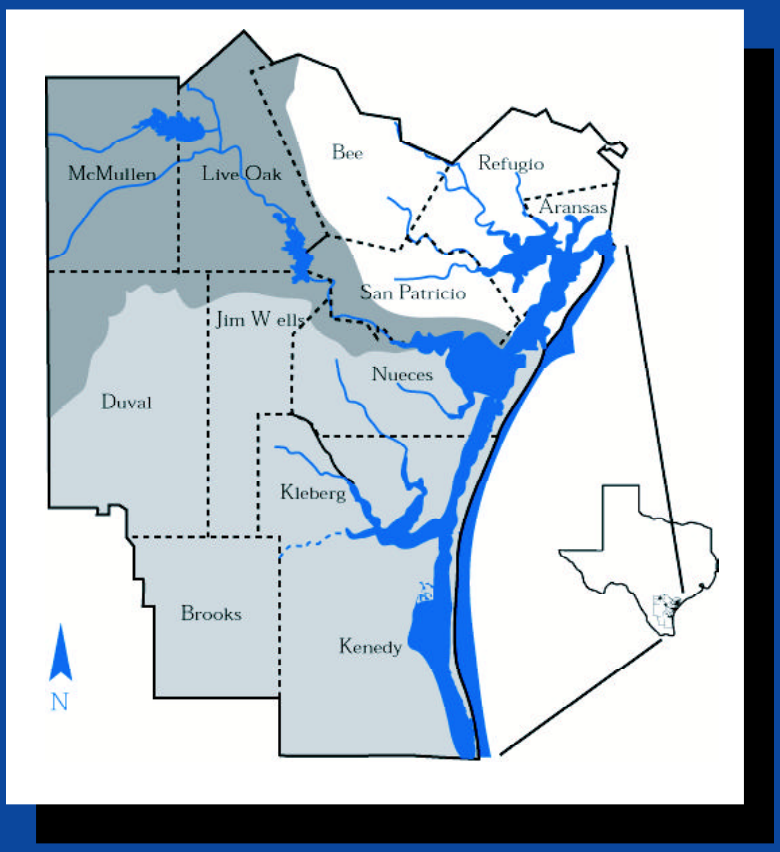
Sediment Quality Assessment of Storm Water Outfalls and Other Selected Sites in the Corpus Christi Bay National Estuary Program Study Area



Corpus Christi Bay National Estuary Program
CCBNEP-32 • September 1998

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Sediment Quality Assessment of Storm Water Outfalls and Other Selected Sites in the Corpus Christi Bay National Estuary Program Study Area

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A Note to Readers

In the compilation of this report, considerable discussion emerged among Project Review Team members concerning the relative 'weight' or 'significance' to be ascribed to the results obtained from the various toxicity tests. Due to the range of results between the standard solid-phase amphipod and mysid toxicity tests and the more sensitive sea urchin fertilization and embryo development tests, there were differing opinions regarding how to characterize the sample sites in the final analysis. An additional concern arose regarding the methodology and applicability of the extracted porewater analysis.

The U.S. Environmental Protection Agency (USEPA) first published a sea urchin toxicity test methodology in 1987, which was subsequently revised in 1994 (USEPA, 1994). This method was intended for use in testing ambient waters and effluents. Ankley and Thomas (1992) state, however, that the use of extracted porewater can provide useful data when used with toxicity identification evaluations (TIEs). They therefore conclude that extracted porewater toxicity assessment is applicable to virtually all environmental conditions and sediment types, and that a wide variety of test organisms can be evaluated with this approach. The sea urchin porewater toxicity tests have been used in numerous comprehensive sediment quality assessment surveys in coastal portions of the United States over the last decade. USEPA, Region 6, agrees that extraction of porewater for sediment quality assessment is a scientifically acceptable approach which has been supported by the agency's Office of Research and Development and the scientific community in general (P.Crocker, USEPA, Region 6, pers. comm.).

Since several of the sample sites are located within channels, marinas, or other areas potentially subject to future dredging activities, it is important to clarify that use of the porewater toxicity test is not included in the latest dredged material testing document (Inland Testing Manual, 1998) developed by the USEPA and the U.S. Army Corps of Engineers (USACOE). Hence, the USACOE believes that porewater toxicity tests should not be used in the development or review of projects subject to Clean Water Act Section 404 permits. Furthermore, the USACOE has taken the position that the porewater toxicity tests are not representative of real world conditions and should not be used as a surrogate for effects-based, solid-phase test protocols approved in the USEPA/USACOE dredged material testing manuals (J. Wilson, USACOE, pers. comm.).

It should be noted, however, that this report is intended to be a characterization assessment of the sediments at the selected sample sites and is not intended to address dredged material management actions. The results of the sea urchin fertilization and embryo development tests are being included because they may provide information useful for differentiating among the various sample sites.

Finally, readers are asked to make note of the fact that the City of Corpus Christi is likewise concerned with the methodology used in the report. Since there were numerous monitoring sites within the City limits of Corpus Christi, including areas where the City owns the bay bottom itself (the City marina), the City has a major interest in the project,

and agrees with the position that the USACOE has taken regarding the porewater toxicity tests as stated above.

Moreover, the City is concerned that an absence of comparison data to other estuary systems does not allow an adequate characterization of the tested area. (Note: No comparison data was called for under the consultant contract.) Therefore, while the City participated on the committee reviewing the study, the City wishes to disassociate itself from both the methodology used and the results of the study.

CCBNEP Program Office

USEPA. 1994. Short-term methods for estimating the chronic toxicity of effluents and receiving water to marine and estuarine organisms, 2nd edition. EPA-600-4-91-003.

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USEPA/USACOE. 1998. Evaluation of dredged material proposed for discharge in waters of the U.S. – Testing manual ("Inland Testing Manual").

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

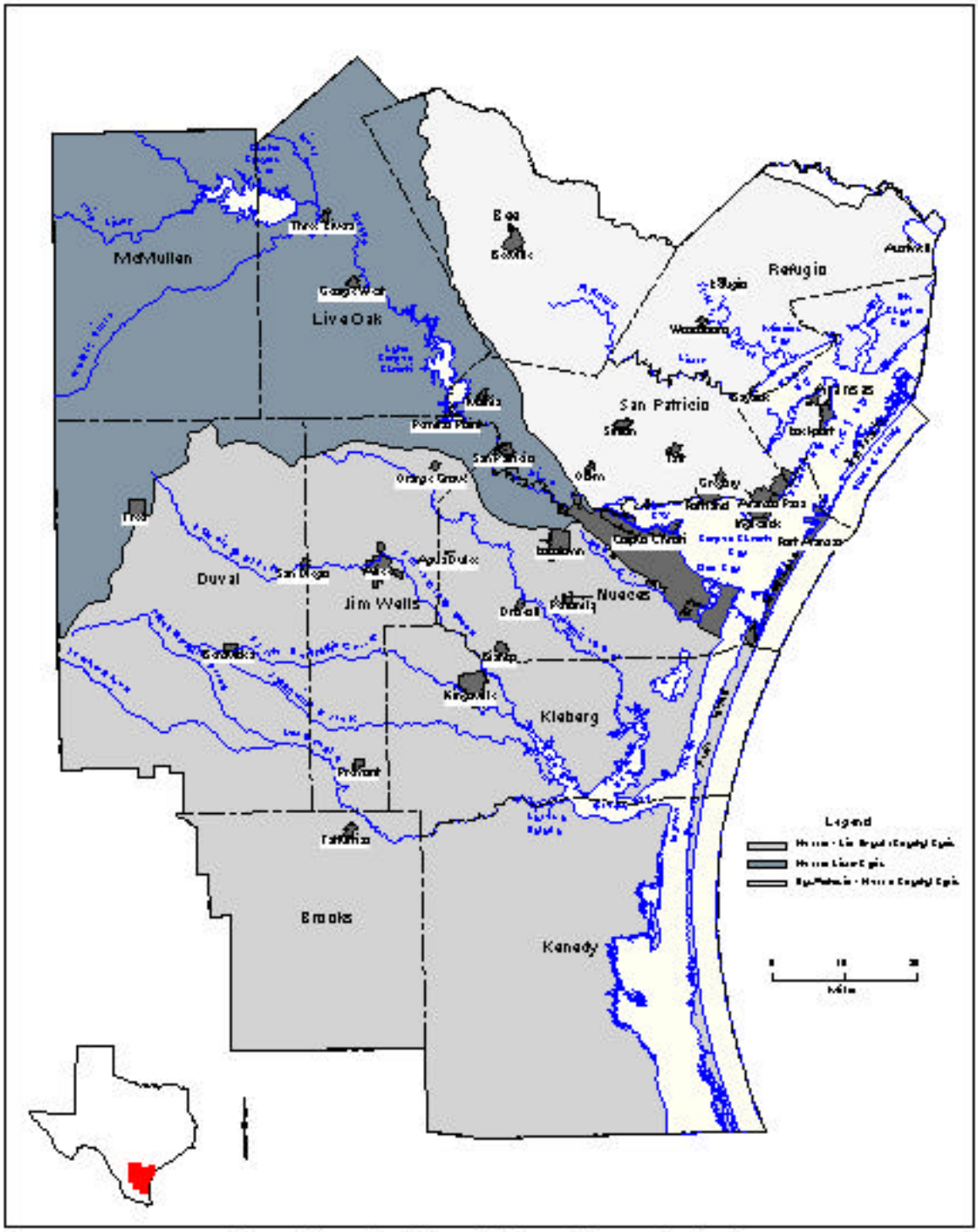
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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There are numerous individuals who contributed to this multidisciplinary project. We are indebted to Jim Biedenbach, Russell Hooten, and Rick Kalke for their expert assistance in collecting and processing the sediment samples. Jim Biedenbach, Russell Hooten, Linda May, Dr. Marion Nipper, and Cintia Pedroso assisted in the performance of the toxicity tests. We are also grateful to Gerri Cripe and her co-workers at the EPA Environmental Research Laboratory in Gulf Breeze, Florida for conducting the toxicity tests with mysids. We thank Dr. Joanna Mott, Arlene Wimer and their assistants for performing the microbial measurements. We are grateful to Rick Kalke for his expert identifications of the benthic organisms. We appreciate the constructive criticism and suggestions from the CCBNEP project review team and others including Ray Allen, Phillip Crocker, and Dr. Varender Sharma.

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Sediment Quality Assessment of Storm Water Outfalls And Other Sites of Concern in The Corpus Christi Bay National Estuary Program Study Area

R. Scott Carr, Paul A. Montagna, and Mahlon C. Kennicutt

EXECUTIVE SUMMARY

To determine the quality of sediments and the degree and extent of potential contaminant impacts associated with storm water outfalls and other selected sites, a Sediment Quality Triad (SQT) study was conducted in the Corpus Christi Bay National Estuary Program (CCBNEP) study area. The majority of the 36 sites were located near storm water outfalls but other sites of concern (industrial and domestic outfalls, produced water discharges, and dredging activity) were also evaluated. Each site was sampled once during a five day period in October, 1997 and analyzed for microbial indicators (total and fecal coliforms), physical characteristics (grain size, TOC) and contaminant concentrations (metals, PAHs, PCBs, and pesticides), toxicity using a suite of tests of increasing sensitivity (amphipod and mysid solid-phase toxicity tests, mysid solid-phase growth test and extracted porewater sea urchin fertilization and embryological development tests), and benthic community structure. This large data matrix was reduced using multivariate analysis to create new variables for each component representing overall means. The new variables were used to conduct the correlation analysis.

Sediment quality guidelines developed by Long (et al.) in 1995 and MacDonald (et al.) in 1996 were employed to provide a basis for estimating potential biological impacts associated with sediment contaminants and as a tool to differentiate among sample sites even when no toxicity was observed in the standard solid-phase toxicity tests. Concentrations of contaminants (polycyclic aromatic hydrocarbon (PAHs) metals, pesticides or PCBs) at several storm water outfall sites exceeded sediment quality guideline values. Elevated fecal coliform measurements were also observed at a number of sites most of which were located away from heavily urbanized areas.

Only one site (S8) of the 36 sample sites was significantly toxic in the amphipod solid-phase test and no toxicity was observed at any of the sample sites in the mysid survival test. Both growth enhancement and reduction were observed at a number of sites for the mysid growth test. Fourteen of the 36 sites showed growth reduction and 13 sites showed growth enhancement. The growth response exhibited in this test, both reduction and enhancement, may be confounded by the nutritional quality or grain size of the sediments.

Sea urchin porewater toxicity tests are considerably more sensitive than the standard solid-phase amphipod and mysid toxicity tests. The sea urchin toxicity tests used in this study serve as a tool to assess interstitial water toxicity among sample sites even when no toxicity was observed in the solid-phase tests. In the sea urchin fertilization test 7 of the 36 sample sites showed toxicity with full strength (100%) water quality adjusted extracted porewater. Two of the 7 sites (S1, S15) also showed toxicity at 50% and 25% dilutions. In the sea urchin embryo development test, 16 of the 36 sites showed toxicity with full strength (100%) water quality adjusted extracted porewater. Eight of the 16 sites were toxic at 50% dilution and 3 sites (S1, R1, R7) were toxic at 25% dilution. Six of the 7 sites exhibiting toxicity for the urchin fertilization test were also toxic for the embryo development test.

A total of 136 species were found during the benthic community assessment. The eight most dominant species accounted for 90% of all organisms found. The dominant species was the polychaete *Streblospio benedicti*, accounting for 26% of total abundance. The second most dominant was the bivalve *Mulinia lateralis* (17%). The remaining dominant species were all annelids: *Medimastus ambiseta* (14%), *Tharyx setigera* (10%), *Polydora caulleryi* (8%), Oligochaetes (7%), *Capitella capitata* (6%), *Paraonis fulgens* (2%). All the remaining 128 species represented less than 1% of the organisms found. These dominant eight species were not found evenly distributed among sites. The only exception was *Mulinia lateralis*, which was found in 25 of the 36 sites. One species, *Paraonis fulgens*, appeared to be characteristic of storm water outfall sites, occurring in 11 of the 13 where living organisms were found, and occurring at only 3 other sites. *Mulinia lateralis* and *Syllis cornuta*, one of the less abundant species, were also consistently found at storm water outfall sites.

The study conducted by the Bureau of Economic Geology (BEG) in the mid-1970s, provides historical data for comparison with the present study. The dominant macrobenthic invertebrates in the bay margin habitats of Corpus Christi Bay in the BEG study were three bivalves (*Mulinia lateralis, Lyonsia hyalina floridana* and *Nuculana acuta*), the polychaete *Paraprionospio pinnata*, and the amphipod *Lepidactylus* sp. In the present study, *Mulinia lateralis* represented 97.5% of bivalves observed with only one individual of *Nuculana acuta* and *Lyonsia hyalina floridana* observed at only 1 and 3 sites, respectively. The polychaete *Paraprionospio pinnata* was rarely observed in the present study with the opportunistic *Streblospio benedicti* and *Mediomastus ambiseta* now dominating. The amphipod *Lepidactylus* sp., which accounted for over 50% of the crustaceans observed in the BEG study, was not observed at any of the 36 sites in the present study. Thirty-nine species of amphipods were observed in Corpus Christi Bay in the BEG study as compared with 13 in the present study. Amphipods are known to be pollution sensitive species and are often the first species to disappear from a disturbed ecosystem. In the BEG study, the open-bay species assemblages were less diverse and more depauperate in comparison with the sandy bay-margin assemblages. In the present study the reverse seems to be true with the open-bay sites (e.g., 5, R3, and S4) exhibiting the highest species diversity, biomass and abundance as compared with the bay-margin sites. In the recent REMAP study conducted by the USEPA in 1994 in which benthic communities at 52 sites were examined, approximately 50% of Corpus Christi Bay was determined to be degraded based on their benthic index. Benthic abundance, biomass and diversity at the long-term reference sites (R1-R5) during the present study were in the lower third of the range reported since 1987. However, the low benthic characteristics recorded during the present study may be due, in part, to higher than normal salinity salinities at the time of sampling.

There were three types of data collected during this study: chemical contaminants in sediments, toxicity as determined in experimental exposures, and ecological characteristics of the sediments as revealed by benthic invertebrate communities. Each of these data sets are multivariate. The chemistry data set was the largest with 11 trace metals, 44 polynuclear aromatic hydrocarbons (PAHs), and 61 polychlorinated biphenyls (PCBs). These variables were first reduced by summing the constituents of families of compounds into five categories: National Status and Trends PAHs (NSTPAHs), chlordanes, DDTs, HCHs, and PCBs. In addition, sediment grain size and total organic

carbon (TOC) were also included in the chemistry data set. There were five separate toxicity tests with three different species. A benthic index of biotic integrity (BIBI) was used to quantify benthic community structure data. The BIBI incorporated ten independent metrics including biomass, density, Shannon-Wiener diversity index, percent of pollution indicator species, percent of pollution sensitive species, percent of biomass in deeper section (3 - 10 cm), percent of species that are carnivores or omnivores, and percent of species that are deep deposit feeders. Principal component analysis was performed independently on the chemical, toxicity and ecological data. The first two principal components from each analysis were then analyzed for significant correlations among SQT variables. Toxicity was significantly correlated with both chemistry and ecological responses.

Probable effects level (PEL) values, which are the concentration of a chemical above which biological effects are likely to occur, were used to assess 31 chemicals or classes of chemicals. For each site, the bulk sediment chemistry concentration for each chemical or class of chemicals was divided by its PEL value and the resulting quotients were summed, divided by 31 (the number of PEL values used) and multiplied by 100 to calculate a PEL index. Using the combined information from the SQT in scaled ranking approach, four of the five most degraded sites were storm water discharge sites (S1, S2, S15, and S9). Two of these sites (S1 and S15) were completely devoid of a benthic community. Site S9 (Resort by the Sea Apartments) was by far the most chemically contaminated site in this study but the contaminants were apparently not bioavailable because toxicity was not observed at this site.

A summary of the SQT data is presented in Table *i*. Each site was categorized on the basis of their PCA scores into high, medium or low quality for the three components. Using a conservative estimate which favored making a type I error (false positive) rather than a type II error (false negative), only sites which were classified in the low category were considered to be significantly impacted for each parameter and received a minus (-) designation. Using these criteria, only two sites (S1 and S2) were ranked low for all three components of the triad, which is indicative of contaminant induced degradation. Fourteen sites (7, 10, 11, 12, 13, S4, S10, S11, S14, R2, R4, R6 and R8) were high or medium quality for all three components, which suggests there is no contaminant-induced degradation. The remaining twenty sites were ranked low quality for toxicity, chemistry or benthic alterations but not all three, which indicates that contaminants may be stressing the system or that unmeasured contaminants or other conditions are causing degradation.

It is apparent that several of the sites included in this study have been impacted by anthropogenic influences. While the more severe effects appear to be localized, this study has served to identify some specific areas of concern where more comprehensive monitoring should be conducted. Some specific storm drains, for example, appear to have high levels of particular types of contaminants or exhibited significant toxicity.

Table *i*. Summary of Sediment Quality Triad data. A minus sign for chemistry, toxicity or benthos indicates a principal component analysis (PCA) score in the low quality category for that parameter.

Chemistry	Toxicity	Benthos	Sites (Station Number)	Possible Conclusion
-	-	-	SWO near the L-head in Corpus Christi marina **(S_1)**, Cole Park SWO **(S_2)**	Evidence of contaminant-induced degradation
+	+	+	NAS effluent outfall **(7)**, Shamrock Island **(10)**, La Quinta channel south **(11)**, La Quinta channel north **(12)**, mitigation site near JFK bridge **(13)**, Cole Park SWO - 500 m station **(S_4)**, Airline SWO **(S_{10})**, Swantner Park SWO **(S_{11})**, Ennis Joslin SWO **(S_{13})**, TAMU-CC SWO **(S_{14})**, eastern Nueces Bay **(R_2)**, NE Corpus Christi Bay **(R_4)**, SE Corpus Christi Bay - Fish Pass **(R_6)**, Southern Corpus Christi Bay **(R_8)**	No evidence of contaminant-induced degradation
-	+	+	NAS boat basin breakwater **(8)**	Contaminants are not bioavailable
+	-	+	Corpus Christi Inner Harbor **(3)**, ship channel dredge spoil site **(5)**, Oso Pass in Corpus Christi Bay **(6)**, western Nueces Bay **(R_1)**, NW Corpus Christi Bay **(R_3)**, Eastern Corpus Christi Bay **(R_5)**	Unmeasured chemicals or conditions exist with the potential to cause degradation
+	+	-	Cole Park SWO - 200 m station **(S_3)**, South Cole Park **(S_5)**, First Baptist Church SWO **(S_6)**, Ocean Drive SWO **(S_7)**, Dodderidge Park SWO **(S_8)**, Poenish Park SWO **(S_{12})**	Benthic response probably not due to contaminants
+	-	-	West Whites Point **(1)**, CP&L cooling water discharge site in Nueces Bay **(2)**, Texas State Aquarium **(4)**, Oso Wastewater Treatment Plant outfall **(9)**, Padre Island SWO **(S_{15})**, The Boat Hole near NAS **(R_7)**	Unmeasured contaminants or other conditions are causing degradation of benthos
-	+	-	Resort by the Sea Apartments SWO **(S_9)**	Contaminants are not bioavailable or benthic response not due to contaminants

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I. INTRODUCTION

The majority of the contaminants of concern entering estuaries eventually become associated with sediment particles and are deposited in the estuary. Many of the contaminants that become associated with sediments may not be bioavailable because of their chemical and physical association with particulates or organic moieties (Swartz et al., 1985). It is not possible, however, to predict which sediment samples may be toxic on the basis of analytical chemistry information alone, as has been repeatedly demonstrated (Long and Chapman, 1985; Chapman, 1986, 1990; Chapman et al., 1987; Long et al., 1990; Carr et al., 1996a; 1996b). The most powerful tool for determining the degree to which contaminants are responsible for the degradation of sediment quality is the Sediment Quality Triad (SQT) approach (Chapman, 1990). The SQT is an effects-based approach for evaluating and assessing pollution-induced degradation consisting of three components: sediment chemistry (a measure of contamination), sediment toxicity tests (measures of bioavailability and biological effects), and *in situ* parameters (e.g., alterations of benthic community structure). The information provided by each component is unique and complementary. All three measures are essential for determining sediment quality because no single component provides comprehensive information.

Anthropogenic activities in the CCBNEP study area have introduced metals and organic chemicals to bay sediments at concentrations elevated above naturally occurring background levels. One potential source of sediment contaminants is urban storm water runoff. However, other potential sources of sediment contaminants include historic or current activities associated with municipal and industrial discharges, marine transportation, oil and gas production and marinas. The primary objective of this study was to characterize sediment contaminant levels, toxicity, and benthic community structure of sediments associated with urban storm water outfalls, as well as with other sources at targeted sites. The current study was designed to assess the potential effects of persistent or bioaccumulative sediment contamination on estuarine biota in the study area.

II. METHODS

Sampling Site Selection

The existing and available data on sediment contaminant levels, toxicity, and benthic community structure in the CCBNEP study area was reviewed and used to help prioritize potential sites of concern. Potentially valuable data sets which were reviewed include (1) National Oceanic and Atmospheric Administration (NOAA) Status and Trends, (2) EPA's Environmental Monitoring and Assessment Program (EMAP) and Regional program (REMAP) data, (3) the Bureau of Economic Geology, University of Texas study of sediments, geochemistry, and benthic macroinvertebrates (BEG, 1983), (4) contaminants survey reports prepared by U.S. Fish and Wildlife Service (Barrera et al., 1995), and (6) the recent synopsis of water and sediment quality data for the CCBNEP study area (Ward and N.E. Armstrong, 1996). Similar types of data and/or literature from other estuarine areas (e.g., Galveston Bay, Florida NEPs) were also reviewed.

Based on this information, a pre-study selection survey was conducted on 18 June 1996 to determine which storm drains should be included and to ensure that the sediment texture information from the BEG (1983) study was accurate. Other potential sites of concern were also visited. A total of 36 sites were selected (Table 1). Of the 28 potentially impacted sites, 15 were storm water outfall sites, and 13 sites represented other types of concerns to bay bottom sediments. These other sites include spoil islands, ship channels, produced water discharges, thermal effluent, refinery processed water effluent, industrial sites, wastewater effluents, and sites identified with high mercury levels in past surveys. An additional 8 sites were designated as reference sites because they had either been used as historical reference sites in past studies (Montagna and Kalke 1992; Martin and Montagna, 1995) or were far removed from local contaminant inputs but had sediment textures similar to the majority of the storm water outfall sites. All sites (except S15 which is on Padre Island adjacent to Laguna Madre) are within Corpus Christi or Nueces Bays (Figure 1).

Sample Collection

Sediment samples were collected by researchers from the Center for Coastal Studies, and the University of Texas Marine Science Institute using the U.S. Geological Survey research vessel, a 22' Baymaster tunnel hull boat. An attempt was made to locate all the storm drain sites ~100 m from shore (except for S_3 and S_4 which were located 200 m and 500 m from shore along a transect) which is beyond the State designated mixing zone in order to ensure comparability among sites. The position of all sites was established with a Magellan Global Positioning System (GPS) with an accuracy of ±3 m.

The sediment samples (8 ± 2 cm deep) were collected with a four-inch diameter coring device equipped with a transparent PVC barrel to enable the depth and integrity of the core to be determined before it was included in the composite sample. The PVC corer was equipped with a valve that closes when the sample is withdrawn and can be opened manually to release the sample from the corer. The corer has multiple attachments which allow sampling at depths up to 5 meters. The sediment cores (8-10) were placed in a Kynar®-lined stainless steel pan and the composite sample (~5 liters) was homogenized with a Teflon® spatula. The sediment subsamples for chemical analyses were placed in glass I-Chem containers cleaned to EPA specifications (Protocol A which includes nitric acid and methylene chloride rinses) and kept on ice until they were frozen. The sediment subsamples for toxicity testing were placed in presoaked one-gallon high density polyethylene containers and held on ice or refrigerated until they were processed. Sediment pore water were extracted from the sediment samples within two days of the time of sample collection; the pore water was stored frozen until just prior to testing.

Separate samples were collected for the benthic community structure analyses because these samples must be collected undisturbed. The cores are 6.72 cm diameter, covering an area of 35.4 cm^2. The cores were sectioned (at 0-3 cm, and 3-10 cm) to examine the vertical distribution of macrofauna. Five replicates were taken per site. Each section replicate was placed in a polyethylene container and the sample fixed with buffered formalin. These samples were sieved and processed back at the laboratory at UTMSI.

Table 1. Sampling Sites for Corpus Christi Bay National Estuary Program Sediment Quality Assessment Study. Site nomenclature: an R prefix is a reference site, an S prefix is a storm water drain site, and no prefix is a site of other concern.

Site	Site Description	Reason for Selection
R1	Western Nueces Bay near the Nueces River Delta. Reference site A (Montagna and Kalke, 1992).	Historical reference site for benthic community structure studies.
R2	Eastern Nueces Bay near Nueces Bay Causeway. Reference site B (Montagna and Kalke, 1992).	Historical reference site for benthic community structure studies.
R3	Northwestern Corpus Christi Bay near Indian Point. Reference site C (Montagna and Kalke, 1992).	Historical reference site for benthic community structure studies.
R4	Northeastern Corpus Christi Bay near Aransas Pass Ship Channel. Reference site E (Montagna and Kalke, 1992).	Historical reference site for benthic community structure studies.
R5	Eastern Corpus Christi Bay near Mustang Island. Reference site D (Montagna and Kalke, 1992).	Historical reference site for benthic community structure studies
R6	Southeastern Corpus Christi Bay near Fish Pass on Mustang Island.	Sandy nearshore environment with minimal influence from point or non-point source inputs.
R7	The Boat Hole in Southeastern Corpus Christi Bay near the south side of Corpus Christi Naval Air Station.	Sandy nearshore environment with minimal influence from point or non-point source inputs.
R8	Southern Corpus Christi Bay between Texas A&M University -Corpus Christi and Corpus Christi Naval Air Station.	Sandy nearshore environment with minimal influence from point or non-point source inputs.
S1	Storm water outfall near the L-head in Corpus Christi marina.	Primary storm water outfall inside the marina breakwater. Only outfall with an obvious flow observed during a preliminary site selection survey in June, 1996.
S2	Cole Park storm water outfall - 100 m transect station.	This is a major outfall and is likely the largest in the study area.
S3	Cole Park storm water outfall - 200 m transect station.	This transect will provide information concerning the areal extent of any impacts from this outfall.

