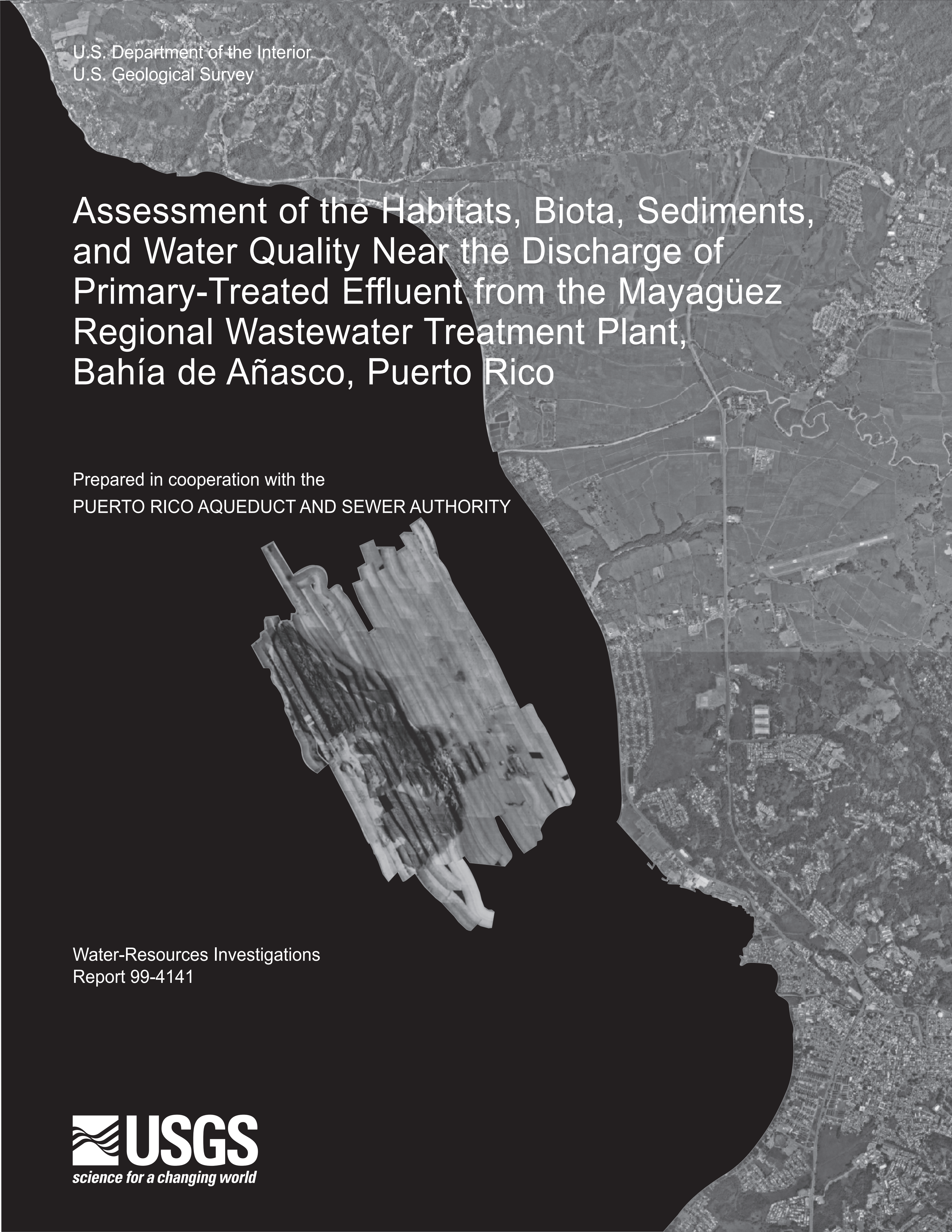

U.S. Department of the Interior
U.S. Geological Survey

Assessment of the Habitats, Biota, Sediments, and Water Quality Near the Discharge of Primary-Treated Effluent from the Mayagüez Regional Wastewater Treatment Plant, Bahía de Añasco, Puerto Rico

Prepared in cooperation with the
PUERTO RICO AQUEDUCT AND SEWER AUTHORITY

Water-Resources Investigations
Report 99-4141

USGS
science for a changing world

Cover

Vertical image of western Puerto Rico, the Bahía de Añasco and the Bahía de Mayagüez. The terrestrial portion is a mosaic of digital orthophotoquads (note the differences in tone along the quad margins). The side-scan-sonar image west of the coast depicts the Manchas Interiores-Manchas Exteriores reef complex (dark, textured area), and the muddy bottom surrounding the outfall (light gray tones). The trenched ocean floor around the outfall is visible east of the reef complex, 1.7 kilometers west of the coast. The cover image is about 15 kilometers from north to south.

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PUERTO RICO AQUEDUCT AND SEWER AUTHORITY

San Juan, Puerto Rico: 2000

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ACRONYMS, and TRANSLATIONS

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch
centimeter (cm)	0.032808	foot
meter (m)	3.2808	foot
kilometer (km)	0.62137	mile
Area		
square meter (m^2)	10.764	square foot
square kilometer (km^2)	0.3861	square mile
square kilometer (km^2)	247.11	acre
Volume		
cubic meter (m^3)	35.315	cubic foot
million cubic meters (Mm^3)	810.7	acre-foot
cubic meter (m^3)	0.0008107	acre-foot
Volume per unit time (includes flow)		
cubic meter per second (m^3/s)	35.315	cubic foot per second
cubic meter per second (m^3/s)	15,850	gallon per minute
cubic meter per second (m^3/s)	22.826	million gallons per day
Density		
gram per cubic centimeter (g/cm^3)	62.428	pound per cubic foot
Mass per area (includes sediment yield)		
megagram per square kilometer per year ($Mg/km^2/yr$)	2.855	ton per square mile per year

Shannon-Weaver diversity index (H′)

Multiply	By	To obtain
H′ calculated using ln	1.443	H′ calculated using $\log_2$
H′ calculated using ln	0.434	H′ calculated using $\log_{10}$

Acronyms used in this report:

AAS	Atomic-absorption spectrophotometry
BOD	Biological oxygen demand
BIP	Balanced indigenous population
CFR	Code of Federal Regulations
DPW	Department of Public Works
EPA	U.S. Environmental Protection Agency
LOI	Loss on ignition
MRWTP	Mayagüez Regional Wastewater Treatment Plant
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
OOM	Other organic matter
PRASA	Puerto Rico Aqueduct and Sewer Authority
PREQB	Puerto Rico Environmental Quality Board
STP	Sewage Treatment Plant
TOC	Total organic carbon
USGS	U.S. Geological Survey

Translations

Bahía	Bay
de	of
Escollo	Shoal
Punta	Point
Río	River

Assessment of the Habitats, Biota, Sediments, and Water Quality Near the Discharge of Primary-Treated Effluent from the Mayagüez Regional Wastewater Treatment Plant, Bahía de Añasco, Puerto Rico

By **Richard M.T. Webb, Paul D. Collar, William C. Schwab, Carlos Goenaga, Jorge R. García, *and* Roberto Castro**

Abstract

A multidisciplinary study was carried out during December 1990 and January 1991 to assess the effects of wastewater discharges from the ocean outfall of the Mayagüez Regional Wastewater Treatment Plant on natural resources in the Bahía de Añasco, Puerto Rico. In 1987, the Mayagüez Regional Wastewater Treatment Plant began discharging primary-treated effluent through the ocean outfall, located 1.7 kilometers off the west coast, in an area of strong currents with good dilutional capacity. The receiving waters are home to a diverse community of biota that has adapted to living in the silt-laden waters that receive the runoff from the largest rivers on the west coast. No causal relationship could be established between the ocean outfall and adverse impacts on the biota, sediments, and water quality of the Bahía de Añasco.

The variability observed in the biological communities in the Bahía de Añasco and the offshore reef complex can be explained as adaptations to natural conditions. Patch reefs growing in the Bahía de Añasco have been smothered by a naturally prograding delta. Coral colonies present in the Manchas Interiores-Manchas Exteriores coral reef complex consist predominantly of species that are adapted to high levels of siltation and turbidity. Algal species form an integral part of the community, utilizing nutrients discharged from the rivers, released by bacterial degradation of organic material in the sediments, and produced by poriferans. The mixing and dilution occurring at the present discharge site appears to be effective. The macrobenthic infauna, icthyofauna, and sessile benthos, observed in the Bahía de Añasco in 1985, were similar to those observed in 1990, after three years of outfall operation. The diversity and community composition of macrobenthic infauna sampled in the Bahía de Añasco vary both through time and between stations. Diversity measurements correlated with percent opportunistic species; both values decreased with distance from the shore, whereas no relationship was detected with distance from the outfall. The extensional rates of colonies of the star coral, *Montastrea annularis*, sampled only 650 meters from the outfall, have not decreased since the outfall became operational. Ratios of carbon and oxygen isotopes and trace elements measured in the aragonitic lattice of the *Montastrea annularis* colonies suggest that corals growing both in the Bahía de Añasco and in the Escollo Negro are affected by three main factors: river runoff, shifting oceanic circulation, and fluxes of metals and organic material from the sediments.

The Río Yagüez and the Río Guanajibo discharge sediments eroded from serpentinite deposits rich in magnesium, nickel, chromium, cobalt, and copper. Sediments discharged from the Río Grande de Añasco are deposited in the Bahía de Añasco, occasionally reaching the Bahía de Mayagüez, but only rarely affecting the reefs in the western part of the Manchas Interiores. Bacterial mediation of organic matter in the sediments for long periods of time is evidenced by dark staining on carbonate grains.

Receiving waters sampled at the limit of the mixing zone at the outfall site at the end of January 1991 met all water-quality standards and criteria. Total coliform bacteria, present at a concentration of 29,000 colonies per 100 milliliters in the homogenized effluent sample (collected at the treatment plant), averaged 315 colonies per 100 milliliters for the two sites sampled at the limit of the zone of initial diffusion. Carbon tetrachloride concentrations exceeded 8.0 micrograms per liter in the effluent, but were below the detection limit at all marine and freshwater stations. Ammonia concentrations exceeded 20 milligrams per liter in the effluent, but was less than 0.7 milligram per liter in the zone of initial diffusion in the bay. Total phosphorous concentrations, present at 6.1 milligrams per liter in the effluent, were less than the detection level of 0.05 milligram per liter at all but one station in the bay, far from the outfall.

INTRODUCTION

The Mayagüez Regional Wastewater Treatment Plant (MRWTP) is one of 10 large regional facilities built by the Puerto Rico Aqueduct and Sewer Authority (PRASA) to accept and treat large volumes of point-source discharges. The plant was designed to treat a maximum of 0.92 cubic meters per second (m^3/s) (21 million gallons per day) of wastewater before discharging it into the Bahía de Añasco through an outfall located 1,700 meters (m) offshore from Barrio Maní. The PRASA applied for a waiver of secondary-treatment requirements for discharges in marine waters under section 301(h) of the Clean Water Act (33 U.S.C. § 1311(h)).

The U.S. Environmental Protection Agency (EPA) issued its final National Pollutant Discharge Elimination System (NPDES) permit for the Mayagüez plant in September 1987, specifying secondary-treatment levels for the discharge. In order to comply with the biological oxygen demand (BOD) load limitations for secondary treatment, the discharge of the primary-treatment plant, with its inherently lower BOD removal rates, is limited to approximately 0.39 m^3/s (9 million gallons per day). The plant began discharging primary-treated wastewater through the present ocean outfall at the end of 1987.

Wastewater received by the MRWTP contains sediments, inorganic and organic compounds, including toxins, nutrients, and pathogens. The MRWTP is a primary-treatment plant that removes the majority of the solid material and adds chlorine to kill pathogens before discharging the effluent into Bahía de Añasco through an ocean outfall 1.7 kilometers (km) west of the town of Maní. The effluent from the plant contains significant amounts of particulate matter, metals (trace elements), organic compounds, and a certain amount of pathogens. Most contaminant concentrations drop below detectable values as the effluent turbulently mixes with the receiving waters. However, depending on the composition of the effluent, the design of the diffuser, and the physical and chemical conditions present in the receiving waters, the discharge can have adverse impacts on the environment. Therefore, applicants for waivers from secondary-treatment requirements must carry out monitoring programs to evaluate the impact of the discharge on marine biological communities, to demonstrate compliance with applicable water-quality standards or criteria, and to monitor the effectiveness of urban pretreatment and toxics-control programs.

A properly designed monitoring program is an integrated study that describes the water quality of the influent, effluent, and receiving waters, in addition to spatial and temporal variability of biological communities in the area of the discharge. Also, bioaccumulation determinations and sediment sampling should be used to indicate the potential for adverse effects on human health, especially in areas of recreational activities or with active fisheries.

A key condition for granting a waiver from secondary-treatment requirements is that the receiving waters must support a balanced indigenous population (BIP) of shellfish, fish, and wildlife. A BIP is defined in Section 301(h) regulations [40 CFR Part 125.58(f)] as "an ecological community that: (1) exhibits characteristics similar to those of nearby, healthy communities existing under comparable but unpolluted environmental conditions; or (2) may reasonably be expected to become re-established in the polluted water body segment from adjacent waters if sources of pollution were removed." The presence of a BIP in the zone of initial dilution, by definition [40 CFR Part 125.58(z)], indicates that the receiving waters are not "stressed."

Potential Impacts of Wastewater on Biological Communities

Wastewater discharged through an ocean outfall can affect biological communities in the following ways [40 CFR Part 125.62(c)]:

- Modifications to the structure of benthic communities (bottom-dwelling/feeding fishes and invertebrates) caused by accumulation of discharged solids on the seabed;
- increases in phytoplankton or macroalgal growth due to turbidity inputs;
- reductions in dissolved oxygen due to phytoplankton blooms and subsequent die-offs, leading to mass mortalities of fish or invertebrates;
- bioaccumulation of toxic substances in marine organisms due to direct contact with sediment, ingestion of sediment, direct uptake from effluent, or ingestion of contaminated organisms; and
- induction of diseases in marine organisms caused by contact with contaminated sediments, ingestion of contaminated organisms, or exposure to effluent.

If the wastewater discharged through the MRWTP ocean outfall is producing these effects, expected shifts in the community structure of biota living nearby should be observable. Because of the importance of coral reefs to the ecosystem of the Bahía de Añasco, a detailed discussion of potential impacts on this community is warranted.

Sewage discharge into coastal waters may affect coral reef communities (reviewed in Hatcher and others, 1989, and in Goenaga, 1991) by (1) causing nutrient enrichment and enhancing the growth of algae at the expense of corals (Marszalek, 1981), (2) depressing oxygen levels (Wade and others, 1972), and (3) by introducing toxic substances such as chlorine (Campbell, 1977; Best and others, 1982; Muchmore and Eepel, 1973). Coral morbidity and mortality under experimental conditions apparently results from competition for space with algae, and does not appear to be directly related to effluent toxicity (Marszalek, 1981). Large inputs of nutrients from sewage outfalls can produce blooms of planktonic and benthic algae which may displace other organisms, including corals (Banner, 1974; Smith and others, 1981; Walker and Ormond, 1982). Sewage pollution to coral reefs can take the form of dissolved inorganic nutrients, dissolved organic materials and/or particulate organic material (Pastorok and Bilyard, 1985; Marszalek, 1987). Coral reefs develop in oligotrophic waters. The introduction of additional nutrients is likely to affect them, although the effect is not always linear. For example, Tomascik and Sander (1985) found that coral growth rate correlated positively with slight increases in nutrient concentrations and other factors (for example, turbidity, sedimentation, toxicity and bacterial production), but at higher nutrient levels coral growth and diversity declined.

In Puerto Rico, coral reefs growing close to sanitary discharges, as they are, for example, off Ponce, show proliferations of green algae, namely *Ulva lactuca*, *Enteromorpha sp*. and *Dyctyosphaeria sp*. (V.P. Vicente and C. Goenaga, personal observations). These algae tend to colonize corals from their bases, eventually overgrowing them. Smith and others (1981) reported similar extensive macroalgal blooms in Kaneohe Bay, Hawaii, and concluded that the predominant source of nitrogen was in the form of particulate organics rather than in dissolved forms. The source of the nitrogen was a sewage outfall that discharged into the bay. Kaneohe Bay has a parallel in the earlier discharges of raw sewage into the Bahía de Mayagüez, which also has a poor dilutional capacity. Similarly, the Kaneohe Bay outfall was relocated to a nearby oceanic site with greater dilutional capacity, as was done when the Mayagüez outfall was relocated to its present site west of Maní. After a period of slow initial recovery (Smith and others, 1981; Russo, 1982; Evans and others, 1986), the now clear waters of Kaneohe Bay once again host thriving coral communities (Eric De Carlo, University of Hawaii, oral commun., 1998).

Tropical marine organisms live in waters that are usually oligotrophic or with generally low nutrient concentrations. It has been suggested that the predominance of symbiotic relationships in coral reefs, such as that between microalgae (for example, zooxanthellae) and corals (Muscatine and Porter, 1977; Taylor, 1981), and between sponges and corals (Corredor and others, 1988), has evolved in response to low nutrient concentrations. This symbiosis has resulted in an efficient recycling of nutrients between host and symbiont. Under eutrophic conditions (high nutrient concentration in the water column), organisms with faster growth rates and that are capable of rapid transformation of nutrients into biomass, such as fleshy and filamentous algae, will usually outcompete or displace the slower growing corals (Johannes, 1975). High nutrient concentration in the water column is also known to stimulate bioerosion (for example, the biochemical erosion by boring sponges, boring annelids, and sipunculids of the vertical calcium/carbonate ($CaCO_3$) structure produced by corals) (Highsmith, 1981). The dynamic interplay between $CaCO_3$ accretion (for example, by coral growth) and destruction (for example, by bioerosion) of coral reefs is, therefore, strongly influenced by nutrient availability. Examples illustrating this relationship are known from the fossil record (Hallock, 1988). In addition, cnidarian larval settlement, including those of corals, is precluded where the substrate is covered by dense algal growth (Sammarco, 1980). Coral planulae need clean substrates that are free of algae to develop. The most probable outcome in eutrophic areas, as observed elsewhere around Puerto Rico (for example, Ponce; C. Goenaga and V.P. Vicente, personal observations) and in the Caribbean, is a relict reef in which the vertical $CaCO_3$ structure may, for some time, be preserved, but in which the main reef building organisms, namely corals, become an inconspicuous element of the new community. This new community, dominated by fleshy and filamentous algae, is incapable of producing the structure necessary to maintain reef growth.

Tropical shallow-water communities are subject to many of the same anthropogenic stresses as communities from high latitudes (Hatcher and others, 1989), but the relative importance of these differ, and attempts to extrapolate the results of studies from higher latitudes to the tropics have been unsuccessful. The use of temperate marine species employed in existing procedures for bioassays may not be representative of the responses of tropical species subjected to similar testing (Gelabert and Singh, 1992). For example, dissolved-nutrient concentrations are usually much lower in tropical surface waters than in temperate waters. The elevation of phosphate concentrations by 0.023 milligram per liter (mg/L) (phosphate as P), in New England waters would result on the average in doubling of the phosphate concentration there, whereas in the eastern Caribbean it would constitute an approximately 40-fold increase (Hatcher and others, 1989). In this context it is worth mentioning that it is well documented that phosphate suppresses calcium mineralization in coral reef organisms (Kinsey and Davies, 1979).

Substrate variables, such as the taxonomic composition of benthic biota (Bakus, 1966; Risk, 1972) and physical habitat complexity (Luckhurst and Luckhurst, 1978; Roberts and Ormond, 1987) have been shown to influence the diversity and abundance of reef fishes on microspatial scales. On the temporal scale, the marked seasonality of the discharge of large rivers and the associated sediment and nutrient loadings imposed by rainfall have potentially important implications to the reef communities of Bahía de Añasco. Therefore, an assessment of natural variability, both in temporal (seasonal) and spatial scales, is critically needed as a background to discuss any possible impacts of the PRASA's sewage treatment plant operations upon ichthyofaunal community structure in the reefs of the Bahía de Añasco.

The marine communities in the Bahía de Añasco, and in the Caribbean in general, have been vulnerable to regional impacts of undetermined cause over the past decades, previous to the existence of the Mayagüez plant. Over the last decade, both a massive sea urchin die-off (Vicente and Goenaga, 1984) and widespread coral bleaching (Williams and others, 1987) have been documented in the western Atlantic. Previously healthy colonies of the elkhorn coral *Acropora palmata* have disappeared from the reefs in the Bahía de Añasco during the last 20 years (Morelock and others, 1983). The reefs in the Bahía de Añasco are vulnerable to the sediments and contaminants discharged by the Río Grande de Añasco and the Río Yagüez, sediments and contaminants discharged through the outfall, and those resuspended by wave action. Any natural or anthropogenic shift in loadings of nutrients, particulate organic matter, sediments, or in siltation can result in changes in habitat (Banner, 1974; Johannes, 1975; Kinsey and Davies, 1979; Pastorok and Bilyard, 1985; Marszalek, 1987). Site-specific data are essential to determine the degree of potential impact of sewage discharge on the surrounding community.

A multidisciplinary sampling expedition was carried out by the U.S. Geological Survey (USGS) in cooperation with the PRASA, during December 1990 and January 1991 to provide data needed to evaluate the effects of wastewater discharges from the ocean outfall on natural resources in the Bahía de Añasco, Puerto Rico. In December 1990, an image of the ocean floor surrounding the ocean outfall was created and used to select sites for more detailed analyses of the biota and sediments in the bay. In January 1991, water quality was analyzed for the MRWTP waste stream, the Río Grande de Añasco, the Río Yagüez, and the marine waters off the west coast (fig. 1). This report presents the results along with additional historical and recent data to provide decision makers with a more complete picture of observed or potential impacts of the MRWTP ocean outfall discharge on the marine environment.

Purpose and Scope

This report documents temporal and spatial variations in the habitats, biota, sediments, and water quality at and around the ocean outfall of the MRWTP where it discharges into the Bahía de Añasco. Specific objectives of the sampling program and the approaches that were used include the following.

- Define the precise extent and location of sea-floor habitats capable of supporting coral communities that may be especially vulnerable to impact from the outfall. Marine geophysical equipment including sidescan sonar and reflection seismic equipment were used to map approximately 10 square kilometers (km^2) of the ocean floor in the Bahía de Añasco, including the Manchas Interiores-Manchas Exteriores coral reef complex. The sidescan-sonar mosaic and seismic-reflection data were used to describe sea-floor habitats, sediment deposition patterns and to locate sampling stations in the Bahía de Añasco.
- Describe the macrobenthic infauna at eight stations previously surveyed in 1985 (PRASA, 1985). Compare the makeup and diversity of these communities with those observed in 1985. Grab samples of macrobenthic infauna were collected and identified to the lowest possible taxon. Community statistics and comparison of variance with time and both within and between sampling sites are presented.
- Describe the sessile benthos and fish at two stations previously surveyed in 1985 (Center for Energy and Environment Research, 1985), at a station with a hard-bottom substrate near the outfall identified in the sidescan-sonar mosaic, and at a control site in the Escollo Negro. Compare the communities observed in 1990-91 with those observed in 1985. The sessile benthos and fish communities were censused by visual identification along linear transects. Community statistics and comparison of variance with time and both within and between sampling sites are presented.

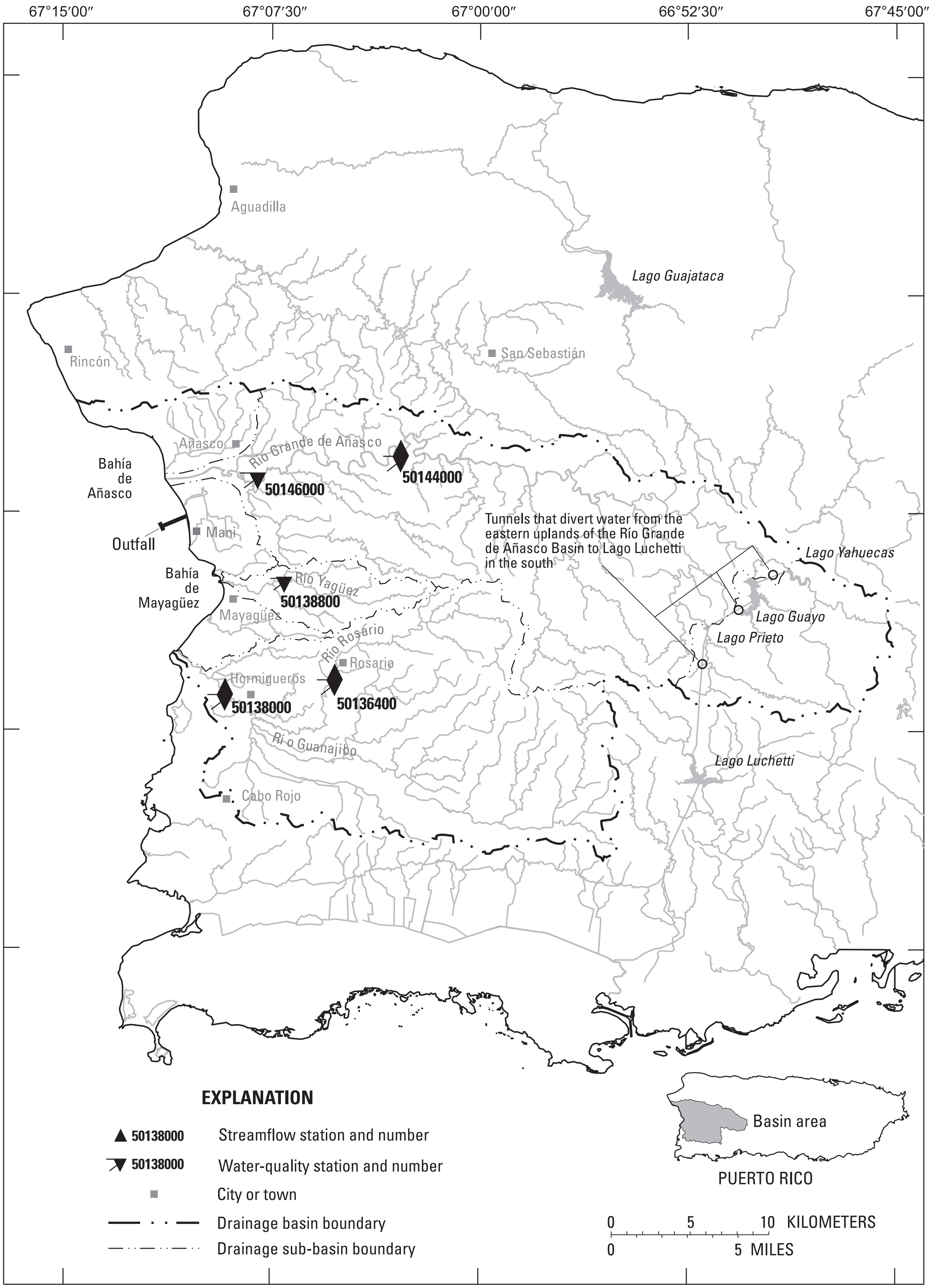


Figure 1. Location of drainage-basin boundaries, localities, and USGS streamflow and water-quality monitoring stations for west coast rivers discharging to the Bahía de Añasco and Bahía de Mayagüez, Puerto Rico.

- Document interannual changes of extensional rates, fluorescence, trace metal content, and the ratios of stable isotopes of carbon and oxygen, for the star coral *Montastrea annularis,* at a site located near the outfall, and at a control site located away from the influence of the rivers and the outfall. For four coral core samples, the extensional rates, fluorescence, elemental and isotopic composition of annual samples representing the years 1984-90 are presented, as are those for seventeen 3-year composites (1938-89) from one of the cores sampled at the station nearest the outfall.

- Describe sediment transport and deposition patterns in the Bahía de Añasco and the Manchas Interiores-Manchas Exteriores coral reef complex. Bottom-sediments in the study area and at distant control stations were sampled. In addition, sediment cores were recovered from near the outfall, in the deltas of the Río Grande de Añasco and the Río Yagüez, and in a sand channel located in the coral reefs. Results of core-sample analyses of grain size, percent $CaCO_3$, clay mineralogy, total organic material, trace elements, and cesium-137 activity, are presented and interpreted to describe recent and historical sedimentation patterns in the study area.

- Describe the water quality in the Río Grande de Añasco, the Río Yagüez, and the Río Guanajibo, and the plant influent and effluent, in the initial mixing zone, the far field, and at reference stations far removed from the outfall. The rivers, the plant influent and effluent, and the receiving waters, were sampled and analyzed for the full array of priority pollutants, total metals, general inorganics, radionuclides, and non-conservative properties. In addition, acute and chronic bioassays were conducted on whole effluent. The results are compared with water-quality criteria established by the Puerto Rico Environmental Quality Board (PREQB) and the EPA. Supplementary data are presented to describe observations of water quality in west coast rivers for the period 1970-97.

The results are synthesized with ancillary data describing the upland watershed and active oceanic processes to evaluate the possible role of wastewater discharged through the outfall as a causal factor in the observed variations in habitat, biota, sediments and water quality in the Bahía de Añasco.

Acknowledgments

The authors would like to thank the following people and organizations: The Puerto Rico Department of Natural and Environmental Resources (DNER), for making the Research Vessel Jean A available on short notice; Captain Richy Paul-Rodríguez and mate Henry Colón-Vazquez, for their patience and seamanship; John Schlee, for providing additional seismic data for the area around Punta Algorrobo; Rafael Rodríguez, for support, equipment, and the use of his parents' house for deployment of a navigation transponder; radio station WOLE, for allowing us to locate our other transponder at their Atalaya site; the personnel of the DNER lab, for aiding in the sediment analysis; the Puerto Rico Ports Authority, for the use of their docks; Glen Shen, at the University of Washington, for help with the trace metals in the coral; and Ted McConnaughey, who offered key insight on stable isotopes in corals. Analyses of stable isotopes of carbon and oxygen were done by K.C. Lohmann at the University of Michigan. Bob Halley provided expertise and the use of his facilities at the USGS Center for Coastal Geology in St. Petersburg. Art Horowitz analyzed the sediments for total metals. Sherwood McIntyre helped both in the field and in the lab by analyzing the cesium-137 activity in the sediments. Roy Armstrong at the University of Puerto Rico, supplied the Airborne Ocean Color Image of the study area. John Neil identified the minerals, using X-ray diffraction. Rafael Andreu, Wanda Alvarez, and Luis Montezuma at the PRASA, assisted greatly both in the field and in the laboratory. Luis Soler and Miguel Rodríguez were indispensable during the water-quality sampling. Luis Menoyo assisted in diving operations and creating presentations. Ruth Guzmán and Francisco Maldonado prepared the report for publication. Finally, we thank Marilyn tenBrink, José Rivera, Eric De Carlo, Briant Kimball, Vance Vicente, Bruce Taggart, Joe Troester, and Hans Perl, for their critical reviews of the manuscript.

STUDY AREA

Puerto Rico is the easternmost of the four islands making up the Greater Antilles. The roughly rectangular island is bounded to the north by the Atlantic Ocean, to the east by the broad, shallow Puerto Rico-Virgin Islands Platform, to the south by the Caribbean Sea, and to the west by the Mona Passage. The width of the insular platform of Puerto Rico varies from less than a kilometer along much of the north and southeast coasts, to more than 20 km off the east and southwest coasts. The broad carbonate platform off the southwest coast narrows to the west and north of Mayagüez (fig. 2). The main shipping channel into the Bahía de Mayagüez passes through a narrow gap between two reefs, Manchas Grandes and Manchas Interiores. Manchas Interiores is the name for the southern part of the shoal that lies on the insular shelf break west of Maní and west of the outfall; the northern part of the shoal is known as Manchas Exteriores. In this report Manchas Interiores and Manchas Exteriores may be referred to separately or together as the Manchas Interiores-Manchas Exteriores coral reef complex. The reefs act as barriers to normal wave energy, allowing muds to settle on the floor of the Bahía de Mayagüez and the Bahía de Añasco. The sediments in the Bahía de Mayagüez and the Bahía de Añasco contain varying amounts of autochthonous biogenic carbonate, but are predominantly composed of sediments discharged from the three rivers that drain the upland area.

Upland Areas

The geology of the uplands draining into the Bahía de Añasco is distinct from that draining into the Bahía de Mayagüez. The southwestern volcanic-plutonic subprovince (Cox and Briggs, 1973) contains large bodies of serpentinite that provide a bedrock source for laterite deposits containing nickel, iron, and cobalt. The greenish metal-rich serpentinite deposits, known as the Bermeja complex (Mattson, 1960), are unique to southwestern Puerto Rico, which is formed from thick marine deposits scraped off a descending oceanic crust long ago. Studies of the serpentinite sampled from deep drill holes in the outcrops southwest of Mayagüez were used to better understand the now globally accepted theory of plate tectonics (Burk, 1964).

The diverse geology results in equally diverse soils. Detailed descriptions of the soils in the watersheds draining into the study area are presented by Gierbolini (1975). The main soil associations in the western watersheds are Coloso-Toa, Descalabrado, Consumo-Humatas, Humatas-Maricao-Los Guineos, Caguabo-Múcara, all formed above volcanic rock or metamorphosed marine deposits, and Nipe-Rosario, formed on the serpentinite terrain (National Resources Conservation Service, 1998). More than 99 percent of the areal coverage of Nipe-Rosario is within the Río Yagüez and the Río Guanajibo basins, and less than one percent in the Río Grande de Añasco basin (National Resources Conservation Service, 1998). The metal-rich soils of the Nipe-Rosario thus provide a key geochemical tracer to distinguish the sediments discharged to the Bahía de Mayagüez from those discharged to the Bahía de Añasco.

Independent of their composition, sediments eroded from the uplands impact ecosystems and have deleterious effects on water quality and water supply. Average annual soil loss (for the period 1938-47) on experimental slopes (40-60 percent gradients) in the Mayagüez area ranged from 500 megagrams per square kilometer per year (Mg/km^2/yr) (1,400 tons per square mile per year) for pasture to 35,000 Mg/km^2/yr (100,000 tons per square mile per year) for fallow desurfaced slopes (Smith and Abruña, 1955). Of the 12 municipalities that share parts of the watersheds discharging into the study area, only two, Cabo Rojo and Hormigueros, are not included in the zones dedicated to coffee production. Approximately 120 km^2 of the upland areas is dedicated to coffee production, resulting in almost 200,000 tons of soil loss from the upland basins every year (National Resources Conservation Service, 1998). The most significant point and nonpoint sources identified in the basins draining into the Bahía de Añasco and the Bahía de Mayagüez are agricultural activities, urban runoff, sand extraction sites, rural and isolated community wastewaters, industrial discharges, municipal wastewater discharges, and coffee processing plants (National Resources Conservation Service, 1998). The relative loadings from each of these sources depends on the intensity of activity and prevailing weather conditions.

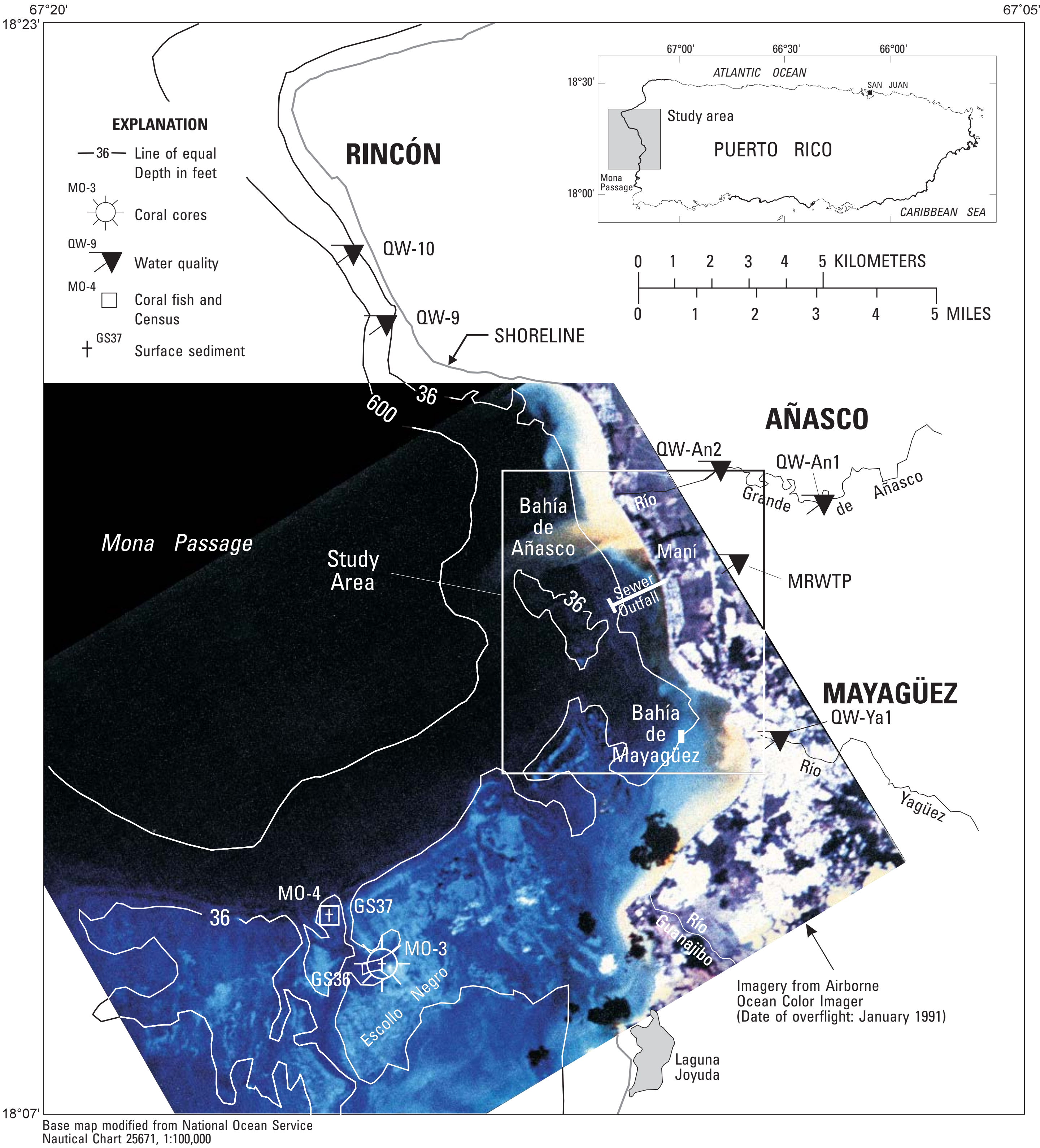


Figure 2. Locations of study area and remote sampling stations outside of the study area, used as control stations, Mona Passage, Puerto Rico.

During a typical year, streamflow in the Río Grande de Añasco is lowest during February and March, increases with May rains, decreases during June and early July, is highest from August through November, and declines through December and January. Seasonal trends in the streamflow and sediment-discharge records for data collected from three streamflow monitoring stations in western Puerto Rico over the period 1970-97 are shown in figure 3.

Rivers and marine waters were sampled in December 1990 and January 1991, during generally declining base flows for the western rivers (fig. 4). The western rivers drain into the Bahía de Añasco and the Bahía de Mayagüez, where they mix with the marine waters.

Coastal Morphology, Tides, Ocean Currents, and Wave Climate

Currents in the Bahía de Añasco (fig. 5) as a whole respond predominantly to the daily sea breezes and tidal fluctuations (Department of Public Works, 1971, 1974; Morelock and others, 1983). Definite vertical velocity gradients exist. Bottom waters in the Bahía de Mayagüez and the Bahía de Añasco commonly flow towards shore, replacing surface waters that are driven away from shore by the prevailing northeast Trade Winds. General upwelling of deeper waters onto the insular shelf was documented in 1971 (Department of Public Works, 1971), and again in 1983 (Morelock and others, 1983). At the outfall site, the net transport direction of the water column is clearly to the north-northwest, although currents to the east and west have been documented to persist for up to 6 hours (PRASA, 1985). In the afternoons, the occurrence of sea breeze is common as localized low pressure cells form over the hot terrain in western Puerto Rico. The sea breeze can push the surface waters towards the coast, effectively trapping the discharge of the rivers in the near vicinity of the coastline. Coast-parallel currents are observed in aerial photographs and remote sensing imagery to converge near Maní and travel away from shore, carrying sediments into deeper waters, where they settle out (fig. 2). Northerly currents may be expected to accelerate through the restricted channel between shore and the reefs in the area of the outfall. This would also enhance good dispersion of the effluent.

Currents west of the Manchas Interiores-Manchas Exteriores coral reef complex are generally to the north (Department of Public Works, 1971). Current intensity changes throughout the year in response to the position and intensity of the North Atlantic Equatorial Current. Landward of the reefs, the net transport is to the northwest, though rotary tidal currents can produce flows in any direction for limited periods of time.

Depending on the prevailing wave climate, the littoral currents at the coastline can travel either to the north or south. The percentage of dark minerals and igneous rock fragments in beach sands is greatest near the outlet of the Río Guanajibo, and decreases northward along the coast throughout the Bahía de Mayagüez and to the mouth of the Río Grande de Añasco (Morelock, 1987). This indicates a net northerly transport of coastal sediments from the Río Guanajibo to the Río Grande de Añasco. However, in the nearshore region of the mouth of the Río Grande de Añasco, wave energy arrives predominantly from the north, setting up a southerly littoral drift (Morelock and others, 1983) that can travel along the coast until it meets the northerly littoral current traveling from the Bahía de Mayagüez. When they meet, rip currents will form, and carry the water and its mixed constituents into the Bahía de Añasco (fig. 2).

The coastal morphology and marine currents are major factors in determining the fate of the effluent discharged from the ocean outfall, and also in determining the makeup and distribution of biotic communities in the waters off western Puerto Rico. Both the position of the shoreline and the behavior of marine currents respond to sea-level changes. During the last million years, sea level has risen and fallen repeatedly in response to the advance and retreat of the polar ice caps. The last of the great glacial advances ceased only around 16,000 years ago, when the sea stood at least 80 m below its present level (Dillon and Oldale, 1978).

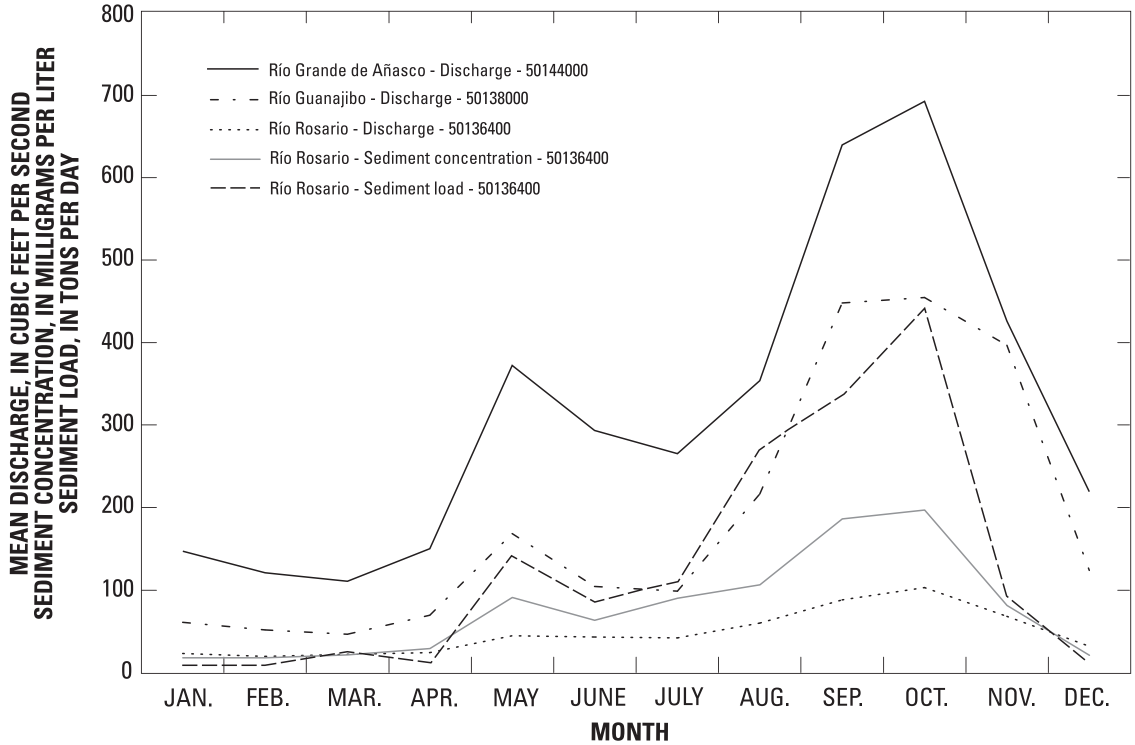


Figure 3. Monthly average streamflow for the Río Grande de Añasco, the Río Guanajibo, and the Río Rosario, and suspended-sediment concentrations and loads for the Río Rosario, Puerto Rico (1970-97).

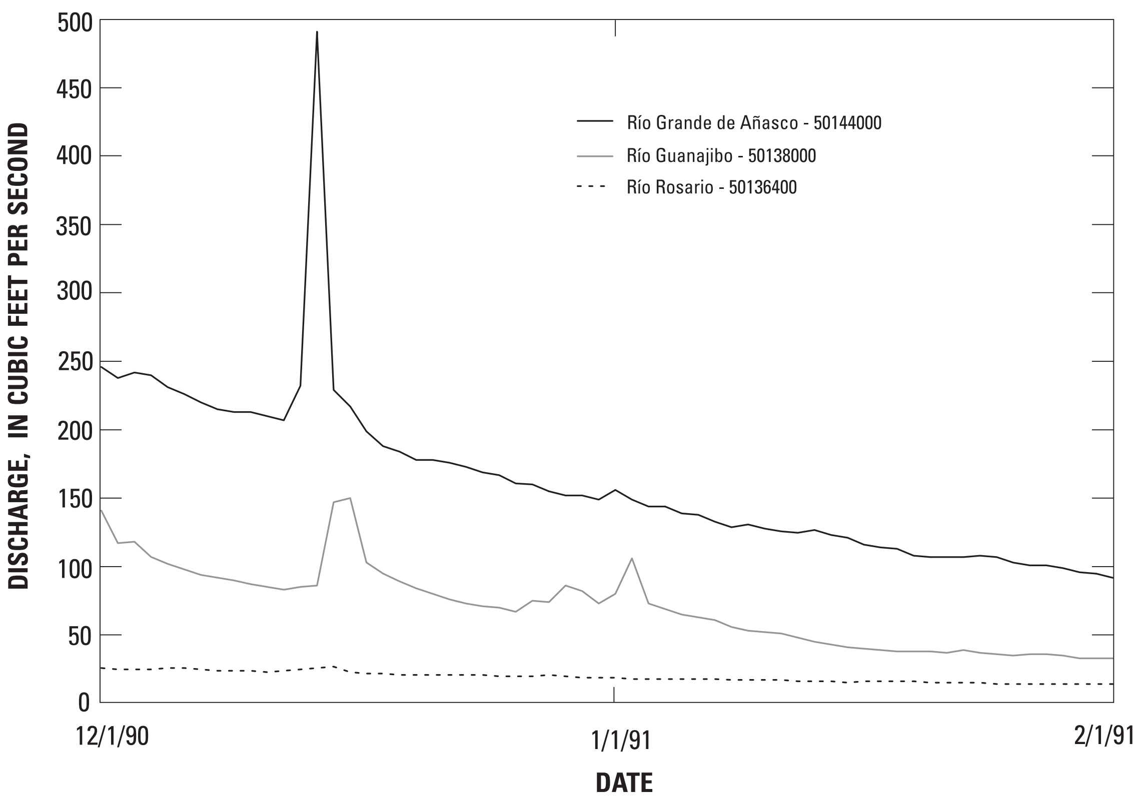


Figure 4. Discharge for the period December 1, 1990, through January 31, 1991, for the Río Grande de Añasco, the Río Guanajibo, and the Río Rosario, Puerto Rico.

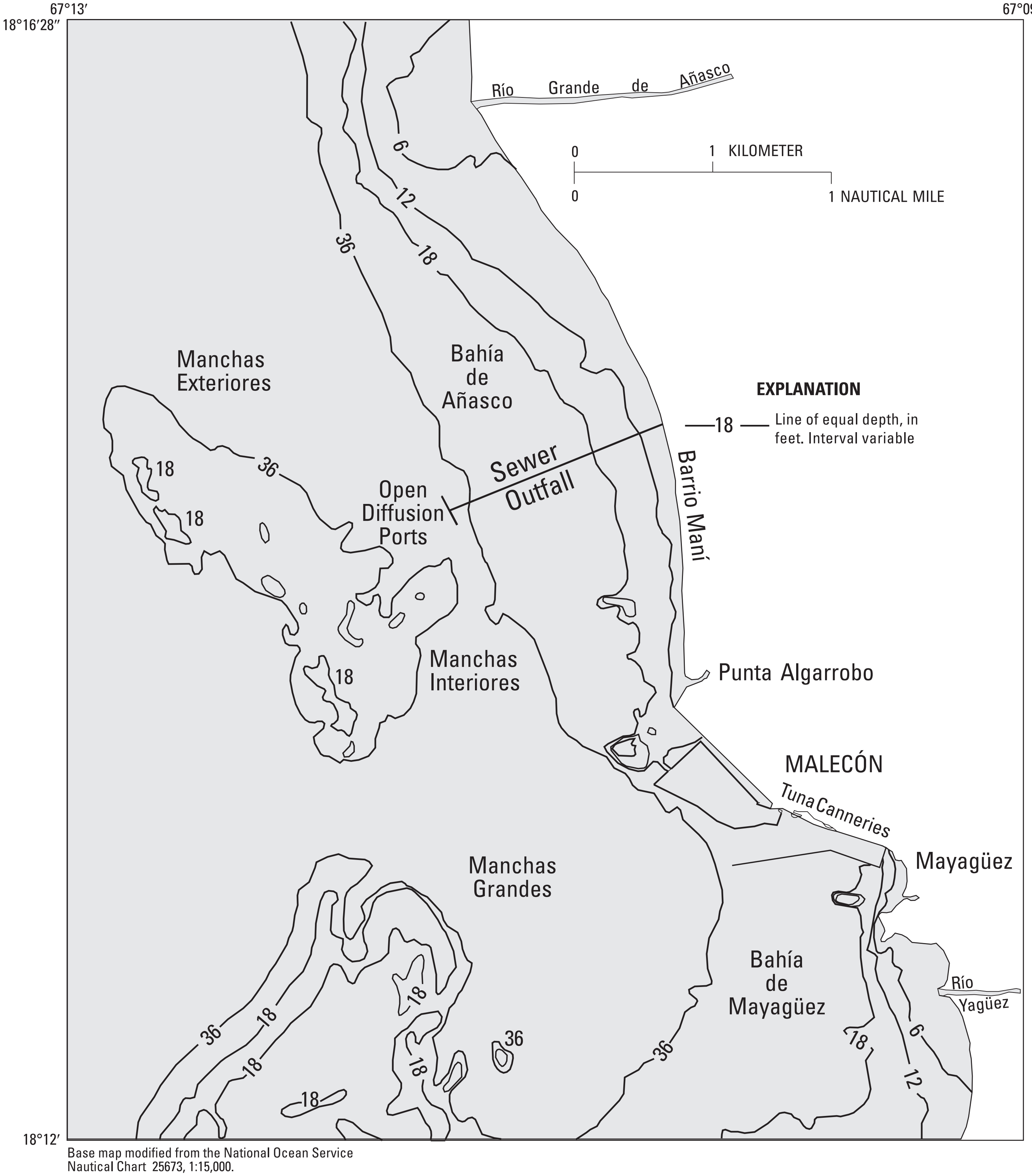


Figure 5. Site localities and nearshore bathymetry in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico.

Biological Resources

Sea level around Puerto Rico has risen more than 80 m during the last 16,000 years. A wave-cut terrace lies submerged under 80 m of water off the western flank of the Manchas Exteriores (Macintyre, 1972). Relict assemblages of the foraminifer *Amphistegina* collected from the submerged terrace are similar to those found at similar depths on the slopes bounding Manchas Grandes and Escollo Negro (Seiglie, 1968). The abundance of living *Amphistegina* assemblages sampled at the three reefs was lowest at Manchas Exteriores, most likely as a result of the influence of muds discharged from the Bahía de Añasco. Seiglie (1971a) also documented shifts in the microfauna resulting from intense loading of organic matter near the docks in the Bahía de Mayagüez.

Previous observations of submerged reefs in the Bahía de Añasco documented a marked shore-normal gradient of coral health. Coral communities that are healthy and diverse offshore in the Manchas Interiores are found to be increasingly degraded with proximity to Punta Algorrobo, a fringing reef in the northern part of the Bahía de Mayagüez (García, 1990b). The Punta Algorrobo reefs are colonized by algae and encrusting marine fauna other than live corals, but are still important fish habitats. In terms of reef fish community structure, the fundamental problem of scleractinian coral degradation is that the physical habitat will not grow to maintain its structure against the continuous marine erosion process. Thereby, a reduction of habitat space for fish populations may result. In addition, important alterations in fish community structure can result as coral polyps, consumed as the main diet of many species, disappear.

The reefs of the Bahía de Añasco represent an invaluable habitat for reef fishes and invertebrates, some of which are commercially important. The combination of different habitats present in the Bahía de Añasco, such as coral reefs, sea grass beds, mud bottoms, river mouths, and the estuarine-open water spectrum of water quality, promote high heterogeneity, and, thereby, high diversity of species. The Bahía de Añasco is, therefore, a highly complex and heterogeneous environment which serves as an important reservoir of marine life.

Previous Surveys

Benthic surveys carried out at the turn of the century found pauperate benthic communities in the southern part of the Bahía de Mayagüez, whereas healthy and diverse communities were found in the northern part of the bay (Evermann, 1900). This may represent a natural background gradient resulting from the high concentrations of nickel, cobalt, copper and chromium drained from the Río Yagüez and the Río Guanajibo drainage basins, as mentioned previously. Circulation and dilution in the Bahía de Mayagüez is poor. By 1963, discharge of sewage and organic matter into the Río Yagüez and the Bahía de Mayagüez by public and private entities resulted in pathogen-rich, oxygen-depleted conditions in the eastern and northern parts of the Bahía de Mayagüez (PRASA, 1963). The organic contamination in the Bahía de Mayagüez resulted in shifts in the community structure of foraminifers living in the sediments (Seiglie, 1971a), and the near extermination of corals in the Punta Algarrobo reef, in the northern part of the Bahía de Mayagüez (Morelock and others, 1983). Reconnaissance surveys of the Bahía de Añasco as an alternative disposal site were completed in June 1971 (Department of Public Works, 1971). High current velocities favoring good mixing and rapid dispersion were documented, as well as the occurrence of upwelling of deep ocean waters onto the shallow insular shelf. The Bahía de Añasco was investigated further by the Puerto Rico Department of Public Works (1974) with similar results. Rotary currents with dominant northwest transport at the site were confirmed by Guzmán and Associates (1974). Sediments and biota in the Bahía de Añasco and the Manchas Interiores-Manchas Exteriores coral reef complex were found to be under the influence of sediments discharged by west-coast rivers (Goenaga and Cintrón, 1979; Morelock and others, 1983), though the role of anthropogenic stressors could not be separated from the stress of natural deltaic progradation.

Previous to the start of MRWTP operations in 1987, baseline studies characterizing the community of fishes in the vicinity of the plant's discharge were performed (Center for Energy and Environment Research, 1985). After the plant began operations, another survey of the icthyofauna in the Manchas Interiores was prepared as baseline to the potential impact of the proposed Cogentrix power plant (García, 1990b). The data presented in these previous studies are only descriptive of the taxonomic composition and abundance of fishes at a given point in space and time. These stations were revisited during this study to see if they have been adversely affected by the outfall. These and other studies are presented in the application materials submitted by PRASA with their 301(h) application for the MRWTP (PRASA, 1979; Metcalf & Eddy, Inc., 1985c, 1987b). The application materials present detailed data and discussion of the area to be served, the water quality, oceanographic conditions, and biological communities, in addition to the engineering studies describing the plant and ocean outfall design. The outfall design includes the initial and final mixing zone dimensions. Mixing of the effluent with the receiving waters within the zone of initial dilution should be such that all applicable water-quality standards are met by the time the mixed water parcels reach the boundary of the final mixing zone.

SAMPLING PROGRAM, METHODS, AND RESULTS

The sampling program was designed to provide the data needed to describe natural variations in the biota, sediments, and water quality in the Bahía de Añasco, and to determine if a causal relationship exists between the outfall and adverse impacts on the surrounding biological community.

The first step to understanding the processes active in the bay was to map the ocean floor. The mapping involved sub-bottom profiling using high resolution single-channel seismic reflection equipment run simultaneously with high-frequency sidescan-sonar data acquisition. Using the image, stations were then selected for biological surveys (table 1) and sediment sampling (table 2). Water-quality was measured for samples collected from the influent and effluent at the MRWTP for three river samples, and for samples collected in the receiving waters at varying distances from the outfall (table 3).

Table 1. Biological census and coring site locations, dates, and water depths

[Puerto Rico Coordinate system (equivalent to the local implementation of the North American Datum of 1927). Ten coral cores, C1 through C10, were recovered from stations MO-1 and MO-3. Abbreviations: m, meters; --, no remarks]

Station	Date of sampling	Latitude			Longitude			Water depth (m)	Remarks
		Degrees	Minutes	Seconds	Degrees	Minutes	Seconds		
Macrobenthic Infauna Census									
B1	12-15-90	18	15	24.6	67	12	0.0	15	--
B2	12-15-90	18	14	51.6	67	12	1.5	15	--
B3	12-15-90	18	14	49.9	67	11	45.9	12	--
B4	12-15-90	18	14	35.1	67	11	26.1	11	Inside of initial mixing zone
B5	12-15-90	18	14	42.2	67	10	59.9	6	--
B6	12-15-90	18	14	17.9	67	11	6.1	8	--
B7	12-15-90	18	13	35.1	67	11	37.0	20	Bahía de Mayagüez
B8	12-15-90	18	13	10.7	67	11	6.8	17	Bahía de Mayagüez
Coral and Fish Census									
MSG-1	12-13-90	18	14	39.3	67	12	32.5	9	1,970 m from outfall
MSG-2	12-14-90	18	14	13.0	67	12	3.3	8	1,290 m from outfall
MO-5	12-18-90	18	14	18.0	67	11	28.2	8	350 m from outfall
MO-4	12-17-90	18	9	55.0	67	15	39.0	9	El Negro reef
Coral cores									
MO-1	12-14-90	18	14	11.9	67	11	9.0	5	610 m from outfall (C1-C6)
MO-3	12-17-90	18	9	12.0	67	14	50.0	9	El Negro reef (C7-C10)

Table 2. Sediment-sample locations, dates, and water depths

[Puerto Rico Coordinate system (Equivalent to the local implementation of the North American Datum of 1927). Abbreviations: m, meters; --, no depth measurement or no remarks]

Station	Date of sampling	Latitude			Longitude			Water depth (m)	Remarks
		Degrees	Minutes	Seconds	Degrees	Minutes	Seconds		
Surface Sediments									
GS1	12-15-90	18	15	29.1	67	11	55.7	--	--
GS2	12-15-90	18	15	33.2	67	11	48.5	8	--
GS3	12-15-90	18	15	11.3	67	12	22.4	27	--
GS4	12-15-90	18	15	17.4	67	12	10.9	30	--
GS5	12-15-90	18	15	2.0	67	12	39.6	28	--
GS6	12-15-90	18	15	5.2	67	11	34.0	--	--
GS7	12-15-90	18	15	1.1	67	11	47.3	12	--
GS8	12-15-90	18	14	52.2	67	12	3.1	15	--
GS9	12-15-90	18	14	45.8	67	12	21.9	9	Hard bottom
GS10	12-15-90	18	14	50.1	67	11	21.9	--	--
GS11	12-15-90	18	14	34.9	67	11	33.8	11	--
GS12	12-15-90	18	14	37.9	67	11	45.9	7	--
GS13	12-15-90	18	14	34.1	67	11	55.7	14	--
GS14	12-15-90	18	14	0.4	67	12	3.3	10	Hard bottom
GS15	12-15-90	18	14	25.2	67	11	5.3	8	--
GS16	12-15-90	18	14	22.1	67	11	11.0	9	--
GS17	12-15-90	18	14	12.5	67	11	27.0	7	Hard bottom
GS18	12-16-90	18	14	2.8	67	10	58.5	9	--
GS19	12-16-90	18	13	53.0	67	11	18.7	15	--
GS20	12-16-90	18	13	43.0	67	11	27.0	16	--
GS21	12-16-90	18	14	1.2	67	11	26.1	14	--
GS22	12-16-90	18	13	32.5	67	11	34.7	20	--
GS23	12-16-90	18	13	26.7	67	11	40.1	27	--
GS24	12-16-90	18	13	37.0	67	12	1.1	34	--
GS25	12-16-90	18	13	51.1	67	12	15.4	48	--
GS26	12-16-90	18	14	2.0	67	12	18.8	49	--
GS27	12-16-90	18	14	1.8	67	11	55.0	15	--
GS28	12-16-90	18	13	52.9	67	11	42.6	9	--
GS29	12-16-90	18	14	20.1	67	12	10.3	21	--
GS30	12-16-90	18	14	20.4	67	12	16.8	20	--
GS31	12-16-90	18	14	14.7	67	12	19.8	38	--
GS32	12-16-90	18	14	49.6	67	12	58.8	50	--
GS33	12-16-90	18	14	38.6	67	12	4.7	12	--
GS34	12-13-90	18	14	12.0	67	11	25.8	7	--
GS35	12-13-90	18	14	11.9	67	11	9.0	5	--
GS36	12-17-90	18	9	12.0	67	14	50.0	9	--
GS37	12-17-90	18	9	55.0	67	15	39.0	9	--
GS38	01-26-91	18	14	5.5	67	11	54.6	15	--
Sediment cores									--
VCO	12-14-90	18	14	25.2	67	11	16.8	6	160 m from outfall
VCC	01-26-91	18	13	53.4	67	11	44.2	10	Coral channel sands
VCA	01-26-91	18	15	34.8	67	11	38.2	3	Río Grande de Añasco delta
VCY	01-27-91	18	12	34.6	67	9	50.6	5	Río Yagüez delta

Table 3. Water-quality sampling locations, dates, water depths, and distance from outfall

[Puerto Rico Coordinate system (Equivalent to the local implementation of the North American Datum of 1927). Locations for onshore sites were determined from the topographic quadrangle. Remarks indicate the intended sampling site: IMZ, initial mixing zone; BND, boundary of the initial mixing zone; FMZ, at the boundary of the final mixing zone; FAR, beyond the final mixing zone where effect from the outfall may be reasonably expected; and CTL, the control stations off Rincón. Abbreviations: Repl, replicate; NA, not applicable; --, no remarks]

Station	Date of sampling	Latitude			Longitude			Water depth (m)	Remarks	Distance to outfall (m)
		Degrees	Minutes	Seconds	Degrees	Minutes	Seconds			
EFFL	01-29-91	18	15	5.7	67	9	22.5	NA	--	NA
INFL	01-29-91	18	15	5.7	67	9	22.5	NA	--	NA
QW-An1	01-29-91	18	15	58.7	67	8	3.7	NA	--	NA
QW-An1 (Repl)	01-29-91	18	15	58.7	67	8	3.7	NA	--	NA
QW-An2	01-31-91	18	16	28.6	67	9	42.7	NA	--	NA
QW-Ya1	01-28-91	18	12	30.4	67	8	43.8	NA	--	NA
QW-1	01-29-91	18	14	11.7	67	11	11.8	11	FAR	570
QW-2	01-29-91	18	14	20.7	67	11	17.8	12	FMZ	240
QW-3	01-30-91	18	14	27.4	67	11	21.5	11	BND	10
QW-4	01-30-91	18	14	27.8	67	11	21.8	11	IMZ	0
QW-5	01-30-91	18	14	34.4	67	11	25.4	10	IMZ	0
QW-5 (Repl)	01-30-91	18	14	34.4	67	11	25.4	10	IMZ	0
QW-6	01-30-91	18	14	34.9	67	11	25.7	10	BND	10
QW-7	01-29-91	18	14	45.0	67	11	32.9	11	FMZ	390
QW-8	01-29-91	18	14	55.4	67	11	42.2	11	FAR	800
QW-9	01-28-91	18	18	35.1	67	14	48.9	14	CTL	9,500
QW-10	01-28-91	18	19	37.4	67	15	19.5	10	CTL	11,500

Habitats in the Bahía de Añasco

Despite shallow depths in the Bahía de Añasco, high turbidity makes mapping of the sea floor from the surface an unreasonable proposition. A detailed and contemporary map of the sea floor was needed to describe the spatial distribution of bottom habitats in the bay and to develop a representative sampling program. High-frequency sidescan sonar was selected as the geophysical technique most appropriate to the level of detail desired for the present study, and for use in comparisons by future monitoring studies. The system produces an image of backscattered energy from the ocean floor. Fine-grained sediments (silts and clays), the habitat for macrobenthic infaunal communities, return only minimal energy back to the sonar transducer, resulting in light areas (less ink placed on a white background) in the sidescan-sonar image. Coarse-grained sediments (sands and gravel), rocky bottoms, and coral communities, return more energy, and so appear as darker areas in the image. Gases discharging from the organic-rich, fine-grained sediments, also reflect energy, and appear as dark blotches in some areas in the interior of the bay. The imagery was used to map the spatial distribution of soft-bottom habitats that support communities of infauna and hard-bottom habitats capable of supporting coral communities, thereby providing a basis for subsequent sampling programs. In addition, the image was inspected for evidence of accumulation of sediment deposited from the outfall itself. Fine-grained sediments settled out around the outfall should be detectable as a shadow if they settle in an area previously covered by coarse-grained deposits. High-resolution seismic-reflection profiles (3.5 kHz and UNIBOOM) were also collected along with the sidescan-sonar traverses, and provided data of the thickness of accumulated sediments and the expression of the underlying substrate.

