0 U
Zn	4.32	11	4.06	6.66	1.41	2.04

Compound	LTOC14	LTOC15	LTOC16	LTOC17	LTOC18	LTOC19	LTOC22
Ag	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Al	497	12,100	4,840	780	508	4,570	12,200
As	0 U	5.84	0 U	0 U	0 U	0 U	7.7
Cd	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Cr	3.66	31	14.2	4.25	4.81	13.9	30.4
Cu	0 U	7.83	3.28	0 U	0 U	3.16	7.4
Fe	428	8,850	5,510	662	456	5,480	8,820
Hg	0 U	0 U	0 U	0 U	0 U	0 U	0 U
Mn	20.1	174	108	16.8	18.8	104	173
Ni	1.14	20.9	8.97	1.4	1.1	8.92	20.3
Pb	0.206	2.77	1.59	0.187	0.232	1.48	2.78
Sb	0 U	0.1	0.0866	0 U	0.0425	0.0918	0.11
Se	0.05744	0.315	0.146	0 U	0.08689	0.161	0.322
Si	1,680	35,900	16,000	2,250	2,180	15,000	36,600
Sn	0 U	0.429	0 U	0 U	0 U	0.231	0.419
Zn	0.42	15	7.7	1.21	0 U	7.54	14.9

Qualifiers (Q): J=Below the MDL; U=Not detected

Appendix J. Trace and major elements in sediment samples from southwest Puerto Rico ( $\mu\text{g}/\text{dry g}$ ) (continued).

Compound	HTOC1	HTOC2	HTOC3	HTOC4	HTOC6	HTOC7
Ag	0 U	0 U	0 U	0 U	0 U	0 U
Al	485	924	7,050	2,970	6,220	580
As	0 U	6.61	0 U	0 U	0 U	0 U
Cd	0 U	0 U	0 U	0 U	0 U	0 U
Cr	4.51	11.5	14.3	10.8	18	3.21
Cu	0 U	0 U	6.04	2.15	4.01	0 U
Fe	506	1,390	4,280	2,460	5,990	477
Hg	0 U	0 U	0 U	0 U	0 U	0 U
Mn	22.8	66.1	61	85.4	125	26.9
Ni	0 U	2.06	8.21	5.35	10.8	1.12
Pb	1.54	0.749	3.49	1.04	1.9	0.247
Sb	0 U	0.145	0.127	0.0472	0.0806	0 U
Se	0.07967	0.153	0.301	0.13	0.169	0.07136
Si	1,950	2,580	21,700	10,500	19,700	1,990
Sn	0 U	0 U	0.34	0 U	0 U	0 U
Zn	0.577	0.898	11.9	3.9	9.18	1.01

Compound	HTOC8	HTOC9	HTOC10	HTOC12	HTOC14	HTOC15
Ag	0 U	0 U	0 U	0 U	0 U	0 U
Al	1,440	2,670	973	476	564	1,110
As	0 U	4.23	5.19	0 U	0 U	6.5
Cd	0 U	0 U	0 U	0.223	0 U	0 U
Cr	6.54	9	9.56	4.14	3.24	9.77
Cu	1.04	3.11	0 U	0.934	0 U	1.6
Fe	1,030	1,890	1,110	399	444	1,680
Hg	0 U	0 U	0 U	0 U	0 U	0 U
Mn	32.9	24.4	58.8	20.3	17.8	66.7
Ni	2.48	4.88	2.71	0 U	0 U	2.42
Pb	0.441	2.23	0.524	4	0.345	0.95
Sb	0.0608	0.0838	0.0915	0.196	0.0472	0.176
Se	0.124	0.267	0.094	0.079	0.104	0.135
Si	4,810	11,700	3,630	1,650	2,080	2,820
Sn	0 U	0 U	0 U	2.93	0 U	0 U
Zn	1.91	4.03	1.32	0.437	1.03	1.19

Qualifiers (Q): J=Below the MDL; U=Not detected

Appendix J. Trace and major elements in sediment samples from southwest Puerto Rico ( $\mu\text{g}/\text{dry g}$ ) (continued).

Compound	HTOC16	HTOC17	HTOC19	HTOC20	HTOC21	HTOC22
Ag	0 U	0 U	0.0806	0 U	0 U	0 U
Al	12900	41100	66600	3630	1410	12000
As	4.83	0 U	3.94	0 U	0 U	0 U
Cd	0 U	0.0578	0.11	0 U	0 U	0 U
Cr	30.3	440	394	11.3	9.03	29.8
Cu	7.67	38.7	80.6	3.79	1.03	7.23
Fe	9910	42400	58900	2460	1030	7830
Hg	0 U	0.0954	0.0879	0 U	0 U	0 U
Mn	199	774	567	39	34	204
Ni	19.8	442	434	7.35	2.53	20.6
Pb	2.81	12.9	13.7	1.01	0.436	3.06
Sb	0.0989	0.243	0.325	0.0908	0.0453	0.0827
Se	0.279	0.252	0.432	0.356	0.123	0.279
Si	41400	143000	187000	12700	4310	36000
Sn	0.329	1.22	2.17	0 U	0 U	0.316
Zn	15.1	55.2	90.7	5.4	1.94	14

Qualifiers (Q): J=Below the MDL; U=Not detected

Appendix K. *Clostridium perfringens* in sediment samples from southwest Puerto Rico.