Table 1. (continued)

Site	Site Description	Reason for selection
S4	Cole Park storm water outfall – 500 m Transect station.	This transect will provide information concerning the areal extent of any impacts from this outfall.
S5	South Cole Park - duel storm water outfalls.	Two medium-sized outfalls located close together
S6	Storm water outfall across the street from First Baptist Church on Ocean Drive.	Major outfall located approximately 500 m south of S_5.
S7	Storm water outfall approximately 100 m south of large pink estate.	Medium-sized outfall.
S8	Dodderidge Park storm water outfall located near the northern end of the park.	Medium-sized outfall.
S9	Storm water outfall at Resort by the Sea Apartments ~150 m from shore.	Major outfall.
S10	Airline storm water outfall located approximately 250 m from 10-story condominium.	Medium-sized outfall.
S11	Major storm water outfall located near the middle of Swantner Park.	Major outfall.
S12	Poenish Park storm water outfall.	Medium-sized outfall.
S13	Storm water outfall near County Line Restaurant at intersection of Ennis Joslin and Ocean Drive.	Medium-sized outfall.
S14	New storm water outfall located opposite Texas A&M University - Corpus Christi.	This medium-sized outfall was installed less than two years ago and could provide information relevant to the time required for any impacts to become discernable.
S15	Padre Island storm water outfall.	Medium-sized outfall located in residential canal.
1	West Whites Point - near a recently discontinued produced water discharge site.	This site has been significantly impacted by chronic discharge of produced water. Although discharges have recently ceased from this outfall, the continuing impact of these chronic discharges on the benthic community has not been assessed.

Site	Site Description	Reason for Selection
2	CP&L cooling water discharge site in Nueces Bay	Cooling water from the Corpus Christi Inner Harbor is the largest discharge into Nueces Bay.
3	Refinery process water effluent discharge in Inner Harbor.	This is the largest discharge into the Inner Harbor.
4	Texas State Aquarium.	This site inside the breakwater near the Corpus Christi Aquarium is a depositional zone for material coming from the Inner Harbor.
5	Open bay Ship Channel dredge spoil site.	This is an active open bay disposal site for dredged material from the Corpus Christi ship channel which has received dredged material within the past year.
6	Oso Pass in Corpus Christi Bay.	This is a site which will incorporate the impacts of the multiple discharges into Oso Creek and Oso Bay.
7	Naval Air Station effluent outfall.	This is a combined municipal/industrial outfall from the operations at the Naval Air Station.
8	Naval Air Station boat basin breakwater.	This is a site where high levels of mercury were detected during the BEG (1983) sediment survey.
9	Oso Wastewater Treatment Plant outfall.	This is one of the largest municipal outfalls which is discharged into a marsh that serves as a refuge for waterfowl.
10	Shamrock Island	This is a site that had the highest mercury levels in a recent sediment survey conducted by the USFWS (Barrera et al., 1996).
11	La Quinta channel south (B in Martin and Montagna, 1995)	This is a site adjacent to industrial activity and dredging operations.
12	La Quinta channel north (A in Martin and Montagna, 1995)	This is a site adjacent to industrial activity and dredging operations.
13	Open bay spoil island mitigation site near the JFK Bridge.	This is a mitigation site near the GIWW where sediments had been placed and sea grass transplanted approximately one-year prior to sampling.

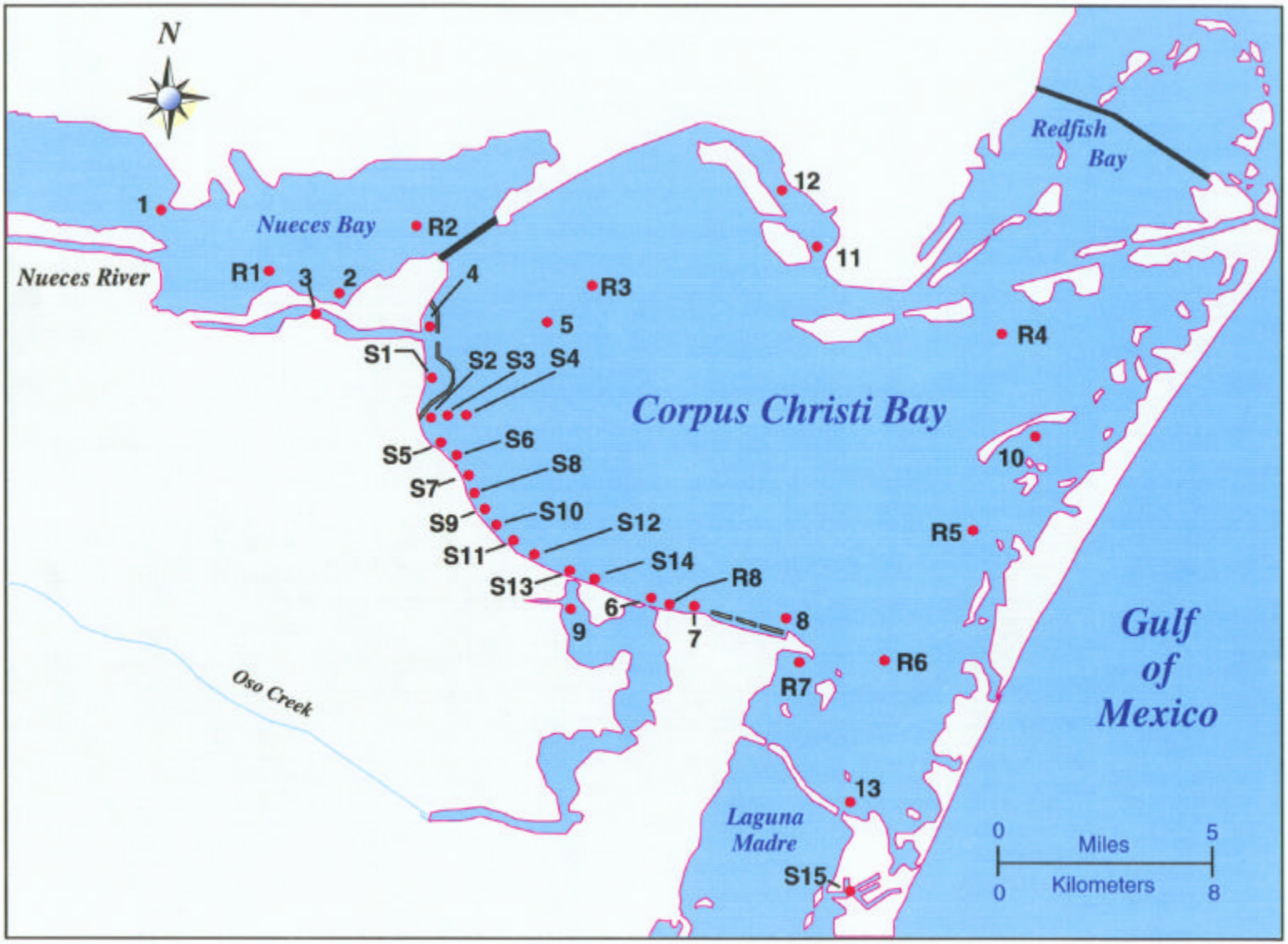


Figure 1. Location of sampling sites in the Corpus Christi Bay National Estuary Program Study (CCBNEP) area.

Hydrography

Hydrographic measurements were made at each site with a multi parameter instrument (Hydrolab Surveyor II). The sonde unit is lowered to just beneath the surface and to the bottom for surface and bottom water measurements. The instrument allows us to collect a variety of water quality parameters rapidly. The following parameters are read from the digital display unit (accuracy and units): temperature (± 0.15 C), pH (± 0.1 units), dissolved oxygen (mg/l ± 0.2), specific conductivity (± 0.015 - 1.5 mmhos/cm depending on range), redox potential (± 0.05 mV), depth (± 1 m), and salinity (ppt). Salinity was automatically corrected to 25 C.

Chemical Analyses

The subsamples for chemical analyses were shipped on dry ice to the Geochemical and Environmental Research Group (GERG) in College Station, Texas with chain-of-custody forms for analysis. Chemical analysis included a suite of trace metals (SOP- ST02), polycyclic aromatic hydrocarbons (PAHs, SOP-9406), pesticides (SOP-9302), and polychlorinated biphenyls (PCBs) (Kennicutt et al., 1994). Additional ancillary parameters which include % moisture, grain size and total organic carbon (TOC) were also analyzed. Details for these analyses can be found in the SOPs located in the Quality Assurance Project Plan (QAPP; Carr et al., 1996c).

Toxicity Testing

Solid-phase test with amphipod Ampelisca abdita

Test sediments were press-sieved through a 1.0 mm mesh stainless steel screen and homogenized. A total of 200 mL of sediments were added to each 1 liter glass jar and the jars were filled with approximately 600 mL of seawater. All tests were conducted using standardized ASTM protocols for estuarine and marine amphipods (ASTM, 1992; SOP F10.15). Five replicates of each sample were tested for 10 days. Test chambers were aerated and lighted continuously. All tests and control samples were tested simultaneously. Two control sediments were tested: (1) sediment collected from the amphipod collection site in San Francisco Bay and (2) sediment from our local control site in Redfish Bay which is far from any known contaminant sources and has been used as a control site for numerous toxicity studies over the past seven years.

Twenty subadult amphipods were placed in each jar and the tests were performed at 20°C. Each jar was checked daily for dead or moribund animals. After 10 days, the sediments were sieved through a 0.5 mm mesh stainless steel screen to recover the test animals. Material retained on the screen was preserved in 5% buffered formalin with rose bengal stain, and sorted under a stereo microscope. The number of survivors was recorded for each replicate. A 96-hour reference toxicant test with sodium dodecyl sulfate (SDS) without sediment was also conducted to provide a measure of the viability of the amphipods. The data were analyzed by ANOVA and Dunnett's t-test to determine significant differences between the treatment and control samples.

Survival and growth test with the mysid Mysidopsis bahia

Subsamples of the composite sediment samples were stored refrigerated and shipped on October 28, 1997 with blue ice by overnight express mail to the U.S. Environmental Protection Agency, Environmental Research Laboratory in Gulf Breeze, Florida where they were held refrigerated until the tests were commenced. Mysids (*Mysidopsis bahia*) were exposed under static conditions for 10 days in covered 600 ml vessels containing 1 cm depth test sediment and 300 ml of overlying clean 20 $^{o}/_{oo}$ salinity seawater (see SOP EPA-1 in QAPP). Eight replicate vessels were used for each sample sediment and the control sediment. Due to the number of sediments to be tested and the limited number of test organisms available, sediments were divided into 5 groups for testing. The first test series was commenced on November 1, 1997 and the last series was commenced on November 15. Each test group contained a set of control sediment replicates (8). Each test vessel was continuously aerated and daily, one replicate of each treatment, chosen randomly, was monitored for salinity, pH, dissolved oxygen and temperature. Test organisms in each test vessel were fed once daily at a rate of 40 (day 1-3) or 60 (day 4-10) *Artemia* nauplii/mysid/day.

At the termination of the 10-day test, the number of animals surviving in each replicate was recorded. The survivors from each replicate were washed with deionized water, placed in a tared weigh boat and then dried in an oven. Dry weights were measured and the average weight per treatment used as a measure of growth during the test. The data were analyzed by ANOVA and Dunnett's t-test to determine significant differences between the treatment and control samples for growth and survival.

Sea urchin porewater toxicity tests

The pore water was extracted from the sediments and tested for toxicity with the sea urchin (*Arbacia punctulata*) fertilization and embryological development tests. Sediments were held at 4°C and the pore water extracted within two days of the date of collection. Pore water was extracted using a pneumatic extraction method (Carr and Chapman, 1995). The pore water was frozen immediately after extraction until the day before toxicity tests commenced. The salinity of the samples was adjusted, if necessary, to 30±1 $^{o}/_{oo}$ by the addition of hypersaline brine, stored refrigerated overnight, and adjusted to 20°C prior to testing. The water quality of porewater samples (dissolved oxygen, pH, temperature, sulfide, and ammonia) was measured before the toxicity tests were performed. The tests were performed with water-quality adjusted pore water (100%), and with 50% and 25% dilutions of full strength for each sample for a total of 108 samples. Samples were diluted with 30 filtered (0.45 m) seawater from the toxicity testing laboratory at the University of Texas, Marine Science Institute, Port Aransas, Texas. Five replicates were tested for each sample from each site. Reference toxicity (positive control) tests with SDS were run with each series of tests to assess the viability of the gametes.

The tests were conducted with gametes of the sea urchin, *Arbacia punctulata*, following the methods of Carr et al. (Carr and Chapman, 1992; 1995; Carr et al. 1996a; 1996b; see SOPs F10.6 and F10.7). Pore water from a reference area in Redfish Bay, Texas, previously documented to be

nontoxic, was tested with each batch and used as a negative control. Adult male and female urchins were stimulated to spawn with a mild electric shock and the gametes were collected separately. Prior to each series of tests, a pretest was conducted to determine the optimum sperm/egg ratio for maximizing the sensitivity of the test. The fertilization test involves exposing the sperm in 5 mL of the test solution for 30 min., followed by the addition of approximately 2,000 eggs. After an additional 30 min. incubation period, the test was terminated by the addition of formalin. An aliquot of the egg suspension was examined under a compound microscope to determine the presence or absence of a fertilization membrane surrounding the egg, and percent fertilization was recorded for each replicate. In the embryological development test, the embryos are allowed to develop for 48 hr. before the test is terminated and the percentage of normally developing embryos determined.

For both the fertilization and embryological development tests, statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed *t*-test (which controls the experiment wise error rate) on the arcsine square root transformed data with the aid of SAS (SAS, 1991). The trimmed Spearman-Karber method (Hamilton et al., 1977) with Abbott's correction (Morgan, 1992) was used to calculate EC_{50} (50% effective concentration) values for dilution series tests. Prior to statistical analyses, the transformed data sets were screened for outliers (SAS, 1992). Outliers were detected by comparing the studentized residuals to a critical value from a *t*-distribution chosen using a Bonferroni-type adjustment. The adjustment is based on the number of observations, *n*, so that the overall probability of a type I error is at most 5%. The critical value, *cv*, is given by the following equation: $cv = t(df_{Error}, .05/(2 \times n))$. After omitting outliers but prior to further analyses, the transformed data sets were tested for normality and for homogeneity of variance using SAS/LAB® Software (SAS, 1992). Several treatments in the fertilization test and the embryological development test with means of zero or very low numbers were found to violate the assumption of normal distribution for our test. However, differences between the means of these treatments and the controls were so great as to be considered statistically significant despite the violation of this assumption.

A second criterion was also used to compare test means to reference means. The detectable significance criteria was developed to determine the 95% confidence value based on power analysis of all similar tests performed by our laboratory (Carr and Biedenbach, 1998). This value is the minimum significant difference that is necessary to accurately detect a difference from the reference (=0.05). The minimum significant difference value for the sea urchin fertilization assay at = 0.05 is 15.5. At = 0.01, the minimum significant difference value is 19. For the sea urchin embryological development assay, the minimum significant difference values are 16.4 and 20.6 for = 0.05 and = 0.01, respectively.

Benthic Infaunal Communities

At each site, five replicate sediment samples were taken using a 6.72 cm diameter plastic core tube covering an area of 35.4 cm^2 (Montagna and Kalke, 1992). Samples were divided into 0-3 cm and 3-10 cm depth sections to examine vertical distribution of macrofauna. Samples were preserved with 10% formalin solution in the field. In the laboratory, animals were extracted using a 0.5 mm

sieve, and removed by hand sorting. The retained organisms were identified to the lowest possible taxa (generally species) and counted. Biomass was measured by combining the organisms into the following higher taxonomic groups: Crustacea, Mollusca, Polychaeta, Nemertinea, Ophiuroidea, and Others, which included all other rare taxa. Samples were placed on a tared aluminum pan, dried at 55^{o}C for 24 hours, and weighed to the nearest 0.01 mg. All carbonate shells from the mollusks were removed with 1 M hydrochloric acid before weighing.

Species diversity was calculated by replicate and by pooling all five replicate cores for each site. Diversity is calculated using Hill's diversity number one (N1) (Hill, 1973). It is a measure of the effective number of species in a sample, and indicates the number of abundant species (Ludwig and Reynolds, 1988). It is calculated as the exponentiated form of the Shannon diversity index:

$$N1 = {}_{e}H' \qquad (1)$$

As diversity decreases N1 will tend toward 1. The Shannon index is the average uncertainty per species in an infinite community made up of species with known proportional abundances (Shannon and Weaver, 1949; Hutcheson, 1970). The Shannon index is calculated by:

$$H' = \sum_{i=1}^{S} [(n_i/n) \ln (n_i/n)] \qquad (2)$$

Where n_i is the number of individuals belonging to the *i*th of *S* species in the sample and *n* is the total number of individuals in the sample. Hill's N1 was used in most analyses because it is easier to interpret than most diversity indices.

Evenness is an index that expresses that all species in a sample are equally abundant. Evenness is a component of diversity. Two evenness indices, E1 and E5, have been calculated. E1 is probably the most common, it is the familiar *J'* of Pielou (1975). It expresses *H'* relative to the maximum value of *H'*:

$$E1 = \frac{H'}{\ln(S)} = \frac{\ln(N1)}{\ln(N0)} \qquad (4)$$

E1 is sensitive to species richness. E5 is an index that is not sensitive to species richness. E5 is a modified Hill's ratio (Alatalo, 1981):

$$E5 = \frac{(1/\lambda)-1}{N1-1} \quad \text{where, } \lambda = \sum_{i=1}^{S} \frac{n_i(n_i-1)}{n(n-1)} \qquad (5)$$

λ is the Simpson (1949) diversity index. E5 approaches zero as a single species becomes more and more dominant.

A benthic index of biotic integrity (BIBI) was also calculated from 10 metrics. High values of each metric indicate high environmental quality as predicted by current ecological understanding (i.e., succession theory). The theory states that good sediment quality is defined by a deeply distributed and highly diverse community containing equilibrium species (Rhoads et al., 1978; Pearson and Rosenberg, 1978). Communities with high biomass, diversity and abundance in the deeper sediment section (3-10 cm) indicate high quality. In contrast, communities with high abundance, low diversity, and limited to surface sediment (0-3 cm sections) are considered disturbed. At least two previous attempts have been made to create benthic indices (Engle et al., 1994; Weisberg et al, 1997).

Engle et al. (1994) examined 24 candidate measures and determined three were sufficient to discriminate between degraded and reference sites among 16 Gulf of Mexico estuaries. These metrics were: diversity (H'), percent total abundance as tubificid oligochaetes, and percent of total abundance as bivalves. Multivariate discriminant analysis was used to calculate the BIBI. The data was adjusted for salinity habitat, but sediment variation was not a significant factor. Sites were classified as undegraded *a priori* if they met the following three criteria: 1) minimum dissolved oxygen > 3.0 mg l^{-1} over a 24-h period, 2) sediment concentrations for any contaminant did not exceed an ER-M value (Long et al., 1995) and 3) percent survival for *Ampelisca abdita* or *Mysidopsis bahia* in acute sediment toxicity tests were indistinguishable from controls.

Weisberg et al. (1997) examined 17 candidate measures and determined 11 were efficient at distinguishing degraded from reference sites in Chesapeake Bay. A non-parametric ranking approach was used. The BIBI was calculated as the sum of the ranks. Metrics were scored as 1, 3, or 5 based upon whether its value at a site deviates from an *a priori* reference. The reference values were calculated for seven different habitat classes, which included salinity and sediment classes. Sites were classified as references if they met the following five criteria: 1) dissolved oxygen measurements always > 2 ppm, 2) sediment concentrations for any contaminant did not exceed any ER-M values, and 3) percent survival for *Ampelisca abdita* was no less than 80% of controls, 4) were not in highly developed watersheds or contained point source discharges, and 5) TOC did not exceed 2%.

The BIBI calculated for the present study combines both approaches described above, but mainly modifies the Weisberg et al. (1997) approach. Tubificids are rare in the CCBNEP study area, and mollusks were rare in the study area at the time of sampling. Therefore, the metrics and ranking approach of Weisberg et al. (1997) were used. Only biomass of pollution indicative taxa was not used, because biomass was not measured at the species level, so 10 metrics were calculated (Table 2).

Two metrics, percent of species that are pollution indicators and sensitive require a list of species that are so identified. These species are designated by Weisberg et al. (1997) for Chesapeake Bay. Of these species, 14 were found in the present study (Table 3). Two substitutions were employed. We found an unidentified capitellid that we listed as a pollution-indicator. Trophic guild designations are also used to calculate BIBI variables (Table 2). We used designations for the feeding guilds based on those listed in Ranasinghe et al. (1994).

Table 2. Variable names and definitions for BIBI analyses used by Weisberg et al. (1997).

Variable Name	Definition
Biomass	Total Biomass
Density	Total Density
H'	Shannon-Weiner diversity index
%PolInd.	Percent of species **not** pollution indicators (i.e., 1 - %polInd.)
%PolSen.	Percent of species that are pollution sensitive
%Bm>3	Percent of biomass in deeper (3-10 cm) section
%Den>3	Percent of density in deeper (3-10 cm) section
%Sp>3	Percent of species in deeper (3-10 cm) section
%CarnOmn	Percent of species that carnivores or omnivores
%DeepDep	Percent of species that are deep (subsurface) deposit feeders

Table 3. Taxa defined as pollution-indicative or pollution-sensitive by Weisberg et al. (1997).

Phylum	Pollution-Indicative	Pollution-Sensitive
Mollusca	*Mulinia lateralis*	*Tagelus divisus*
Polychaeta	*Paraprionospio pinnata* *Streblospio benedicti* *Capitella capitata* Capitellidae (unidentified)	*Glycinde solitaria* *Diopatra cuprea* *Spiophanes bombyx* *Spiochaetopterus costarum* *Mediomastus ambiseta* *Clymenella torquata* *Asychis elongata*
Crustacea		*Listriella clymenellae*

All statistical analyses were performed using SAS software (SAS 1991). All data were log transformed prior to analysis. A one-way ANOVA was used to test for differences in macrofauna abundance biomass, and diversity among sites. Tukey multiple comparison procedures were used to find *a posteriori* differences among sample means. Community structure of macrofauna was analyzed by principal components analysis (PCA) on log-transformed data. Further details on the multivariate techniques are provided in a latter section (pg. 19).

Sediment Microbiological Indicators

Surficial (2-4 cm) sediment samples (3 replicates/site) were taken from the center of 4 cores for total coliform and fecal coliform analyses. An attempt was made to also measure *Escherichia coli*, which is a member of the fecal coliform group and indicates fecal contamination, but due to problems with the media used for this assay, no useable results were obtained. A brief description of the standardized procedures for total and fecal coliform which were used in this study (APHA, AWWA and WPCF, 1995; Fujioka, 1997) follows:

Standard total coliform fermentation technique

For the presumptive phase, lauryl tryptose broth (LTB) was used in this multiple-tube test. The medium was made per instructions on the container. Six ml of medium was dispensed in fermentation tubes with an inverted Durham tube and covered with a heat resistant plastic cap. This amount of medium covered the Durham tube half to two-thirds after sterilization. The tubes were sterilized for 15 minutes.

The tubes were arranged with 5 tubes per dilution, a total of 25 tubes per core (75/site). The tubes were inoculated with the appropriate dilution and mixed with gentle agitation. The inoculated tubes were incubated at 35 ± 0.5 C. After 24 ± 2 h, each tube was swirled and examined for growth, gas, and acidic reaction (shades of yellow). If no gas or acidic reaction was evident, the tubes were reincubated and reexamined at the end of 48 ± 3 h. The presence or absence of growth, gas, and acid production was recorded within the 48 ± 3 h. The production of gas or an acidic reaction constitutes a positive presumptive reaction. Positive tubes were submitted to the confirmed phase.

For the confirmed phase, brilliant green lactose bile [BG] broth was used with inverted Durham tubes. The medium was made per instructions on the container. Six ml of medium was dispensed in fermentation tubes with inverted Durham tubes and covered with caps. This is sufficient medium to cover the inverted tube half to two-thirds after sterilization. The tubes were sterilized for 15 minutes and pH checked (7.2 ± 0.2). All presumptive tubes showing growth, any amount of gas, or acidic reaction within 48 ± 3 h of incubation were submitted to the confirmed phase. The presumptive tubes were gently shaken and rotated. Using a sterile loop, one or more loopfuls of culture was transferred to a fermentation tube containing brilliant green bile broth. The process was repeated for all positive presumptive tubes. The inoculated BG broth tubes were incubated at 35 ± 0.5 C and the formation of gas in any amount in the inverted vial of brilliant green lactose bile broth

fermentation tube within 48 ± 3 h constitutes a positive confirmed phase. The Most Probable Number (MPN) value was calculated from the number of positive brilliant green lactose bile tubes.

For the completed phase, positive EC broths (see below - for fecal coliforms) are considered a positive completed test response. As a QC measure, 10% of the positive confirmed samples were inoculated onto LES-Endo agar, typical colonies transferred onto a nutrient agar slant and a single strength lauryl tryptose broth fermentation tube. Bacteria from the slant were Gram stained. Formation of gas in the fermentation tube within 48 hr and demonstration of gram negative, nonspore forming rod shaped bacteria constituted a positive result for the completed test.

Fecal coliform procedure

The fecal coliform procedure is used to distinguish those total coliform organisms that are fecal coliforms. EC medium is used. The medium was made per instructions on the container. Six ml of medium was dispensed into fermentation tubes with inverted Durham tubes and covered with caps. This was sufficient medium to cover the inverted tubes half to two-thirds after sterilization. Tubes were sterilized for 15 minutes.

All presumptive fermentation tubes from the total coliform procedure that were positive within 48 ± 3 h of incubation were submitted to the fecal coliform test. Presumptive tubes were gently rotated, then, using a sterile loop, growth was transferred from the presumptive tubes to the EC medium. This inoculation procedure was simultaneous with the brilliant green lactose bile broth inoculation for the confirmed phase of the total coliform procedure. Incubation of the inoculated EC tubes was in a water bath at 44.5 ± 0.2 C for 24 ± 2 h. All EC tubes were placed in a water bath within 30 minutes after inoculation. Water level was maintained to keep the medium immersed. Gas production with growth within 24 ± 2 h or less was considered a positive fecal coliform reaction.

Estimation of bacterial density

The precision of the fermentation tube test is rather low unless a large number of sample portions is examined. Great caution has to be exercised in interpreting the sanitary significance of coliform results. As recommended by Fujioka (1997) the five tube test was used as the monitoring assay. It should be noted that for regulatory purposes (e.g., closure of beaches, etc.) a ten tube assay should be used. Coliform density is reported as the MPN (most probable number) per 100 ml.

Multivariate Analysis

Multiple variables were measured at each site and for each sample taken at a site during this study. A common problem in multivariate data sets is that the variables may covary. Another problem is encountered when employing several univariate tests on such a data set, because this violates assumptions of independence. A multivariate analysis is required to maintain experiment-wide error rates at the 0.05 level. Principal components analysis (PCA) is a multivariate method to transform the data matrix to create new variables that are 1) mutually orthogonal, which means they

are uncorrelated, and 2) extracted in order of decreasing variance. Principal components analysis is a variable reduction technique because of the decreasing variance property, which implies that much of the information (i.e., variance) of the original set of variables is concentrated in the first few principal components (PCs). The PCs can also be used as predictors in regression analysis because they are orthogonal and collinearity does not exist. All multivariate analyses were performed with the SAS FACTOR procedure (SAS, 1991) using the PC method on the covariance matrix. When performing PCA on the covariance matrix, the analysis does not treat all the variables as if they have the same variance. All count or measurement data was log transformed and percent data was arcsine transformed prior to multivariate analysis.