Approximately 10 km^2 of the Bahía de Añasco, containing the diffuser array, and adjacent areas, potentially subject to its influence, were successfully mapped. The survey lines were oriented with an azimuth of 330° N, parallel to the coastline. The outfall trench, the bay floor, and the coral reefs are prominent features of the sidescan-sonar mosaic.

The bottom was mapped by traversing the study area with a sonar fish towed behind the research vessel. A detailed description of the theory, instrumentation, and processing of the sidescan-sonar data is given by Danforth and others (1991). Precise positioning was indispensable in the assembly of the images generated along each track.

Marine navigation during sidescan-sonar imaging as well as other phases of the field work depended upon range-range navigation using the MINIRANGER Falcon microwave transponder system. The master unit on board the ship would interrogate the two shore-based transponders once every ten seconds and then update the position. Navigation fixes were printed on paper and recorded digitally. The error associated with the ship's position is estimated to be not greater than 5 m. Because the sonar fish was not navigated independently, the total possible error associated with the mosaic was the sum of 5 m from the MINIRANGER and the 10 to 20 m length of the cable towing the fish.

The mosaic was constructed by piecing together the series of parallel track lines. The first mock-up of the sidescan-sonar image was completed on December 13, two days after recording the last sonar data. The image was used immediately as a base map (fig. 6) (Schwab and others, 1991). Sampling of bottom sediments for the ground truthing and for macrobenthic infauna was conducted with a Shipek grab sampler on December 15-16, 1990.

Biota

The diversity and abundance of macrobenthic infauna, fish, and corals were measured. Where possible, surveys of the biota were conducted at the locations of previously studied stations. The locations for the survey stations are presented in figures 7 and 2.

The presence or absence of a balanced indigenous population living in the upper layers of the sediment column can be used as an indicator of pollution stress. The EPA (1984) notes that certain opportunistic species are more resistant to pollution than others, and as a result are expected to exist in higher numbers in polluted sediment than in unpolluted sediment. A decrease in diversity is expected to accompany the proliferation in numbers of the more pollution-tolerant species. The macrobenthic infauna populations at stations B1 through B6, and B8, were measured in January and May of 1985 (Metcalf and Eddy, 1987a). This study represents the third visit to these stations.

Measurements of community structure included identification of individuals to the lowest taxa and calculations of species diversity for macrobenthic infauna, sessile benthos, and fish. In addition, indices of species richness, evenness, and dominance, were calculated for the macrobenthic infauna.

The Shannon-Weaver (or Shannon-Weiner) diversity index (H') (Shannon and Weaver, 1949) measures the degree of uncertainty of predicting the correct species of an individual picked at random from a community. The index can be written as

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

where

s = total number of species, and

$p_i = \dfrac{n_i}{N}$ the proportion of the number of individuals of a given species (n_i) to the total number of individuals (N).

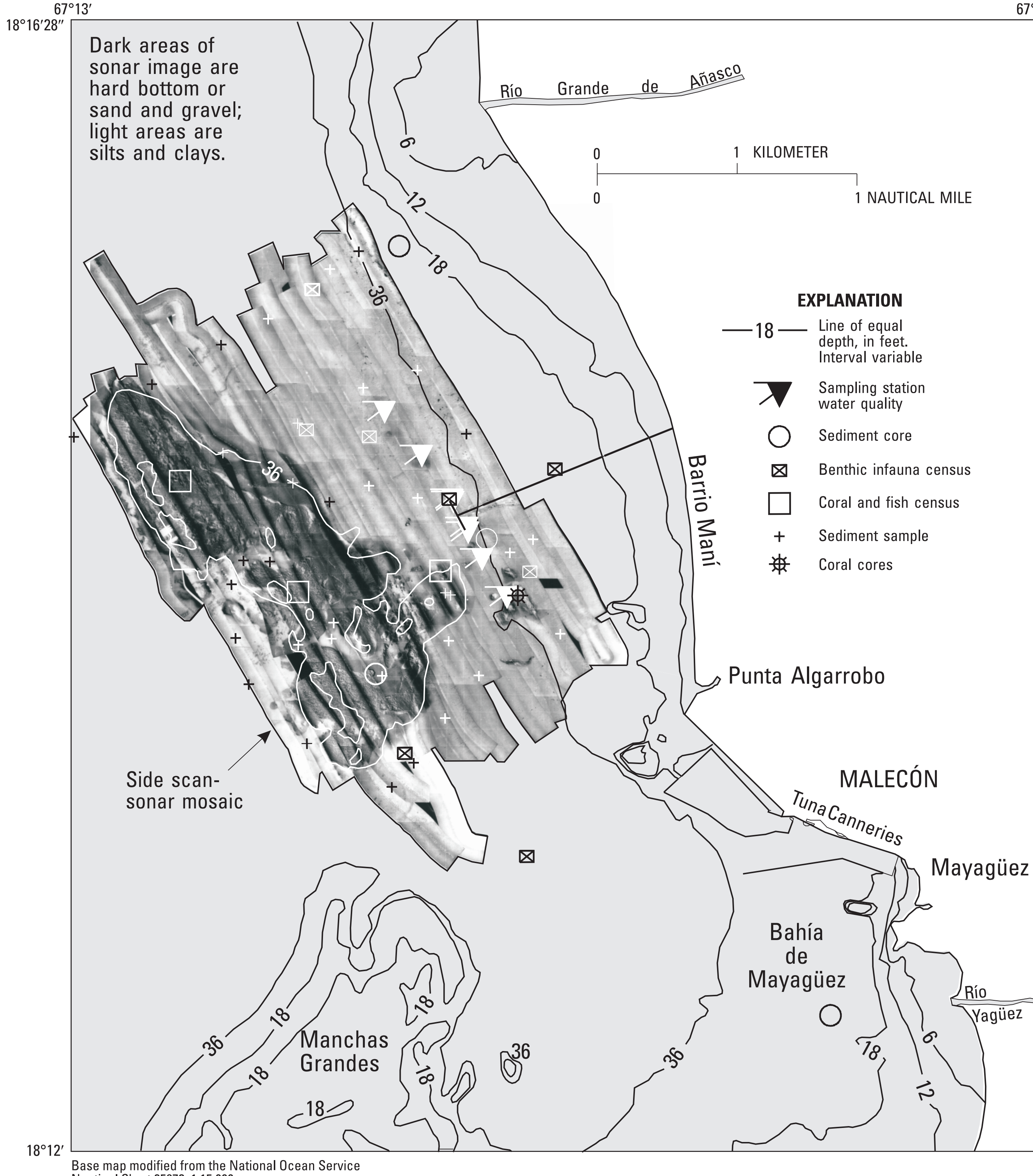


Figure 6. Locations of sampling stations, superimposed on a sidescan-sonar mosaic, Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Additional sampling was completed north of the study area at water-quality sites QW-9 and QW-10, and southwest of the study area at biological sites MO-3 and MO-4, and at sediment sites GS-36 and GS-37 (see figure 2).

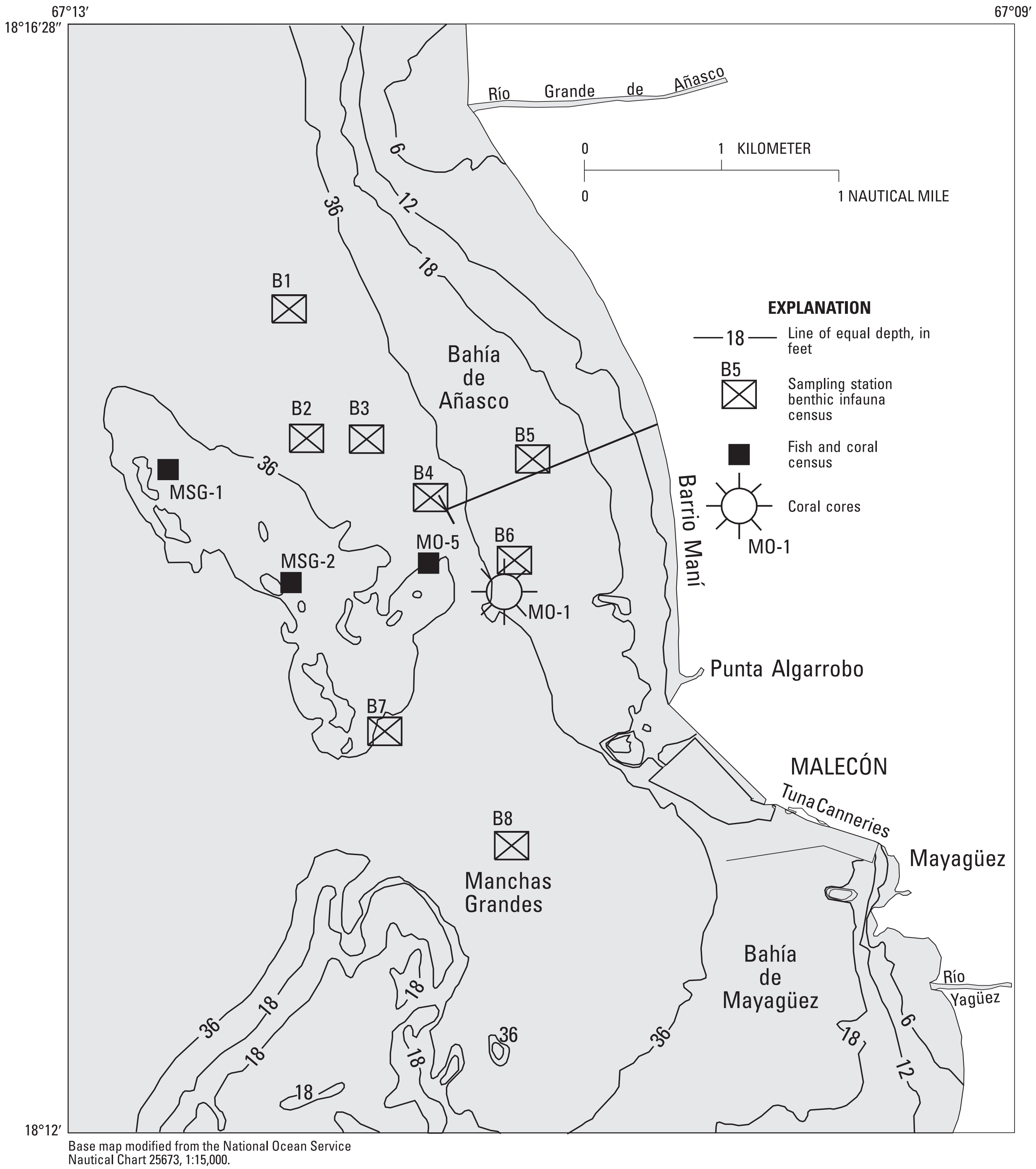


Figure 7. Sampling sites for macrobenthic infauna, coral and fish census, for and coral coring the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Additional sites for fish and coral census and coral coring are located near Escollo Negro (fig. 2).

The Shannon-Weaver diversity index was selected as the most appropriate measure of diversity, because of its independence from sample size (Bowman and others, 1970), and because its proportionality approach reflects community structure (McErlean and others, 1973; Kimmel, 1978). The index varies from a value of 0 for communities with only a single species to high values for communities having many species, each with similar numbers of individuals.

Note that the diversity index will change with the base of the logarithm used. All diversity index values in this report were calculated using natural logarithms. Results of macrobenthic infauna are sometimes reported using base 2 logarithms ($\log_2$), whereas diversity of sessile bethos is sometimes reported using common logarithms ($\log_{10}$). Where this was found to be the case, the values from previous studies were converted to equivalent diversity indices using natural logarithms. The linear conversion factors are included in the preface of this report.

Margalef's index of species richness (SR) is an indicator of the number of species present. The calculated SR of a collection increases monotonically as the total number of individuals (N) examined increases. A species-area curve can be constructed by plotting SR, or species density as it is sometimes referred to, versus number of individuals. The curve increases rapidly at first and eventually levels off once the majority of the most common species present in the area have been included in the sampled population. The curve is commonly used to develop an appropriate sampling program that will ensure an adequate level of characterization for the community of interest. SR is calculated as

$$SR = (N-1)/(\ln(S)),$$

where

N = total number of individuals, and

S = total number of species.

The species evenness (J'), or equitability, is a measure of the homogeneity of the community. It is the ratio of the measured diversity (H'), to the theoretical maximum level of diversity for a community, $\ln(S)$. The maximum diversity is attained when all of the individuals are equally divided among all of the species. J' is calculated as

$$J' = \frac{H'}{\ln(S)},$$

where

H' = Shannon-Weaver diversity index calculated using natural logarithms, and

S = total number of species.

Simpson's dominance index (SI'), varies inversely with species diversity. It is sensitive to the abundance of one or two of the most common species and can be regarded as a measure of "dominance concentration" (Ourso, 1997). If contaminants from the outfall effluent deposited in the sampling area resulted in an increase of the dominance of a few pollutant-tolerant species, this index may be expected to increase. (SI') is calculated as

$$SI' = \sum_{i=1}^{S} p_i^2,$$

where

S = total number of species, and

$p_i = \frac{n_i}{N}$ the proportion of the number of individuals of a given species (n_i) to the total number of individuals (N).

If the outfall is having a negative impact on the biota of the Bahía de Añasco, it should be reflected in shifts with time in some or all of these indices for stations closest to the outfall. Therefore, statistical analysis of the macrobenthic infauna observed at stations B1 to B8 and the census data collected for sessile benthos observed in December 1990 at stations MSG-1, MSG-2, MO-5, and MO-4 was carried out.

Diversity measured for infaunal communities at stations B1 to B8, collected in December 1990, were compared between stations to determine if they were significantly different. Additional testing was completed to compare diversity measured at stations B1 to B6 and B8 in December 1990 with the diversity measured at the same stations in January 1985 (station B7 was not sampled in 1985).

The null hypothesis that the diversities measured for two populations are equal was evaluated using a t-test (Hutchinson, 1970; as quoted in Zar, 1974).

$$t = \frac{H'_1 - H'_2}{s_{H'_1 - H'_2}},$$

where H' is the diversity described above and

$$s_{H'_1 - H'_2} = \sqrt{s_{H'_1}^2 + s_{H'_2}^2}.$$

The variance of H' may be approximated by

$$s_{H'}^2 = \frac{\sum_{i=1}^{S} p_i(\ln p_i)^2 - \left(\sum_{i=1}^{S} p_i \ln p_i\right)^2}{100}.$$

The degrees of freedom (v) associated with the preceding t are approximated by

$$v = \frac{(s_{H'_1}^2 + s_{H'_2}^2)^2}{\frac{(s_{H'_1}^2)^2}{n_1} + \frac{(s_{H'_2}^2)^2}{n_2}}.$$

Since diversity can be equal for two communities composed of completely different taxa, the percentage similarity (PS) (Bray and Curtis, 1957; as quoted in Gauch, 1982) was calculated to compare community compositions observed at stations B1 to B8 in December 1990. The PS between samples j and k is

$$PS_{jk} = \frac{200 \sum_{i=1}^{S} min(n_{ij}, n_{ik})}{\sum_{i=1}^{S} (n_{ij} + n_{ik})},$$

where S is the total number of species in common, *min* is the minimum of the two values, and n_{ij} and n_{ik} are the abundances of species *i* in samples *j* and *k,* respectively. To arrive at a distance measure, percentage dissimilarity, for comparing sample pairs, the similarity has to be subtracted from the similarity among replicate samples, the *internal association*. Because overestimation of the internal association is less problematic than underestimation (Gauch, 1982), the value of 100 is often suitable if one cannot supply an empirical estimate of the replicate. Therefore, dissimilarity values used to place sampling stations on a common ordination axis presented later were calculated as 100 - PS. Stations with dissimilar taxa were identified and used as poles for showing community structure on both one-dimensional and two-dimensional plots using polar ordination techniques (Bray and Curtis, 1957). Finally, values of diversity and percent opportunistic species were plotted against distance from shore and distance from the outfall to ascertain if community structure varied along an environmental gradient.

Sessile benthos are less susceptible to transient or seasonal variations than populations of macrobenthic infauna or fishes. The analyses on the sessile benthos data consisted of one-way analysis of variance (ANOVA) and a Duncan's Multiple Range Test (MRT), to document significant changes in community structure. Sessile benthos at stations MSG-1 and MSG-2 were surveyed in January and May of 1985 (PRASA, 1985). Stations close to the originally identified coordinates for the 1985 stations were revisited during this study. The censuses of the sessile benthos for stations MSG-1, MSG-2, for 1985 and 1990, were subjected to a Duncan's Multiple Range Test to determine if significant changes in benthic populations had occurred in the interim.

Macrobenthic Infauna

Five replicate samples were collected at each of the eight stations B1 through B8. Samples were collected on December 15, 1990. A total of 0.2 square meter (m^2) was sampled using a Shipeck sampler at each station (five replicate sites of 0.04 m^2 at each station). Upon recovery, the samples were anesthetized with 35 percent magnesium chloride and stained with rose bengal dye. Upon reaching shore, the samples were placed in a 10 percent formaldehyde buffer to preserve the specimens before these were transferred to 70 percent alcohol, 48 hours later. Specimens that were retained on a 0.5 millimeter (mm) sieve were then identified to the lowest taxonomic species.

Coral and Fish Surveys

Coral and fish communities were surveyed at four stations from December 13 through December 18, 1990. The survey stations are located in figures 2 and 7. Of the four stations selected for diversity studies of corals and fish, two stations were located as close as possible to stations MSG-1 and MSG-2, reported in previous studies (Metcalf & Eddy, Inc., 1987). Two new stations were established: MO-5, identified in the sidescan-sonar image as being the closest reef community to the outfall; and MO-4, a control site in the Escollo Negro, presumably outside of the area influenced by pollutants discharged into the Bahía de Mayagüez. All transects within and between stations were set at similar depths, to reduce variability associated with depth. The stations MSG-1 and MSG-2 (Metcalf & Eddy, Inc., 1985) were relocated from the positions recorded in the previous study. Rudimentary navigational techniques employed during the original surveys (Metcalf & Eddy, 1985) could have resulted in a positioning error of a few hundred meters. The locations of MSG-1 and MSG-2, listed by PRASA (1985), corresponded to sandy areas; the nearest hard-bottom areas, observed in the sidescan-sonar mosaic, were occupied for the surveys. All present surveys were conducted at similar depths to ensure comparability.

Corals are an important natural resource of limited geographic distribution. The distribution of soft and hard corals is determined by the type of substrate available, the light levels, wave energy, suspended and settleable sediments, and physical and chemical characteristics of the water column. Fish are usually abundant in reef areas, because of the diverse habitats and food supplies.

Station localities were selected on the basis of similar prior studies (Center for Energy and Environment Research, 1985), conducted before the sewage treatment plant was built, with the intention of making before-and-after comparisons of the zoobenthos. Five line transects were surveyed to determine the relative abundance of benthic organisms at stations MSG-1 and MSG-2. Results were compared with observations made in 1985, when four line transects were surveyed at each of these stations. Because of the limited hard-bottom area at station MO-5, near the outfall, only two line transects were surveyed there. At station MO-4 in the Escollo Negro, oscillatory surges, resulting from the arrival of North Atlantic swells, made it difficult for the divers to maintain their position over the transect line. For this reason, observations of only two line transects at this station were possible before darkness set in and the expedition had to return to port.

Line transects were randomly located at each station and a 10-m metric tape stretched taught between two stakes driven into the substrate. The linear cover of sessile benthos under the tape was recorded, while fish were observed by traversing above the tape from end to end at a rate of approximately one meter per minute.

Topographic relief was estimated by hand contouring the substrate along the 10-m line transects with a 15-m plastic-link chain carried to the bottom by the diver. The chain was previously marked at a distance of 10 m. At the end of each 10-m transect line, the total length of the chain in excess of the 10-m mark on the chain was recorded as the substrate-relief index. A flat substrate would have a relief index of 0, and the index would increase with increasing substrate relief.

The main targets for the sessile benthos study were the non-branching zoobenthos (mainly encrusting, massive and platy corals), which were described to the lowest possible taxonomic category. Notes on the phytobenthos were also included, although taxonomic ranking was generally higher (for example, generally up to genus). All erect soft corals (for example, gorgonians or octocorals) whose branches overlapped the metric tape were also counted, but their linear cover was not determined. Therefore, the relative abundance of non-branching zoobenthos is quantified in terms of linear cover per transect, whereas that of branching zoobenthos is quantified in terms of numbers per transect. Photographs of the selected sessile benthos, and the position along the tape of each organism was also noted in case future studies on spatial patterns are deemed necessary. The photographs and positional data are available in the District office. In addition, the mean cover of non-branching zoobenthos was utilized to compare relative colony size of measured portions among stations. Non-cryptic, motile benthos one meter to each side of the transect were also individually counted.

To summarize, the following were quantified: total number of species per station for corals, gorgonians, and other abundant sessile benthos; total linear cover per transect, and mean cover per station, for corals and other benthos; total number of gorgonian colonies passing through the vertical plane that included the survey line; and observable motile benthos. In addition, qualitative observations of the general site characteristics were recorded. These include mean depth, visually conspicuous biota, uncommon biota (outside of the transect lines), bottom topography, and general site appearance.

Quantitative data on fish abundance and species composition were obtained by enumeration of species and individuals along transects covering a surface area of 30 m^2 (3-m wide × 10-m long). Only diurnal, demersal, non-cryptic fish species were quantified. Fish abundance was reported as number of individuals per transect. The data can be normalized to individuals per m^2 by dividing the number of individuals (n) by the total surface area surveyed (30 m^2). All data were recorded underwater on plastic paper. Fish identifications follow Randall's (1983) guidelines.

Coral Cores

Numerous environmental proxies are available within the aragonitic structures built by corals. Four commonly used proxies were examined in this study: annual growth bands, fluorescence, lattice-bound stable isotopes, and trace metals.

The yearly addition of recognizable growth increments in the hermatypic coral *Montastrea annularis* (Dodge and Thomson, 1974) has been used extensively as the basis of interpretation of historical environment experienced during the life-span of a reef. Variations in extension rate provide indications of the relative rate of coral growth, which varies as a function of the environment's favorability for coral health (Goreau and MacFarlane, 1990).

Variations in fluorescence of the yearly growth bands has been related to river discharges. The intensity of fluorescence observed in annual bands deposited by corals sampled off New Guinea (Scoffin and others, 1989) and Australia (Isdale, 1984; Susic and others, 1991) was correlated with large discharges from the nearest rivers. The fluorescence is derived from humic substances contained in the riverine water masses.

Ratios of stable isotopes of carbon and oxygen can be used as proxies of sea temperature, light levels, salinity, and other factors (Fairbanks and Dodge, 1979). Emiliani and others (1978) found that, for deep-dwelling solitary corals lacking zooxanthellae, *Bathypsammia tintinnabulum*, the values for carbon and oxygen isotopes display a strong inverse relation. They found the relationship to be present, but much weaker, for shallow-water corals, *Montastrea annularis*, with active zooxanthellae. Carbon and oxygen isotopes are incorporated into coralline skeletons in disequilibria with the surrounding seawater (Swart, 1983). Ratios of carbon and oxygen isotopes incorporated into coralline skeletons are affected mainly by temperature and salinity ("kinetic effect"), whereas enrichment of carbon isotopes is also affected by a variety of physiologic factors reflecting such environmental effects as insolation, water turbidity, and specific coral stressors ("metabolic effect") (McConnaughey, 1989a). When the kinetic effect is dominant, relative depletions and enrichments of carbon and oxygen isotopes will correlate well (McConnaughey, 1989b). The warm waters resulting from the strong El Niño event of 1982-83 were accurately recorded by isotopic variations in corals growing in the eastern Pacific around the Isla de Caño, Costa Rica (Carriquiry and others, 1988).

The use of coral chemistry is particularly suited to assessing possible outfall effects in that the changes in aqueous metal concentrations are preserved in the lattice. Trace metal substitution for calcium in the aragonitic lattice can provide a proxy of the concentration of that metal in solution during that segment's growth. Concentration of barium and cadmium, which are enriched in deep oceanic waters, increase in coralline skeletons during periods of intense upwelling in the equatorial Pacific (Lea and others, 1989). Taken together, the various coral proxies offer the possibility of preserving a record of the water quality in the vicinity of the coral sampled.

Ten coral cores from heads of *Montastrea annularis* were collected during this study. Six of these were recovered from colonies on a rocky substrate 610 m southeast of the outfall, identified in the sidescan-sonar image (figs. 6, 7). The remaining four were collected in the Escollo Negro to serve as control samples (fig. 2). Corals were cored with a hydraulic rotary drill attached to a 1-m long stainless steel barrel with a tungsten carbide cutter head (inside diameter equal to 5.35 centimeter (cm)). Concrete plugs were placed into the voids left by the core extraction to avoid degradation of the colony by boring organisms and algae.

Processing of coral cores was undertaken at the USGS Coastal Research Division office in St. Petersburg, Florida. All coral samples were cut into slabs 4-mm in thickness using a water-cooled diamond saw dedicated for coral sectioning. Individual slabs were X-rayed to reveal annual banding (Buddemeier and Kinzie, 1976). To reveal possible relations with river discharge, the coral slabs were exposed to UV radiation and the resultant fluorescence observed. X-ray and slab fluorescence images were digitized for subsequent data analysis.

X-radiography and Fluorescence of Coral Cores

Coral cores were processed to document annual accretional rates and to select samples to be analyzed for trace metals and stable isotopes. Slabs were subsequently exposed to X-rays generated at 50 mA and 38 kV for 2 seconds. The distance to the table top from the X-ray source was 122 cm. Four of the ten coral cores (C1, C2, C7, and C9) were selected for additional analysis, because the X-radiographs indicated that the slabs were successfully cut parallel to the growth axis. Samples representing annual accretions for the most recent 7 years were cut from sections of C1 and C2 (near the outfall diffusers) and C7 and C9 (control site), using a high-rpm diamond bit blade in a Dremel Tool. Splits of selected samples were collected to estimate analytical precision. Couplets of adjacent coral mass that accumulated during the same years were also sampled in each of the cores, in order to evaluate intra-year compositional variation within the coral colony. In core C2, in addition to the 7-year annual sampling, seventeen 3-year composite samples were collected along the length of the recovered coral core. The composite samples were extracted and analyzed for trace metals and stable isotopes. Together, they represent approximately 51 years of coral growth (1938-89).

The fluorescence of the coral lattices was observed under ultraviolet (UV) light. The distance from the UV source to the table top was kept constant. A high-resolution CCD with a constant gain was used to record the fluorescence induced by the UV light for each sample.

Analysis of Carbon and Oxygen Isotopes in Annual Coral Bands

Stable isotope analyses for oxygen and carbon of the aragonite coral samples were supervised by Dr. K.C. Lohmann, at the University of Michigan's Department of Geology stable-isotope laboratory. Carbonate samples weighing between 10 micrograms (µg) and 1 milligram (mg) were placed in stainless steel boats. Samples were roasted at 200° C *in vacuo* for one hour to remove volatile contaminants while preventing conversion of the aragonite to calcite. Samples were then placed in individual borosilicate reaction vessels and reacted at 72° ± 2° C with three drops of anhydrous phosphoric acid for 8 minutes in a Finnigan "Kiel" extraction system coupled directly to the inlet of a Finnigan MAT 251 triple-collector isotope-ratio mass spectrometer. Isotopic enrichments are corrected for acid fractionation and oxygen-17 contribution, by calibration to a best fit-regression line defined by two NBS standards, NBS 18 and NBS 19. Data are reported in δ (del) notation, units are ‰ (per mil) relative to Peedee belemnite (PDB), an international standard isotopic composition of carbon dioxide that is prepared from belemnites collected from the Peedee Formation, an Upper Cretaceous unit found in South Carolina, United States.

$$\delta\ (‰) = [(R_{sample}/R_{standard}) - 1] \times 1000;$$

where

$R = C^{13}/C^{12}$ or

$R = O^{18}/O^{16}$.

The precision of the data is monitored through daily analysis of a variety of powdered carbonate standards. At least six standards are reacted and analyzed daily, bracketing the sample suite at the beginning, middle, and end of the day's run. Measured precision is maintained at better than 0.1‰ for both carbon and oxygen isotope compositions.

Replicate samples of the same annual band (assigned a suffix of A/B) and of the coarse (suffix C) fraction of the crushed aragonite from the coral bands were run in order to estimate interannual variability and potential partitioning problems between the coarse and fine fractions. The results, including the average values and relative percent difference for each replicate analysis, are presented in table 4.

Trace Elements in Annual Coral Bands

Trace element analyses were conducted with the assistance of Dr. Glen Shen at the University of Washington's School of Oceanography. Individual subsamples —representing both individual years and three-year composites— were subjected to a series of cleaning procedures prior to digestion and analysis of the sample. In order to measure the low concentrations of metals present in the aragonitic coral lattice, a coprecipitation step was employed to concentrate all the metals into a precipitated bead, which was digested in concentrated acid and analyzed. The complete cleaning and wet-chemistry method is detailed in Shen and Boyle (1988).

Metals were analyzed on a graphite-furnace atomic-absorption spectrometer. Consistency standards were carried through the sample preparation procedure in order to assess the efficiency of the cobalt coprecipitation of these metals.

For all metals except zinc, metal concentrations in the corals were expressed as a ratio of metal concentration to calcium concentration. Calcium concentrations were measured using flame atomic absorption. The absorption/concentration plots for the standard zinc solutions were non-linear. Blanks were subtracted from zinc absorbance data, but these data were not converted to concentrations and are reported in units of absorbance. Zinc was excluded from the discussion sections but the results are presented with the rest of the lattice-bound metals data in appendix C. Cadmium concentrations were adjusted to compensate for the incomplete coprecipitation. Manganese recoveries were very near 100 percent in the concentration range of the samples, hence no correction was applied. Coprecipitation efficiency of other metals was unmeasured and was assumed to be 100 percent. Two coral samples on which Shen has performed multiple analyses (GTS) were similarly carried through the sample preparation and analysis procedures as a test of sampling and analytical accuracy. Extrapolation of the absorbance values measured for Cr and Ni using the assumption of a 100 percent coprecipitation efficiency resulted in negative values for the GTS samples. The negative values for Cr and Ni measured for the GTS sample are therefore listed as non-detects. No negative values were calculated for any of the coral samples from stations MO-1 or MO-3, so no corrections were applied to Cr or Ni. The analyses run for the GTS samples and for other replicate samples are used to estimate variability and precision (table 5).

Means and standard deviations were calculated for the normalized lattice-bound trace metals. The ratios of the abundance of the metals to the abundance of calcium in the corals were compared to that observed in average seawater. The composition used for average seawater is presented in table 6 (Nozaki, 1997). Comparisons were made with average seawater because many of the trace metals are present in the receiving waters at concentrations below the minimum reporting limit for the methods used in this study. The specific analytical methods are presented later in this report, in the water-quality section.

To elucidate processes affecting the incorporation of the trace metals into corals, a principal component analysis of the trace-metal data was carried out.

Sediments

Waters in the Bahía de Añasco are almost always cloudy; sometimes from sediments and debris discharged from the rivers, and other times from fines being resuspended from the bottom by storm swells. The majority of the suspended sediments are clay-sized particles and organic material. The fine particles settle slowly, interacting with the surrounding water for longer periods of time than the silts and sands that quickly settle to the bottom.

Table 4. Variability in stable-isotope ratios measured in different parts of the same annual band, and that measured in fine and coarse fractions of coral core samples of annual growth bands deposited by colonies of *Montastrea annularis* growing at station MO-1 (cores C1 and C2) and station MO-3 (cores C7 and C9)

[The sample ID C7-2A_C indicates that the sample came from core 7 - second (2) sample (1989) - one of two intra-annual samples (A/B) - and that it was a coarse fraction (C). Except for the five coarse samples indicated here, all isotopic analyses of corals were run on the fine fraction. Abbreviations: $\delta^{13}C$, del carbon-13; $\delta^{18}O$, del oxygen-18; ‰, parts per mil; PDB, Peedee belemnite; RPD, relative percent difference]

Sample ID	Year	$\delta^{13}C$	$\delta^{18}O$
		‰ relative to PDB	‰ relative to PDB
Interannual variability			
C1-7A	1984	-4.47	-5.99
C1-7B	1984	-3.63	-4.13
Average		-4.05	-5.06
RPD		20.74	36.76
C7-2A	1989	-2.17	-4.99
C7-2B	1989	-1.52	-4.69
Average		-1.84	-4.84
RPD		35.23	6.20
C7-2A_C	1989	-0.76	-4.61
C7-2B_C	1989	-0.86	-3.53
Average		-0.81	-4.07
RPD		12.35	26.54
C9-7A	1984	-1.81	-6.98
C9-7B	1984	-0.02	-3.01
Average		-0.92	-5.00
RPD		195.63	79.48
Coarse/Fine variability			
C7-1	1990	-0.79	-4.01
C7-1_C	1990	-0.61	-4.5
Average		-0.70	-4.26
RPD		25.71	11.52
C7-2A	1989	-2.17	-4.99
C7-2A_C	1989	-0.76	-4.61
Average		-1.46	-4.80
RPD		96.25	7.92
C7-2B	1989	-1.52	-4.69
C7-2B_C	1989	-0.86	-3.53
Average		-1.19	-4.11
RPD		55.46	28.22
C7-3	1988	-1.06	-4.43
C7-3_C	1988	-0.33	-4.30
Average		-0.70	-4.36
RPD		105.04	2.98
C7-4	1987	-1.62	-5.52
C7-4_C	1987	-2.66	-7.29
Average		-2.14	-6.40
RPD		48.60	27.63

Table 5. Trace metals measured in a laboratory standard (GTS), sample replicates, and intra-annual replicates from samples of annual growth bands deposited by colonies of *Montastrea annularis* growing at station MO-1 (cores C1 and C2) and station MO-3 (cores C7 and C9)

[Cadmium was the only metal corrected for recovery. An assumption of 100 percent coprecipitation efficiency for the other metals resulted in negative values being calculated for Cr/Ca (-14.7 and -34.4) and for Ni/Ca (-0.1 and -0.8) for the GTS laboratory standard. These values are reported as non-detects. Abbreviations: Ca, calcium; Cd, cadmium; Cr, chromium; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; nmol/mol, nanomole per mole; µmol/mol, micromole per mole; ND, not detected; --, not calculated; RPD, relative percent difference]

Core	Year	Cd/Ca nmol/mol	Cr/Ca nmol/mol	Cu/Ca nmol/mol	Fe/Ca nmol/mol	Mn/Ca nmol/mol	Ni/Ca µmol/mol	Pb/Ca nmol/mol
Laboratory replicates								
GTS	--	49.8	ND	324.6	2493.5	222.1	ND	12.9
GTS	--	50.8	ND	558.5	2260.4	185.1	ND	13.5
Average		50.3	--	441.6	2376.9	203.6	--	13.2
RPD		2.0	--	53.0	9.8	18.2	--	4.8
C2	1984	28.6	78.1	78.1	1937.3	424.1	0.6	21.5
C2	1984	15.7	80.4	521.7	476.8	1273.9	1.4	40.6
Average		22.2	79.3	299.9	1207.1	849.0	1.0	31.0
RPD		58.4	2.8	147.9	121.0	100.1	75.1	61.5
C2	1950	24.0	65.2	372.1	169.9	639.1	7.5	19.4
C2	1950	6.2	48.6	197.9	223.8	547.0	0.4	12.4
Average		15.1	56.9	285.0	196.8	593.0	4.0	15.9
RPD		117.9	29.1	61.1	27.4	15.5	179.6	44.0
C9	1989	32.2	11.6	87.4	2186.6	475.9	0.7	9.8
C9	1989	18.4	165.4	699.7	896.0	378.4	1.3	26.1
Average		25.3	88.5	393.6	1541.3	427.1	1.0	18.0
RPD		54.4	173.8	155.6	83.7	22.8	56.4	91.0
Intra-annual replicates								
C7	1989	17.6	88.7	365.8	100.2	417.9	1.1	16.1
C7	1989	15.1	76.5	169.8	125.4	364.4	0.4	7.3
Average		16.4	82.6	267.8	112.8	391.1	0.7	11.7
RPD		15.5	14.8	73.2	22.3	13.7	106.3	74.7
C9	1984	16.2	58.2	210.3	119.3	288.4	0.8	19.2
C9	1984	9.2	69.6	186.8	252.7	295.0	0.8	59.5
Average		12.7	63.9	198.5	186.0	291.7	0.8	39.4
RPD		55.6	17.9	11.9	71.7	2.3	3.0	102.3
C2	1989	2.9	55.7	208.6	188.0	671.1	0.5	11.4
C2	1989	2.6	45.0	268.9	293.3	522.4	0.5	67.4
Average		2.7	50.3	238.7	240.6	596.7	0.5	39.4
RPD		10.2	21.3	25.3	43.7	24.9	17.2	142.1
C1	1984	8.7	50.0	309.4	452.4	608.4	0.5	9.7
C1	1984	0.0	217.9	325.4	1402.1	904.9	1.0	10.6
Average		4.4	133.9	317.4	927.3	756.6	0.7	10.1
RPD		200.0	125.4	5.0	102.4	39.2	70.4	9.0

Table 6. Average abundances of selected elements in seawater

[Concentrations are in nanograms per kilogram (ng/kg)]

Trace metal	Concentration[1]
Ca	412 x 10^6
Cd	70
Cr	212
Cu	150
Fe	30
Mn	20
Ni	480
Pb	2.7

[1] Values from Nozaki (1997).

Clay-sized particles and organic material offer good substrates for the adsorption of metals, pesticides, and other hydrophobic molecules (Horowitz, 1985). By looking at the distribution of certain sediment characteristics throughout the surface sediments of the bay, and at the characteristics of the different sediment layers in the cores, the relative importance of the various sediment sources, and the general circulation patterns that distribute the sediments on the insular shelf, can be discerned.

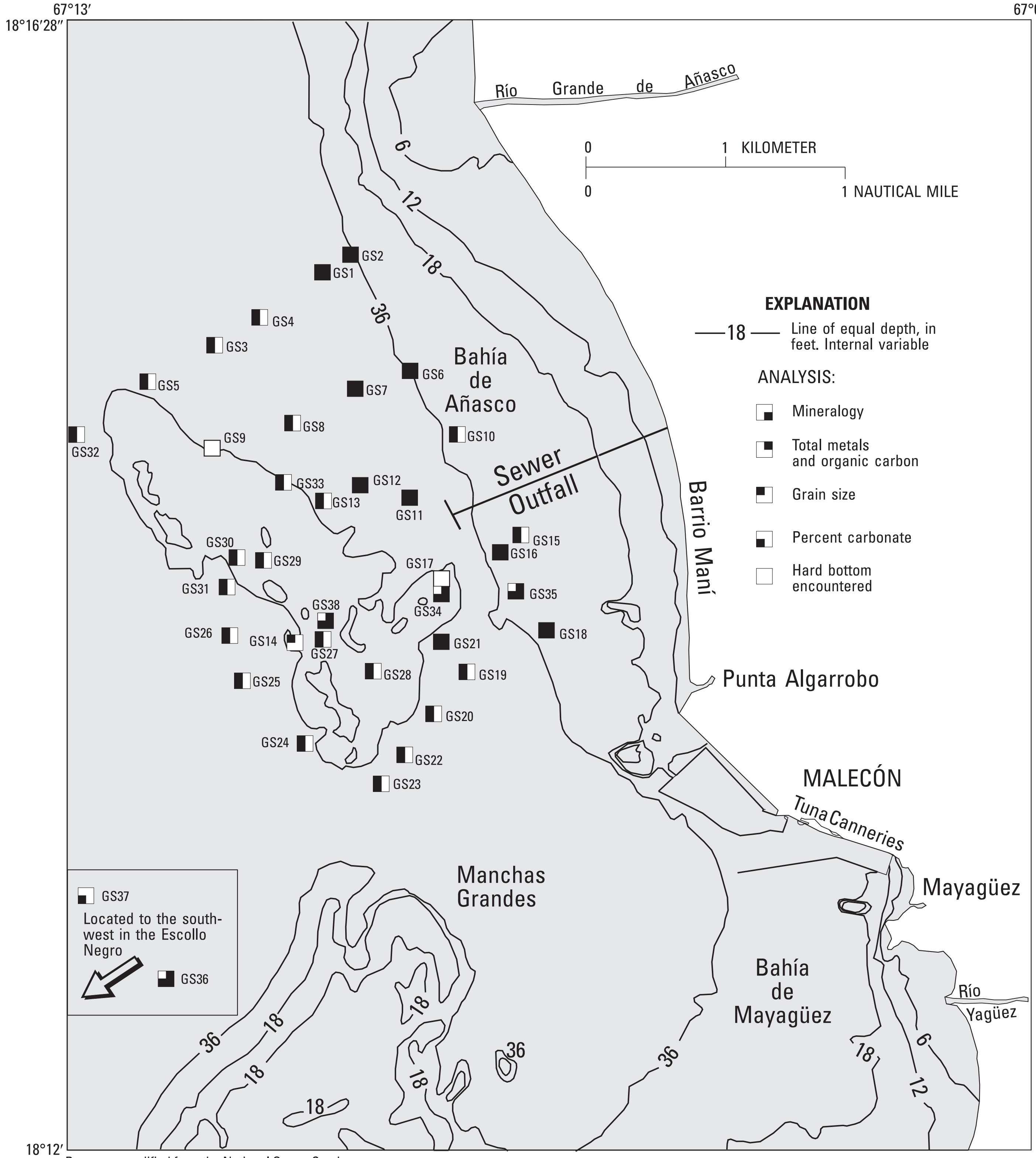
Sediment cores were used to characterize changes in the sediments and contaminants introduced into the Bahía de Añasco over the past decades. The surface sediments around an outfall may contain contaminants discharged by an outfall on an irregular basis. Sediment cores were recovered from the deltas of the Río Grande de Añasco and the Río Yagüez, from a station near the outfall, and from a station in a large sand channel in the Manchas Interiores. The average sedimentation rate since 1964 was estimated by examining downcore variations in the cesium-137 concentrations.

Bottom-Sediment Sampling

During December 15-16, 1990, collection of bottom sediments was attempted at 33 stations (GS1-GS33) using a Shipek grab sampler. The Shipek failed to return a sample from hard-bottom areas after three attempts at two of these stations (GS9 and GS17). Five additional surface samples (GS34 to GS38) were collected by hand during SCUBA-diving operations conducted during other parts of the study. Selected splits were analyzed for detailed grain size (31 sites), percent calcium carbonate (35 sites+3 field replicates), mineralogy (13 sites), trace metal and total organic carbon (13 sites) (fig. 8).

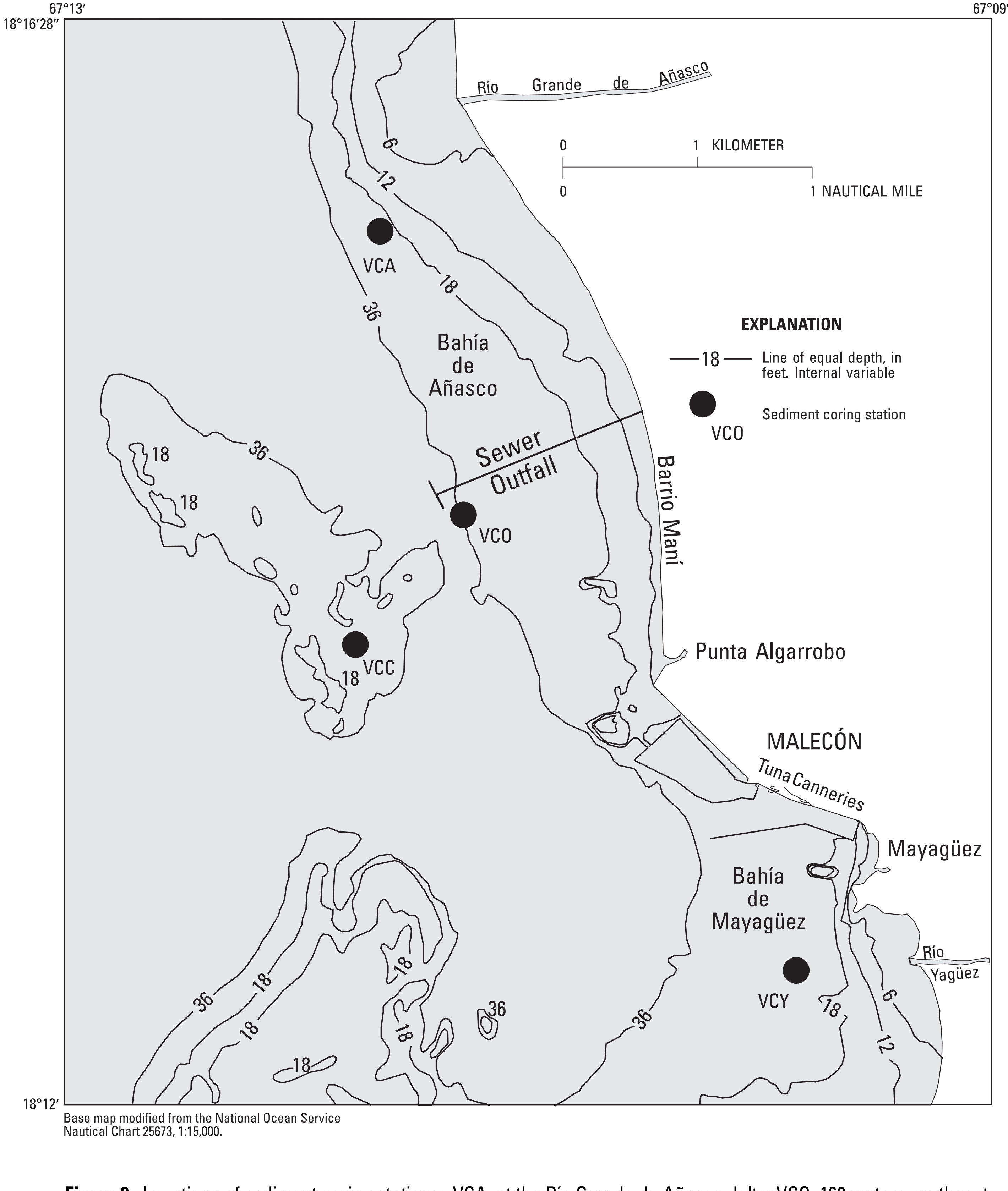
Bottom-Sediment Cores and Sedimentation Rates

Four sediment cores were recovered. A 66-cm core was collected on December 15, 1990, from near the outfall (VCO), whereas a 258-cm core from the Río Grande de Añasco delta (VCA); a 220-cm core from the Río Yagüez delta (VCY); and a 110-cm core from a large sand channel in the Manchas Interiores (VCC) were collected January 26-27, 1991 (fig. 9). A 3-in.-diameter aluminum tube was inserted vertically into the sediments by divers in the soft sediments at stations VCO, VCA, and VCY. A hydraulically operated jack hammer was used to facilitate coring of the coarse carbonate sands at station VCC. Once maximum penetration of the core barrel was attained (the full length of the tube or rejection), the jackhammer was removed. A diver then cut off the upper end of the tube with a tube cutter, inserted a rubber stopper, and secured a vinyl cap with a hose clamp to provide a hermetic seal. The core was then lifted using a block and tackle arrangement between inflated air bags on the surface and a lifting collar clamped onto the core. The bottom end was capped by a diver once the core was lifted clear of the sediment. On board the survey vessel, each core was sectioned into smaller cylinders using a tube cutter. The samples in each cylinder were then extruded onto a clean plastic trough, maintaining the stratigraphic order. The cylindrical samples were then split open using a plastic spatula or teflon blade. The cores were then photographed and described, and subsamples were collected for analysis of texture, mineralogy, total organic carbon, trace metals, and cesium-137.



Base map modified from the National Ocean Service Nautical Chart 25673, 1:15,000.

Figure 8. Locations of 38 bottom-sediment stations with descriptions of laboratory analyses performed on samples collected from the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Sediments were sampled at two additional sites, GS-36 and GS-37, in the Escollo Negro reef complex, approximately 10 kilometers to th e southwest of the study area (fig. 2).



Base map modified from the National Ocean Service Nautical Chart 25673, 1:15,000.

Figure 9. Locations of sediment coring stations: VCA, at the Río Grande de Añasco delta; VCO, 160 meters southeast of the outfall; VCC, in a sand channel in the Manchas Interiores; and VCY, at the Río Yagüez delta, Puerto Rico.

Texture

The sediment texture or grain-size distribution, of sediment samples GS1 through GS33, was analyzed by Larry Poppe at the USGS Sediment Laboratory, in Woods Hole, Massachusetts. Moist samples from the field were wet-sieved through a 62.5-µm sieve, to separate the sand and gravel from silts and clays. Floating material, organic flock, and whole shells were removed from the sand and gravel fraction before processing with a stack of sieves, as described by Folk (1980). The silt and clay fraction was analyzed using a Coulter counter, as described by Poppe and others (1985). The salinity of the interstitial waters of the bottom sediments, needed to adjust the results of the Coulter counter analysis, was assumed to be 25 parts per thousand (ppt). For core samples analyzed for cesium-137, grain size was determined for three size classes, percent sand and gravel, silt, and clay.

Carbonate

Percent carbonate was determined by titration (Carver, 1971) for 40 samples, 35 from bottom samples, and five from core samples (top and bottom of core VCO, and three samples from core VCC). Samples were ground and dried at 110 °C for 24 hours, and placed in a desiccator to cool. Approximately 1-gram (g) samples were carefully weighed to the nearest mg, then dissolved in 50 ml of a standardized hydrochloric (HCl) acid solution (0.5 N) and heated at 90 °C for 20 minutes. If the measured pH of the solution was greater than 2, another 50 ml of HCl was added and the process was repeated. When the pH remained less than 2 after heating, distilled water was added and the solution was back-titrated with a previously standardized NaOH solution (0.25 N) to pH 7, stirring constantly. The results were calculated as follows (assuming that all the carbonate occurs as calcium carbonate):

$$\text{percent } CaCO_3 = 100 \times 0.05 \times [(ml_{HCl} \times N_{HCl}) - (ml_{NaOH} \times N_{NaOH})] / wt_{initial.}$$

Clay Mineralogy

The clay mineralogy of the sediments deposited in the Bahía de Añasco and the Bahía de Mayagüez was determined to better understand the elemental compositions observed in the sediments. A sample with high concentrations of calcium carbonate could consist of calcite, indicating an inorganic precipitate or deposits of calcareous algae, or it could consist of aragonite, a carbonate pseudomorph that is precipitated predominantly by corals. Similarly, a sample containing high concentrations of iron could contain minerals such as goethite, indicating deposition in an oxygen-rich environment, or the sample could contain pyrite, an iron sulphide indicative of reducing conditions. Goethite and glauconite are present in various abundances in the Cabo Rojo carbonate platform (Seiglie, 1971b). Clay minerals are major constituents of the sediments deposited in the Bahía de Añasco and the Bahía de Mayagüez. Clay minerals generally refer to phyllosilicates, such as illite and kaolinite that naturally break down into small-diameter (2 µm or less) particles. However, samples often contain larger-sized clay minerals, such as mica and chlorite, in addition to many “non-clay” minerals, such as quartz, feldspar, amphiboles, and carbonates.

Twenty-three samples, nine from core samples, 13 from bottom-grab samples, and one of suspended sediments filtered from the Río Grande de Añasco, were processed by John Neil at the USGS Laboratory in Sacramento, California. The fine fraction (less than 62-µm diameter) was used almost exclusively, as it contains more of the terrigenous grains that were of primary interest to this study.

The samples were prepared for X-ray diffraction analysis by washing through U.S. Standard No. 230 stainless-steel sieve screen. The silt/clay fractions were dried at 95 °C and were packed into a front-loading, 30 mm × 30 mm plexiglass sample holder. The actual sample volume was 26 mm × 26 mm × 1 mm. A glass slide was used to press the sample into the holder and smooth the sample surface.

Three samples from core VCC, collected from the sand channel in the Manchas Interiores, had a significant amount of coarse and fine carbonates that obscured the peaks presented by the terrigenous fraction. The sample from this core received additional treatments, including digestion by sodium acetate/acetic acid buffer (pH of 5) and digestion by weak and strong hydrochloric acid, to better discern changes in the terrestrial sediments deposited there, and to identify diagenetic processes.

All X-ray diffraction data were collected on a Scintag Pad V Automated Diffraction System that was equipped with scintillation detector and a graphite monochromator. The radius of the goniometer was set at 220 mm, and the sample holder was in the horizontal configuration. The divergent slits were 2 mm and 4 mm, and the receiving slits were 0.3 mm and 0.4 mm. Cu K_{α} radiation ($\lambda = 1.54091$) was produced by a Cu X-ray tube running with an accelerating voltage of 45 kV and a current of 40 mA. The scan rate was 0.5°/min, and the step size was 0.02°. Calibration of the instrument was checked by measuring the principal peak (101) of quartz at 26.652° (2θ). If the position of the principal peak was in error by more than 0.002° (2θ), the goniometer position counter was reset. The product of a sample run was a diffractograph for that sample. The diffractographs were processed using signal-processing software, to provide a list of significant peaks and intensities. Minerals were then identified by comparing the processed data with peak/intensity patterns cataloged for known minerals.

Trace Elements

Fifty-three samples were analyzed for 16 trace elements (Fe, Mn, Al, Ti, Cu, Zn, Cd, Pb, Ni, Co, Cr, As, Ag, Sb, Se, and Hg), total organic matter, and total organic carbon. These included nine samples from core VCO, 13 from core VCA, 11 from core VCY, 6 from core VCC, 13 from selected grab samples, and 1 from a sample backflushed from a filter paper containing suspended sediments from the Río Grande de Añasco. Samples were stored in new ziplock bags and transported to the laboratory of Dr. Art Horowitz, in Doraville, Georgia. Each sample was homogenized by stirring with acid-rinsed glass rod and then sieved through a 2,000-µm plastic screen. The samples were freeze-dried, then ground to less than 100 mesh in a ball mill for subsequent bulk chemical analysis. Chemical analyses were performed by Dr. Horowitz following the procedures of Horowitz and Elrick (1985), and Elrick and Horowitz (1985, 1987). For all chemical elements other than As, Sb, Se, and Hg, 500-mg samples were digested with a combination of hydrofluoric, perchloric, and nitric acids in Teflon beakers, at 200 °C taken to dryness, and the resulting salts solubilized with 50 mL of 2 percent hydrochloric acid. Determinations were done by flame atomic-absorption spectrophotometry (AAS) using mixed-salt standards. As, Sb, and Se determinations used the same digestion procedure, but final solutions were made up in 50 percent HCl. The Se was determined directly in the digestate; As and Sb were determined after additional reduction with Potassium Iodide (KI), and heating. Quantitation of all three was performed by hydride generation AAS. Hg was determined by using a 500-mg aliquot digested with LeFort aqua regia at 100 °C, followed by a cold-vapor AAS quantitation technique. Precision (usually better than ± 10 percent) and bias were monitored by replicate analyses of selected samples and the concomitant digestion and analysis of NBS sediment, and USGS rock standards, and are similar to those reported previously (Elrick and Horowitz, 1985, 1987; Horowitz and Elrick, 1985). Total organic carbon (TOC) was determined, usually in duplicate, on sample aliquots pretreated with 10 percent HCl, using a Leco Carbon Analyzer. Loss on ignition (LOI) was used as a measure of the total organic matter in the samples, and was determined by the ignition of preweighed samples and their subsequent reweighing after 1 hour at 550 °C in a muffle furnace (Fishman and Friedman, 1989). Other organic matter (OOM) was determined by subtracting TOC from LOI.

Multivariate Analysis of Sediment Chemistry

The results of the trace element and organic material analysis were subjected to extended Q-mode factor analysis (Miesch, 1976a, 1976b) to elucidate the provenance of sediments deposited in the study area. A cursory review of the sediment chemistry revealed that the sediments deposited in the Bahía de Mayagüez were elevated in concentrations of nickel, cobalt, and chromium, the origin of which is laterite deposits that weather and wash into the Río Yagüez and the Río

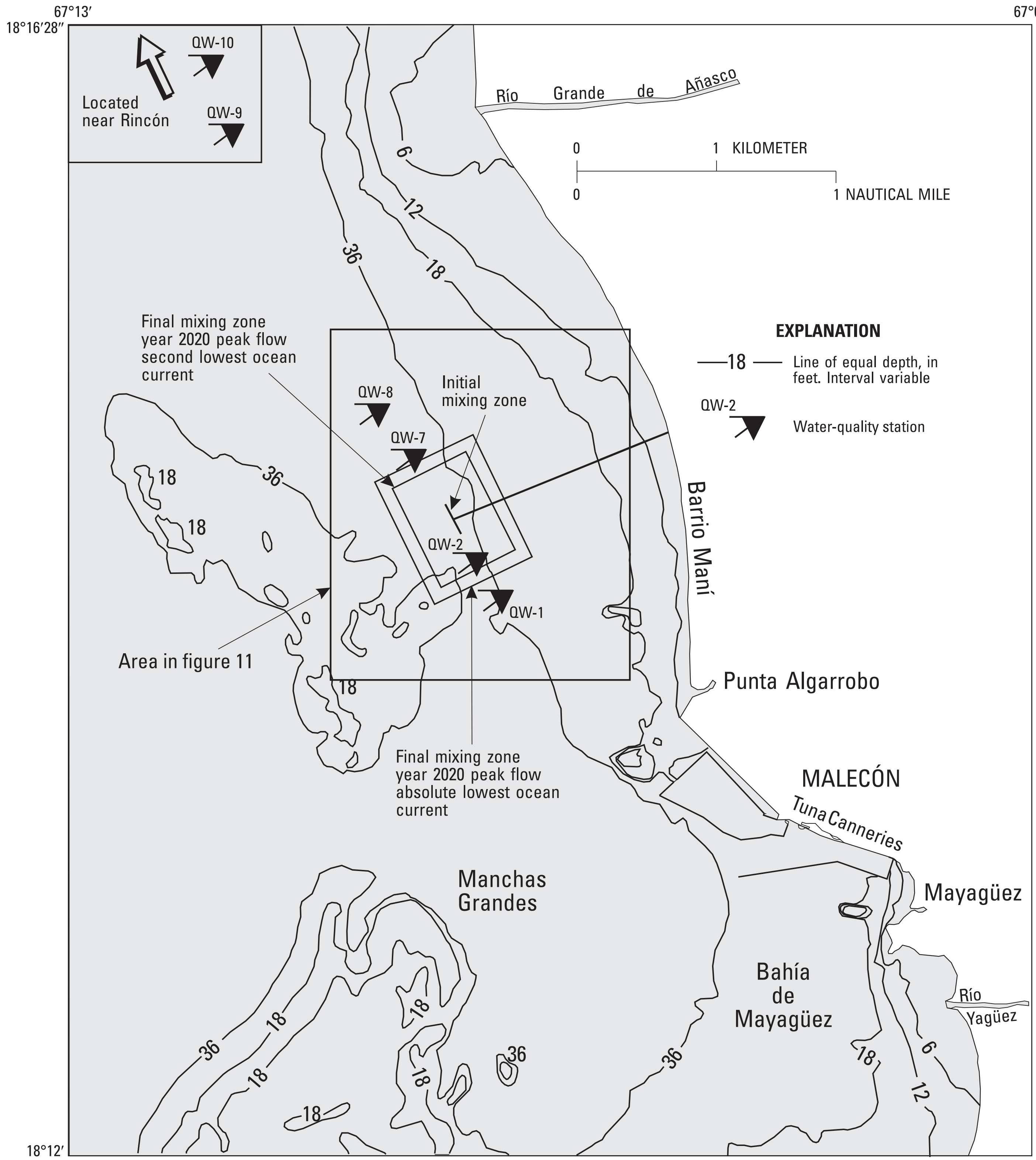
Guanajibo, which transport their sediment loads to the Bahía de Mayagüez. Two outlier samples were eliminated from the dataset, the suspended-sediment sample from the Río Grande de Añasco, and the carbonate sands sampled from the Escollo Negro (GS36). Both of these samples were geochemically distinct and showed up as isolated extreme samples, accounting for a large amount of the variance on their own, but only containing weak correlations with the remainder of the data set. By eliminating them from the database, a more robust mixing model for sediments in the study area could be constructed. The simplified mixing model consists of three endmembers, one typical of sediments deposited in the Río Grande de Añasco delta, one typical of sediments deposited in the Río Yagüez delta, and a third typical of carbonate sediments formed and deposited in the Manchas Interiores-Manchas Exteriores coral reef complex. Loss on ignition was eliminated as a variable as it is the sum of the TOC and OOM. The total weight percent of elemental composition accounted for by the observed variables in the data set varied from approximately 30 percent, for samples consisting predominantly of terrigenous sediments, to less than 10 percent, for those samples consisting mostly of carbonate skeletal material. Major elements missing to obtain an adequate compositional accounting of the terrigenous samples include silica, magnesium, and oxygen, whereas calcium and oxygen would make up most of the missing mass for the carbonate-rich samples. Percent calcium carbonate was determined for a subset of the dataset, but its use as a variable was discarded because some of the core samples were not analyzed for this variable, and it could not be expected to be a variable independent of the OOM. To force a closed solution that would provide a mixing model of the three sediment endmembers, TOC, OOM, and the trace element data, were converted to weight percents and proportioned such that the sum of all observed variables accounted for 100 percent of each sample, as described in Miesch (1976a). The transformed data were entered into the EQMODE and EQCOMP routines of STATPAC (Miesch, 1976b) to determine endmember compositions and mixing proportions of the endmembers for all samples. The vectors describing the endmembers were obliquely rotated in data space such that each of the three endmembers is 100 percent of a given factor, and 0 percent of the other two.

Water Quality

The quantity and quality of water, sediments, nutrients, and contaminants discharged from the Río Grande de Añasco, the Río Yagüez, and the outfall, have the potential to affect the evolution and health of the coral reef communities of the Bahía de Añasco. The water quality from both rivers, the effluent, and the receiving waters, were sampled from January 28 to 31, 1991.