Site	Sample composition	% water	% sediment	<i>Cperf</i> dry (CFU/g)
Coral 1	lg.particles/sandy	25.49	74.51	0
Coral 2	fine sand	26.67	73.33	0
Coral 3	crushed shells	36.49	63.51	0
Coral 4	sand, mostly crushed shells	29.41	70.59	0
Coral 5	fine sand	33.93	66.07	0
Coral 6	crushed shells, sand	30.77	69.23	5.21
Coral 8	crushed shells, sand	37.50	62.50	0
Coral 9	crushed shells, sand	40.00	60.00	0
LTOC1	lg. particles/sand/shells	22.95	77.05	2.30
LTOC2	sandy	26.42	73.58	0
LTOC3	sandy	29.63	70.37	0
LTOC7	mud	40.68	59.32	13.49
LTOC8	mud	35.21	64.79	0
LTOC9	mud	40.63	59.38	25.26
LTOC10	sandy	36.05	63.95	0
LTOC11	dry sand	32.08	67.92	0
LTOC12	lg. particles/dry sand	27.54	72.46	2.51
LTOC13	lg. particles/dry sand	28.41	71.59	0
LTOC13	lg. particles/dry sand	28.57	71.43	0
LTOC14	crushed shells	30.43	69.57	0
LTOC15	watery mud	43.59	56.41	46.65
LTOC16	crushed shells/mud	34.43	65.57	0
LTOC17	sand	25.86	74.14	0
LTOC18	crushed shells	29.17	70.83	0
LTOC19	crushed shells	34.38	65.63	2.72
LTOC22	mud	43.28	56.72	18.08
HTOC1	fine sand	29.85	70.15	0
HTOC2	wet sand, shells	19.74	80.26	0
HTOC3	wet sand, shells	44.64	55.36	9.68
HTOC4	sandy	30.00	70.00	0
HTOC4	sandy	29.82	70.18	0
HTOC6	watery sand	35.71	64.29	12.32
HTOC7	crushed shells, sand	30.00	70.00	0
HTOC8	crushed shells, sand	27.78	72.22	0
HTOC9	wet sand, crushed shells	49.09	50.91	7.21
HTOC10	crushed shells, sand	25.61	74.39	0
HTOC12	crushed shells	28.75	71.25	0
HTOC14	crushed shells	33.78	66.22	0
HTOC15	lg.particles/sand/shells	22.41	77.59	0
HTOC16	watery mud	41.18	58.82	0
HTOC17	watery mud	42.86	57.14	184.21
HTOC19	watery sand	63.41	36.59	1760.69
HTOC20	watery sand	52.83	47.17	3.82
HTOC20	watery sand	56.90	43.10	0
HTOC21	fine sand	32.00	68.00	0
HTOC22	mud	42.31	57.69	9.37

CFU = [(Mean *Clostridium* spores x 40)/volume assayed]/assay weight

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Appendix L. Total nitrogen and phosphorus detected in water samples from southwest Puerto Rico (mg/L).

Site	Total Nitrogen	Total Phosphorus
Coral 1	0.204	0.0096
Coral 2	0.278	0.0077
Coral 3	0.100	0.0069
Coral 4	0.084	0.0065
Coral 5	0.335	0.0095
Coral 6	0.098	0.0080
Coral 8	0.114	0.0066
Coral 9	0.104	0.0057
LTOC1	0.125	0.0069
LTOC2	0.146	0.0065
LTOC3	0.153	0.0065
LTOC5	0.107	0.0065
LTOC7	0.197	0.0068
LTOC8	0.173	0.0076
LTOC9	0.088	0.0057
LTOC10	0.202	0.0065
LTOC11	0.146	0.0061
LTOC12	0.157	0.0072
LTOC13	0.150	0.0065
LTOC14	0.143	0.0061
LTOC15	0.215	0.0076
LTOC16	0.085	0.0058
LTOC17	0.196	0.0065
LTOC18	0.102	0.0061
LTOC19	0.100	0.0065
LTOC20	0.106	0.0061
LTOC22	0.157	0.0073
HTOC1	0.110	0.0058
HTOC2	0.164	0.0062
HTOC3	0.156	0.0062
HTOC4	0.100	0.0061
HTOC6	0.079	0.0058
HTOC7	0.084	0.0065
HTOC8	0.106	0.0062
HTOC9	0.152	0.0069
HTOC10	0.118	0.0069
HTOC11	0.098	0.0061
HTOC12	0.094	0.0054
HTOC14	0.096	0.0065
HTOC15	0.193	0.0057
HTOC16	0.178	0.0091
HTOC17	0.378	0.0238
HTOC18	0.097	0.0065
HTOC19	0.368	0.0483
HTOC20	0.095	0.0065
HTOC21	0.216	0.0069
HTOC22	0.165	0.0084

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