Results of the PCA are visualized in bivariate plots. Generally, only the first two PC factors (PC1 and PC2) are used in the plots. The results are visualized in two ways: as factor patterns and as loading scores. Each data set is simply a matrix, i.e., rows of observations versus columns of variables. The factor patterns are the PC coefficients for each variable or column. These vector patterns are used to interpret what PC1 and PC2 represent by plotting the column heading as the symbol for each point. Next, the loading scores for each observation are plotted using the site name as the symbol for each point. The plot of the loading scores allows us to visualize the relationships or correlation among the sites.

There were basically three types of data collected during this study: chemical contaminants in sediments, toxicity as determined in experimental exposures, and ecological characteristics of the sediments as revealed by benthic invertebrate communities. Each of these data sets are multivariate. The chemistry data set was the largest with 11 trace metals, 44 polynuclear aromatic hydrocarbons (PAHs), 29 pesticides, and 61 polychlorinated biphenyls (PCBs). These variables were first reduced by summing the constituents of families of compounds into five categories: National Status and Trends PAHs (NSTPAHs), chlordanes, DDTs, HCHs and PCBs. In addition, sediment grain size and total organic carbon (TOC) were also included in the chemistry data set. There were five separate toxicity tests for three species. Finally, there were 10 metrics used to quantify the status of the benthic community which included biomass, density, Shannon-Wiener diversity index, percent of pollution indicator species, percent of pollution sensitive species, percent of biomass in deeper section (3-10 cm), percent of density in deeper section (3-10 cm), percent of species in deeper section (3-10 cm), percent of species that are carnivores or omnivores, and percent of species that are deep (3-10 cm) deposit feeders The PCA was performed on the chemistry, toxicity, and ecological data.

Sediment Quality Triad Analysis

The SQT concept is designed to integrate the biological and ecological responses to the environmental setting as characterized by the quantity of sediment contaminants and the natural background. For example, it is known that contaminants are often associated with high levels of TOC and that infauna can be regulated by different salinity and sediment regimes (Mannino and Montagna, 1997). Therefore, adjusting response by these variables is necessary to determine the effects of the contaminants alone. The statistical approach taken here follows Green et al. (1993)

and Green and Montagna (1996). The approach is based on the concept that the experiment wide error rate must be controlled, and that the easiest way to do this is to reduce the number of variables in the analysis. Therefore, a series of multivariate analyses were performed to reduce the data set to just three variables based on the chemical, toxicological, and ecological data. The chemical data were reduced to two PCs labeled ChemPC1 and ChemPC2. The prefix "Chem" is used to distinguish this result from the PC performed on other data. The suffix "PC1" or "PC2" is used to denote the first and second extracted PC. Using the same convention, the toxicity data (5 variables) was reduced to ToxPC1 and ToxPC2, and the benthic data (10 variables) was reduced to EcolPC1 and EcolPC2. The final step is to perform regression and correlation analysis on the PCs of the three types of data.

The chemical data set is quite complex consisting of 145 variables in four major classes of compounds. A PCA can be influenced by the number of variables in a data set, therefore it was necessary to reduce the number of variables that went into the chemistry PCA (Kennicutt et al., 1996). The first analysis was performed to choose representative metals. The second analysis was performed to choose representative hydrocarbons. The final chemistry PCA was performed on selected chemical and other abiotic variables that describe the contaminant and hydrographic background at each site.

III. RESULTS

Sediment Sample Collection and Storage

Sediment sampling was conducted between October 24th to 28th, 1997 for the 36 sites in the study area. Surface and bottom water salinities ranged from 40.1 to 28.0 $^{o}/_{oo}$ and temperatures ranged from 27.4 to 22.1 C among the sampling sites (Appendix 1). The maximum water depth sampled was 4.75 m. The GPS coordinates for the sampling sites are shown in Appendix 1. The reference sediment from Redfish Bay (LAR) was collected on October 19th, 1997. Pore water was extracted from the samples within 48 hours of collection and the sediments for the solid-phase amphipod test were held at 4 C until they were tested. The sediments for the mysid tests were shipped on blue-ice to the EPA laboratory in Gulf Breeze, Florida by overnight express mail on October 29th. Samples for grain size analysis were kept refrigerated but not frozen. All other samples for chemical analyses were held frozen and shipped frozen on dry ice to GERG in College Station, Texas for analysis. Benthic samples were collected separately and preserved with 10% buffered formalin at the time of collection. The samples were then sieved to remove the organisms in the laboratory at UTMSI and the retained material was preserved in methanol.

Chemical and Physical Analyses

The organic carbon content of the sediments sampled in this study ranged from 0.03 to 1.86% with the majority of samples having TOC values <0.5% (Appendix 2). The majority of samples were comprised primarily of sand, especially the storm water outfall sites (Appendix 2).

Site S1 located in the Corpus Christi marina near a storm water outfall had significantly higher concentrations than any of the other sites in this study for a number of trace metals including arsenic, lead, aluminum, copper, nickel, zinc, cadmium, and chromium (Appendix 3). The highest concentration of PAHs was observed at the storm water outfall site S9 with a total PAH concentration of 59,671 g/kg (Appendix 4). This concentration was almost an order of magnitude higher than the next highest PAH concentrations which were observed at sites S1, S2 and site 8 near the Naval Air Station. The majority of the PAHs at these sites were high molecular weight PAHs which is indicative of chronic inputs and not recent spills. Sites S9, 8, S2, and S1 had the highest concentrations of DDTs as well (Appendix 5). The highest concentrations of chlordanes were also observed at the storm water discharge sites S9, S1, S8, and S2 (Appendix 6). The concentration of other pesticides was below detection limits at most sites, the exception being HCHs at S1 and S4 and Dieldrin at S9 (Appendix 7). The highest concentration of total PCBs was observed at the newest storm water outfall S14 located opposite Texas A&M University and may be indicative of the new plumbing and construction activities occurring adjacent to this site. Elevated PCB concentrations were also observed at S1 and S9 (Appendix 8).

Sediment quality guidelines have recently been developed for Florida coastal waters (MacDonald et al., 1996). Probable effects level (PEL) values, which are the concentration of a chemical above which biological effects are likely to occur, have been calculated for 34 chemicals or classes of chemicals. For each site, the bulk sediment chemistry concentration for each chemical or class of chemicals was divided by its PEL value and the resulting quotients were summed, divided by 31 (the number of PEL values used) and multiplied by 100 to calculate a PEL index (Carr et al., 1996b; Figure 2). The highest PEL index was observed at the storm drain site S9, primarily due to the high concentrations of PAHs. The second highest PEL index occurred at the Corpus Christi Bay marina storm drain site S1 due to high concentrations of metals and PAHs.

Detection limits for the metals, pesticides, PAHs and PCBs are shown in Appendices 9 and 10. Appendix 11 gives the sample dry weights used in the different analyses. Percent recovery data for the different analyses are shown in Appendices 12-14. QA data for metals, TOC, and grain size analyses are provided in Appendix 15. QA data for PAHs are shown in Appendix 16.

Toxicity Testing

Solid-phase test with amphipod Ampelisca abdita

Water quality parameters were within acceptable limits at both the initiation and termination of the 10-day solid-phase test with *Ampelisca abdita* (Appendices 17 and 18). Statistically significant toxicity was observed at only one site (S8) of the 36 sites tested (Table 4, Figure 3). This site was only marginally significant, however, and one of the five replicates had considerably more toxicity than the other four replicates but was not eliminated in the outlier test.

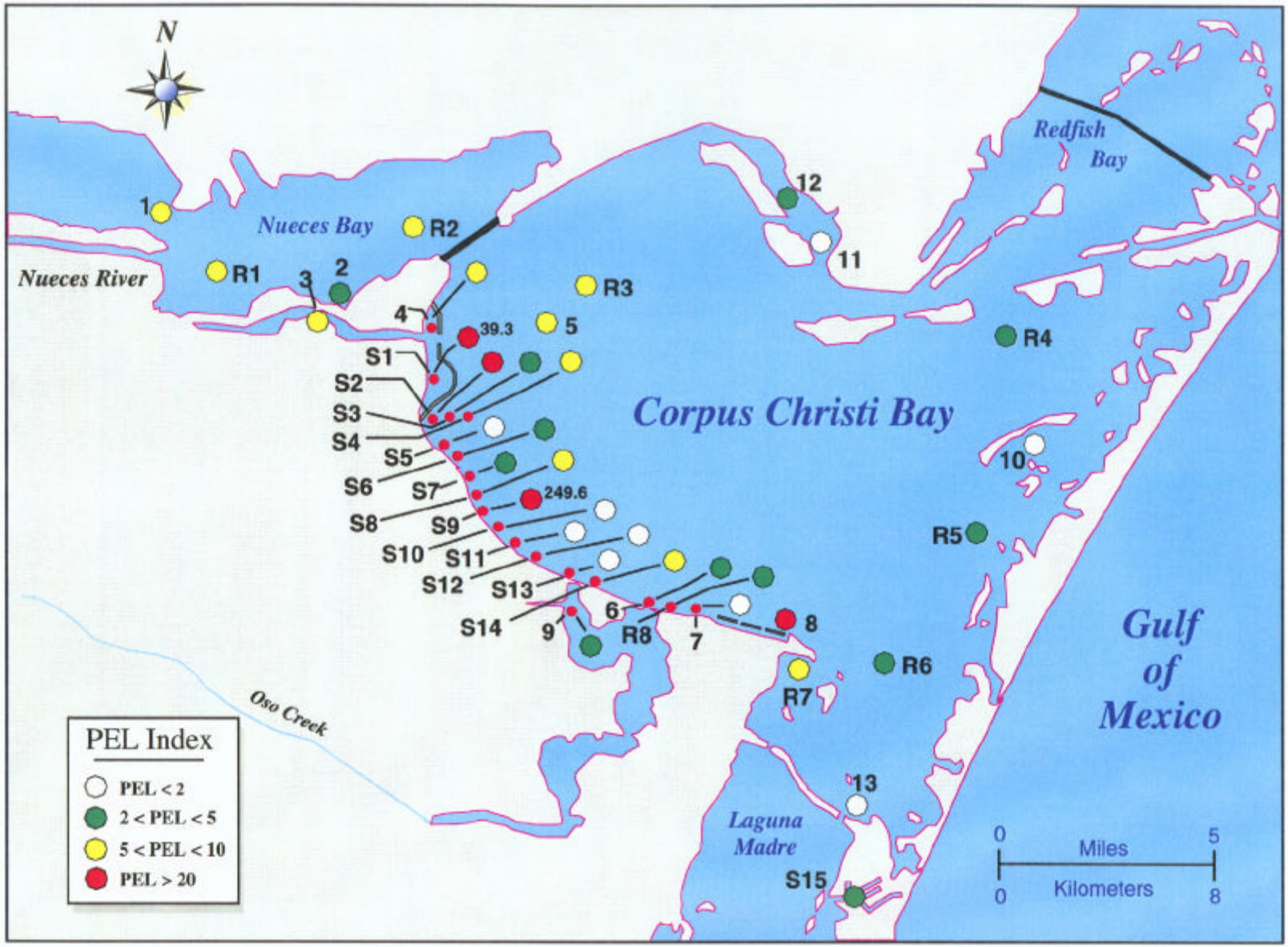


Figure 2. Probable effects level (PEL) indices for key contaminants for sites in the CCBNEP study area.

Table 4. Survival of *Ampelisca abdita* (amphipod) in 10-day solid-phase toxicity test with Corpus Christi Bay National Estuary Program sediments. Asterisk denotes significant difference between test and reference site (Dunnett's *t*-test, * 0.05).

Site [1]	% Survival					Mean±SD	& of REF [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
REF [2]	100	95	80	95	90	92.0 ± 7.6	100
1	80	85	95	85	80	85.0 ± 6.1	92
2	95	95	90	95	90	93.0 ± 2.7	101
3	95	70	90	80	90	85.0 ± 10.0	92
4	95	75	85	95	100	90.0 ± 10.0	98
5	100	90	85	90	90	91.0 ± 5.5	99
6	95	95	90	95	90	93.0 ± 2.7	101
7	95	85	85	75	85	85.0 ± 7.1	92
8	80	100	80	90	100	90.0 ± 10.0	98
9	95	100	85	90	95	93.0 ± 5.7	101
10	100	80	95	100	85	92.0 ± 9.1	100
11	100	90	80	90	90	90.0 ± 7.1	98
12	90	85	95	95	90	91.0 ± 4.2	99
13	95	95	95	85	85	91.0 5.5.1	99
S1	95	100	95	100	90	96.0 ± 4.2	104
S2	75	85	75	100	100	87.0 ± 12.6	95
S3	95	85	75	100	65	84.0 ± 14.3	91
S4	85	85	80	60	95	81.0 ± 12.9	88
S5	100	55	70	70	90	77.0 ± 17.9	84
S6	100	55	70	80	80	77.0 ± 16.4	84
S7	85	85	80	90	75	83.0 ± 5.7	90

Table 4. (continued)

Site [1]	% Survival					Mean±SD	% of REF [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
S8	70	70	80	85	40	69.0 ± 17.5*	75
S9	100	95	90	95	100	96.0 ± 4.2	104
S10	80	70	80	85	65	76.0 ± 8.2	83
S11	95	95	100	90	75	91.0 ± 9.6	99
S12	80	85	95	85	75	84.0 ± 7.4	91
S13	65	85	85	75	100	82.0 ± 13.0	89
S14	85	80	90	65	70	78.0 ± 10.4	85
S15	90	95	90	90	90	91.0 ± 2.2	99
R1	75	80	85	100	95	87.0 ± 10.4	95
R2	100	95	85	75	90	89.0 ± 9.6	97
R3	80	85	80	95	75	83.0 ± 7.6	90
R4	75	80	80	95	90	84.0 ± 8.2	91
R5	100	100	95	80	95	94.0 ± 8.2	102
R6	100	100	95	95	70	92.0 ± 12.6	100
R7	95	95	90	90	100	94.0 ± 4.2	102
R8	100	95	95	85	100	95.0 ± 6.2	103

[1] Site refers to sample ID. (Numbers only, S's and R's refer to sites of concern, stormwater discharge and historical reference sites, respectively.)

[2] Reference sediment collected in Redfish Bay, Texas.

Survival and growth test with the mysid Mysidopsis bahia

Water quality parameters where within acceptable limits for the mysid tests (Appendices 19 and 20). Like the amphipod test, no significant toxicity was observed at any of the 36 sites (Table 5). Significant growth reduction (p 0.05) was observed at 14 of the 36 sites and significant growth enhancement (p 0.05) was observed at 13 sites (Table 6, Figure 3). Eight of the 15 storm water drain site sediments produced an enhanced growth response. Six of the eight "reference" sites produced a reduced growth response. This growth end point has not been used routinely in sediment toxicity tests with this species and it is not known whether the growth response is confounded by the nutritional quality or grain size of the sediments which may mask any contaminant effects (Gerri Cripe, USEPA, personal communication).

Sea urchin porewater toxicity tests

Water quality parameters for the sea urchin porewater tests are shown in Appendix 21. Significant toxicity was observed at 7 and 18 of the sites for the fertilization and embryological development tests, respectively (Tables 7 and 8; Figure 3). Six of the 7 sites which were toxic in the fertilizations test were also toxic in the embryological development test. The most toxic sites for both tests combined were S1 and S15. No toxicity was observed for the eight storm water outfall sites S3, S4, and S9-S14. The EC_{50} values ranged from <25% to >100% of the water quality adjusted porewater sample for both the fertilization and embryological development tests (Table 9).

The lowest observed effect concentrations (LOECs) for the fertilization and embryological development test in water only exposure tests are 800 g/L and 90 g/L unionized ammonia (UAN), respectively. Sixteen samples exceeded the LOEC of 90 g/L and 12 of these 16 were toxic in the 100% porewater embryological development test. Four of these 12 samples were also significantly toxic in the fertilization test with UAN concentrations well below the LOEC for the fertilization test. An additional four of the 12 toxic samples were also toxic at lower dilutions in which the UAN concentration was below the LOEC. Therefore, UAN could have been a major contributing factor in the toxicity observed at these four sites (3, 5, 9 and R3) but these elevated UAN concentrations are likely the result of anthropogenic influences.

Benthic Infaunal Communities

Benthic infaunal samples were taken at 36 sites and organisms were identified, enumerated and weighed (Figure 4; see Appendix 22 for species list by site). No organisms were found at two sites, S1 and S15 in all five replicates. S1 was the site with the highest contaminant loadings and S15 had near anoxic conditions. These sites will not be dealt with further in the following discussion.

Table 5. Survival of *Mysidopsis bahia* in 10-day solid-phase toxicity test with Corpus Christi Bay National Estuary Program sediments. Samples were evaluated in five separate tests.

Site [1]	% Survival								Mean±SD	% of Control [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8		
CTL[2]-A	100	100	80	100	100	100	100	100	97.5 ± 7.1	100
CTL[2]-B	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
CTL[2]-C	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
CTL[2]-D	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
CTL[2]-E	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
1 [c]	60	100	100	100	100	80	100	100	92.5 ± 14.8	93
2 [c]	100	100	80	100	100	100	80	100	95.0 ± 9.3	95
3 [b]	100	80	60	100	80	80	80	100	85.0 ± 14.1	85
4 [c]	80	80	100	100	100	80	100	100	92.5 ± 10.4	93
5 [b]	100	80	100	100	100	100	100	100	97.5 ± 7.1	98
6 [c]	100	100	100	100	100	100	80	80	95.0 ± 9.3	95
7 [a]	100	100	100	100	100	80	100	100	97.5 ± 7.1	100
8 [a]	100	100	100	100	100	80	80	100	95.0 ± 9.3	97
9 [b]	100	100	100	80	100	80	100	100	95.0 ± 9.3	95
10 [b]	100	100	100	100	80	100	100	100	97.5 ± 7.1	98
11 [c]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
12 [d]	100	100	80	100	100	100	100	100	97.5 ± 7.1	98
13 [d]	100	100	80	100	100	80	100	100	95.0 ± 9.3	95
S1 [c]	100	100	100	100	100	80	80	100	95.0 ± 9.3	95
S2 [c]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S3 [d]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100

Table 5. (continued)

Site [1]	% Survival								Mean±SD	% of Control [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8		
S4 [e]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S5 [e]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S6 [a]	100	100	100	80	100	80	100	100	95.0 ± 9.3	97
S7 [d]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S8 [d]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S9 [c]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S10 [e]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S11 [b]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S12 [d]	80	100	100	100	80	100	100	100	95.0 ± 9.3	95
S13 [d]	100	100	100	100	100	100	100	100	100.0 ± 0.0	100
S14 [e]	60	100	80	100	100	100	100	100	92.5 ± 14.8	93
S15 [e]	100	100	80	100	80	100	100	100	95.0 ± 9.3	95
R1 [a]	100	100	80	100	100	60	70	na [3]	88.6 ± 15.7	91
R2 [c]	100	100	80	100	80	100	100	100	95.0 ± 9.3	95
R3 [d]	100	100	80	100	100	100	100	100	92.5 ± 14.8	93
R4 [e]	100	100	100	100	100	100	100	80	97.5 ± 7.1	98
R5 [e]	100	100	100	100	100	100	80	100	97.5 ± 7.1	98
R6 [e]	100	100	100	100	80	100	100	100	97.5 ± 7.1	98
R7 [a]	100	100	100	100	80	100	100	na [3]	97.5 ± 7.1	100
R8 [c]	100	100	100	100	100	80	100	100	97.5 ± 7.1	98

[1] Site refers to sample ID. (Numbers only, S's and R's refer to sites of concern, stormwater discharge and historical reference sites, respectively.)

[2] The control for each test (indicated ([a]) through ([e])) was used for statistical analysis of the respective samples. The control sediment was from Redfish Bay, Texas.

[3] Data is not available.

[a-e] Indicate tests one through five, respectively.

Table 6. Growth of *Mysidopsis bahia* in 10-day solid-phase toxicity test with Corpus Christi Bay National Estuary Program sediments. Samples were evaluated in five separate tests.

Site [1]	Weight (mg dry weight)								Mean±SD	Sig [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8		
CTL[3]-A	0.25	0.26	0.27	0.33	0.26	0.26	0.27	0.29	0.27 ± 0.02	
CTL[3]-B	0.26	0.29	0.30	0.25	0.25	0.27	0.24	0.29	0.27 ± 0.02	
CTL[3]-C	0.27	0.26	0.25	0.24	0.21	0.24	0.24	0.23	0.24 ± 0.02	
CTL[3]-D	0.21	0.22	0.19	0.23	0.24	0.24	0.22	0.25	0.22 ± 0.02	
CTL[3]-E	0.24	0.23	0.23	0.25	0.22	0.26	0.25	0.25	0.24 ± 0.01	
1 [c]	0.14	0.19	0.17	0.17	0.15	0.20	0.12	0.20	0.17 ± 0.03	--
2 [c]	0.23	0.18	0.23	0.23	0.28	0.20	0.23	0.22	0.22 ± 0.03	
3 [b]	0.17	0.16	0.24	0.19	0.19	0.21	0.19	0.18	0.19 ± 0.02	--
4 [c]	0.17	0.15	0.18	0.20	0.17	0.21	0.16	0.20	0.18 ± 0.02	--
5 [b]	0.13	0.17	0.18	0.17	0.16	0.19	0.11	0.24	0.17 ± 0.04	--
6 [c]	0.19	0.19	0.17	0.17	0.16	0.17	0.18	0.16	0.17 ± 0.01	--
7 [a]	0.37	0.37	0.35	0.38	0.35	0.38	0.39	0.40	0.37 ± 0.02	++
8 [a]	0.16	0.13	0.12	0.15	0.15	0.16	0.15	0.18	0.15 ± 0.02	--
9 [b]	0.20	0.15	0.16	0.23	0.19	0.13	0.11	0.17	0.17 ± 0.04	--
10 [b]	0.30	0.35	0.39	0.35	0.34	0.35	0.35	0.66	0.39 ± 0.11	++
11 [c]	0.33	0.32	0.33	0.38	0.35	0.33	0.31	0.33	0.34 ± 0.02	++
12 [d]	0.24	0.21	0.20	0.21	0.21	0.22	0.20	0.19	0.21 ± 0.02	
13 [d]	0.40	0.44	0.40	0.38	0.36	0.36	0.39	0.42	0.39 ± 0.02	++
S1 [c]	0.17	0.14	0.17	0.15	0.19	0.18	0.16	0.21	0.17 ± 0.02	--
S2 [c]	0.24	0.29	0.28	0.30	0.23	0.29	0.30	0.29	0.28 ± 0.03	--
S3 [d]	0.18	0.17	0.22	0.20	0.17	0.21	0.19	0.19	0.19 ± 0.02	
S4 [e]	0.14	0.13	0.16	0.19	0.17	0.19	0.18	0.27	0.18 ± 0.04	--
S5 [e]	0.28	0.27	0.26	0.29	0.32	0.34	0.33	0.28	0.30 ± 0.03	++

Table 6. (continued)

Site [1]	Weight (mg dry weight)								Mean±SD	Sig [2]
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8		
S6 [a]	0.32	0.34	0.39	0.32	0.37	0.42	0.43	0.31	0.36 ± 0.05	++
S7 [d]	0.38	0.30	0.30	0.36	0.41	0.39	0.35	0.37	0.36 ± 0.04	++
S8 [d]	0.33	0.33	0.36	0.33	0.32	0.35	0.33	0.34	0.34 ± 0.01	++
S9 [c]	0.26	0.27	0.30	0.27	0.23	0.31	0.26	0.28	0.27 ± 0.02	
S10 [e]	0.30	0.37	0.33	0.35	0.39	0.35	0.38	0.38	0.36 ± 0.03	++
S11 [b]	0.32	0.30	0.30	0.27	0.30	0.35	0.42	0.38	0.33 ± 0.05	
S12 [d]	0.26	0.28	0.28	0.31	0.20	0.31	0.30	0.27	0.28 ± 0.04	++
S13 [d]	0.35	0.30	0.29	0.33	0.30	0.32	0.30	0.34	0.32 ± 0.02	++
S14 [e]	0.46	0.45	0.57	0.42	0.43	0.47	0.50	0.46	0.47 ± 0.05	++
S15 [e]	0.14	0.18	0.12	0.17	0.22	0.15	0.19	0.15	0.16 ± 0.03	--
R1 [a]	0.14	0.12	0.13	0.15	0.14	0.14	0.13	na [4]	0.14 ± 0.01	--
R2 [c]	0.15	0.23	0.17	0.16	0.17	0.17	0.17	0.18	0.18 ± 0.02	--
R3 [d]	0.12	0.12	0.13	0.15	0.14	0.08	0.14	0.16	0.13 ± 0.02	--
R4 [e]	0.14	0.16	0.14	0.16	0.17	0.17	0.19	0.22	0.17 ± 0.03	--
R5 [e]	0.22	0.16	0.22	0.17	0.18	0.18	0.21	0.12	0.18 ± 0.03	--
R6 [e]	0.21	0.26	0.26	0.24	0.25	0.26	0.30	0.30	0.26 ± 0.03	
R7 [a]	0.14	0.13	0.13	0.08	0.14	0.14	0.16	na [4]	0.13 ± 0.02	--
R8 [c]	0.28	0.30	0.27	0.28	0.29	0.26	0.27	0.28	0.28 ± 0.01	++

[1] Site refers to sample ID. (Numbers only, S's and R's refer to sites of concern, storm water discharge and reference sites, respectively.)

[2] Significantly different from control.

[3] The control for each test (indicated ([a]) through ([e])) was used for statistical analysis of the respective samples.

[4] Data is not available.

[a-e] Indicate tests one through five, respectively.

— Indicates reduced growth compared with control (p =0.05).

[++] Indicates enhanced growth compared with control (p=0.05).