The sampling stations included the influent, effluent, the Río Añasco, the Río Yagüez, two stations in the initial mixing zone (IMZ), two stations at the boundary of the IMZ, two stations at the boundary of the final mixing zone (FMZ), and two stations beyond the location of the FMZ (farfield), where discharge effects might reasonably be expected, and at two control stations (figs. 2, 10, 11). The delineation of the mixing zone was defined by Environmental Science and Engineering, Inc. (1986). While on site, it was observed that the outfall diffuser has been modified so that only the last two ports on each end are discharging. This was probably done to increase the exit velocities and improve mixing. Discharge, temperature, pH, and alkalinity, were measured at the rivers and the waste-treatment plant. Marine sampling stations also included vertical profiles of temperature, dissolved oxygen, light transmission, specific conductance, and chlorophyll 'a' concentration. Laboratories set up on board and onshore measured nonconservative properties, bacteria levels, BOD, settleable solids, oil and grease.

The influent and effluent were sampled on the grounds of the MRWTP with flow-regulated, refrigerated automatic samplers. The initial stock of effluent used for the bioassays was collected along with the samples sent for pollutant analysis.



Base map modified from the National Ocean Service Nautical Chart 25673, 1:15,000.

Figure 10. Water-quality stations at the boundary of the final mixing zone, QW-2 and QW-7, and in the far field, QW-1 and QW-8, Bahía de Añasco, Puerto Rico. Water-quality control stations, QW-9 and QW-10, are located approximately 10 kilometers to the northwest, near the town of Rincón (fig. 2). Water-quality stations in the initial mixing zone, QW-3, QW-4, QW-5, and QW-6 are located in the immediate vicinity of the outfall diffusers (fig. 11).

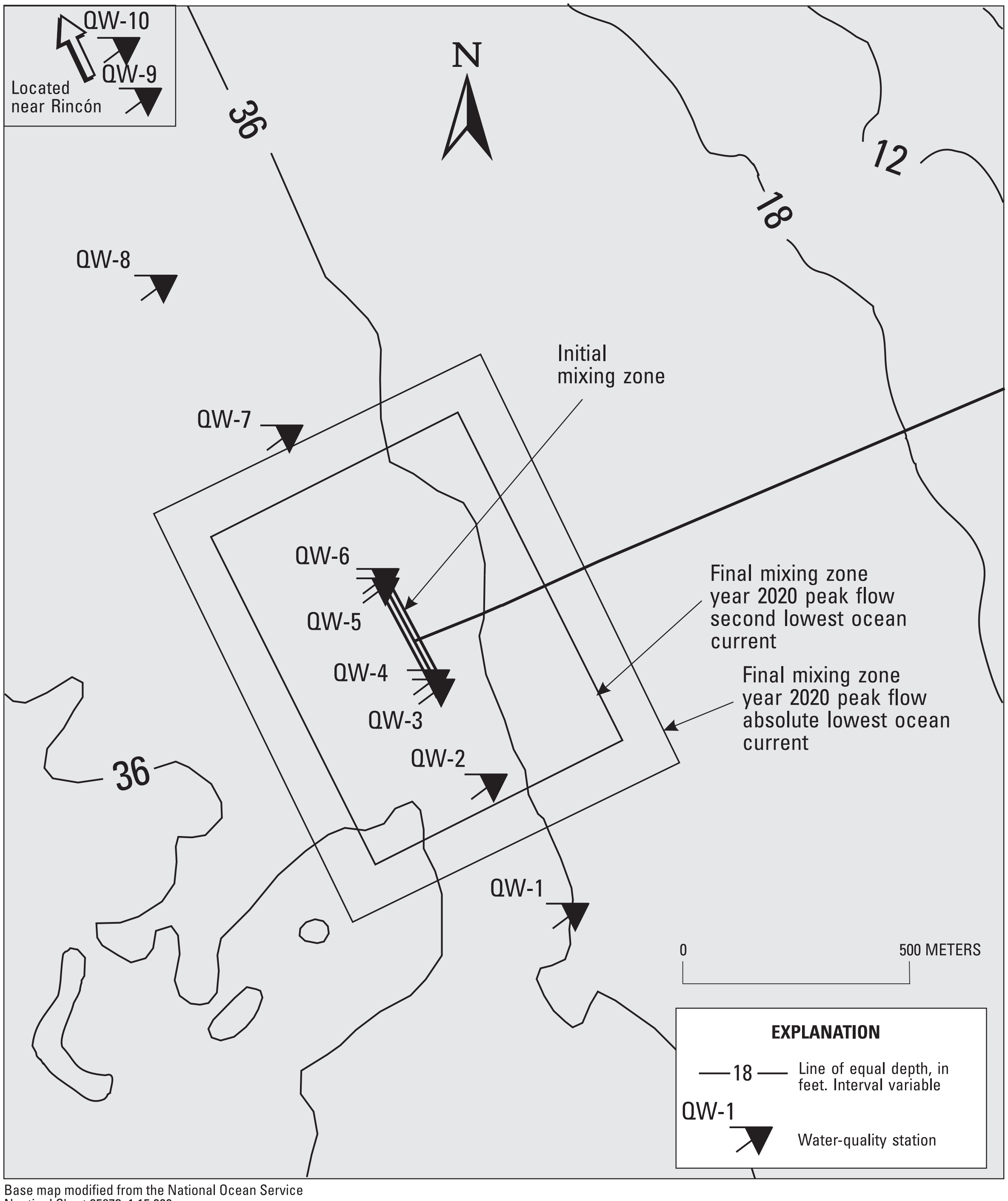


Figure 11. Enlargement of figure 10, detailing the initial and final mixing zones and locations of water-quality sampling stations, QW-1 to QW-8, Bahía de Añasco, Puerto Rico. Water-quality control stations, QW-9 and QW-10, are located approximately 10 kilometers to the northwest near the town of Rincón (fig. 2).

Water-quality sampling techniques followed standard USGS and EPA procedures. At the offshore stations, the RV Jean A was navigated to the sampling station and a buoy was set. The research vessel was then anchored several hundred meters downcurrent of the buoy so as to avoid contamination from the anti-fouling paint. The sampling crew then boarded a rubber raft and motored to the buoy. After anchoring, a peristaltic pump was used to retrieve a composite sample through a 50-ft teflon hose from 10, 50 and 90 percent of the water depth. Composites were collected in a stainless steel and a plastic bucket. Even though a sealed weight was attached to the end of the hose, currents could move the sampling hose off vertical. In 35 ft of water the operator might release 40 ft of teflon hose before it hit bottom. The hose was purged before recovering a sample from a new depth. VOC samples were collected and stored on ice immediately after the sample had been composited. The chlorophyll 'a' samples were collected from mid-depth. Oil and grease samples were taken from the surface and immediately stored on ice. Depth profiles of temperature, pH, conductivity, and light extinction, were also determined.

Phytoplankton blooms are common where nutrients mix with ocean waters. Chlorophyll 'a' has long been used as a phytoplankton biomass indicator, and was measured at all water-quality stations. Water samples were collected and analyzed by Fernando Gilbes, a graduate student studying phytoplankton fluctuations in the Bahía de Añasco. Three replicate 1.5 mL samples were placed in test tubes and 8.5 mL of 100 percent acetone was added to each (Phinney and Yentsch, 1985). Samples were placed in the dark for 24 hours at a temperature of 2 to 5 °C. After this time, the fluorescence was measured using a Turner Model 111 Fluorometer. Measurements of fluorescence before and after acidification were recorded. The fluorescence values were converted to values of chlorophyll 'a' in milligrams per cubic meter, using a regression equation that was calibrated using chlorophyll 'a' from *Anacystis nidulans* algae. Measurements of light were taken in place at 2, 4, 6, 8, and 10 m depth, using a photometer. These measurements were used to calculate the extinction coefficient (k) in the water column.

Biological assays were conducted on three test species, *Mysidopsis bahia* (mysid shrimp), *Cyprinodon variegatus* (sheepshead minnow), and *Champia parvula* (red macro algae), in accordance with the EPA methodology specified for conducting marine acute and chronic tests (Webber and others, 1988). The bioassays were run with static renewal of effluent collected between January 29 and February 8, 1991.

SUMMARY OF RESULTS

The following is a synopsis of the results obtained as part of the sampling of the biota, water quality, and bottom sediments, in the vicinity of the ocean outfall of the Mayagüez Regional Wastewater Treatment Plant. During the initial site reconnaissance and sampling expedition, carried out from December 7-17, 1990, a sidescan-sonar mosaic of the floor of the Bahía de Añasco was created, bottom sediments were sampled for characterization of infauna, texture, and chemistry, a sediment core was recovered from a station near the outfall, and fish and sessile benthos were censused. During the second expedition, from January 25-30, 1991, sediment cores were recovered from three more stations, and water quality was sampled in the vicinity of the outfall and at the control stations near Rincón.

All field data and analytical results are given in the appendices of the report as follows:

Appendix A. Macrobenthic infauna identified at stations B1 through B8, December 15, 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico.

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and the Escollo Negro reef complex, Puerto Rico.

Appendix C. Elemental and isotopic composition of annual coral bands of *Montastrea annularis*, sampled from cores C1 and C2, recovered at station MO-1 near the outfall, December 14, 1990, and cores C7 and C9, sampled at station MO-3 in the Escollo Negro, Puerto Rico, December 17, 1990.

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and the Escollo Negro, Puerto Rico.

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at 10 water-quality sampling site in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Watewater Treatment Plant, January 25-30, 1991.

Because of the limited scope of sampling during this study, associated data sets compiled during past and ongoing studies by the USGS in cooperation with agencies of the Commonwealth of Puerto Rico were accessed and evaluated to identify historical trends in changing water quality in the estuary system.

Associated Data Sets

Water-quality data for samples collected at stations in the upland drainage basins for the years 1970 through 1997 were retrieved from the National Water-Data Storage and Retrieval System (WATSTORE). Direct access to the WATSTORE data base may be obtained by signing a Memorandum of Agreement with the USGS, available through the USGS National Water Data Exchange office in Reston, Virginia. In addition, data can be provided in various machine-readable formats, such as magnetic tape, floppy disk, or compact disk. Yearly Water-Resources Data Reports for Puerto Rico and the U.S. Virgin Islands are published by the USGS and distributed to libraries and to Federal and Commonwealth agencies. The most recent report presents the data for water year 1998 (Díaz and others, 1999).

The WATSTORE database is populated with data collected by USGS personnel in support of a wide range of missions. Data from five stations within the basins draining into the Bahía de Añasco and the Bahía de Mayagüez (fig. 1) have been collected as part of the USGS-Commonwealth of Puerto Rico water-quality monitoring network or the National Stream Quality Accounting Network (NASQAN), both of which were established to provide data to describe areal variability and detection of changes or trends in water-quality characteristics over broad geographical areas.

Habitats and Sedimentation Patterns Observed in Sidescan-Sonar Mosaic and Seismic Reflection Profiles

The progradation of the Río Grande de Añasco delta into the bay precluded mapping as far inshore as originally planned; the 10-m contour shown on the nautical chart, based on data collected at the turn of the century, has shifted approximately 300 m to the west. Approximately 3,000,000 m^3 of silt and clay deposited on the delta during the period 1903-95 (Grove, 1998). In the sidescan-sonar mosaic, the outfall trench can be clearly identified, along with the muddy floor of the bay, and a hard bottom area with the potential for reef development (fig. 6). The calibration with actual bottom samples enabled the classification of the seafloor into hard bottom, mud, and sand (Schwab and others, 1991). Near the south leg of the diffuser pipe, a halo of coarse sediments is located east of a small area of hard bottom. No noticeable deposition of fines from the outfall is observed in this area. Fines deposited from the outfall could be expected to appear as a darker shade in the bright returns in the halo of coarse sediments deposited around the top of a now nearly extinct patch reef. The same cannot be determined for the area to the north of the outfall, because the image does not allow for the distinction between outfall sediment and fine-grained river sediment deposited there.

Macrobenthic infauna in the immediate area of the outfall was sampled at station B4. The January 1985 survey of infauna found 106 taxa there in comparison with only 22 taxa found in

December 1990. The sediments for station B4 in 1985 were described as rubble, suggesting that the area sampled was probably from the coarse-sediment area near the south leg of the diffuser, approximately 200 m to the southeast from its indicated position near the north leg of the diffuser. The coarse-sediment area should be a heterogeneous habitat, with associated increased diversity, in comparison with the homogeneous fine sediments in the area sampled as station B4 in December 1990.

Seismic reflection profiles revealed that the rocky outcrops to the northwest and southeast of the diffuser are the tops of reef structures buried by sediment. This interpretation was supported by the high-relief indurated structures revealed in high-frequency seismic reflection data and by the inability to penetrate the sediments to a depth greater than about 1 m during coring near the outfall. Observations by SCUBA-divers at one of the outcrops verified that the substrate matrix consisted of the skeletal remains of hermatypic corals. The seismic profiles collected are stored at the data library in Woods Hole, Massachusetts. A copy is available for examination at the USGS office in Guaynabo, Puerto Rico.

Biota

Temporal changes in the community structure of macrobenthic infauna, sessile benthos, and fishes, were observed between the surveys of biota carried out in 1985 and 1995. The observed changes appear to be well within the range of expected natural variability and responses to shifting environmental gradients.

Macrobenthic Infauna

A variety of biological and physical factors can contribute to changes in the community structure of infauna. This section discusses the temporal and spatial changes in the community structure observed from 1985 to 1990 in the Bahía de Añasco and the Bahía de Mayagüez. The following conclusions were reached:

- There is a strong seasonal variability in the infaunal community.
- Diversity and percentage of opportunistic organisms decrease with distance from shore.
- The two station-pairs with the greatest dissimilarity of taxa were B2-B5 and B4-B7. The first pair present a depth/grain size gradient, whereas the second pair presents what could be a bottom-energy gradient favoring conveyor-belt feeders.

Basic community statistics are reported to describe the infaunal community, how species richness and diversity changed from 1985 to 1990, and to document any evidence of changes in the community structure in response to the discharge from the outfall. Marked natural seasonal and spatial variations of the soft-bottom communities were observed in previous studies of infaunal communities in the area, and during the current study. Patchy distributions and intense seasonal variations are common for infaunal communities in the tropics (Calderón-Aguilera, 1992; Plate and Husemann, 1991). The 200 taxa, with an average of 2,235 organisms/m^2, found in January 1985[1], increased to 295 taxa, with an average of 6,883 organisms/m^2, found in the May 1985 survey (Metcalf & Eddy, 1987a). The December 1990 survey, yielded 56 taxa with an average of 472 organisms/m^2. A VanVeen sampler was used in 1985 (0.1 m^2/replicate), whereas a Shipeck grab sampler (0.04 m^2/replicate) was used in 1990. The overall number of taxa is not directly comparable because of the different sampling areas, but the density of individuals can be compared, as the number of individuals at each station in the 1990 survey was multiplied by 2.5 to correct for the difference in surface area sampled. As discussed in the following sections, the effect of dissimilar sample sizes on the calculation of community statistics and the interpretation of temporal and spatial variability appears to be minor. The data collected in 1990 are sufficient in quantity and quality to derive meaningful conclusions on the structure of the sampled communities, and the differences between previous sampling expeditions.

[1] Re-examination of the unedited data from January 1985 found only 156 taxa with an average of 1,303 organisms/m^2. These are the values used for subsequent plots and t-test comparisons.

The number of taxa increased at all stations from January to May 1985, except for station B4, where the number of taxa increased but diversity decreased. The anomaly at station B4 was likely the result of sampling a different substrate, as discussed in the previous section. The presence of a heterogenous substrate at the station sampled as B4 in January 1985 is further supported by the observation that just two replicates at the station (0.2 m^2 total area) contained 85 different species, more than the total number of taxa contained at the eight stations (40 replicates) sampled in December 1990.

The significant seasonal change between the January and May sampling was recognized as typical of coastal tropical communities. The species-area curves for January 1985 and December 1990 (fig. 12) show two things: (1) the number of taxa at each station was significantly less in December 1990 than it was in January 1985, and (2) the sampling effort in December 1990, while covering only 40 percent of the area sampled at each station in January 1985, appears to have been sufficient to identify the majority of the species at each station, as revealed by the decreasing slope of the species-area curve.

Diversity (H´) is a measure of the uncertainty in being able to correctly predict the species of an individual selected at random from the population. The measure is less subject to the effect of sample size and provides a better estimate of the heterogeneity of the infaunal community than simply the number of taxa. For example, the species-area curves for 1985 and 1990 (fig. 12) for station B2 are more similar than the corresponding curves for station B6. However, using the t-test (α-0.05) explained earlier in the methods section, it was found that the diversity was significantly different for four out of seven stations (station B7 was not surveyed in January 1985) surveyed in January 1985 and December 1990 (table 7). The diversities measured at stations B2 and B5 in 1985 were significantly different than those measure at the same stations in 1990 (fig. 13). At station B2 in 1985, the most common species, *Scoloplos texana*, accounted for only 25 percent of the individuals, and 10 species each accounted for more than 2 percent of the individuals. In December 1990, *Sipuncula* accounted for 59 percent of the individuals, and only five species accounted for more than 2 percent of the individuals. On the contrary, even though the number of taxa identified at station B6 in 1985 was much greater than the number identified at the station in 1990, the overall distribution of species and abundances were similar, resulting in insignificant differences in the calculated diversity values. In general, although the four stations that showed significant changes in the diversity were located near the outfall, the changes were not accompanied by increases in taxa identified as opportunistic and pollution-tolerant species.

Table 7. Differences in the diversity of macrobenthic infauna measured at stations B1 to B6 and B8, January 1985 and December 1990

[A two-tailed t-test (Hutcheson, 1970) at α-0.05 was used to determine whether to reject the null hypothesis that the diversity measured at the same site in 1985 and 1990 was the same.]

Site	Theoretical variance $s_{H'_1 - H'_2}$	*t* statistic	Degrees of freedom v	$t_{0.05,v}$	Diversity different?
B1	0.18	-0.96	198	1.97	No
B2	0.20	-4.17	183	1.97	Yes
B3	0.18	-3.46	196	1.97	Yes
B4	0.18	-7.85	197	1.97	Yes
B5	0.14	-4.86	192	1.97	Yes
B6	0.17	-1.53	175	1.97	No
B8	0.17	0.72	185	1.97	No

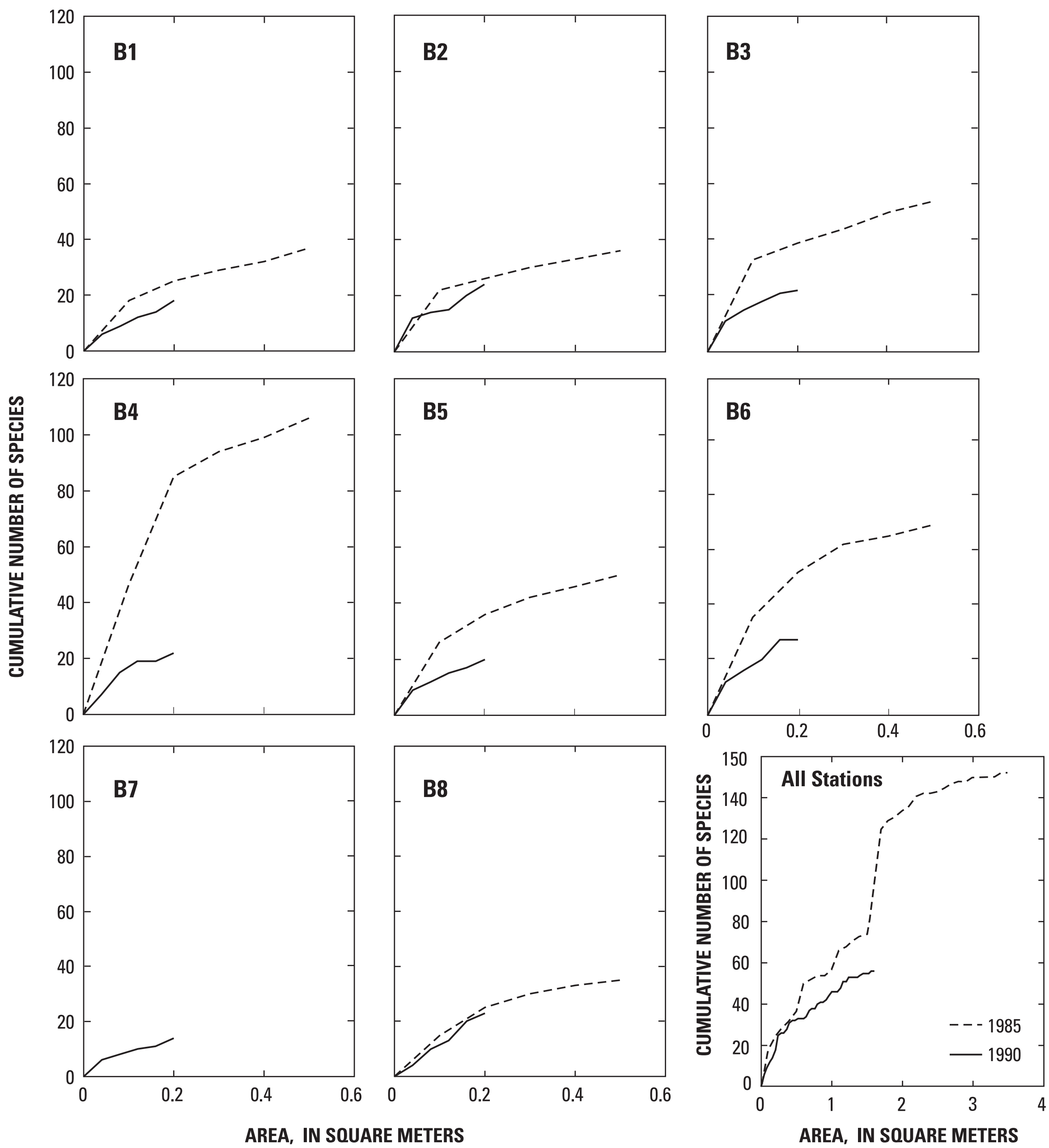


Figure 12. Species-area curves for macrobenthic infauna measured in January 1985 and December 1990 at stations B1 to B8, Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico (station B7 was not sampled in 1985). In general, sampling was sufficient to collect most species present at each station for each sampling expedition, as indicated by the flattening-out of the species-area curves. For each station, five replicates were collected. The Van Veen used in 1985, sampled 0.1 m^2 for each replicate. The Shipeck used in 1990, sampled 0.04 m^2 for each replicate. In 1985, station B4 was identified as containing rubble, a substrate not present in the area of site B4 as identified in the sidescan-sonar imagery collected in 1990 as part of this study.

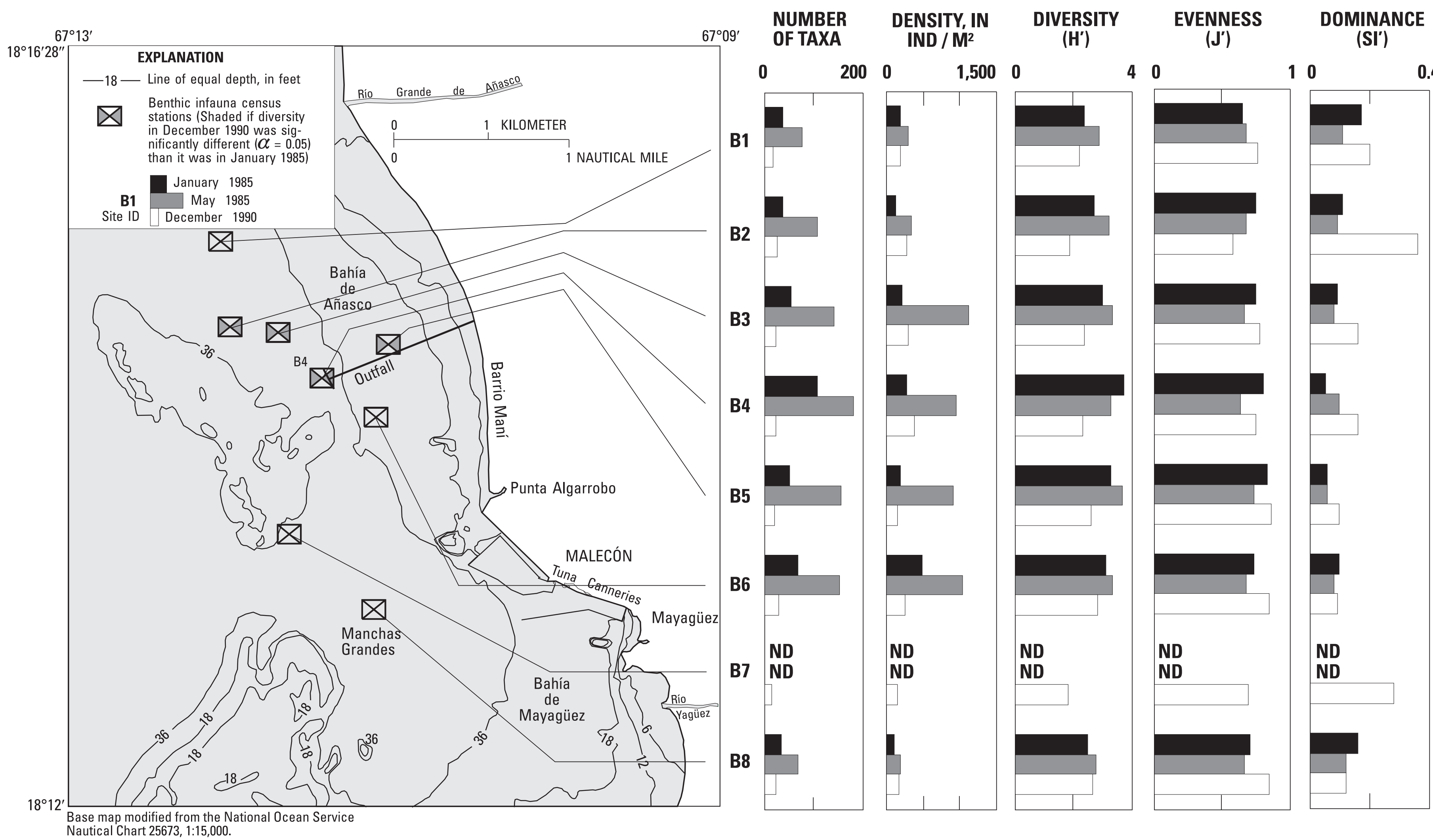


Figure 13. Number of taxa, density of individuals, diversity, evenness, and dominance observed for macrobenthic infauna census stations B1-B8 in January and May 1985, and December 1990 in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Abbreviations: IND/M^2, individuals per square meter; H′, Shannon-Weaver Diversity Index; J′, evenness; SI′, Simpson's Dominance Index; ND, no data.

Opportunistic and pollution-tolerant taxa identified by Pearson and Rosenberg (1978) did not appear enriched at any station. Six taxa were represented, all of them annelids: *Neanthes sp. A*, three species of *Prionospio*, *Mediomastus sp. A*, and *Capitellidae sp. A* (table 8). The percentage of opportunistic species was markedly less than in the January 1985 survey, when the percentages ranged from 5.3 percent at station B3 to 22.8 percent at station B5.

To further understand the heterogeneity of the community structure in the Bahía de Añasco and the Bahía de Mayagüez, the differences in diversity was examined as well as the similarity of fauna common to pairs of stations. For the 28 combinations of paired stations, the two-tailed t-test was used to determine if observed differences in diversity were significant at the α-0.05 level. The Bray-Curtis similarity values were calculated to determine the degree that the compositions were similar for pairs of stations. Of the 28 comparisons made, 17 showed significant differences in diversity and 12 showed similarity values less than 50 percent (fig. 14).

The predominant pattern in both the diversity and similarity values appears to be related to an onshore-offshore gradient. Ordination of stations and species along the B2-B5 axis reveals a gradient from deeper, muddier stations, with lower diversity (predominance of *Sipuncula*), to shallower, more sandy stations, with higher diversity (more *Scoloplos*, *Amphiodia*, and total opportunistic species) (fig. 15). The gradient in station diversity (which correlated also with percent opportunistic species) with distance offshore is not present if the same values are plotted with distance from the outfall (fig. 16).

A secondary gradient in the community structure may reflect a combination of the grain size and the amount of organic carbon in the sediment (fig. 17). Excluding stations B2 and B5 from selection for a secondary polar ordination axis, the most dissimilar of the remaining stations were B4 and B7. Similarity values shown in figure 14 were converted to Percent Dissimilarity by subtracting from 100 (this assumes an internal association of 100 percent for replicates). The two-dimensional ordination graphs plotted with the species abundances indicates an increase in the percentage of the bamboo worm *Maldane* from B7 (1.8 percent) to B4 (13.2 percent). *Maldane* is a conveyor belt feeder that often indicates low organic carbon content in the sediments (Gallagher and Keay, 1998).

Table 8. Percent of benthic infauna represented by various opportunistic taxa at stations B1 to B8, December 1990

Site	*Neanthes sp. A*	*Prionospio sp. A*	*Prionospio sp. C*	*Prionospio sp. B*	*Mediomastus sp. A*	*Capitellidae sp. A*
B1	5.0	2.5	0.0	0.0	0.0	0.0
B2	5.4	0.9	1.8	0.0	0.9	0.0
B3	2.5	0.0	1.6	2.5	0.0	0.0
B4	1.3	3.9	2.0	0.0	0.0	0.0
B5	1.6	0.0	9.5	1.6	0.0	1.6
B6	1.9	3.8	0.0	3.8	1.0	0.0
B8	2.9	4.4	2.9	1.5	1.5	0.0

Diversity significantly different at α-0.05 level?

YES NO

	B1	B2	B3	B4	B5	B6	B7
B2	NO						
B3	NO	YES					
B4	NO	YES	NO				
B5	YES	YES	NO	NO			
B6	YES	YES	YES	YES	NO		
B7	YES	NO	YES	YES	YES	YES	
B8	YES	YES	NO	NO	NO	YES	YES

Bray-Curtis similarity values

	B1	B2	B3	B4	B5	B6	B7
B2	59.4						
B3	62.4	63.2					
B4	51.7	58.3	66.4				
B5	47.6	34.3	43.2	40.9			
B6	48.9	40.7	55.8	57.8	46.7		
B7	65.2	50.3	52.0	45.4	42.4	69.2	
B8	55.4	46.7	53.7	48.2	47.3	58.1	60.2

Percentage Similarity: 70, 60, 50, 40, 30

Figure 14. Matrices of interstation comparisons of diversity and similarity for macrobenthic infauna identified for stations B1-B8, December 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. The upper matrix indicates whether the diversity measured at the stations were significantly different, using a two-tailed t-test at the 0.05 alpha level. The lower matrix lists the Bray-Curtis similarity values that indicate the percentage similarity of taxa found at each station. The backgrounds behind the t-test results and similarity values are shaded darker for stations that are statistically different or less similar.

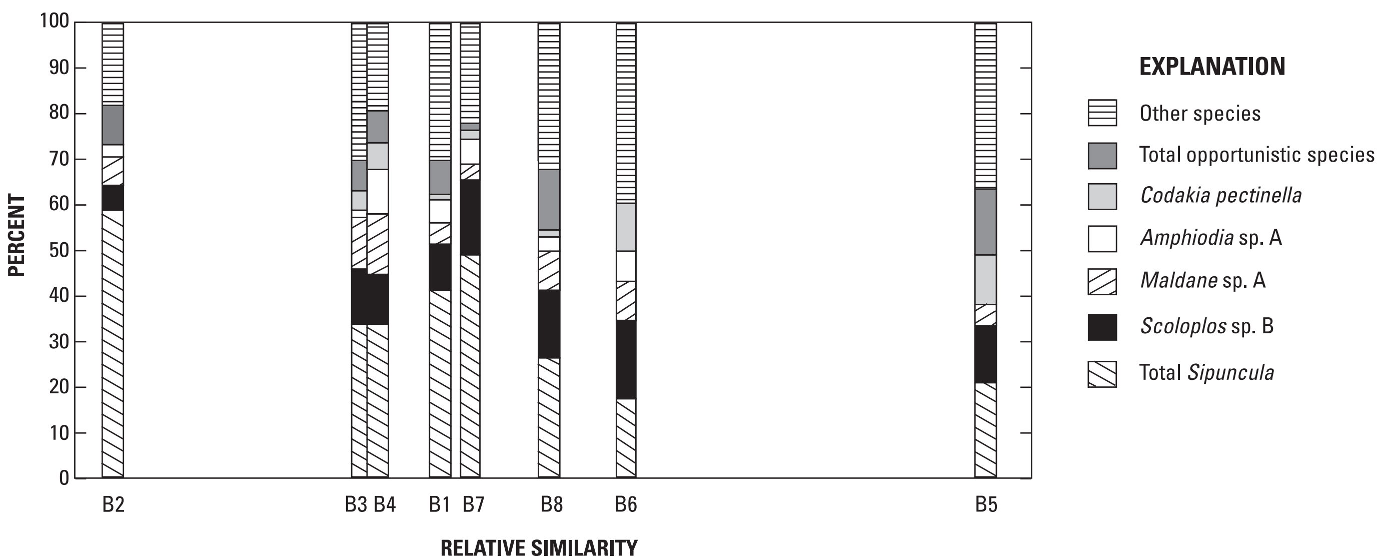


Figure 15. Ordination graph with percentages of the five most common macrobenthic infauna species, total opportunistic species, and other species identified in samples collected at stations B1-B8, December 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. The order and spacing of the stations along the horizontal axis were determined by using ordination techniques (Bray and Curtis, 1957) as explained in Gauch (1982). The horizontal axis is a measure of dissimilarity of species compositions between stations, so that stations that are closer together are more similar in composition. In general, the stations show gradients in community structure.

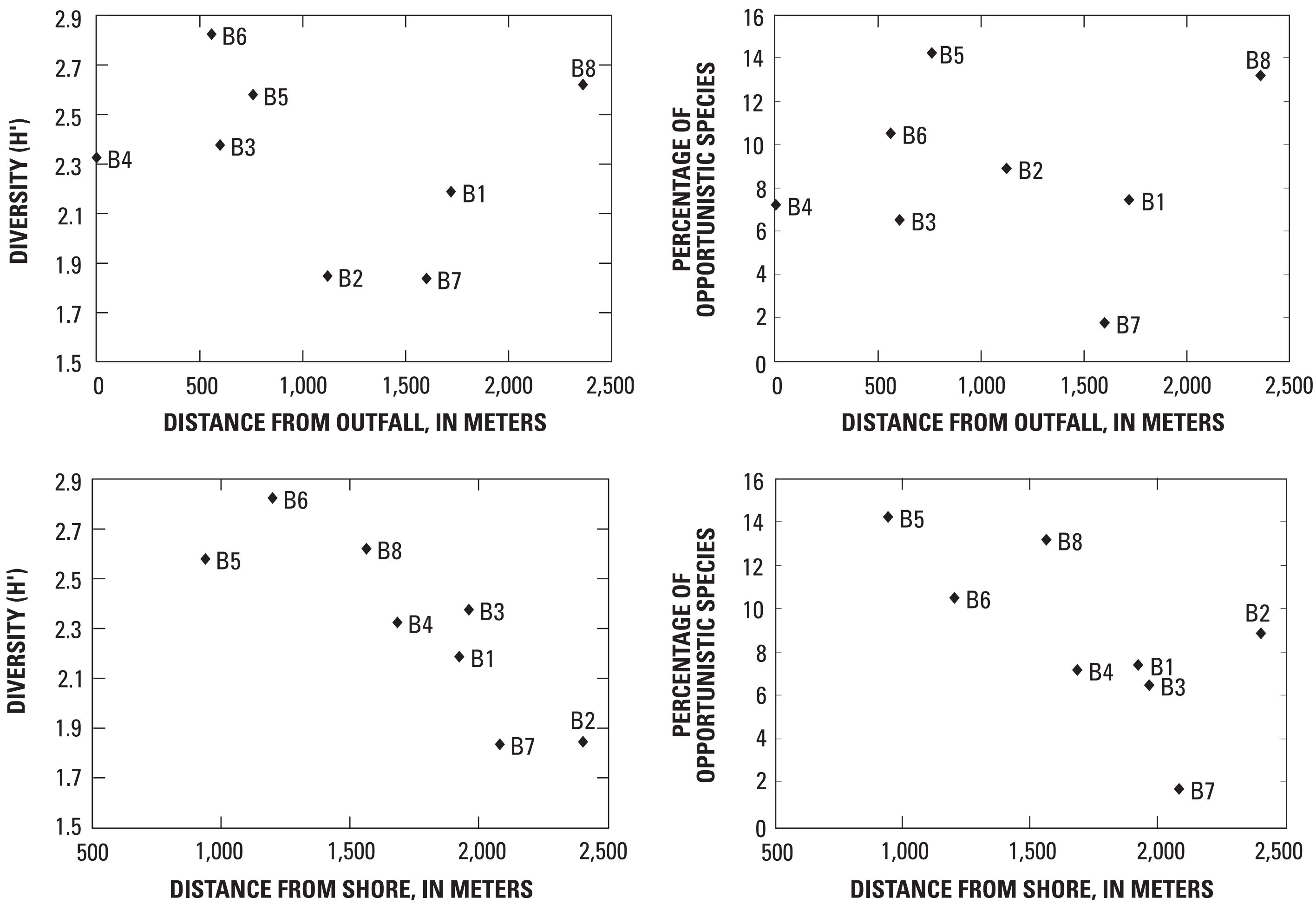


Figure 16. Diversity and percentage of opportunistic species versus distance from the outfall and distance from shore, stations B1 to B8, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico.

Fish and Coral Surveys

The populations of fishes and sessile benthos vary from station to station in response to local environmental conditions. The community structure of the sessile benthos and icthyofauna was observed from December 13-17, 1991, at three stations in the Bahía de Añasco, MSG-1, MSG-2, and MO-5, and at the control station in the Escollo Negro, MO-4 (figs. 2, 7). Detailed observations by transect for each station are presented in appendix B. Water depths at all stations were between 8 and 9 m. However, substrate relief (table 9) and environmental conditions varied at each station. Station MSG-1, in the Manchas Exteriores, located approximately 3.3 km southwest of the Río Grande de Añasco river mouth, had low substrate relief, and was subject to significant wave energy arriving from the northwest. Station MSG-2, in the Manchas Interiores, located 1.2 km to the west of the ocean outfall, had high substrate relief, and was subject to moderate wave energy. Station MO-5, located 350 m southwest of the outfall, had high relief and low wave energy. Station MO-4, located in the Escollo Negro on the extensive Cabo Rojo carbonate platform, more than 8 km to the west of the Río Guanajibo river mouth, had intermediate relief and was subject to intense wave energy arriving from the deep waters of the North Atlantic through Mona Passage.

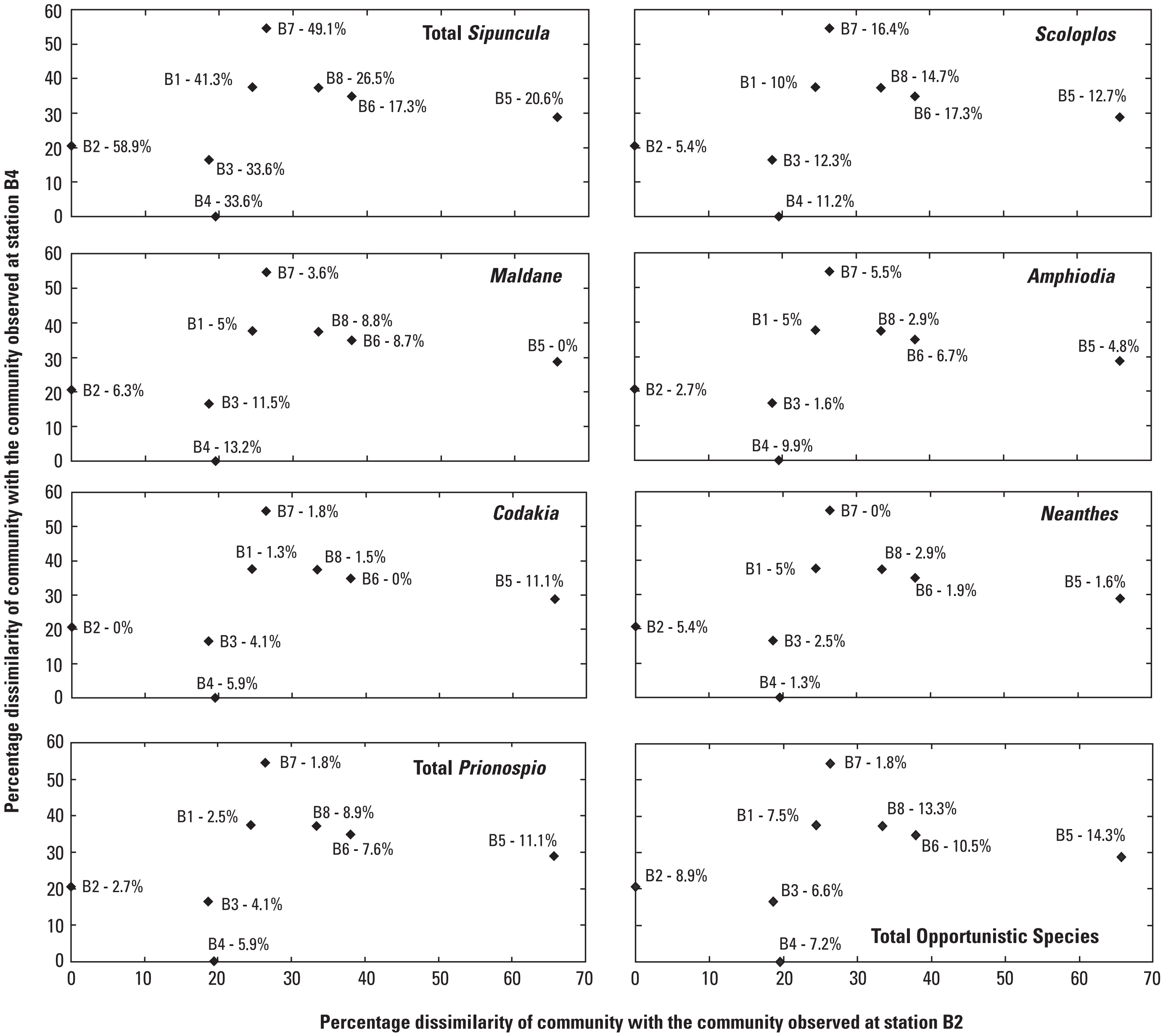


Figure 17. Two-dimensional ordination showing the abundance of major taxa and opportunistic species for macrobenthic infauna survey stations B1 to B8, sampled December 1990 in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. At each sample point, the stations and the percentage of a given taxa are given. The coordinates for the points were calculated by using polar ordination techniques (Bray and Curtis, 1957), by using the independent sample pairs with the greatest dissimilarity. Stations B2 and B5 are the poles for the abscissa and B4 and B7 are the poles for the ordinate. Stations that plot close together share more common taxa than stations that plot farther apart.

Table 9. Substrate relief index measured at biological census stations

[The relief index is the length of chain in excess of 10 meters required to trace the substrate surface for a horizontal distance of 10 meters. Standard deviation in parentheses.]

	MSG-1	MSG-2	MO-5	MO-4
Relief index	1.3 (0.2)	2.3 (0.3)	2.8 (0.6)	1.2 (0.6)

The circumstances under which data on fishes and sessile benthos at the Escollo Negro station were collected impede comparison with the other stations. In particular, rough seas and heavy surge prevented the observer from staying over the transect line while observing fishes or observing sessile benthos below the metric tape. The resulting high parallax did not permit precise location and measurement. Quantification of gorgonian taxa was less affected as their densities were readily noted regardless of the position of the observer. Temporal variations of fishes and sessile benthos at stations MSG-1 and MSG-2 were documented by comparing observations made in this study with those made in 1985 (Center for Energy and Environment Research, 1985).

Limited numbers of motile benthos were observed at the four stations. This precludes inferences being made about the effect of the sewage outfall on these organisms. Nevertheless, the observations of these organisms presented in appendix B, represent a record for future comparisons.

MSG-1 (Manchas Exteriores: 18°14'39.3" N., 67°12'32.5" W., depth 8-9 m)

A total surface area of 150 m^2 was surveyed (five transects) in the Manchas Exteriores. The depth at which the surveys were made ranged between 8 and 9 m. Topographic relief ranged between 0.9 and 1.5 m (mean ± 1.3 m).

Fishes

A total of 24 species were identified in the transects at this station. The number of species per transect ranged between 8 and 15 (mean: 12 ± 3 S.D.). Values of the Shannon-Weaver diversity index ranged between 1.66 and 2.50 (mean: 2.14). Mean fish abundance was 36.2 ind/transect.

The taxonomic distribution and abundance of fishes present at MSG-1 are presented in appendix B. Two species represented 39 percent of the total fish abundance. They were the bluehead wrasse, *Thalassoma bifasciatum* (7.2 ind/transect), and the bicolor damselfish, *Stegastes partitus* (6.8 ind/Transect). The bluehead wrasse was found in only three of the five transects, its abundance variance to mean ratio was 8.2, suggesting an aggregated or ’patchy’ distribution pattern. This type of distribution is quite typical of the bluehead wrasse, and is related to the occurrence of relatively high numbers of females in guilds dominated by one male. Together with the yellowhead wrasse, *Halichoeres garnoti*, wrasses were the numerically dominant family of fishes found at this station. Wrasses are small carnivores that forage for benthic invertebrates in the reef. The bicolor damselfish was present in all five transects surveyed, and was distributed more evenly (variance to mean ratio = 0.7) between and also within transects. This species is highly territorial and defends its microhabitat in the reef. The yellow damselfish, *Stegastes planifrons*, was present in four of the transects surveyed, showing some degree of niche overlap with the bicolor damselfish.

Damselfishes represented the numerically dominant family of herbivorous fishes. Parrotfishes and doctorfishes (*Acanthuridae*), together with damselfishes, comprise the assemblage of herbivores at MSG-1. Commercially important fish species identified in the transects included the coney (*Cephalopholis fulva*), red hind (*Epinephelus guttatus*), French grunt (*Haemulon flavolineatum*), and the spotted goatfish (*Pseudupeneus maculatus*).

Sessile Benthos

Station MSG-1 was characterized by a relatively high abundance and diversity of soft corals. The most commonly observed gorgonian was *Pseudopterogorgia americana*. Coral cover and diversity are quite high, with *Montastrea cavernosa* as the dominant species. Many scleractinian colonies, however, exhibit partial death and/or boring by sponges. Also the abundance of the major Caribbean reef builder, *Montastrea annularis,* is low in comparison to station MSG-2. Poriferans are abundant. The bottom is of a generally low relief, and substrate that is uncovered with sessile fauna is profusely covered by red filamentous algae with fleshy brown algae in scattered patches.

MSG-2 (Manchas Interiores: 18°14'13.0" N., 67°12'3.3" W., depth 7-8 m)

A total surface area of 150 m^2 was surveyed (five transects) in the Manchas Interiores. The depth at which the surveys were made ranged between 8 and 9 m. Topographic relief ranged between 1.9 and 2.7 m (mean = 2.3 m).

Fishes

In total, 34 species were identified. The number of species per transect ranged between 16 and 19 (mean: 18 ± 1 S.D). Values of the Shannon-Weaver diversity index varied between 2.46 and 2.80 (mean: 2.64). The average abundance of fishes was 39.8 ind/transect.

Damselfishes dominated the numerical abundance of fishes at MSG-2, representing, with four species, 29 percent of the total individuals. The bicolor damselfish, *Stegastes partitus,* was the most abundant (4.8 ind/transect) followed by the yellow damselfish, *Stegastes planifrons* (3.8 ind/transect). The yellow damselfish was present in all five transects, while the bicolor Damselfish was present in four. Another damselfish species, the blue chromis, *Chromis cyanea*, was also common at this station (2.2 ind/transect). Unlike the more demersal and herbivorous *Stegastes spp*. aforementioned, the blue chromis occupies parcels of the water column just above the reef and feeds upon reef zooplankton.

Six parrotfish species (*Sparisoma spp*. and *Scarus spp*.) accounted for 24 percent of the total individuals at this station. Together with two other species of doctorfishes (*Acanthurus spp*.), herbivores represented more than half of the total fishes surveyed. Wrasses, which were the numerically dominant fish family at MSG-1, ranked third in abundance at MSG-2. The bluehead wrasse, *Thalassoma bifasciatum*, and the yellowhead wrasse, *Halichoeres garnoti*, had a combined abundance of 4.4 ind/transect. Groupers and hamlets, included in the *Serranidae*, presented five species and a cumulative abundance of 3.2 ind/transect. These included three species of hamlets (*Hypoplectrus spp*.), the coney, *Cephalopholis fulva,* and the graysby, *C. cruentatus*. Serranids, together with the wrasses, grunts, snappers, lizardfishes, and barracudas, represented the carnivorous trophic component at the Manchas Interiores station.

García (1990) noted the occurrence of very high activity of pelagic fishes at this station. Top predators, such as the tarpon (*Megalops atlantica*) were reported feeding upon large schools of sardines (*Clupeidae*). It is uncertain if sardines, as planktivores, are directly associated with food resources in the reef.

Sessile Benthos

The benthic community is dominated visually by gorgonians, which are of a large mean size, highly abundant, and diverse. *P. americana* and species of *Eunicea* are the predominant gorgonians. Poriferans are an important component of the benthos with abundant *Anthosigmella varians*, an encrusting species. *M. annularis* is common in comparison with the limited abundance observed at the stations in the Manchas Interiores-Manchas Exteriores coral reef complex. Colony height of this species is also greater on the average. The abundance of the more sediment-tolerant *M. cavernosa* (Hubbard, 1972) is less than that of MSG-1. Corals, in general, appear to be healthier (for example, with less necrotic tissue and less bioeroded) than in other stations. Bottom vertical relief is medium, and the substrate consists of red crustose algae overlain by a thin film of fine sediment. Fleshy algae are rare.

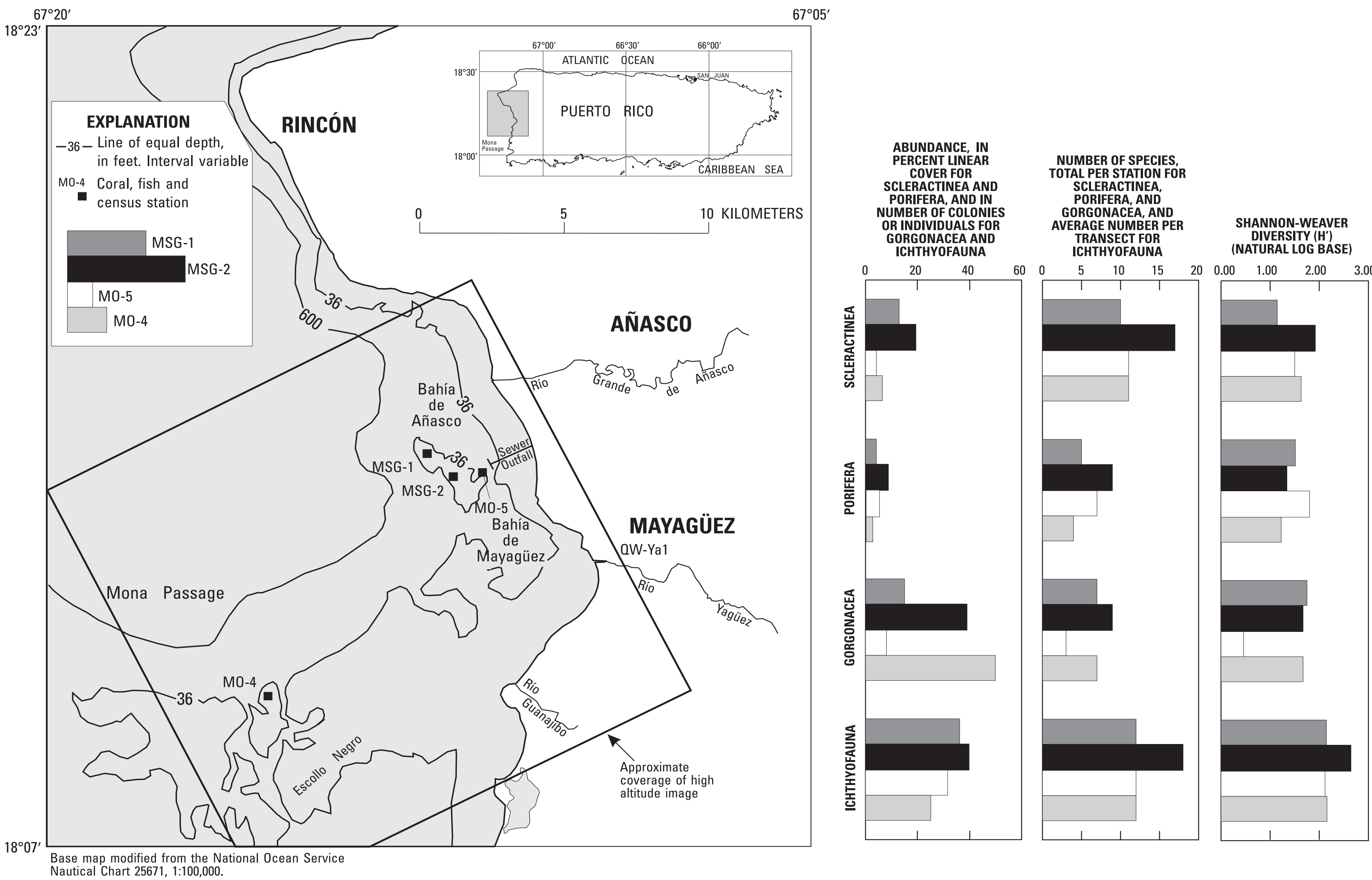


Figure 18. Abundance, number of species, and diversity of scleractinea, porifera, gorgonacea, and icthyofauna at stations MSG-1, MSG-2, and MO-5 in the Bahía de Añasco and at station MO-4 in the Escollo Negro, Puerto Rico, December 1990.

MO-5 (350 m west of outfall: 18°14'18" N., 67°11'28.2" W., depth 8-10 m)

This station is a submerged outcrop to the south-southwest of the outfall. The water was appreciably more turbid than at the other two stations in the Manchas Interiores-Manchas Exteriores coral reef complex, at least during the December 1990 survey. A total surface area of 90 m^2 was surveyed (three transects) at station MO-5. The depth at which the surveys were made ranged between 8 and 9 m. Topographic relief ranged between 2.2 and 3.4 m (mean = 2.8 m).

Fishes

A total of 20 species were identified at this station. The number of species per transect ranged between 9 and 15 (mean: 12 ± 3 S.D.). Values of the Shannon-Weaver diversity index varied between 1.88 and 2.47 (mean: 2.12). The average abundance of fishes was 31.5 ind/transect.

Two species of damselfishes dominated the numerical abundance of fishes, representing 34 percent of total individuals. The dusky damselfish, *Stegastes fuscus*, was the most abundant species (6.7 ind/transect), and was present in all three transects. This damselfish species was only found at MO-5, while the bicolor damselfish (*S. partitus*), which was the most abundant damselfish at stations MSG-l and MSG-2, was not found at MO-5. The yellow damselfish (*S. Planifrons*) was the other damselfish present (4.0 ind/transect). The bluehead wrasse, *Thalassoma bifasciatum*, and the yellowhead wrasse, *Halichoeres garnoti*, had a combined abundance of 5.3 ind/transect, second to damselfishes in numerical abundance. The sharpnose puffer, *Canthigaster rostrata,* and the coney, *Cephalopholis fulva*, were the other two fishes present at all three transects surveyed.

Pelagic fishes were very abundant at this station but were not quantified in the transect survey. Schools of red-ear sardine (*Harengula humeralis*) and threadherring (*Opisthonema oglinum*) were being predated upon by smaller schools of cero and king mackrel (*Scomberomorus regalis* and *S. cavalla*, respectively).

Sessile Benthos

Gorgonians are not abundant but are the most conspicuous fauna. There are many species of scleractinians, but their cover is low, and most colonies are partially dead and/or exhibit necrotic tissue. The substrate is covered by a thick (1-2 mm) sediment film trapped in the filaments of red algal carpet, with green fleshy and/or brown algae in many places. Biotic elements of deeper waters are common, possibly due to the predominantly high mean water turbidity. These include the scleractinian *Agaricia lamarcki* and the antipatharian *Stichopathes sp*. Arborescent, colonial hydrozoans are common. In general, the area is heavily silted and living coral cover is quite low. Relief is quite high in relation to other stations (table 9), and it is evident that its origin is scleractinian related. Upon scraping silted surfaces, one can observe the underlying coral calices below the sediment film.

MO-4 (Escollo Negro: 18°9'55" N., 67°15'39" W., depth 8-9 m)

This station was surveyed under unfavorable conditions which precluded adequate assessment of general characteristics. A total surface area of 60 m^2 was surveyed in two transects at station MO-4. The depth at which the surveys were made ranged between 8 and 9 m. Topographic relief ranged between 0.7 and 1.8 m (mean = 1.2 m). A total of 16 species was identified at this station. The two values for number of species observed per transect were 9 and 14 (mean: 12 ± 4 S.D.). Shannon-Weaver diversity index values corresponding to the two transects surveyed were 2.00 and 2.32. The average abundance of fishes was 25 ind/transect.

Nine out of the 16 fish species recorded at this station were present in only one of the transects surveyed. Also, most of these species refer back to only one individual. Therefore, the quantitative information has very limited statistical significance, and the reader is advised to evaluate with caution the data from this station. Only four fishes presented more than one individual at the two transects. It seems that the bicolor damselfish (*Stegastes partitus*) is one of the numerically dominant fishes in this reef. In addition to the bicolor damselfish, the yellowhead wrasse (*Halichoeres garnoti*), and the striped and redband parrotfishes (*Scarus iserti* and *Sparisoma aurofrenatum*), appear to be common here, as they are all typical of shallow water coral reef environments in Puerto Rico. Additional observations are critically needed to characterize the community of fishes at this reef.

Sessile Benthos

In general, the area has low to medium relief substrate and high gorgonian abundance. This taxa predominates visually. Scleractinians are abundant and diverse, although generally small. Sponges are a minor component of the community.

Species Diversity and Abundance Patterns

Whereas the station nearest the outfall, MO-5, is noteworthy for the limited abundance of scleractinians, poriferans, and gorgonians, the community of scleractinians and poriferans present is as diverse as at the other stations (fig. 18). The communities established at station MO-5 are deeper water communities.

Fishes

Fish abundance and diversity were highest at station MSG-2, located in Manchas Interiores, 1,200 m west of the outfall. This station also had the most diverse coral community. The correlation between fish diversity and bottom relief increases if the station closest to the outfall, MO-5, is withdrawn from the data set. The habitats at station MO-5, as discussed previously, are affected by sediments and nutrients discharged from west coast rivers. Diversity and mean number of species per transect were roughly equal at the three stations, MSG-1, MO-5, and MO-4, the control site. Mean fish abundance per transect was lowest at station MO-4. This site was affected by swells arriving from the north when visited. The surge caused by the swells made surveying difficult, both due to the inability of the observer to remain stationary in the water column and to the turbidity resulting from the resuspended sediments. The sites presenting least-to-greatest mean fish abundance, in order of increasing abundance, were MO-4, MO-5, MSG-1, and finally MSG-2. In conclusion, the fish communities near the outfall, station MO-5, were similar to those at three of the four survey stations. In general, it could be observed that fish populations reflected natural variations in food and habitat availability.

A scatter diagram of abundance and diversity values plotted against substrate relief for all stations is presented in figure 19. Fish abundance and species diversity values varied independently from substrate relief at MSG-1 (abundance, $r^2 = 0.01$; diversity $r^2 = 0.23$). Substrate relief was relatively constant at MSG-1. Only one of the five transects measured was different from the others in substrate relief within the precision limits of the method (~ 10 percent). Therefore, the variability of fish abundance and diversity between transects may reflect a scale of variation that could be expected to occur naturally or at a constant substrate relief.

Patterns of fish abundance and diversity were also statistically independent of substrate relief at MSG-2. Although four out of five diversity values increased as substrate relief increased (suggesting a positive association), the suggestion of direct relationship is contradicted by a single observation in which the highest diversity value corresponded to the transect of lowest relief. As was the case with MSG-1, variation in substrate relief between transects at MSG-2 was relatively low. Therefore, the variability of fish abundance and diversity at MSG-2 may be reflecting a scale of natural variation inherent to a given substrate relief.

A trend of increasing fish abundance and diversity with substrate relief emerged from the two observations at station MO-4. Substrate relief varied more than two-fold between the two transects surveyed. The limited number of observations, however, constrains further analysis of fish diversity and abundance patterns at this station. Observations at station MO-5 were limited to three, again resulting in high uncertainty in the analysis of fish abundance and diversity patterns. Figure 20 shows that two out of the three values obtained fall at the extreme lower right of the scatter diagram. The trend of the three points from station MO-5 suggests a pattern of lower fish abundance and diversity with increasing substrate relief.

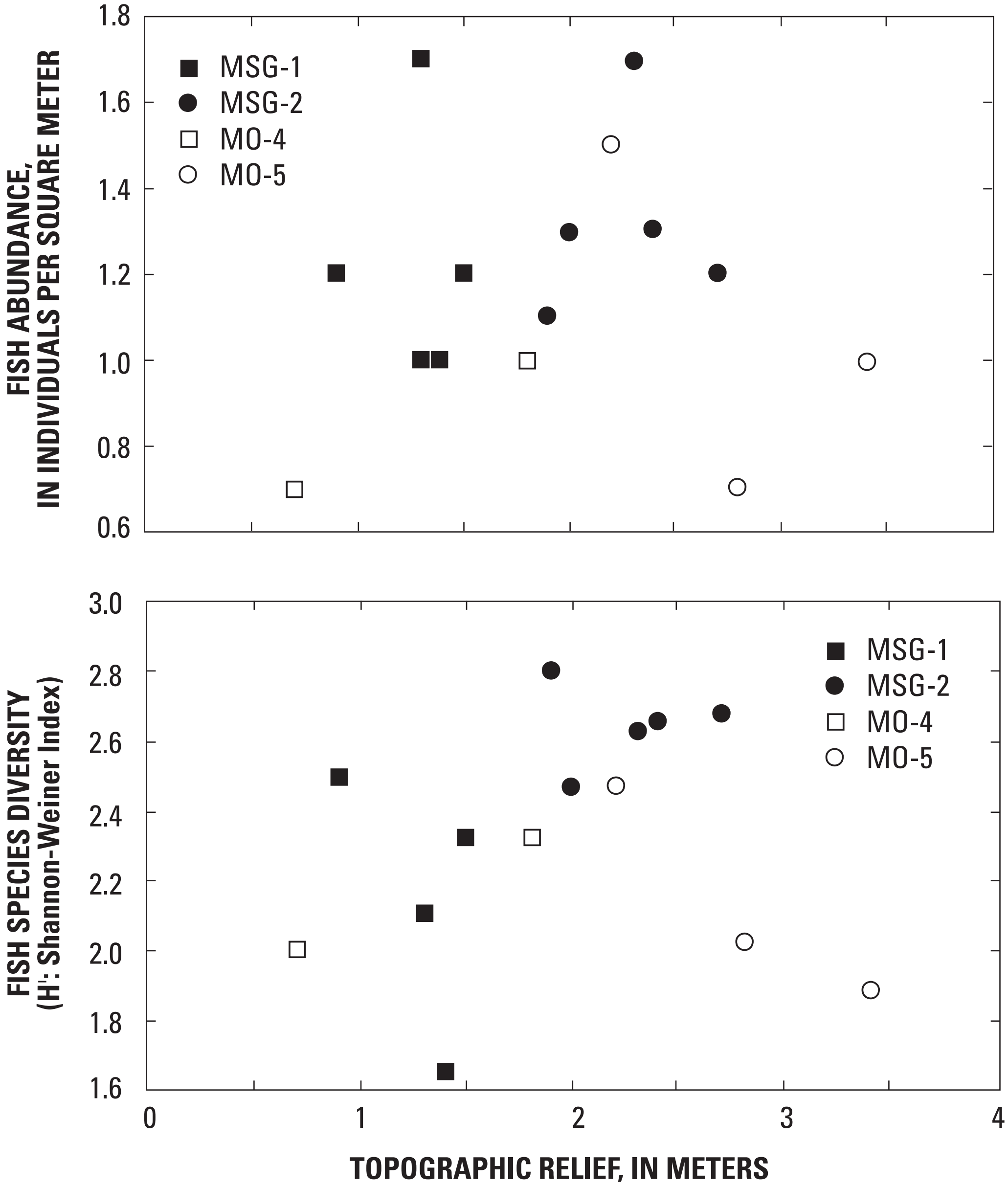


Figure 19. Fish abundance and diversity versus relief for stations MSG-1, MSG-2, and MO-5 in the Manchas Interiores-Manchas Exteriores, and for station MO-4 in the Escollo Negro, Puerto Rico, December 1990.

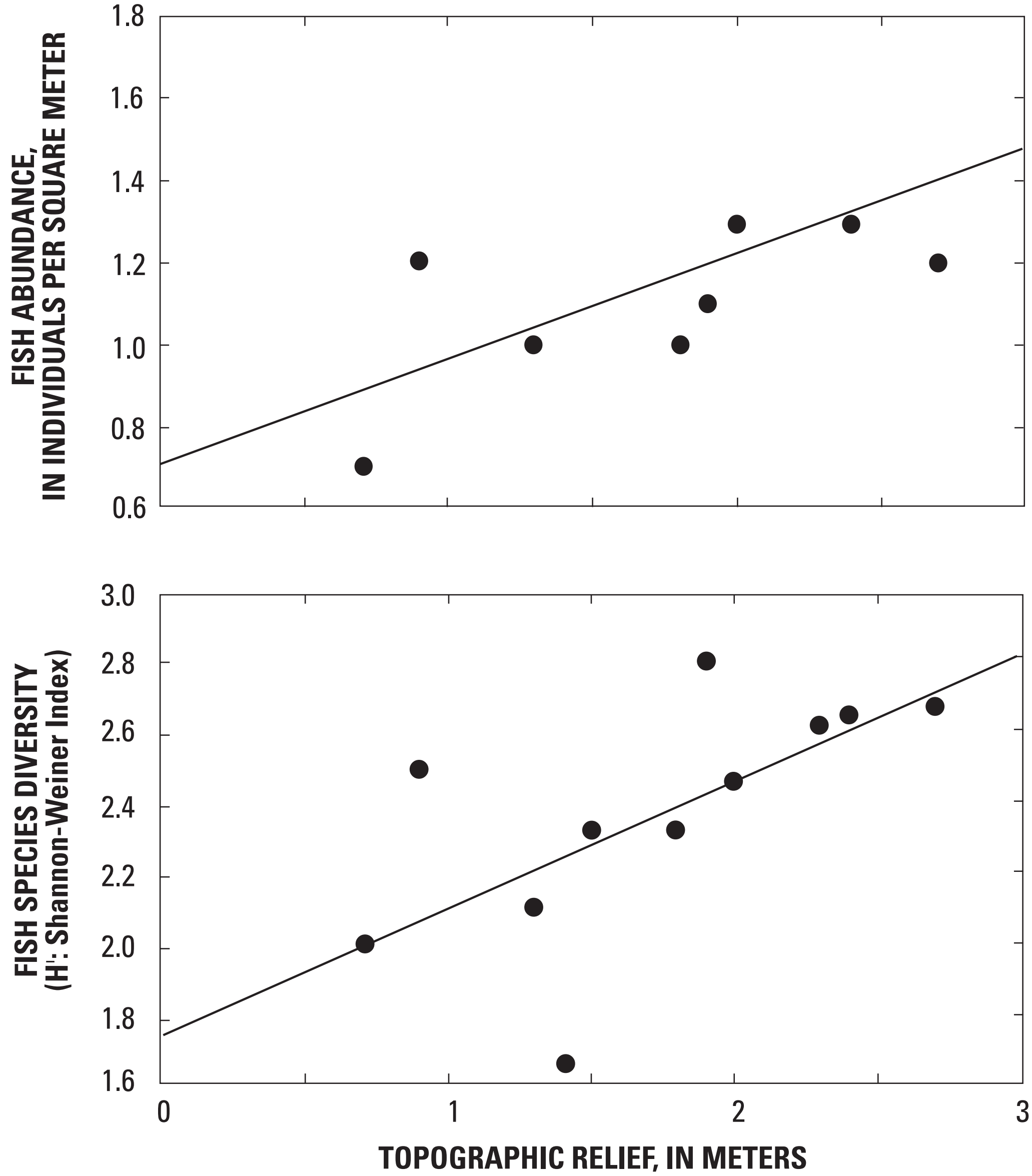


Figure 20. Relation of fish abundance and diversity versus relief for composite plots of data from stations MSG-1 and MSG-2 in the Manchas Interiores-Manchas Exteriores coral reef complex, and for station MO-4 in the Escollo Negro, Puerto Rico, December 1990.

A preliminary hypothesis was developed from the descriptive information available: fish abundance and diversity increase as a function of substrate relief in unpolluted shallow reefs. Due to the relatively large differences in substrate relief between stations, it was possible to examine the potential influence of substrate relief on fish abundance and diversity. Exclusion of the data set for station MO-5 resulted in a positive significant ($p < 0.05$; d.f.=10) correlation between fish abundance and substrate relief ($r^2 = 0.41$), and between species diversity (H' values) and substrate relief ($r^2 = 0.42$). Linear fits to the preliminary models that correlate fish abundance and diversity with substrate relief are presented in figure 20. Inclusion of the MO-5 data set virtually nullified the apparent relationship between substrate relief and fish abundance and diversity.

Sessile Benthos

The total number of species (scleractinians, poriferans, and gorgonians), mean and total benthic cover per station (scleractinians and poriferans), and total number of colonies per station (gorgonians), were highest for station MSG-2 (Manchas Interiores), intermediate at station MSG-1 (Manchas Exteriores), and lowest at Station MO-5. However, in spite of being at a similar depth, the sessile benthos observed at station MO-5 are not readily comparable with the other stations. Shallow-water communities were common at all other stations, and even form the substrate at station MO-5, where a deeper-water community has now become established. The diversity of scleractinians at MO-5, exceeds that observed at station MSG-1, and is comparable to that observed at the control site MO-4 in the Escollo Negro.

The diversity of porifera (sponges) at station MO-5 was the highest of all of the stations. Poriferans are second only to scleractinians in abundance in many tropical habitats (Reiswig, 1973). Sponges appear to be vulnerable to shifts in community structure in response to regional warm-water episodes (Vicente and Smith, 1990; Vicente, 1989). Poriferans feed primarily on particulate organic material. Their diversity and abundance at station MO-5 are further evidence that hard-bottom communities in the inner parts of the Bahía de Añasco have adapted to high levels of siltation and particulate organic material. Although sponges may provide additional nutrients needed to maintain high levels of reef productivity (Corredor and others, 1988), they may also be aggressive when competing with corals for limited substrate (Vicente, 1985, 1978).

Gorgonacea were low in abundance and diversity at MO-5, although the abundance of encrusting gorgonacea *Erythropodium caribaeorum* and *Briaerum asbestinum* were similar to that observed at station MSG-2. Gorgonian density at the Escollo Negro station MO-4 was above that of MSG-2.

Mean cover and density observed during this survey were compared among stations and with mean cover and density observed in the previous survey (Metcalf & Eddy, 1985) to determine if there were gross differences between the two studies (fig. 21). Scleractinian cover was significantly higher at MSG-2 than at the other stations (table 10). Gorgonian density was higher at MO-4 than at MSG-2 and at MSG-1. Gorgonian density at MO-5 was significantly less than the other three stations. Sponge cover was not significantly different among stations.

Scleractinian cover at MSG-1 and MSG-2 does not differ significantly between the current survey and the 1985 survey (tables 11, 12). Gorgonian density at MSG-2 was higher in the 1990 survey than the 1985 survey. The reverse was observed at MSG-1. Differences in sponge cover from 1985 to 1990 were insignificant at both sites.

Coral abundance and diversity were greatest at station MSG-2 and lowest near the outfall. Considering a transect starting at Punta Algarrobo, near the probable major point source of nutrients, continuing to station MO-3, 350 m from the outfall, and finishing at station MSG-2, about 1,200 m west of the outfall, a clear trend of improving coral condition is seen (see fig. 6 for general locations). The corals at the patch reef off Punta Algarrobo, at the north end of the Bahía de Mayagüez were once healthy (Evermann, 1900). By 1980, the reef was heavily silted over, with only two coral species, *Porities asteroides* and *Montastrea cavernosa*, together with *Millepora alcicornis,* occupying less than 2 percent of the reef (Morelock and others, 1983). Moving to the west, station MSG-2 has the most diverse and populated coral community studied, including that of the control site MO-4. If the transect is continued north to station MSG-1, about 1,900 m from the outfall, conditions of the corals worsen as the distance to the Río Grande de Añasco decreases.

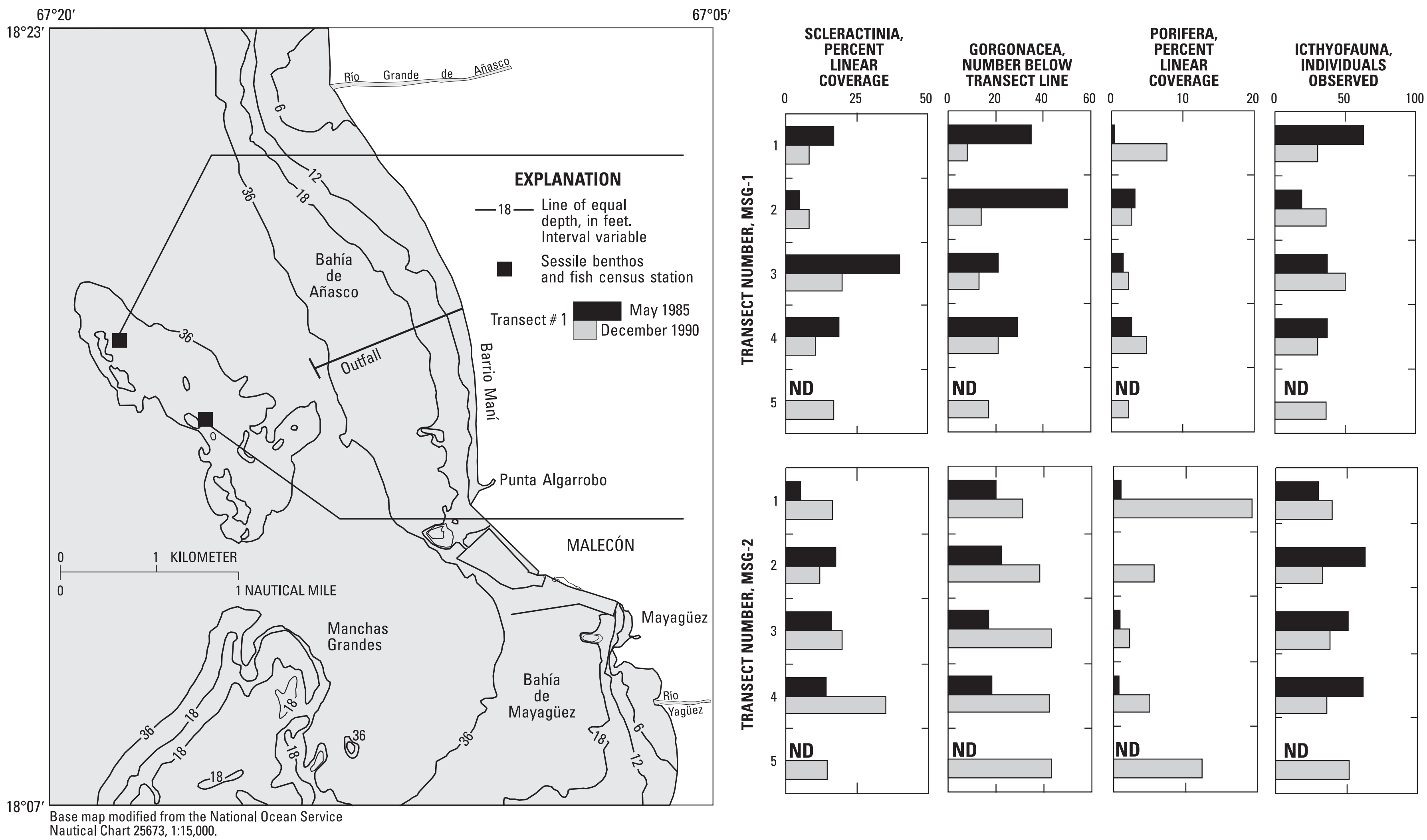


Figure 21. Linear coverage of scleractinia and porifera, and number of gorgonacea and icthyofauna observed per transect at stations MSG-1 and MSG-2, May 1985 and December 1990 in the Manchas Interiores-Manchas Exteriores coral reef complex, Puerto Rico. Statistical comparisons of interstation and interannual variations of scleractinia, porifera, and gorgonacea are discussed in the text, as well as possible relations between surface relief and abundance of icthyofauna. Data are listed in appendix B. ND indicates no data.

Table 10. Differences in cover (scleractinians and sponges) and density (gorgonians) among stations in this study

[One way ANOVA (p = probability; F = F ratio; df = degrees of freedom) and multiple range test (MRT) based on 95 percent confidence interval. Data are detailed in appendix B.]

	p	F	df	MRT
Scleractinia	0.07	3.11	13	MSG2>rest
Porifera	0.36	1.19	13	non-significant
Gorgonacea	<0.0001	32.06	13	MO-4> MSG-2> MSG-1>>MO-5

Table 11. Differences in cover (scleractinians and sponges) and density (gorgonians) at station MSG-1 for the 1985 and 1990 surveys

[One way ANOVA (p = probability; F = F ratio; df = degrees of freedom) and multiple range test (MRT) based on 95 percent confidence intervals. The data collected in this study (detailed in appendix B) were compared with the observations made in the same vicinity before the outfall became operational (PRASA, 1985).]

	p	F	df	MRT
Scleractinia	0.32	1.1	8	non-significant
Gorgonacea	0.01	10.4	8	1985>1990
Porifera	0.17	2.3	8	non-significant

Table 12. Differences in cover (scleractinians and sponges) and density (gorgonians) at station MSG-2 for the 1985 and 1990 surveys

[One way ANOVA (p = probability; F = F ratio; df = degrees of freedom) and multiple range test (MRT) based on 95 percent confidence intervals. The data collected in this study (detailed in appendix B) were compared with the observations made in the same vicinity before the outfall became operational (PRASA, 1985).]

	p	F	df	MRT
Scleractinia	0.26	1.44	8	non-significant
Gorgonacea	0.0002	52.6	8	1990>1985
Porifera	0.051	5.5	8	non-significant

Interannual Variations in Coral Extension Rates and Skeletal Chemistry

Interannual variations in coral extensional rates and skeletal chemistry have been shown to be useful proxies for a variety of oceanographic and hydrologic events (Hudson and others, 1976). Hermatypic corals derive energy from the precipitation of calcium carbonate, which is deposited as an aragonitic skeleton that also serves as a protective habitat. This ability to extend the substrate upon which they live upward, toward the light that energizes the symbiotic zooxanthellae, gives them a unique advantage in areas where sea level is rising. Many species of corals will deposit aragonite at differing rates throughout the year, in response to ambient conditions and vital processes, thus forming annual high-density/low-density couplets similar to tree rings (Hudson and others, 1976). Corals generally deposit their high-density bands during late summer, when water temperatures are warmest (Hudson and others, 1976; Winter and others, 1991), although the exact timing varies in response to reproduction, temperature, and food supply (Wellington and Glynn, 1983; Goenaga, 1988). Variations in the concentrations of lattice-bound cadmium and manganese comprise paleo-upwelling indicators that display great sensitivity in the eastern Pacific Ocean (Shen and Sanford, 1989). Shen and Sanford also documented that variations in barium trapped in the aragonitic lattice of reef-building corals growing in Barbados and Tobago reflect variations of discharges of the Río Orinoco and Amazon, that drain large parts of South America. The increase of lead in surface waters of the North Atlantic in response to late 19th century- and 20th century-industrialization, and subsequent reductions in lead concentrations following the mid 1970's, resulted in variations in lattice-bound lead concentrations in corals growing at North Rock, Bermuda (Shen and Boyle, 1988).

Enhanced fluorescence of annual bands precipitated by corals has been related to the discharge events in other regions (Scoffin and other, 1989; Isdale, 1984; Susic and others, 1991). Humic acids discharged with flood waters can be incorporated into the aragonitic coral lattice, resulting in greater fluorescence of annual bands during years of greater runoff. Analyses of fluorescence displayed by the skeletons of four corals growing off the west coast of Puerto Rico indicated that fluorescence is not a useful proxy for flooding of the rivers discharging to the area. Significant fluorescence was observed only in coral core C9, the fastest growing of the four cores (fig. 22). Fluorescence in the other cores was faint and did not correlate consistently with annual banding. Contamination of the slab surfaces by cutting oil is discounted, as the rock saw used to cut the slabs used non-recycled tap water. To provide additional comparisons, coral cores from the Parguera area in southern Puerto Rico were retrieved from the archives at the USGS Coastal Processes office in St. Petersburg, Florida.

Fluorescence of the coral cores from the Parguera area was much more intense than that of any of the coral cores sampled from the Bahía de Añasco or Escollo Negro. Whereas surface runoff clearly affects the reefs off the west coast to a greater extent than the reefs of the south coast, the reefs off the south coast are bathed in waters receiving humic and fulvic acids exported from the mangrove communities prevalent there. Water sampled from channels in the mangroves in southern Florida fluoresces intensely when exposed to ultraviolet light (Bob Halley, personal commun., 1990).

Extensional Rates

Average extensional rates, as measured by distance between high-density bands, varied from 4.3 mm/yr in core C2, growing at station MO-1, 610 m from the outfall, to 10.5 mm/yr in core C9, growing at station MO-3, at Escollo Negro. The X-radiographs of the corals show that the growth rates of three of the four colonies sampled at the two stations were stunted coincident with a bleaching event experienced throughout the Caribbean in 1987-88 (fig. 23). Coral core C7, the fastest growing core, was an exception; it actually grew faster in 1988. However, as seen in figure 24, core C7 did show an extended period of high-density deposition during the same period. The three coral cores that slowed growth during the bleaching event recovered; during 1989-90 they began growing at rates equal to or greater than before the event occurred (fig. 24).

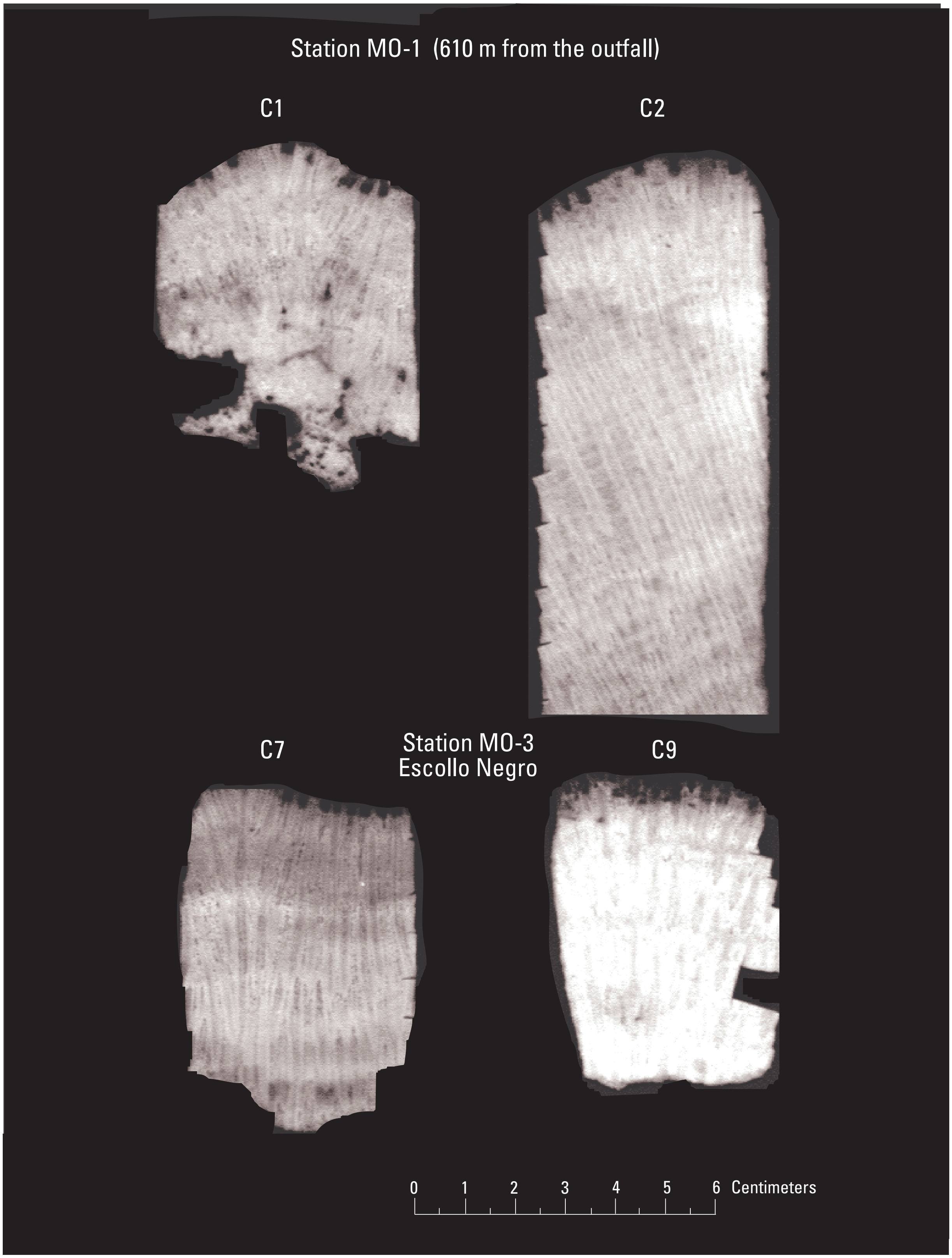


Figure 22. Fluorescence for four samples of *Montastrea annularis* at station MO-1, 610 meters southeast of the outfall, and at station MO-3 in the Escollo Negro, Puerto Rico. These images of C2, C7, and C9 were recorded after samples were cut from the slabs. The voids and cut marks are seen on the margins of the coral slabs. Scale and incident UV light intensities were constant for all samples.

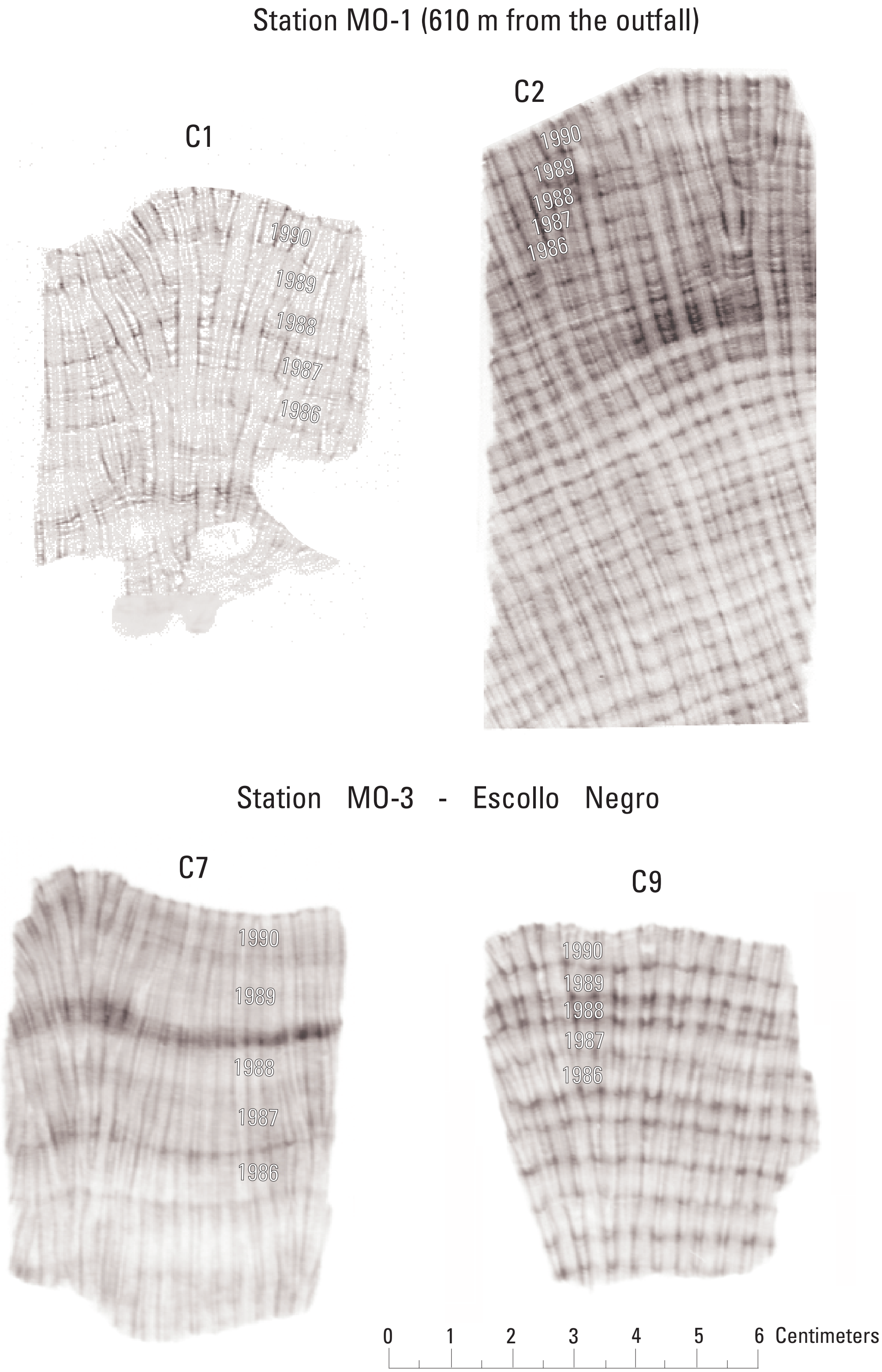


Figure 23. X-radiographs of four samples of *Montastrea annularis* cored at station MO-1, 610 meters southeast of the outfall, and at station MO-3 in the Escollo Negro, Puerto Rico. In these positives of the X-radiographs, high-density bands appear darker than the low-density bands. Note that the annual banding indicates that the extensional rates of these corals have not significantly decreased since 1987.

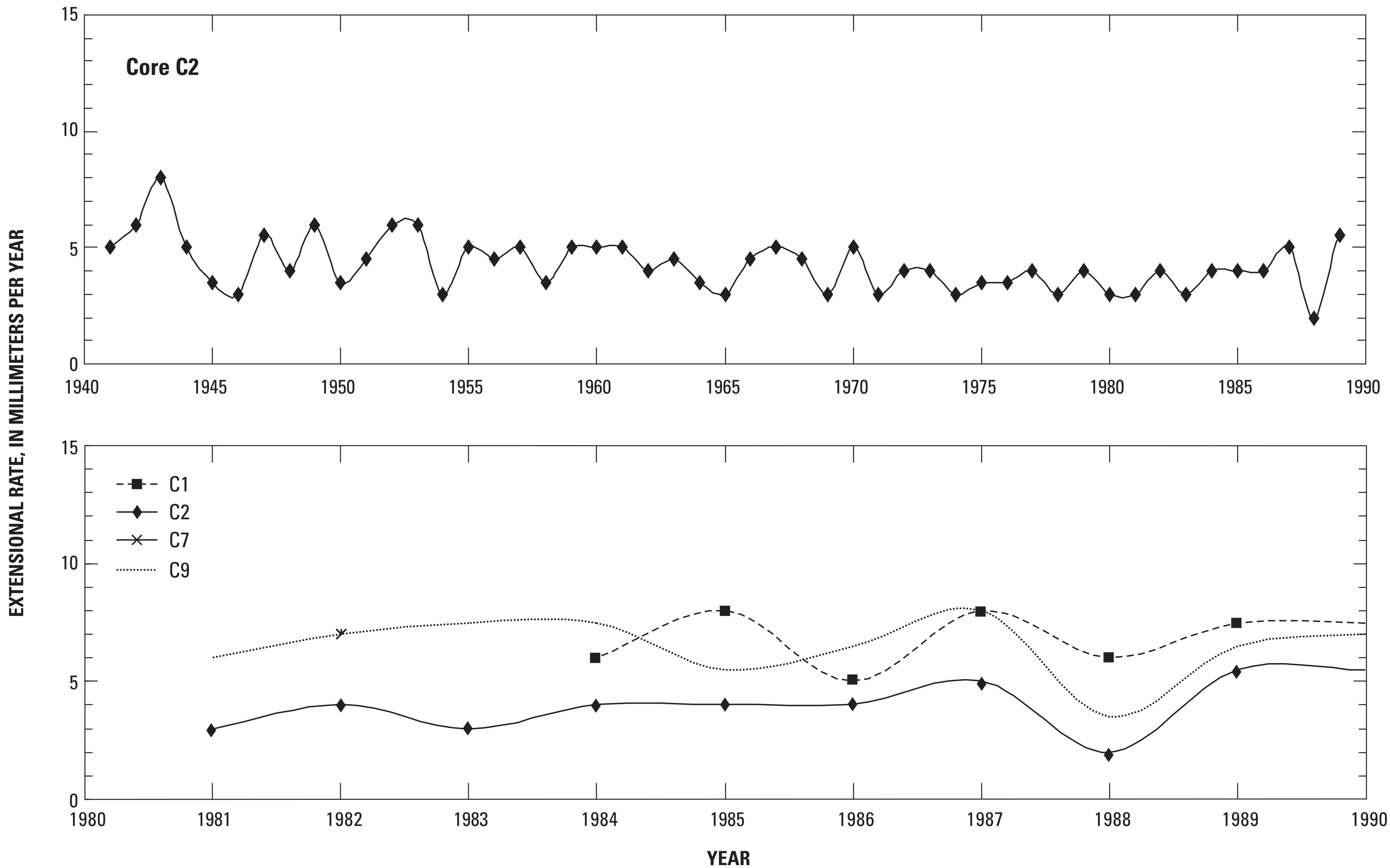


Figure 24. Annual extensional rates for variable time periods between 1941 and 1990 in X-radiographs of four samples of *Montastrea annularis* cored at station MO-1 (cores C1 and C2) in the Bahía de Añasco, and at station MO-3 (cores C7 and C9) in the Escollo Negro, Puerto Rico.

Chemistry of the Coral Lattice

The chemistry of the aragonite lattice deposited by coral communities varies in response to ambient environmental conditions such as water temperature and light, in addition to vital metabolic processes such as growth and reproduction. Correlations of ratios for carbon and oxygen isotopes measured during this study vary through time, from site to site, and from colony to colony (fig. 25). Values of $\delta^{18}O$ varied from -6.88 to -4.01. Values for $\delta^{13}C$ varied from -4.05 to -0.09. The average $\delta^{18}O$ value for the 1984-90 period for core C7, the fastest growing coral colony (10.5 mm/yr), was -4.6, whereas the average value for core C9, an adjacent slower growing community (6.5 mm/yr), was -5.18. Even though the average values are different for communities growing at the same site, the relative changes in isotopic ratios are generally similar. Goenaga (1988) showed that high-density bands do not necessarily form at the same time of the year for all communities in a given area. Values of $\delta^{18}O$ measured in annual bands deposited from 1964 through 1982 at Enrique Reef in southwestern Puerto Rico varied between -4.96 and -4.08, whereas values for $\delta^{13}C$ varied from -2.4 to 0.60 (Winter and others, 1991). For the period measured from 1984-90, variations of carbon isotopes in the cores from Escollo Negro correlated with oxygen isotopes better than similarly paired carbon/oxygen measurements for the cores from the Bahía de Añasco. Paired $\delta^{18}O/\delta^{13}C$ values for samples from cores C7 and C9 (1984-90), had correlation coefficients of 0.69 and 0.91, respectively. Cores C1 and C2 had a correlation coefficient of 0.40 (1984-90). This indicates that the corals growing in the Escollo Negro respond more linearly to changes in light, temperature, and salinity, than those growing at the station sampled in the Bahía de Añasco. McConnaughey (1989) may describe the reefs of Escollo Negro as being more subject to "kinetic" isotope effects (physical properties of the water and climate) than the reefs growing in the Bahía de Añasco, that apparently are more subject to "vital" isotope effects (metabolic effects of respiration, photosynthesis, and reproduction).

The isotopic ratios measured in the 3-year composites for the period 1938-89, sampled from core C2 in the Bahía de Añasco, reveal that the "kinetic" isotope effect or strength of correlation between carbon and oxygen isotopes has varied greatly in the Bahía de Añasco through the years (fig. 26). In general, the correlations were good except for two periods, 1950-53 and 1962-65. This could be a result of changing circulation or changing water quality. Winter and others (1991) did not find statistically significant correlations between the carbon and oxygen isotopes measured in annual bands deposited by *Montastrea annularis* living at Enrique Reef, off southwestern Puerto Rico, for the period 1964-82. However, they noted that correlations between the isotopes and sea surface temperature improved considerably after 1969. They attributed the change in trends to changes in the interannual variability of the North Atlantic circulation.

Whereas isotope values do not correlate well with observed extensional rates in core C2 for the period 1938-90 (fig. 27), there is evidence that warm waters associated with strong El Niño years are recorded faithfully. During years when "kinetic" effects are dominant, isotopic minima should occur in years of higher temperatures and clearer waters (McConnoughey, 1989). The four minima (excluding the outermost year) observed in the average annual $\delta^{18}O$ and $\delta^{13}C$ values for the long-term C2 core coincide with the years 1941, 1959, 1968, and 1982. The two most significant of these minima were centered at years 1941 and 1982, corresponding to two of the strongest El Niño years of this century (1940 and 1982). During El Niño years, there is a transfer of warm sea surface temperatures from the eastern equatorial Pacific to the western equatorial Atlantic, which is very distinct up to 10° latitude and is observable at the latitude of Puerto Rico (Kawamura, 1994). Malmgren and others (1998) verified that El Niño events are strongly related to increased sea and air temperature in Puerto Rico, whereas interannual precipitation is related more strongly to the North Atlantic Oscillation.

Lattice-bound trace-metal concentrations varied between stations and also with time, although the analyses were problematic. Because the duplicate analyses had low precision (table 5), interannual variations of specific trace metals throughout the coral skeleton are considered only as qualitative.

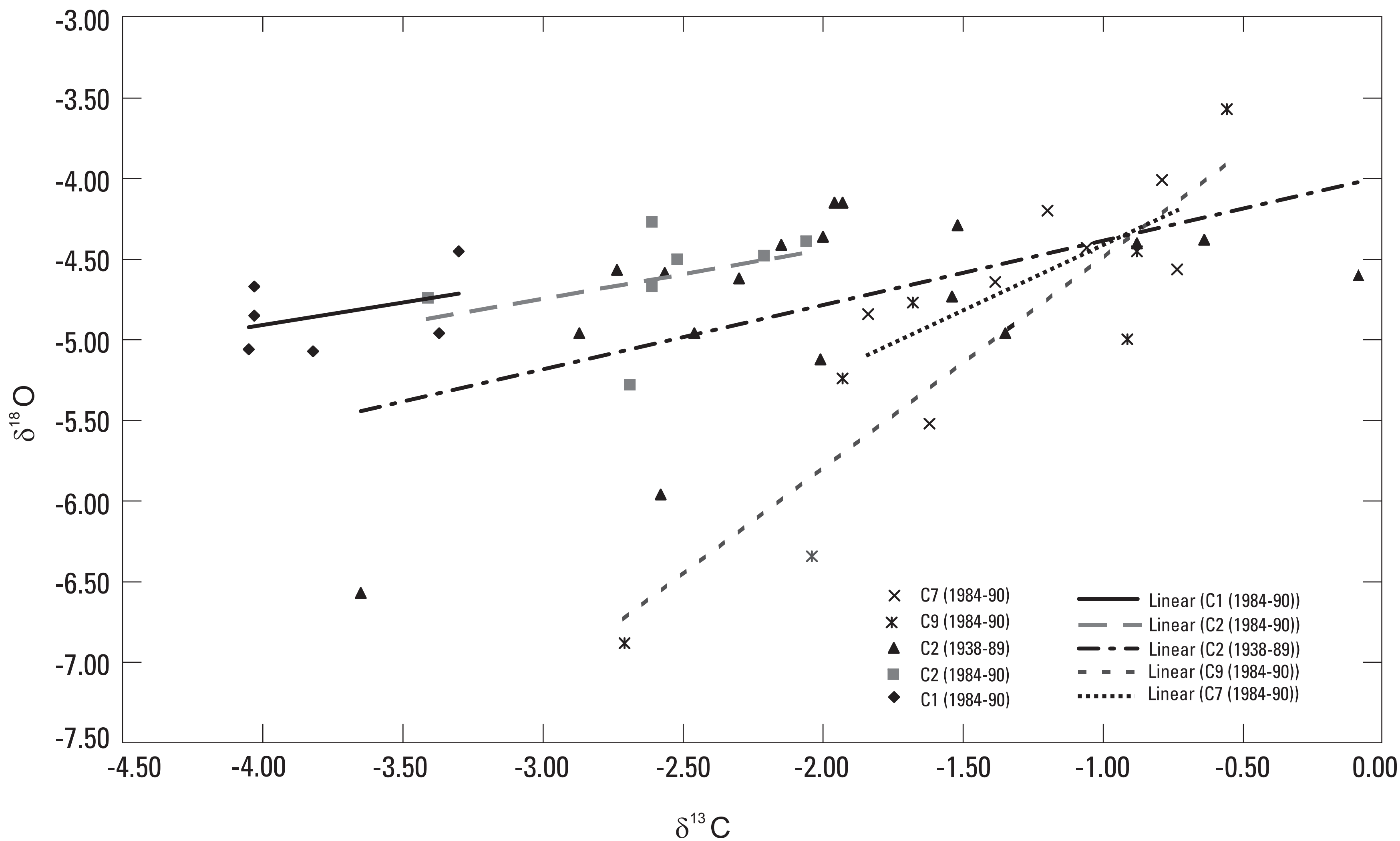


Figure 25. Relation of $\delta^{13}C$ to $\delta^{18}O$ for annual bands deposited by *Montastrea annularis* at station MO-1 (cores C1 and C2) near the outfall, and at station MO-3 (cores C7 and C9) in the Escollo Negro, Puerto Rico.

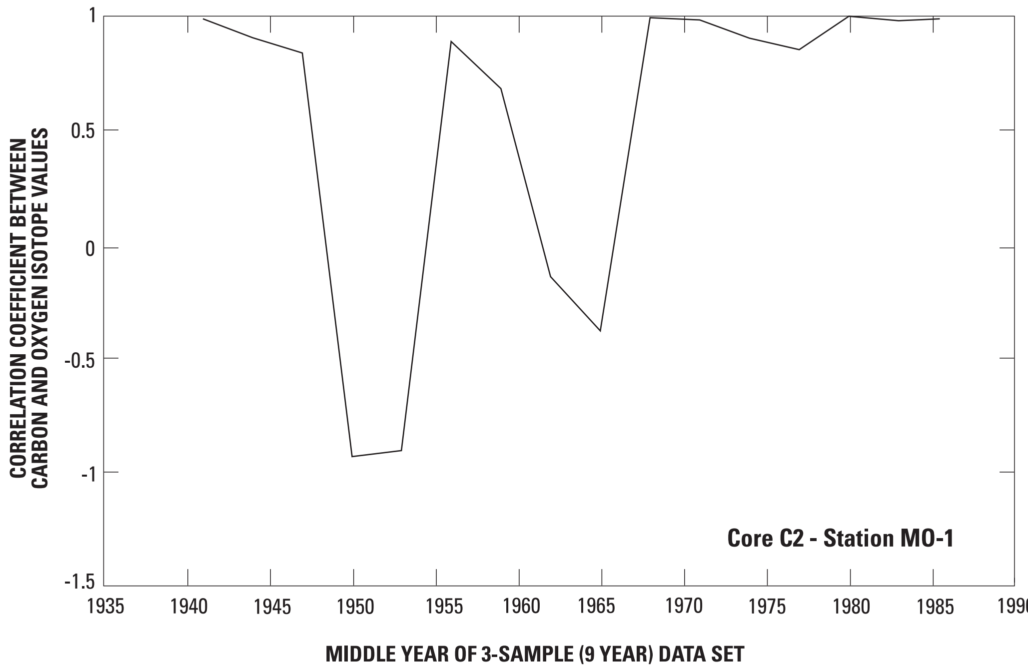


Figure 26. Three-period (9-year) moving average of correlation coefficients between carbon and oxygen values for the period 1941-86, measured in the lattice of coral core C2, growing at station MO-5 near the outfall in the Bahía de Añasco, Puerto Rico. The dataset includes isotope values measured for the period 1938-89.

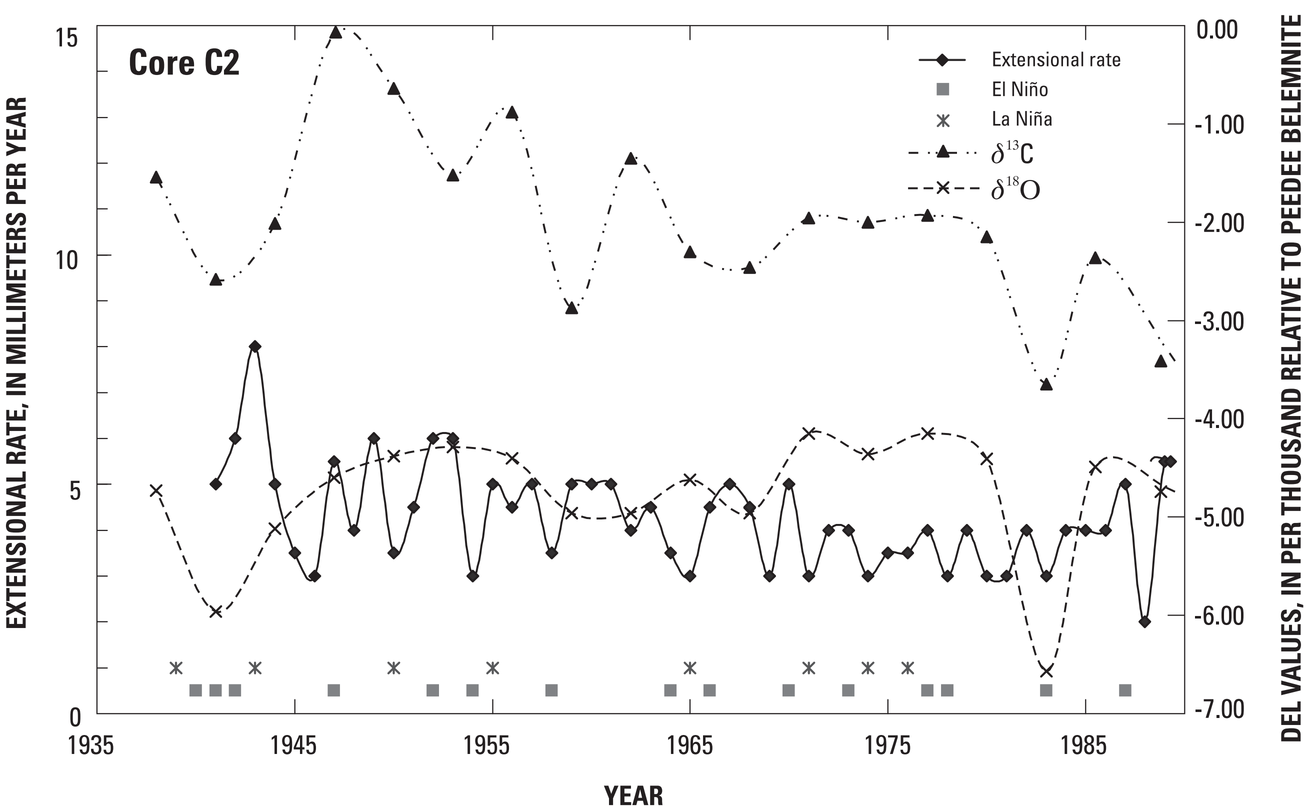


Figure 27. Extensional rates and $\delta^{13}C$ to $\delta^{18}O$ values for the period 1938-90 measured in core C2, growing at station MO-5 near the outfall in the Bahía de Añasco, Puerto Rico.

Duplicate samples were run in a separate analytical run after the primary samples run. The time-series samples were run sequentially and bracketed by runs of standard solutions, so there is some confidence that the observed temporal changes in trace-element concentrations in the coral lattices are indicative of changing water quality through time. Additional confidence may be derived from the differences observed between the average trace-metal concentrations among all stations, and also in the differences in the average concentrations between station MO-1 near the outfall and station MO-3 in the Escollo Negro. In order of decreasing concentration, lattice-bound trace metals detected were nickel, manganese, copper and iron (similar concentrations), zinc, chromium, and lead (table 13 and appendix C).

The enrichment relative to seawater of lattice-bound manganese in corals sampled in the Bahía de Añasco is significantly greater than those measured in corals sampled in the Escollo Negro, whereas the enrichment of cadmium in the corals sampled in the Escollo Negro is significantly greater than that observed in the corals sampled in the Bahía de Añasco (fig. 28). Average seawater concentrations were used for comparison, because trace-metal concentrations measured for the receiving waters during this study were often below the minimum reporting limit. The manganese is apparently an indicator of proximity to the discharge of the Río Grande de Añasco. Cadmium is more concentrated in deeper ocean water and its variations in coralline lattices have been related to upwelling intensity in the area in which the corals are growing. The rotation of the earth results in net surface-water movements 90 degrees to the right of the prevailing winds in the northern hemisphere, a phenomenon known as Ekman transport. Ekman transport produced by the easterly trade winds blowing over the deep waters west of Mayagüez should move surface water to the north in the area of the Escollo Negro. Escollo Negro lies on the northern margin of the extensive carbonate platform that lies off of southwest Puerto Rico. Water depths that are commonly less than 10 m on the platform increase to over 200 m within a few km to the north. Therefore, in terms of the intermediate ocean depths that Ekman transport operates, the platform may be considered subaerial, effectively an east-west oriented shoreline. The deeper waters to the north of the platform could be expected to upwell along the shelf break as the surface waters are transported to the north. Overall, the chromium, copper, nickel, and lead values measured in the lattice of the corals growing in the Escollo Negro exceeded those measured for the Bahía de Añasco corals. This suggests that a significant amount of the dissolved metals discharged from the Río Yagüez and the Río Guanajibo may travel westward into the waters bathing the Escollo Negro.

Variations in manganese/calcium and cadmium/calcium ratios measured for the period 1938-90 in the lattice of core C2 suggest that the effect of the Río Grande de Añasco is increasing in the area of the outfall and that periodic upwelling of deep water may affect the interior portions of the Bahía de Añasco (fig. 29).

Table 13. Mean concentrations of lattice-bound trace metals measured in corals growing at station MO-1 (C1 and C2) near the ocean outfall, and at station MO-3 (C7 and C9) in the Escollo Negro reef complex

[Units are nanomoles per mole of calcium, except for nickel, which is in micromoles per mole of calcium. Standard deviations are listed in parentheses.]

Core	Cd/Ca	Cr/Ca	Cu/Ca	Fe/Ca	Mn/Ca	Ni/Ca	Pb/Ca
C1 (1984-90) (n=7)	4.6 (2.3)	59.8 (26)	250.2 (81.2)	386.2 (463)	823.7 (116.3)	0.5 (0.2)	12.4 (3.7)
C2 (1984-90) (n=7)	7.5 (4.8)	65.5 (12.8)	376.6 (140.8)	447.4 (287.5)	901.3 (248.1)	0.9 (0.5)	29.5 (18.4)
C2 (1943-89) (n=16)	8.4 (5.1)	63.7 (16.4)	266.9 (151.2)	341 (340.1)	637.4 (121.2)	0.6 (0.3)	18 (8.8)
C7 (1985-90) (n=6)	34.1 (25.2)	71.8 (11.7)	606.9 (706.1)	287.2 (312.3)	342.5 (51.3)	0.9 (0.1)	19.9 (7.1)
C9 (1984-90) (n=7)	19.3 (8.3)	73.4 (42.2)	414 (204.5)	665.1 (561.5)	308.1 (94.3)	1.6 (0.4)	26.4 (5)

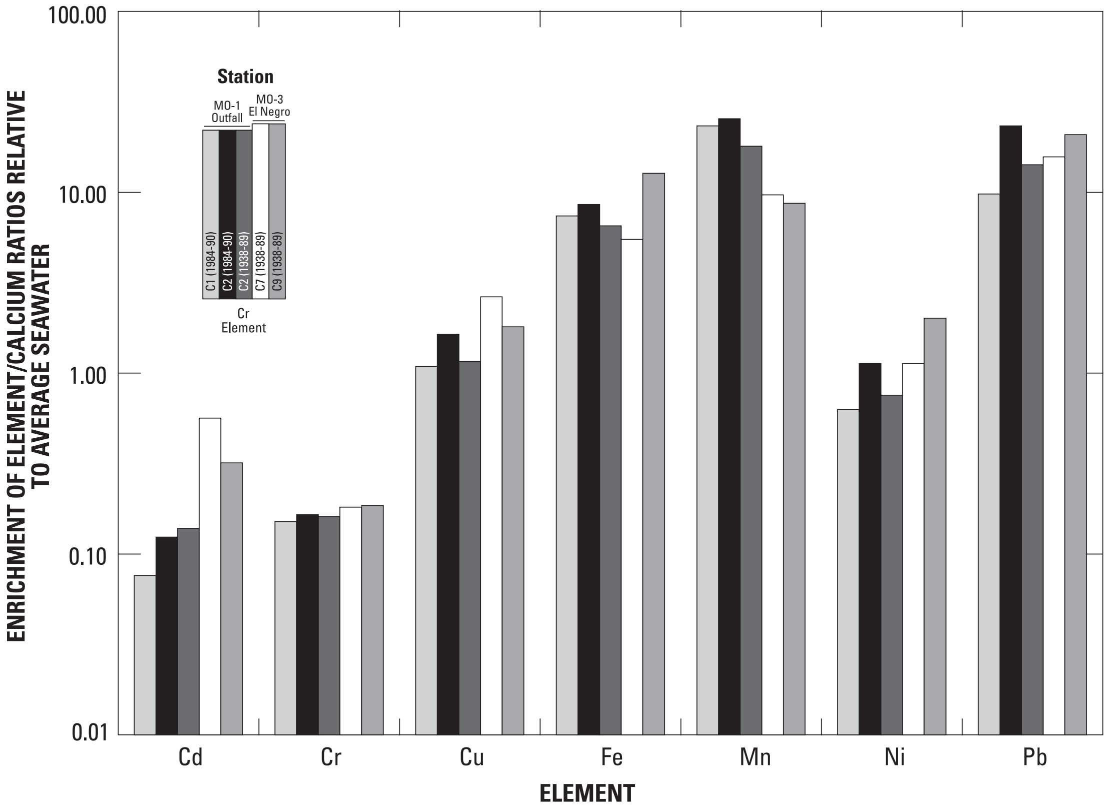


Figure 28. Average enrichment of coral lattice-bound elements relative to average concentrations in seawater for coral cores C1 and C2, growing at station MO-1 near the outfall, and cores C7 and C9, growing at station MO-3 in the Escollo Negro, Puerto Rico.

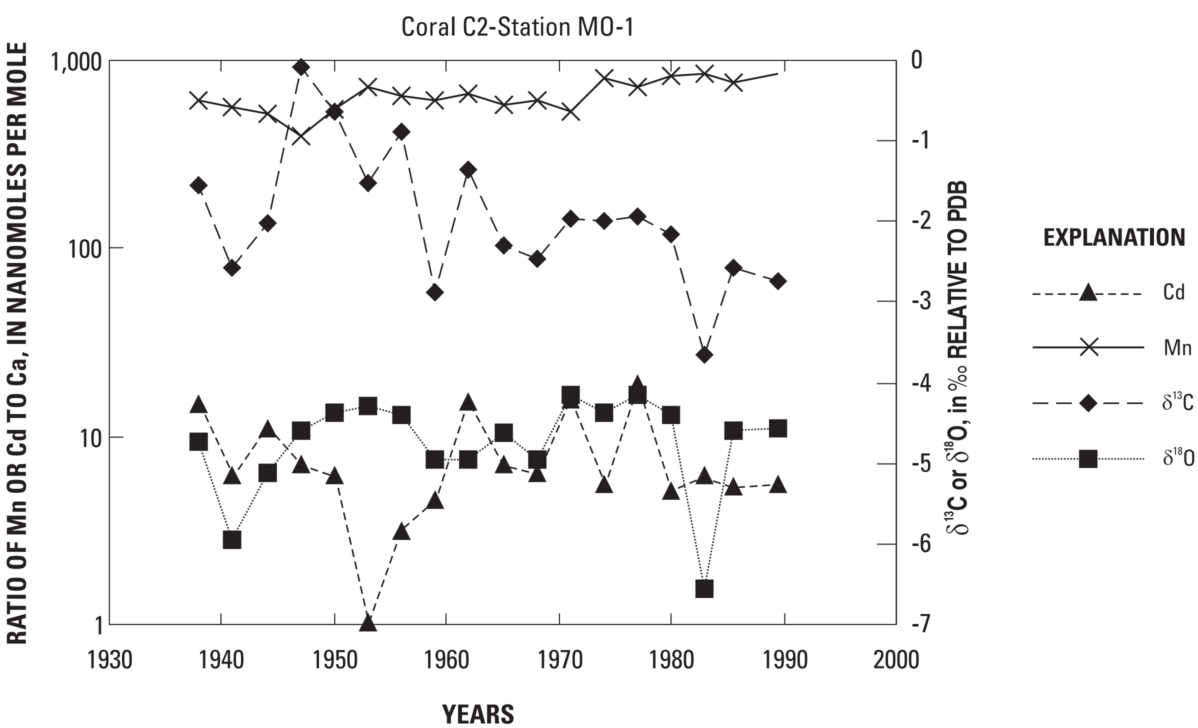


Figure 29. Manganese/calcium and cadmium/calcium ratios, and $\delta^{18}O$ to $\delta^{13}C$ values for the period 1938-90 measured in core C2, growing at station MO-1 in the Bahía de Añasco, Puerto Rico.

To evaluate whether groups of lattice-bound metals are responding similarly to environmental conditions, such as river discharge and ocean circulation patterns (upwelling or downwelling), a principal component analysis was completed using the 8 metal/calcium ratios measured in 41 samples obtained from the corals at stations MO-1 and MO-3. The largest factor could account only for 38 percent of the variance; increasing the number of factors to three helped only slightly, accounting for 68 percent of the variance. Therefore, the data for the 28 samples analyzed from station MO-1 were analyzed separately from the 13 samples for station MO-3. This eliminates the variance, due to differences between stations, and is reasonable in light of their distinct environments.

Using the separated data sets, three factors could account for 78 percent of variance observed at station MO-1 and for 74 percent at station MO-3. The factors appear to be associated with river discharge and ocean currents. For convenience, they are named river (factor 1), oceanic (factor 2 at MO-1 and factor 3 at MO-3), and calm (factor 3 at MO-1 and factor 2 at MO-3). The river factor is likely associated with periods of intense runoff, whereas the oceanic and calm factors are likely associated with changes in surface water chemistry resulting from shifts in local and regional oceanic circulation patterns. The river factor accounted for 49 percent of the variance at MO-1 and 37 percent of the variance at MO-3. The oceanic factor accounted for 17 percent of the variance at MO-1 and 16 percent of the variance at MO-3. The calm factor accounted for 12 percent of the variance at MO-1 and 21 percent of the variance at MO-3. The elements, communalities, and loadings for the three factors are presented in table 14. The three factors poorly fit (as determined by the communalities) the observations of chromium and lead at MO-1, and copper and iron at station MO-3. To highlight groups within the decreasingly important factors (shaded in table 14), significant elements are here described as those with scores greater than 0.6 for the river factor, greater than 0.5 for oceanic or calm factor (whichever was the second most significant factor), and greater than 0.4 for the calm or oceanic factor (whichever was the third most significant factor). Thus defined, the significant elements in the river factor are copper, manganese, nickel, lead, and zinc, for station MO-1, and iron, nickel, lead, and zinc, for station MO-3. All the river-factor metals are positively correlated. The oceanic factor consists of cadmium inversely correlated with chromium and manganese at both stations MO-1 and MO-3. Increasing cadmium concentrations coincident with decreasing manganese and chromium concentrations could be expected during oceanic processes such as upwelling, which may produce a diffuse flow of cadmium-rich deep water toward the shelf, effectively displacing manganese-rich coastal waters either

Table 14. Factor loadings and communalities for river, oceanic, and calm factors, derived from a principal- component analysis of lattice-bound trace-metal/calcium ratios measured in coral cores C1 and C2 (station MO-1 near the outfall), and cores C7 and C9 (station MO-3 in the Escollo Negro reef complex)

[Factors for each site are listed from left to right in order of decreasing significance in explaining the variability observed at that site. Shaded values identify the significant constituents as described in the text. Abbreviations: comm, communality; prop, proportion of variation accounted for by this factor; --, not applicable]

Metal	Station MO-1				Station MO-3			
	River	Oceanic	Calm	Comm	River	Calm	Oceanic	Comm
Cd	0.56	0.72	-0.04	0.83	-0.07	0.67	-0.62	0.84
Cr	0.51	-0.52	-0.43	0.72	-0.22	0.37	0.75	0.75
Cu	0.84	0.20	-0.18	0.78	-0.15	0.53	-0.12	0.32
Fe	0.57	-0.06	-0.67	0.78	0.66	0.43	0.11	0.63
Mn	0.61	-0.51	0.39	0.78	-0.45	0.61	0.41	0.74
Ni	0.93	-0.01	0.12	0.88	0.91	-0.19	0.14	0.89
Pb	0.71	-0.33	0.30	0.70	0.75	0.45	-0.18	0.80
Zn	0.77	0.36	0.27	0.80	0.92	0.04	0.25	0.91
Prop	0.49	0.17	0.12	--	0.37	0.21	0.16	--

against the shore or to a shallow surface lens, or during downwelling, when shifts in cadmium versus manganese and chromium may reverse. The calm factor consists of chromium and iron at station MO-1, and cadmium, manganese, and copper, at station MO-3. During periods when river discharge is low and a distinct oceanic influence is not present, variations in trace metals in the surface waters will reflect those present in the regional water masses, modified by metals diffused upward from the surrounding sediments. Iron and manganese oxyhydroxides are constituents of natural aquatic systems, and are thought to play a predominant role in the cycling of toxic trace elements in both marine and freshwater sediments (Belzile and others, 1989).

Plotting the factor scores (relative magnitude of each factor in a given sample) with time showed that the mineral assemblages are dissimilar for the two cores growing at different rates at each station (fig. 30). At station MO-3, the oceanic factor reached a minimum in 1987. Negative values for the oceanic factor at station MO-3 would correspond to increasing cadmium and decreasing manganese and chromium, effectively an upwelling event. The greatest river score observed was for the 3-year composite of aragonite deposited in coral core C2 during 1976-79, immediately following the September 1975 flood, the largest on record for the Río Grande de Añasco (Johnson and Quiñones-Aponte, 1982). The river factor in the two cores at MO-3 show mirrored trends, perhaps reflecting that faster growing corals add considerable mass during clear-water periods. This is supported by the observation that the calm factor is more dominant in the two fastest growing cores, C1 and C7, than it is in the two slower growing corals, C2 and C9. Again, the validity of these arguments can only be verified by additional laboratory analyses of the coral-core slabs, to obtain records with finer temporal resolution, and relate the observed variations with oceanographic observations.

Sediments

Sediments sampled in the Bahía de Añasco and the Bahía de Mayagüez were analyzed for texture, percent carbonate, trace elements, and clay mineralogy. In addition, core samples were analyzed for the radioisotope cesium-137 to estimate sedimentation rates. The results were used to elucidate the varying roles of terrigenous and carbonate sediment production, and to clarify how currents and waves are distributing the sediments throughout the study area. Specific results are presented in appendix D.

Texture and Carbonate Content of Bottom Sediments

The texture of the sediments was similar to that sampled and described by Morelock and others (1983), with groups of sand and gravel, silty sand, and silty clay. Coarser sediments (fig. 31) with higher carbonate content (fig. 32), were sampled in the Manchas Interiores-Manchas Exteriores coral reef complex. The reefal material was dominated by coral fragments, calcareous algae grains, and mollusc fragments. A significant portion of the carbonate grains were darkened. Swift (1967) also found significant darkened carbonate grains in the Bahía de Añasco, as well as terrigenous grains originating from the Río Grande de Añasco, the Río Guanajibo, and local carbonate production.

Texture and Cesium-137 Analytical Results for Discrete Depth Intervals of Core Samples

The concentration of cesium-137 was measured for four sediment cores (appendix D). The minimum reporting limit for the cesium-137 was 1 milliBecquerel per gram (mBq/g). The outfall site (station VCO) apparently has a low sedimentation rate, as significant cesium-137 concentrations were only measured in the most recently deposited sample (0-15 cm). The percent carbonate as determined by wet chemistry was approximately 35 percent, significantly higher than samples recovered in finer sediments nearby that had 10 to 15 percent calcium carbonate. The sidescan-sonar mosaic shows that the southern leg of the outfall is located near a recently buried patch reef. The cesium activity in the sediment core collected from the sand channel in the Manchas Interiores (VCC) was so diluted with carbonate grains that no significant concentrations of cesium-137 were measured. Therefore, no sedimentation rate was calculated for station VCC. The sedimentation rate for the Río Grande de Añasco (station VCA) was calculated to be 3.46 centimeter per year (cm/yr), while that for the Río Yagüez (station VCY) was 2.3 cm/yr.

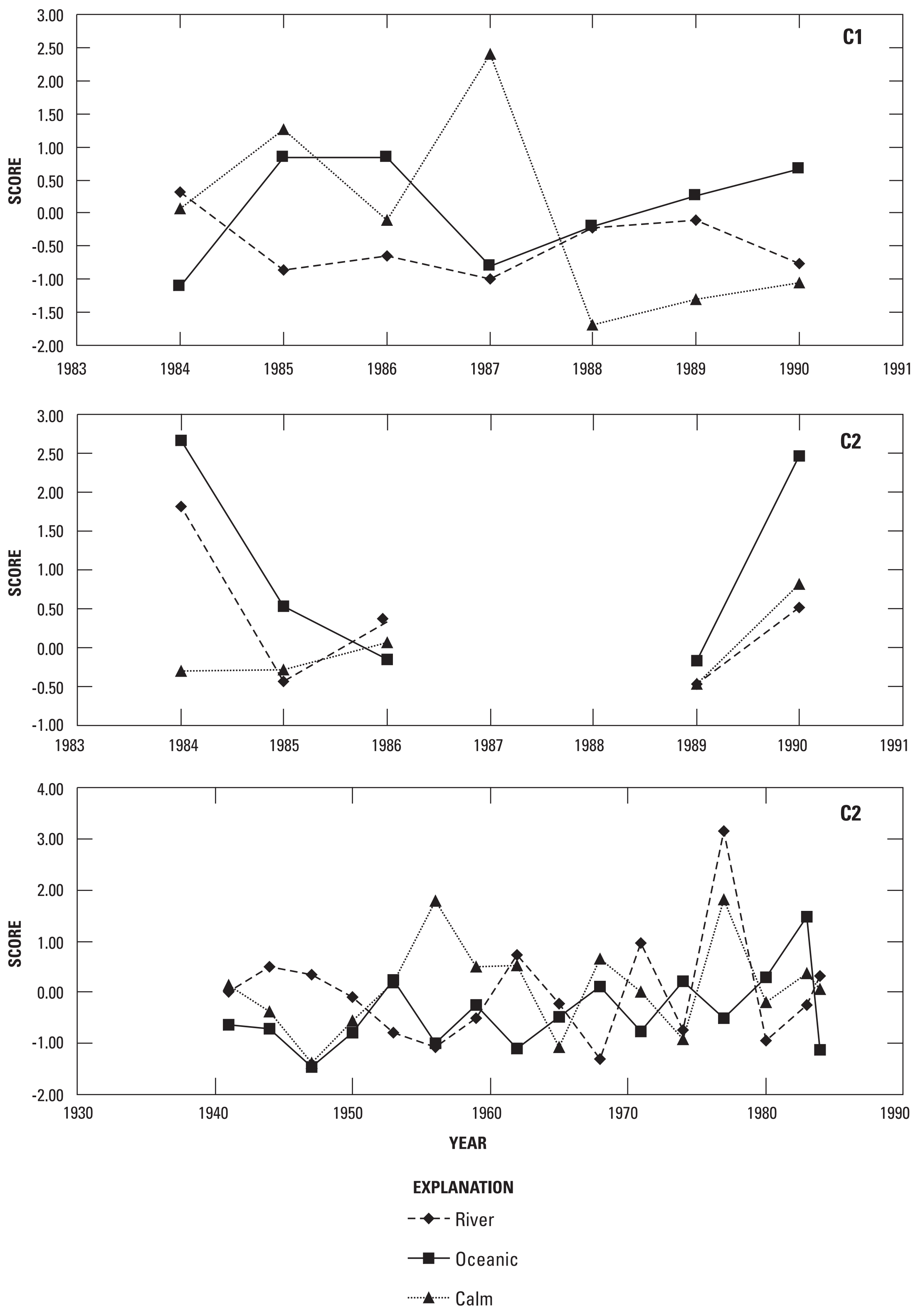


Figure 30. Time series of scores for river, oceanic, and calm factors for the period 1985-90, calculated from trace metals measured in cores C1 and C2, growing at station MO-1 near the outfall, and in cores C7 and C9, growing at station MO-3 in the Escollo Negro, Puerto Rico.