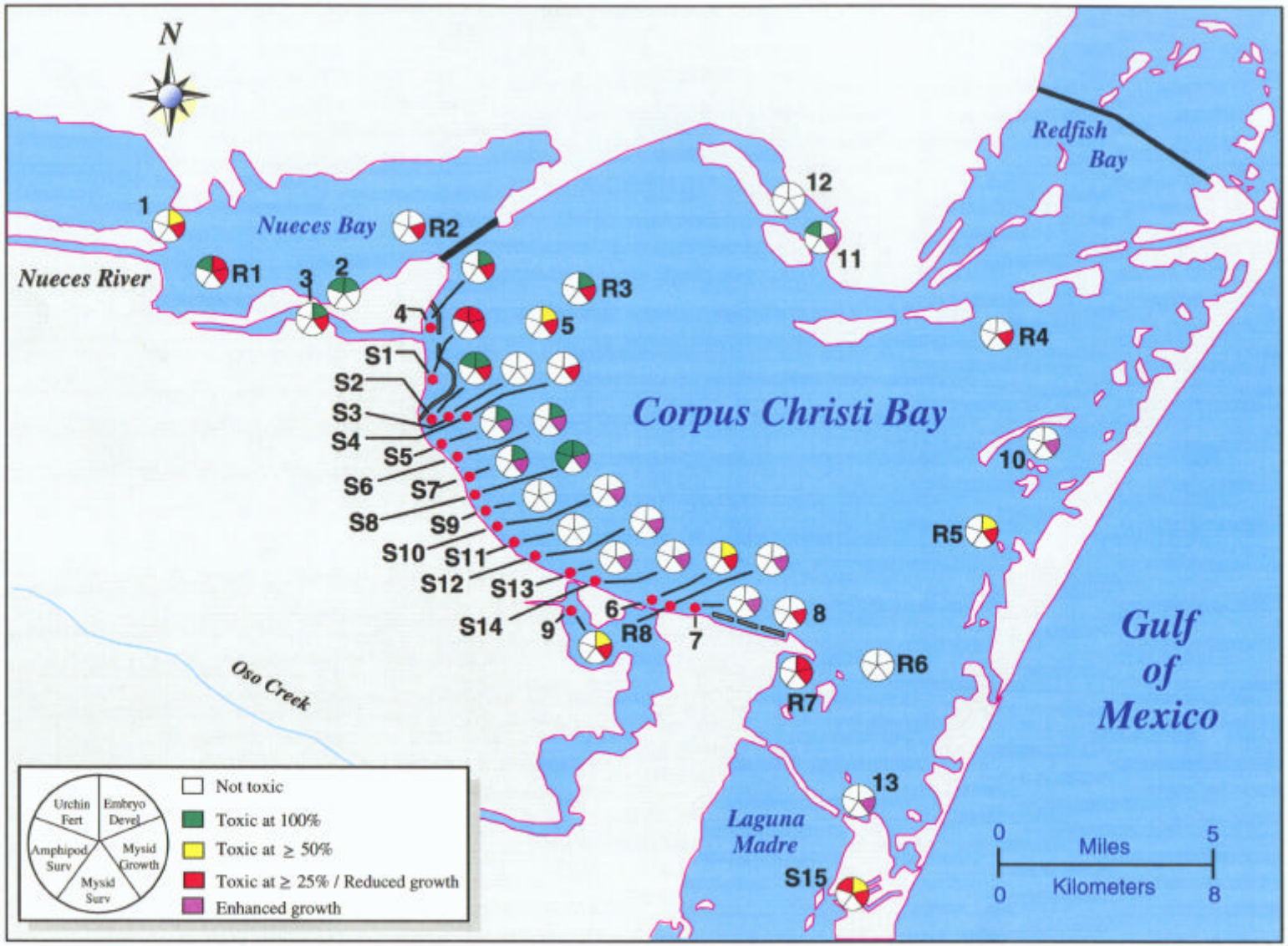


Figure 3. Results of amphipod, mysid, and sea urchin fertilization and embryological development toxicity tests for sites in the CCBNEP study area.

Table 7. Sea urchin fertilization test raw data and means for sediment porewater samples from Corpus Christi Bay National Estuary Program study. Asterisks denote significant difference between test and reference sites (Dunnett's *t*-test,* 0.05, 0.01).**

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
REF [3]	100	82	92	86	88	92	86.6 ± 5.7	100
		85	81	76	91	93		
REF [3]	50	87	91	92	89	90	89.6 ± 2.4	100
		86	90	88	89	94		
REF [3]	25	98	99	91	95	98	95.2 ± 3.1	100
		94	91	94	99	93		
1	100	78	84	87	88	80	83.4 ± 4.3	96
1	50	98	97	99	92	98	96.8 ± 2.8	108
1	25	95	99	98	100	91	96.6 ± 3.6	101
2	100	36	52	59	57	45	49.8 ± 9.4**	58
2	50	77	80	89	81	87	82.8 ± 5.0	92
2	25	98	98	98	97	98	97.8 ± 0.4	103
3	100	93	97	96	96	97	95.8 ± 1.6	111
3	50	97	97	96	97	94	96.2 ± 1.3	107
3	25	97	98	98	99	97	97.8 ± 0.8	103
4	100	100	95	93	94	96	95.6 ± 2.7	110
4	50	99	97	96	100	98	98.0 ± 1.6	109
4	25	99	97	98	92	98	96.8 ± 2.8	102
5	100	92	86	84	97	91	90.0 ± 5.2	104
5	50	96	94	95	96	97	95.6 ± 1.1	107
5	25	94	98	97	94	95	95.6 ± 1.8	100

Table 7. (continued)

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
6	100	81	90	94	92	94	90.2 ± 5.4	104
6	50	99	99	96	99	97	98.0 ± 1.4	109
6	25	100	98	98	97	99	98.4 ± 1.1	103
7	100	99	99	95	96	96	97.0 ± 1.9	112
7	50	98	98	98	97	98	97.8 ± 0.4	109
7	25	99	98	97	98	98	98.0 ± 0.7	103
8	100	97	94	92	100	97	96.0 ± 3.1	111
8	50	95	98	98	97	97	97.0 ± 1.2	108
8	25	97	98	99	97	99	98.0 ± 1.0	103
9	100	97	82	92	92	94	91.4 ± 5.6	106
9	50	92	93	94	88	93	92.0 ± 2.4	103
9	25	95	94	98	98	97	96.4 ± 1.8	101
10	100	90	83	81	83	80	83.4 ± 3.9	96
10	50	98	97	100	95	98	97.6 ± 1.8	109
10	25	96	99	96	98	98	97.4 ± 1.3	102
11	100	69	63	76	72	66	69.2 ± 5.1**	80
11	50	96	100	96	97	96	97.0 ± 1.7	108
11	25	97	100	97	98	96	97.6 ± 1.5	103
12	100	95	89	95	97	91	93.4 ± 3.3	108
12	50	99	97	99	96	95	97.2 ± 1.8	108
12	25	98	94	97	96	94	95.8 ± 1.8	101
13	100	99	96	99	97	96	97.4 ± 1.5	112
13	50	97	98	99	97	99	98.0 ± 1.0	109

Table 7. (continued)

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
13	25	98	98	97	99	98	98.0 ± 0.7	103
S1	100	0	2	1	0	10	2.6 ± 4.2**	3
S1	50	20	38	31	28	19	27.2 ± 7.9**	30
S1	25	38	31	55	35	37	39.2 ± 9.2**	41
S2	100	62	71	67	69	80	69.8 ± 6.6**	81
S2	50	98	97	100	98	100	98.6 ± 1.3	110
S2	25	98	99	97	98	98	98.0 ± 0.7	103
S3	100	96	97	98	93	94	95.6 ± 2.1	110
S3	50	100	100	97	99	98	98.8 ± 1.3	110
S3	25	99	96	97	99	99	98.0 ± 1.4	103
S4	100	97	92	98	99	96	96.4 ± 2.7	111
S4	50	95	97	95	98	100	97.0 ± 2.1	108
S4	25	97	100	92	97	95	96.2 ± 3.0	101
S5	100	95	91	95	95	86	92.4 ± 4.0	107
S5	50	98	99	98	96	96	97.4 ± 1.3	109
S5	25	99	99	99	97	98	98.4 ± 0.9	103
S6	100	82	77	86	84	81	82.0 ± 3.4	95
S6	50	98	99	97	97	94	97.0 ± 1.9	108
S6	25	94	98	95	98	99	96.8 ± 2.2	102
S7	100	93	86	83	86	88	87.2 ± 3.7	101
S7	50	97	95	99	98	99	97.6 ± 1.7	109
S7	25	98	99	98	96	98	97.8 ± 1.1	103
S8	100	75	75	73	74	67	72.8 ± 3.4*	84

Table 7. (continued)

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
S8	50	96	88	94	92	97	93.4 ± 3.6	104
S8	25	96	93	97	99	98	96.6 ± 2.3	101
S9	100	99	96	99	97	96	97.4 ± 1.5	112
S9	50	94	99	97	98	98	97.2 ±1.9	108
S9	25	99	97	95	97	99	97.4 ± 1.7	102
S10	100	87	76	86	83	77	81.8 ± 5.1	94
S10	50	100	97	99	93	98	97.4 ± 2.7	109
S10	25	98	98	98	99	98	98.2 ± 0.4	103
S11	100	96	89	90	77	96	89.6 ± 7.8	103
S11	50	99	96	97	97	100	97.8 ± 1.6	109
S11	25	97	98	97	99	97	97.6 ± 0.9	103
S12	100	98	89	94	92	94	93.4 ± 3.3	108
S12	50	100	97	97	98	98	98.0 ± 1.2	109
S12	25	100	96	98	99	99	98.4 ± 1.5	103
S13	100	96	94	88	93	96	93.4 ± 3.3	108
S13	50	97	97	98	100	99	98.2 ± 1.3	110
S13	25	99	99	99	98	100	99.0 ± 0.7	104
S14	100	91	96	99	93	100	95.8 ± 3.8	111
S14	50	100	97	97	98	97	97.8 ± 1.3	109
S14	25	99	99	98	98	100	98.8 ± 0.8	104
S15	100	18	11	15	16	24	16.8 ± 4.8**	19
S15	50	33	24	29	31	26	28.6 ± 3.6**	32
S15	25	33	32	42	39	41	37.4 ± 4.6**	39

Table 7. (continued)

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
R1	100	65	48	69	71	63	63.2 ± 9.1**	73
R1	50	89	83	87	89	86	86.8 ± 2.5	97
R1	25	93	96	93	92	95	93.8 ± 1.6	99
R2	100	93	97	99	91	98	95.6 ± 3.4	110
R2	50	99	97	96	98	96	97.2 ± 1.3	108
R2	25	100	99	98	99	98	98.8 ± 0.8	104
R3	100	94	98	99	94	99	96.8 ± 2.6	112
R3	50	96	96	98	98	97	97.0 ± 1.0	108
R3	25	97	100	98	100	100	99.0 ± 1.4	104
R4	100	100	99	99	97	100	99.0 ± 1.2	114
R4	50	96	100	98	96	98	97.6 ± 1.7	109
R4	25	100	98	99	95	96	97.6 ± 2.1	103
R5	100	94	94	82	85	90	89.0 ± 5.4	103
R5	50	92	98	92	94	94	94.0 ± 2.4	105
R5	25	95	98	97	97	95	96.4 ± 1.3	101
R6	100	95	98	97	99	98	97.4 ± 1.5	112
R6	50	98	98	98	98	97	97.8 ± 0.4	109
R6	25	97	99	99	99	96	98.0 ± 1.4	103
R7	100	72	83	84	83	82	80.8 ± 5.0	93
R7	50	89	92	90	90	91	90.4 ± 1.1	101
R7	25	92	97	94	95	97	95.0 ± 2.1	100
R8	100	86	85	72	92	86	84.2 ± 7.4	97

Table 7. (continued)

Designation [1]	% WQAS [2]	% Fertilized					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
R8	50	93	88	95	86	89	90.2 ± 3.7	101
R8	25	94	93	96	93	96	94.4 ± 1.5	99

[1] Designation refers to sample ID. (Numbers only, S's and R's refer to sites of concern, storm water discharge, and reference sites, respectively.)

[2] Percent of water quality adjusted porewater sample.

[3] Reference pore water extracted from sediment collected in Redfish Bay, Texas.

Table 8. Sea urchin embryological development test raw data and means for sediment porewater samples from Corpus Christi Bay National Estuary Program. Asterisks denote significant difference between test and reference sites (Dunnett's *t*-test,* 0.05, 0.01).**

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
REF [3]	100	75	86	80	75	82	79.7 ± 5.5	100
		78	71	88	85	77		
REF [3]	50	88	83	90	80	83	81.2 ± 5.4	100
		71	79	82	79	77		
REF [3]	25	83	80	86	87	77	82.0 ± 4.6	100
		87	78	80	87	75		
1	100	0	0	0	0	0	0.0 ± 0.0**	0
1	50	55	78	73	49	63	63.6 ± 12.1*	78
1	25	87	88	83	76	92	85.2 ± 6.1	104
2	100	13 [4]	0	0	0	0	0.0 ± 0.0**	0
2	50	85	81	85	87	77	83.0 ± 4.0	102
2	25	82	74	86	79	91	82.4 ± 6.5	100
3	100	35	40	25	31	43	34.8 ± 7.2**	44
3	50	77	83	74	84	76	78.8 ± 4.4	97
3	25	58	78	73	64	76	69.8 ± 8.5	85
4	100	2	6	2	1	3	2.8 ± 1.9**	4
4	50	68	62	77	71	73	70.2 ± 5.6	86
4	25	85	78	78	83	78	80.4 ± 3.4	98
5	100	0	0	0	0	0	0.0 ± 0.0**	0
5	50	0	0	0	0	0	0.0 ± 0.0**	0
5	25	78	79	74	81	78	78.0 ± 2.6	95
6	100	0	0	0	0	0	0.0 ± 0.0**	0

Table 8. (continued)

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
6	50	20	12	22	27	16	19.4 ± 5.7**	24
6	25	92	86	91	83	80	86.4 ± 5.1	105
7	100	84	88	85	90	93	88.0 ± 3.7	110
7	50	83	93	84	87	92	87.8 ± 4.6	108
7	25	71	94	86	86	87	84.8 ± 8.4	103
8	100	88	79	89	84	79	83.8 ± 4.8	105
8	50	88	85	86	84	82	85.0 ± 2.2	105
8	25	70	84	90	77	88	81.8 ± 8.3	100
9	100	0	0	0	0	0	0.0 ± 0.0**	0
9	50	16	20	52	38	56	36.4 ± 18.1**	45
9	25	83	91	79	90	86	85.8 ± 5.0	105
10	100	82	83	91	88	85	85.8 ± 3.7	108
10	50	78	90	83	92	82	85.0 ± 5.8	105
10	25	94	91	77	88	84	86.8 ± 6.6	106
11	100	76	84	80	88	89	83.4 ± 5.5	105
11	50	80	84	84	81	75	80.8 ± 3.7	100
11	25	76	78	79	87	78	79.6 ± 4.3	97
12	100	84	85	80	80	96	85.0 ± 6.6	107
12	50	84	85	84	88	79	84.0 ± 3.2	103
12	25	81	86	66	78	84	79.0 ± 7.9	96
13	100	72	81	76	74	70	74.6 ± 4.2	94
13	50	84	83	81	80	82	82.0 ± 1.6	101

Table 8. (continued)

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
13	25	84	84	88	84	87	85.4 ± 1.9	104
S1	100	0	0	0	0	0	0.0 ± 0.0**	0
S1	50	0	0	0	0	0	0.0 ± 0.0**	0
S1	25	0	6	2	1	0	1.8 ± 2.5**	2
S2	100	0	0	0	1	0	0.2 ± 0.4**	0
S2	50	68	78	74	80	82	76.4 ± 5.6	94
S2	25	80	77	84	84	82	81.4 ± 3.0	99
S3	100	77	76	83	78	86	80.0 ± 4.3	100
S3	50	76	61	79	89	73	75.6 ± 10.1	93
S3	25	70	73	77	72	76	73.6 ± 2.9	90
S4	100	72	83	80	79	72	77.2 ± 5.0	97
S4	50	67	75	83	79	92	79.2 ± 9.3	98
S4	25	81	75	67	75	84	76.4 ± 6.5	93
S5	100	46	30	24	39	28	33.4 ± 8.9**	42
S5	50	71	89	73	80	82	79.0 ± 7.2	97
S5	25	94	75	94	82	86	86.2 ± 8.1	105
S6	100	22	29	28	26	21	25.2 ± 3.6**	32
S6	50	85	81	93	90	85	86.8 ± 4.7	107
S6	25	88	84	80	83	88	84.6 ± 3.4	103
S7	100	30	19	28	55	40	34.4 ± 13.7**	43
S7	50	85	88	84	85	76	83.6 ± 4.5	103
S7	25	64 [4]	86	84	86	84	85.0 ± 1.2	104

Table 8. (continued)

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
S8	100	70	47	0 [4]	65	69	62.8 ± 10.7*	79
S8	50	72	83	72	76	83	77.2 ± 5.5	95
S8	25	74	81	77	78	88	79.6 ± 5.3	97
S9	100	66	74	70	79	90	75.8 ± 9.3	95
S9	50	69	70	77	66	78	72.0 ± 5.2	89
S9	25	74	74	76	79	89	78.4 ± 6.3	96
S10	100	38 [4]	78	70	68	73	72.2 ± 4.4	91
S10	50	81	75	78	80	78	78.4 ± 2.3	97
S10	25	78	72	82	74	81	77.4 ± 4.3	94
S11	100	86	83	83	84	82	83.6 ± 1.5	105
S11	50	78	89	85	85	83	84.0 ± 4.0	103
S11	25	76	77	86	85	74	79.6 ± 5.5	97
S12	100	88	90	86	79	73	83.2 ± 7.0	104
S12	50	85	84	81	78	78	81.2 ± 3.3	100
S12	25	83	77	86	77	72	79.0 ± 5.5	96
S13	100	91	79	83	88	90	86.2 ± 5.1	108
S13	50	84	80	69	88	79	80.0 ± 7.1	99
S13	25	62 [4]	81	82	80	86	82.2 ± 2.6	100
S14	100	77	81	75	80	84	79.4 ± 3.5	100
S14	50	87	68	79	73	75	76.4 ± 7.1	94
S14	25	73	76	83	78	81	78.2 ± 4.0	95
S15	100	0	0	0	0	0	0.0 ± 0.0**	0

Table 8. (continued)

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
S15	50	26	19	23	32	29	25.8 ± 5.1**	32
S15	25	79	85	87	68	74	78.6 ± 7.8	96
R1	100	0	0	0	0	0	0.0 ± 0.0**	0
R1	50	0	0	0	0	0	0.0 ± 0.0**	0
R1	25	0	0	0	0	0	0.0 ± 0.0**	0
R2	100	74	72	70	71	71	71.6 ± 1.5	90
R2	50	80	77	84	81	84	81.2 ± 3.0	100
R2	25	81	78	64	74	78	75.0 ± 6.6	91
R3	100	0	0	0	0	0	0.0 ± 0.0**	0
R3	50	79	78	75	82	80	78.8 ± 2.6	97
R3	25	87	84	83	88	86	85.6 ± 2.1	104
R4	100	71	71	71	73	68	70.8 ± 1.8	89
R4	50	67	84	78	57	80	73.2 ± 11.0	90
R4	25	78	76	60	81	75	74.0 ± 8.2	90
R5	100	0	0	0	0	0	0.0 ± 0.0**	0
R5	50	76	47	52	55	83	62.6 ±15.9**	77
R5	25	88	77	87	80	86	83.6 ± 4.8	102
R6	100	77	78	76	80	82	78.6 ± 2.4	99
R6	50	80	84	87	92	78	84.2 ± 5.6	104
R6	25	78	77	91	75	71	78.4 ± 7.5	96
R7	100	0	0	0	0	0	0.0 ± 0.0**	0
R7	50	0	0	0	0	0	0.0 ± 0.0**	0

Table 8. (continued)

Designation [1]	% WQAS [2]	% Normal Development					Mean±SD	% of REF [3]
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
R7	25	32	17	14	39	26	25.6 ± 10.4**	31
R8	100	85	82	82	85	83	83.4 ± 1.5	105
R8	50	84	88	85	89	81	85.4 ± 3.2	105
R8	25	89	88	88	86	82	86.6 ± 2.8	106

[1] Designation refers to sample ID. (Numbers only, S's and R's refer to sites of concern, storm water discharge, and reference sites, respectively.)

[2] Percent of water quality adjusted porewater sample.

[3] Reference pore water extracted from sediment collected in Redfish Bay, Texas.

[4] Value is an outlier and was omitted from statistical analysis.

Table 9. EC_{50} values of sediment porewater samples from Corpus Christi Bay National Estuary Program study assayed in the sea urchin fertilization and embryological development tests.

Designation[1]	Fertilization Test		Embryological Development Test	
	EC_{50}[2]	95% Confidence Limits	EC_{50}[2]	95% Confidence Limits
1	>100	-	61.56	58.24-65.07
2	>100	-	70.71	nr [3]
3	>100	-	92.72	82.93-103.65
4	>100	-	66.77	63.19-70.55
5	>100	-	34.98	nr [3]
6	>100	-	41.75	39.35-44.30
7	>100	-	>100	-
8	>100	-	>100	-
9	>100	-	48.30	45.08-51.75
10	>100	-	>100	-
11	>100	-	>100	-
12	>100	-	>100	-
13	>100	-	>100	-
S1	<25	-	<25	-
S2	>100	-	68.30	66.27-70.40
S3	>100	-	>100	-
S4	>100	-	>100	-
S5	>100	-	89.80	81.31-99.19
S6	>100	-	82.62	77.24-88.38
S7	>100	-	90.88	82.09-100.61
S8	>100	-	>100	-

Table 9. (continued)

Designation[1]	Fertilization Test		Embryological Development Test	
	EC_{50}[2]	95% Confidence Limits	EC_{50}[2]	95% Confidence Limits
S9	>100	-	>100	-
S10	>100	-	>100	-
S11	>100	-	>100	-
S12	>100	-	>100	-
S13	>100	-	>100	-
S14	>100	-	>100	-
S15	<25	-	43.87	41.06-46.88
R1	>100	-	<25	-
R2	>100	-	>100	-
R3	>100	-	70.22	69.26-71.20
R4	>100	-	>100	-
R5	>100	-	61.13	57.78-64.68
R6	>100	-	>100	-
R7	>100	-	<25	-
R8	>100	-	>100	-

[1] Designation refers to the sample ID. (Numbers only, S's and R's refer to sites of concern, storm water discharge, and reference sites, respectively.)

[2] Percent of water quality adjusted porewater sample.

[3] 95% confidence limits not reliable.

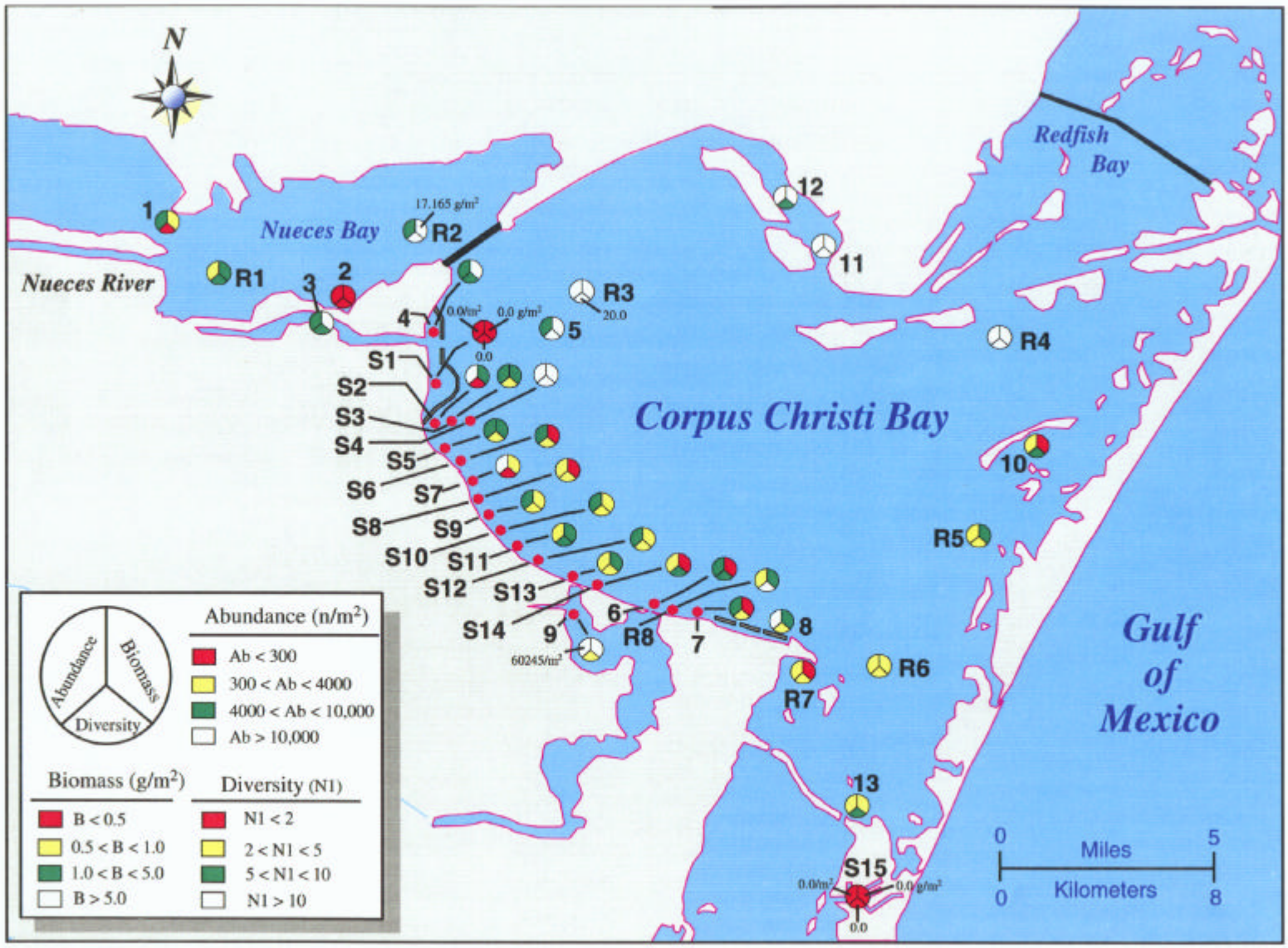


Figure 4. Infaunal abundance (n/m^2), biomass (g/m^2), and diversity (N1) for sites in the CCBNEP study area.

Biomass measurements were performed by pooling all organisms to major taxa. Normally, rare taxa (including Anthozoa, Turbellaria, and Ascidacea) are pooled in a category entitled "others". However, in the current study Ophiuroidea, Nemertinea, Sipunculida, and Hemichordata were also very rare, comprising less than 1% of the fauna found (Table 10). Although rare in number, Ophiuroidea are large, and therefore contributed to 11% of the biomass overall. In contrast, Crustacea are small and represented 3% of the abundance but only 1% of the biomass. Polychaetes and mollusks were ranked first and second for both biomass and abundance (Table 10).

There were large differences between biomass ($P < 0.0001$) and abundance ($P < 0.0001$) found among sites. Because of their rareness, Nemertinea, Sipunculida, and Hemichordata, were pooled into the "other" category to compare sites. In addition, Crustacea were added to the other category for biomass comparisons (Figure 5) and Ophiuroidea were added to the other category for density comparisons (Figure 6). The Tukey minimum significant difference for total biomass average for a site is 9.8 g m^{-2}. Therefore, biomass at sites 9 through 4 are the same, R3 is similar to sites through S2, and all sites from 5 down are the same (Figure 5). Polychaetes dominated the biomass at all sites, except for R3, which was dominated by ophiuroids, and 3, R1, S5, S2, S10, S9, S7, which were dominated by mollusks. The Tukey minimum significant difference for total density average for a site is 12,600 individuals m^{-2}. Therefore, density at site 9 is different from all other sites, R4 is similar to sites through S4, and all sites from S2 down are the same (Figure 6). Polychaetes dominated the density at all sites, except S7, S2, S3, S6, and S5, which were dominated by mollusks.

There were significant interactions between site and vertical sections for both biomass ($P < 0.0001$; Figure 7) and abundance ($P < 0.0001$; Figure 8). In general, the average biomass across all samples (0.87 g m^{-2}) was less in the surface 3 cm of sediment than in the lower 3-10 cm of sediment (2.24 g m^{-2}). In contrast, the density in the surface (6,138 m^{-2}) was greater than below the surface (2,810 m^{-2}). In general, sites with higher densities had higher biomass in the lower section whereas, sites with lower densities had both density and biomass concentrated at the surface (contrast Figures 7 and 8). In general, polychaetes and crustaceans were evenly distributed throughout the sediment, but mollusks were restricted to the surface (Table 11).

A total of 136 species were found in all samples (Table 12). Most species were very rare, the eight most dominant species accounted for 90% of all organisms found. The dominant species was the polychaete *Streblospio benedicti*, accounting for 26% of the total abundance. The second most dominant was the bivalve *Mulinia lateralis* (17%). All of the other six most dominant species were annelids: *Mediomastus ambiseta* (a polychaete, 14%), *Tharyx setigera* (a polychaete, 10%), *Polydora caulleryi* (a polychaete, 8%), Oligochaetes (7%), *Capitella capitata* (a polychaete, 6%), *Paraonis fulgens* (a polychaete, 2%). All of the other 128 species accounted for less than 1% of the organisms found. These eight species were not found evenly distributed among the different sites (Table 13).

Table 10. Overall average density (n/m^2) and biomass (g/m^2)and percent contribution for each taxa at all sites to a depth of 10 cm. Others = Anthozoa, Turbellaria, and Ascidacea.

Taxa	Abundance		Biomass	
	$n\ m^{-2}$	%	$g\ m^{-2}$	%
Polychaeta	7100	79.36	2.084	67.02
Mollusca	1183	13.23	0.500	16.10
Crustacea	312	3.49	0.034	1.09
Other	211	2.36	0.063	2.02
Ophiuroidea	61	0.69	0.350	11.29
Nemertinea	60	0.67	0.060	1.92
Sipunculida	17	0.19	0.016	0.51
Hemichordata	2	0.02	0.002	0.06

The only exception was *Mulinia lateralis*, which was found in 25 of the 36 sites. One species, *Paraonis fulgens* appeared to be characteristic of storm water outfall sites, occurring in 11 of the 13 outfall sites where living organisms were found, and occurring at only 3 other sites. *Mulinia lateralis* was the only other species that was consistently found at storm outfall sites.

Because of the dominance by such a few species, community structure analysis by PCA was performed only on species that represented at least 0.5% of the community. Still this added only six more species, but two more higher taxa. So, in addition to the eight species listed in Table 13, the following species were used in the PCA: *Syllis cornuta* (a polychaete, 1%), Anthozoa (0.8%), *Paleanotus heteroseta* (a polychaete, 0.8%), *Glycinde solitaria* (a polychaete, 0.7%), *Polydora ligni* (a polychaete, 0.6%), and *Ampelisca abdita* (an amphipod, 0.5%). Altogether, these 14 species represented 94% of all species found. Except for *Ampelisca abdita*, all the other 13 species contributed substantially to two PCs (Figure 9). The first PC accounted for 52% of the variance in the data set and the second PC accounted for an additional 23% of the variance. Together, the first two PCs accounted for 75% of the variance in the data set. Three species (*S. benedicti, C. capitata*, and *P. ligni*) had the highest PC1 factor scores (Figure 9), where as the other species sorted out on PC2. There were three main site groups, and two sites stood alone (Figure 10). Except for S4, all storm outfall sites grouped together in the negative quadrat. These sites are characterized by a community of *P. fulgens, S. cornuta*, and *M. lateralis*. Another community was characterized by seven species (*M. ambiseta*, oligocheates, *G. solitaria, P. heteroseta, P. caulleryi, T. setiger*, and Anthozoans) in the negative PC1, positive PC2 quadrant. A third community was formed in the positive PC1 quadrant composed of three species (*S. benedicti, C. capitata*, and *P. ligni*). Two sites, 8 and 9, were unique.

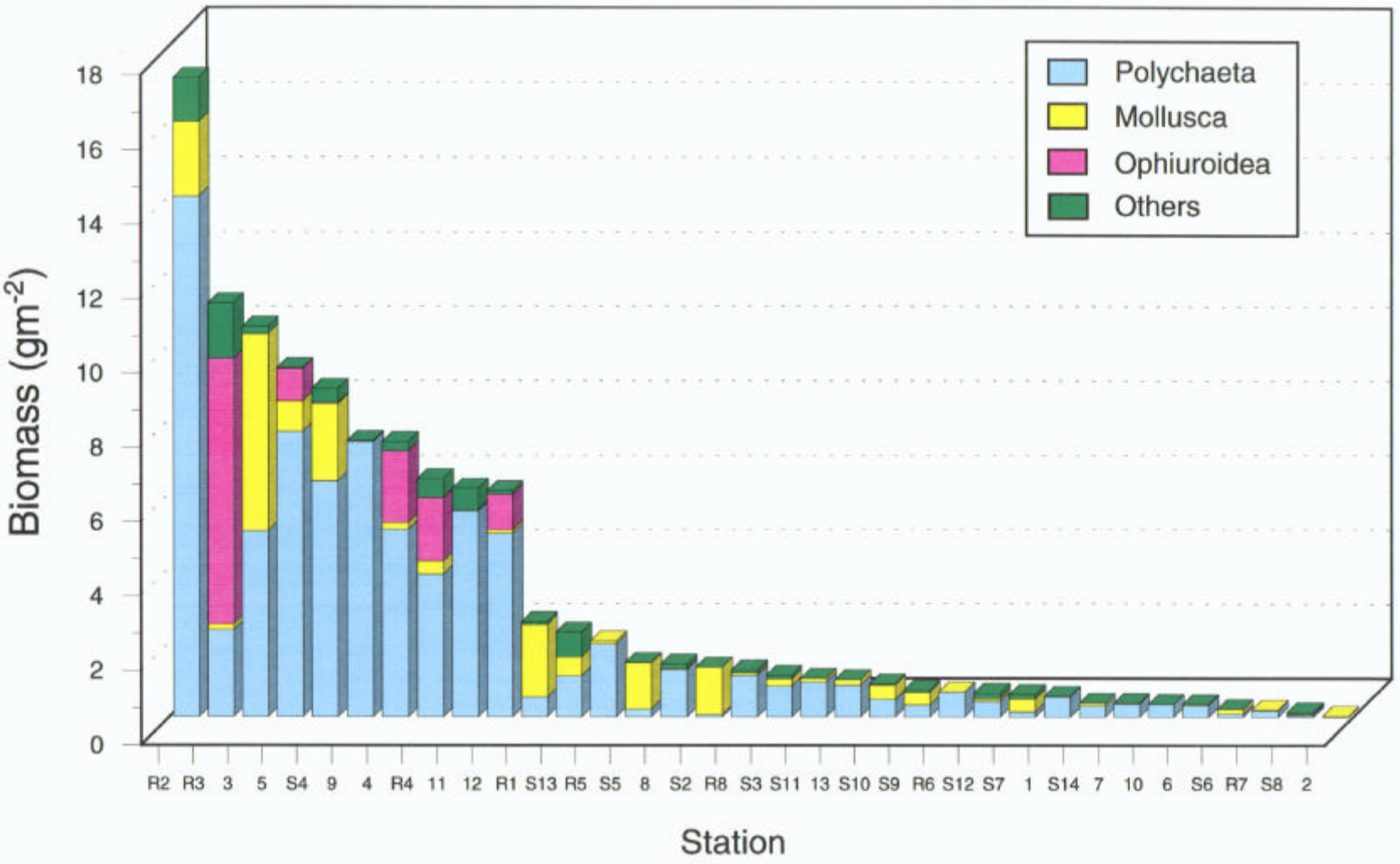


Figure 5. Contribution of higher taxa to average biomass at each site in the CCBNEP study area.

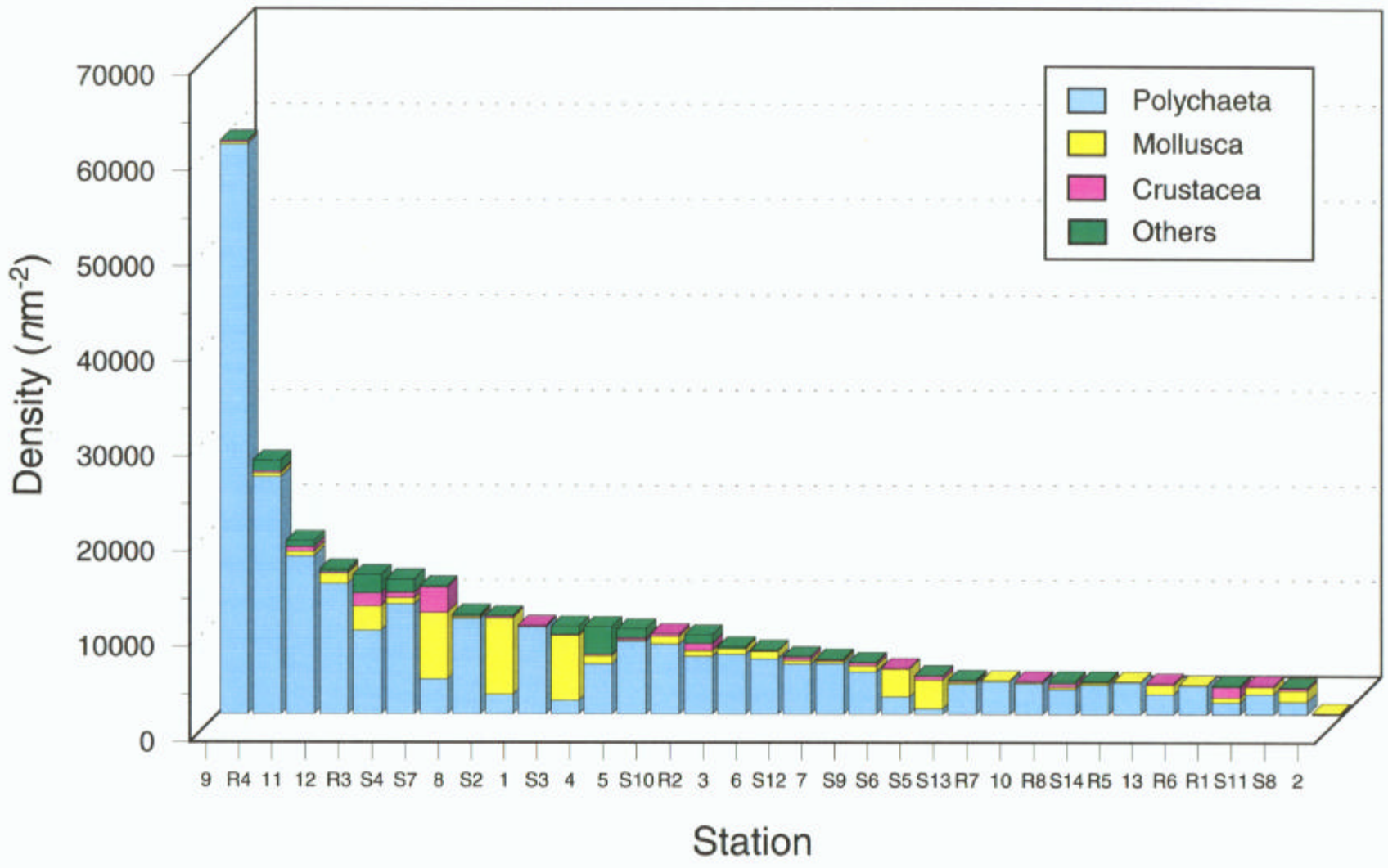


Figure 6. Contribution of higher taxa to average density at each site in the CCBNEP study area.

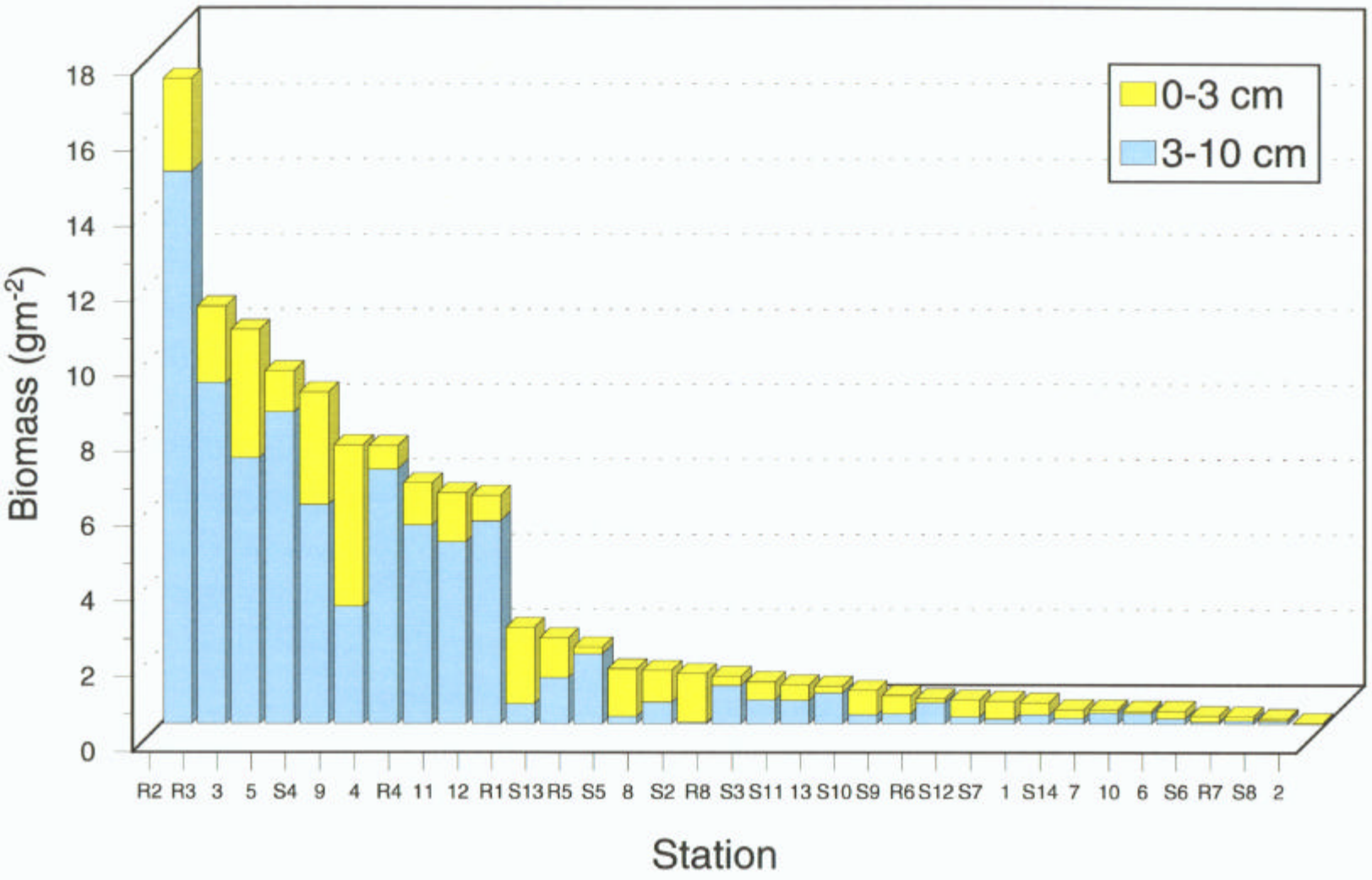


Figure 7. Vertical distribution of average biomass at each site in the CCBNEP study area.

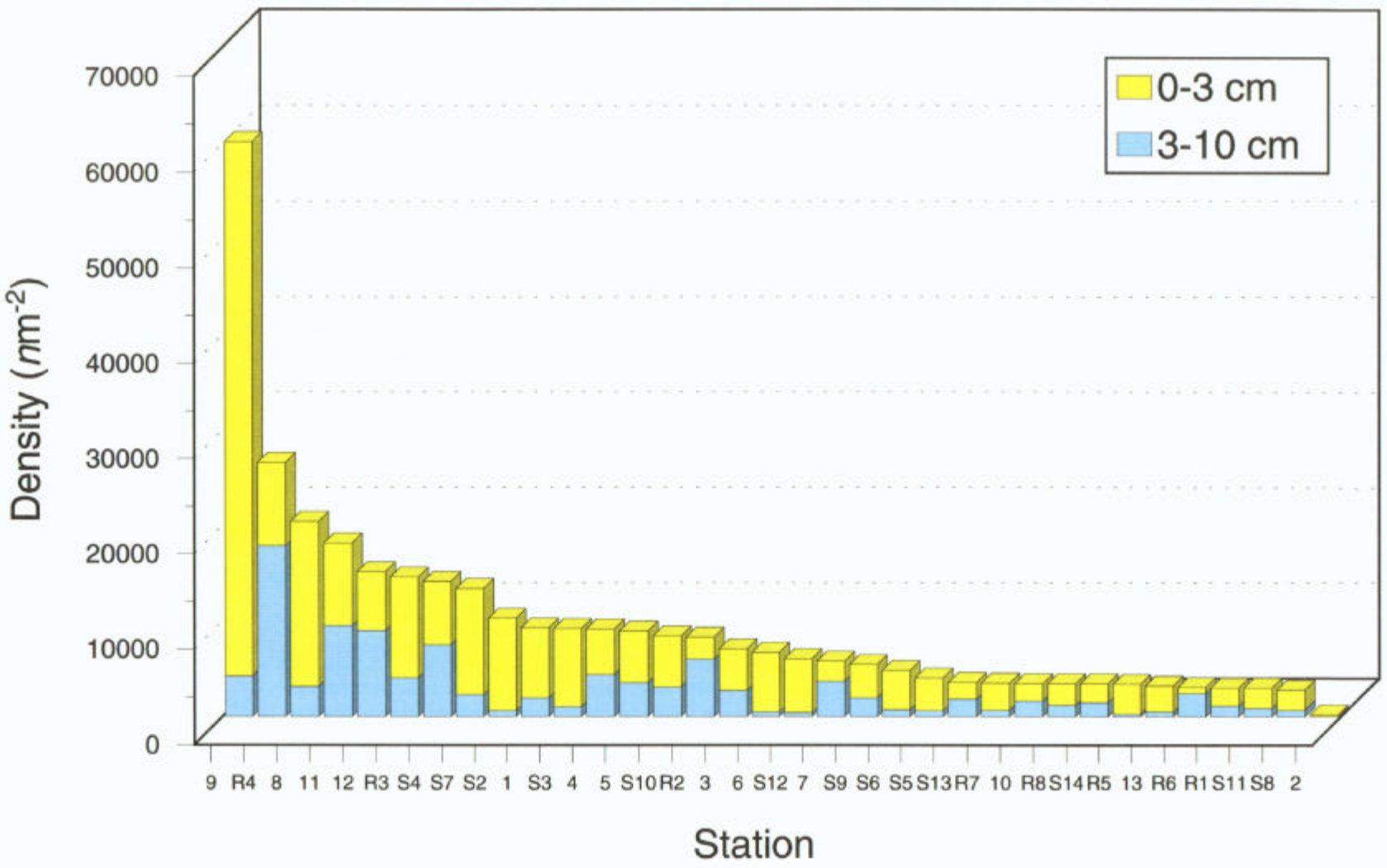


Figure 8. Vertical distribution of average density at each site in the CCBNEP study area.

Table 11. Vertical distribution of macrofauna taxa. Average density (n/m^2) and biomass (g/m^2) and standard deviation (STD) in each section for each taxa at each site (Sta). Five replicates taken at each site.

		0 - 3 cm				3 -10 cm			
Sta	**Taxa**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**
01	Crustacea	113	(155)	0.0159	(0.0240)	0	(0)	0.0000	(0.0000)
01	Mollusca	57	(127)	0.0017	(0.0038)	0	(0)	0.0000	(0.0000)
01	Polychaeta	7148	(3733)	0.3001	(0.2484)	1929	(1336)	0.2377	(0.2185)
02	Mollusca	57	(127)	0.0142	(0.0317)	0	(0)	0.0000	(0.0000)
02	Polychaeta	170	(155)	0.0119	(0.0156)	0	(0)	0.0000	(0.0000)
03	Crustacea	0	(0)	0.0000	(0.0000)	57	(127)	0.0414	(0.0926)
03	Mollusca	454	(323)	2.2771	(2.7978)	113	(155)	3.0236	(4.1404)
03	Other	57	(127)	0.0023	(0.0051)	113	(254)	0.1588	(0.3552)
03	Polychaeta	3801	(1823)	1.1363	(1.4688)	2439	(1587)	3.8507	(3.9122)
04	Crustacea	113	(254)	0.0147	(0.0330)	57	(127)	0.0074	(0.0165)
04	Mollusca	851	(874)	0.1861	(0.2224)	0	(0)	0.0000	(0.0000)
04	Other	1702	(1460)	0.1946	(0.1972)	567	(983)	0.0374	(0.0537)
04	Ophiuroidea	454	(430)	0.0085	(0.0115)	170	(155)	1.9134	(3.5325)
04	Polychaeta	1645	(1193)	0.2229	(0.2212)	3574	(1992)	4.8071	(3.6793)
05	Crustacea	113	(155)	0.0068	(0.0137)	113	(155)	0.0057	(0.0080)
05	Mollusca	113	(155)	0.8209	(1.1364)	0	(0)	0.0000	(0.0000)
05	Nemertinea	170	(155)	0.0040	(0.0047)	0	(0)	0.0000	(0.0000)
05	Other	454	(553)	0.0119	(0.0144)	0	(0)	0.0000	(0.0000)
05	Ophiuroidea	227	(237)	0.0034	(0.0037)	113	(155)	0.8662	(1.2333)
05	Polychaeta	4311	(2410)	0.2502	(0.2337)	3290	(5822)	7.4166	(10.114)
06	Crustacea	0	(0)	0.0000	(0.0000)	57	(127)	0.0006	(0.0013)
06	Mollusca	794	(546)	0.0261	(0.0262)	0	(0)	0.0000	(0.0000)
06	Nemertinea	57	(127)	0.0011	(0.0025)	0	(0)	0.0000	(0.0000)
06	Polychaeta	5389	(1187)	0.1781	(0.0403)	397	(323)	0.1356	(0.2068)
07	Crustacea	113	(155)	0.0011	(0.0016)	0	(0)	0.0000	(0.0000)
07	Mollusca	284	(201)	0.0199	(0.0237)	0	(0)	0.0000	(0.0000)
07	Nemertinea	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)
07	Other	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)
07	Polychaeta	1588	(475)	0.0584	(0.0247)	3687	(1924)	0.2933	(0.2566)
08	Crustacea	113	(254)	0.0113	(0.0254)	0	(0)	0.0000	(0.0000)
08	Mollusca	170	(254)	0.0323	(0.0632)	0	(0)	0.0000	(0.0000)
08	Nemertinea	57	(127)	0.0006	(0.0013)	57	(127)	0.1027	(0.2296)
08	Other	57	(127)	0.0017	(0.0038)	0	(0)	0.0000	(0.0000)
08	Polychaeta	16905	(1755)	0.7931	(0.0766)	3063	(1959)	0.4697	(0.4795)
09	Crustacea	170	(254)	0.0023	(0.0037)	0	(0)	0.0000	(0.0000)
09	Mollusca	170	(254)	0.0261	(0.0537)	0	(0)	0.0000	(0.0000)
09	Other	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)

Table 11. (continued)

		0 - 3 cm				3 -10 cm			
Sta	**Taxa**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**
09	Polychaeta	55650	(15242)	4.2801	(1.3364)	4198	(1787)	3.1087	(1.7045)
10	Crustacea	113	(254)	0.0017	(0.0038)	0	(0)	0.0000	(0.0000)
10	Mollusca	113	(155)	0.0028	(0.0049)	0	(0)	0.0000	(0.0000)
10	Polychaeta	1588	(841)	0.0613	(0.0285)	1645	(1395)	0.2780	(0.3644)
11	Crustacea	113	(155)	0.0034	(0.0061)	397	(475)	0.0165	(0.0277)
11	Mollusca	397	(254)	0.0119	(0.0088)	57	(127)	0.0074	(0.0165)
11	Nemertinea	0	(0)	0.0000	(0.0000)	113	(155)	0.0028	(0.0049)
11	Other	113	(155)	0.0034	(0.0061)	57	(127)	0.2150	(0.4808)
11	Ophiuroidea	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)
11	Polychaeta	7715	(4048)	0.9332	(1.0673)	8850	(4824)	4.5916	(1.8519)
11	Sipunculida	284	(284)	0.3494	(0.3867)	0	(0)	0.0000	(0.0000)
12	Crustacea	170	(155)	0.0057	(0.0067)	0	(0)	0.0000	(0.0000)
12	Hemicordata	0	(0)	0.0000	(0.0000)	57	(127)	0.0624	(0.1395)
12	Mollusca	964	(1091)	0.0970	(0.1158)	57	(127)	0.0006	(0.0013)
12	Nemertinea	57	(127)	0.0289	(0.0647)	0	(0)	0.0000	(0.0000)
12	Ophiuroidea	57	(127)	0.0079	(0.0178)	113	(155)	0.9474	(1.4057)
12	Polychaeta	4935	(1845)	0.5452	(0.4615)	8736	(6841)	4.3749	(1.8729)
13	Crustacea	113	(254)	0.0011	(0.0025)	57	(127)	0.0006	(0.0013)
13	Mollusca	964	(475)	0.1492	(0.0970)	0	(0)	0.0000	(0.0000)
13	Polychaeta	1645	(421)	0.0295	(0.0125)	454	(323)	0.8180	(1.8038)
R01	Crustacea	964	(430)	0.0664	(0.0256)	113	(155)	0.0062	(0.0111)
R01	Mollusca	511	(421)	1.9373	(1.5142)	0	(0)	0.0000	(0.0000)
R01	Nemertinea	57	(127)	0.0017	(0.0038)	113	(155)	0.0096	(0.0141)
R01	Polychaeta	340	(370)	0.0159	(0.0209)	908	(466)	0.5100	(0.4134)
R02	Crustacea	170	(254)	0.0034	(0.0051)	567	(531)	0.0238	(0.0189)
R02	Mollusca	511	(507)	1.9900	(1.9667)	113	(155)	0.0068	(0.0095)
R02	Nemertinea	0	(0)	0.0000	(0.0000)	57	(127)	0.8912	(1.9928)
R02	Other	794	(615)	0.2575	(0.3520)	57	(127)	0.0062	(0.0140)
R02	Polychaeta	851	(567)	0.2150	(0.2562)	5162	(3968)	13.771	(14.172)
R03	Crustacea	1361	(2173)	0.3863	(0.4400)	0	(0)	0.0000	(0.0000)
R03	Mollusca	2553	(2698)	0.1515	(0.1647)	0	(0)	0.0000	(0.0000)
R03	Nemertinea	284	(491)	0.0618	(0.1367)	0	(0)	0.0000	(0.0000)
R03	Other	964	(1197)	1.0398	(1.8877)	0	(0)	0.0000	(0.0000)
R03	Ophiuroidea	397	(588)	0.0159	(0.0182)	284	(0)	7.1352	(5.5975)
R03	Polychaeta	4992	(4787)	0.3937	(0.5032)	3744	(1853)	1.9339	(2.0955)
R04	Crustacea	170	(155)	0.0068	(0.0107)	0	(0)	0.0000	(0.0000)
R04	Mollusca	284	(347)	0.3358	(0.6899)	113	(155)	0.0182	(0.0285)
R04	Nemertinea	170	(155)	0.0176	(0.0166)	397	(323)	0.2649	(0.2452)
R04	Other	170	(155)	0.0136	(0.0152)	0	(0)	0.0000	(0.0000)