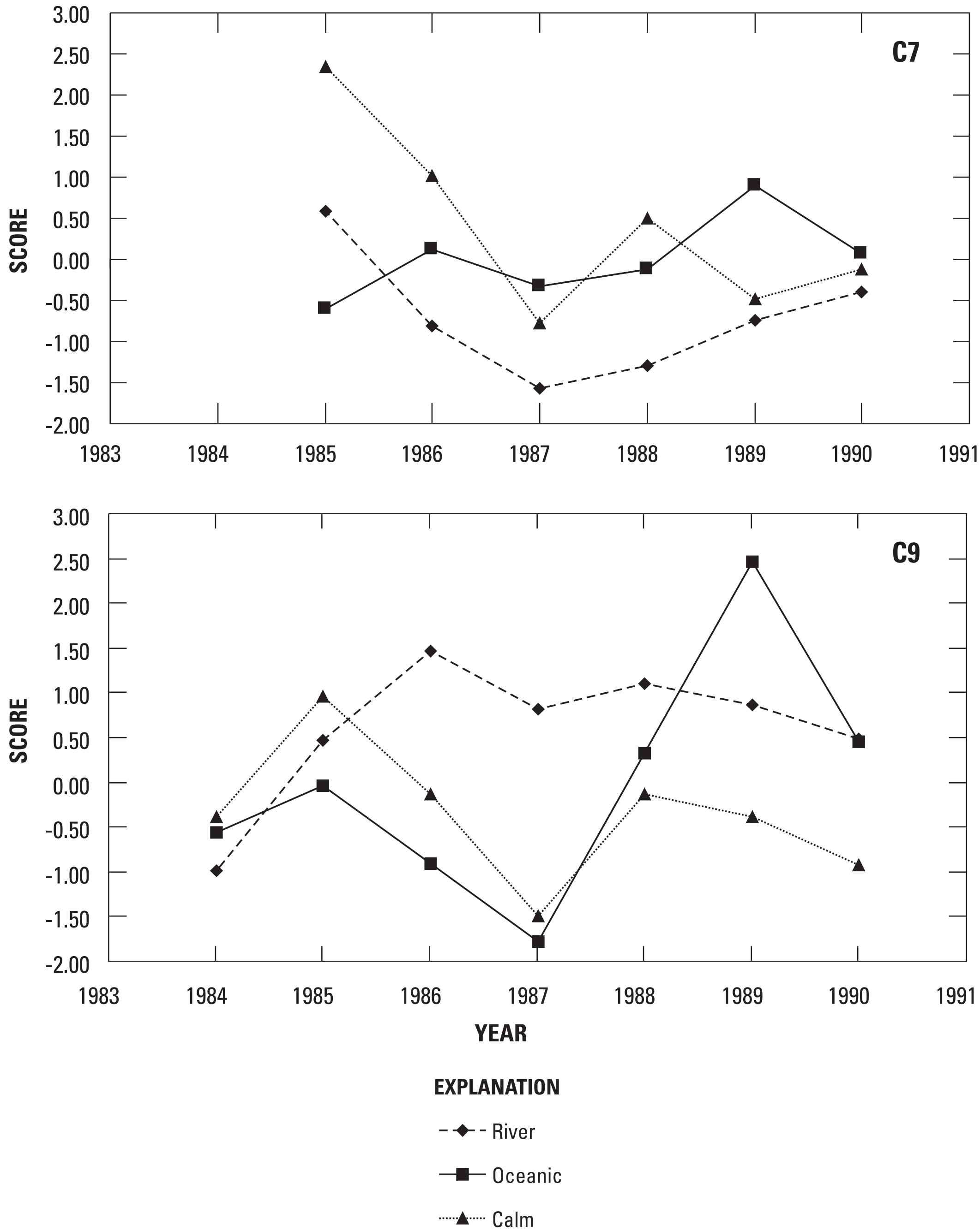
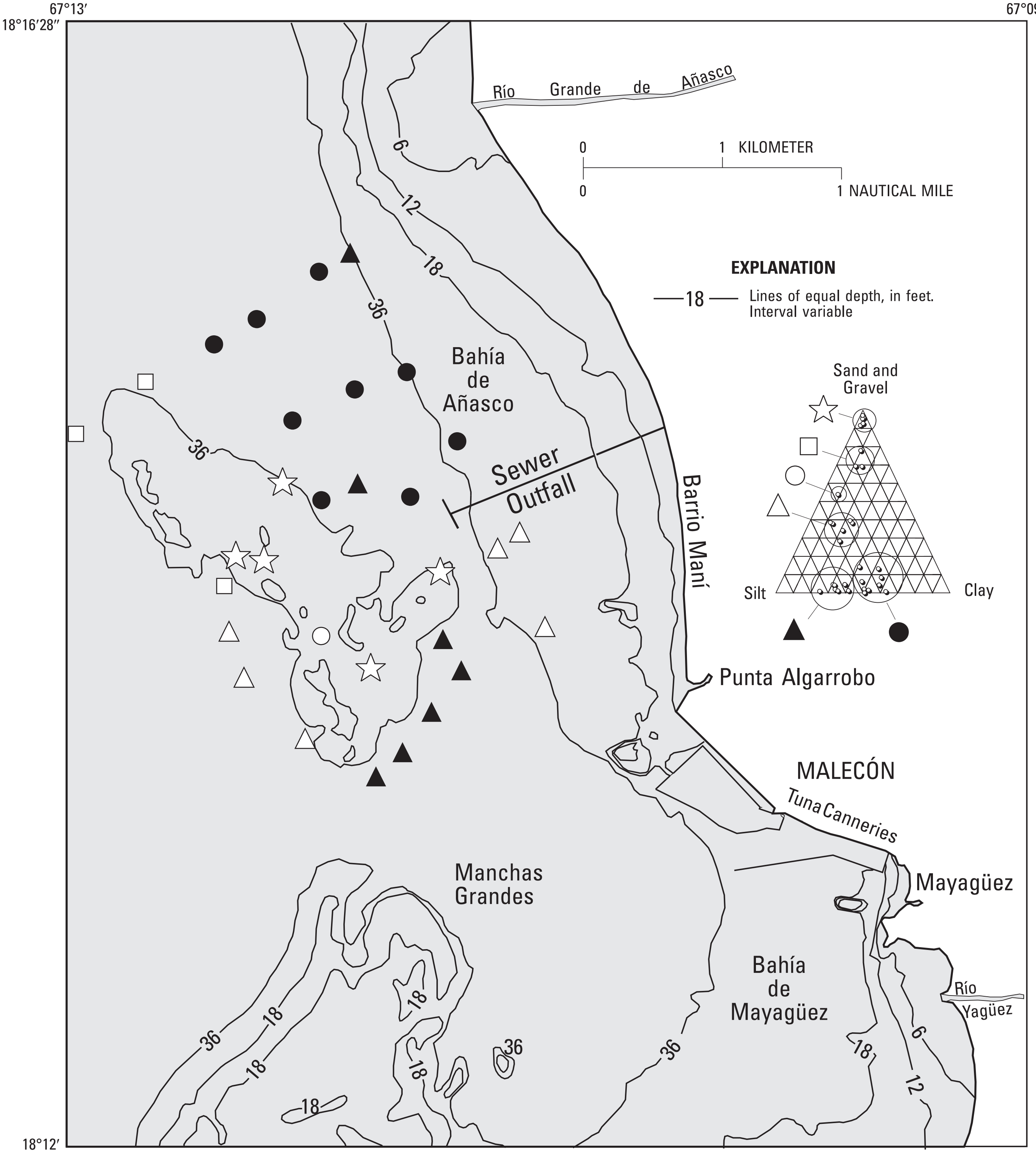


Figure 30. Time series of scores for river, oceanic, and calm factors for the period 1985-90, calculated from trace metals measured in cores C1 and C2, growing at station MO-1 near the outfall, and in cores C7 and C9, growing at station MO-3 in the Escollo Negro, Puerto Rico—Continued.



Base map modified from the National Ocean Service Nautical Chart 25673, 1:15,000.

Figure 31. Texture of sediment samples from 31 stations in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. The ternary diagram indicates the relative percentages of sand and gravel, silt, and clay. Depths measured near the delta of the Río Grande de Añasco during this study were shallower than those indicated by the depths shown from the dated navigation chart used as the base map.

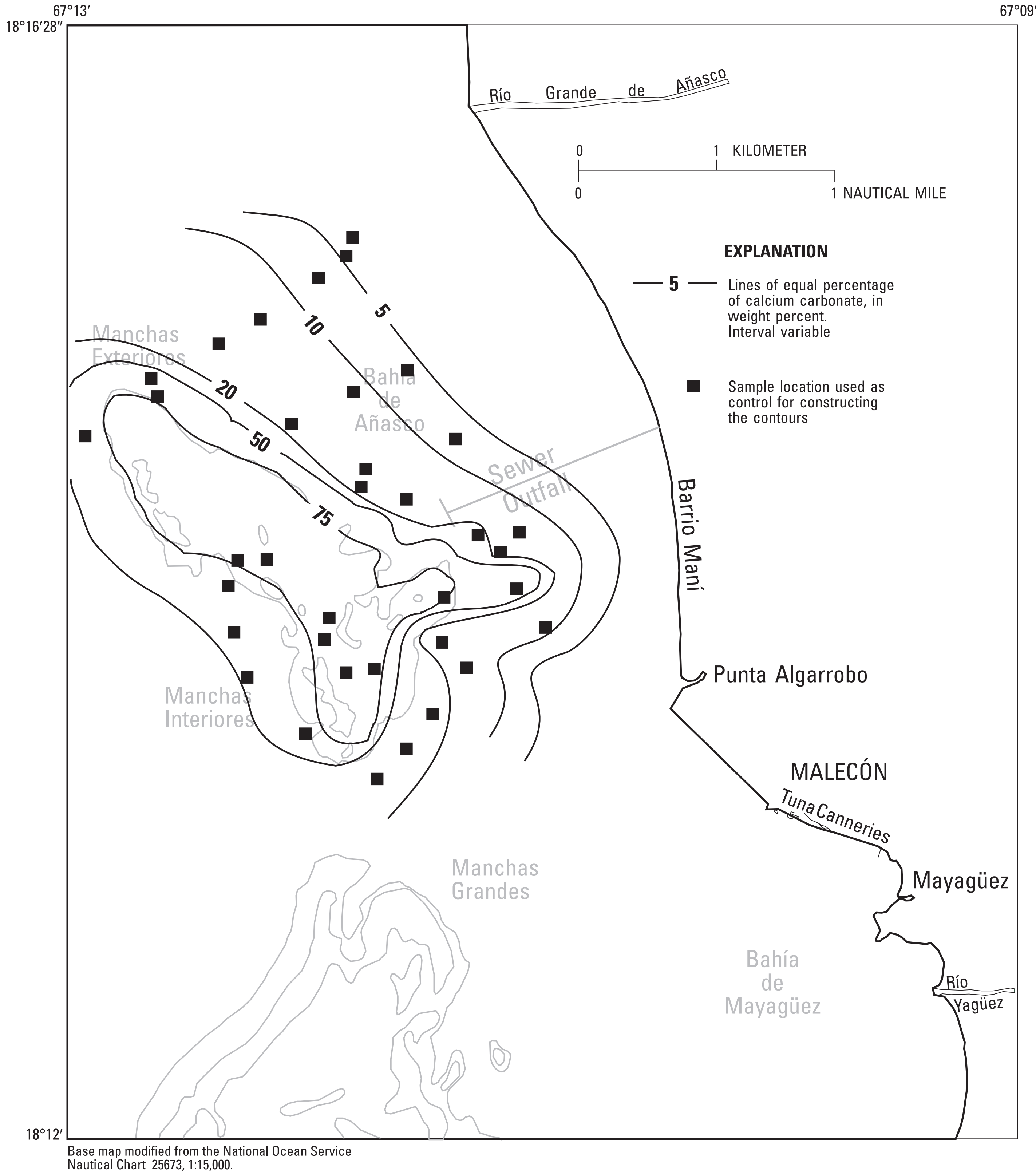


Figure 32. Percentage calcium carbonate measured in sediments sampled in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Unlabeled bathymetric lines are shown in gray.

Clay Mineralogy

The mineralogy of sediments deposited in the Bahía de Añasco (appendix D) reflect the sources in the uplands watersheds, carbonate production, and diagenesis of the marine sediments. Pirie (1967) identified the major clay types illite, chlorite, kaolinite and montmorillonite. The target of Pirie's work was specifically the terrigenous grains. Therefore, he used aggressive digestion techniques that eliminated or obscured the presence of aragonite muds and diagenetic fabrics that were documented during the current study. The presence of kutnahorite and glauconite in the sediments of the Bahía de Añasco and the Manchas Interiores-Manchas Exteriores coral reef complex suggest that terrigenous sediments, organic material, carbonate grains and bacteria have commonly mixed together during the evolution of the Puerto Rico insular shelf. Glauconite is a green micaceous mineral that can be found filling voids of carbonate grains sampled from almost any area off western Puerto Rico (Schneidermann and others, 1976), and has been observed in the tests of foraminifers sampled from the submerged reef immediately west of Manchas Exteriores (Seiglie, 1968). It forms under moderately reducing conditions through the mediation, in some cases at least, of sulfate-reducing bacteria (Deer and others, 1977). The presence of reducing conditions and the presence of reduced sulfur is confirmed by the identification of pyrite, FeS_2, in the sediments. Glauconite was not identified as a separate phase in the diffractographs of the samples obtained during the current study; its presence was likely included within the smectite group which shares similar crystallographic properties. Aragonite, manganese-magnesium carbonates, and calcite, were common components of almost all of the sediments sampled away from the mouth of the Río Grande de Añasco. A particularly strong pattern for a manganese carbonate was present in sample GS18 and the mineral kutnahorite, $CaMn(CO_3)_2$, was identified. Kutnahorite resembles dolomite, $CaMn(CO_3)_2$, in X-ray diffractographs, and forms a solid solution between rhodochrosite, $MnCO_3$, and calcite, $CaCO_3$. Its formation is bacterially-mediated, and it has been observed in electron microscopy to form as rims on calcite grains in laminated lake sediments (Lora R. Stevens, University of Minnesota, oral commun., 1997). Bacterially-mediated diagenesis of the carbonate grains in the Bahía de Añasco has apparently produced an impure carbonate population within the sediments that is geochemically distinct from carbonates accumulating west of Puerto Rico in areas far removed from the effect of the rivers.

Provenance of Sediments

Organic material and trace metals contained in core samples and surface grab samples were analyzed by Dr. Art Horowitz at the USGS Sediment Quality laboratory in Doraville, Georgia. The results are presented in appendix D. Significant temporal and spatial variability in the sediment constituents are present. Concentrations of nickel and chromium deposited in the Bahía de Mayagüez are about 10 times greater than those deposited in the Río Grande de Añasco delta. The concentrations of nickel and chromium in the sediments in the core collected in front of the Río Yagüez (core VCY) varied from 310 to 450 mg/kg and from 299 to 548 mg/kg, respectively. These values exceed the Probable Effects Level (PEL) (42.8 mg/kg for nickel and 160 mg/kg for chromium) used in the sediment-quality guidelines developed for Florida (Florida Department of Environmental Protection, 1994). The sources of these sediments are naturally occurring metal-rich laterite deposits southeast of Mayagüez. The mercury concentration of 1.49 mg/kg measured in one sample (core VCO; 5-10 cm) also exceeds the PEL of 0.696 mg/kg established for mercury.

Lead concentrations measured in core VCO, near the outfall, have increased from 5 mg/kg in the oldest strata to 11 mg/kg in the most recently deposited sediments. However, even these concentrations are still below those measured for the Río Yagüez core site (station VCY), where lead concentrations varied from 11 to 27 mg/kg. All are well below the PEL for lead, established at 112 mg/kg. As with chromium, cobalt, and nickel, lead concentrations in the rocks draining into the Bahía de Mayagüez are elevated in comparison to those draining into the Bahía de Añasco.

To more clearly understand the sources and fates of sediments in the Bahía de Añasco, a provenance analysis was carried out. The results of the provenance study helped to define the sampled sediments as mixtures of distinct sources, each consisting of a suite of associated elements.

To study the provenance of the sediments, an endmember mixing model was developed using a dataset of trace element concentrations measured for 51 sediment samples collected in the Bahía de Añasco. The mixing model was developed using extended Q-mode factor analysis that calculated constituent concentrations of "idealized" mathematical endmembers that closely matched the concentrations measured in "observed" endmembers included in the dataset. Sediment sampling was largely confined to the Bahía de Añasco and the reef area, so the dataset excluded the results of a sediment sample collected in the Escollo Negro (GS36). The geochemistry of the carbonate sample collected in the Escollo Negro was significantly different from the diagenetically-altered carbonates of the Bahía de Añasco, and its inclusion reduced the overall fit of a 3-endmember model tentatively used to describe all of the sediments sampled. The overall fit of the model is described by the communalities, defined as the percentage of variance in the data that can be accounted for by the 3-endmember model.

The endmembers were readily attributed to three sources: sediments discharged by the Río Grande de Añasco, sediments produced by carbonate-fixing organisms within the bay, and sediments discharged by the Río Yagüez/Guanajibo. The three idealized endmembers and their associated observed samples were Añasco (core VCA: 120-140 cm), carbonates (core VCC: 60-110 cm), and Yagüez (core VCY: 40-60 cm) (fig. 33).

For this dataset, communalities averaged 96 percent, with a standard deviation of 5 percent. The worst fit was for a downcore sample near the outfall that had an anomalous mercury value of over 1 part per million, whereas no other sample exceeded 0.5 part per million. The communality using the three endmembers for that sample was 71 percent. In general, the 3-endmember model described the mixing of fine terrigenous sediments in the Bahía de Añasco and the Bahía de Mayagüez with communalities exceeding 98 percent. Communalities for carbonate samples varied between 81 percent and 100 percent (table 15).

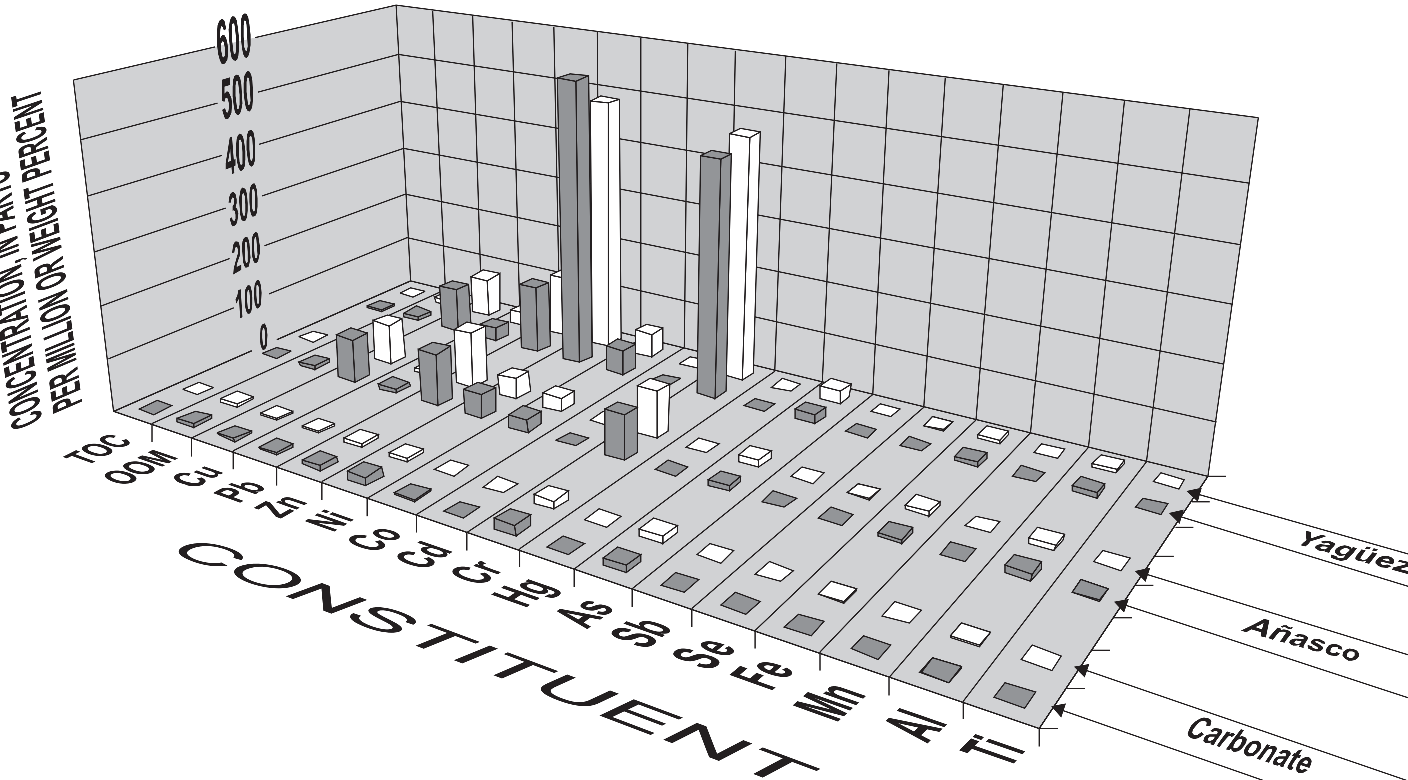
Results from the provenance study show that sediments discharged from the Río Grande de Añasco and sediments resuspended from the interior of the bay are not transported to the western portion of the Manchas Interiores, where the healthiest coral communities were documented. Samples collected from the sand channels in that area contain negligible amounts of the Añasco endmember (fig. 34).

The nickel and cobalt-rich sediments typical of the Río Yagüez and the Río Guanajibo, identified as the Yagüez endmember, are dispersed to the northwest, both to the west and east of the Manchas Interiores (fig. 35).

The percentages of specific endmember contributions at each of the core stations has changed through time. The sedimentation rates calculated for the stations VCA (3.46 cm/yr) and VCY (2.3 cm/yr) were used to convert the sample depths to approximate age of deposition. The percentage of the Añasco endmember in core VCY (Río Yagüez delta) apparently decreased from the beginning of the century until reaching a minimum in 1975, and increased since then. This correlates well with decreasing sediment yields throughout the century, as previously cultivated lands were allowed to go fallow, and the Río Grande de Añasco caused a major flood in 1975. The percentage of the Yagüez endmember in the sediments deposited in the sand channels in the western part of the Manchas Interiores is apparently increasing. The percentage of the Yagüez endmember increased toward the surface of core VCC. The Añasco endmember also increased in core VCC from the base at 110 cm to a maximum in the sediments sampled at between 15 and 20 cm, and decreased in the more recently deposited sediments (fig. 36).

Water Quality

The Río Grande de Añasco, the Río Yagüez, and the Río Guanajibo, affect the water quality of the receiving waters, including the Bahía de Añasco and the Bahía de Mayagüez. The Río Grande de Añasco has the largest discharge of the three rivers and is the principal source of sediments deposited in the Bahía de Añasco. Criteria for dissolved oxygen are often not met in the coastal waters near the tuna canneries (fig. 5) (Natural Resources Conservation Service, 1998). Concentrations of total zinc, boron, iron, lead, manganese, and fecal coliform in the Bahía de Mayagüez also have exceeded coastal water-quality criteria (Natural Resources Conservation Service, 1998).



	TOC	OOM	Cu	Pb	Zn	Ni	Co	Cd	Cr	Hg	As	Sb	Se	Fe	Mn	Al	Ti
Carbonate: Observed	0.20	6.70	4.00	4.00	7.00	15.00	4.00	0.20	17.00	0.02	12.00	0.60	0.30	0.40	0.02	0.60	0.03
Carbonate: Ideal	0.19	6.48	3.02	4.40	6.71	7.96	2.82	0.11	13.78	0.02	13.99	0.34	0.22	0.50	0.02	0.73	0.04
Añasco: Observed	1.30	8.20	84.00	8.00	101.00	46.00	24.00	0.10	83.00	0.07	10.00	0.40	0.20	6.50	0.09	11.30	0.55
Añasco: Ideal	1.26	7.99	78.63	6.21	105.85	39.58	26.81	0.11	89.02	0.11	13.25	0.40	0.23	7.05	0.09	10.99	0.56
Yagüez: Observed	1.40	9.40	88.00	27.00	132.00	548.00	48.00	0.20	450.00	0.07	18.00	0.60	0.40	8.00	0.09	9.10	0.55
Yagüez: Ideal	1.48	10.13	78.34	25.40	121.02	486.12	46.37	0.11	466.28	0.12	26.30	0.56	0.32	7.80	0.10	8.51	0.53

Figure 33. Elemental compositions of observed and idealized endmembers that describe unique sources for sediments deposited in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico. Endmembers were identified by using extended Q-mode factor analysis. The endmember samples are identified as Yagüez (core VCY: 40-60 cm), Añasco (core VCA: 120-140 cm), and carbonate (core VCC: 60-110 cm). Units are weight percent for TOC, OOM, Fe, Mn, Al, and Ti. Units for all other constituents are parts per million. Abbreviations: TOC, total organic carbon; OOM, other organic material.

Table 15. Communalities explaining percent of variability measured in geochemical composition of sediment samples that can be accounted for as a mixture of the three idealized endmember compositions detailed in figure 33

[Intervals are depth below the sediment/water interface, in centimeters. The 12 bottom sediment sites in the GS series are assigned a sampling depth of 10 centimeters, the average depth of the Shipeck sampling bucket. Abbreviations: comm, communality]

Site	Sampled interval		Comm	Site	Sampled interval		Comm
	Top	Bottom			Top	Bottom	
VCA	0	20	0.98	VCC	10	15	0.98
VCA	20	40	0.98	VCC	15	20	0.91
VCA	40	60	0.98	VCC	20	60	0.90
VCA	60	80	0.99	VCC	60	110	0.90
VCA	80	100	0.98	VCO	0.0	5.1	0.96
VCA	100	120	0.99	VCO	5.1	10.2	0.71
VCA	120	140	0.99	VCO	10.2	15.2	0.97
VCA	140	160	0.95	VCO	15.2	20.3	0.97
VCA	160	180	0.99	VCO	25.4	30.5	0.97
VCA	180	200	0.99	VCO	30.5	35.6	0.95
VCA	200	220	0.97	VCO	35.6	45.7	0.93
VCA	220	240	0.98	VCO	45.7	50.8	0.95
VCA	240	258	0.98	VCO	61.0	63.5	0.92
VCY	0	20	0.99	GS1	0.0	5.0	0.97
VCY	20	40	0.99	GS2	0	10	0.97
VCY	40	60	0.99	GS6	0	10	0.97
VCY	60	80	0.99	GS7	0	10	0.97
VCY	80	100	0.99	GS11	0	10	0.99
VCY	100	120	0.99	GS12	0	10	0.97
VCY	120	140	0.99	GS16	0	10	0.92
VCY	140	160	0.99	GS18	0	10	0.92
VCY	160	180	0.99	GS21	0	10	0.97
VCY	180	200	0.98	GS34	0	10	0.81
VCY	200	220	0.97	GS35	0	10	0.85
VCC	0	5	0.90	GS38	0	10	0.96
VCC	5	10	0.92				

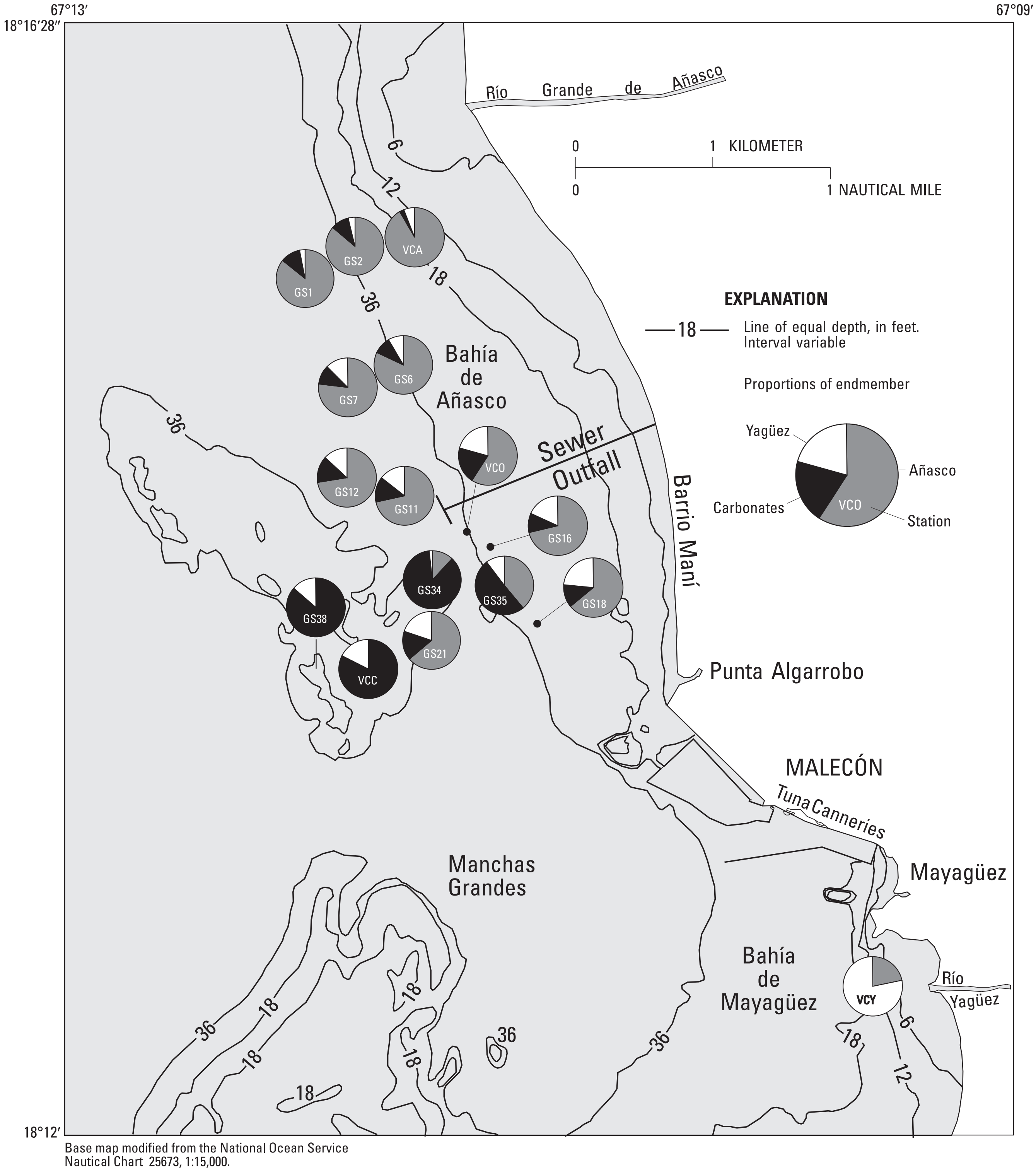


Figure 34. Relative percentages of source material for bottom sediments sampled from 16 stations in the Bahía de Añasco and in and around the Manchas Interiores-Manchas Exteriores coral reef complex, Puerto Rico. The pie charts indicate the relative percentages contributed from idealized endmember sources identified with extended Q-mode factor analysis as typical of the Río Grande de Añasco, the Río Yagüez (includes sediment from the Río Guanajibo), and carbonate grains produced by local benthos (fig. 33). Pie charts are centered over the sample location unless otherwise indicated. Depths measured near the delta of the Río Grande de Añasco during this study were shallower that those indicated by the depths shown from the dated navigation chart used as the base map.

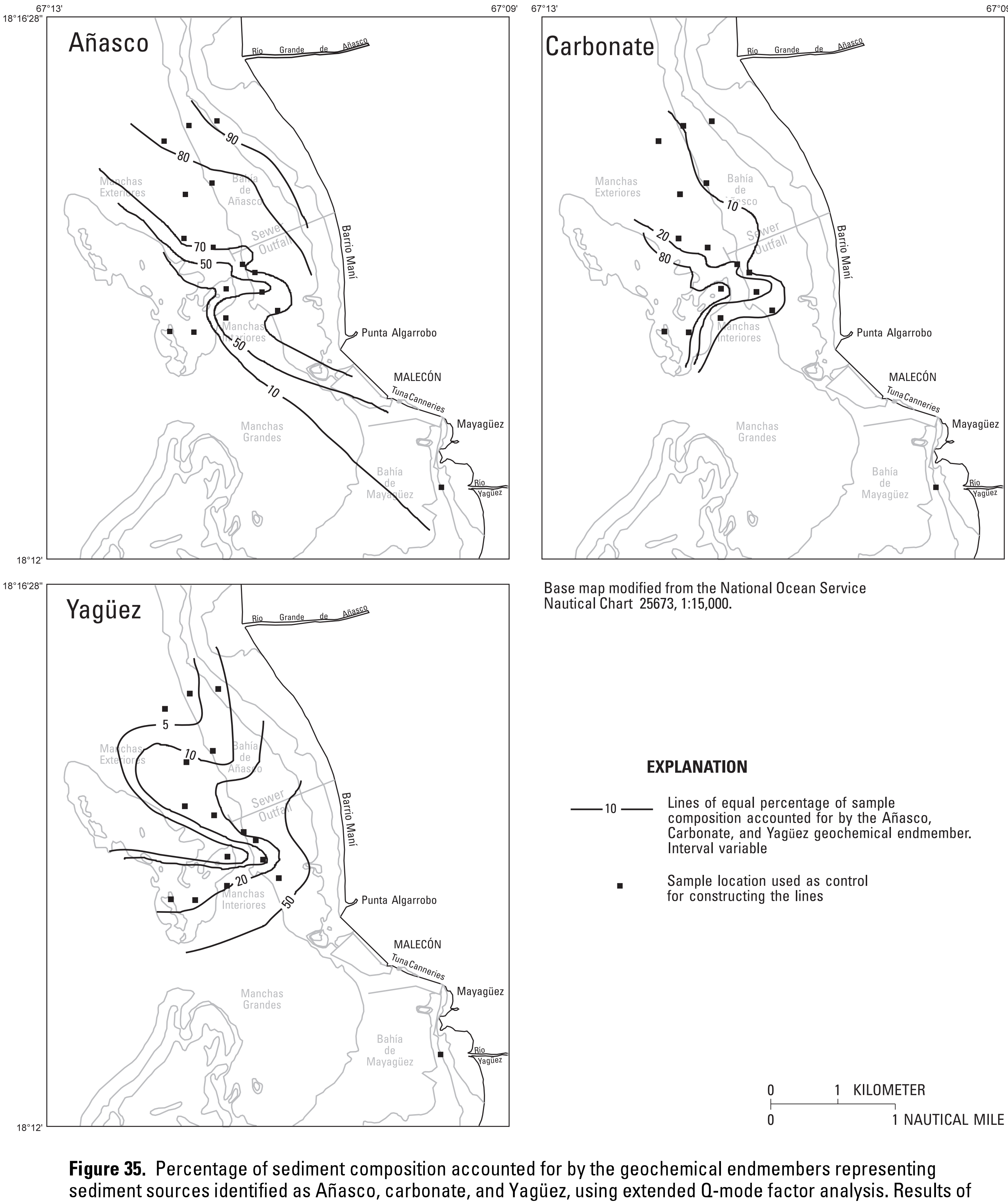


Figure 35. Percentage of sediment composition accounted for by the geochemical endmembers representing sediment sources identified as Añasco, carbonate, and Yagüez, using extended Q-mode factor analysis. Results of the factor analysis are listed in appendix D-7.

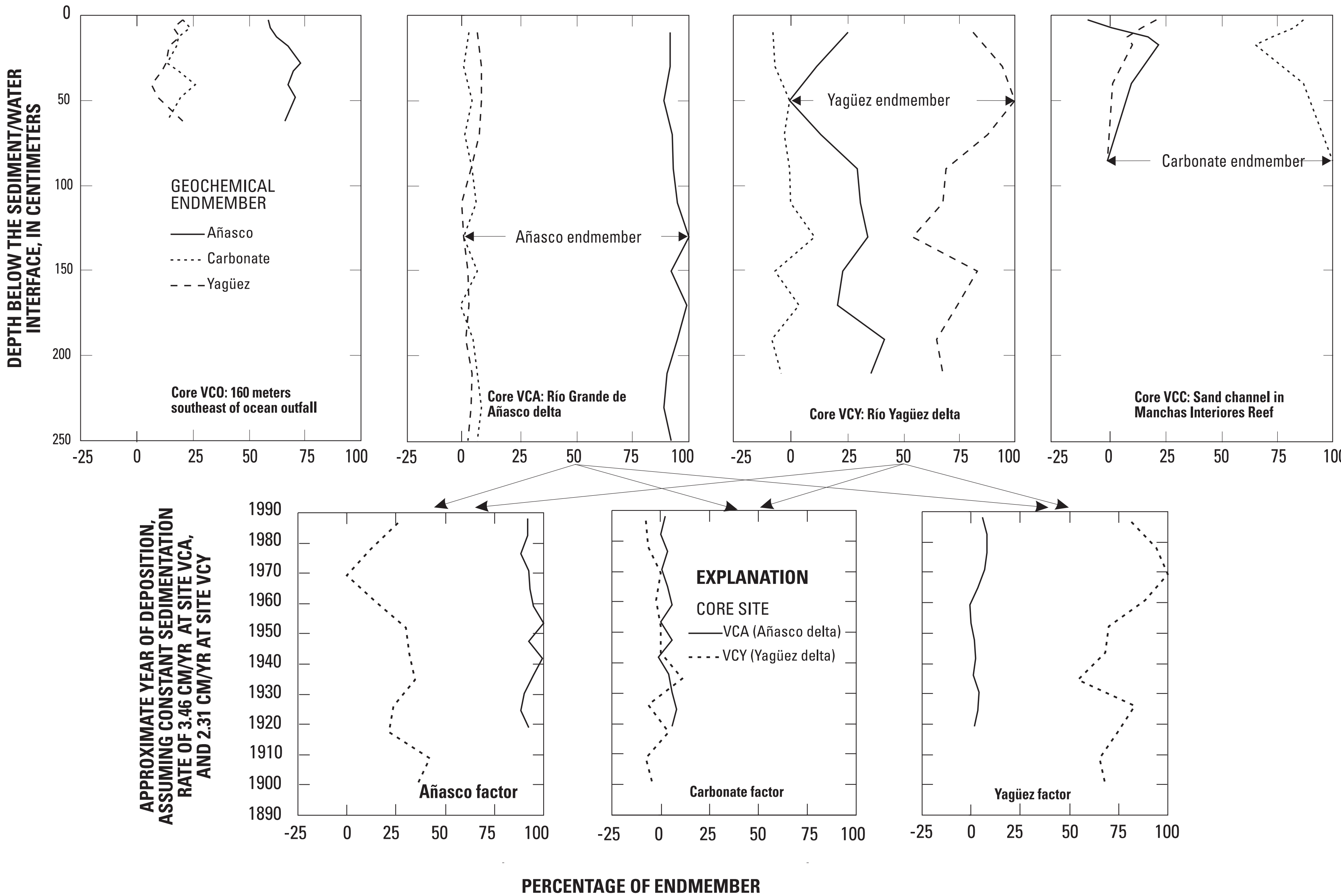


Figure 36. Variations in percentages of geochemical endmembers representing sediments from the Río Grande de Añasco (Añasco factor), biogenic carbonates (carbonate factor), and sediments from the Río Yagüez and the Río Guanajibo (Yagüez factor) documented for the cored sites VCO, VCA, VCY, and VCC. Site locations are shown in figure 9. The elemental compositions of the endmembers are shown in figure 33. Negative proportions indicate that the selected three endmembers do not explain the variations in geochemistry well for that sample. Reasons for a poor fit could include the presence of unidentified sources or the removal of a selected endmember. For the two sites where sedimentation rates were estimated (VCA and VCY) the variations through time are plotted assuming a constant sedimentation rate throughout this century.

Historical Water Quality of the Río Grande de Añasco, the Río Yagüez, and the Río Guanajibo

Several local wastewater plants discharge into the drainage system of the Río Guanajibo, resulting in higher overall contaminant loadings for that river in comparison with the Río Grande de Añasco (Natural Resources Conservation Service, 1998). Wet and dry years for the Río Grande de Añasco and the Río Guanajibo covary (fig. 37). Data collected at the stream gage and water-quality site on the Río Rosario (USGS station number 50136400) show that, in general, sediment loads discharged from the uplands also correlate with average discharge. The greatest daily load of sediment, 74,700 tons, passed the Río Rosario station on October 7, 1985, the day of the tragic landslides that occurred in the Mameyes sector of Ponce.

Specific conductivity is higher and dissolved oxygen concentrations are lower in the Río Guanajibo than they are in the Río Grande de Añasco (fig. 38). The Río Guanajibo drainage basin contains more municipal wastewater treatment plants, has lower average slopes, and has more ground water storage than the Río Grande de Añasco. The Río Guanajibo has an extensive alluvial valley underlain by 50 to 150 feet of clay, sand, and gravel, deposited on limestone in the southern part of the watershed, and deposited directly on andesite and basalt in the northern part of the watershed (Colón-Dieppa and Quiñones-Márquez, 1985).

Receiving Water Quality, January 1991

Vertical profiles of the marine water quality in the area of the ocean outfall showed that the waters are well mixed and oxygen saturated. A summary of all analyses for priority pollutants, pesticides, herbicides, metals, general inorganics, and radionuclides, done at Rocky Mountain Analytical Laboratory (RMAL) are presented in table 16 (page 91). Detailed results are presented in appendix E.

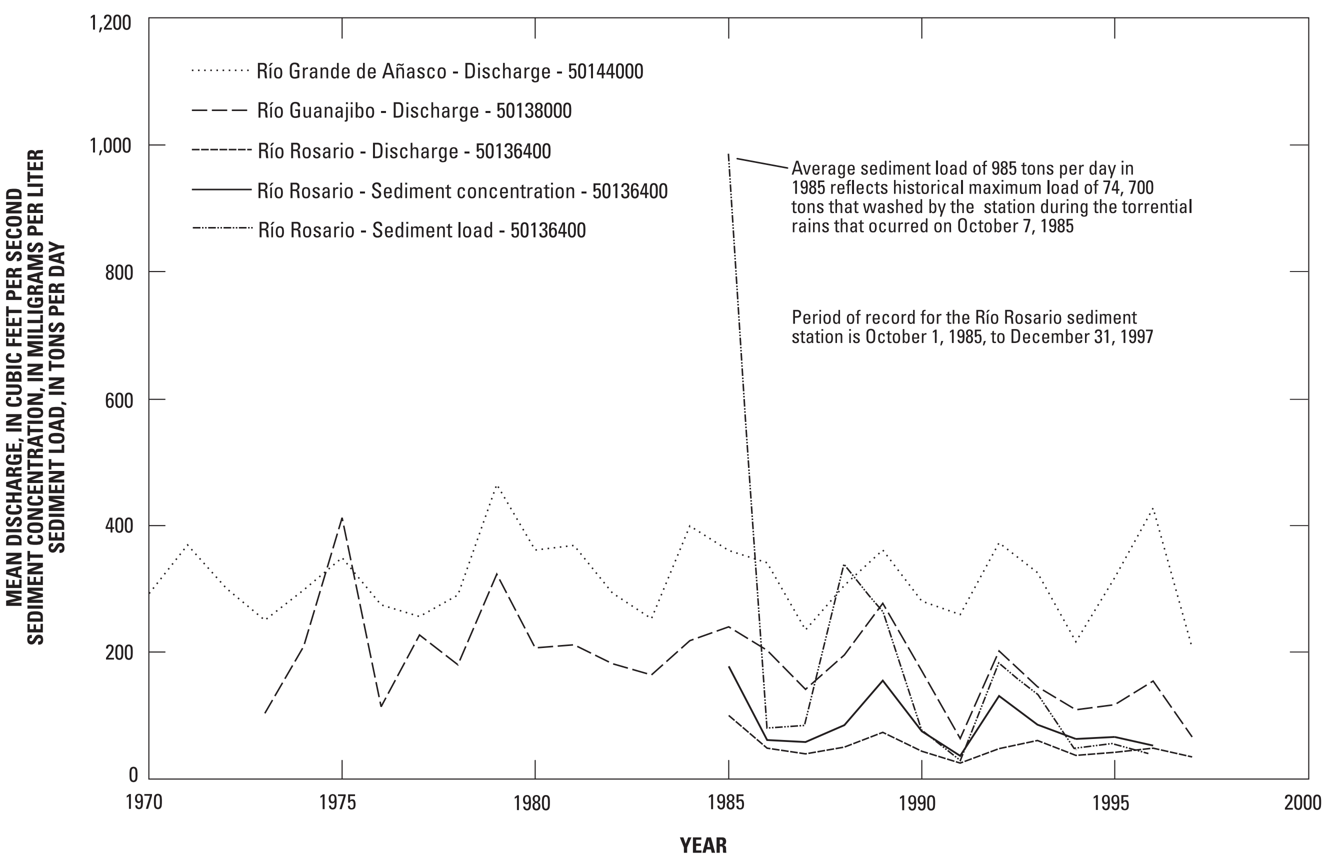


Figure 37. Yearly mean discharges for Río Grande de Añasco, the Río Guanajibo, and the Río Rosario, and sediment concentrations and loads measured at the Río Rosario station.

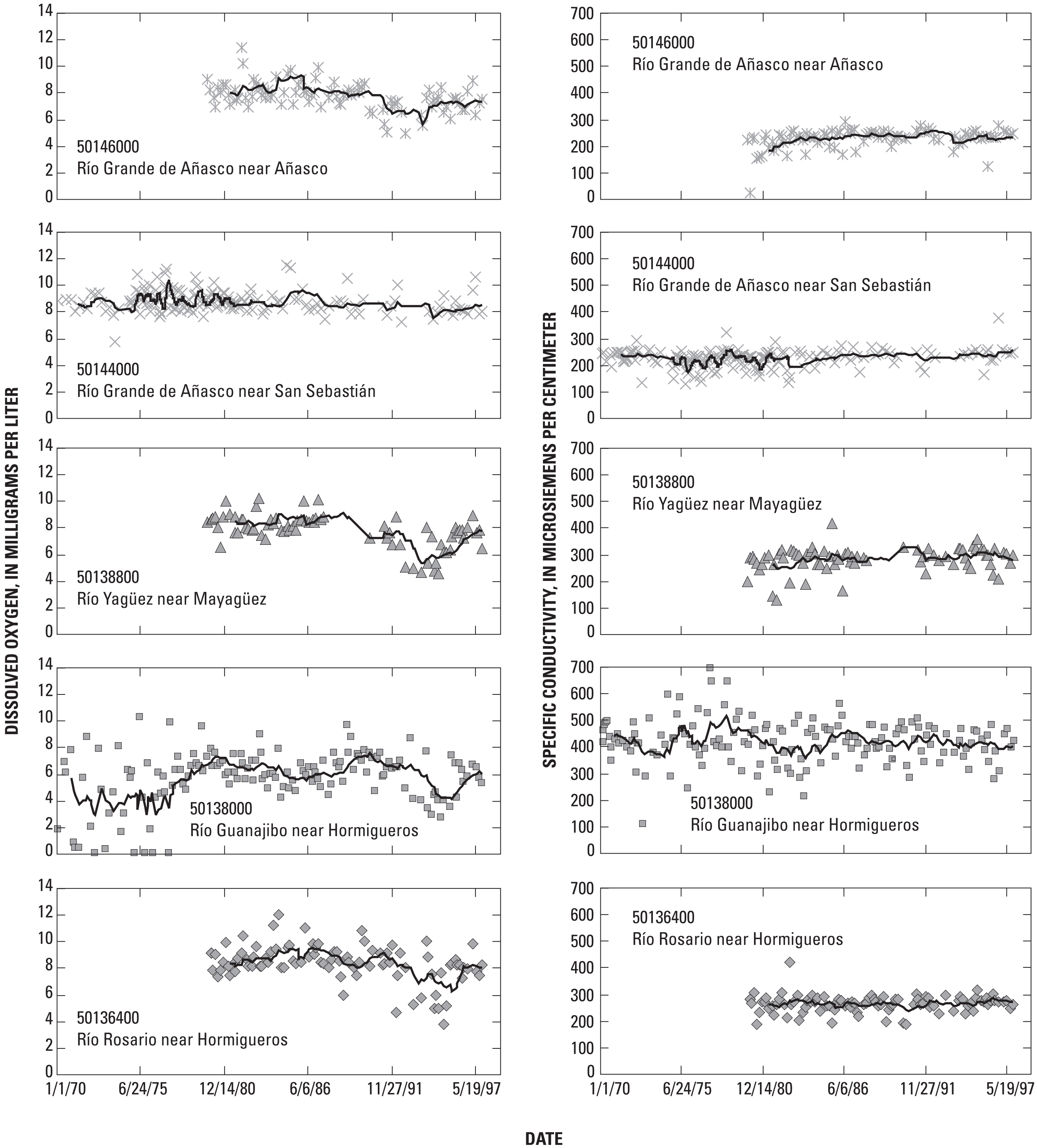


Figure 38. Specific-conductivity values and dissolved-oxygen concentrations measured at five west coast water-quality monitoring sites for the period 1970-97. The solid line is a 5-point moving average of the individual results.

Flow-weighted composites of the effluent were collected daily over a period of eight days in a refrigerated sampler and sent by overnight courier to Envirosystems Inc., in New Hampshire. The results of the chronic and acute bioassays are presented in appendix E.

Synthetic organic compounds and trace metals were analyzed in marine water, as well as influent and effluent wastewater and fresh water from the Río Grande de Añasco and the Río Yagüez. Results of the water-quality sampling verify that the outfall is effectively dispersing the effluent within the prescribed mixing zone. The data are briefly summarized below.

Dissolved Nutrients, Chlorophyll, and Bacteria in the Surface Waters

Ammonia concentrations of 20.6 mg/L were measured in the effluent waste stream at the plant. The highest value measured in the zone of initial dilution, inside of the plume, was 0.68 mg/L. Ammonia was not detected at the boundary of the initial mixing zone or at any other marine sampling station. Ammonia was not detected above the minimum reporting limit of 0.1 mg/L in the Río Yagüez, and had a concentration of 0.25 mg/L in the Río Grande de Añasco.

Neither nitrate nor nitrite was detected (<0.1 mg/L) in the influent, effluent, or in marine samples. Concentrations in the rivers were 0.28 (Río Grande de Añasco) and 0.46 mg/L (Río Yagüez).

Orthophosphate concentrations in the wastewater were 4.4 and 5.3 mg/L for the influent and effluent, respectively. This constituent was not found in the Río Grande de Añasco and was measured at a concentration of 0.068 mg/L in the Río Yagüez. Orthophosphate was not detected above the minimum reporting limit of 0.05 mg/L in any of the marine samples.

Total phosphorus concentration was 7.9 and 6.1 mg/L, as phosphorus, in influent and effluent, respectively. Phosphorus was non-detectable (< 0.05 mg/L) in river water, and was found at a concentration of 2.7 mg/L in one marine sample collected in the far mixing zone (QW-7), between the outfall and the Río Grande de Añasco. No phosphorus was measured at any other marine station.

Total Kjeldahl nitrogen was detected in the influent and effluent and at the control marine station. At a detection limit of 5.0 mg/L, total Kjeldahl nitrogen was not found in any of the remaining saltwater stations. It was not detected at a limit of 0.5 mg/L in river waters.

Both chlorophyll ‘a’ and the light extinction coefficient (LEC) are listed in table 16 and in appendix E. At station QW-5, in the northernmost plume in the initial mixing zone (IMZ), chlorophyll ‘a’ measured 0.0879 mg/m^3 at 10:40 a.m. By 3:00 p.m., station QW-4, the other IMZ site, was sampled, and chlorophyll ‘a’ measured 0.1771 mg/m^3. The effluent (1.32 mg/m^3) and the Río Yagüez (1.64 mg/m^3) had the highest levels. Significant diurnal variations occur in phytoplankton populations. Chlorophyll ‘a’ increased throughout the day for the receiving waters measured on January 29. The lowest concentration for the day (0.096 mg/m^3) was measured at QW-8 at 9:30 a.m. Station QW-7 was sampled at 10:45 a.m., and measured 0.098 mg/m^3. The next site, QW-1, was sampled at 12:40 p.m., and chlorophyll ‘a’ measured 0.1098 mg/m^3. The last station of the day, QW-2, was sampled at 5:46 p.m. and measured 0.154 mg/m^3. The concentrations of chlorophyll ‘a’ measured for all of the receiving water stations ranged from 0.05 mg/m^3 at the control stations QW-9 and QW-10, to 0.18 mg/m^3 at the IMZ boundary station QW-3. These values are still far below those measured in the Río Grande de Añasco (0.53 mg/m^3), the effluent (0.61 mg/m^3), and the Río Yagüez (1.64 mg/m^3). The potential for the development of significant algal blooms is not suggested by the data collected during this study.

Trace Elements

The majority of the regulated trace elements were detected in the wastewater samples and/or river water samples. Cadmium was detected in both rivers but not in the wastewater. Trace elements that were detected in marine water samples include: chromium, boron, selenium, and lead. Selenium and lead were detected at one of the control stations and not at any other location, suggesting that these trace-metal ‘hits’, which coincided with the only total Kjeldahl nitrogen marine water detection, are not related to outfall activity. Boron is present at uniform concentrations in marine samples at approximately 50 times the concentration found in waste water. This results from boron's natural occurrence as a marine water constituent. Chromium was detected in each of the mixing zones sampled, and its presence is expected in areas influenced by the runoff from the Río Yagüez and the Río Guanajibo, which drain laterite deposits formed on the serpentinite. No reduction in concentration was observed for chromium. All chromium concentrations were beneath applicable limits.

Organic Compounds in the Surface Waters

The following volatile organic compounds were detected in either the influent or the effluent: carbon tetrachloride, chloroform, ethylbenzene, and toluene. For all but carbon tetrachloride, the concentrations of the effluent sampled from the waste stream on the grounds of the MRWTP met the stricter standards for the receiving waters. The concentration of carbon tetrachloride measured in the effluent (8.7 µg/L) exceeded the strictest EPA marine criterion (4.5 µg/L, for waters harvested for organisms) by a factor of 2; concentrations of the compound were below the detection limit for all other stations, including those sampled within the outfall plume. Volatile organic compounds were not detected in either the river waters or in the set of marine water samples. None of the regulated semivolatiles were detected in any of the samples collected. No organochlorine pesticides or PCB's were detected in any of the samples collected. No organophosphorus pesticides were detected in any of the samples collected. No chlorinated herbicides were detected in any of the samples collected.

SUMMARY

The discharge of anthropogenic contaminants from previous sewage outfalls in the Bahía de Mayagüez and from industries discharging to coastal waters has resulted in clear and documented degradation of water quality in the Bahía de Mayagüez. The degraded water quality was linked to shifts in the populations of foraminifers in the northern parts of the Bahía de Mayagüez and the near extinction of corals growing at Arrecife Algarrobo in the northern part of the bay. To relieve the obvious acute and chronic stresses produced by the previous outfalls and other industrial discharges around the perimeter of the Bahía de Mayagüez, the present discharge site in the Bahía de Añasco was located and identified as an area with good mixing capabilities.

The U.S. Geological Survey and the Puerto Rico Aqueduct and Sewer Authority carried out a study in 1990-91, to determine if primary-treated wastewater, discharged through the Mayagüez Regional Wastewater Treatment Plant ocean outfall since 1987, had resulted in adverse impacts on the natural resources in the Bahía de Añasco. It was found that the physical environment and biota in the Bahía de Añasco, including the area around the outfall, continue to evolve in response to sediments and nutrients discharged from the rivers and upwelled from deep waters. Data collected during the study did not implicate the outfall as a stressor.

The diffuser is located at a depth of 11 m, about 1,700 m offshore. The immediate area around the outfall is characterized by muddy sediments deposited on an irregular bedrock surface. A high-resolution sidescan-sonar image clearly defined the outfall's position relative to the coral reefs and unconsolidated sediments deposited in the bay. The seismic reflection lines also reveal reeflike structures buried underneath the fine sediments deposited between the shelf-edge reefs and shore. Diverse communities of organisms were found living both in the soft sediments and on the hard bottom.

Balanced indigenous populations were documented in the soft-bottom communities at eight stations in the bay, including a station in the initial mixing zone of the outfall. No enrichment of pollution-tolerant species with time was observed. Community diversity was found to covary with the percentage of pollution-tolerant species, and both decreased with distance from shore. It must be noted, however, that one of the stations downcurrent from the outfall, station B2, showed a significant increase in dominance by peanut worms (*sipunculans*).

Sipunculans make up a relatively small phylum of organisms that are adept in living in a wide array of shallow-water marine habitats, and have not been identified as opportunistic species tolerant of pollutants. Some burrow into sand or mud, while others bore into shells or test. The possibility exists that since the area around the outfall has good dispersion and strong currents, wastewater-related impacts may not appear around the outfall at all, but rather appear in lower energy areas downcurrent where sediments and contaminants may accumulate.

Hard-bottom communities in the bay have adapted to the discharge of sediments and nutrients from the rivers and the presence of upwelled nutrients from deeper waters to the west. The community of sessile benthos observed at station MO-5, located 350 m from the outfall, included species adapted to growing in deeper waters, such as the scleractinian *Agaricia lamarcki* and the antipatharian *Stichopathes sp*. The coverage and abundance was low at the station, but the measured diversity was similar to that observed at other stations. This was the first visit to the site and, therefore, no comparison could be made with pre-outfall conditions. At two stations in the reefs west of the outfall, previously surveyed in 1985, no significant changes in the hard-bottom communities were found.

The taxonomic composition of fishes in the Manchas Interiores-Manchas Exteriores coral reef complex in the Bahía de Añasco is typical of shallow coral reef ecosystems. In general, fish abundance and diversity increased with substrate relief. Contrary to this trend, low abundance and diversity of fishes were found at station MO-5, a high-relief habitat surveyed near the outfall. The high-relief substrate is one of several relict patch reefs located in the interior portions of the Bahía de Añasco. Subbottom profiling of the interior of the bay verified that these structures were patch reefs that succeed in keeping pace with the rising sea level, but eventually succumbed to the significant loads of sediment discharged from the Río Grande de Añasco over the last few millennia.

The mineralogy of sediments deposited in the Bahía de Añasco reflect the sources in the uplands watersheds, carbonate production, and diagenesis of the marine sediments. Around the outfall the sediments consist mostly of terrigenous grains discharged by the Río Grande de Añasco with roughly similar secondary proportions from the Río Yagüez/Río Guanajibo and skeletal carbonate grains. Bacterial mediation in the diagenesis of carbonate grains is suggested by the dark staining of carbonate grains and the identification of the calcian-manganese carbonate, kutnahorite, in X-ray diffractographs. The sediment provenance study also revealed that one of the reasons that sessile benthos at station MSG-2 are so abundant and diverse is that the area is hydrodynamically sheltered from discharge from the Río Grande de Añasco. Trace-metal concentrations in the coralline skeletons from the interior of the Bahía de Añasco suggest that deep waters to the west of the coral complex commonly upwell to the east to replace surface waters blown away from shore by the winds.The deep waters to the west, therefore, commonly pass up and through the coral reef complex to the east.

Water quality measured at and near the outfall diffuser at the end of January met all applicable criteria established for marine waters by the United States Environmental Protection Agency and the Puerto Rico Environmental Quality Board. Nutrients present in the effluent fell below detection limits at the boundary of the initial mixing zone.

The stressed condition of corals in the Bahía de Añasco could be attributed to the sediments and nutrients discharged from the Río Grande de Añasco, the Río Yagüez, the Río Guanajibo, industrial sources discharging directly into the Bahía de Mayagüez, or the discharge from the ocean outfall. Nutrient-rich discharges into the Bahía de Mayagüez are commonly trapped close to shore, where they flow northward until mixing with water masses from the Río Grande de Añasco, before travelling offshore into the Bahía de Añasco. This transport pattern has resulted in the rapid demise of coral communities at Punta Algarrobo and at other small reefs nearby, and may account for the higher percentages of opportunistic infaunal species documented for stations closest to shore. The abundance and diversity of coral communities are greater at stations near the outfall than they are at Punto Algarrobo, and greater still at station MSG-2, in the Manchas Interiores to the west. The net transport of effluent by the currents in the area of the outfall is to the northwest, an area floored by muds and populated by balanced indigenous species of macrobenthic infauna. Nonetheless, the existing data collected in this report and by previous studies do not implicate the outfall as being responsible for any recent changes in the coral community, the macrobenthic infauna, fish populations, or deposited sediments.