		0 - 3 cm				3 -10 cm			
Sta	**Taxa**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**	**n/m^2**	**(STD)**	**g/m^2**	**(STD)**
R04	Ophiuroidea	0	(0)	0.0000	(0.0000)	57	(127)	1.6996	(3.8004)
R04	Polychaeta	7602	(2532)	0.5298	(0.1677)	17302	(12201)	3.2931	(1.9595)
R04	Sipunculida	340	(507)	0.2190	(0.3047)	0	(0)	0.0000	(0.0000)
R05	Mollusca	57	(127)	0.0783	(0.1750)	0	(0)	0.0000	(0.0000)
R05	Polychaeta	3063	(615)	0.1084	(0.0226)	284	(284)	1.8425	(4.1137)
R06	Mollusca	57	(127)	0.0028	(0.0063)	0	(0)	0.0000	(0.0000)
R06	Polychaeta	567	(448)	0.1038	(0.1347)	2439	(888)	0.5599	(0.3938)
R07	Mollusca	113	(254)	0.0261	(0.0583)	0	(0)	0.0000	(0.0000)
R07	Polychaeta	2723	(430)	0.0794	(0.0409)	681	(381)	0.0908	(0.0852)
R08	Crustacea	340	(370)	0.0153	(0.0184)	57	(127)	0.0040	(0.0089)
R08	Mollusca	227	(127)	0.0562	(0.0470)	0	(0)	0.0000	(0.0000)
R08	Nemertinea	170	(155)	0.0664	(0.1421)	0	(0)	0.0000	(0.0000)
R08	Other	57	(127)	0.0023	(0.0051)	0	(0)	0.0000	(0.0000)
R08	Polychaeta	1475	(860)	0.1015	(0.1029)	1135	(602)	1.0103	(1.6108)
S02	Crustacea	0	(0)	0.0000	(0.0000)	170	(155)	0.0057	(0.0083)
S02	Mollusca	7828	(6079)	1.2599	(1.1685)	170	(254)	0.0023	(0.0037)
S02	Ophiuroidea	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)
S02	Polychaeta	1759	(3465)	0.0352	(0.0724)	284	(0)	0.0284	(0.0305)
S03	Crustacea	0	(0)	0.0000	(0.0000)	113	(155)	0.0062	(0.0086)
S03	Mollusca	6807	(2113)	0.1934	(0.0987)	0	(0)	0.0000	(0.0000)
S03	Other	567	(284)	0.0522	(0.0174)	284	(201)	0.0363	(0.0348)
S03	Polychaeta	794	(421)	0.2343	(0.3923)	624	(466)	0.5905	(0.7989)
S04	Crustacea	284	(284)	0.0102	(0.0169)	284	(201)	0.2184	(0.4079)
S04	Mollusca	624	(615)	2.0706	(2.1709)	0	(0)	0.0000	(0.0000)
S04	Nemertinea	113	(254)	0.0011	(0.0025)	0	(0)	0.0000	(0.0000)
S04	Other	851	(201)	0.0925	(0.0820)	227	(311)	0.0556	(0.0768)
S04	Ophiuroidea	227	(237)	0.0357	(0.0660)	0	(0)	0.0000	(0.0000)
S04	Polychaeta	4538	(2035)	0.7874	(0.4358)	6978	(5056)	5.5474	(4.6634)
S05	Crustacea	57	(127)	0.0034	(0.0076)	340	(311)	0.0074	(0.0068)
S05	Mollusca	3007	(1145)	1.2310	(1.1185)	0	(0)	0.0000	(0.0000)
S05	Other	57	(127)	0.0006	(0.0013)	0	(0)	0.0000	(0.0000)
S05	Polychaeta	284	(284)	0.0227	(0.0431)	284	(284)	0.1895	(0.3660)
S06	Crustacea	0	(0)	0.0000	(0.0000)	113	(254)	0.0057	(0.0127)
S06	Mollusca	2893	(1647)	0.1186	(0.0987)	0	(0)	0.0000	(0.0000)
S06	Polychaeta	1191	(237)	0.0363	(0.0145)	624	(546)	0.0556	(0.0505)
S07	Crustacea	2666	(5805)	0.1095	(0.2432)	0	(0)	0.0000	(0.0000)
S07	Mollusca	6978	(4411)	0.3415	(0.5267)	0	(0)	0.0000	(0.0000)
S07	Other	0	(0)	0.0000	(0.0000)	113	(155)	0.0045	(0.0074)
S07	Polychaeta	1475	(615)	0.0221	(0.0105)	2156	(653)	0.1214	(0.1764)

Table 11. (continued)

Sta	Taxa	0 - 3 cm n/m^2 (STD)	0 - 3 cm g/m^2 (STD)	3 -10 cm n/m^2 (STD)	3 -10 cm g/m^2 (STD)
S08	Crustacea	227 (237)	0.0136 (0.0174)	0 (0)	0.0000 (0.0000)
S08	Mollusca	1135 (602)	0.0199 (0.0096)	57 (127)	0.0006 (0.0013)
S08	Nemertinea	0 (0)	0.0000 (0.0000)	57 (127)	0.0431 (0.0964)
S08	Polychaeta	737 (254)	0.0227 (0.0087)	567 (201)	0.0318 (0.0166)
S09	Crustacea	284 (284)	0.0074 (0.0074)	0 (0)	0.0000 (0.0000)
S09	Mollusca	624 (546)	0.3438 (0.7387)	0 (0)	0.0000 (0.0000)
S09	Other	57 (127)	0.0062 (0.0140)	57 (127)	0.0607 (0.1357)
S09	Polychaeta	2553 (1268)	0.1231 (0.1279)	1872 (588)	0.2088 (0.3115)
S10	Crustacea	113 (155)	0.0199 (0.0311)	170 (155)	0.0108 (0.0101)
S10	Mollusca	794 (370)	0.3818 (0.7215)	0 (0)	0.0000 (0.0000)
S10	Polychaeta	4425 (3105)	0.2411 (0.2539)	2893 (2098)	0.2269 (0.1970)
S11	Crustacea	113 (155)	0.0017 (0.0025)	57 (127)	0.0006 (0.0013)
S11	Mollusca	681 (653)	0.0976 (0.1456)	57 (127)	0.0006 (0.0013)
S11	Polychaeta	1361 (615)	0.3103 (0.3889)	737 (475)	0.6212 (0.6538)
S12	Crustacea	340 (370)	0.1344 (0.2912)	0 (0)	0.0000 (0.0000)
S12	Mollusca	397 (430)	0.0800 (0.0873)	0 (0)	0.0000 (0.0000)
S12	Nemertinea	57 (127)	0.0023 (0.0051)	0 (0)	0.0000 (0.0000)
S12	Polychaeta	4822 (2016)	0.2263 (0.3883)	397 (254)	0.1883 (0.3769)
S13	Crustacea	113 (155)	0.0102 (0.0161)	0 (0)	0.0000 (0.0000)
S13	Mollusca	170 (381)	0.5071 (1.1340)	0 (0)	0.0000 (0.0000)
S13	Nemertinea	0 (0)	0.0000 (0.0000)	57 (127)	0.6512 (1.4562)
S13	Other	57 (127)	0.0034 (0.0076)	0 (0)	0.0000 (0.0000)
S13	Polychaeta	1418 (827)	0.5332 (1.1212)	1759 (1259)	0.5639 (0.3810)
S14	Crustacea	0 (0)	0.0000 (0.0000)	57 (127)	0.0023 (0.0051)
S14	Mollusca	227 (370)	0.0754 (0.1433)	0 (0)	0.0000 (0.0000)
S14	Nemertinea	57 (127)	0.0011 (0.0025)	0 (0)	0.0000 (0.0000)
S14	Other	57 (127)	0.0006 (0.0013)	0 (0)	0.0000 (0.0000)
S14	Polychaeta	1645 (421)	0.1498 (0.0946)	1418 (347)	0.1475 (0.1221)

Table 12. Species list. Overall average abundance (n/m^2) for all sites and replicates and number of sites species occurred at.

Taxa	n/m^2	Occurrence
Anthozoa		
Anthozoan unidentified	52.0	6
Turbellaria		
Turbellarian unidentified	16.4	15
Nemertinea		
Nemertinean unidentified	12.0	16
Phoronis architecta	15.1	10
Mollusca		
Gastropoda Cuvier,1797		
Acteocinidae		
Acteocina canaliculata	1.9	5
Calyptraeidae Blainville,1824		
Cyclinella tenuis	0.3	1
Crepidula sp	0.3	1
Crepidula plana	0.3	1
Ctenobranchia Schweigger, 1820		
Vitrinellidae		
Vitrinellidae (unidentified)	0.9	2
Caecidae Gray, 1850		
Caecum pulchellum	0.3	1
Nassariidae		
Nassarius acutus	11.0	5
Nassarius vibex	1.6	1
Columbellidae		
Anachis obesa	0.9	1
Entomotaeniata Cossman,1896		
Pyramidellidae		
Pyrgiscus sp.	1.9	4
Pelecypoda		
Pelecypoda (unidentified)	1.3	4
Nuculoidea Dall, 1889		
Nuculanidae		
Nuculana acuta	0.3	1
Hippuritoidea Newell, 1965		
Kelliidae Forbes & Hanley,1848		
Aligena texasiana	0.3	1
Leptonidae		
Mysella planulata	0.3	1

Table 12. (continued)

Taxa	*n*/m^2	Occurrence
Mactridae		
Mulinia lateralis	1137.7	27
Semelidae		
Abra aequalis	0.3	1
Cumingia tellinoides	0.9	2
Solecurtidae		
Tagelus divisus	3.2	1
Veneridae		
Anomalocardia auberiana	7.2	4
Chione cancellata	4.7	5
Pholadomyoidea Newell, 1965		
Lyonsiidae		
Lyonsia hyalina floridana	4.7	3
Periplomatidae		
Periploma margaritaceum	6.0	4
Annelida		
Polychaeta		
Polychaete juv. (unidentified)	0.3	1
Polynoidae		
Malmgreniella taylori	0.3	1
Palmyridae (= Chrysopetalidae)		
Paleanotus heteroseta	52.0	6
Amphinomidae		
Paramphinome jeffreysii	0.3	1
Phyllodocidae		
Mystides rarica	0.3	1
Eteone heteropoda	3.2	3
Pilargiidae		
Cabira incerta	1.6	1
Ancistrosyllis groenlandica	0.6	2
Sigambra sp.	0.9	1
Hesionidae		
Gyptis vittata	2.5	4
Microphthalmus abberrans	14.2	2
Syllidae		
Syllis cornuta	66.5	15
Exogone sp.	5.4	5
Brania clavata	1.3	1
Sphaerosyllis sp. A	1.3	3
Syllidae (unidentified)	1.3	1

Table 12. (continued)

Taxa	n/m^2	Occurrence
Nereidae		
Ceratonereis irritabilis	12.6	6
Laeonereis culveri	22.1	5
Nereidae (unidentified)	0.3	1
Goniadidae		
Glycinde solitaria	45.7	13
Eunicidae		
Lysidice ninetta	4.4	1
Onuphidae		
Diopatra cuprea	0.6	2
Onuphis eremita	5.0	10
Lumbrineridae		
Lumbrineris parvapedata	3.2	2
Arabellidae		
Drilonereis magna	0.9	2
Dorvilleidae		
Schistomeringos rudolphi	1.6	2
Schistomeringos sp. A	24.6	10
Spionidae		
Polydora ligni	41.0	5
Paraprionospio pinnata	11.0	7
Apoprionospio pygmaea	0.9	3
Prionospio heterobranchia	0.6	1
Scolelepis texana	1.3	3
Spiophanes bombyx	2.8	3
Spio pettiboneae	0.3	1
Polydora socialis	0.9	3
Streblospio benedicti	1816.9	11
Polydora caulleryi	526.3	10
Polydora sp.	0.3	1
Magelonidae		
Magelona pettiboneae	2.8	7
Magelona phyllisae	0.6	1
Magelona rosea	0.3	1
Chaetopteridae		
Spiochaetopterus costarum	1.6	4
Cirratulidae		
Tharyx setigera	661.8	11
Cossuridae		
Cossura delta	5.0	3
Orbiniidae		
Haploscoloplos foliosus	4.7	3

Table 12. (continued)

Taxa	n/m^2	Occurrence
Scoloplos rubra	15.8	6
Haploscoloplos sp.	2.8	4
Naineris sp. A	0.6	1
Paraonidae		
Aricidea fragilis	20.5	15
Cirrophorus lyra	11.7	3
Aricidea catharinae	11.0	3
Paraonis fulgens	143.1	14
Opheliidae		
Armandia agilis	3.8	5
Armandia maculata	9.1	11
Capitellidae		
Capitella capitata	427.0	9
Notomastus latericeus	3.2	5
Notomastus cf. latericeus	0.6	2
Mediomastus ambiseta	986.4	20
Capitellidae (unidentified)	0.3	1
Maldanidae		
Branchioasychis americana	1.3	3
Clymenella torquata	1.9	2
Asychis elongata	1.3	2
Euclymene sp. B	0.3	1
Axiothella mucosa	1.9	4
Axiothells sp. A	1.6	2
Maldanidae (unidentified)	4.4	7
Ampharetidae		
Isolda pulchella	1.9	1
Melinna maculata	11.0	4
Terebellidae		
Terebellidae (unidentified)	0.3	1
Sabellidae		
Fabricia sp. A	0.3	1
Chone sp.	0.3	1
Megalomma bioculatum	9.5	4
Serpulidae		
Pomatoceros americanus	10.7	2
Eupomatus dianthus	1.3	1
Eupomatus protulicola	7.9	3
Oligochaeta		
Oligochaetes (unidentified)	472.7	19

Table 12. (continued)

Taxa	*n*/m^2	Occurrence
Sipuncula		
Phascolion strombi	3.5	2
Crustacea		
Branchiopoda		
F. Sidirdae		
Latonopsis occidentalis	1.6	2
Ostracoda		
Myodocopa		
Sarsiella texana	0.3	1
Sarsiella zostericola	0.3	1
Copepoda		
Calanoida		
Diaptomidae		
Pseudodiaptomus coronatus	0.9	3
Branchiura		
Argissa Hamatipes	0.6	1
Malacostraca		
Reptantia		
Paguridae		
Pagurus annulipes	0.9	1
Pagurus longicarpus	0.9	2
Paguridae juv.	0.3	1
Pinnotheridae		
Pinnixa sp.	4.1	6
Brachyuran Larvae		
Megalops	0.6	2
Cumacea		
Leptocuma sp.	1.9	4
Amphipoda		
Amphipoda (unidentified)	0.3	1
Ampeliscidae		
Ampelisca sp. B	0.3	1
Ampelisca abdita	31.5	2
Oedicerotidae		
Synchelidium americanum	3.2	5
Corophiidae		
Erichthonias brasiliensis	2.5	2
Corophium ascherusicum	1.3	1
Corophium louisianum	0.3	1
Microprotopus sp.	1.3	2

Table 12. (continued)

Taxa	*n*/m^2	Occurrence
Grandidierella bonnieroides	0.9	1
Bateidae		
Batea catharinensis	0.3	1
Liljeborgiidae		
Listriella clymenellae	3.8	4
Caprellidae		
Caprellidae sp.	4.7	2
Amphilochidae		
Amphilochus sp.	0.3	1
Isopoda		
Anthuridae		
Xenanthura brevitelson	7.6	11
Idoteidae		
Edotea montosa	0.3	1
Tanaidacea		
Tanaidae		
Leptochelia rapax	3.2	2
Echinodermata		
Ophiuroidea		
Ophiuroidea (unidentified)	12.3	8
Holothuroidea		
Thyome mexicana	0.3	1
Chordata		
Urochordata		
Ascidiaceae		
Ascidiacea (unidentified)	0.3	1
Hemichordata		
Schizocardium sp.	0.3	1

Table 13. Dominant macrofauna species. Average abundance (n/m^2) at each site. Species abbreviations: Sb = *Streblospio benedicti*, Ml = *Mulinia lateralis*, Ma = *Mediomastus ambiseta*, Ts = *Tharyx setigera*, Pc = *Polydora caulleryi*, Ol = Oligochaetes, Cc = *Capitella capitata*, Pf = *Paraonis fulgens*.

Site	Sb	Ml	Ma	Ts	Pc	Ol	Cc	Pf
01	8396	57	57	0	0	0	284	0
02	0	0	0	0	0	0	170	0
03	0	57	113	3858	567	624	0	0
04	0	567	340	2893	681	681	0	0
05	0	57	1702	1305	2326	57	0	0
06	908	511	3858	0	0	57	170	0
07	170	284	0	0	0	0	0	908
08	6921	170	8850	1078	511	1702	0	0
09	43113	113	340	0	0	57	13671	0
10	964	0	227	0	0	1248	397	0
11	0	0	3858	454	2099	2836	57	0
12	0	57	3177	1418	1815	5106	0	0
13	851	0	0	0	0	227	454	0
R01	170	511	284	0	0	0	0	0
R02	0	397	851	3007	1021	0	0	0
R03	0	2326	1929	1191	397	113	0	0
R04	0	57	5503	5106	7375	1702	0	0
R05	1645	0	1078	0	0	227	0	0
R06	113	0	0	0	0	0	113	442
R07	2156	57	511	0	0	397	0	0
R08	0	113	454	0	0	340	57	113
S01	0	0	0	0	0	0	0	0
S02	0	9587	0	0	0	57	0	57
S03	0	6751	0	113	0	170	0	0
S04	0	0	1985	3404	2156	1361	0	0
S05	0	2950	0	0	0	0	0	11
S06	0	2836	0	0	0	0	0	306
S07	0	9587	0	0	0	0	0	715
S08	0	1191	0	0	0	0	0	182
S09	0	624	0	0	0	0	0	465
S10	0	794	0	0	0	0	0	647
S11	0	737	170	0	0	57	0	159
S12	0	227	0	0	0	0	0	454
S13	0	113	0	0	0	0	0	397
S14	0	227	227	0	0	0	0	295
S15	0	0	0	0	0	0	0	0
Total	**65407**	**40958**	**35514**	**23827**	**18948**	**17019**	**15373**	**5151**

Figure 9. Factor pattern scores for 14 dominant species in the CCBNEP study. Abbreviations: Sb = *Streblospio benedicti*, Ml = *Mulinia lateralis*, Ma = *Mediomastus ambiseta*, Ts = *Tharynx setigera*, Pc = *Polydora caulleryi*, Ol = Oligochaetes, Cc = *Capitella capitata*, Pf = *Paraonis fulgens*, Sc = *Syllis cornuta*, A = Anthozoa, Ph = *Paleanotus heteroseta*, Gs = *Glycinde solitaria*, Pl = *Polydora ligni*, and Aa = *Ampelisca abdita*

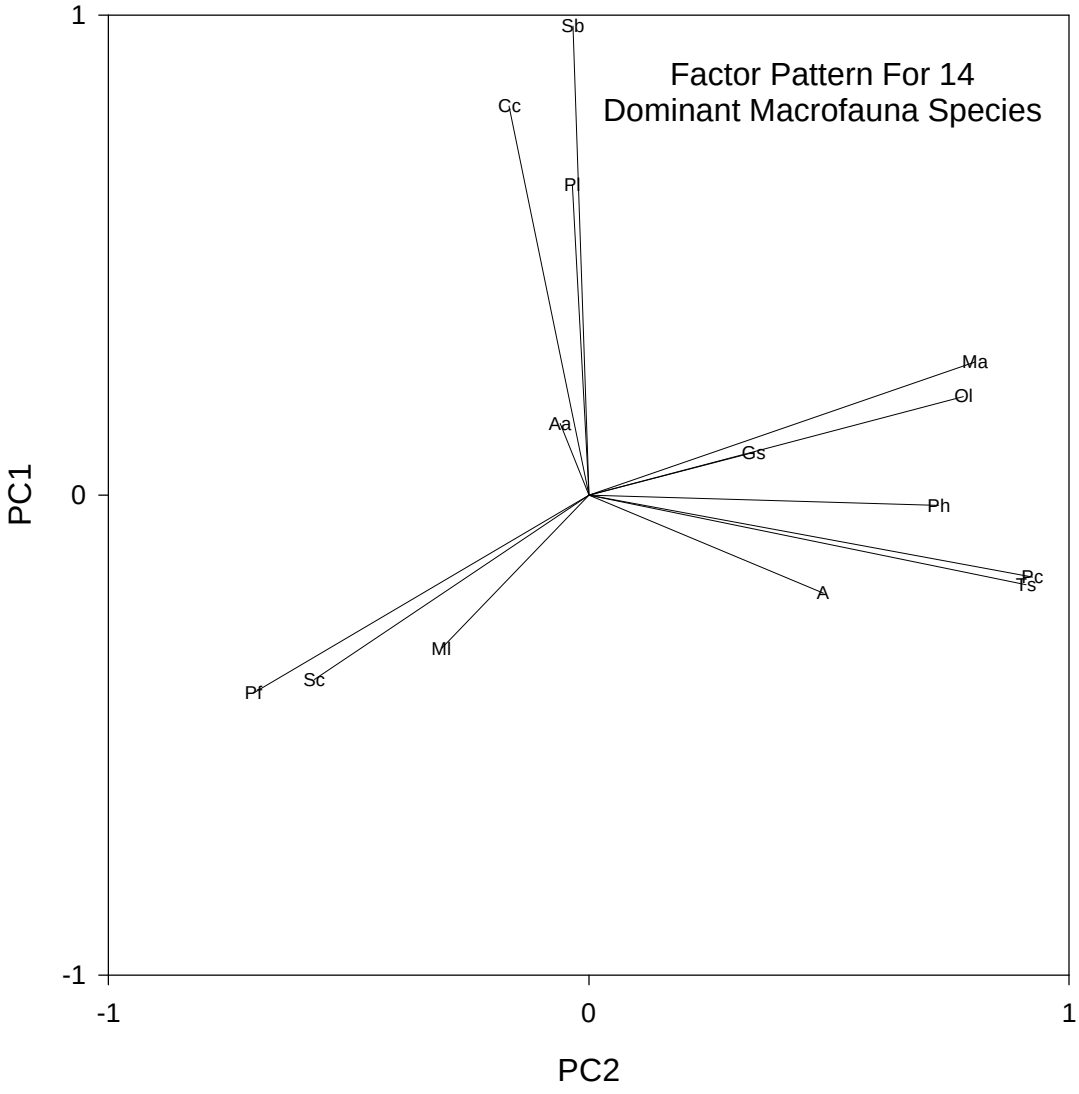
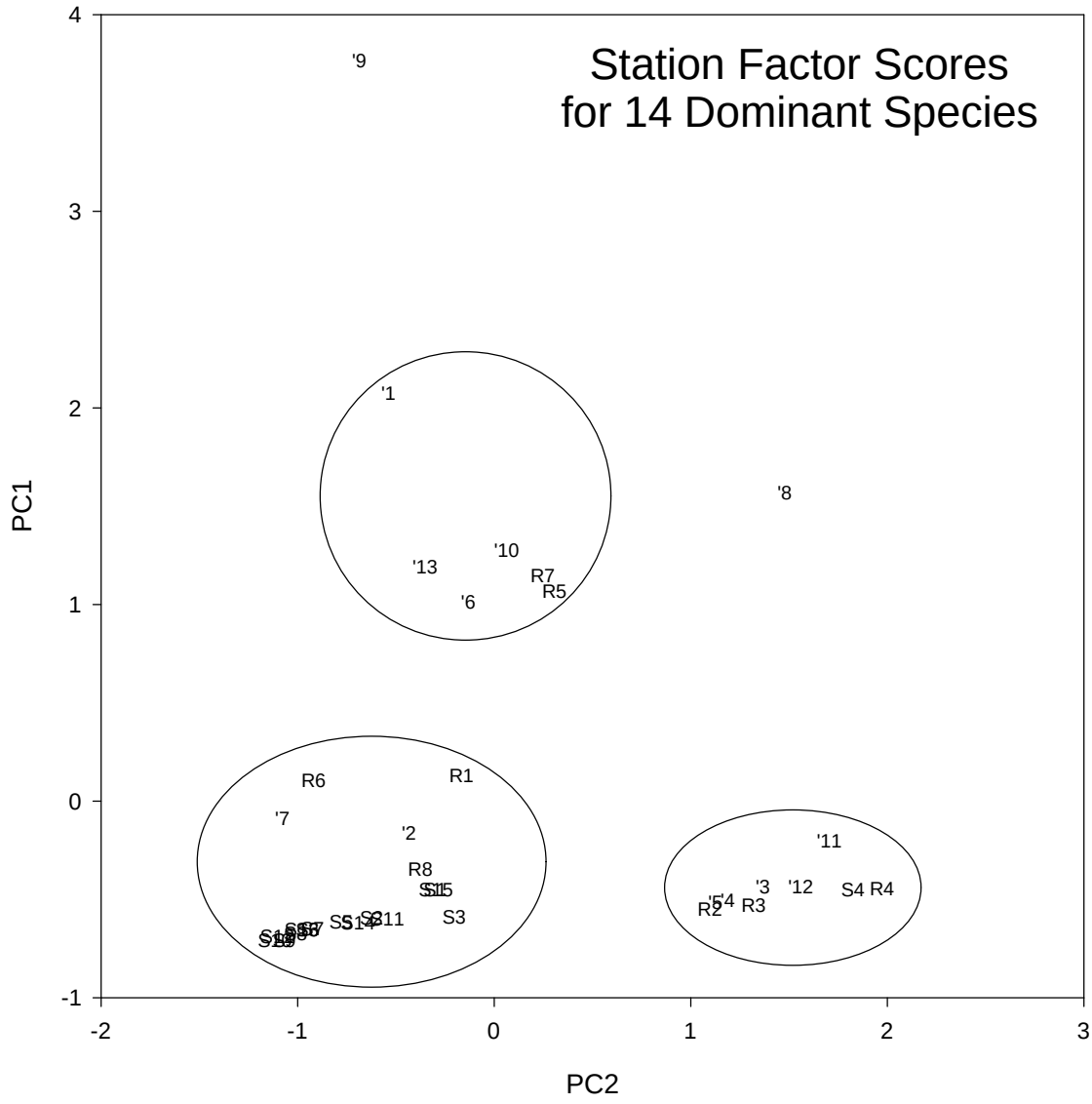


Figure 10. Factor loading scores for stations based on 14 dominant species listed in Figure 9.



Diversity, no matter how it is calculated, was significantly different among all sites ($P < 0.0001$; Table 14). Because there were many rare species, the total number of species found at a site is about twice as great as the average number of species found at a site (Table 14). Site R4 had the highest diversity, 45 species found (Figure 11). The minimum significant distance is about 10, so many sites had similar numbers of species.

The BIBI metrics were calculated for each site (Table 15), and then ranked into 5 groups with values of 0 - 4 (Table 16). Therefore, an average BIBI value of 4.0 would indicate that the site always ranked in the top 20% of sites for every metric. The highest average rank was 3.6 for site 11. In contrast, an average rank of 0 indicates that every metric for the site ranked in the lower 20% of all sites, and two sites, S1 and S15 had this value. Indices < 2 indicate that on average, the site had metric ranks lower than 50% of all sites.

Sediment Microbiological Indicators

A number of sites had elevated sediment total coliform and fecal coliform concentrations (Table 17, Figure 12). The highest values were observed at sites R5 and R6 near Mustang Island and at site 1 in Nueces Bay. It is difficult to interpret these data, however, because no criteria have been established for sediments. It is evident that some areas have considerably higher levels of fecal coliform than most of the sites examined.

Sediment Quality Triad Analysis

The Sediment Quality Triad (SQT) analysis is composed of a correlation between the three main components in the study: sediment chemistry, biological toxicity response, and ecological benthic community response. Each component is actually a composite of many variables as described above, therefore PCA was performed to reduce the number of variables that would go into the final PCA for each component, then the PC's of each component were compared.

There were two initial PCAs performed on the chemistry data set, one on metals and one on hydrocarbons. There was really just one PC, which explained 81% of the variance in the data set (Figure 13). The highest PC1 factor scores were for Pb, Al, Zn, Cr, and Cu. Results for the hydrocarbon data set were similar. There was just one PC, which explained 73% of the variance in the data set (Figure 14). The highest PC1 factor scores were for chlordanes, PCBs, DDTs, and NSTPAHs. Based on these initial PCAs, the following variables were chosen for a reduced set to characterize the physical-chemical environment: Pb, Cu, Zn, Cr, chlordanes, PCBs, DDTs, NSTPAHs, TOC, UAN, sand, clay, salinity, and DO. This group of variables was used in the final PCA for chemistry (ChemPC).

The chemistry component had two PC axes (ChemPC1 and ChemPC2) that represented 69% of the variance in the data set. The first axis, ChemPC1 represents changes in the abiotic setting with respect to contamination, where positive values represent higher concentrations of DDTs,

Table 14.Species diversity pooled by sites. TN=total number of individuals, other diversity indices described in text.