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Table 16. Summary of criteria and water quality, January 1991

[These results are maximum values for groups of stations. Results for individual samples are listed in appendix E. The criteria are those enforced by the EPA for marine waters; max, maximum acute concentration; cont, maximum continuous concentration; and cons, the criteria for waters where organisms may be harvested for human consumption. The Commonwealth of Puerto Rico applies the standards for SC marine water, open ocean more than 1 mile from the shore. Seventeen sites were sampled (15 sites plus two duplicates), 11 offshore and 6 onshore. The freshwater sites are the influent (INF), the effluent (EFF), the Río Grande de Añasco (RGA), and the Río Yagüez (RY). The marine sites include two stations in the initial mixing zone (IMZ), at the boundary of the IMZ (BND), at the boundary of the final mixing zone (FMZ), in the far field (FAR), and at the control stations off Rincón (CTL). The values under the rule denote the highest value measured for any sample in that area. The most common detection limits are listed here for comparison to the criteria. Unless indicated otherwise, all units are in µg/L, micrograms per liter; other units are mg/L, milligrams per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; °C, degrees Celsius; k, extinction coefficient; col/100mL, colonies of bacteria per 100 milliliters; µmS/cm, microsiemens per centimeter; Mgal/d, million gallons per day; mg/m^3, milligrams per cubic meter; NA, not applicable; NR, not reported; NF, not found; ND, not detected; --, no data]

Constituent	Analytical method	units	Criteria						Maximum values measured								
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
Volatile organic compounds																	
Method 624																	
Acrolein			NA	NA	780	NA	100	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acrylonitrile			NA	NA	0.67	NA	100	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene			NA	NA	71	400	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromodichloromethane			12000	6400	470	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform			NA	NA	470	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromomethane			NA	NA	NF	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon tetrachloride			NA	NA	4.5	69.4	5	5	ND	8.7	ND	ND	ND	ND	ND	ND	ND
Chlorobenzene			NA	NA	NA	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroethane			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform			NA	NA	470	NA	5	5	8.3	12	ND	ND	ND	ND	ND	ND	ND
Chloromethane			NA	NA	NA	NA	10	10	ND	50	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane			12000	6400	470	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-Dichloroethane			NA	NA	NA	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane			NA	NA	99	2430	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-Dichloroethene			NA	NA	3.2	18.5	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethene (total)			NA	NA	NA	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloropropane			NA	NA	NA	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
cis-1,3-Dichloropropene			790	NA	NF	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
trans-1,3-Dichloropropene			790	NA	NF	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene			NA	NA	29000	NA	5	5	ND	6.4	ND	ND	ND	ND	ND	ND	ND
Methylene chloride			NA	NA	470	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria				Maximum values measured										
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
1,1,2,2-Tetrachloroethane			NA	NA	11	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene			10200	450	0.8	8.85	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene			NA	NA	300000	NA	5	5	32	69	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane			NA	NA	170000	1030	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,2-Trichloroethane			NA	NA	42	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene			2000	NA	92	NA	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl chloride			NA	NA	525	5246	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Semivolatile organics																	
Method 625																	
Acenaphthene			NA	NA	2700	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Anthracene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzidine			NA	NA	0.00054	NA	100	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo a-anthracene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo b-fluoranthene			300	NA	NF	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo k-fluoranthene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (g,h,i)perylene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo (a)pyrene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Bromophenyl phenyl ether			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl benzyl phthalate			NA	NA	5200	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Chloroethoxy)-methane			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Chloroethyl) ether			NA	NA	1.4	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Chloroisopropyl)-ether			NA	NA	170000	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Chloro-3-methylphenol			440	NA	NF	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Chloronaphthalene			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Chlorophenol			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Chlorophenyl phenyl ether			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene			NA	NA	NF	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Di-n-butyl phthalate			NA	34	12000	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria				Maximum values measured										
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
1,2-Dichlorobenzene			NA	NA	17000	2600	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-Dichlorobenzene			NA	NA	2600	2600	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-Dichlorobenzene			NA	NA	2600	2600	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
3,3'-Dichlorobenzidine			NA	NA	0.077	NA	20	20	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dichlorophenol			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Diethyl phthalate			NA	NA	120000	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethyl phenol			NA	NA	765	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dimethyl phthalate			NA	NA	2900000	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,6-Dinitro-2-methylphenol			4850	NA	NF	NA	50	50	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dinitrophenol			NA	NA	14000	NA	50	50	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dinitrotoluene			NA	NA	9.1	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,6-Dinitrotoluene			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Di-n-octylphthalate			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Diphenylhydrazine			NA	NA	0.54	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Ethylhexyl) phthalate			NA	NA	5.9	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene			NA	NA	54	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene			NA	NA	0.031	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexachlorobenzene			NA	NA	0.00074	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexachlorobutadiene			NA	NA	0.35	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexachlorocyclopentadiene			NA	NA	17400	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexachloroethane			NA	NA	8.9	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Isophorone			NA	NA	600	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nitrobenzene			NA	NA	1900	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Nitrophenol			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Nitrophenol			NA	NA	NA	NA	50	50	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosodimethylamine			NA	NA	8.1	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-Nitrosodiphenylamine			NA	NA	16	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria				Maximum values measured											
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater					
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
N-Nitroso-di-n-propylamine			NA	NA	1.4	NA	50	50	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentachlorophenol			13	7.9	NA	7.9	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phenol			NA	NA	4600	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pyrene			NA	NA	0.0311	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trichlorobenzene			NA	NA	NA	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,6-Trichlorophenol			NA	NA	3.6	NA	10	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Organochlorine pesticides / PCB's																	
Method 8080																	
alpha-BHC			NA	NA	0.013	NA	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
beta-BHC			NA	NA	0.04	NA	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
delta-BHC			NA	NA	NA	NA	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
gamma-BHC (Lindane)			0.16	NA	0.063	0.074	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toxaphene			0.21	0.0002	0.00052	0.0002	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor			0.053	0.0036	0.0001	0.001	0.02	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin			1.3	NA	0.00014	0.00074	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor epoxide			0.053	0.0036	0.0002	NA	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan I			0.034	0.0087	2	0.0087	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin			0.71	0.0019	0.00014	0.00074	0.02	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDE			NA	NA	0.00059	NA	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin			0.037	0.0023	0.49	0.0023	0.06	0.06	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan II			0.034	0.0087	2	0.0087	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDD			NA	NA	0.00083	NA	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan sulfate			NA	NA	2	NA	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDT			0.13	0.001	0.00059	0.00024	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin aldehyde			NA	NA	0.49	NA	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlordane			0.09	0.004		0.0046	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1016			NA	0.03	0.000045	NA	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1221			NA	0.03	0.000045	NA	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1232			NA	0.03	0.000045	NA	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1242			NF	NF	NF	NA	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria				Maximum values measured										
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
Aroclor 1248			NA	0.03	0.000045	NA	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1254			NA	0.03	0.000045	NA	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1260			NA	0.03	0.000045	NA	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mirex			NA	0.001	NF	0.001	0.05	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylan (perthane)			NA	NA	NF	0.07	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methoxychlor			NA	0.03	NF	0.02	0.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Organophosphorus pesticides																	
SW-846 List - Method 8141																	
Azinphos-methyl (Guthion)			NA	0.01	NA	0.01	5	2.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorpyrifos (Dursban)			NA	NA	NA	0.0056	0.5	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND
Coumaphos			NA	NA	NA	0.01	1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
Demeton O&S			NA	0.1	NA	0.1	0.5	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fenthion (Baytex)			NA	NA	NA	0.4	0.5	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND
Malathion			NA	0.1	NA	0.1	2.4	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naled (dibrom)			NA	NA	NA	0.4	20	10	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethyl parathion			NA	0.04	NA	NF	0.5	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methyl parathion			NA	0.04	NA	NF	0.5	0.25	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorinated herbicides																	
Method 8150																	
2,4-D			NA	NA	NA	80	1.2	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,5-TP (Silvex)			NA	NA	NA	10	0.17	0.17	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Metals																	
Antimony	7041	mg/L	NA	NA	8.6	NA	0.2	0.04	ND	ND	ND	ND	ND	ND	ND	ND	ND
Beryllium	7090	mg/L	NA	NA	0.131	NA	0.5	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	7210	mg/L	0.0029	0.0029	NA	0.05	0.05	0.05	0.29	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	7520	mg/L	0.075	0.0083	3.8	0.0083	0.1	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium (VI)	7196	mg/L	1.1	0.05	3.2	0.05	0.01	0.01	0.011	0.017	ND	ND	ND	ND	ND	ND	ND
Aluminum	6010	mg/L	NF	NF	NF	NA	0.1	2	1.2	0.26	0.88	0.31	ND	ND	ND	ND	ND
Silver	7761	mg/L	0.0023	NA	NA	0.002	0.0025	0.001	0.011	0.0033	ND	ND	ND	ND	ND	ND	ND
Cadmium	7131	mg/L	0.043	0.0093	0.17	0.005	0.005	0.002	ND	ND	0.0027	0.00084	ND	ND	ND	ND	ND
Zinc	7950	mg/L	0.095	0.086	NA	0.05	0.02	0.02	0.16	0.062	ND	ND	ND	ND	ND	ND	ND

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria						Maximum values measured								
			U.S. EPA			P.R. EQB	Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
Chromium	7191	mg/L	10.3	NA	NA	0.3	0.01	0.01	0.034	0.02	0.018	0.0096	0.018	0.018	0.022	0.026	0.0052
Arsenic	7060	mg/L	0.069	0.036	0.00014	0.15	0.005	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium	6010	mg/L	NA	NA	NF	1	0.01	0.2	0.12	0.076	0.045	0.11	ND	ND	ND	ND	ND
Boron	6010	mg/L	NA	NA	NF	4.8	0.1	2	0.14	0.13	ND	ND	5.1	5.2	5.4	5.6	4.6
Calcium	6010	mg/L	NA	NA	NF	NA	0.2	4	48	47.3	28.3	31.9	452	442	460	471	450
Iron	6010	mg/L	NA	NA	NF	0.2	0.1	2	2.1	0.75	1.1	0.2	ND	ND	ND	ND	ND
Lead	7421	mg/L	0.22	0.0085	NA	0.015	0.005	0.01	0.011	ND	0.12	ND	ND	ND	0.12	ND	0.14
Magnesium	6010	mg/L	NA	NA	NF	NA	0.2	4	19.4	19	10.1	16.3	1390	1370	1430	1490	1390
Manganese	6010	mg/L	NA	NA	NF	0.1	0.01	0.2	0.13	0.11	0.1	0.027	ND	ND	ND	ND	ND
Mercury	7470	mg/L	0.0021	0.000025	0.00015	0.001	0.0002	0.0002	0.00082	ND	ND	ND	ND	ND	ND	ND	ND
Potassium	6010	mg/L	NA	NA	NF	NA	5	100	11.99	11.4	ND	ND	390	410	388	496	424
Selenium	7740	mg/L	0.3	0.071	6.8	0.01	0.005	0.02	ND	ND	ND	ND	ND	ND	ND	ND	0.21
Silica as SiO2	6010	mg/L	NA	NA	NF	NA	0.5	10	20.8	23.1	21.2	28.6	ND	ND	ND	ND	ND
Sodium	6010	mg/L	NA	NA	NF	NA	5	100	91.3	89.8	11.3	12.4	11000	11000	11300	12500	11200
Strontium	6010	mg/L	NA	NA	NF	NA	0.05	1	0.28	0.26	0.15	0.15	7.7	7.6	8	8	7.9
Thallium	7841	mg/L	NA	NA	0.0032	NA	0.01	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 The bottles for total metals for QW-7 and QW-An1 were apparently switched upon arrival at RMAL. The results were therefore switched to attain an acceptable charge balance.																	
General Inorganics																	
Chloride	A429	mg/L	NA	NA	NA	NA	0.5	300	112	137	8.4	11.5	20800	2100	21100	21100	20600
Cyanide	9012	mg/L	1	1	21.5	0.02	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
Color	110.2	units	NA	NA	NA	NA	5	5	NR	NR	5	5	ND	ND	ND	ND	ND
Fluoride	A429	mg/L	NF	NF	NF	NF	0.1	5	5.4	9.7	ND	--	40.1	40.6	47.7	30.2	29.1
Surfactants (MBAS)	425.1	mg/L	NF	NF	NF	NF	0.1	1	1.1	2	ND	0.12	ND	ND	ND	ND	ND
Ammonia as N	350.1	mg/L	NA	NA	NA		1	0.1	20.9	20.6	0.25	ND	0.68	ND	ND	ND	ND
Nitrate plus nitrite	353.2	mg/L	NF	NF	NF	NF	0.1	0.1	ND	ND	0.28	0.46	ND	ND	ND	ND	ND
Orthophosphate as P	365.3	mg/L	NF	NF	NF	NF	0.5	0.05	4.4	5.3	ND	0.068	ND	ND	ND	ND	ND
Phenolics	9065	mg/L	NF	NF	NF	NF	0.01	0.01	ND	0.058	ND	ND	0.037	ND	ND	ND	ND
Sulfide, Total	376.2	mg/L	NF	NF	NF	NF	0.5	0.05	6.2	0.84	0.057	0.065	ND	ND	ND	ND	ND
Sulfate	A429	mg/L	NF	NF	NF	NA	0.5	50	18.8	16.8	8.1	8.2	2650	2650	2850	2820	2810
Total Kjeldahl nitrogen as N	351.2	mg/L	NA	NA	NA	NA	0.5	5	49.9	34.2	ND	ND	ND	ND	ND	ND	0.89
Phosphorus, total as P	365.3	mg/L	NA	NA	NA	NA	0.05	0.05	7.9	6.1	ND	ND	ND	ND	2.7	ND	ND
Turbidity	180.1	NTU	NF	NF	NF	<10	0.1	0.1	185	50	13	0.21	0.62	0.58	0.22	0.18	0.34

Table 16. Summary of criteria and water quality, January 1991—Continued

Constituent	Analytical method	units	Criteria: U.S. EPA			P.R. EQB	Maximum values measured: Detection limit		Freshwater				Saltwater				
			max	cont	cons	(SC)	fresh	marine	INF	EFF	RGA	RY	IMZ	BND	FMZ	FAR	CTL
Total dissolved solids	160.1	mg/L	NF	NF	NF	NF	20	50	532	615	200	242	37200	37600	37100	39200	37100
Total suspended solids	160.2	mg/L	NA	NA	NA	NA	2	2	266	57	20	7.2	46.8	50	12	14.8	19.6
Total volatile solids	160.4	mg/L	NA	NA	NA	NA	10	200	300	205	43	46	3980	3440	3150	3340	3620
Volatile suspended solids	160.4	mg/L	NA	NA	NA	NA	10	10	194	49.5	ND	ND	ND	ND	ND	ND	ND
Radiochemistry																	
Gross Alpha	900	pCi/L	NF	NF	NF	NF			0±2.3	1.1±2.7	0.8±2	0.4±0.4	50±150	0±140	0±130	80±170	50±50
Gross Beta	900	pCi/L	NF	NF	NF	1,000			11 ±5	14±5	0.8±2.7	0±8.8	410±170	380±160	400±170	290±160	380±170
Radium 226	705 Mod.	pCi/L	NF	NF	NF	3			0±0.5	0±0.5	0.1±0.5	0±1.9	0±0.5	0±0.5	0±71	0±0.4	0.3±0.6
Strontium 90	A704	pCi/L	NF	NF	NF	10			0±0.7	0±0.7	0±0.8	0±0.9	0±2	0±2.3	0±1.4	0±2.9	0±1.4
Non -conservative properties																	
BOD-5	405.1	mg/L	NA	NA	NA	NA	2		390	170	5.9	NR	2.1	ND	ND	ND	ND
Oil and grease	413.1	mg/L	NA	NA	NA	NA	5		NR	NR	ND	ND	ND	5.8	ND	ND	ND
Settleable solids	160.5	mg/L	NA	NA	NA	NA			3.3	0	0	0	0	0	0	0	0
Water temperature		°C	NA	NA	NA	NA			26	NR	24	22	25	26	26	26	32
Alkalinity		mg/L	NA	NA	NA	NA			NR	NR	110	150	120	120	120	120	130
Specific conductance		µS/cm	NA	NA	NA	NA			NR	NR	265	334	>50000	>50000	49000	48000	44000
pH		units	NA	NA	NA	7.3-8.5			6.9	7	7.7	8.6	8.2	8.2	8.2	8.26	8.4
Dissolved oxygen		mg/L	NA	NA	NA	>5			NR	NR	6	9.9	8	7.2	7.3	7.4	NR
Extinction coefficient		k	NA	NA	NA	NA			NA	NA	NA	NA	0.15	0.21	0.3	0.12	0.12
Chlorophyll-a		mg/m^3	NA	NA	NA	NA			0.6081	1.3268	0.5257	1.6423	0.1771	0.1813	0.0985	0.1098	0.0466
Discharge		Mgal/d	NA	NA	NA	NA			7.2	7.2	27.1	3.6	NA	NA	NA	NA	NA
Bacteria																	
Fecal coliform	B-0050-85	cols/ 100mL	NA	NA	NA	<200			b>6,000,000	6000	b-18	4500	490	110	b<2	b-2	b-22
Total coliform	B-0025-85	cols/ 100mL	NA	NA	NA	NA			b>8,000,000	29000	b-1450	26000	b>800	320	b-180	190	b-6
Enterococcus	1106.1	cols/ 100mL	NA	NA	NA	NA			b>2,000,0000	b-1100	b-40	b-1000	b>600	b-7	NR	NR	b<2

APPENDIXES

Appendix A. Macrobenthic infauna identified at stations B1 through B8, December 15, 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico.

Appendix A-1. Summary of macrobenthic infauna observed in the Bahía de Añasco and the Bahía de Mayagüez, December 15, 1990.

Site	Number of individuals	Number of species	Shannon's diversity index	Species richness	Species evenness	Simpson's dominance index
B1	80	18	2.18	3.88	0.76	0.20
B2	112	24	1.84	4.87	0.58	0.36
B3	122	22	2.38	4.37	0.77	0.16
B4	152	22	2.33	4.18	0.75	0.16
B5	63	20	2.58	4.59	0.86	0.10
B6	104	27	2.82	5.6	0.85	0.09
B7	55	14	1.83	3.24	0.69	0.28
B8	68	23	2.62	5.21	0.84	0.12
B1-B8	756	56	2.70	8.30	0.67	0.15

Appendix A-2. Summary of statistics describing macrobenthic infauna communities observed from sampling carried out in January and May 1985 and December 1990.

[--, indicates no data]

Survey date	B1	B2	B3	B4	B5	B6	B7	B8
	Number of taxa							
Jan-85	38	36	54	106	50	68	--	35
May-85	75	108	142	179	156	151	--	67
Dec-90	18	24	22	22	20	27	14	23
	Density, in individuals per 0.1 m^2							
Jan-85	192	124	202	267	190	476	--	106
May-85	286	344.6	1112	941	911.8	1042.8	--	179.6
Dec-90	200	280	305	380	157.5	260	137.5	170
	Shannon-Weaver's Diversity (*H´*, using natural logarithms)							
Jan-85	2.36	2.70	2.99	3.71	3.24	3.09	--	2.49
May-85	2.87	3.19	3.30	3.25	3.64	3.33	--	2.78
Dec-90	2.18	1.84	2.38	2.33	2.58	2.82	1.83	2.62
	Evenness (*J´*)							
Jan-85	0.65	0.75	0.75	0.80	0.83	0.73	--	0.70
May-85	0.67	0.68	0.66	0.63	0.73	0.67	--	0.66
Dec-90	0.76	0.58	0.77	0.75	0.86	0.85	0.69	0.84
	Simpson's Dominance Index (*SI´*)							
Jan-85	0.17	0.11	0.09	0.05	0.06	0.10	--	0.16
May-85	0.11	0.09	0.08	0.1	0.06	0.08	--	0.12
Dec-90	0.20	0.36	0.16	0.16	0.10	0.09	0.28	0.12

Appendix A-3. Percentages of taxa of macrobenthic infauna identified at all sampled stations (B1-B8) in the Bahía de Añasco and the Bahía de Mayagüez, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Species are those retained on a 0.50-mm sieve .

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	267	35.32	35.32
Scoloplos sp. B (An)	91	12.04	47.35
Maldane sp. A (An)	62	8.20	55.56
Amphiodia sp. A (E)	39	5.16	60.71
Codakia pectinella (M)	24	3.17	63.89
Maldanidae A (An)	20	2.65	66.53
Magelona sp. A (An)	19	2.51	69.05
Neanthes sp. A (An)	19	2.51	71.56
Scoloplos sp. A (An)	18	2.38	73.94
Prionospio sp. A (An)	17	2.25	76.19
Callianassidae A (Ar)	16	2.12	78.31
Cirrophorus sp. A (An)	15	1.98	80.29
Prionospio sp. C (An)	15	1.98	82.28
Nephtyidae A (An)	12	1.59	83.86
Marphysa sp. A (An)	11	1.46	85.32
Myrthea pristiphora (M)	9	1.19	86.51
Prionospio sp. B (An)	9	1.19	87.70
Diplodonta punctata (M)	7	0.93	88.62
Nemertea (R)	6	0.79	89.42
Eunice sp. A (An)	6	0.79	90.21
Oligochaeta (An)	6	0.79	91.01
Aphroditidae A (An)	5	0.66	91.67
Leiolambrus nitidus (Ar)	4	0.53	92.20
Xanthidae A (Ar)	4	0.53	92.72
Oliva caribaeensis (M)	4	0.53	93.25
Tellina sp. A (M)	4	0.53	93.78
Pilumnus sp. A (Ar)	3	0.40	94.18
Corbula caribaea (M)	3	0.40	94.58
Mediomastus sp. A (An)	3	0.40	94.97
Paradoneis sp. A (An)	3	0.40	95.37
Poecilochaetus sp. A (An)	3	0.40	95.77
Alpheidae A (Ar)	2	0.26	96.03
Axiopsis sp. A (Ar)	2	0.26	96.30
Mitrella nitens (M)	2	0.26	96.56
Scaphopoda (M)	2	0.26	96.83

Appendix A-3. Percentages of taxa of macrobenthic infauna identified at all sampled stations (B1-B8) in the Bahía de Añasco and the Bahía de Mayagüez, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Species are those retained on a 0.50-mm sieve--Continued.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Aphroditidae B (Polynoinae) (An)	2	0.26	97.09
Glycera sp. A (An)	2	0.26	97.35
Nereidae A (An)	2	0.26	97.62
Chasmocarcinus cylindricus (Ar)	1	0.13	97.75
Gonoplacidae A (Ar)	1	0.13	97.88
Pygnigonida A (Ar)	1	0.13	98.02
Amphiuridae A (E)	1	0.13	98.15
Holothuroidea A (E)	1	0.13	98.28
Corbula contracta (M)	1	0.13	98.41
Gouldia sp. A (M)	1	0.13	98.54
Phacoides muricatus (M)	1	0.13	98.68
Trigoniocardia antillarum (M)	1	0.13	98.81
Aphroditidae C (An)	1	0.13	98.94
Aphroditidae D (Sigalioninae) (An)	1	0.13	99.07
Capitellidae A (An)	1	0.13	99.21
Chloeia sp. A (An)	1	0.13	99.34
Ophelia sp. A (An)	1	0.13	99.47
Scoloplos sp. C (An)	1	0.13	99.60
Palmyridae A (An)	1	0.13	99.74
Phyllodocidae A (An)	1	0.13	99.87
Sigambra sp. A (An)	1	0.13	100.00
Total	756	100.00	

Appendix A. Macrobenthic infauna identified at stations B1 through B8, December 15, 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico—Continued.

Appendix A-4. Percentages of taxa of macrobenthic infauna identified at station B1 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	33	41.25	41.25
Scoloplos sp. B (An)	8	10	51.25
Magelona sp. A (An)	6	7.5	58.75
Myrthea pristiphora (M)	5	6.25	65
Amphiodia sp. A (E)	4	5	70
Neanthes sp. A (An)	4	5	75
Maldane sp. A (An)	4	5	80
Cirrophorus sp. A (An)	4	5	85
Nemertea (R)	2	2.5	87.5
Prionospio sp. A (An)	2	2.5	90
Codakia pectinella (M)	1	1.25	91.25
Scaphopoda (M)	1	1.25	92.5
Gonoplacidae A (Ar)	1	1.25	93.75
Pilumnus sp. A (Ar)	1	1.25	95
Nephtyidae A (An)	1	1.25	96.25
Marphysa sp. A (An)	1	1.25	97.5
Ophelia sp. A (An)	1	1.25	98.75
Scoloplos sp. A (An)	1	1.25	100
Total	80	100.00	

Appendix A-5. Percentages of taxa of macrobenthic infauna identified at station B2 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	66	58.93	58.93
Maldane sp. A (An)	7	6.25	65.18
Scoloplos sp. B (An)	6	5.36	70.54
Neanthes sp. A (An)	6	5.36	75.89
Amphiodia sp. A (E)	3	2.68	78.57
Axiopsis sp. A (Ar)	2	1.79	80.36
Prionospio sp. C (An)	2	1.79	82.14
Paradoneis sp. A (An)	2	1.79	83.93
Magelona sp. A (An)	2	1.79	85.71
Eunice sp. A (An)	2	1.79	87.50
Oliva caribaeensis (M)	1	0.89	88.39
Pilumnus sp. A (Ar)	1	0.89	89.29
Leionambrus nitidus (Ar)	1	0.89	90.18
Callianassidae A (Ar)	1	0.89	91.07
Amphiuridae A (E)	1	0.89	91.96
Oligochaeta (An)	1	0.89	92.86
Glycera sp. A (An)	1	0.89	93.75
Scoloplos sp. C (An)	1	0.89	94.64
Prionospio sp. A (An)	1	0.89	95.54
Mediomastus sp. A (An)	1	0.89	96.43
Marphysa sp. A (An)	1	0.89	97.32
Cirrophorus sp. A (An)	1	0.89	98.21
Scoloplos sp. A (An)	1	0.89	100.00
Aphroditidae B (An)	1	0.89	100.00
Total	112	100	

Appendix A-6. Percentages of taxa of macrobenthic infauna identified at station B3 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	41	33.61	33.61
Scoloplos sp. B (An)	15	12.30	45.90
Maldane sp. A (An)	14	11.48	57.38
Maldanidae A (An)	9	7.38	64.75
Callianassidae A (Ar)	6	4.92	69.67
Codakia pectinella (M)	5	4.10	73.77
Magelona sp. A (An)	5	4.10	77.87
Marphysa sp. A (An)	4	3.28	81.15
Neanthes sp. A (An)	3	2.46	83.61
Prionospio sp. B (An)	3	2.46	86.07
Cirrophorus sp. A (An)	3	2.46	88.52
Amphiodia sp. A (E)	2	1.64	90.16
Prionospio sp. C (An)	2	1.64	91.80
Eunice sp. A (An)	2	1.64	93.44
Oliva caribaeensis (M)	1	0.82	94.26
Scaphopoda A (M)	1	0.82	95.08
Leiolambrus nitidus (Ar)	1	0.82	95.90
Oligochaeta (An)	1	0.82	96.72
Glycera sp. A (An)	1	0.82	97.54
Nephtyidae A (An)	1	0.82	98.36
Paradoneis sp. A (An)	1	0.82	99.18
Scoloplos sp. A (An)	1	0.82	100.00
Total	122	100	

Appendix A-7. Percentages of taxa of macrobenthic infauna identified at station B4 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative Percent
Sipuncula (S)	51	33.55	33.55
Maldane sp. A (An)	20	13.16	46.71
Scoloplos sp. B (An)	17	11.18	57.89
Amphiodia sp. A (E)	15	9.87	67.76
Codakia pectinella (M)	9	5.92	73.68
Scoloplos sp. A (An)	6	3.95	77.63
Prionospio sp. A (An)	6	3.95	81.58
Callianassidae a (Ar)	3	1.97	83.55
Aphroditidae A (An)	3	1.97	85.53
Prionospio sp. C (An)	3	1.97	87.50
Diplodonta punctata (M)	2	1.32	88.82
Xanthidae A (Ar)	2	1.32	90.13
Nemertea (R)	2	1.32	91.45
Maldanidae A (An)	2	1.32	92.76
Neanthes sp. A (An)	2	1.32	94.08
Nephtyidae A (An)	2	1.32	95.39
Magelona sp. A (An)	2	1.32	96.71
Mitrella nitens (M)	1	0.66	97.37
Gouldia sp. A (M)	1	0.66	98.03
Corbula contracta (M)	1	0.66	98.68
Oligochaeta (An)	1	0.66	99.34
Aphroditidae C (An)	1	0.66	100.00
Total	152	100	

Appendix A-8. Percentages of taxa of macrobenthic infauna identified at station B5 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	13	20.63	20.63
Scoloplos sp. B (An)	8	12.70	33.33
Codakia pectinella (M)	7	11.11	44.44
Prionospio sp. C (An)	6	9.52	53.97
Cirrophorus sp. A (An)	6	9.52	63.49
Scoloplos sp. A (An)	4	6.35	69.84
Amphiodia sp. A (E)	3	4.76	74.60
Magelona sp. A (An)	3	4.76	79.37
Tellina sp. A (M)	2	3.17	82.54
Corbula caribaea (M)	1	1.59	84.13
Diplodonta punctata (M)	1	1.59	85.71
Phacoides muricatus (M)	1	1.59	87.30
Alpheidae A (Ar)	1	1.59	88.89
Aphroditidae A (An)	1	1.59	90.48
Prionospio sp. B (An)	1	1.59	92.06
Poecilochaetus sp. A (An)	1	1.59	93.65
Neanthes sp. A (An)	1	1.59	95.24
Aphroditidae B (Polynoinae) (An)	1	1.59	96.83
Capitellidae sp. A (An)	1	1.59	98.41
Maldanidae A (An)	1	1.59	100.00
Total	63	100.00	

Appendix A-9. Percentages of taxa of macrobenthic infauna identified at station B6 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	18	17.31	17.31
Scoloplos sp. B (An)	18	17.31	34.62
Maldane sp. A (An)	9	8.65	43.27
Amphiodia sp. A (E)	7	6.73	50.00
Nephtyidae A (An)	6	5.77	55.77
Marphysa sp. A (An)	5	4.81	60.58
Scoloplos sp. A (An)	5	4.81	65.38
Prionospio sp. A (An)	4	3.85	69.23
Prionospio sp. B (An)	4	3.85	73.08
Diplodonta punctata (M)	3	2.88	75.96
Maldanidae A (An)	3	2.88	78.85
Corbula caribaea (M)	2	1.92	80.77
Tellina sp. A (M)	2	1.92	82.69
Callianassidae A (Ar)	2	1.92	84.62
Nemertea (R)	2	1.92	86.54
Poecilochaetus sp. A (An)	2	1.92	88.46
Nereidae A (An)	2	1.92	90.38
Trioniocardia antillarum (M)	1	0.96	91.35
Pygnigonida A (Ar)	1	0.96	92.31
Holothuroidea A (E)	1	0.96	93.27
Eunice sp. A (An)	1	0.96	94.23
Cirrophorus sp. A (An)	1	0.96	95.19
Magelona sp. A (An)	1	0.96	96.15
Aphroditidae	1	0.96	97.12
Mediomastus sp. A (An)	1	0.96	98.08
Neanthes sp. A (An)	1	0.96	99.04
Palmyridae A (An)	1	0.96	100.00
Total	104	100.00	

Appendix A. Macrobenthic infauna identified at stations B1 through B8, December 15, 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico—Continued.

Appendix A-10. Percentages of taxa of macrobenthic infauna identified at station B7 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	27	49.09	49.09
Scoloplos sp. B (An)	9	16.36	65.45
Callianassidae A (Ar)	3	5.45	70.91
Amphiodia sp. A (E)	3	5.45	76.36
Myrthea pristiphora (M)	2	3.64	80.00
Leiolambrus nitidus (Ar)	2	3.64	83.64
Maldane sp. A (An)	2	3.64	87.27
Codakia pectinella (M)	1	1.82	89.09
Chasmocarcinus cylindricus (Ar)	1	1.82	90.91
Xanthidae A (Ar)	1	1.82	92.73
Phyllodocidae A (An)	1	1.82	94.55
Eunice sp. A (An)	1	1.82	96.36
Prionospio sp. A (An)	1	1.82	98.18
Chloeia sp. A (An)	1	1.82	100.00
Total	55	100.00	

Appendix A-11. Percentages of taxa of macrobenthic infauna identified at station B8 in the Bahía de Añasco Mayagüez, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, sipuncula*]

Taxa	Count	Percent	Cumulative percent
Sipuncula (S)	18	26.47	26.47
Scoloplos sp. B (An)	10	14.71	41.18
Maldane sp. A (An)	6	8.82	50.00
Maldanidae A (An)	5	7.35	57.35
Oligochaeta (An)	3	4.41	61.76
Prionospio sp. A (An)	3	4.41	66.18
Myrthea pristiphora (M)	2	2.94	69.12
Oliva caribaeensis (M)	2	2.94	72.06
Amphiodia sp. A (E)	2	2.94	75.00
Neanthes sp. A (An)	2	2.94	80.88
Nephtyidae A (An)	2	2.94	83.82
Prionospio sp. C (An)	2	1.47	98.53
Prionospio sp. B (An)	1	2.94	77.94
Codakia pectinella (M)	1	1.47	85.29
Diplodonta punctata (M)	1	1.47	86.76
Mitrella nitens (M)	1	1.47	88.24
Pilumnus sp. A (Ar)	1	1.47	89.71
Alpheidae A (Ar)	1	1.47	91.18
Xanthidae A (Ar)	1	1.47	92.65
Callianassidae A (Ar)	1	1.47	94.12
Aphroditidae D (Sigalioninae) (An)	1	1.47	95.59
Mediomastus sp. A (An)	1	1.47	97.06
Sigambra sp. A (An)	1	1.47	100.00
Total	68	100.00	

Appendix A-12. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B1 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	5	8	9	6	5	33	6.6
Scoloplos sp. B (An)	0	0	0	0	8	8	1.6
Magelona sp. A (An)	1	1	0	2	2	6	1.2
Myrthea pristiphora (M)	3	0	0	1	1	5	1
Amphiodia sp. A (E)	0	1	1	1	1	4	0.8
Neanthes sp. A (An)	2	1	0	1	0	4	0.8
Maldane sp. A (An)	0	2	1	0	1	4	0.8
Cirrophorus sp. A (An)	0	0	0	0	4	4	0.8
Nemertea (R)	1	0	0	0	1	2	0.4
Prionospio sp. A (An)	1	1	0	0	0	2	0.4
Codakia pectinella (M)	0	0	0	1	0	1	0.2
Scaphopoda (M)	0	1	0	0	0	1	0.2
Gonoplacidae A (Ar)	0	0	0	0	1	1	0.2
Pilumnus sp. A (Ar)	0	0	1	0	0	1	0.2
Nephtyidae A (An)	0	0	1	0	0	1	0.2
Marphysa sp. A (An)	0	0	1	0	0	1	0.2
Ophelia sp. A (An)	0	0	0	1	0	1	0.2
Scoloplos sp. A (An)	0	0	0	0	1	1	0.2
Total	13	15	14	13	25	80	16

Appendix A-13. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B2 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	11	9	17	13	16	66	13.2
Maldane sp. A (An)	1	1	0	2	3	7	1.4
Scoloplos sp. B (An)	0	3	1	2	0	6	1.2
Neanthes sp. A (An)	1	0	5	0	0	6	1.2
Amphiodia sp. A (E)	1	1	0	1	0	3	0.6
Axiopsis sp. A (Ar)	0	1	0	1	0	2	0.4
Prionospio sp. C (An)	1	0	0	1	0	2	0.4
Paradoneis sp. A (An)	1	0	0	0	1	2	0.4
Magelona sp. A (An)	0	0	0	1	1	2	0.4
Eunice sp. A (An)	0	0	0	1	1	2	0.4
Oliva caribaeensis (M)	1	0	0	0	0	1	0.2
Pilumnus sp. A (Ar)	0	0	0	1	0	1	0.2
Leionambrus nitidus (Ar)	0	0	0	1	0	1	0.2
Callianassidae A (Ar)	0	0	0	0	1	1	0.2
Amphiuridae A (E)	1	0	0	0	0	1	0.2
Oligochaeta (An)	0	0	0	0	1	1	0.2
Glycera sp. A (An)	1	0	0	0	0	1	0.2
Scoloplos sp. C (An)	1	0	0	0	0	1	0.2
Prionospio sp. A (An)	1	0	0	0	0	1	0.2
Mediomastus sp. A (An)	1	0	0	0	0	1	0.2
Marphysa sp. A (An)	0	0	1	0	0	1	0.2
Cirrophorus sp. A (An)	0	0	0	1	0	1	0.2
Scoloplos sp. A	0	0	0	0	1	1	0.2
Aphroditidae B (An)	0	0	0	0	1	1	0.2
Total	22	15	24	25	26	112	22.4

Appendix A-14. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B3 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	7	16	6	3	9	41	8.2
Scoloplos sp. B (An)	2	7	0	4	2	15	3
Maldane sp. A (An)	5	7	1	0	1	14	2.8
Maldanidae A (An)	0	0	5	4	0	9	1.8
Callianassidae A (Ar)	1	1	1	2	1	6	1.2
Codakia pectinella (M)	2	0	0	3	0	5	1
Magelona sp. A (An)	1	1	1	1	1	5	1
Marphysa sp. A (An)	0	0	1	1	2	4	0.8
Neanthes sp. A (An)	1	0	0	1	1	3	0.6
Prionospio sp. B (An)	1	2	0	0	0	3	0.6
Cirrophorus sp. A (An)	0	3	0	0	0	3	0.6
Amphiodia sp. A (E)	0	1	0	0	1	2	0.4
Prionospio sp. C (An)	2	0	0	0	0	2	0.4
Eunice sp. A (An)	0	2	0	0	0	2	0.4
Oliva caribaeensis (M)	0	0	0	0	1	1	0.2
Scaphopoda A (M)	1	0	0	0	0	1	0.2
Leiolambrus nitidus (Ar)	0	1	0	0	0	1	0.2
Oligochaeta (An)	1	0	0	0	0	1	0.2
Glycera sp. A (An)	0	0	1	0	0	1	0.2
Nephtyidae A (An)	0	0	0	1	0	1	0.2
Paradoneis sp. A (An)	0	0	0	1	0	1	0.2
Scoloplos sp. A (An)	0	0	0	1	0	1	0.2
Total	24	41	16	22	19	122	24.4

Appendix A-15. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B4 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	8	9	5	12	17	51	10.2
Maldane sp. A (An)	0	14	2	2	2	20	4
Scoloplos sp. B (An)	3	3	1	5	5	17	3.4
Amphiodia sp. A (E)	4	1	4	1	5	15	3
Codakia pectinella (M)	1	7	0	1	0	9	1.8
Scoloplos sp. A (An)	4	0	0	2	0	6	1.2
Prionospio sp. A (An)	0	0	4	1	1	6	1.2
Callianassidae a (Ar)	0	0	2	0	1	3	0.6
Aphroditidae A (An)	0	1	1	1	0	3	0.6
Prionospio sp. C (An)	0	1	0	2	0	3	0.6
Diplodonta punctata (M)	0	1	0	0	1	2	0.4
Xanthidae A (Ar)	0	0	1	0	1	2	0.4
Nemertea (R)	0	0	0	0	2	2	0.4
Maldanidae A (An)	0	1	0	0	1	2	0.4
Neanthes sp. A (An)	0	1	1	0	0	2	0.4
Nephtyidae A (An)	0	1	0	1	0	2	0.4
Magelona sp. A (An)	0	0	1	0	1	2	0.4
Mitrella nitens (M)	0	0	0	0	1	1	0.2
Gouldia sp. A (M)	0	0	0	0	1	1	0.2
Corbula contracta (M)	0	1	0	0	0	1	0.2
Oligochaeta (An)	1	0	0	0	0	1	0.2
Aphroditidae C (An)	1	0	0	0	0	1	0.2
Total	22	41	22	28	39	152	30.4

Appendix A-16. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B5 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	2	4	1	2	4	13	2.6
Scoloplos sp. B (An)	1	2	1	1	3	8	1.6
Codakia pectinella (M)	0	1	0	1	5	7	1.4
Prionospio sp. C (An)	1	1	2	1	1	6	1.2
Cirrophorus sp. A (An)	0	0	1	1	4	6	1.2
Scoloplos sp. A (An)	1	0	3	0	0	4	0.8
Amphiodia sp. A (E)	2	0	0	1	0	3	0.6
Magelona sp. A (An)	0	0	1	1	1	3	0.6
Tellina sp. A (M)	0	0	0	0	2	2	0.4
Corbula caribaea (M)	0	0	0	1	0	1	0.2
Diplodonta punctata (M)	1	0	0	0	0	1	0.2
Phacoides muricatus (M)	0	0	0	0	1	1	0.2
Alpheidae A (Ar)	1	0	0	0	0	1	0.2
Aphroditidae A (An)	1	0	0	0	0	1	0.2
Prionospio sp. B (An)	1	0	0	0	0	1	0.2
Poecilochaetus sp. A (An)	0	0	1	0	0	1	0.2
Neanthes sp. A (An)	0	1	0	0	0	1	0.2
Aphroditidae B (Polynoinae) (An)	0	1	0	0	0	1	0.2
Capitellidae sp. A (An)	0	0	0	1	0	1	0.2
Maldanidae A (An)	0	0	0	0	1	1	0.2
Total	11	10	10	10	22	63	12.6

Appendix A-17. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B6 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

Phylum enclosed in parentheses. Abbreviations: Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	9	3	0	1	5	18	3.6
Scoloplos sp. B (An)	3	5	2	6	2	18	3.6
Maldane sp. A (An)	2		3	2	2	9	1.8
Amphiodia sp. A (E)	2	2	1	0	2	7	1.4
Nephtyidae A (An)	3	2	0	0	1	6	1.2
Marphysa sp. A (An)	0	1	0	0	3	4	0.8
Scoloplos sp. A (An)	0	2	3	0	0	5	1
Prionospio sp. A (An)	0	1	1	0	2	4	0.8
Prionospio sp. B (An)	1	2	1	0	0	4	0.8
Diplodonta punctata (M)	3	0	0	0	0	3	0.6
Maldanidae A (An)	2	1	0	0	0	3	0.6
Corbula caribaea (M)	0	0	0	1	1	2	0.4
Tellina sp. A (M)	0	0	0	1	1	2	0.4
Callianassidae A (Ar)	0	0	2	0	0	2	0.4
Nemertea (R)	1	1	0	0	0	2	0.4
Poecilochaetus sp. A (An)	1	0	0	0	1	2	0.4
Nereidae A (An)	0	0	1	0	1	2	0.4
Trioniocardia antillarum (M)	0	0	0	1	0	1	0.2
Pygnigonida A (Ar)	0	0	0	1	0	1	0.2
Holothuroidea A (E)	0	0	1	0	0	1	0.2
Eunice sp. A (An)	1	0	0	0	0	1	0.2
Cirrophorus sp. A (An)	1	0	0	0	0	1	0.2
Magelona sp. A (An)	0	1	0	0	0	1	0.2
Aphroditidae A (An)	0	0	0	1	0	1	0.2
Mediomastus sp. A (An)	0	0	1	0	0	1	0.2
Neanthes sp. A (An)	0	0	0	1	1	2	0.4
Palmyridae A (An)	0	0	0	1	0	1	0.2
Total	29	21	16	16	22	104	20.8

Appendix A-18. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B7 in the Bahía de Añasco, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	8	5	3	11	0	27	5.4
Scoloplos sp. B (An)	0	0	0	8	1	9	1.8
Callianassidae A (Ar)	0	0	2	0	1	3	0.6
Amphiodia sp. A (E)	1	1	0	0	1	3	0.6
Myrthea pristiphora (M)	0	0	1	0	1	2	0.4
Leiolambrus nitidus (Ar)	0	2	0	0	0	2	0.4
Maldane sp. A (An)	1	0	1	0	0	2	0.4
Codakia pectinella (M)	1	0	0	0	0	1	0.2
Chasmocarcinus cylindricus (Ar)	1	0	0	0	0	1	0.2
Xanthidae A (Ar)	0	1	0	0	0	1	0.2
Phyllodocidae A (An)	1	0	0	0	0	1	0.2
Eunice sp. A (An)	0	0	0	0	1	1	0.2
Prionospio sp. A (An)	0	0	0	0	1	1	0.2
Chloeia sp. A (An)	0	0	0	0	1	1	0.2
Total	13	9	7	19	7	55	11

Appendix A. Macrobenthic infauna identified at stations B1 through B8, December 15, 1990, in the Bahía de Añasco and the Bahía de Mayagüez, Puerto Rico—Continued.

Appendix A-19. Number of individuals identified by taxa in each of five replicate samples of taxa of macrobenthic infauna identified at station B8 in the Bahía de Mayagüez, December 15, 1990. A surface area of 0.04 m^2 was sampled using a Shipeck grab sampler. Taxa are those retained on a 0.50-mm sieve.

[Phylum enclosed in parentheses. Rep, replicate; Avg, average; *An, Annelida; Ar, Arthropoda; E, Echinodermata; M, Mollusca; R, Nemertia; S, Sipuncula*]

Taxa	Rep A	Rep B	Rep C	Rep D	Rep E	Total	Avg
Sipuncula (S)	3	4	4	4	3	18	3.6
Scoloplos sp. B (An)	1	1	0	3	5	10	2
Maldane sp. A (An)	0	4	1	0	1	6	1.2
Maldanidae A (An)	0	0	1	2	2	5	1
Oligochaeta (An)	0	0	0	3	0	3	0.6
Prionospio sp. A (An)	0	0	0	0	3	3	0.6
Myrthea pristiphora (M)	0	1	0	1	0	2	0.4
Oliva caribaeensis (M)	0	2	0	0	0	2	0.4
Amphiodia sp. A (E)	1	0	1	0	0	2	0.4
Neanthes sp. A (An)	0	0	0	1	1	2	0.4
Nephtyidae A (An)	0	0	0	2	0	2	0.4
Prionospio sp. C (An)	0	0	0	1	1	2	0.4
Prionospio sp. B (An)	0	0	0	1	0	1	0.2
Codakia pectinella (M)	0	0	0	1	0	1	0.2
Diplodonta punctata (M)	0	1	0	0	0	1	0.2
Mitrella nitens (M)	0	1	0	0	0	1	0.2
Pilumnus sp. A (Ar)	0	0	0	0	1	1	0.2
Alpheidae A (Ar)	0	0	0	0	1	1	0.2
Xanthidae A (Ar)	0	0	1	0	0	1	0.2
Callianassidae A (Ar)	0	1	0	0	0	1	0.2
Aphroditidae D (Sigalioninae) (An)	1	0	0	0	0	1	0.2
Mediomastus sp. A (An)	0	0	1	0	0	1	0.2
Sigambra sp. A (An)	0	0	0	1	0	1	0.2
Total	6	15	9	20	18	68	13.6

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and at the Escollo Negro reef complex, Puerto Rico.

Appendix B-1. Summary of ichthyofaunal communities.

[Standard deviation in parentheses. Complete list of species is included in appendix B.]

Site	Total surface area surveyed (m^2)	Total number of species	Mean number of species per transect	Shannon-Weaver diversity index	Mean fish abundance per transect
MSG-1	150	24	12 (3)	2.14	36.2
MSG-2	150	34	18 (1)	2.64	39.8
MO-5	90	20	12 (3)	2.12	31.5
MO-4	60	16	12 (4)	2.16	25

Appendix B-2. Station transect statistics on fish abundance, diversity and substrate relief for station MO-5.

[*H'*, Shannon-Weaver diversity index (natural log base); No., number; Sub, substrate; Ind/tra, individuals per transect]

Transect	*H'*	Abundance (Ind/tra)	No. species	Sub relief (meters)
1	1.88	29	9	3.4
2	2.47	44	15	2.2
3	2.02	22	11	2.8
Mean	2.12	32	12	2.8

Appendix B-3. Station transect statistics on fish abundance, diversity and substrate relief for station MSG-1.

[*H'*, Shannon-Weaver diversity index (natural log base); No., number; Sub, substrate; Ind/tra, individuals per transect]

Transect	*H'*	Abundance (Ind/tra)	No. species	Sub relief (meters)
1	1.66	30	8	1.4
2	2.32	36	13	1.5
3	2.10	50	13	1.3
4	2.10	30	10	1.3
5	2.50	36	15	0.9
Mean	2.14	36	12	1.3

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and at the Escollo Negro reef complex, Puerto Rico—Continued.

Appendix B-4. Station transect statistics on fish abundance, diversity and substrate relief for station MSG-2.

[*H'*, Shannon-Weaver diversity index (natural log base); No, number; Sub, substrate; Ind/tra, individuals per transect]

Transect	*H'*	Abundance (Ind/tra)	No. species	Sub relief (meters)
1	2.46	40	16	2.0
2	2.80	33	19	1.9
3	2.65	38	18	2.4
4	2.67	36	18	2.7
5	2.62	52	19	2.3
Mean	2.64	40	28	2.3

Appendix B-5. Station transect statistics on fish abundance, diversity and substrate relief for station MO-4.

[*H'*, Shannon-Weaver diversity index (natural log base); No., number; Sub, substrate; Ind/tra, individuals per transect]

Transect	*H'*	Abundance (Ind/tra)	No. species	Sub relief (meters)
1	2.32	30	14	1.8
2	2.00	20	9	0.7
Mean	2.16	25	12	1.2

Appendix B-6. Summary of coral diversity studies conducted from December13-18, 1990.

[cm, centimeter; Por, Porifera; Scler, Scleractinia; Gorg, Gorgonacea. Standard deviation in parentheses. *H'*, Shannon-Weaver diversity uses natural logarithms. Complete list of taxa are listed in appendix B]

Site	Total number of species per transect			Mean percent linear cover per transect		Total cover per station (cm)		Gorgonian colonies		Diversity (*H'*)		
	Scler	Por	Gorg	Scler	Por	Scler	Por	Mean number per transect per station	Total number per station	Scler	Por	Gorg
MSG-1	10	5	7	128.4 (7.7)	40.6 (20.9)	642	203	15(4)	73	1.15	1.51	1.74
MSG -2	17	9	9	195.2 (81.3)	88.8 (61.8)	976	444	39(5)	197	1.92	1.34	1.68
MO-5	11	7	3	41.0 (3.0)	51 (30.0)	82	102	8(3)	16	1.50	1.80	0.46
MO-4	11	4	7	65.5 (45.5)	27 (5.0)	131	54	50(8)	100	1.63	1.22	1.67

Appendix B-7. Summary of results from censuses of sessile benthos and fishes conducted in 1985 and 1990.

[Units are percent linear coverage under the transect survey line for scleractinia and porifera, number passing through the vertical plane that includes the survey tape for gorgonians, and total number of individuals per transect for the fishes. The survey transect line was 30 feet in 1985 and 10 meters in 1990.]

Site/ Transect	SCLERACTINIA		GORGONACEA		PORIFERA		FISHES	
	1985	1990	1985	1990	1985	1990	1985	1990
Site MSG-1								
1	16.8	8.4	35	8	0.5	7.8	63	30
2	5.0	8.3	50	14	3.3	2.8	19	36
3	40.3	20.1	21	13	1.6	2.4	37	50
4	18.8	10.6	29	21	2.9	4.9	37	30
5		16.8		17		2.4		36
Site MSG-2								
1	5.4	16.5	20	31	1.0	19.3	30	40
2	17.6	11.8	22	38	0.0	5.6	63	33
3	16.0	19.9	17	43	0.9	2.2		
4	14.1	34.9	18	42	0.7	5.0	63	30
5		14.5		43		12.3	19	36

Appendix B-8. Taxonomic composition and abundance of fishes surveyed at station MSG-1 in the Manchas Exteriores coral reef in the Bahía de Añasco, Puerto Rico.

[TR, transect; Std. Dev., standard deviation]

Species	Common name	Individuals per transect						
		TR-1	TR-2	TR-3	TR-4	TR-5	Mean	Std. Dev.
Thalassoma bifasciatum	Bluehead Wrasse	10	8	18	0	0	7.2	7.6
Stegastes partitus	Bicolor Damselfish	9	4	6	6	9	6.8	2.2
Serranus tigrinus	Harlequin Bass	2	2	3	5	3	3.0	1.2
Scarus iserti	Striped Parrotfish	5	5	2	0	0	2.4	2.5
Stegastes planifrons	Yellow Damselfish	0	1	5	3	3	2.4	1.9
Halichoeres garnoti	Yellowhead Wrasse	0	3	3	4	2	2.4	1.5
Sparisoma aurofrenatum	Redband Parrotfish	1	4	1	2	3	2.2	1.3
Acanthurus bahianus	Ocean Surgeon	1	2	0	5	0	1.6	2.1
Myripristis jacobus	Blackbar Soldierfish	0	0	5	1	2	1.6	2.1
Cephalopholis fulva	Coney	1	0	2	2	2	1.4	0.9
Chromis cyanea	Blue Chromis	0	0	2	1	4	1.4	1.7
Canthigaster rostrata	Sharpnose Puffer	1	2	1	0	1	1.0	0.7
Haemulon flavolineatum	French Grunt	0	1	1	0	0	0.4	0.5
Chaetodon capistratus	Four-eye Butterflyfish	0	0	0	0	2	0.4	0.9
Hypoplectrus chlorurus	Yellowtail Hamlet	0	1	0	0	0	0.2	0.4
Pseudupeneus maculatus	Spotted Goatfish	0	1	0	0	0	0.2	0.4
Stegastes variabilis	Cocoa Damselfish	0	1	0	0	0	0.2	0.4
Bodianus rufus	Spanish Hogfish	0	0	1	0	0	0.2	0.4
Sparisoma radians	Bucktooth Parrotfish	0	0	0	1	0	0.2	0.4
Holocentrus rufus	Squirrelfish	0	0	0	0	1	0.2	0.4
Halichoeres maculipinna	Clown Wrasse	0	0	0	0	1	0.2	0.4
Epinephelus guttatus	Red Hind	0	0	0	0	1	0.2	0.4
Hypoplectrus puella	Barred Hamlet	0	0	0	0	1	0.2	0.4
Sparisoma viride	Stoplight Parrotfish	0	0	0	0	1	0.2	0.4

Appendix B-9. Taxonomic composition and abundance of fishes surveyed at station MSG-2 in the Manchas Interiores coral reef in the Bahía de Añasco, Puerto Rico.

[TR, transect; Std. Dev., standard deviation]

Species	Common name	Individuals per transect						
		TR-1	TR-2	TR-3	TR-4	TR-5	Mean	Std. Dev.
Stegastes partitus	Bicolor Damselfish	8	4	3	0	9	4.8	3.7
Stegastes planifrons	Yellow Damselfish	7	1	2	6	3	3.8	2.6
Thalassoma bifasciatum	Bluehead Wrasse	0	0	7	1	10	3.6	4.6
Scarus iserti	Striped Parrotfish	3	2	4	3	3	3.0	0.7
Sparisoma radians	Bucktooth Parrotfish	4	4	0	1	2	2.2	1.8
Chromis cyanea	Blue Chromis	3	3	0	2	3	2.2	1.3
Sparisoma aurofrenatum	Redband Parrotfish	1	2	3	2	2	2.0	0.7
Chaetodon capistratus	Four-eye Butterflyfish	3	2	1	0	4	2.0	1.6
Cephalopholis fulva	Coney	1	1	4	3	1	2.0	1.4
Scarus vetula	Queen Parrotfish	1	0	0	5	1	1.4	2.1
Canthigaster rostrata	Sharpnose Puffer	1	0	3	2	1	1.4	1.1
Serranus tigrinus	Harlequin Bass	0	1	1	3	0	1.0	1.2
Halichoeres garnoti	Yellowhead Wrasse	0	0	1	1	2	0.8	0.8
Ocyurus chrysurus	Yellowtail Snapper	0	0	0	0	4	0.8	1.8
Sparisoma viride	Stoplight Parrotfish	1	1	0	0	2	0.8	0.8
Scarus taeniopterus	Princess Parrotfish	0	3	0	1	0	0.8	1.3
Hypoplectrus unicolor	Butter Hamlet	1	1	1	0	0	0.6	0.5
Aulostomus maculatus	Trumpetfish	0	2	0	0	1	0.6	0.9
Acanthurus bahianus	Ocean Surgeon	1	1	0	0	1	0.6	0.5
Myripristis jacobus	Blackbar Soldierfish	0	1	1	1	0	0.6	0.5
Anisotremus virginicus	Porkfish	0	0	1	1	1	0.6	0.5
Pseudupeneus maculatus	Spotted Goatfish	0	0	1	1	1	0.6	0.5
Stegastes variabilis	Cocoa Damselfish	3	0	0	0	0	0.6	1.3
Holacanthus tricolor	Rock Beauty	1	0	1	0	0	0.4	0.5
Haemulon flavolineatum	French Grunt	0	0	2	0	0	0.4	0.9
Chaetodon aculeatus	Longsnout Butterflyfish	0	0	1	1	0	0.4	0.5
Acanthurus chirurgus	Doctorfish	0	1	0	1	0	0.4	0.5
Cephalopholis cruentatum	Graysby	1	0	0	0	0	0.2	0.4
Sphoeroides greeleyi	Caribbean Puffer	0	1	0	0	0	0.2	0.4
Hypoplectrus puella	Barred Hamlet	0	1	0	0	0	0.2	0.4
Synodus intermedius	Sand Diver	0	1	0	0	0	0.2	0.4
Odontoscion dentex	Reef Croaker	0	0	1	0	0	0.2	0.4
Sphyraena barracuda	Great Barracuda	0	0	0	1	0	0.2	0.4
Hypoplectrus nigricans	Black Hamlet	0	0	0	0	1	0.2	0.4

Appendix B-10. Taxonomic composition and abundance of fishes surveyed at station MO-5 in the Bahía de Añasco, Puerto Rico.

[TR, transect; Std. Dev., standard deviation]

Species	Common name	Individuals per transect				
		TR-1	TR-2	TR-3	Mean	Std. Dev.
Stegastes fuscus	Dusky Damselfish	6	6	8	6.7	1.2
Thalassoma bifasciatum	Bluehead Wrasse	7	8	0	5.0	4.4
Canthigaster rostrata	Sharpnose Puffer	5	4	4	4.3	0.6
Stegastes planifrons	Yellow Damselfish	6	5	1	4.0	2.6
Pomacanthus arcuatus	Gray Angelfish	0	5	2	2.3	2.5
Cephalopholis fulva	Coney	1	2	1	1.3	0.6
Myripristis jacobus	Blackbar Soldierfish	0	3	0	1.0	1.7
Cephalopholis cruentatum	Graysby	1	2	0	1.0	1.0
Haemulon flavolineatum	French Grunt	0	2	1	1.0	1.0
Haemulon macrostomum	Spanish Grunt	0	1	1	0.7	0.6
Chaetodon capistratus	Four-eye Butterflyfish	0	2	0	0.7	1.2
Anisotremus virginicus	Porkfish	0	1	1	0.7	0.6
Hypoplectrus nigricans	Black Hamlet	1	1	0	0.7	0.6
Odontoscion dentex	Reef Croaker	1	0	0	0.3	0.6
Anisotremus surinamensis	Black Margate	0	1	0	0.3	0.6
Haemulon aurolineatum	Tomtate	1	0	0	0.3	0.6
Halichoeres garnoti	Yellowhead Wrasse	0	1	0	0.3	0.6
Aulostomus maculatus	Trumpetfish	0	0	1	0.3	0.6
Serranus tigrinus	Harlequin Bass	0	0	1	0.3	0.6
Amblycirrhitus pinos	Redspotted Hawkfish	0	0	1	0.3	0.6

Appendix B-11. Taxonomic composition and abundance of fishes surveyed at station MO-4 in the Escollo Negro reef complex west of Mayagüez, Puerto Rico.

[TR, transect; Std. Dev., standard deviation]

Species	Common name	Individuals per transect			
		TR-1	TR-2	Mean	Std. Dev.
Stegates partitus	Bilocolor Damselfish	9.0	3.0	6.0	4.2
Halichoeres garnoti	Yellowhead Wrasse	3.0	4.0	3.5	0.7
Scarus iserti	Striped Parrotfish	3.0	4.0	3.5	0.7
Sparisoma aurofrenatum	Redband Parrotfish	3.0	3.0	3.0	0.0
Acanthurus bahianus	Ocean Surgeon	1.0	2.0	1.5	0.7
Chaetodon capistratus	Foureye Butterflyfish	2.0	0.0	1.0	1.4
Scarus taeniopterus	Princess Parrotfish	2.0	0.0	1.0	1.4
Sparisoma radians	Bucktooth Parrotfish	1.0	1.0	1.0	0.0
Pseudupeneus maculatus	Spotted Goatfish	1.0	1.0	1.0	0.0
Canthigaster rostrata	Sharpnose Puffer	1.0	0.0	0.5	0.7
Cephalopholis fulva	Coney	1.0	0.0	0.5	0.7
Carangoides ruber	Bar Jack	1.0	0.0	0.5	0.7
Acanthurus coeruleus	Blue Tang	1.0	0.0	0.5	0.7
Thalassoma bifasciatum	Bluehead Wrasse	1.0	0.0	0.5	0.7
Halichoeres radiatus	Pudding Wife	0.0	1.0	0.5	0.7
Aulostomus maculatus	Trumpetfish	0.0	1.0	0.5	0.7

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and at the Escollo Negro reef complex, Puerto Rico—Continued.

Appendix B-12. Sessile benthos observed at site MSG-1.

[The numbers represent the total coverage in centimeters for all species except branching or erect gorgonians, for which the number represents the number that pass through the vertical plane that includes the survey tape.]

	Transect				
	1	2	3	4	5
PORIFERA					
Anthosigmella varians	55				18
Amphimedon compressa		1	5	21	1
Iotrochota birotulata	7			2	
Ulosa ruetzleri		5	12		
Xestospongia muta				11	
unidentified sp	16	22	7	15	5
TOTAL/TRANSECT	78	28	24	49	24
TOTAL/STATION	203				
mean/station	40.6				
standard deviation	20.9				
GORGONACEA (CUB)					
Erythropodium caribaeorum +	38	8		5	20
Briaerum asbestinum (incrustantes)					
GORGONACEA					
Briaerum asbestinum (erecto)	2	2	3	7	
Eunicea sp	3	2	2	2	2
Gorgonia ventallina	1	5	5	7	5
Plexaura sp				2	2
Pseudoplexaura sp	2		3		2
Pseudopterogorgia americana		3		3	6
Pterogorgia sp		2			
TOTAL/TRANSECT	8	14	13	21	17
TOTAL/STATION	73				
mean/station	15				
standard deviation	4				
ZOANTHIDEA					
Palythoa caribaea			4		
HYDROZOA					
Millepora alcicornis			8	2	
TOTAL	0	0	8	2	0
SCLERACTINIA					
Agaricia agaricites	13	1	12		
Colpophyllia natans					10
Diploria strigosa			10	25	
Montastrea cavernosa	59	62	107	59	154
Montastrea annularis		17	42	5	
Meandrina meandrites	2				
Porites astreoides	10	3	30		4
Siderastrea siderea				17	
TOTAL/TRANSECT	84	83	201	106	168
TOTAL/STATION	642				
mean/station	128.4				
Standard deviation	47.7				

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and at the Escollo Negro reef complex, Puerto Rico—Continued.

Appendix B-13. Sessile benthos observed at station MSG-2 .

[The numbers represent the total coverage in centimeters for all species except branching or erect gorgonians, for which the number represents the number of individuals that pass through the vertical plane that includes the survey tape.]

	Transect				
	1	2	3	4	5
PORIFERA					
Anthosigmella varians	179	25		12	64
Amphimedon compressa	6	7	5		10
Chondrilla nucula		10	10	2	5
Cinachira sp					9
Ircinia campana					5
Iotrochota birotulata		4	2	24	15
Pellina sp	2			10	
Spinosella vaginalis			5		
Ulosa ruetzleri	6	10		2	15
TOTAL/TRANSECT	193	56	22	50	123
TOTAL/STATION	444				
mean/station	88.8				
standard deviation	61.8				
GORGONACEA (CUB)					
Erythropodium caribaeorum + Briaerum asbestinum (incrustantes)	30	105	23		66
GORGONACEA					
Briaerum asbestinum (erecto)	2	2	1	2	1
Eunicea sp	10	9	19	12	22
Gorgonia ventallina	7		8	3	1
Plexaurella sp	1	1	1	2	
Pseudoplexaura sp	3	9	9	10	14
Pseudopterogorgia americana	6	13	4	12	3
Pseudopterogorgia acerosa		1	1		
Pterogorgia sp	2	2			
Plexaura flexuosa		1		1	2
TOTAL/TRANSECT	31	38	43	42	43
TOTAL/STATION	197				
mean/station	39				
standard deviation	5				
ZOANTHIDEA					
Palythoa caribaea			28	20	
HYDROZOA					
Millepora alcicornis		1		1	6
TOTAL	0	1	0	1	6
SCLERACTINIA					
Agaricia agaricites	34	30	10	16	13
Agaricia tenuifolia		5			

Appendix B-13. Sessile benthos observed at station MSG-2 --Continued.

[The numbers represent the total coverage in centimeters for all species except branching or erect gorgonians, for which the number represents the number of individuals that pass through the vertical plane that includes the survey tape.]

	Transect				
	1	2	3	4	5
Colpophyllia natans				69	
Diploria strigosa				2	6
Leptoseris cucullata					5
Montastrea cavernosa	38	25	19	75	20
Montastrea annularis	4	20	73	23	30
Meandrina meandrites			20		5
Porites porites	23			2	5
Porites astreoides	66	36	77	89	61
Siderastrea siderea		2		55	
Stephanocoenia michelini				18	
TOTAL/TRANSECT	165	118	199	349	145
TOTAL/STATION	976				
mean/station	195.2				
Standard deviation	81.3				

Appendix B-14. Sessile benthos observed at stations MO-5 and MO-4 .

[The numbers represent the total coverage in centimeters for all species except branching or erect gorgonians, for which the number represents the number that pass through the vertical plane that includes the survey tape.]

	MO-5		MO-4	
	Transect 1	Transect 2	Transect 1	Transect 2
PORIFERA				
Anthosigmella varians	20			
Amphimedon compressa		11	7	
Aplysina lacunosa		17		
Cliona aprica				20
Chondrilla nucula		8		
Desmapsama anchorata		2		
Iotrochota birotulata		22		
Spinosella vaginalis			20	2
Ulosa ruetzleri			5	
unidentified sp	1	21		
TOTAL/TRANSECT	21	81	32	22
TOTAL/STATION	102		54	
mean/station	51		27	
Standard deviation	30.0		5.0	
GORGONACEA (CUB)				
Erythropodium caribaeorum + Briaerum asbestinum (incrustantes)	101	7	2	
GORGONACEA				
Eunicea sp	4	10	19	13
Gorgonia ventallina	1		7	6
Plexaurella sp			1	1
Pseudoplexaura sp			11	5
Pseudopterogorgia americana		1	13	12
Pterogorgia sp			2	1
Plexaura flexuosa			5	4
TOTAL/TRANSECT	5	11	58	42
TOTAL/STATION	16		100	
mean/station	8		50	
Standard deviation	3		8	
ZOANTHIDEA				
Palythoa caribaea				8
HYDROZOA				
Millepora complanata			10	
Millepora alcicornis			8	2
TOTAL	0	0	18	2
SCLERACTINIA				
Acropora cervicornis			10	
Agaricia agaricites		10	29	

Appendix B. Biological census data for fish and sessile benthos at stations MSG-1, MSG-2, MO-5, and MO-4, December 13-17, 1990, in the Bahía de Añasco and at the Escollo Negro reef complex, Puerto Rico—Continued.

Appendix B-14. Sessile benthos observed at stations MO-5 and MO-4 --Continued.

[The numbers represent the total coverage in centimeters for all species except branching or erect gorgonians, for which the number represents the number that pass through the vertical plane that includes the survey tape.]

	MO-5		MO-4	
	Transect 1	Transect 2	Transect 1	Transect 2
Diploria labyrinthiformes			20	
Diploria strigosa			37	15
Dichocoenia stokesi			5	
Madracis mirabilis	8			
Montastrea cavernosa		16		
Montastrea annularis			10	
Porites astreoides		18		
Siderastrea siderea	30			
Stephanocoenia michelini				5
TOTAL/TRANSECT	38	44	111	20
TOTAL/STATION	82		131	
mean/station	41		65.5	
Standard deviation	3.0		45.5	

Appendix B-15. List of motile and associated benthos observed at stations MSG-1, MSG-2, MO-5, and MO-4.

[T, transect]

	T1	T2	T3	T4	T5
Station MSG-1					
Cnidaria					
Lebrunia danae		1			
Polychaeta					
Sabellastarte magnifica	2		1	2	
Mollusca					
Cyphoma gibbosum	2	1			
Station MSG-2					
Cnidaria					
Palythoa caribbaeorum (patch)	1				
unidentified actiniarian				1	
Polychaeta					
Spirobranchus giganteus			1		
Sabellastarte magnifica				1	
Mollusca					
Cyphoma gibbosum				1	
Crustacea					
Mysidium sp. (patch)	1				
Tunicata					
Clavelina oblonga				1	2
unidentified tunicate				1	
Station MO-5					
Polychaeta					
Sabellastarte magnifica	1	1			
Station MO-4					
Polychaeta					
Sabellastarte magnifica	1				
Mollusca					
Cyphoma gibbosum	1				
Tunicata					
Clavelina oblonga	2				

Appendix C. Elemental and isotopic composition of annual coral bands of *Montastrea annularis* sampled from cores C1 and C2, recovered at site MO-1 near the outfall, December 14, 1990, and cores C7 and C9, sampled at site MO-3 in the Escollo Negro, Puerto Rico, December 17, 1990.

Appendix C-1. Stable isotopes and trace metals measured in the annual bands deposited by colonies of *Montastrea annularis* at station MO-1 (cores C1 and C2), 610 meters from the outfall, and at station MO-3 (cores C7 and C9), at El Negro reef, more than 11 km to the southwest .

[Units: PDB, per dem belemnite; nmol/mol, nanomole per mole; µmol/mol, micromole per mole. Abbreviations: $\delta^{13}C$, delta Carbon 13; $\delta^{18}O$, delta Oxygen 18; Ca, Calcium; Cd, cadmium; Cr, chromium; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; rel, relative; ‰, parts per mil; Std. Dev., standard deviation; --, indicates no data]

Year of band	$\delta^{13}C$ (‰ rel to PDB)	$\delta^{18}O$ (‰ rel to PDB)	Cd/Ca nmol/mol	Cr/Ca nmol/mol	Cu/Ca nmol/mol	Fe/Ca nmol/mol	Mn/Ca nmol/mol	Ni/Ca µmol/mol	Pb/Ca nmol/mol	Zn/Ca µmol/mol
Core C1 - Site MO-1 (1984-1990)										
1990	-3.82	-5.07	3.4	47	131	138	875	0.6	17.1	0.1
1989	--	--	5.1	37	358	16	880	0.3	13.4	0.1
1988	-3.37	-4.96	4.3	31	169	2	751	0.3	7.9	0.1
1987	-4.03	-4.85	2.9	80	259	1346	803	0.3	9.1	0.1
1986	-4.03	-4.67	3.9	71	221	292	963	0.8	12.9	0.1
1985	-3.30	-4.45	3.0	104	305	458	887	0.8	17.1	0.1
1984	-4.05	-5.06	9.7	50	309	452	608	0.5	9.7	0.0
n	6	6	7	7	7	7	7	7	7	7
Average	-3.77	-4.84	4.6	59.8	250.3	386.3	823.8	0.50	12.5	0.07
Std. Dev.	0.35	0.24	2.4	26.1	81.3	463.0	116.3	0.22	3.7	0.02
Core C2 - Site MO-1 (1984-1990)										
1990	-3.41	-4.74	8.0	73	492	848	1032	1.6	56.3	0.1
1989	-2.06	-4.39	3.2	56	209	188	671	0.5	11.4	0.1
1988	-2.61	-4.27	--	--	--	--	--	--	--	--
1987	-2.21	-4.48	--	--	--	--	--	--	--	--
1986	-2.52	-4.50	6.8	49	410	572	756	0.5	20.6	0.1
1985	-2.61	-4.67	4.1	69	251	153	773	0.7	18.7	0.1
1984	-2.69	-5.28	15.4	80	522	477	1274	1.4	40.6	0.2
n	7	7	5	5	5	5	5	5	5	5
Average	-2.59	-4.62	7.5	65.6	376.6	447.5	901.4	0.95	29.5	0.10
Std. Dev.	0.43	0.33	4.8	12.9	140.8	287.6	248.1	0.52	18.5	0.05
Core C2 - Site MO-1 (1938-1990) * Values for 1989.5 is average of 1989-90, and 1985.5 is average of 1985-86 from annual samples above.										
1989.5	-2.74	-4.57	5.6	65	350	518	852	1.1	33.8	0.1
1985.5	-2.57	-4.59	5.5	59	331	362	765	0.6	19.7	0.1
1983	-3.65	-6.57	6.3	74	285	543	846	1.0	44.1	0.1
1980	-2.15	-4.41	5.1	67	174	212	823	0.4	18.4	0.0
1977	-1.93	-4.15	19.3	80	691	1232	717	1.5	19.6	0.2
1974	-2.00	-4.36	5.6	49	90	176	797	0.4	19.1	0.1
1971	-1.96	-4.15	15.7	74	237	219	540	0.9	15.6	0.1
1968	-2.46	-4.96	6.3	92	147	153	615	0.5	29.4	0.0
1965	-2.30	-4.62	7.1	50	126	0	586	0.4	14.1	0.1
1962	-1.35	-4.96	15.2	55	344	696	671	0.4	18.5	0.0

Appendix C-1. Stable isotopes and trace metals measured in the annual bands deposited by colonies of *Montastrea annularis* at station MO-1 (cores C1 and C2), 610 meters from the outfall, and at station MO-3 (cores C7 and C9), at El Negro reef, more than 11 km to the southwest--Continued.

[Units: PDB, per dem belemnite; nmol/mol, nanomole per mole; µmol/mol, micromole per mole. Abbreviations: $\delta^{13}C$, delta Carbon 13; $\delta^{18}O$, delta Oxygen 18; Ca, Calcium; Cd, cadmium; Cr, chromium; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; rel, relative; ‰, parts per mil; Std. Dev., standard deviation; --, indicates no data]

Year of band	$\delta^{13}C$ (‰ rel to PDB)	$\delta^{18}O$ (‰ rel to PDB)	Cd/Ca nmol/mol	Cr/Ca nmol/mol	Cu/Ca nmol/mol	Fe/Ca nmol/mol	Mn/Ca nmol/mol	Ni/Ca µmol/mol	Pb/Ca nmol/mol	Zn/Ca µmol/mol
1959	-2.87	-4.96	4.6	75	429	146	605	0.5	20.5	0.0
1956	-0.88	-4.40	3.1	70	273	954	649	0.4	11.7	0.0
1953	-1.52	-4.29	1.0	75	304	148	720	0.7	11.5	0.1
1950	-0.64	-4.38	6.2	49	198	224	547	0.4	12.4	0.1
1947	-0.09	-4.60	7.1	28	82	162	393	0.4	6.7	0.1
1944	-2.01	-5.12	11.0	65	223	146	519	0.6	15.9	0.1
1941	-2.58	-5.96	6.3	73	287	200	556	0.6	10.1	0.1
1938	-1.54	-4.73	15.0	44	382	245	615	0.7	21.4	0.1
n	18	18	18	18	18	18	18	18	18	18
Average	-1.96	-4.77	8.1	63.5	275.1	352.1	656.4	0.64	19.0	0.07
Std. Dev.	0.86	0.62	5.0	15.5	144.1	322.2	127.4	0.31	9.1	0.04
Core C7 - Site MO-3 (1984-1990)										
1990	-0.79	-4.01	16.7	62	261	573	357	1.0	23.2	0.1
1989	-1.84	-4.84	19.7	89	366	100	418	1.1	16.1	0.1
1988	-1.06	-4.43	42.0	68	294	219	357	0.8	15.7	0.0
1987	-1.62	-5.52	17.3	82	82	0	268	0.9	13.9	0.0
1986	-1.20	-4.20	27.6	58	2000	62	352	1.0	17.8	0.1
1985	-1.39	-4.64	81.8	71	639	770	304	1.2	33.0	0.1
1984	-0.74	-4.56	--	--	--	--	--	--	--	--
n	7	7	6	6	6	6	6	6	6	6
Average	-1.23	-4.60	34.2	71.8	607.0	287.3	342.5	1.00	20.0	0.07
Std. Dev.	0.41	0.49	25.2	11.7	706.2	312.4	51.4	0.15	7.1	0.03
Core C9 - Site MO-3 (1984-1990)										
1990	-2.71	-6.88	12.9	77	273	486	364	1.7	21.6	0.1
1989	-1.93	-5.24	18.4	165	700	896	378	1.3	26.1	0.1
1988	-0.88	-4.45	19.6	65	501	922	377	1.9	28.7	0.1
1987	-2.04	-6.34	8.5	50	188	53	137	2.3	28.2	0.2
1986	-1.68	-4.77	22.7	39	391	1684	233	1.8	26.5	0.2
1985	-0.56	-3.57	35.1	61	635	495	380	1.4	34.9	0.1
1984	-0.92	-5.00	18.1	58	210	119	288	0.8	19.2	0.1
n	7	7	7	7	7	7	7	7	7	7
Average	-1.53	-5.18	19.3	73.5	414.0	665.1	308.1	1.62	26.5	0.13
Std. Dev.	0.77	1.12	8.4	42.3	204.5	561.6	94.4	0.49	5.1	0.03

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico.

Appendix D-1. Size breaks and verbal descriptions for surficial sediment samples GS1 to GS33.

Site	Gravel percent	Sand percent	Silt percent	Clay percent	Verbal description
GS1	0	0.11	49.06	50.84	Silty Clay
GS2	0	0.93	74.42	24.65	Clayey Silt
GS3	0	8.45	35.25	56.3	Silty Clay
GS4	0.13	0.62	36.52	62.73	Silty Clay
GS5	1.93	76	12.31	9.76	Sand
GS6	0.77	0.8	46.03	52.4	Silty Clay
GS7	1.6	2.8	38.48	57.12	Silty Clay
GS8	0.22	13.04	34.55	52.19	Silty Clay
GS9					Hard Bottom
GS10	0.74	5.51	47.51	46.25	Clayey Silt
GS11	0.42	13.89	44.91	40.77	Clayey Silt
GS12	0.04	4.6	58.14	37.22	Clayey Silt
GS13	0	2.15	48.24	49.6	Silty Clay
GS14					Hard Bottom
GS15	1.62	32.62	44.57	21.19	Sandy Silty Clay
GS16	2.34	35.97	37.08	24.61	Sandy Silty Clay
GS17	49.64	46.29	1.57	2.51	Gravel>10 percent
GS18	0.44	27.97	49.16	22.43	Sandy Silty Clay
GS19	3.63	0.97	64.94	30.46	Clayey Silt
GS20	0.38	1.55	65.06	33.01	Clayey Silt
GS21	0.11	1.12	57.76	41.01	Clayey Silt
GS22	0.06	1.09	63.88	34.97	Clayey Silt
GS23	0.6	3.71	64.2	31.49	Clayey Silt
GS24	0.37	37.64	48.51	13.47	Sandy Silt
GS25	0.79	37.74	49.46	12.02	Sandy Silt
GS26	1.9	37.65	37.65	22.79	Sandy Silty Clay
GS27	2.21	51.74	37.43	8.63	Silty Sand
GS28	11.72	83.59	2.55	2.15	Gravel>10 percent
GS29	2.99	88.71	5.61	2.69	Sand
GS30	5.57	87.2	3.55	3.69	Sand
GS31	1.08	68.32	19.56	11.04	Silty Sand
GS32	10.52	58.73	15.98	14.77	Gravel>10 percent
GS33	10.34	86.8	1.59	1.28	Gravel>10 percent

Appendix D-2. Inclusive graphics statistics for surficial sediment samples GS1 to GS33.

[Units are phi, the negative logarithm (base 2) of the size in millimeters.]

Site	Median	Mean	Standard deviation	Skewness	Kurtosis	Description
GS1	8.05	7.97	1.63	-0.08	0.76	Poorly sorted, nearly-symmetrical, platykurtic
GS2	6.02	6.63	1.76	0.49	0.84	Poorly sorted, strongly fine-skewed, platykurtic
GS3	8.33	8.02	2.06	-0.5	1.1	Very poorly sorted, strongly coarse-skewed, mesokurtic
GS4	8.58	8.3	1.64	-0.31	0.89	Poorly sorted, strongly coarse-skewed, platykurtic
GS5	2.2	2.92	2.66	0.49	1.87	Very poorly sorted, strongly fine-skewed, very leptokurtic
GS6	8.15	7.88	1.79	-0.2	0.72	Poorly sorted, coarse-skewed, platykurtic
GS7	8.34	8.1	1.78	-0.33	0.94	Poorly sorted, strongly coarse-skewed, mesokurtic
GS8	8.12	7.76	2.25	-0.49	1.09	Very poorly sorted, strongly coarse-skewed, mesokurtic
GS9						Hard Bottom
GS10	7.71	7.41	2.15	-0.22	0.75	Very poorly sorted, coarse-skewed, platykurtic
GS11	7.14	6.94	2.41	-0.14	0.74	Very poorly sorted, coarse-skewed, platykurtic
GS12	7.31	7.41	1.82	0	0.94	Poorly sorted, nearly-symmetrical, mesokurtic
GS13	7.98	7.82	1.75	-0.16	0.76	Poorly sorted, coarse-skewed, platykurtic
GS14						Hard Bottom
GS15	5.03	5.69	2.43	0.37	0.8	Very poorly sorted, strongly fine-skewed, platykurtic
GS16	4.83	5.68	2.63	0.39	0.75	Very poorly sorted, strongly fine-skewed, platykurtic
GS17	-0.95	-1.23	2.68	-0.08	0.61	Very poorly sorted, nearly-symmetrical, very platykurtic
GS18	4.93	5.71	2.36	0.46	0.75	Very poorly sorted, strongly fine-skewed, platykurtic
GS19	9.09	7.82	1.76	-0.98	0.95	Poorly sorted, strongly coarse-skewed, mesokurtic
GS20	7.14	7.2	1.69	0.07	0.84	Poorly sorted, nearly-symmetrical, platykurtic
GS21	7.56	7.57	1.62	0.01	0.82	Poorly sorted, nearly-symmetrical, platykurtic
GS22	6.93	7.01	1.99	0.07	0.73	Poorly sorted, nearly-symmetrical, platykurtic
GS23	6.58	6.77	2.03	0.15	0.71	Very poorly sorted, fine-skewed, platykurtic
GS24	4.39	4.9	2.32	0.35	1.69	Very poorly sorted, strongly fine-skewed, very leptokurtic
GS25	4.51	4.87	2.27	0.27	1.31	Very poorly sorted, fine-skewed, leptokurtic
GS26	4.98	5.52	2.83	0.23	0.8	Very poorly sorted, fine-skewed, platykurtic
GS27	3.85	3.88	1.95	0.19	1.73	Poorly sorted, fine-skewed, very leptokurtic
GS28	0.49	0.5	1.44	0.15	1.27	Poorly sorted, fine-skewed, leptokurtic
GS29	2.34	2.16	1.55	-0.07	1.4	Poorly sorted, nearly-symmetrical, leptokurtic
GS30	1.18	1.28	19.62	0.54	27.15	Extremely poorly sorted, strongly fine-skewed, extremely leptokurtic
GS31	3.36	3.75	2.82	0.26	1.2	Very poorly sorted, fine-skewness, leptokurtic
GS32	2.07	3.11	3.78	0.37	0.88	Very poorly sorted, strongly fine-skewed, platykurtic
GS33	1.28	1.03	1.3	-0.45	1.36	Poorly sorted, strongly coarse-skewed, leptokurtic

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-3. Cesium-137 concentrations, dry bulk density, and grain size of sediment core layers for cores VCA, VCC, VCY, VCO, with derived sedimentation rates for sites VCA and VCY .

[Units: mBq/g, milliBecquerels per gram; µm, microns; cm/yr, centimeters per year. Dry bulk density is the weight of dry sediments per wet volume. The sedimentation rate was calculated by dividing the estimated depth of the maximum activity of cesium-137 by the number of years since 1964, in this case 26 years.]

Core	Interval (cm) Top	Interval (cm) Bottom	Cesium-137 (mBq/g)	Dry bulk density (gm/cm^3)	Grain size: Sand (>62 µm) percent	Grain size: Silt percent	Grain size: Clay (<2 µm) percent	Sedimentation rate (cm/yr)
VCA	0	20	2.44	0.75	12	46	42	3.46
	20	40	2.02	0.87	11	56	33	
	40	60	3.23	0.84	5	66	29	
	60	80	5.78	0.9	10	49	41	
	80	100	7.92	0.91	4	51	45	
	100	120	2.28	0.79	2	50	48	
	120	140	< 1	0.75	2	51	47	
	140	160	< 1	0.79	3	67	30	
	160	180	1.95	0.87	10	50	40	
	180	200	< 1	0.79	3	46	51	
	200	220	< 1	0.86	2	41	57	
	220	240	< 1	0.85	5	43	52	
	240	258	< 1	0.74	3	53	44	
VCC	0	10	< 1	1.07	80	7	13	
	10	20	< 1	1.13	72	8	20	
	20	30	< 1	1.05	62	13	25	
	30	40	< 1	1.34	82	6	12	
	40	50	< 1	1.09	80	8	12	
	50	60	< 1	1.27	79	7	14	
	60	70	< 1	1.26	81	6	13	
	70	80	< 1	1.15	86	5	9	
	80	90	< 1	1.32	88	4	8	
	90	100	< 1	1.39	92	3	5	
	100	110	< 1	1.22	89	5	6	
VCY	0	20	2.62	0.49	2	44	54	2.3
	20	40	4.74	0.53	1	42	57	
	40	60	5.94	0.59	1	47	52	
	60	80	5.98	0.56	2	39	59	
	80	100	< 1	0.59	2	35	63	
	100	120	< 1	0.56	4	37	59	
	120	140	< 1	0.63	1	25	74	
	140	160	< 1	0.64	2	36	62	
	160	180	< 1	0.69	1	39	60	
	180	200	< 1	0.62	1	29	70	
	200	220	< 1	0.76	3	48	49	
VCO	0	15	2.53	0.64	43	28	29	
	15	30	< 1	0.87	26	35	39	
	30	45	< 1	0.91	22	38	40	
	45	60	< 1	1.18	23	38	39	

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-4. Total organic carbon and total metals measured in the cores recovered from the outfall site (VCO), the Río Grande de Añasco delta (VCA), the Río Yagüez delta (VCY), and from the channel of carbonate sands in the Manchas Interiores (VCC).

[Units: wt.%, weight percent; ppm, parts per million; Abbreviations: cm, centimeter; TOC, Total Organic Carbon; LOI, Loss on Ignition; OOM, Other Organic Material (LOI-TOC)]

Interval (cm)		TOC wt.%	LOI wt.%	OOM wt.%	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Ni ppm	Co ppm	Cd ppm	Cr ppm	Hg ppm	As ppm	Sb ppm	Se ppm	Fe wt.%	Mn wt.%	Al wt.%	Ti wt.%
Top	Bottom																			
Core VCO																				
0	5.08	0.9	10.2	9.3	0.7	43	11	85	73	24	<0.1	111	0.06	26	0.5	0.2	5.5	0.08	6.7	0.37
5.08	10.16	0.7	11.5	10.8	<0.2	41	8	72	75	23	0.1	109	1.49	23	0.4	0.2	4.9	0.07	6.3	0.34
10.16	15.24	0.8	8.9	8.1	<0.2	39	8	72	70	22	<0.1	104	0.04	25	0.3	0.2	5.1	0.07	6.1	0.33
15.24	20.32	0.8	9.8	9	<0.2	45	7	75	84	23	<0.1	122	0.05	21	0.4	0.3	5.5	0.08	7.2	0.39
25.4	30.48	0.9	9	8.1	0.4	41	5	71	77	21	0.1	117	0.02	23	0.4	0.2	5.3	0.07	6.8	0.39
30.48	35.56	0.9	8.6	7.7	<0.2	35	4	61	61	19	<0.1	100	0.04	24	0.4	0.2	4.7	0.07	5.8	0.32
35.56	45.72	0.7	12.2	11.5	<0.2	43	5	70	77	22	0.1	123	0.09	24	0.6	0.3	5.1	0.07	7.5	0.4
45.72	50.8	0.7	8.7	8	<0.2	43	5	71	73	21	<0.1	115	0.05	24	0.5	0.3	5.4	0.07	7.2	0.38
60.96	63.5	0.6	8.2	7.6	<0.2	38	5	74	92	23	<0.1	148	0.04	29	0.3	0.2	5.5	0.07	6.7	0.38
Core VCA																				
0	20	0.9	8.7	7.8	<0.2	75	9	104	49	28	<0.1	91	0.07	9	0.5	0.2	6.6	0.09	10.2	0.54
20	40	0.9	8.2	7.3	<0.2	77	10	105	49	29	<0.1	90	0.07	9	0.4	0.2	6.7	0.09	10.3	0.54
40	60	1.1	8.7	7.6	<0.2	86	11	108	63	28	0.2	101	0.06	9	0.6	0.2	6.8	0.09	11.1	0.56
60	80	1	8	7	<0.2	78	10	104	48	27	0.1	89	0.06	10	0.4	0.2	6.7	0.09	10.4	0.55
80	100	1.4	9.5	8.1	<0.2	86	9	102	46	25	0.1	85	0.06	10	0.5	0.3	6.6	0.08	10.6	0.55
100	120	1.3	9.7	8.4	<0.2	88	8	104	47	25	0.2	82	0.07	9	0.4	0.3	6.6	0.09	11.4	0.55
120	140	1.3	9.5	8.2	<0.2	84	8	101	46	24	0.1	83	0.07	10	0.4	0.2	6.5	0.09	11.3	0.55
140	160	1.8	10.4	8.6	<0.2	85	8	101	51	25	0.2	80	0.07	12	0.4	0.3	6.6	0.1	11	0.55
160	180	1.1	8.5	7.4	<0.2	80	7	101	55	27	0.2	96	0.05	8	0.3	0.2	6.5	0.09	11.2	0.55
180	200	1.4	9.9	8.5	<0.2	82	7	100	55	25	0.2	90	0.06	13	0.4	0.2	6.6	0.1	10.8	0.55
200	220	1.6	10	8.4	<0.2	82	8	100	54	25	0.1	92	0.07	12	0.6	0.3	6.4	0.09	10.5	0.55
220	240	1.5	9.7	8.2	<0.2	81	8	98	54	24	0.1	94	0.06	14	0.4	0.4	6.4	0.09	10.4	0.55
240	258	1.4	9.6	8.2	<0.2	88	8	102	57	24	0.1	92	0.06	12	0.4	0.4	6.5	0.09	10.9	0.57
Core VCY																				
0	20	1.5	8.5	7	0.3	85	19	124	392	40	0.1	395	0.17	18	0.5	0.3	7.3	0.09	9	0.53
20	40	1.5	10.8	9.3	0.3	87	24	129	471	44	0.1	410	0.15	17	0.4	0.3	7.6	0.09	9	0.54
40	60	1.4	10.8	9.4	0.3	88	27	132	548	48	0.2	450	0.07	18	0.6	0.4	8	0.09	9.1	0.55
60	80	1.5	10.8	9.3	0.3	85	24	131	449	43	0.1	400	0.07	20	0.6	0.3	7.5	0.09	9.1	0.54
80	100	1.5	9.6	8.1	0.2	83	22	126	325	37	0.1	350	0.08	19	0.5	0.3	7.2	0.1	9	0.52
100	120	1.4	8.1	6.7	<0.2	80	19	107	336	37	0.1	340	0.07	23	0.6	0.3	7.1	0.1	9.2	0.5
120	140	1.3	12.5	11.2	0.2	68	14	94	302	35	0.1	310	0.06	26	0.7	0.3	6.7	0.1	8.6	0.49
140	160	1.4	10.5	9.1	<0.2	84	17	110	405	44	0.1	410	0.12	14	0.5	0.3	7.2	0.1	8.8	0.53
160	180	1.5	10.7	9.2	<0.2	79	26	109	331	39	<0.1	350	0.12	18	0.5	0.3	7.1	0.1	9.1	0.52
180	200	1.3	9.8	8.5	<0.2	77	12	90	315	39	<0.1	330	0.08	20	0.4	0.2	7	0.09	9	0.53
200	220	1.4	9.6	8.2	<0.2	61	11	84	299	36	<0.1	330	0.06	26	0.4	0.2	6.6	0.09	8	0.48
Core VCC																				
0	5	0.3	7.1	6.8	<0.2	7	9	12	21	4	<0.1	25	0.02	14	0.4	0.2	0.8	0.02	1.1	0.06
5	10	0.3	8.8	8.4	<0.2	11	8	17	33	6	<0.1	39	0.01	16	0.4	0.3	1.2	0.02	1.8	0.09
10	15	0.4	8.8	8.4	<0.2	13	6	19	38	6	<0.1	47	0.01	18	0.5	0.3	1.4	0.03	2.1	0.11
15	20	0.5	6.9	6.4	<0.2	12	5	18	36	6	<0.1	43	0.01	19	0.4	0.3	1.3	0.03	2	0.1
20	60	0.3	9.9	9.6	<0.2	11	5	17	32	7	0.2	41	0.03	16	0.5	0.3	1.1	0.02	1.8	0.1
60	110	0.2	6.9	6.7	<0.2	4	4	7	15	4	0.2	17	0.02	12	0.6	0.3	0.4	0.02	0.6	0.03

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-5. Total organic carbon and total metals measured in selected surface sediments in addition to those measured in a suspended-sediment sample collected from Río Grande de Añasco water quality site QW-An1.

[Units: wt.%, weight percent; ppm, parts per million. Abbreviations: TOC, Total Organic Carbon; LOI, Loss on Ignition; OOM, Other Organic Material (LOI-TOC); --, no data]

Sample Identific ation	TOC wt.%	LOI wt.%	OOM wt.%	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Ni ppm	Co ppm	Cd ppm	Cr ppm	Hg ppm	As ppm	Sb ppm	Se ppm	Fe wt.%	Mn wt.%	Al wt.%	Ti wt.%
GS1	1.4	11.8	10.4	<0.2	89	11	103	66	25	0.1	92	0.09	14	0.6	0.4	6.3	0.08	11.7	0.55
GS2	1.5	11	9.5	<0.2	88	11	101	56	25	0.1	81	0.08	11	0.6	0.4	6.7	0.09	11.1	0.53
GS6	1.5	10.9	9.4	<0.2	84	11	103	77	25	<0.1	103	0.09	14	0.5	0.4	6.3	0.08	10.7	0.53
GS7	1.5	10.5	9	<0.2	79	12	101	89	25	0.1	120	0.09	17	0.6	0.4	6.5	0.08	10.6	0.51
GS11	1.2	12	10.8	<0.2	67	11	99	87	28	0.1	121	0.07	20	0.6	0.3	6.5	0.08	9.3	0.48
GS12	1.5	12.9	11.4	<0.2	72	10	95	84	25	0.1	112	0.08	18	0.5	0.3	6.1	0.08	8.3	0.47
GS16	0.7	9.7	9	<0.2	52	10	104	91	32	0.1	125	0.06	27	0.5	0.2	7.1	0.09	8.7	0.5
GS18	0.7	9.5	8.8	<0.2	51	10	107	109	33	0.2	167	0.06	26	0.6	0.2	7.2	0.09	8.3	0.51
GS21	1.3	13.7	12.4	<0.2	70	12	97	130	26	0.2	159	0.08	15	0.6	0.3	6	0.07	9.4	0.47
GS34	0.2	6.1	5.9	<0.2	3	3	9	12	4	0.1	17	0.02	22	0.3	0.2	0.7	0.03	0.7	0.03
GS35	0.7	14.8	14.1	<0.2	28	8	45	69	13	0.2	86	0.06	7	0.2	0.3	2.7	0.06	3.9	0.23
GS36	0.1	3.3	3.2	<0.2	1	5	2	5	2	0.1	6	0.01	4.1	0.1	0.1	0.1	1	0.1	0.01
GS38	0.2	6.4	6.2	<0.2	7	6	10	18	4	<0.1	24	0.03	14	0.2	0.2	0.7	0.02	1	0.05
Añasco Susp Seds	--	--	--	19.5	90	30	120	40	20	2.5	40	1	3.3	0.6	0.3	4.3	0.07	7.3	0.35

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-6. Mineral phases identified in selected sediments from cores, the suspended sediments of the Río Grande de Añasco, and the surface samples, using X-ray diffraction .

Site	Depth interval units		Size fraction (mm)	Type and strength of acid used to dissolve the carbonates	Principal phase	Major phases	Minor phases	Clay mineralogy	Other phases
	Top	Bottom							
Sediment cores									
VCO	0	10.16	<.062		quartz	albite	7A clay 10A clay aragonite (Mn, Mg) calcite calcite	kaolinite kaolinite-smectite	brookite
	0	10.16	<.062	Na acet.@pH5	quartz	albite	7A clay	kaolinite kaolinite-smectite halloysite	
	10.16	35.56	<.062		quartz	aragonite (Mn, Mg) calcite albite	calcite 7A clay	kaolinite	pyrite
	35.56	63.5	<.062		quartz	(Mn, Mg) calcite albite	aragonite calcite 7A clay	kaolinite-smectite	pyrite
	35.56	63.5	<.062	Na acet.@pH5	quartz	albite	7A clay brookite pyrite	kaolinite kaolinite-smectite halloysite	
VCA	0	5	<.062		quartz	albite 7A clay		kaolinite kaolinite-smectite	aragonite pyrite
	240	258	<.062		quartz	albite	7A clay	kaolinite kaolinite-smectite	
Añasco Susp Sed	NA	NA	<.062		quartz 7A clay			kaolinite kaolinite-smectite	10A illite
VCY	0	20	<.062		quartz	7A clay	albite	kaolinite kaolinite-smectite halloysite	calcite aragonite (Mn, Mg) calcite
	200	220	<.062		quartz	albite 7A clay (Mn, Mg) calcite		kaolinite kaolinite-smectite	aragonite calcite
VCC	0	60	<.062		quartz	aragonite calcite 7A clay		kaolinite-smectite	(Mn, Mg) calcite
	0	60	>.062	Na acet.@pH5	(Mn, Mg) calcite	aragonite	calcite		
			>.062	Na acet.@pH5	(Mn, Mg) calcite	aragonite	calcite (Mn, Mg) calcite		
	0	60	>.062	cold dilute HCl	(Mn, Mg) calcite	aragonite			quartz calcite
	0	60	>.062	hot HCl @ 6M	quartz	albite pyrite		present	7A clay
	60	110	<.062		(Mn, Mg) calcite	quartz	(Mn, Mg) calcite		albite

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-6. Mineral phases identified in selected sediments from cores, the suspended sediments of the Río Grande de Añasco, and the surface samples, using X-ray diffraction--Continued.

Site	Depth interval units		Size fraction (mm)	Type and strength of acid used to dissolve the carbonates	Principal phase	Major phases	Minor phases	Clay mineralogy	Other phases
	Top	Bottom							
						aragonite calcite			
	60	110	<.062	Na acet.@pH5	quartz	albite 7A clay	pyrite	kaolinite kaolinite-smectite	brookite
Surface samples									
GS1	NA	NA	<.062		quartz	7A clay 10A clay	albite calcite brookite	kaolinite kaolinite-smectite	pyrite
GS2	NA	NA	<.062		quartz		albite 7A clay	kaolinite kaolinite-smectite	aragonite calcite
GS6	NA	NA	<.062		quartz	7A clay 10A clay	albite	kaolinite kaolinite-smectite	calcite brookite pyrite
GS7	NA	NA	<.062		quartz	7A clay albite	calcite	kaolinite kaolinite-smectite	aragonite
GS11	NA	NA	<.062		quartz	7A clay albite		kaolinite kaolinite-smectite	calcite aragonite (Mn, Mg) calcite
GS12	NA	NA	<.062		quartz	albite	7A clay 10A clay	kaolinite kaolinite-smectite	calcite aragonite (Mn, Mg) calcite
GS16	NA	NA	<.062		albite quartz	7A clay		kaolinite kaolinite-smectite	aragonite calcite
GS18	NA	NA	<.062		quartz	albite	7A clay calcian kutno- horite	kaolinite kaolinite-smectite	calcite aragonite
GS21	NA	NA	<.062		quartz	7A clay		kaolinite kaolinite-smectite	albite aragonite calcite
GS34	NA	NA	<.062		quartz 7A clay	aragonite		kaolinite-smectite	(Mn, Mg) calcite
GS35	NA	NA	<.062		quartz			kaolinite-smectite	aragonite calcite albite 7A clay
GS36	NA	NA	<.062		quartz	aragonite calcite			
GS38	NA	NA	<.062		quartz aragonite (Mn, Mg) calcite	albite calcite 7A clay		kaolinite kaolinite-smectite	

Appendix D. Texture, elemental composition, percent carbonate, cesium-137 activity, and clay mineralogy for bottom sediments and core samples collected from December 15, 1990, through January 27, 1991, in the Bahía de Añasco and in the Escollo Negro, Puerto Rico—Continued.

Appendix D-7. Composition of surficial sediment samples as percentages of three geochemical endmember sources identified as typical of the Río Grande de Añasco, carbonates, and the Rio Yagüez.

[Also included are the uppermost samples from the four sediment-core sites. The endmember compositions are described in the text. Three of the surficial sediment samples were indicated to have a negative percentage of a certain endmember, indicating either a removal of elements typical of that endmember or the presence of another endmember not well described by the three presented here. To facilitate plotting pie charts and drawing component contours in the report, the negative percentages present in those three samples were set equal to zero and the other two factors decreased by one-half of the cancelled value. The resultant values are listed below with the original values in parenthesis.]

ID	Añasco	Carbonate	Yagüez
GS1	85.9	10.9	3.2
GS2	86.2	10.2	3.6
GS6	81.8	9.9	8.3
GS7	76.5	11.0	12.4
GS11	71.5	14.2	14.3
GS12	72.6	14.5	12.9
GS16	71.2	10.6	18.2
GS18	63.7	12.6	23.7
GS21	63.6	16.5	20.0
GS34	11.8	86.6	1.6
GS35	38.9	51.0	10.2
GS-38	0 (-1)	86.5 (87)	13.5 (14)
VCO	58.8	20.4	20.7
VCC	0 (-9)	82.5 (87)	17.5 (22)
VCA	91.7	2.5	5.9
VCY	22.1 (26)	0 (-7)	77.9 (82)

Appendix D-8. Percent calcium carbonate in selected surface-sediment samples, the core VCO, and the core VCC.

[Values in parenthesis indicate the relative percent difference (RPD) for samples where laboratory replicates were analyzed. cm, centimeter]

Surface samples				Sediment cores			
					Interval (cm)		
Site	%$CaCO_3$	Site	%$CaCO_3$	Site	Top	Bottom	%$CaCO_3$
GS1	5.3	GS20	30.3	VCO	0	5.08	34.2
GS2	4.7	GS21	16.6		50.8	63.5	34.2
GS2	5.5 (15.7)	GS22	31.9				
GS3	15.2	GS23	35.2	VCC	0	20	84.6
GS4	14.6	GS24	68.3		20	60	78.3
GS5	76.8	GS25	58.9		60	110	89.7
GS5	76.4 (0.5)	GS26	65.4				
GS6	6.8	GS27	75.6				
GS7	10.8	GS28	91.5				
GS8	19.5	GS29	85.7				
GS10	9.7	GS30	87.7				
GS11	12.0	GS31	74.8				
GS12	15.5	GS32	71.2				
GS12	13.4 (14.5)	GS33	93.7				
GS13	17.1	GS34	90.3				
GS15	13.7	GS35	61.5				
GS16	12.9	GS36	95.7				
GS18	11.3	GS37	96.3				
GS19	19.6	GS38	87.3				

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at 10 water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991.

Appendix E-1. Summary of the results of acute and chronic exposure bioassays conducted during January 1991.

[Analysis of effluent water quality is given in appendixes E-2 through E-7. Concentrations are expressed as nominal values; actual values are 78 percent of nominal. This variation is due to adjustment of effluent salinity by addition of natural seawater brine. Units: LC-50, median lethal concentration. NA, not applicable. Concentrations are percent effluent of the total effluent dilution water-effluent mix.]

Species	Acute toxicity evaluation			Chronic toxicity evaluation			
	Exposure (hours)	LC-50 (percent)	No observed acute effect level (percent)	Exposure (days)	No observed effect concentration (percent)	Lowest observed effect concentration (percent)	Chronic value (percent)
Mysidopsis bahia	96	8.3	1	7	15	25	19.4
Cyprinodon variegatus	96	43.3	10	7	1	10	3.2
Champia parvula	48/168	NA	1	7	5	10	7.1

Appendix E-2. Volatile organic compounds measured in the Mayagüez Regional Wastewater Treatment Plant, January 29, 1991.

[Method 624. Samples to be analyzed for volatile compounds cannot be composited. Therefore, four samples each of the influent and effluent were individually collected throughout the day. Units are micrograms per liter. Abbreviations: WWTP, Wastewater Treatment Plant; Rep. Limit, Reporting Limit; ND, not detected. Values for surrogates represent percent recovery.]

Constituent	Influent					Effluent				
	WWTP 1	WWTP 2	WWTP 3	WWTP 4	Rep. Limit	WWTP 5	WWTP 6	WWTP 7	WWTP 8	Rep. Limit
Acrolein	ND	ND	ND	ND	100	ND	ND	ND	ND	100
Acrylonitrile	ND	ND	ND	ND	100	ND	ND	ND	ND	100
Benzene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Bromodichloromethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Bromoform	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Bromomethane	ND	ND	ND	ND	10	ND	ND	ND	ND	10
Carbon tetrachloride	ND	ND	ND	ND	5	ND	ND	ND	8.7	5
Chlorobenzene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Chloroethane	ND	ND	ND	ND	10	ND	ND	ND	ND	10
Chloroform	ND	8.3	6.5	ND	5	9.7	7.7	9.6	12	5
Chloromethane	ND	ND	ND	ND	10	36	23	30	50	10
Dibromochloromethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,1-Dichloroethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,2-Dichloroethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,1-Dichloroethene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,2-Dichloroethene (total)	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,2-Dichloropropane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
cis-1,3-Dichloropropene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
trans-1,3-Dichloropropene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Ethylbenzene	ND	ND	ND	ND	5	ND	6.4	ND	ND	5
Methylene chloride	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Tetrachloroethene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Toluene	13	32	28	13	5	ND	62	69	13	5
1,1,1-Trichloroethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
1,1,2-Trichloroethane	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Trichloroethene	ND	ND	ND	ND	5	ND	ND	ND	ND	5
Vinyl chloride	ND	ND	ND	ND	10	ND	ND	ND	ND	10
Surrogate	Recovery									
Toluene-d8	99	102	104	96		102	102	103	104	
4-Bromofluorobenzene	100	105	105	106		104	106	103	101	
1,2-Dichloroethane-d4	98	95	98	92		90	99	97	98	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at 10 water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-3. Semivolatile organic compounds measured in the Mayagüez Regional Wastewater Treatment Plant, January 29, 1991 .

[Method 625. Units are micrograms per liter; ND, not detected; conc., concentration; Rep. Limit, Reporting Limit; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	Influent		Effluent	
	conc.	Rep. Limit	conc.	Rep. Limit
Acenaphthene	ND	40	ND	20
Acenaphthylene	ND	40	ND	20
Anthracene	ND	40	ND	20
Benzidine	ND	400	ND	200
Benzo a-anthracene	ND	40	ND	20
Benzo b fluoranthene	ND	40	ND	20
Benzo k fluoranthene	ND	40	ND	20
Benzo (g,h,i)perylene	ND	40	ND	20
Benzo (a)pyrene	ND	40	ND	20
4-Bromophenyl phenyl ether	ND	40	ND	20
Butyl benzyl phthalate	ND	40	ND	20
bis(2-Chloroethoxy)-methane	ND	40	ND	20
bis(2-Chloroethyl) ether	ND	40	ND	20
bis(2-Chloroisopropyl)-ether	ND	40	ND	20
4-Chloro-3-methylphenol	ND	40	ND	20
2-Chloronaphthalene	ND	40	ND	20
2-Chlorophenol	ND	40	ND	20
4-Chlorophenyl phenyl ether	ND	40	ND	20
Chrysene	ND	40	ND	20
Dibenz(a,h)anthracene	ND	40	ND	20
Di-n-butyl phthalate	ND	40	ND	20
1,2-Dichlorobenzene	ND	40	ND	20
1,3-Dichlorobenzene	ND	40	ND	20
1,4-Dichlorobenzene	ND	40	ND	20
3,3'-Dichlorobenzidine	ND	80	ND	40
2,4-Dichlorophenol	ND	40	ND	20
Diethyl phthalate	ND	40	ND	20
2,4-DimethylPhenol	ND	40	ND	20
Dimethyl phthalate	ND	40	ND	20
4,6-Dinitro-2-methylphenol	ND	200	ND	100
2,4-Dinitrophenol	ND	200	ND	100

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at 10 water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991--Continued

Appendix E-3. Semivolatile organic compounds measured in the Mayagüez Regional Wastewater Treatment Plant, January 29, 1991--Continued.

[Method 625. Units are micrograms per liter; ND, not detected; conc., concentration; Rep. Limit, Reporting Limit; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	Influent		Effluent	
	conc.	Rep. Limit	conc.	Rep. Limit
2,4-Dinitrotoluene	ND	40	ND	20
2,6-Dinitrotoluene	ND	40	ND	20
Di-n-octylphthalate	ND	40	ND	20
1,2-Diphenylhydrazine	ND	40	ND	20
bis(2-Ethylhexyl)phthalate	ND	40	ND	20
Fluoranthene	ND	40	ND	20
Fluorene	ND	40	ND	20
Hexachlorobenzene	ND	40	ND	20
Hexachlorobutadiene	ND	40	ND	20
Hexachlorocyclopentadiene	ND	40	ND	20
Hexachloroethane	ND	40	ND	20
Indeno(1,2,3-cd)pyrene	ND	40	ND	20
Isophorone	ND	40	ND	20
Naphthalene	ND	40	ND	20
Nitrobenzene	ND	40	ND	20
2-Nitrophenol	ND	40	ND	20
4-Nitrophenol	ND	200	ND	100
N-Nitrosodimethylamine	ND	40	ND	20
N-Nitrosodiphenylamine	ND	40	ND	20
N-Nitroso-di-n-Propylamine	ND	40	ND	20
Pentachlorophenol	ND	200	ND	100
Phenanthrene	ND	40	ND	20
Phenol	ND	40	ND	20
Pyrene	ND	40	ND	20
1,2,4-Trichlorobenzene	ND	40	ND	20
2,4,6-Trichlorophenol	ND	40	ND	20

Surrogate	Recovery	
Nitrobenzene-d5	70	66
2-Fluorobiphenyl	54	68
Terphenyl-dl4	14	35

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at 10 water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-3. Semivolatile organic compounds measured in the Mayagüez Regional Wastewater Treatment Plant, January 29, 1991--Continued.

[Method 625. Units are micrograms per liter; ND, not detected; conc., concentration; Rep. Limit, Reporting Limit; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	Influent conc.	Influent Rep. Limit	Effluent conc.	Effluent Rep. Limit
Surrogate	**Recovery**			
Phenol-d5	80		75	
2-Fluorophenol	75		74	
2,4,6-Tribromophenol	67		68	

Tentatively identified compounds

Influent Constituent	Influent conf. level	Influent conc.	Effluent Constituent	Effluent conf. level	Effluent conc.
Cyclohexane,Methyl-	2	100	1-Butanol,3-Methyl-	1	89
Propanoic Acid	2	180	Propanoic Acid	2	150
Propanoic Acid,2-Methyl-	2	120	Propanoic Acid,2-Methyl-	2	76
Butanoic Acid	2	170	Butanoic Acid,3-Methyl-	1	69
Butanoic Acid,3-Methyl-	2	300	Butanoic Acid,-Methyl	1	88
Butanoic Acid,2-Methyl	2	100	2,4-Pentanediol,2-Methyl	2	63
Pentanoic Acid	2	150	Hexanoic Acid	2	66
Hexanoic Acid,Anhydride	1	210	Benzeneethanol	2	75
Benzeneethanol	2	79	Benzoic Acid,Ammonium Salt	1	170
3-Cyclohexene-1-Methanol,. .Alpha.,.Alpha.,4-Trimethyl-	1	140	3-Cyclohexene-1-Methanol,.Alpha.,.Alpha., 4-Trimethyl-	1	87
Benzeneacetic Acid	2	200	Benzeneacetic Acid	2	140
Dodecanoic Acid	1	120	Dodecanoic Acid	1	86
Tetradecanoic Acid	1	280	9-Hexadecenoic Acid	1	64
9-Hexadecenoic Acid	1	75	Hexadecanoic Acid	1	410
Hexadecanoic Acid	1	1300	Oxygenated Hydrocarbon		370
9-Hexadecenoic Acid	1	910	Octadecanoic Acid	1	170
Oxygenated Hydrocarbon	2	82	Cholestan-3-OL	1	83
Octadecanoic Acid	1	230	Cholest-5-EN-3-OL	1	47
Cholestan-3-OL	1	130			
Cholest-5-EN-3-OL	1	78			

Appendix E-4. Concentrations of pesticides, PCB's, and herbicides, Mayagüez Regional Wastewater Treatment Plant, January 29, 1991 .

[Units are micrograms per liter; ND, not detected; conc., concentration; Rep. Limit, Reporting Limit. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	Influent Site 18		Effluent Site 11	
	conc.	Rep. Limit	conc.	Rep. Limit
Organochlorine Pesticides/PCB’s				
Method 8080				
alpha-BHC	ND	0.1	ND	0.1
beta-BHC	ND	0.1	ND	0.1
delta-BHC	ND	0.1	ND	0.1
gamma-BHC (Lindane)	ND	0.1	ND	0.1
Toxaphene	ND	2	ND	2
Heptachlor	ND	0.04	ND	0.04
Aldrin	ND	0.04	ND	0.04
Heptachlor epoxide	ND	0.1	ND	0.1
Endosulfan I	ND	10	ND	10
Dieldrin	ND	0.04	ND	0.04
4,4’-DDE	ND	0.12	ND	0.12
Endrin	ND	0.12	ND	0.12
Endosulfan II	ND	0.2	ND	0.2
4,4’-DDD	ND	0.2	ND	0.2
Endosulfan sulfate	ND	0.2	ND	0.2
4,4’-DDT	ND	0.2	ND	0.2
Endrin aldehyde	ND	0.2	ND	0.2
Chlordane	ND	0.1	ND	0.1
Aroclor 1016	ND	1	ND	1
Aroclor 1221	ND	1	ND	1
Aroclor 1232	ND	1	ND	1
Aroclor 1242	ND	1	ND	1
Aroclor 1248	ND	1	ND	1
Aroclor 1254	ND	2	ND	2
Aroclor 1260	ND	2	ND	2
Mirex	ND	0.1	ND	0.1
Ethylan (Perthane)	ND	1	ND	1

Appendix E-4. Concentrations of pesticides, PCB's, and herbicides, Mayagüez Regional Wastewater Treatment Plant, January 29, 1991--Continued.

[Units are micrograms per liter; ND, not detected; conc., concentration; Rep. Limit, Reporting Limit. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	Influent Site 18		Effluent Site 11	
	conc.	Rep. Limit	conc.	Rep. Limit
Methoxychlor	ND	1	ND	1
Surrogate	**Recovery**			
Dibutyl chlorendate	98		120	
Organophosphorus Pesticides SW-846 List Method 8141				
Azinphos-methyl (Guthion)	ND	5	ND	5
Chlorpyrifos (Dursban)	ND	0.5	ND	0.5
Coumaphos	ND	1	ND	1
Demeton O&S	ND	0.5	ND	0.5
Fenthion (Baytex)	ND	0.5	ND	0.5
Malathion	ND	2.4	ND	2.4
Naled (Dibrom)	ND	20	ND	20
Ethyl parathion	ND	0.5	ND	0.5
Methyl parathion	ND	0.5	ND	0.5
Chlorinated Herbicides Method 8150				
2,4-D	ND	1.2	ND	1.2
2,4,5-TP (Silvex)	ND	0.17	ND	0.17
Surrogate	**Recovery**			
DCAA	113		76	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-5. Concentrations of total metals, Mayagüez Regional Wastewater Treatment Plant, January 29, 1991.

[Units are milligrams per liter; Abbreviation: conc., concentration; Rep. Limit, Reporting Limit; ND, not detected.]

Constituent	Analytical Method	Influent		Effluent	
		Conc.	Rep. Limit	Conc.	Rep. Limit
Antimony	7041	ND	0.2	ND	0.01
Beryllium	7090	ND	0.5	ND	0.05
Copper	7210	0.29	0.05	ND	0.05
Nickel	7520	ND	0.1	ND	0.1
Chromium (VI)	7196	0.011	0.01	0.017	0.01
Aluminum	6010	1.2	0.1	0.26	0.1
Silver	7761	0.011	0.0025	0.0033	0.001
Cadmium	7131	ND	0.005	ND	0.005
Zinc	7950	0.16	0.02	0.062	0.02
Chromium	7191	0.034	0.01	0.02	0.006
Arsenic	7060	ND	0.005	ND	0.005
Barium	6010	0.12	0.01	0.076	0.01
Boron	6010	0.14	0.1	0.13	0.1
Calcium	6010	48	0.2	47.3	0.2
Iron	6010	2.1	0.1	0.75	0.1
Lead	7421	0.011	0.005	ND	0.005
Magnesium	6010	19.4	0.2	19	0.2
Manganese	6010	0.13	0.01	0.11	0.01
Mercury	7470	0.00082	0.0002	ND	0.0002
Potassium	6010	11.99	5	11.4	5
Selenium	7740	ND	0.005	ND	0.005
Silica as SiO_2	6010	20.8	0.5	23.1	0.5
Sodium	6010	91.3	5	89.8	5
Strontium	6010	0.28	0.05	0.26	0.05
Thallium	7841	ND	0.01	ND	0.01

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-6. General inorganics and radiochemistry, Mayagüez Regional Wastewater Treatment Plant, January 29, 1991.

[Units are in mg/L, milligrams per liter. Abbreviations: conc., concentration; Rep. Limit, Reporting Limit; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; ND, not detected.]

Constituent	Analytical method	Influent			Effluent	
		units	conc.	Rep. Limit	conc.	Rep. Limit
General Inorganics						
Chloride	A429	mg/L	112	3	137	3
Cyanide	9012	mg/L	ND	0.01	ND	0.01
Color	110.2	units	NR		_	_
Fluoride	A429	mg/L	5.4	0.1	9.7	0.1
Surfactants (MBAS)	425.1	mg/L	1.1	0.1	2	0.2
Ammonia as N	350.1	mg/L	20.9	1	20.6	1
Nitrate plus Nitrite	353.2	mg/L	ND	0.1	ND	0.1
Orthophosphate as P	365.3	mg/L	4.4	0.5	5.3	0.5
Phenolics	9065	mg/L	ND	0.01	0.058	0.01
Sulfide, Total	376.2	mg/L	6.2	0.5	0.84	0.25
Sulfate	A429	mg/L	18.8	0.5	16.8	0.5
Total Kjeldahl Nitrogen as N	351.2	mg/L	49.9	5	34.2	5
Phosphorus, Total as P	365.3	mg/L	7.9	1	6.1	0.5
Turbidity	180.1	NTU	185	0.5	50	0.1
Total Dissolved Solids	160.1	mg/L	532	20	615	50
Total Suspended Solids	160.2	mg/L	266	10	57	2.5
Total Volatile Solids	160.4	mg/L	300	10	205	10
Volatile Suspended Solids	160.4	mg/L	194	50	49.5	12.5
Radiochemistry						
				(+/-)		(+/-)
Gross Alpha	900	pCi/L	0	2.3	1.1	2.7
Gross Beta	900	pCi/L	11	5	14	5
Radium 226	705 Mod.	pCi/L	0	0.5	0	0.5
Strontium 90	A704	pCi/L	0	0.7	0	0.7

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-7. General water quality, Mayagüez Regional Wastewater Treatment Plant, January 29, 1991.

[Units and abbreviations are mg/L, milligrams per liter; °C, degrees Celsius; k, extinction coefficient; dil/count, dilution (per 100 ml) and number of bacteria colonies counted using the filter membrane method; col/100ml, colonies of bacteria per 100 milliliters; TNTC, too numerous to count; µS/cm, microsiemens per centimeter; mg/m^3, milligram per cubic meter; Mgal/d, million gallons per day; NA, not applicable; NR, not reported]

Constituent	units		Influent		Effluent
BOD-5	mg/L		390		170
Oil and Grease	mg/L		NR		NR
Settleable Solids	mg/L		3.3		0
Water Temperature	°C		26		NR
Alkalinity	mg/L		NR		NR
Spec. Cond.	µS/cm		NR		NR
pH	units		6.9		7
Dissolved Oxygen	mg/L		NR		NR
Extinction Coefficient	k		NA		NA
Chlorophyll-a	mg/m^3		0.6081		1.3268
Discharge	Mgal/d		7.2		7.2
Bacteria		vol. filt.	count	vol. filt.	count
Fecal Coli(dil/count)		0.1	TNTC	1	60
Fecal Coli(dil/count)		0.01	TNTC	0.1	18
Fecal Coli(dil/count)		0.001	TNTC	0.01	0
	cols/100mL		b>6000000		6000
Total Coli(dil/count)		0.1	TNTC	1	TNTC
Total Coli(dil/count)		0.01	TNTC	0.1	29
Total Coli(dil/count)		0.001	TNTC	0.01	2
	cols/100mL		b>8000000		29000
Enterococcus(dil/count)		1	TNTC	1	11
Enterococcus(dil/count)		0.01	TNTC	0.1	0
Enterococcus(dil/count)		0.001	204	0.01	0
	cols/100mL		b>20000000		b-1100

Appendix E-8. Volatile organic compounds, Río Grande de Añasco and Río Yagüez.

[Method 624. Units are micrograms per liter. Abbreviations: Repl., replicate sample; Rep. Limit, Reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sample dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
Constituent	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Acrolein	ND	100	ND	100	ND	100	ND	100
Acrylonitrile	ND	100	ND	100	ND	100	ND	100
Benzene	ND	5	ND	5	ND	5	ND	5
Bromodichloromethane	ND	5	ND	5	ND	5	ND	5
Bromoform	ND	5	ND	5	ND	5	ND	5
Bromomethane	ND	10	ND	10	ND	10	ND	10
Carbon tetrachloride	ND	5	ND	5	ND	5	ND	5
Chlorobenzene	ND	5	ND	5	ND	5	ND	5
Chloroethane	ND	10	ND	10	ND	10	ND	10
Chloroform	ND	5	ND	5	ND	5	ND	5
Chloromethane	ND	10	ND	10	ND	10	ND	10
Dibromochloromethane	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethane	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethane	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethene	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethene (total)	ND	5	ND	5	ND	5	ND	5
1,2-Dichloropropane	ND	5	ND	5	ND	5	ND	5
cis-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5
trans-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5
Ethylbenzene	ND	5	ND	5	ND	5	ND	5
Methylene chloride	ND	5	ND	5	ND	5	ND	5
1,1,2,2-Tetrachloroethane	ND	5	ND	5	ND	5	ND	5
Tetrachloroethene	ND	5	ND	5	ND	5	ND	5
Toluene	ND	5	ND	5	ND	5	ND	5
1,1,1-Trichloroethane	ND	5	ND	5	ND	5	ND	5
1,1,2-Trichloroethane	ND	5	ND	5	ND	5	ND	5
Trichloroethene	ND	5	ND	5	ND	5	ND	5
Vinyl chloride	ND	10	ND	10	ND	10	ND	10
Surrogate	Recovery							
Toluene-d8	100		102		101		101	
4-Bromofluorobenzene	99		104		93		101	
1,2-Dichloroethane-d4	103		90		108		103	

Appendix E-9. Semivolatile organic compounds, Río Grande de Añasco and Río Yagüez .

[Method 625. Units are micrograms per liter. Abbreviations: Repl., replicate; Rep. Limit, reporting limit; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed. Sampling dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Acenaphthene	ND	10	ND	10	ND	10	ND	10
Acenaphthylene	ND	10	ND	10	ND	10	ND	10
Anthracene	ND	10	ND	10	ND	10	ND	10
Benzidine	ND	100	ND	100	ND	100	ND	100
Benzo a-anthracene	ND	10	ND	10	ND	10	ND	10
Benzo b fluoranthene	ND	10	ND	10	ND	10	ND	10
Benzo k fluoranthene	ND	10	ND	10	ND	10	ND	10
Benzo (g,h,i)perylene	ND	10	ND	10	ND	10	ND	10
Benzo (a)pyrene	ND	10	ND	10	ND	10	ND	10
4-Bromophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10
Butyl benzyl phthalate	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethoxy)-methane	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethyl) ether	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroisopropyl)-ether	ND	10	ND	10	ND	10	ND	10
4-Chloro-3-methylphenol	ND	10	ND	10	ND	10	ND	10
2-Chloronaphthalene	ND	10	ND	10	ND	10	ND	10
2-Chlorophenol	ND	10	ND	10	ND	10	ND	10
4-Chlorophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10
Chrysene	ND	10	ND	10	ND	10	ND	10
Dibenz(a,h)anthracene	ND	10	ND	10	ND	10	ND	10
Di-n-butyl phthalate	ND	10	ND	10	ND	10	ND	10
1,2-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
1,3-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
1,4-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
3,3'-Dichlorobenzidine	ND	20	ND	20	ND	20	ND	20
2,4-Dichlorophenol	ND	10	ND	10	ND	10	ND	10
Diethyl phthalate	ND	10	ND	10	ND	10	ND	10
2,4-DimethylPhenol	ND	10	ND	10	ND	10	ND	10

Appendix E-9. Semivolatile organic compounds, Río Grande de Añasco and Río Yagüez--Continued.

[Method 625. Units are micrograms per liter. Abbreviations: Repl., replicate; Rep. Limit, reporting limit; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed. Sampling dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Dimethyl phthalate	ND	10	ND	10	ND	10	ND	10
4,6-Dinitro-2-methylphenol	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrophenol	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10
2,6-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10
Di-n-octylphthalate	ND	10	ND	10	ND	10	ND	10
1,2-Diphenylhydrazine	ND	10	ND	10	ND	10	ND	10
bis(2-Ethylhexyl)phthalate	ND	10	ND	10	ND	10	ND	10
Fluoranthene	ND	10	ND	10	ND	10	ND	10
Fluorene	ND	10	ND	10	ND	10	ND	10
Hexachlorobenzene	ND	10	ND	10	ND	10	ND	10
Hexachlorobutadiene	ND	10	ND	10	ND	10	ND	10
Hexachlorocyclopentadiene	ND	10	ND	10	ND	10	ND	10
Hexachloroethane	ND	10	ND	10	ND	10	ND	10
Indeno(1,2,3-cd)pyrene	ND	10	ND	10	ND	10	ND	10
Isophorone	ND	10	ND	10	ND	10	ND	10
Naphthalene	ND	10	ND	10	ND	10	ND	10
Nitrobenzene	ND	10	ND	10	ND	10	ND	10
2-Nitrophenol	ND	10	ND	10	ND	10	ND	10
4-Nitrophenol	ND	50	ND	50	ND	50	ND	50
N-Nitrosodimethylamine	ND	10	ND	10	ND	10	ND	10
N-Nitrosodiphenylamine	ND	10	ND	10	ND	10	ND	10
N-Nitroso-di-n-Propylamine	ND	10	ND	10	ND	10	ND	10
Pentachlorophenol	ND	50	ND	50	ND	50	ND	50
Phenanthrene	ND	10	ND	10	ND	10	ND	10
Phenol	ND	10	ND	10	ND	10	ND	10
Pyrene	ND	10	ND	10	ND	10	ND	10
1,2,4-Trichlorobenzene	ND	10	ND	10	ND	10	ND	10

Appendix E-9. Semivolatile organic compounds, Río Grande de Añasco and Río Yagüez--Continued.

[Method 625. Units are micrograms per liter. Abbreviations: Repl., replicate; Rep. Limit, reporting limit; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed. Sampling dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
2,4,6-Trichlorophenol	ND	10	ND	10	ND	10	ND	10
Surrogate	**Recovery**							
Nitrobenzene-d5	80		91		70		84	
2-Fluorobiphenyl	73		85		64		68	
Terphenyl-dl4	96		118		87		74	
Phenol-d5	76		85		64		81	
2-Fluorophenol	77		86		66		76	
2,4,6-Tribromophenol	90		108		88		84	

Tentatively identified compounds

Site	Constituent	conf. level	conc.
QW-An2	Oxygenated Hydrocarbon	NR	24
QW-Ya1	Cyclopentane, Ethyl-	2	12

Appendix E-10. Concentrations of pesticides, PCB's, and herbicides, Río Grande de Añasco and Río Yagüez .

[Units are micrograms per liter; Repl., replicate; Rep. Limit, reporting limit; conc., concentration; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test. Sampling date: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Organochlorine Pesticides/PCB's								
Method 8080								
alpha-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
beta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
delta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
gamma-BHC (Lindane)	ND	0.05	ND	1	ND	0.05	ND	0.05
Toxaphene	ND	1	ND	0.05	ND	1	ND	1
Heptachlor	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Aldrin	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Heptachlor epoxide	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Endosulfan I	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Dieldrin	ND	0.02	ND	0.02	ND	0.02	ND	0.02
4,4'-DDE	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endrin	ND	0.06	ND	0.06	ND	0.06	ND	0.06
Endosulfan II	ND	0.1	ND	0.1	ND	0.1	ND	0.1
4,4'-DDD	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endosulfan sulfate	ND	0.1	ND	0.1	ND	0.1	ND	0.1
4,4'-DDT	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endrin aldehyde	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Chlordane	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Aroclor 1016	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1221	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1232	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1242	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1248	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1254	ND	1	ND	1	ND	1	ND	1
Aroclor 1260	ND	1	ND	1	ND	1	ND	1
Mirex	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Ethylan (Perthane)	ND	0.5	ND	0.5	ND	0.5	ND	0.5

Appendix E-10. Concentrations of pesticides, PCB's, and herbicides, Río Grande de Añasco and Río Yagüez--Continued.