Site	TN	H'	N0	N1	J'	E5
01	163	0.49	10	1.63	0.21	0.34
02	4	0.56	2	1.75	0.81	1.32
03	124	1.95	25	7.00	0.60	0.36
04	161	2.25	18	9.51	0.78	0.66
05	157	2.35	24	10.53	0.74	0.66
06	118	1.62	17	5.08	0.57	0.44
07	102	0.96	10	2.62	0.42	0.38
08	360	1.51	16	4.52	0.54	0.63
09	1062	0.85	14	2.34	0.32	0.58
10	61	1.87	14	6.49	0.71	0.66
11	320	2.68	38	14.62	0.74	0.63
12	267	2.08	24	7.98	0.65	0.63
13	57	1.96	11	7.09	0.82	0.81
R01	53	1.88	9	6.54	0.85	0.81
R02	146	2.34	26	10.38	0.72	0.53
R03	257	3.00	39	20.00	0.82	0.68
R04	469	2.36	45	10.55	0.62	0.54
R05	60	1.42	10	4.13	0.62	0.65
R06	54	1.21	11	3.37	0.51	0.39
R07	62	1.27	8	3.56	0.61	0.57
R08	61	2.63	21	13.88	0.86	0.85
S02	181	0.35	7	1.41	0.18	0.35
S03	162	1.14	13	3.13	0.44	0.39
S04	249	2.58	28	13.24	0.78	0.63
S05	71	0.99	7	2.68	0.51	0.49
S06	85	1.04	7	2.83	0.53	0.69
S07	236	0.68	5	1.97	0.42	0.74
S08	49	1.29	5	3.63	0.80	0.87
S09	96	1.52	13	4.57	0.59	0.65
S10	148	1.37	10	3.95	0.60	0.69
S11	53	2.14	14	8.53	0.81	0.78
S12	106	1.44	13	4.23	0.56	0.61
S13	63	1.57	13	4.80	0.61	0.51
S14	61	1.77	11	5.90	0.74	0.67

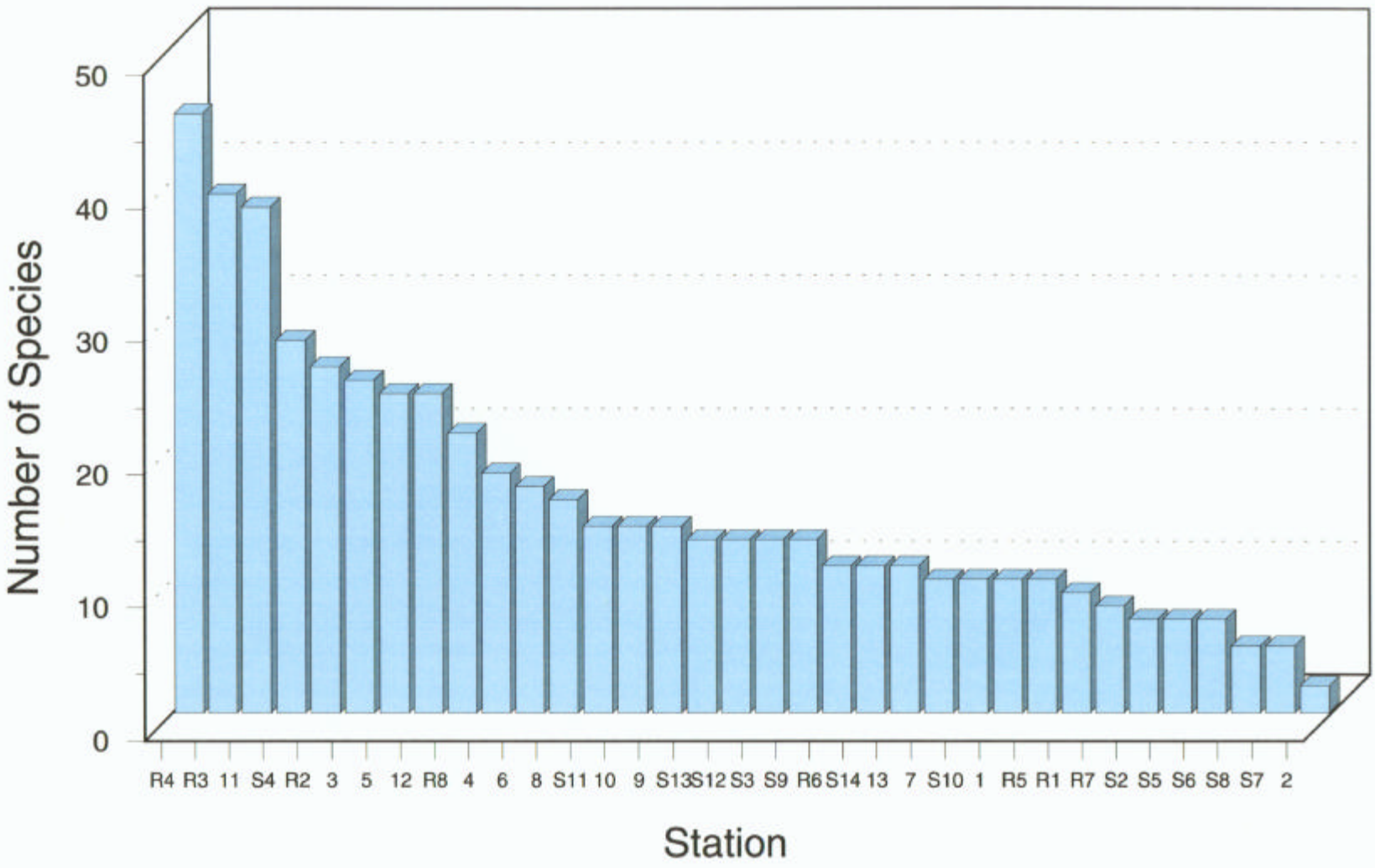


Figure 11. Total number of species found at each site in the CCBNEP study area. Total area sampled was 177 cm^2.

Table 15. Benthic index of biotic integrity metrics. Abbreviations listed in Table 2.

Sta	Biomass ($g\ m^{-2}$)	Density ($n\ m^{-2}$)	H'	%PolInd	%PolSen	%Bm>3	%Den>3	%Sp>3	%Carn/ Omn	%Deep Dep
1	0.56	9,247	0.49	0.06	0.01	0.43	0.21	0.40	0.02	0.04
2	0.03	227	0.56	0.25	0	0	0	0	0	0.75
3	10.49	7,034	1.95	0.98	0.04	0.67	0.39	0.40	0.16	0.13
4	7.39	9,133	2.25	0.94	0.06	0.92	0.48	0.61	0.20	0.22
5	9.39	8,906	2.35	0.99	0.22	0.88	0.39	0.46	0.21	0.24
6	0.34	6,694	1.62	0.75	0.58	0.40	0.07	0.35	0.07	0.65
7	0.37	5,786	0.96	0.92	0	0.78	0.64	0.40	0.06	0.03
8	1.41	20,422	1.51	0.65	0.44	0.41	0.15	0.56	0.04	0.53
9	7.42	60,245	0.85	0.06	0.01	0.42	0.07	0.43	0.03	0.23
10	0.34	3,460	1.87	0.61	0.07	0.81	0.48	0.43	0.05	0.57
11	6.14	18,153	2.68	1.00	0.26	0.79	0.52	0.61	0.18	0.42
12	6.07	15,146	2.08	0.99	0.22	0.89	0.59	0.63	0.05	0.57
13	1.00	3,233	1.96	0.60	0	0.82	0.16	0.45	0.05	0.28
R1	2.55	3,007	1.88	0.77	0.09	0.21	0.38	0.89	0.08	0.34
R2	17.17	8,282	2.34	0.95	0.14	0.86	0.72	0.69	0.24	0.16
R3	11.12	14,579	3.00	0.84	0.14	0.82	0.28	0.33	0.23	0.24
R4	6.40	26,605	2.36	1.00	0.23	0.82	0.67	0.60	0.13	0.31
R5	2.03	3,404	1.42	0.52	0.37	0.91	0.08	0.30	0.05	0.42
R6	0.67	3,063	1.21	0.93	0.02	0.84	0.80	0.64	0.06	0.11
R7	0.20	3,517	1.27	0.35	0.21	0.46	0.19	0.50	0.10	0.26
R8	1.26	3,460	2.63	0.93	0.13	0.81	0.34	0.48	0.34	0.33
S1	0	0	0	0	0	0	0	0	0	0
S2	1.33	10,268	0.35	0.07	0.00	0.03	0.06	0.71	0.02	0.01
S3	1.11	9,190	1.14	0.27	0.00	0.57	0.11	0.46	0.09	0.03
S4	8.82	14,125	2.58	1.00	0.14	0.66	0.53	0.61	0.19	0.27
S5	1.45	4,028	0.99	0.27	0.00	0.14	0.15	0.43	0.18	0.00
S6	0.22	4,822	1.04	0.41	0.00	0.28	0.15	0.43	0.05	0.00
S7	0.60	13,388	0.68	0.28	0.00	0.21	0.17	0.60	0.00	0.00
S8	0.13	2,780	1.29	0.57	0.00	0.57	0.24	0.60	0.16	0.00
S9	0.75	5,446	1.52	0.89	0.00	0.36	0.35	0.38	0.34	0.02
S10	0.88	8,396	1.37	0.91	0.01	0.27	0.36	0.60	0.46	0.03
S11	1.03	3,007	2.14	0.75	0.15	0.60	0.28	0.57	0.19	0.15
S12	0.63	6,013	1.44	0.96	0.02	0.30	0.07	0.15	0.47	0.03
S13	2.27	3,574	1.57	0.97	0.06	0.54	0.51	0.38	0.27	0.06
S14	0.38	3,460	1.77	0.93	0.08	0.40	0.43	0.45	0.28	0.23
S15	0	0	0	0	0	0	0	0	0	0

Table 16. Ranks for BIBI variables and average rank over all.

Sta	Biomass	Density	H'	%PolInd	%PolSen	%Bm>3	%Den>3	%Sp>3	%Carn/ Omn	%Deep Dep	BIBI
11	3	4	4	4	4	3	4	3	3	4	3.6
12	3	4	3	4	4	4	4	4	1	4	3.5
R4	3	4	4	4	4	4	4	3	2	3	3.5
S4	4	4	4	4	3	2	4	4	3	3	3.5
5	4	3	4	4	4	4	3	2	3	3	3.4
R2	4	2	4	3	3	4	4	4	4	2	3.4
4	4	3	3	3	2	4	3	4	3	2	3.1
R3	4	4	4	2	3	3	2	0	3	2	2.7
R8	2	1	4	3	3	3	2	2	4	3	2.7
3	4	2	3	4	2	3	3	1	2	2	2.6
8	2	4	2	2	4	1	1	3	1	4	2.4
R1	3	0	3	2	3	0	3	4	2	3	2.3
S13	3	1	2	4	2	2	3	1	4	1	2.3
R6	1	0	1	3	2	4	4	4	1	2	2.2
S10	2	3	2	2	2	1	2	3	4	1	2.2
S11	2	0	3	2	3	2	2	3	3	2	2.2
10	1	1	3	2	2	3	3	1	1	4	2.1
R5	3	1	2	1	4	4	1	0	1	4	2.1
S14	1	1	2	3	2	1	3	2	4	2	2.1
7	1	2	1	3	0	3	4	1	2	1	1.8
13	2	1	3	1	0	3	1	2	1	3	1.7
6	0	2	2	2	4	1	0	0	2	4	1.7
R7	0	1	1	1	3	2	2	2	2	3	1.7
S9	2	2	2	2	0	1	2	1	4	1	1.7
S12	1	2	2	3	2	1	0	0	4	1	1.6
9	4	4	0	0	1	2	0	1	0	2	1.4
S3	2	3	1	0	0	2	1	2	2	1	1.4
S5	3	2	1	1	0	0	1	1	3	0	1.2
1	1	3	0	0	1	2	2	1	0	1	1.1
S8	0	0	1	1	0	2	2	3	2	0	1.1
S2	2	3	0	0	0	0	0	4	0	0	0.9
S7	1	3	0	1	0	0	1	3	0	0	0.9
S6	0	2	1	1	0	1	1	1	1	0	0.8
2	0	0	0	0	0	0	0	0	0	4	0.4
S1	0	0	0	0	0	0	0	0	0	0	0
S15	0	0	0	0	0	0	0	0	0	0	0

Table 17. Sediment total coliform and fecal coliform numbers for Corpus Christi Bay, Nueces Bay and surrounding areas.

Site	Total Coliform MPN [1]			Geometric Mean[2]	Fecal Coliform MPN [1]			Geometric Mean[2]
	1	2	3		1	2	3	
1	51.4	240.5	182.5	131.1	14.2	1771.2	1644.5	346.2
2	288.4	8.0	37.1	44.2	<1.6	8.1	1.5	2.7
3	234.9	24.8	59.9	70.4	5.7	<1.4	3.2	3.0
4	<1.5	1.4	3.0	1.8	<1.5	1.4	<1.4	1.4
5	1.2	49.6	1.2	4.2	1.2	<1.3	<1.3	1.3
6	3.2	9.4	127.7	15.6	<1.2	<1.1	7.1	2.1
7	98.0	9.2	117.8	47.4	25.2	26.1	37.7	29.1
8	5.1	2.5	5.0	4.0	<1.4	<1.4	93.3	5.6
9	27.7	150.0	155.5	86.5	32.6	150.0	85.9	74.9
10	1.5	17.3	<1.5	3.4	21.4	17.3	<1.6	8.4
11	691.3	63.2	1.5	40.4	<1.5	1782.8	2946.5	199.0
12	<1.5	1.5	<1.5	1.5	<1.5	<1.5	<1.5	1.5
13	24.9	13.0	104.8	32.4	<1.5	<1.6	3.1	2.0
S1	<0.8	<0.7	<0.7	0.7	**	**	**	**
S2	1578.3	235.0	5.1	123.6	1005.0	<1.4	<1.5	13.0
S3	23.7	97.3	16.5	33.6	56.4	13.0	3.4	13.5
S4	<1.2	<1.2	15.0	2.8	<1.2	<1.2	1.3	1.2
S5	<1.5	<1.5	915.5	12.8	<1.5	<1.5	<1.5	1.5
S6	<1.5	1598.7	6.8	25.4	<1.5	285.1	23.1	21.4
S7	1228.3	110.5	80.8	222.2	1605.6	59.8	36.9	152.5
S8	36.9	26.1	53.6	37.3	7.0	<1.5	8.3	4.4
S9	3.4	17.2	23.0	11.1	<1.5	1.5	23.0	3.7
S10	14.1	97.5	22.4	31.4	7.0	9.6	<1.5	4.7
S11	<1.5	<1.5	<1.5	1.5	<1.5	<1.5	<1.5	1.5
S12	<1.6	<1.6	<1.5	1.6	<1.6	<1.6	<1.5	1.6
S13	<1.5	6.3	25.4	6.3	<1.5	3.4	1.5	2.0
S14	<1.5	1.6	<1.6	1.6	<1.5	<1.6	<1.6	1.6
S15	31.0	22.5	24.7	25.8	39.4	918.5	8.1	66.4
R1	472.0	185.1	269.3	286.5	425.4	87.2	14.5	81.4
R2	25.3	**	**	25.3	48.9	44.0	234.2	79.6
R3	<0.9	<1.0	1.8	1.2	1.6	<1.0	6.1	2.1
R4	1.1	1.1	<1.2	1.3	19.1	6.7	7.1	9.7
R5	3266.6	126.0	110.4	356.8	4751.2	5728.5	1.5	344.3
R6	186624.0	2432.2	28.6	2349.2	735.4	13297.5	13.0	502.3
R7	5.3	4.1	3.3	4.1	0.8	<0.9	<0.8	0.8
R8	16.7	9.1	10.5	11.7	<1.6	<1.5	96.5	6.1

[1] Most probable number of organisms (MPN/100 ml) present based on probability formulas.

[2] The detection limit value was used to calculate geometric means.

** Value missing due to technical error.

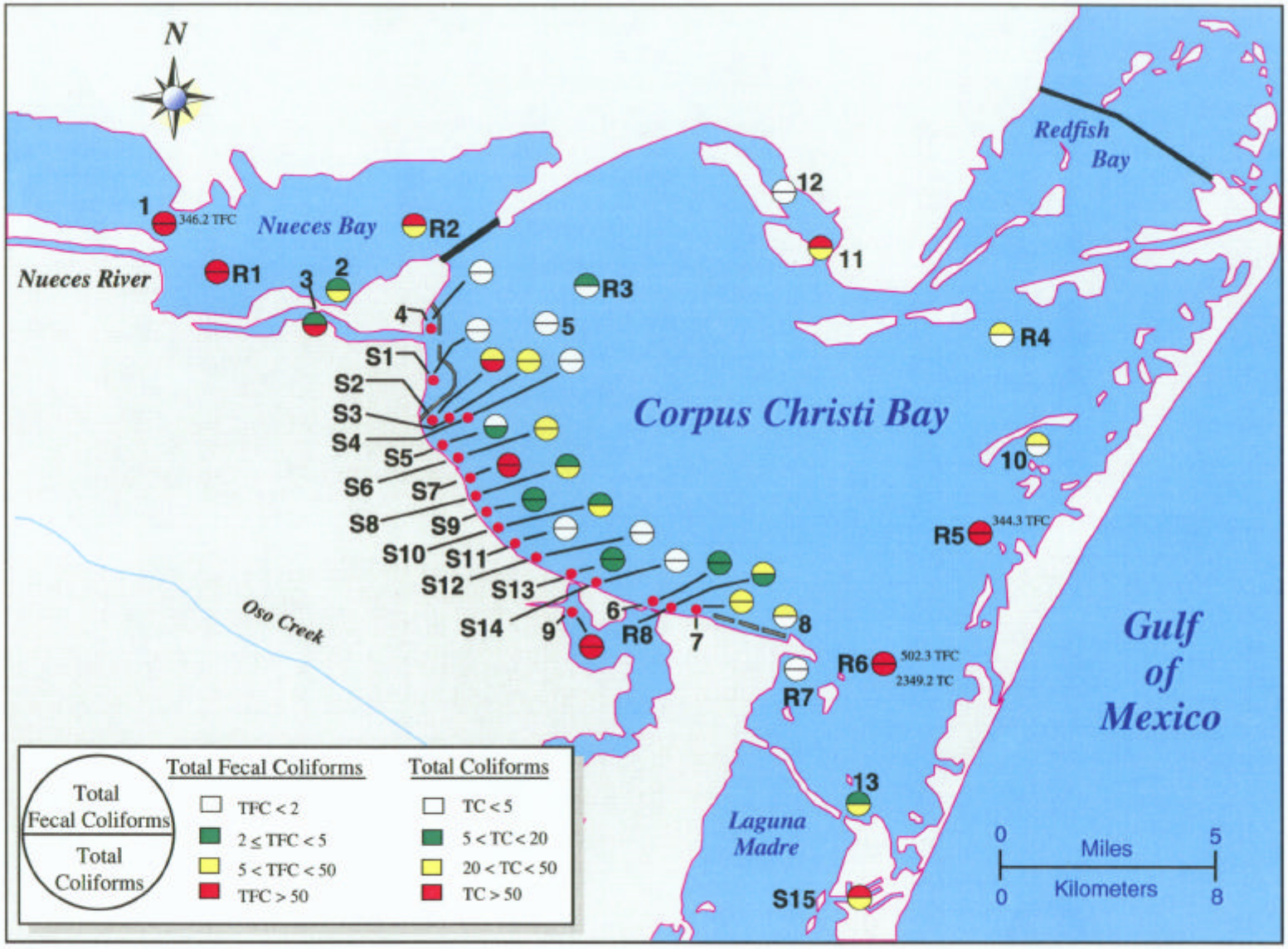


Figure 12. Total fecal coliforms (MPN) and total coliforms (MPN) for sites in the CCBNEP study area.

Figure 13. Factor pattern scores for metals

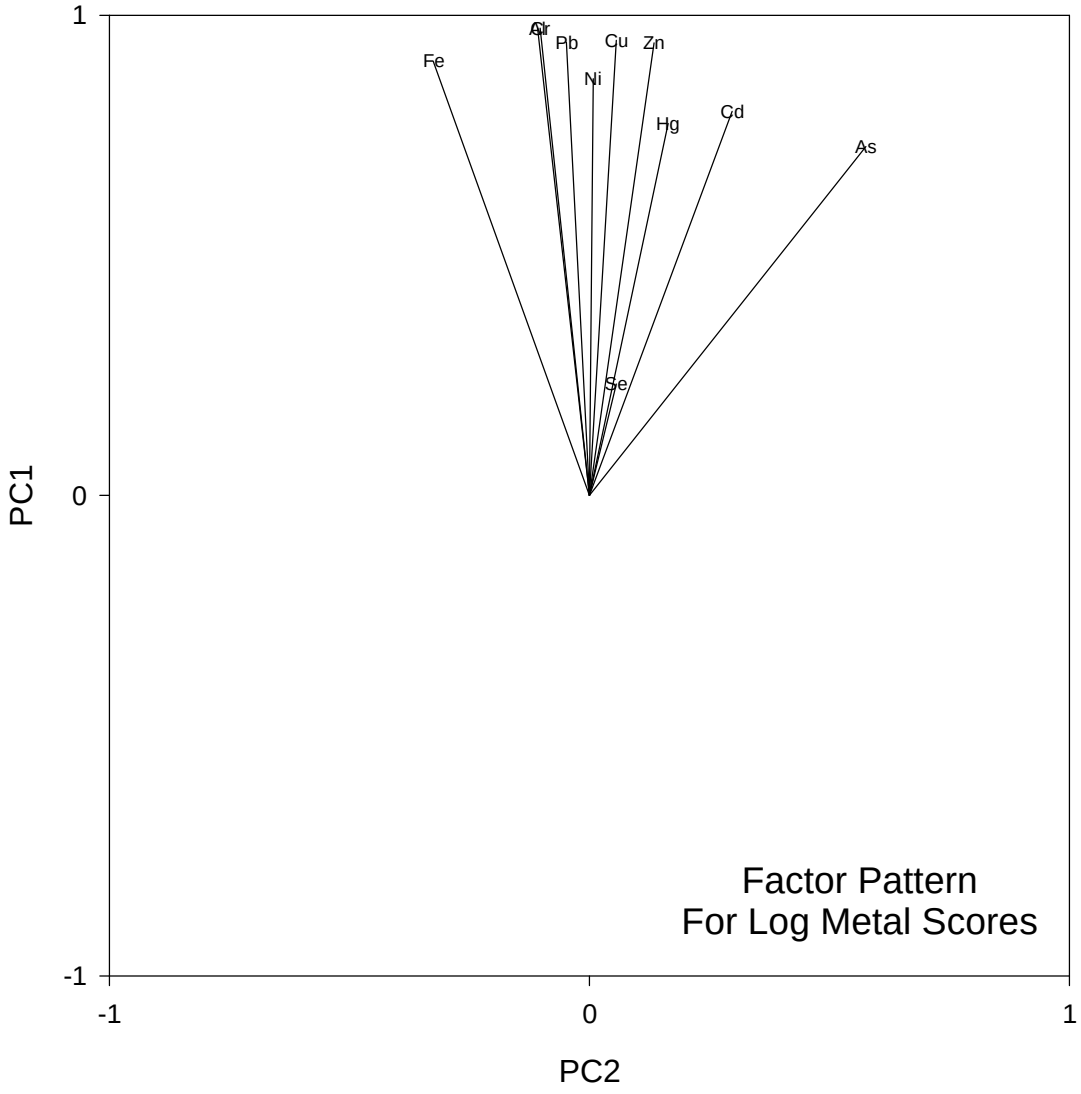
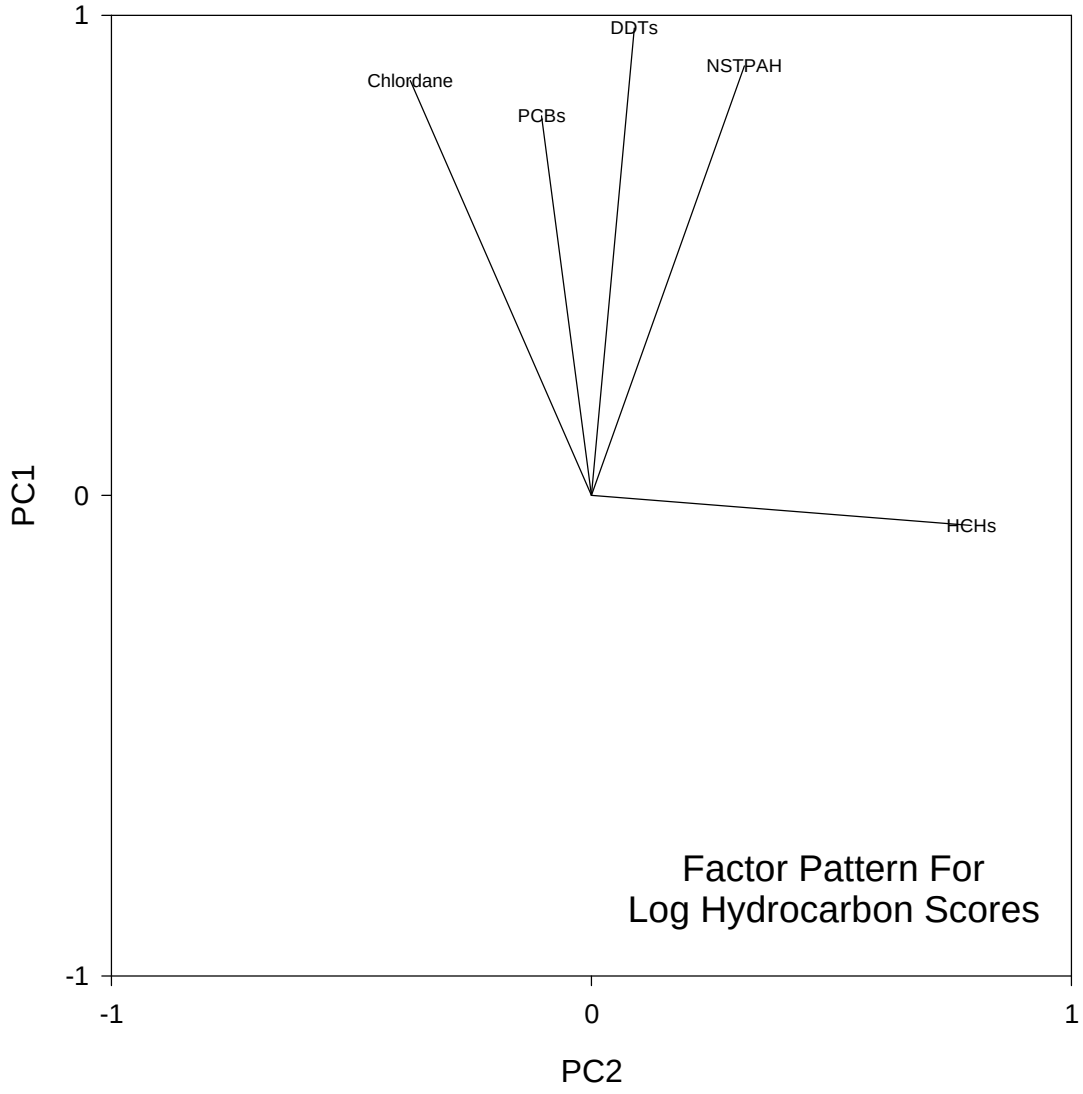


Figure 14. Factor pattern scores for pooled hydrocarbon classes.



NSTPAHs, PCBs, and chlordanes (Figure 15). Also loading high (>0.5) were the metals Pb, Cu, Zn, and Cr, and TOC. ChemPC1 explained 48% of the variance in the data set. Natural hydrographic and geological differences among the sites as well as the concentration of several metals contributed to the variance in the second axis, Chem PC2 (Figure 15). Positive ChemPC2 values are due to sediments with high clay and porewater ammonia (UAN) content, high salinity and elevated concentrations of metals. Negative values of ChemPC2 are due to sediments with high sand content and bottom water DO. ChemPC2 contained 21% of the variance in the data set.

Four sites, S9, S1, S2, and 8 had the highest levels of contaminants, i.e., positive values of ChemPC1 between 2.3 and 1.5 (Figure 16). The two highest values, S9 and S1 were high for different reasons. Site S9 had high values for organics (NSTPAHs, DDTs, and PCBs), while S1 had high metal values (Pb, Cu, and Zn) and some organics (DDTs and PCBs). The next 8 highest sites (in declining order: S8, 4, S4, S3, R7, S6, 6, and S14) all had at least one constituent concentration that was above the effects range low (ER-L; Long et al., 1995) sediment quality guideline. Site S7 had a chlordane value above the ER-L, but only had a ChemPC1 score of 0.08. This indicates that all the sites with positive ChemPC1 values should be treated with concern.