[Units are micrograms per liter; Repl., replicate; Rep. Limit, reporting limit; conc., concentration; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test. Sampling date: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Methoxychlor	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Surrogate	Recovery							
Dibutyl chlorendate	112		107		102		103	
Organophosphorus Pesticides								
SW-846 List								
Method 8141								
Azinphos-methyl (Guthion)	ND	2.5	ND	2.5	ND	2.5	ND	2.5
Chlorpyrifos (Dursban)	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Coumaphos	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Demeton O&S	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Fenthion (Baytex)	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Malathion	ND	1.2	ND	1.2	ND	1.2	ND	1.2
Naled (Dibrom)	ND	10	ND	10	ND	10	ND	10
Ethyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Methyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Chlorinated Herbicides								
Method 8150								
2,4-D	ND	1.2	ND	1.2	ND	1.2	ND	1.2
2,4,5-TP (Silvex)	ND	0.17	ND	0.17	ND	0.17	ND	0.17
Surrogate	Recovery							
DCAA	90		110		114		112	

Appendix E-11. Concentrations of total metals, Río Grande de Añasco and Río Yagüez.

[Units are milligrams per liter. Abbreviations, Repl., replicate; conc., concentration; Rep. Limit, reporting limit; NA, not applicable. Sampling dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	Analytical method	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
		conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Antimony	7041	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Beryllium	7090	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Copper	7210	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Nickel	7520	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Chromium (VI)	7196	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Aluminum	6010	0.58	0.1	0.88	0.1	0.19	0.1	0.31	0.1
Silver	7761	ND	0.0005	ND	0.0005	ND	0.001	ND	0.0005
Cadmium	7131	ND	0.001	0.00053	0.0005	0.0027	0.0025	0.00084	0.0005
Zinc	7950	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Chromium	7191	0.018	0.0061	0.017	0.01	0.016	0.01	0.0096	0.005
Arsenic	7060	ND	0.01	ND	0.005	ND	0.005	ND	0.005
Barium	6010	0.042	0.01	0.045	0.01	0.045	0.01	0.11	0.01
Boron	6010	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Calcium	6010	25.8	0.2	26.1	0.2	28.3	0.2	31.9	0.2
Iron	6010	0.83	0.1	1.1	0.1	0.44	0.1	0.2	0.1
Lead	7421	0.12	0.025	ND	0.005	ND	0.01	ND	0.005
Magnesium	6010	9.1	0.2	9.3	0.2	10.1	0.2	16.3	0.2
Manganese	6010	0.096	0.01	0.099	0.01	0.1	0.01	0.027	0.01
Mercury	7470	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002
Potassium	6010	ND	5	ND	5	ND	5	ND	5
Selenium	7740	ND	0.02	ND	0.005	ND	0.005	ND	0.005
Silica as SiO_2	6010	18.9	0.5	20.5	0.5	21.2	50	28.6	0.5
Sodium	6010	11.1	5	9.6	5	11.3	5	12.4	5
Strontium	6010	0.11	0.05	0.13	0.05	0.15	0.05	0.15	0.05
Thallium	7841	ND	0.005	ND	0.01	ND	0.005	ND	0.01

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-12. General inorganics and radiochemistry, Río Grande de Añasco and Río Yagüez.

[Repl., replicate; conc., concentration; Rep. Limit, reporting limit; mg/L, milligrams per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; ND, not detected. Sampling dates: QW-Ya1, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	Analytical Method	units	QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1	
			conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
General Inorganics										
Chloride	A429	mg/L	7.6	0.5	7.9	0.5	8.4	0.5	11.5	0.5
Cyanide	9012	mg/L	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Color	110.2	units	5	5	5	5	5	5	5	5
Fluoride	A429	mg/L	ND	0.5	ND	5	ND	0.5		0.5
Surfactants (MBAS)	425.1	mg/L	ND	0.1	ND	1	ND	0.1	0.12	0.1
Ammonia as N	350.1	mg/L	ND	0.1	ND	0.1	0.25	0.1	ND	0.1
Nitrate plus Nitrite	353.2	mg/L	0.27	0.1	ND	0.1	0.28	0.1	0.46	0.1
Orthophosphate as P	365.3	mg/L	ND	0.05	0.11	0.05	ND	0.5	0.068	0.05
Phenolics	9065	mg/L	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Sulfide, Total	376.2	mg/L	ND	0.05	0.057	0.05	0.057	0.05	0.065	0.05
Sulfate	A429	mg/L	8.1	0.5	8.3	50	8.1	0.5	8.2	0.5
Total Kjeldahl Nitrogen as N	351.2	mg/L	ND	0.5	ND	5	ND	0.5	ND	0.5
Phosphorus, as Total P	365.3	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Turbidity	180.1	NTU	0.18	0.1	0.19	0.1	13	0.1	0.21	0.1
Total Dissolved Solids	160.1	mg/L	200	20	168	20	166	10	242	20
Total Suspended Solids	160.2	mg/L	12	2	12	2	20	2	7.2	2
Total Volatile Solids	160.4	mg/L	33	10	42	10	43	10	46	11
Volatile Suspended Solids	160.4	mg/L	ND	10	ND	10	ND	10	ND	10
Radiochemistry										
				(+/-)		(+/-)		(+/-)		(+/-)
Gross Alpha	900	pCi/L	0.8	2	0	1.6	0.5	2.3	0.4	0.4
Gross Beta	900	pCi/L	0	4.3	0.8	2.7	0	6.3	0	8.8
Radium 226	705 Mod.	pCi/L	0.1	0.5	0.1	0.5	0	0.5	0	1.9
Strontium 90	A704	pCi/L	0	0.8	0	0.8	1	0.8	0	0.9

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB’s, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-13. General water quality, Río Grande de Añasco and Río Yagüez.

[Repl., replicate; mg/L, milligrams per liter; °C, degrees Celsius; k, extinction coefficient; vol, volume of sample filtered; col/100ml, colonies of bacteria per 100 milliliters; TNTC, too numerous to count; µS/cm, microsiemens per centimeter; mg/m^3, milligram per cubic meter; Mgal/d, million gallons per day; NA, not applicable; NR, not reported; ND, not detected; -- no data. Sampling dates: QW-Ya, 1/28/91; QW-An1, 1/29/91; QW-An2, 1/31/91.]

Constituent	units		QW-An1		QW-An1 (Repl.)		QW-An2		QW-Ya1
			Result		Result		Result		Result
BOD-5	mg/L		ND		5.9		NR		NR
Oil and Grease	mg/L		ND		ND		5.5		ND
Settleable Solids	mg/L		0		0		NR		0
Water Temperature	°C		23.3		--		24		22
Alkalinity	mg/L		--		--		110		150
Spec.Cond.	µS/cm		250		--		265		334
pH	units		--		--		7.8		8.6
Dissolved Oxygen	mg/L		8		--		6		9.9
Extinction Coefficient	k		NA		NA		NA		NA
Chlorophyll-a	mg/m^3		0.5257		--		--		1.6423
Discharge	Mgal/d		88.7		88.7		27.1		3.6
Bacteria		vol	count	vol	count	vol	count	vol	count
Fecal Coli(vol/count)		10	1	10	2	10	3	10	TNTC
Fecal Coli(vol/count)		1	1	1	0	1	1	1	45
Fecal Coli(vol/count)		0.1	0	0.1	0	0.1	0	0.1	1
	cols/100ml		b-18		b-20		b-36		4500
Total Coli(vol/count)		10	TNTC	10	TNTC	10	3	10	TNTC
Total Coli(vol/count)		1	12	1	14	1	1	1	TNTC
Total Coli(vol/count)		0.1	4	0.1	0	0.1	0	0.1	26
	cols/100ml		b-1450		b-1400		350		26000
Enterococcus(vol/count)		10	4	10	1	10	1	10	TNTC
Enterococcus(vol/count)		1	0	1	0	1	0	1	10
Enterococcus(vol/count)		0.1	0	0.1	0	0.1	0	0.1	1
	cols/100ml		b-40		b-10		b-10		b-1000

Appendix E-14. Volatile organic compounds inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30, 1991.

[Method 624. Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Acrolein	ND	100	ND	100	ND	100	ND	100	ND	100
Acrylonitrile	ND	100	ND	100	ND	100	ND	100	ND	100
Benzene	ND	5	ND	5	ND	5	ND	5	ND	5
Bromodichloromethane	ND	5	ND	5	ND	5	ND	5	ND	5
Bromoform	ND	5	ND	5	ND	5	ND	5	ND	5
Bromomethane	ND	10	ND	10	ND	10	ND	10	ND	10
Carbon tetrachloride	ND	5	ND	5	ND	5	ND	5	ND	5
Chlorobenzene	ND	5	ND	5	ND	5	ND	5	ND	5
Chloroethane	ND	10	ND	10	ND	10	ND	10	ND	10
Chloroform	ND	5	ND	5	ND	5	ND	5	ND	5
Chloromethane	ND	10	ND	10	ND	10	ND	10	ND	10
Dibromochloromethane	ND	5	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethane	ND	5	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethane	ND	5	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethene	ND	5	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethene (total)	ND	5	ND	5	ND	5	ND	5	ND	5
1,2-Dichloropropane	ND	5	ND	5	ND	5	ND	5	ND	5
cis-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5	ND	5
trans-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5	ND	5
Ethylbenzene	ND	5	ND	5	ND	5	ND	5	ND	5
Methylene chloride	ND	5	ND	5	ND	5	ND	5	ND	5
1,1,2,2-Tetrachloroethane	ND	5	ND	5	ND	5	ND	5	ND	5
Tetrachloroethene	ND	5	ND	5	ND	5	ND	5	ND	5
Toluene	ND	5	ND	5	ND	5	ND	5	ND	5
1,1,1-Trichloroethane	ND	5	ND	5	ND	5	ND	5	ND	5
1,1,2-Trichloroethane	ND	5	ND	5	ND	5	ND	5	ND	5
Trichloroethene	ND	5	ND	5	ND	5	ND	5	ND	5
Vinyl chloride	ND	10	ND	10	ND	10	ND	10	ND	10

Surrogate	Recovery				
Toluene-d8	103	105	105	105	108
4-Bromofluorobenzene	98	100	100	99	98
1,2-Dichloroethane-d4	103	101	103	100	103

Appendix E-15. Semivolatile organic compounds inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991 .

[Method 625. Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Acenaphthene	ND	10	ND	10	ND	10	ND	10	ND	10
Acenaphthylene	ND	10	ND	10	ND	10	ND	10	ND	10
Anthracene	ND	10	ND	10	ND	10	ND	10	ND	100
Benzidine	ND	100	ND	100	ND	100	ND	100	ND	10
Benzo a-anthracene	ND	10	ND	10	ND	10	ND	10	ND	10
Benzo b fluoranthene	ND	10	ND	10	ND	10	ND	10	ND	10
Benzo k fluoranthene	ND	10	ND	10	ND	10	ND	10	ND	10
Benzo (g,h,i)perylene	ND	10	ND	10	ND	10	ND	10	ND	10
Benzo (a)pyrene	ND	10	ND	10	ND	10	ND	10	ND	10
4-Bromophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10	ND	10
Butyl benzyl phthalate	ND	10	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethoxy)-methane	ND	10	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethyl) ether	ND	10	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroisopropyl)-ether	ND	10	ND	10	ND	10	ND	10	ND	10
4-Chloro-3-methylphenol	ND	10	ND	10	ND	10	ND	10	ND	10
2-Chloronaphthalene	ND	10	ND	10	ND	10	ND	10	ND	10
2-Chlorophenol	ND	10	ND	10	ND	10	ND	10	ND	10
4-Chlorophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10	ND	10
Chrysene	ND	10	ND	10	ND	10	ND	10	ND	10
Dibenz(a,h)anthracene	ND	10	ND	10	ND	10	ND	10	ND	10
Di-n-butyl phthalate	ND	10	ND	10	ND	10	ND	10	ND	10
1,2-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10	ND	10
1,3-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10	ND	10
1,4-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10	ND	10
3,3'-Dichlorobenzidine	ND	20	ND	20	ND	20	ND	20	ND	20
2,4-Dichlorophenol	ND	10	ND	10	ND	10	ND	10	ND	10
Diethyl phthalate	ND	10	ND	10	ND	10	ND	10	ND	10
2,4-DimethylPhenol	ND	10	ND	10	ND	10	ND	10	ND	10

Appendix E-15. Semivolatile organic compounds inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991--Continued.

[Method 625. Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Dimethyl phthalate	ND	10	ND	10	ND	10	ND	10	ND	10
4,6-Dinitro-2-methylphenol	ND	50	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrophenol	ND	50	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10	ND	10
2,6-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10	ND	10
Di-n-octylphthalate	ND	10	ND	10	ND	10	ND	10	ND	10
1,2-Diphenylhydrazine	ND	10	ND	10	ND	10	ND	10	ND	10
bis(2-Ethylhexyl)phthalate	ND	10	ND	10	ND	10	ND	10	ND	10
Fluoranthene	ND	10	ND	10	ND	10	ND	10	ND	10
Fluorene	ND	10	ND	10	ND	10	ND	10	ND	10
Hexachlorobenzene	ND	10	ND	10	ND	10	ND	10	ND	10
Hexachlorobutadiene	ND	10	ND	10	ND	10	ND	10	ND	10
Hexachlorocyclopentadiene	ND	10	ND	10	ND	10	ND	10	ND	10
Hexachloroethane	ND	10	ND	10	ND	10	ND	10	ND	10
Indeno(1,2,3-cd)pyrene	ND	10	ND	10	ND	10	ND	10	ND	10
Isophorone	ND	10	ND	10	ND	10	ND	10	ND	10
Naphthalene	ND	10	ND	10	ND	10	ND	10	ND	10
Nitrobenzene	ND	10	ND	10	ND	10	ND	10	ND	10
2-Nitrophenol	ND	10	ND	10	ND	10	ND	10	ND	10
4-Nitrophenol	ND	50	ND	50	ND	50	ND	50	ND	10
N-Nitrosodimethylamine	ND	10	ND	10	ND	10	ND	10	ND	10
N-Nitrosodiphenylamine	ND	10	ND	10	ND	10	ND	10	ND	10
N-Nitroso-di-n-Propylamine	ND	10	ND	10	ND	10	ND	10	ND	10
Pentachlorophenol	ND	50	ND	50	ND	50	ND	50	ND	50
Phenanthrene	ND	10	ND	10	ND	10	ND	10	ND	10
Phenol	ND	10	ND	10	ND	10	ND	10	ND	10
Pyrene	ND	10	ND	10	ND	10	ND	10	ND	10
1,2,4-Trichlorobenzene	ND	10	ND	10	ND	10	ND	10	ND	10

Appendix E-15. Semivolatile organic compounds inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991--Continued.

[Method 625. Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
2,4,6-Trichlorophenol	ND	10	ND	10	ND	10	ND	10	ND	10
Surrogate	Recovery									
Nitrobenzene-d5	56		61		64		59		55	
2-Fluorobiphenyl	53		63		65		59		53	
Terphenyl-dl4	70		79		83		76		76	
Phenol-d5	56		64		58		57		42	
2-Fluorophenol	52		62		56		54		56	
2,4,6-Tribromophenol	66		74		76		70		68	

Tentatively identified compounds

Site	Constituent	conf. level	conc.
QW-3	Oxygenated Hydrocarbon	2	18
QW-4	Oxygenated Hydrocarbon	2	23
QW-5	Cyclohexane,Methyl-	2	11
QW-5(Repl)	Cyclohexane,Methyl-	2	12
QW-6	Cyclohexane,Methyl-	2	10
QW-6	Cyclopentanol,2-Methyl-	2	98
QW-6	Furan,2,5-Diethyltetrahydro-	1	21

Appendix E-16. Concentrations of pesticides, PCB's, and herbicides, inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991 .

[Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Organochlorine Pesticides/PCB's										
Method 8080										
alpha-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
beta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
delta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
gamma-BHC (Lindane)	ND	0.05	ND	1	ND	0.05	ND	0.05	ND	0.05
Toxaphene	ND	1	ND	0.05	ND	1	ND	0.05	ND	1
Heptachlor	ND	0.02	ND	0.02	ND	0.02	ND	1	ND	0.02
Aldrin	ND	0.05	ND	0.05	ND	0.05	ND	0.02	ND	0.05
Heptachlor epoxide	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Endosulfan I	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Dieldrin	ND	0.02	ND	0.02	ND	0.02	ND	0.05	ND	0.02
4,4'-DDE	ND	0.1	ND	0.1	ND	0.1	ND	0.02	ND	0.1
Endrin	ND	0.06	ND	0.06	ND	0.06	ND	0.1	ND	0.06
Endosulfan II	ND	0.1	ND	0.1	ND	0.1	ND	0.06	ND	0.1
4,4'-DDD	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endosulfan sulfate	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1
4,4'-DDT	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endrin aldehyde	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Chlordane	ND	0.05	ND	0.05	ND	0.05	ND	0.1	ND	0.05
Aroclor 1016	ND	0.5	ND	0.5	ND	0.5	ND	0.05	ND	0.5
Aroclor 1221	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1232	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1242	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1248	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1254	ND	1	ND	1	ND	1	ND	1	ND	1
Aroclor 1260	ND	1	ND	1	ND	1	ND	1	ND	1
Mirex	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Ethylan (Perthane)	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5

Appendix E-16. Concentrations of pesticides, PCB's, and herbicides, inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991--Continued.

[Units are micrograms per liter. Repl., replicate; conc., concentration; Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit	conc.	Rep. Limit
Methoxychlor	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Surrogate	Recovery									
Dibutyl chlorendate	119		118		116		112		118	
Organophosphorus Pesticides										
SW-846 List										
Method 8141										
Azinphos-methyl (Guthion)	ND	2.5	ND	2.5	ND	2.5	ND	2.5	ND	2.5
Chlorpyrifos (Dursban)	ND	0.25	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Coumaphos	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Demeton O&S	ND	0.25	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Fenthion (Baytex)	ND	0.25	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Malathion	ND	1.2	ND	1.2	ND	1.2	ND	1.2	ND	1.2
Naled (Dibrom)	ND	10	ND	10	ND	10	ND	10	ND	10
Ethyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Methyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Chlorinated Herbicides										
Method 8150										
2,4-D	ND	1.2	ND	1.2	ND	1.2	ND	1.2	ND	1.2
2,4,5-TP (Silvex)	ND	0.17	ND	0.17	ND	0.17	ND	0.17	ND	0.17
Surrogate	Recovery									
DCAA	113		123		117		102		115	

Appendix E-17. Concentrations of total metals inside (QW-4, QW-5) and at the limit (QW-3, QW-6), of the initial mixing zone, January 30,1991.

[Units are milligrams per liter. Repl., replicate; Rep. Limit, reporting limit; ND, not detected.]

Constituent	Analytical method	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
		Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Antimony	7041	ND	0.02	ND	0.02	ND	0.04	ND	0.02	ND	0.04
Beryllium	7090	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Copper	7210	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Nickel	7520	ND	0.1	ND	0.1	ND	0.1		0.1	ND	0.1
Chromium (VI)	7196	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Aluminum	6010	ND	2	ND	2	ND	2	ND	2	ND	2
Silver	7761	ND	0.0025	ND	0.0025	ND	0.001	ND	0.0025	ND	0.0005
Cadmium	7131	ND	0.002	ND	0.001	ND	0.002	ND	0.001	ND	0.005
Zinc	7950	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Chromium	7191	ND	0.025	0.018	0.01	ND	0.01	ND	0.001	0.018	0.01
Arsenic	7060	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Barium	6010	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2
Boron	6010	5.2	2	5.1	2	5.1	2	4	2	5.2	2
Calcium	6010	441	4	437	4	452	4	407	4	442	4
Iron	6010	ND	2	ND	2	ND	2	ND	2	ND	2
Lead	7421	ND	0.01	ND	0.01	ND	0.01	0.046	0.025	ND	0.1
Magnesium	6010	1370	4	1350	4	1390	4	1250	4	1370	4
Manganese	6010	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2
Mercury	7470	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002
Potassium	6010	410	100	378	100	390	100	326	100	385	100
Selenium	7740	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Silica as SiO2	6010	ND	10	ND	10	ND	10	ND	10	ND	10
Sodium	6010	11100	100	10800	100	11000	100	9780	100	11000	100
Strontium	6010	7.4	1	7.5	1	7.7	1	6.9	1	7.6	1
Thallium	7841	ND	0.05	ND	0.05	ND	0.02	ND	0.05	ND	0.02

Appendix E-18. General inorganics and radiochemistry, inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991.

[Repl., replicate; Rep.Limit, reporting limit; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; Mod. modified; ND, not detected.]

Constituent	Analytical method	units	QW-3		QW-4		QW-5		QW-5		QW-6	
			Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
General Inorganics												
Chloride	A429	mg/L	20500	300	20100	300	20800	100	18800	300	21000	300
Cyanide	9012	mg/L	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Color	110.2	units	ND	5	ND	5	ND	5	ND	5	ND	5
Fluoride	A429	mg/L	39.3	5	40.1	5	39.2	5	39.3	5	40.6	5
Surfactants (MBAS)	425.1	mg/L	ND	1	ND	1	ND	1	ND	1	ND	1
Ammonia as N	350.1	mg/L	ND	0.1	ND	0.1	0.68	0.1	0.33	0.1	ND	0.1
Nitrate plus Nitrite	353.2	mg/L	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Orthophosphate as P	365.3	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Phenolics	9065	mg/L	ND	0.01	0.016	0.01	0.037	0.01	0.014	0.01	ND	0.01
Sulfide, Total	376.2	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Sulfate	A429	mg/L	2650	50	2650	50	2620	50	2380	50	2640	50
Total Kjeldahl Nitrogen as N	351.2	mg/L	ND	5	ND	5	ND	5	ND	5	ND	5
Phosphorus, Total as P	365.3	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Turbidity	180.1	NTU	0.58	0.1	0.62	0.1	0.58	0.1	0.62	0.1	0.41	0.1
Total Dissolved Solids	160.1	mg/L	36900	50	33000	50	35800	10	37200	50	37600	50
Total Suspended Solids	160.2	mg/L	50	2	46.8	2	9.2	2	38.4	2	6	2
Total Volatile Solids	160.4	mg/L	3440	200	3920	200	2780	200	3980	200	3200	200
Volatile Suspended Solids	160.4	mg/L	ND	10	ND	10	ND	10	ND	10	ND	10
Radiochemistry												
				(+/-)		(+/-)		(+/-)		(+/-)		(+/-)
Gross Alpha	900	pCi/L	0	140	0	120	50	150	30	150	0	140
Gross Beta	900	pCi/L	380	160	410	170	290	160	270	150	290	160
Radium 226	705 Mod.	pCi/L	0	0.5	0	0.5	0	0.5	0	0.4	0	0.5
Strontium 90	A704	pCi/L	0	2.3	0	1.5	0	2	0	1.2	0	1

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-19. General water quality inside (QW-4, QW-5) and at the limit (QW-3, QW-6) of the initial mixing zone, January 30,1991.

[Repl., replicate; Rep. Limit, reporting limit; mg/L, milligrams per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; k, extinction coefficient; vol/count, volume of sample, in milliliters, filtered (diluted to 100 ml) and number of bacteria colonies counted using the filter membrane method; col/100ml, colonies of bacteria per 100 milliliters; TNTC, too numerous to count; mg/m^3, milligram per cubic meter; ND, not detected; --, no data.]

Constituent	units	QW-3		QW-4		QW-5		QW-5 (Repl.)		QW-6	
		Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
BOD-5	mg/L	ND	2	2.1	2	ND	2	ND	2	ND	2
Oil and Grease	mg/L	5.8	5	--	--	ND	5	ND	5	ND	5
Settleable Solids	mg/L	0		0		--		--		0	
Water Temperature	°C	26.3		26		25		25.9		25.8	
Alkalinity	mg/L	120		120		120		120		130	
Spec. Cond.	µS/cm	--		--		>50000		>50000		>50000	
pH	units	8.2		8.3		8.1		8.24		8.23	
Dissolved Oxygen	mg/L	7.7		7.3		7.8		9.3		7.3	
Extinction Coefficient	k	0.21		0.15		0.15		0.15		0.12	
Chlorophyll-a	mg/m^3	0.1813		0.1771		0.0872		0.0872		0.1005	
Bacteria											
Fecal Coli(vol/count)		50 29		50 TNTC		50 85		50 48		50 43	
Fecal Coli(vol/count)		25 11		25 TNTC		25 53		25 18		25 41	
Fecal Coli(vol/count)		10 4		10 49		10 21		10 6		10 16	
	cols/100ml	58		490		210		96		110	
Total Coli(vol/count)		TNTC		50 TNTC		50 TNTC		50 TNTC		50 TNTC	
Total Coli(vol/count)		TNTC		25 TNTC		25 TNTC		25 80		25 TNTC	
Total Coli(vol/count)		31		10 TNTC		10 80		10 30		10 32	
	cols/100ml	310		b>800		800		310		320	
Enterococcus(dil/count)		50 1		50 TNTC		50 30		50 43		50 1	
Enterococcus(dil/count)		25 0		25 TNTC		25 4		25 4		25 4	
Enterococcus(dil/count)		10 0		10 TNTC		10 6		10 2		10 1	
	cols/100ml	b-2		b>600		60		86		b-7	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-20. Volatile organic compounds, final mixing zone limit (QW-2, QW-7) and far-field sites (QW-1, QW-8), January 29, 1991.

[Method 624. Units are micrograms per liter. Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Acrolein	ND	100	ND	100	ND	100	ND	100
Acrylonitrile	ND	100	ND	100	ND	100	ND	100
Benzene	ND	5	ND	5	ND	5	ND	5
Bromodichloromethane	ND	5	ND	5	ND	5	ND	5
Bromoform	ND	5	ND	5	ND	5	ND	5
Bromomethane	ND	10	ND	10	ND	10	ND	10
Carbon tetrachloride	ND	5	ND	5	ND	5	ND	5
Chlorobenzene	ND	5	ND	5	ND	5	ND	5
Chloroethane	ND	10	ND	10	ND	10	ND	10
Chloroform	ND	5	ND	5	ND	5	ND	5
Chloromethane	ND	10	ND	10	ND	10	ND	10
Dibromochloromethane	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethane	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethane	ND	5	ND	5	ND	5	ND	5
1,1-Dichloroethene	ND	5	ND	5	ND	5	ND	5
1,2-Dichloroethene (total)	ND	5	ND	5	ND	5	ND	5
1,2-Dichloropropane	ND	5	ND	5	ND	5	ND	5
cis-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5
trans-1,3-Dichloropropene	ND	5	ND	5	ND	5	ND	5
Ethylbenzene	ND	5	ND	5	ND	5	ND	5
Methylene chloride	ND	5	ND	5	ND	5	ND	5
1,1,2,2-Tetrachloroethane	ND	5	ND	5	ND	5	ND	5
Tetrachloroethene	ND	5	ND	5	ND	5	ND	5
Toluene	ND	5	ND	5	ND	5	ND	5
1,1,1-Trichloroethane	ND	5	ND	5	ND	5	ND	5
1,1,2-Trichloroethane	ND	5	ND	5	ND	5	ND	5
Trichloroethene	ND	5	ND	5	ND	5	ND	5
Vinyl chloride	ND	10	ND	10	ND	10	ND	10
Surrogate	**Recovery**							
Toluene-d8	101		99		100		102	
4-Bromofluorobenzene	101		99		100		99	
1,2-Dichloroethane-d4	95		100		102		98	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-21. Semivolatile organic compounds at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991 .

[Method 625. Units are micrograms per liter; ND, not detected; NR, not reported; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Acenaphthene	ND	10	ND	10	ND	10	ND	10
Acenaphthylene	ND	10	ND	10	ND	10	ND	10
Anthracene	ND	10	ND	10	ND	10	ND	10
Benzidine	ND	100	ND	100	ND	100	ND	100
Benzo a-anthracene	ND	10	ND	10	ND	10	ND	10
Benzo b fluoranthene	ND	10	ND	10	ND	10	ND	10
Benzo k fluoranthene	ND	10	ND	10	ND	10	ND	10
Benzo (g,h,i)perylene	ND	10	ND	10	ND	10	ND	10
Benzo (a)pyrene	ND	10	ND	10	ND	10	ND	10
4-Bromophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10
Butyl benzyl phthalate	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethoxy)-methane	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroethyl) ether	ND	10	ND	10	ND	10	ND	10
bis(2-Chloroisopropyl)-ether	ND	10	ND	10	ND	10	ND	10
4-Chloro-3-methylphenol	ND	10	ND	10	ND	10	ND	10
2-Chloronaphthalene	ND	10	ND	10	ND	10	ND	10
2-Chlorophenol	ND	10	ND	10	ND	10	ND	10
4-Chlorophenyl phenyl ether	ND	10	ND	10	ND	10	ND	10
Chrysene	ND	10	ND	10	ND	10	ND	10
Dibenz(a,h)anthracene	ND	10	ND	10	ND	10	ND	10
Di-n-butyl phthalate	ND	10	ND	10	ND	10	ND	10
1,2-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
1,3-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
1,4-Dichlorobenzene	ND	10	ND	10	ND	10	ND	10
3,3'-Dichlorobenzidine	ND	20	ND	20	ND	20	ND	20
2,4-Dichlorophenol	ND	10	ND	10	ND	10	ND	10
Diethyl phthalate	ND	10	ND	10	ND	10	ND	10
2,4-DimethylPhenol	ND	10	ND	10	ND	10	ND	10
Dimethyl phthalate	ND	10	ND	10	ND	10	ND	10

Appendix E-21. Semivolatile organic compounds at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991--Continued.

[Method 625. Units are micrograms per liter; ND, not detected; NR, not reported; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
4,6-Dinitro-2-methylphenol	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrophenol	ND	50	ND	50	ND	50	ND	50
2,4-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10
2,6-Dinitrotoluene	ND	10	ND	10	ND	10	ND	10
Di-n-octylphthalate	ND	10	ND	10	ND	10	ND	10
1,2-Diphenylhydrazine	ND	10	ND	10	ND	10	ND	10
bis(2-Ethylhexyl)phthalate	ND	10	ND	10	ND	10	ND	10
Fluoranthene	ND	10	ND	10	ND	10	ND	10
Fluorene	ND	10	ND	10	ND	10	ND	10
Hexachlorobenzene	ND	10	ND	10	ND	10	ND	10
Hexachlorobutadiene	ND	10	ND	10	ND	10	ND	10
Hexachlorocyclopentadiene	ND	10	ND	10	ND	10	ND	10
Hexachloroethane	ND	10	ND	10	ND	10	ND	10
Indeno(1,2,3-cd)pyrene	ND	10	ND	10	ND	10	ND	10
Isophorone	ND	10	ND	10	ND	10	ND	10
Naphthalene	ND	10	ND	10	ND	10	ND	10
Nitrobenzene	ND	10	ND	10	ND	10	ND	10
2-Nitrophenol	ND	10	ND	10	ND	10	ND	10
4-Nitrophenol	ND	50	ND	50	ND	50	ND	50
N-Nitrosodimethylamine	ND	10	ND	10	ND	10	ND	10
N-Nitrosodiphenylamine	ND	10	ND	10	ND	10	ND	10
N-Nitroso-di-n-Propylamine	ND	10	ND	10	ND	10	ND	10
Pentachlorophenol	ND	50	ND	50	ND	50	ND	50
Phenanthrene	ND	10	ND	10	ND	10	ND	10
Phenol	ND	10	ND	10	ND	10	ND	10
Pyrene	ND	10	ND	10	ND	10	ND	10
1,2,4-Trichlorobenzene	ND	10	ND	10	ND	10	ND	10

Appendix E-21. Semivolatile organic compounds at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991--Continued.

[Method 625. Units are micrograms per liter; ND, not detected; NR, not reported; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
2,4,6-Trichlorophenol	ND	10	ND	10	ND	10	ND	10
Surrogate	**Recovery**							
Nitrobenzene-d5	57		62		53		55	
2-Fluorobiphenyl	52		59		48		53	
Terphenyl-dl4	88		92		91		88	
Phenol-d5	54		60		50		49	
2-Fluorophenol	52		58		47		47	
2,4,6-Tribromophenol	80		78		64			

Tentatively identified compounds

Site	Constituent	conf. level	conc.
QW-2	Oxygenated hydrocarbon	NR	13
QW-7	Oxygenated hydrocarbon	NR	11

Appendix E-22. Concentrations of pesticides, PCB's, and herbicides at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991 .

[Units are micrograms per liter. Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Organochlorine Pesticides/PCB's								
Method 8080								
alpha-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
beta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
delta-BHC	ND	0.05	ND	0.05	ND	0.05	ND	0.05
gamma-BHC (Lindane)	ND	0.05	ND	0.05	ND	1	ND	0.05
Toxaphene	ND	1	ND	1	ND	0.05	ND	1
Heptachlor	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Aldrin	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Heptachlor epoxide	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Endosulfan I	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Dieldrin	ND	0.02	ND	0.02	ND	0.02	ND	0.02
4,4'-DDE	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endrin	ND	0.06	ND	0.06	ND	0.06	ND	0.06
Endosulfan II	ND	0.1	ND	0.1	ND	0.1	ND	0.1
4,4'-DDD	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endosulfan sulfate	ND	0.1	ND	0.1	ND	0.1	ND	0.1
4,4'-DDT	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Endrin aldehyde	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Chlordane	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Aroclor 1016	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1221	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1232	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1242	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1248	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Aroclor 1254	ND	1	ND	1	ND	1	ND	1
Aroclor 1260	ND	1	ND	1	ND	1	ND	1
Mirex	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Ethylan (Perthane)	ND	0.5	ND	0.5	ND	0.5	ND	0.5

Appendix E-22. Concentrations of pesticides, PCB's, and herbicides at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991--Continued.

[Units are micrograms per liter. Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	QW-1		QW-2		QW-7		QW-8	
	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Methoxychlor	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Surrogate	Recovery							
Dibutyl chlorendate	114		119		114		116	
Organophosphorus Pesticides								
SW-846 List								
Method 8141								
Azinphos-methyl (Guthion)	ND	2.5	ND	2.5	ND	2.5	ND	2.5
Chlorpyrifos (Dursban)	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Coumaphos	ND	0.5	ND	0.5	ND	0.5	ND	0.5
Demeton O&S	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Fenthion (Baytex)	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Malathion	ND	1.2	ND	1.2	ND	1.2	ND	1.2
Naled (Dibrom)	ND	10	ND	10	ND	10	ND	10
Ethyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Methyl parathion	ND	0.25	ND	0.25	ND	0.25	ND	0.25
Chlorinated Herbicides								
Method 8150								
2,4-D	ND	1.2	ND	1.2	ND	1.2	ND	1.2
2,4,5-TP (Silvex)	ND	0.17	ND	0.17	ND	0.17	ND	0.17
Surrogate	Recovery							
DCAA	93		82		104		83	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-23. Concentrations of total metals at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991.

[Units are milligrams per liter. Rep. Limit, reporting limit; ND, not detected.]

Constituent	Analytical method	QW-1		QW-2		QW-7		QW-8	
		Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
Antimony	7041	ND	0.02	ND	0.02	ND	0.02	ND	0.04
Beryllium	7090	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Copper	7210	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Nickel	7520	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Chromium (VI)	7196	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Aluminum	6010	ND	2	ND	2	ND	2	ND	2
Silver	7761	ND	0.0025	ND	0.0005	ND	0.0005	ND	0.0005
Cadmium	7131	ND	0.0005	ND	0.002	ND	0.002	ND	0.001
Zinc	7950	ND	0.02	ND	0.02	ND	0.02	ND	0.02
Chromium	7191	0.026	0.01	0.019	0.01	0.022	0.022	0.017	0.01
Arsenic	7060	ND	0.025	ND	0.01	ND	0.005	ND	0.01
Barium	6010	ND	0.2	ND	0.2	ND	0.2	ND	0.2
Boron	6010	5.6	2	5.4	2	5.3	2	5.1	2
Calcium	6010	471	4	460	4	450	4	433	4
Iron	6010	ND	2	ND	2	ND	2	ND	2
Lead	7421	ND	0.2	0.12	0.025	ND	0.005	ND	0.05
Magnesium	6010	1490	4	1430	4	1400	4	1350	4
Manganese	6010	ND	0.2	ND	0.2	ND	0.2	ND	0.2
Mercury	7470	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002
Potassium	6010	496	100	388	100	373	100	393	100
Selenium	7740	ND	0.01	ND	0.02	ND	0.005	ND	0.02
Silica as SiO^2	6010	ND	10	ND	10	ND	10	ND	10
Sodium	6010	12500	100	11300	100	11000	100	10900	100
Strontium	6010	8	1	8	1	7.9	1	7.4	1
Thallium	7841	ND	0.01	ND	0.05	ND	0.005	ND	0.02

Appendix E-24. General inorganics and radiochemistry at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991.

[Units are milligrams per liter. Abbreviations: Rep. Limit, reporting limit; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; ND, not detected; Mod. modified.]

Constituent	Analytical method	units	QW-1		QW-2		QW-7		QW-8	
			Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
General Inorganics										
Chloride	A429	mg/L	21100	250	21100	250	21100	250	20900	250
Cyanide	9012	mg/L	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Color	110.2	units	ND	5	ND	5	ND	5	ND	5
Fluoride	A429	mg/L	26.6	5	30.8	5	47.7	5	30.2	5
Surfactants (MBAS)	425.1	mg/L	ND	1	ND	1	ND	1	ND	1
Ammonia as N	350.1	mg/L	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Nitrate plus Nitrite	353.2	mg/L	ND	0.1	ND	0.1	ND	0.1	ND	0.1
Orthophosphate as P	365.3	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Phenolics	9065	mg/L	ND	0.01	ND	0.01	ND	0.01	ND	0.01
Sulfide, Total	376.2	mg/L	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Sulfate	A429	mg/L	2820	25	2850	25	2800	25	2810	25
Total Kjeldahl Nitrogen as N	351.2	mg/L	ND	5	ND	5	ND	5	ND	5
Phosphorus, Total as P	365.3	mg/L	ND	0.05	ND	0.05	2.7	0.5	ND	0.05
Turbidity	180.1	NTU	0.15	0.1	0.22	0.1	0.15	0.1	0.18	0.1
Total Dissolved Solids	160.1	mg/L	39200	50	37100	50	35100	50	38600	50
Total Suspended Solids	160.2	mg/L	14.8	2	12	2	9.2	2	8	2
Total Volatile Solids	160.4	mg/L	2530	10	2890	10	3150	10	3340	200
Volatile Suspended Solids	160.4	mg/L	ND	10	ND	10	ND	10	ND	10
Radiochemistry										
				(+/-)		(+/-)		(+/-)		(+/-)
Gross Alpha	900	pCi/L	80	170	0	0.4	0	130	30	140
Gross Beta	900	pCi/L	250	160	380	160	400	170	290	160
Radium 226	705 Mod.	pCi/L	0	0.4	0	71	0	0.4	0	0.4
Strontium 90	A704	pCi/L	0	2.9	0	1.2	0	1.4	0	1.2

Appendix E-25. General water quality at the final mixing zone limit (QW-2, QW-7) and at far-field sites (QW-1, QW-8), January 29, 1991.

[mg/L, milligrams per liter; °C, degrees Celsius; k, extinction coefficient; vol/count, volume of sample filtered (rest made up to 100ml) and number of bacteria colonies counted using the filter membrane method; col/100ml, colonies of bacteria per 100 milliliters; TNTC, too numerous to count; µS/cm, microsiemens per centimeter; mg/m^3, milligram per cubic meter; ND, not detected; --, no data.]

Constituent	units	QW-1		QW-2		QW-7		QW-8	
		Result	Rep.Limit	Result	Rep. Limit	Result	Rep. Limit	Result	Rep. Limit
BOD-5	mg/L	ND	2	ND	2	ND	2	ND	2
Oil and Grease	mg/L	ND	5	ND	5	ND	5	ND	5
Settleable Solids	mg/L	0		0		0		0	
Water Temperature	°C	26		26		26		26	
Alkalinity	mg/L	120		120		120		120	
Spec.Cond.	µS/cm	48000		49500		49500		48000	
pH	units	8.27		8.26		8.25		8.26	
Dissolved Oxygen	mg/L	7.58		7.9		7.3		7.3	
Extinction Coefficient	k	0.12		0.18		0.3		0.06	
Chlorophyll-a	mg/m^3	0.1098		0.1539		0.0985		0.0958	
Bacteria									
Fecal Coli(vol/count)	50	1	50	0	50	0	50	1	
Fecal Coli(vol/count)	25	0	25	0	25	0	25	0	
Fecal Coli(vol/count)	10	0	10	0	10	0	10	0	
	cols/100ml	b-2		b<2		b<2		b-2	
Total Coli(vol/count)	50	TNTC	50	TNTC	50	40	50	42	
Total Coli(vol/count)	25	47	25	TNTC	25	12	25	23	
Total Coli(vol/count)	10	13	10	18	10	0	10	10	
	cols/100ml	190		b-180		80		87	
Enterococcus(vol/count)[a]									
Enterococcus(vol/count)									
Enterococcus(vol/count)									
	col/100ml	--		--		--		--	

a. Enteroccoccus samples were read outside of the acceptable holding time.

Appendix E-26. Volatile organic compounds at water-quality control sites QW-9 and QW-10 near Rincón, January 28, 1991.

[Method 624. Units are micrograms per liter. ND, not detected. Values for surrogates represent percent recovery.]

Constituent	QW-9		QW-10	
	Result	Rep. Limit	Result	Rep. Limit
Acrolein	ND	100	ND	100
Acrylonitrile	ND	100	ND	100
Benzene	ND	5	ND	5
Bromodichloromethane	ND	5	ND	5
Bromoform	ND	5	ND	5
Bromomethane	ND	10	ND	10
Carbon tetrachloride	ND	5	ND	5
Chlorobenzene	ND	5	ND	5
Chloroethane	ND	10	ND	10
Chloroform	ND	5	ND	5
Chloromethane	ND	10	ND	10
Dibromochloromethane	ND	5	ND	5
1,1-Dichloroethane	ND	5	ND	5
1,2-Dichloroethane	ND	5	ND	5
1,1-Dichloroethene	ND	5	ND	5
1,2-Dichloroethene (total)	ND	5	ND	5
1,2-Dichloropropane	ND	5	ND	5
cis-1,3-Dichloropropene	ND	5	ND	5
trans-1,3-Dichloropropene	ND	5	ND	5
Ethylbenzene	ND	5	ND	5
Methylene chloride	ND	5	ND	5
1,1,2,2-Tetrachloroethane	ND	5	ND	5
Tetrachloroethene	ND	5	ND	5
Toluene	ND	5	ND	5
1,1,1-Trichloroethane	ND	5	ND	5
1,1,2-Trichloroethane	ND	5	ND	5
Trichloroethene	ND	5	ND	5
Vinyl chloride	ND	10	ND	10
Surrogate	**Recovery**			
Toluene-d8	112		111	
4-Bromofluorobenzene	104		104	
1,2-Dichloroethane-d4	104		106	

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-27. Semivolatile organic compounds at water-quality control sites QW-9 and QW-10, near Rincón, January 28, 1991 .

[Method 625. Units are micrograms per liter. Rep. Limit, reporting limit; NR, not reported; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-9		QW-10	
	Result	Rep. Limit	Result	Rep. Limit
Acenaphthene	ND	10	ND	10
Acenaphthylene	ND	10	ND	10
Anthracene	ND	10	ND	10
Benzidine	ND	100	ND	100
Benzo a-anthracene	ND	10	ND	10
Benzo b fluoranthene	ND	10	ND	10
Benzo k fluoranthene	ND	10	ND	10
Benzo (g,h,i)perylene	ND	10	ND	10
Benzo (a)pyrene	ND	10	ND	10
4-Bromophenyl phenyl ether	ND	10	ND	10
Butyl benzyl phthalate	ND	10	ND	10
bis(2-Chloroethoxy)-methane	ND	10	ND	10
bis(2-Chloroethyl) ether	ND	10	ND	10
bis(2-Chloroisopropyl)-ether	ND	10	ND	10
4-Chloro-3-methylphenol	ND	10	ND	10
2-Chloronaphthalene	ND	10	ND	10
2-Chlorophenol	ND	10	ND	10
4-Chlorophenyl phenyl ether	ND	10	ND	10
Chrysene	ND	10	ND	10
Dibenz(a,h)anthracene	ND	10	ND	10
Di-n-butyl phthalate	ND	10	ND	10
1,2-Dichlorobenzene	ND	10	ND	10
1,3-Dichlorobenzene	ND	10	ND	10
1,4-Dichlorobenzene	ND	10	ND	10
3,3'-Dichlorobenzidine	ND	20	ND	20
2,4-Dichlorophenol	ND	10	ND	10
Diethyl phthalate	ND	10	ND	10
2,4-DimethylPhenol	ND	10	ND	10
Dimethyl phthalate	ND	10	ND	10

Appendix E-27. Semivolatile organic compounds at water-quality control sites QW-9 and QW-10, near Rincón, January 28, 1991--Continued.

[Method 625. Units are micrograms per liter. Rep. Limit, reporting limit; NR, not reported; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-9		QW-10	
	Result	Rep. Limit	Result	Rep. Limit
4,6-Dinitro-2-methylphenol	ND	50	ND	50
2,4-Dinitrophenol	ND	50	ND	50
2,4-Dinitrotoluene	ND	10	ND	10
2,6-Dinitrotoluene	ND	10	ND	10
Di-n-octylphthalate	ND	10	ND	10
1,2-Diphenylhydrazine	ND	10	ND	10
bis(2-Ethylhexyl)phthalate	ND	10	ND	10
Fluoranthene	ND	10	ND	10
Fluorene	ND	10	ND	10
Hexachlorobenzene	ND	10	ND	10
Hexachlorobutadiene	ND	10	ND	10
Hexachlorocyclopentadiene	ND	10	ND	10
Hexachloroethane	ND	10	ND	10
Indeno(1,2,3-cd)pyrene	ND	10	ND	10
Isophorone	ND	10	ND	10
Naphthalene	ND	10	ND	10
Nitrobenzene	ND	10	ND	10
2-Nitrophenol	ND	10	ND	10
4-Nitrophenol	ND	50	ND	50
N-Nitrosodimethylamine	ND	10	ND	10
N-Nitrosodiphenylamine	ND	10	ND	10
N-Nitroso-di-n-Propylamine	ND	50	ND	10
Pentachlorophenol	ND	10	ND	50
Phenanthrene	ND	10	ND	10
Phenol	ND	10	ND	10
Pyrene	ND	10	ND	10
1,2,4-Trichlorobenzene	ND	10	ND	10
2,4,6-Trichlorophenol	ND	10	ND	10

Appendix E-27. Semivolatile organic compounds at water-quality control sites QW-9 and QW-10, near Rincón, January 28, 1991--Continued.

[Method 625. Units are micrograms per liter. Rep. Limit, reporting limit; NR, not reported; ND, not detected; conc., concentration; conf. level, confidence level. Values for surrogates represent percent recovery. All tentatively identified compounds were found in the base neutral acids. Confidence levels for the tentatively identified compounds: 1- tentative; 2-confident; and 3-confirmed.]

Constituent	QW-9		QW-10	
	Result	Rep. Limit	Result	Rep. Limit
Surrogate	Recovery			
Nitrobenzene-d5	65		72	
2-Fluorobiphenyl	51		58	
Terphenyl-dl4	73		69	
Phenol-d5	64		70	
2-Fluorophenol	59		66	
2,4,6-Tribromophenol	77		78	

Tentatively Identified Compounds

Site	Constituent	conf. level	conc.
QW-9	Cyclopentane, Ethyl-	2	18
	Oxygenated Hydrocarbon	NR	18
QW-10	Oxygenated Hydrocarbon	NR	17

Appendix E-28. Concentrations of pesticides, PCB's, and herbicides at water-quality control sites QW-9 and QW-10, near Rincón, January 28, 1991.

[Units are micrograms per liter. Rep. Limit, reporting limit; ND, not detected. Values for surrogates represent percent recovery. Sporadic hits reported as ND unless verified in 2nd-column test.]

Constituent	QW-9		QW-10	
	Result	Rep. Limit	Result	Rep. Limit
Organochlorine Pesticides/PCB's				
Method 8080				
alpha-BHC	ND	0.05	ND	0.05
beta-BHC	ND	0.05	ND	0.05
delta-BHC	ND	0.05	ND	0.05
gamma-BHC (Lindane)	ND	0.05	ND	0.05
Toxaphene	ND	1	ND	1
Heptachlor	ND	0.02	ND	0.02
Aldrin	ND	0.05	ND	0.05
Heptachlor epoxide	ND	0.05	ND	0.05
Endosulfan I	ND	0.05	ND	0.05
Dieldrin	ND	0.02	ND	0.02
4,4'-DDE	ND	0.1	ND	0.1
Endrin	ND	0.06	ND	0.06
Endosulfan II	ND	0.1	ND	0.1
4,4'-DDD	ND	0.1	ND	0.1
Endosulfan sulfate	ND	0.1	ND	0.1
4,4'-DDT	ND	0.1	ND	0.1
Endrin aldehyde	ND	0.1	ND	0.1
Chlordane	ND	0.05	ND	0.05
Aroclor 1016	ND	0.5	ND	0.5
Aroclor 1221	ND	0.5	ND	0.5
Aroclor 1232	ND	0.5	ND	0.5
Aroclor 1242	ND	0.5	ND	0.5
Aroclor 1248	ND	0.5	ND	0.5
Aroclor 1254	ND	1	ND	1
Aroclor 1260	ND	1	ND	1
Mirex	ND	0.05	ND	0.05
Ethylan (Perthane)	ND	0.5	ND	0.5
Methoxychlor	ND	0.5	ND	0.5
Surrogate	Recovery			
Dibutyl chlorendate	110		113	

Appendix E-29. Concentrations of total metals at water-quality control sites QW-9 and QW-10 near Rincón, January 28, 1991.

[Units are milligrams per liter. Rep. Limit, reporting limit; ND, not detected.]

Constituent	Analytical method	QW-9		QW-10	
		Result	Rep. Limit	Result	Rep. Limit
Antimony	7041	ND	0.02	ND	0.02
Beryllium	7090	ND	0.05	ND	0.05
Copper	7210	ND	0.05	ND	0.05
Nickel	7520	ND	0.1	ND	0.1
Chromium (VI)	7196	ND	0.01	ND	0.01
Aluminum	6010	ND	2	ND	2
Silver	7761	ND	0.0005	ND	0.002
Cadmium	7131	ND	0.001	ND	0.001
Zinc	7950	ND	0.02	ND	0.02
Chromium	7191	0.0052	0.005	0.005	0.005
Arsenic	7060	ND	0.01	ND	0.01
Barium	6010	ND	0.2	ND	0.2
Boron	6010	4.6	2	4.6	2
Calcium	6010	442	4	450	4
Iron	6010	ND	2	ND	2
Lead	7421	0.08	0.025	0.14	0.05
Magnesium	6010	1370	4	1390	4
Manganese	6010	ND	0.2	ND	0.2
Mercury	7470	ND	0.0002	ND	0.0002
Potassium	6010	414	100	424	100
Selenium	7740	0.015	0.005	0.21	0.05
Silica as SiO_2	6010	ND	10	ND	10
Sodium	6010	11100	100	11200	100
Strontium	6010	7.7	1	7.9	1
Thallium	7841	ND	2	ND	0.5

Appendix E-30. General inorganics and radiochemistry at water-quality control sites QW-9 and QW-10 near Rincón, January 28, 1991.

[Rep. Limit, reporting limit; mg/L, milligrams per liter; NTU, nephelometric turbidity units; pCi/L, picocuries per liter; ND, not detected.]

Constituent	Analytical method	units	QW-9		QW-10	
			Result	Rep.Limit	Result	Rep.Limit
General Inorganics						
Chloride	A429	mg/L	20600	250	20800	250
Cyanide	9012	mg/L	ND	0.01	ND	0.01
Color	110.2	units	ND	5	ND	5
Fluoride	A429	mg/L	29.1	5	27.5	5
Surfactants (MBAS)	425.1	mg/L	ND	0.1	ND	0.1
Ammonia as N	350.1	mg/L	ND	0.1	ND	0.1
Nitrate plus Nitrite	353.2	mg/L	ND	0.1	ND	0.1
Orthophosphate as P	365.3	mg/L	ND	0.05	ND	0.05
Phenolics	9065	mg/L	ND	0.01	ND	0.01
Sulfide, Total	376.2	mg/L	ND	0.05	ND	0.05
Sulfate	A429	mg/L	2800	25	2810	25
Total Kjeldahl Nitrogen as N	351.2	mg/L	0.89	0.5	0.86	0.5
Phosphorus, Total as P	365.3	mg/L	ND	0.05	ND	0.05
Turbidity	180.1	NTU	0.3	0.1	0.34	0.1
Total Dissolved Solids	160.1	mg/L	37100	50	32600	50
Total Suspended Solids	160.2	mg/L	12.4	2	19.6	2
Total Volatile Solids	160.4	mg/L	2940	200	3620	200
Volatile Suspended Solids	160.4	mg/L	ND	10	ND	10
Radiochemistry						
				(+/-)		(+/-)
Gross Alpha	900	pCi/L	0	110	50	160
Gross Beta	900	pCi/L	380	170	280	150
Radium 226	705 Mod.	pCi/L	0.3	0.6	0.3	0.6
Strontium 90	A704	pCi/L	0	1	0	1.4

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB’s, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-31. General water quality at water-quality control sites QW-9 and QW-10 near Rincón, January 28, 1991.

[Rep. Limit, reporting limit; mg/L, milligrams per liter; °C, degrees Celsius; k, extinction coefficient; vol/count, volume of sample (rest made up to 100ml) and number of bacteria colonies counted using the filter membrane method; col/100ml, colonies of bacteria per 100 milliliters; TNTC, too numerous to count; µS/cm, microsiemens per centimenter; mg/m^3, milligram per cubic meter; ND, not detected; --, no data.]

Constituent	units		QW-9			QW-10	
			Result	Rep. Limit		Result	Rep. Limit
BOD-5	mg/L		ND	2		ND	2
Oil and Grease	mg/L		ND	5		ND	5
Settleable Solids	mg/L		0			0	
Water Temp.	°C		--			--	
Alkalinity	mg/L		120			130	
Spec.Cond.	µS/cm		44000			--	
pH	units		8.2			8.26	
Dissolved Oxygen	mg/L		--			--	
Extinction Coefficient	k		0.12			0.29	
Chlorophyll-a	mg/m^3		0.0466			0.0479	
Bacteria							
Fecal Coli(dil/count)		50	10		50	10	
Fecal Coli(vol/count)		25	7		25	3	
Fecal Coli(vol/count)		10	2		10	0	
	cols/100ml		b-22			b-17	
Total Coli(vol/count)		50	3		50	3	
Total Coli(vol/count)		25	0		25	0	
Total Coli(vol/count)		10	0		10	0	
	cols/100ml		b-6			b-6	
Enterococcus(vol/count)		50	0		50	0	
Enterococcus(vol/count)		25	0		25	0	
Enterococcus(vol/count)		10	0		10	0	
	cols/100ml		b<1			b<2	

Appendix E-32. Vertical profiles of physical and chemical properties measured inside the initial mixing zone (QW-4, QW-5), January 30,1991.

[Repl., replicate; °C, degrees Celsius; m, meter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Sampled depth (m)	QW-4				QW-5				QW-5 (Repl.)			
	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
0.0	26.2	8.31	7.35	--	25.9	8.2	7.94	>50000	25.9	8.17	8.95	50000
0.6	26.2		7.36		25.9		7.86		25.9		9	
1.2	26.2		7.36		25.9		7.85		25.9		8.85	
1.5		8.31		--		8.22		>50000		8.25		>50000
1.8	26.2		7.4		25.9		7.85		25.9		9.05	
2.4	26.3		7.47		25.9		7.86		25.9		9.05	
3.0	26.3	8.31	7.4	--	25.9	8.26	7.85	>50000	25.9	8.24	9.2	>50000
3.7	26.3		7.45		25.9		7.95		25.9		9.2	
4.3	26.3		7.4		25.9		7.85		25.9		9.16	
4.6		8.32		--		8.25		>50000		8.27		>50000
4.9	26.3		7.4		25.9		7.86		25.9		9.25	
5.5	26.2		7.4		25.9		7.85		25.8		9.27	
6.1	26.3	8.31	7.35	--	25.9	8.23	7.98	>50000	25.9	8.24	9.41	50000
6.7	26.1		7.25		25.9		7.84		25.8		9.35	
7.3	26.1		7.25		25.8		8.01		25.9		9.38	
7.6		8.31		--		8.26		>50000		8.27		>50000
7.9	25.9		7.18		25.9		7.99		25.9		9.34	
8.5	25.9		7.2		25.9		8.01		25.9		9.46	
9.1	25.9	8.31	7.1	--	25.9	8.28	8.19	>50000	25.9	8.26	9.5	>50000
9.8	26.3		7.26		25.9		8.45		25.8		9.47	
10.4	26.3		7.28		25.9		8.3		25.9		8.98	
10.7		8.31		--	25.9	8.27	8.68	>50000	25.9	8.26	8.63	>50000
11.0	26.3		7.2									
11.6												
12.2		8.33		--		8.27		>50000		8.28		>50000

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-33. Vertical profiles of physical and chemical properties measured at the limit (QW-3 and QW-6) of the initial mixing zone, January 30,1991.

[Units: °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Sampled depth (m)	QW-3				QW-6			
	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
0.0	26.6	8.26	7.97	--	25.7	8.23	7.5	>50000
0.6	26.6		8.1		25.7		7.28	
1.2	26.6		8.16		25.8		7.24	
1.5		8.26		--		8.27		>50000
1.8	26.5		8.1		25.8		7.22	
2.4	26.5		8.1		25.8		7.16	
3.0	26.5	8.26	7.95	--	25.8	8.28	7.2	>50000
3.7	26.4		7.95		25.8		7.18	
4.3	26.4		7.93		25.8		7.26	
4.6		8.25		--		8.26		>50000
4.9	26.4		7.83		25.8		7.21	
5.5	26.4		7.75		25.8		7.26	
6.1	26.3	8.26	7.72	--	25.8	8.28	7.2	>50000
6.7	26.3		7.7		25.8		7.21	
7.3	26.3		7.72		25.8		7.19	
7.6		8.26		--		8.27		>50000
7.9	26.3		7.6		25.8		7.23	
8.5	26.2		7.61		25.8		7.2	
9.1	25.8	8.24	7.4	--	25.8	8.26	7.25	>50000
9.8	25.9		7.41		25.8		7.29	
10.4	25.8		7.4		25.8		7.23	
10.7		8.25		--		8.28		>50000
11.0	25.8		7.4		25.8		7.2	
11.6	25.9		7.31					
12.2		8.23		--		8.28		>50000

Appendix E-34. Vertical profiles of physical and chemical properties measured at the limit of the final mixing zone (QW-2 and QW-7), January 29, 1991.

[Units: °C, degrees Celsius; m, meter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Sampled Depth (m)	QW-2				QW-7			
	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
0.0	26	8.25	7.88	49500	26.6	8.23	7.33	49500
0.6	26		7.86		26.5		7.21	
1.2	26		7.88		26.2		7.23	
1.5		8.25		49500		8.25		50000
1.8	26		7.88		26.1		7.35	
2.4	26		7.88		26.1		7.46	
3.0	26	8.26	7.82	49500	26	8.25	7.46	50000
3.7	26		7.8		26		7.46	
4.3	26		7.9		25.9		7.36	
4.6		8.26		50000		8.25		49500
4.9	26		7.94		25.9		7.3	
5.5	26		7.9		25.9		7.34	
6.1	26	8.26	7.87	49500	25.9	8.23	7.28	48500
6.7	26		7.83		25.9		7.31	
7.3	26		7.84		25.9		7.31	
7.6		8.26		50000		8.26		49500
7.9	25.9		7.83		25.9		7.3	
8.5	25.9		7.87		25.9		7.37	
9.1	25.9	8.26	7.87	50000	25.9	8.26	7.2	48500
9.8	25.9		7.9		25.9		7.26	
10.4	25.9		7.83		25.9		7.2	
10.7		8.26		50000		8.25		49000
11.0	25.9		7.86		25.9		7.34	
11.6	--		--		--		--	
12.2		8.26		50000		8.25		49500

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB's, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991--Continued

Appendix E-35. Vertical profiles of physical and chemical properties measured at the farfield stations QW-1 and QW-8, January 29, 1991.

[Units: °C, degrees Celsius; m, meters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Sampled Depth (m)	QW-1				QW-8			
	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
0.0	26.1	8.27	7.59	48000	25.6	8.26	7.45	48000
0.6	26.1		7.54		25.7		7.36	
1.2	26.1		7.53		25.8		7.4	
1.5		8.27		48000		8.24		48000
1.8	26.1		7.57		25.9		7.4	
2.4	26.1		7.52		25.9		7.36	
3.0	26.1	8.27	7.47	48500	25.9	8.26	7.34	49000
3.7	26.1		7.51		25.8		7.31	
4.3	26		7.5		25.9		7.32	
4.6		8.27		47500		8.26		47500
4.9	26		7.54		25.9		7.24	
5.5	26		7.48		25.9		7.26	
6.1	26	8.27	7.58	48000	25.9	8.26	7.29	48000
6.7	26		7.55		26		7.3	
7.3	26		7.52		25.8		7.29	
7.6		8.27		48000		8.26		48000
7.9	26		7.5		25.9		7.3	
8.5	26		7.61		25.9		7.18	
9.1	25.9	8.25	7.58	48500	26	8.26	7.19	48000
9.8	25.9		7.6		25.9		7.14	
10.4	25.9		7.54		25.9		7.15	
10.7		8.25		47500		8.26		48000
11.0	25.9		7.57		26		6.98	
11.6	--		--		26.1		6.9	
12.2		8.25		48000	26	8.26	6.86	49000

Appendix E. General water quality with depth and general water quality, bacteria, volatile organic compounds, semivolatile organic compounds, pesticides, PCB’s, herbicides, total metals and trace elements, general inorganics, and radiochemistry by sample at ten water-quality sampling sites in the Bahía de Añasco and near Rincón, Puerto Rico, at two sites sampled in the Río Grande de Añasco and the Río Yagüez, and at the influent and effluent of the Mayagüez Regional Wastewater Treatment Plant, January 25-30, 1991—Continued

Appendix E-36. Vertical profiles of physical and chemical properties measured at the control stations QW-9 and QW-10 near Rincón, January 28, 1991.

[Units: °C, degrees Celsius; m, meter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Sampled Depth (m)	QW-9				QW-10			
	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Temperature (°C)	pH (units)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)
0.0	--		--		--	8.27	--	--
0.6	--	8.37	--	--	--		--	
1.2	--		--		--		--	
1.5								
1.8	--		--		--	8.28	--	--
2.4	--		--		--		--	
3.0	--		--		--		--	
3.7	--		--		--	8.27	--	--
4.3	--		--		--		--	
4.6		8.36		--				
4.9	--		--		--		--	
5.5	--		--		--	8.28	--	--
6.1	--		--		--		--	
6.7	--		--		--		--	
7.3	--		--		--	8.28	--	--
7.6								
7.9	--		--		--		--	
8.5	--	8.33	--	--	--		--	
9.1	--		--		--	8.27	--	--
9.8	--		--		--		--	
10.4	--		--		--		--	
10.7		--		--		--		--
11.0	--		--		--		--	
11.6	--		--		--		--	
12.2	--		--		--		--	

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Webb and others—ASSESSMENT OF THE HABITATS, BIOTA, SEDIMENTS AND WATER-QUALITY NEAR THE DISCHARGE OF PRIMARY-TREATED EFFLUENT FROM THE MAYAGÜEZ REGIONAL WASTEWATER TREATMENT PLANT, BAHÍA DE AÑASCO, PUERTO RICO—WRIR 99–4141