The separation along axis ChemPC2 is driven primarily by two sites: S15 and 9 (Figure 16). Site S15 had the highest score, had the highest salinity, was relatively uncontaminated, but had near anoxic conditions (0.3 mg/L DO) and the third highest UAN value. Site 9 had the lowest ChemPC2 score, was also relatively uncontaminated, had the lowest salinity, and highest DO value (14.6 mg/L DO) because it was near a waste water treatment disposal where the freshwater is aerated before entering the bay. The axis ChemPC2 is also separating sandy from muddy sediments. Almost all storm drain sites, which were near high energy shorelines had negative ChemPC2 scores. The exception, S15, was also dominated by sandy sediments (72%).

A PCA was also performed on the toxicity data and the first two factors explained 89% of the variation in the data set (Figure 17). The first factor explained 69% of the variance, and was structured by UrchEmbr (percentage of normal developing urchin embryos), UrchFert (percent urchin fertilization), MysidSurv (mysid survival), and Ampesurv (ampeliscid survival) (Figure 17). High values of PC1 represent high rates of fertilization, development, growth and survival. The second factor explained an additional 21% of the variance and separated MysidGrow (mysid growth rate) from the previous four variables. A series of sites had negative PC1 scores indicating that they all had high toxicity (Figure 18). The lowest scores were for sites (S1, S15, R1, and R7) with the highest toxicity rates. Two sites (S6 and S5) had neutral scores or moderate level of toxicity. All other sites that had positive PC1 scores are thus related to low or background toxicity. For the SQT analysis, the first site factor is used as ToxPC1 and the second site factor is used as ToxPC2.

Figure 15. Factor pattern scores for a reduced set of sediment chemical contaminants and physical variables.

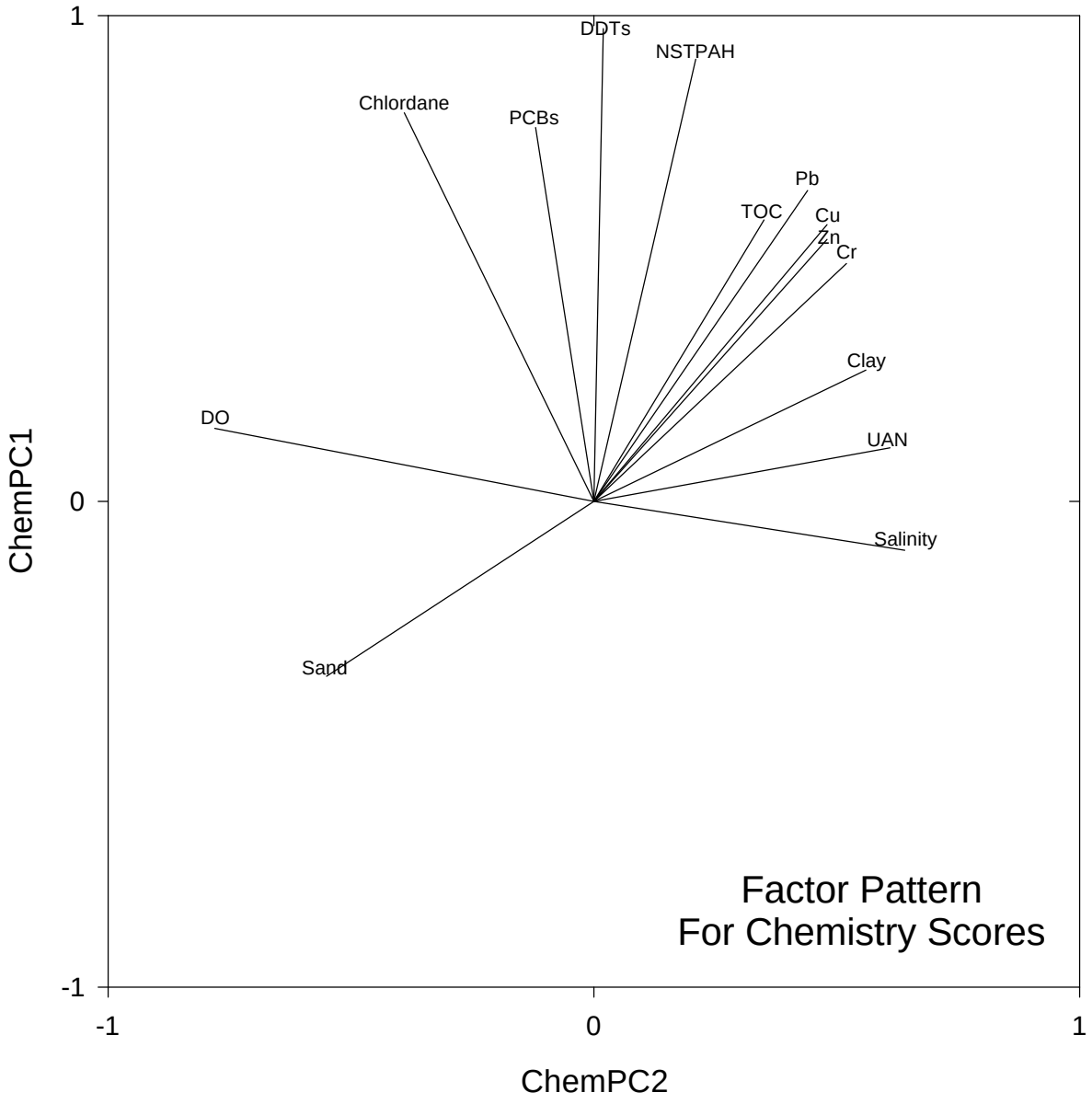


Figure 16. Factor loading scores for sites based on physical-chemical variables shown in Figure 15.

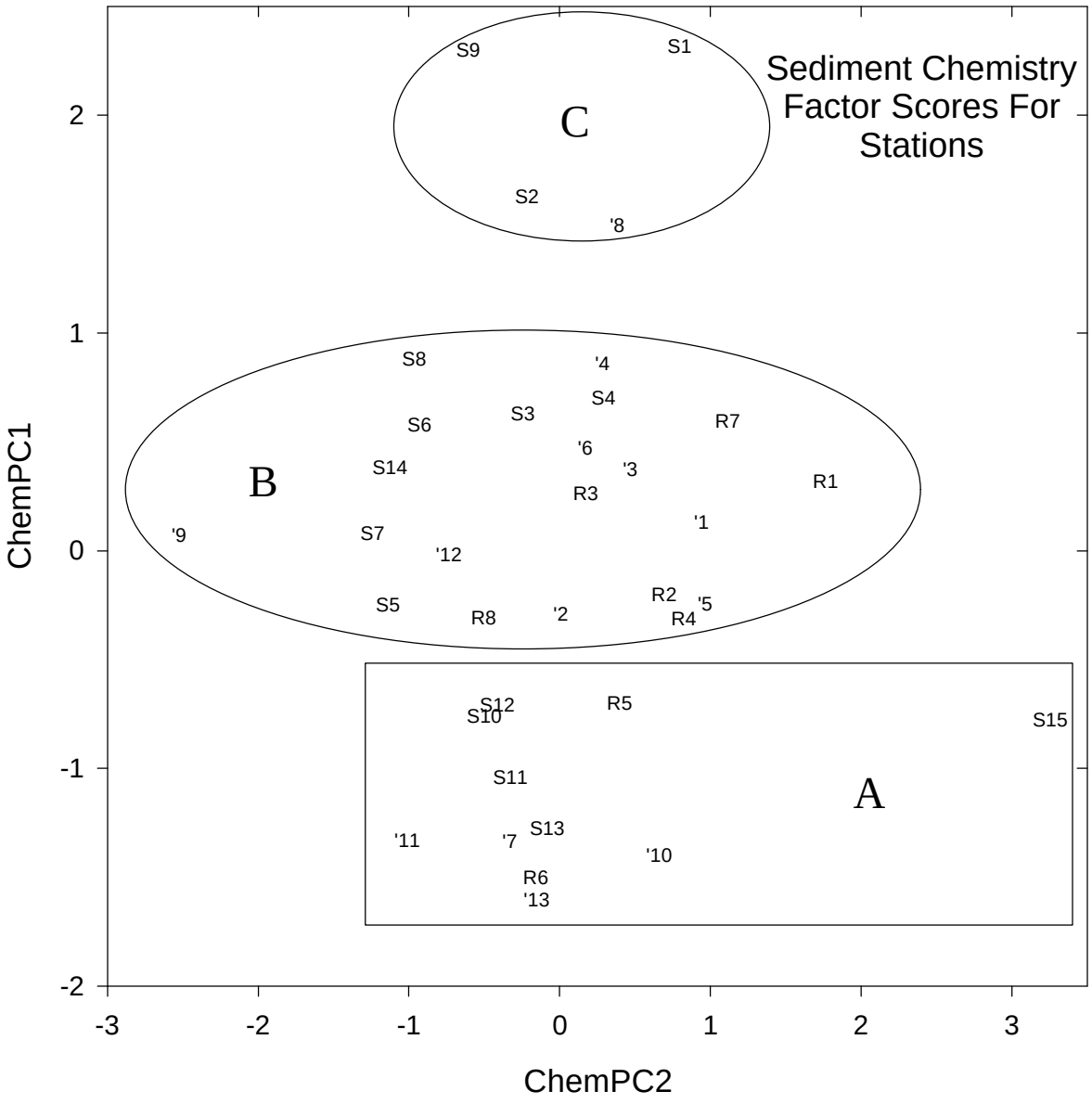


Figure 17. Factor pattern scores for toxicity tests. Abbreviations: UrchEbmr = percent of normal developing urchin embryos, UrchFert = urchin fertilization percent, MysidGrow = mysid growth, MysidSurv = mysid survival, Ampesurv = ampeliscid survival

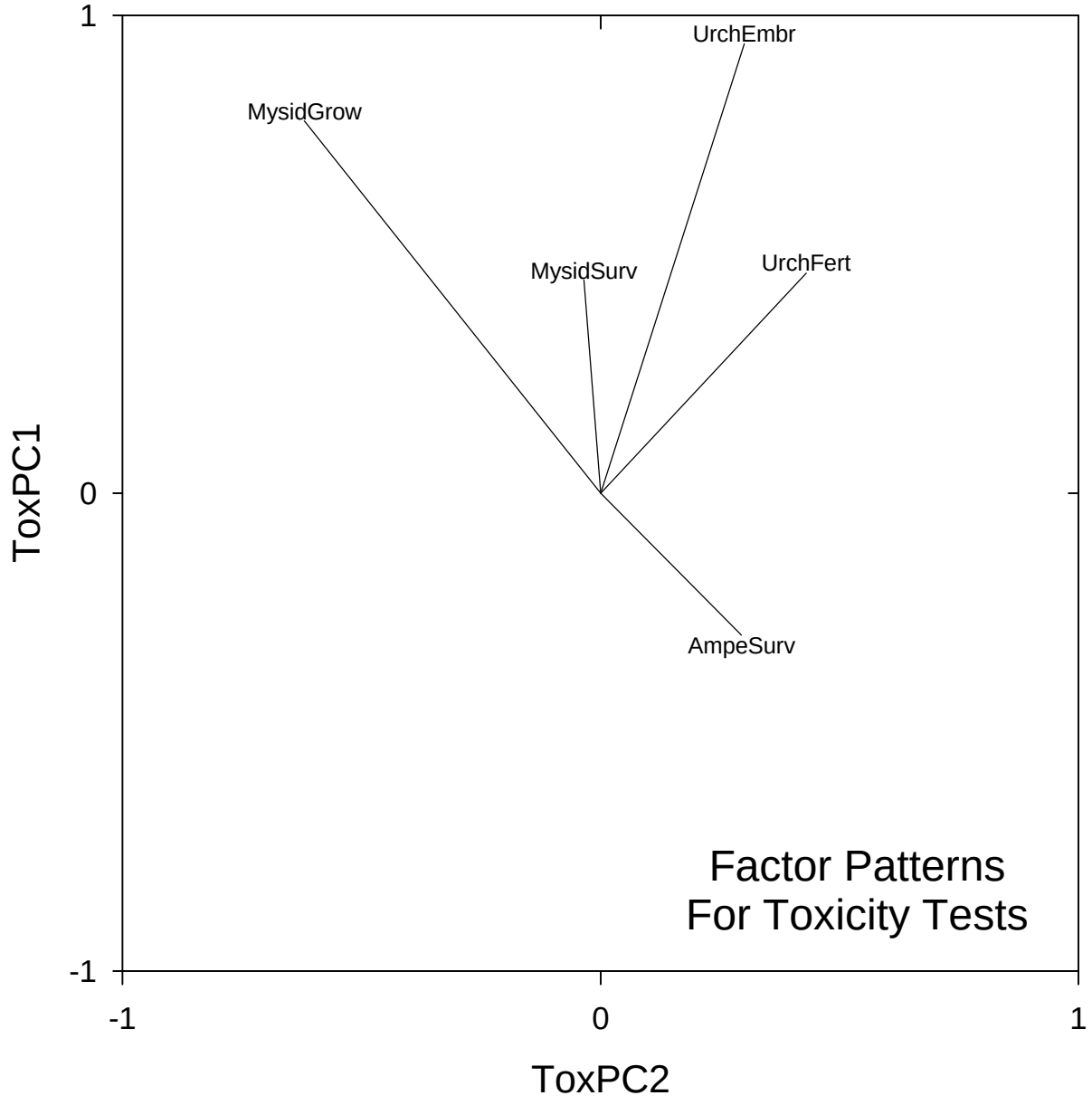
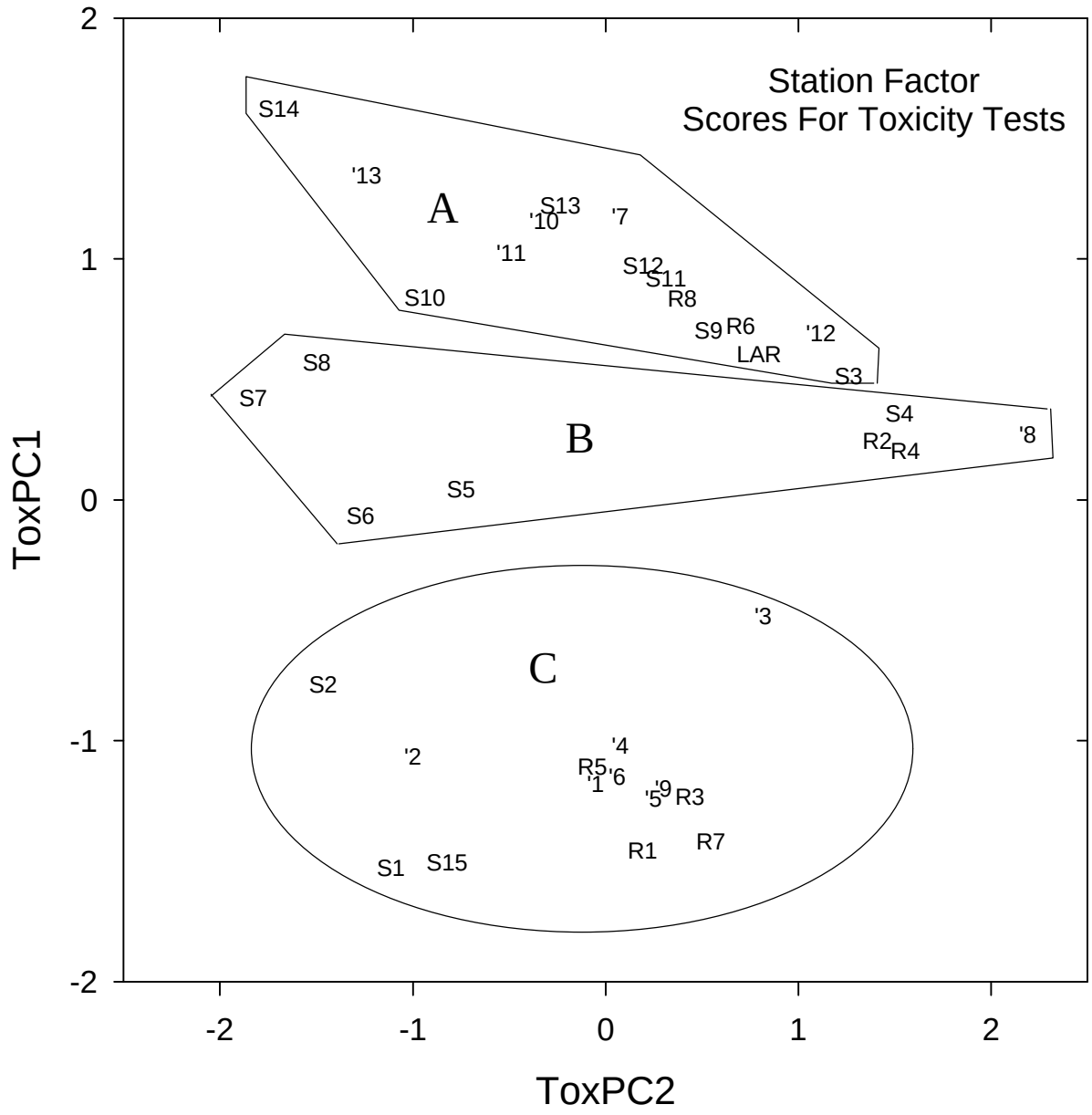


Figure 18. Factor loading scores for sites based on toxicity variables shown in Figure 17.



A PCA was performed on the 10 BIBI metrics (Tables 2 and 15). High values of PC1 indicate high values of all metrics (Fig. 19). So, PC1 is an average benthic index. High values of PC2 indicate a high percentage of pollution sensitive and deep-dwelling deposit feeders, which indicates a healthy benthic system. Therefore, sites with high PC1 and high PC2 values are the areas with the healthiest benthic characteristics. Negative values of PC2 are due to high percentages of pollution indicator species and carnivore/omnivores. It is not easy to separate carnivores from omnivores, so they are lumped together. It is clear that PC2 is discriminating between trophic groups (i.e., carnivore/omnivores versus deposit feeders) and pollution sensitivity (i.e., pollution indicator versus pollution sensitive species). The sites fall in three categories that have healthy, neutral, or degraded characteristics (Fig. 20). The sites with good and neutral ecological indicator scores are obvious due to positive PC1 values and high BIBI scores. Based on PC1 alone three sites (S12, S9, and S8) might be considered neutral. However, these sites had the lowest overall pollution indicator (i.e., PC2) values. Arguably, site S10 might also be included as a degraded sites because it had the absolute lowest PC2 score even though it also had a positive PC1 score.

Toxicological (ToxPC1 and ToxPC2) and ecological responses (EcolPC1 and EcolPC2) were correlated with ChemPC1 and ChemPC2 to determine if a relationship exists between contaminants and responses (Table 18, Figures 21-25). There was a significant correlation with ToxPC1 and ChemPC1 indicating that as contaminants increase, negative values for toxicity increase (Figure 21). ToxPC2 was significantly related to EcolPC1 which means that where mysid growth was poor, pollution indicator species were present.

Sites S1 and S15, which had no organisms and were completely toxic, acted as levers in the EcolPC1 data set (Figure 20). The sites of concern can be identified as those with high contaminants and high toxicity as the lower right quadrant in Figure 21. These sites include: S1, S2, S6, 1, 3, 4, 6, 9, R1, R3, R7. Other sites had high toxicity (R5, S15, 2, and 5), but this was not due to the contaminants analyzed for in this study. The observed toxicity may have been due to unmeasured contaminants, the natural background variables, or a combination of these factors (Figure 22). There was a positive correlation between EcolPC1 and ToxPC1 (Fig. 24). The lower left hand quadrant identifies sites of concern where toxicity is high and benthic response is low. This includes sites S1, S15, 1, 2, and S2, R7 and 9. Other sites in this region are S5 and S6 with moderate toxicity and poor benthic quality, and sites R1, R5, and 6 with high toxicity but moderate benthic response. All toxicology and benthic components correlated with one another (Figure 25). High benthic indices (EcolPC1) increased with increasing mysid growth (ToxPC2). Pollution sensitive species (EcolPC2) decreased with increasing toxicity (ToxPC1). Overall, sites form clusters based on both contaminant and natural background variability, and this gradient can be related to both toxic and ecological responses.

Figure 19. Factor pattern scores for benthic index variables.

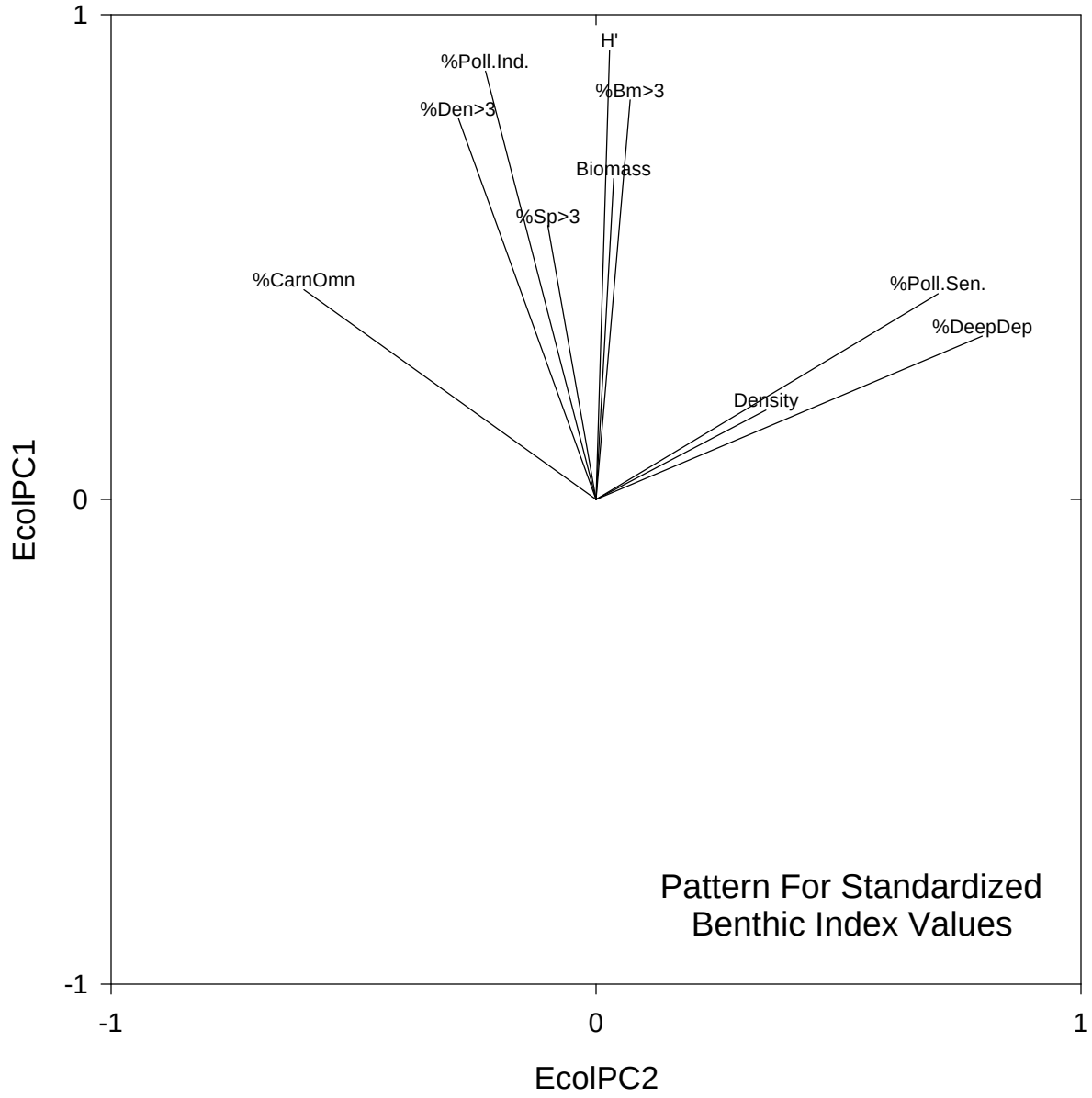


Figure 20. Factor loading scores for stations based on benthic index variables shown in Figure 19.

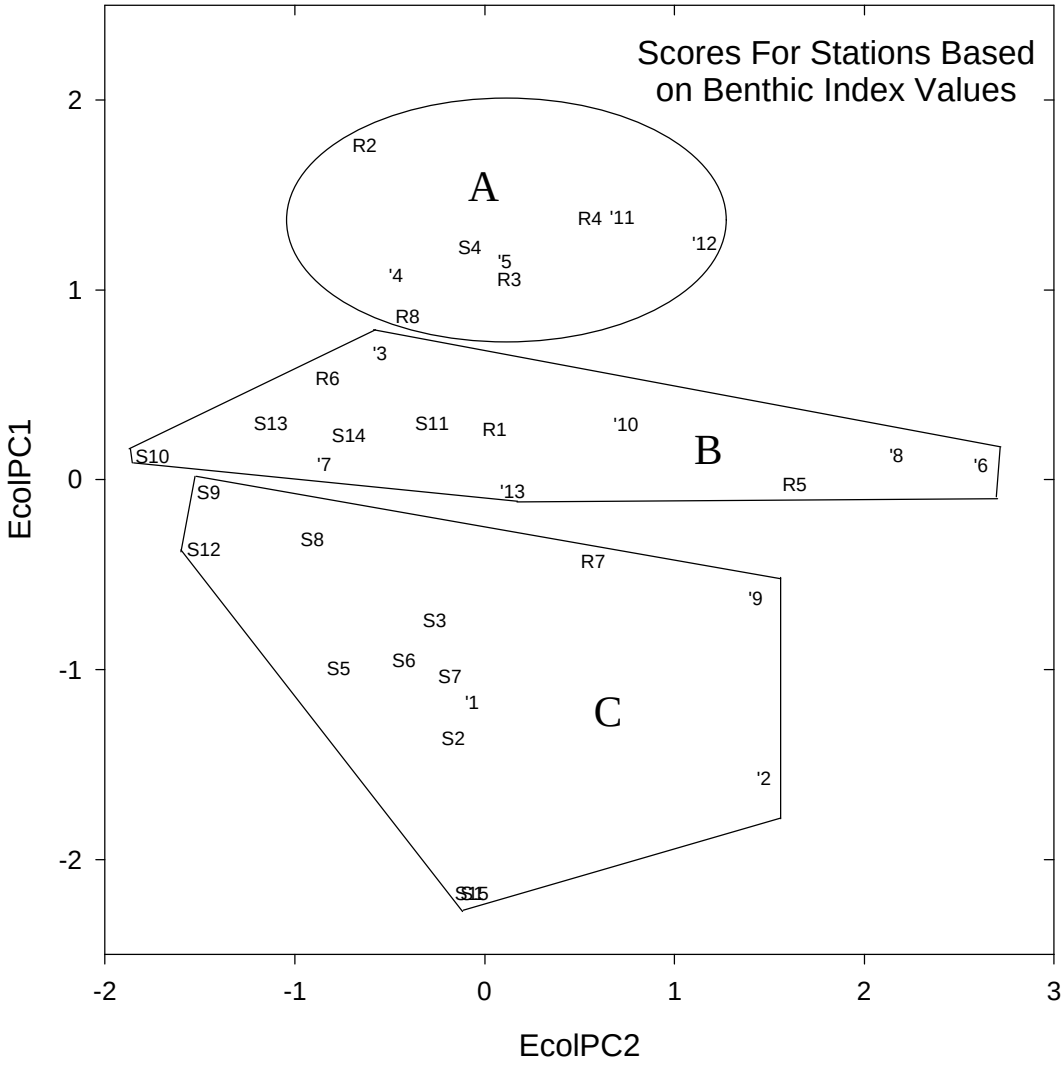


Figure 21. Toxicological (ToxPC1) responses to contaminant concentrations (ChemPC1).

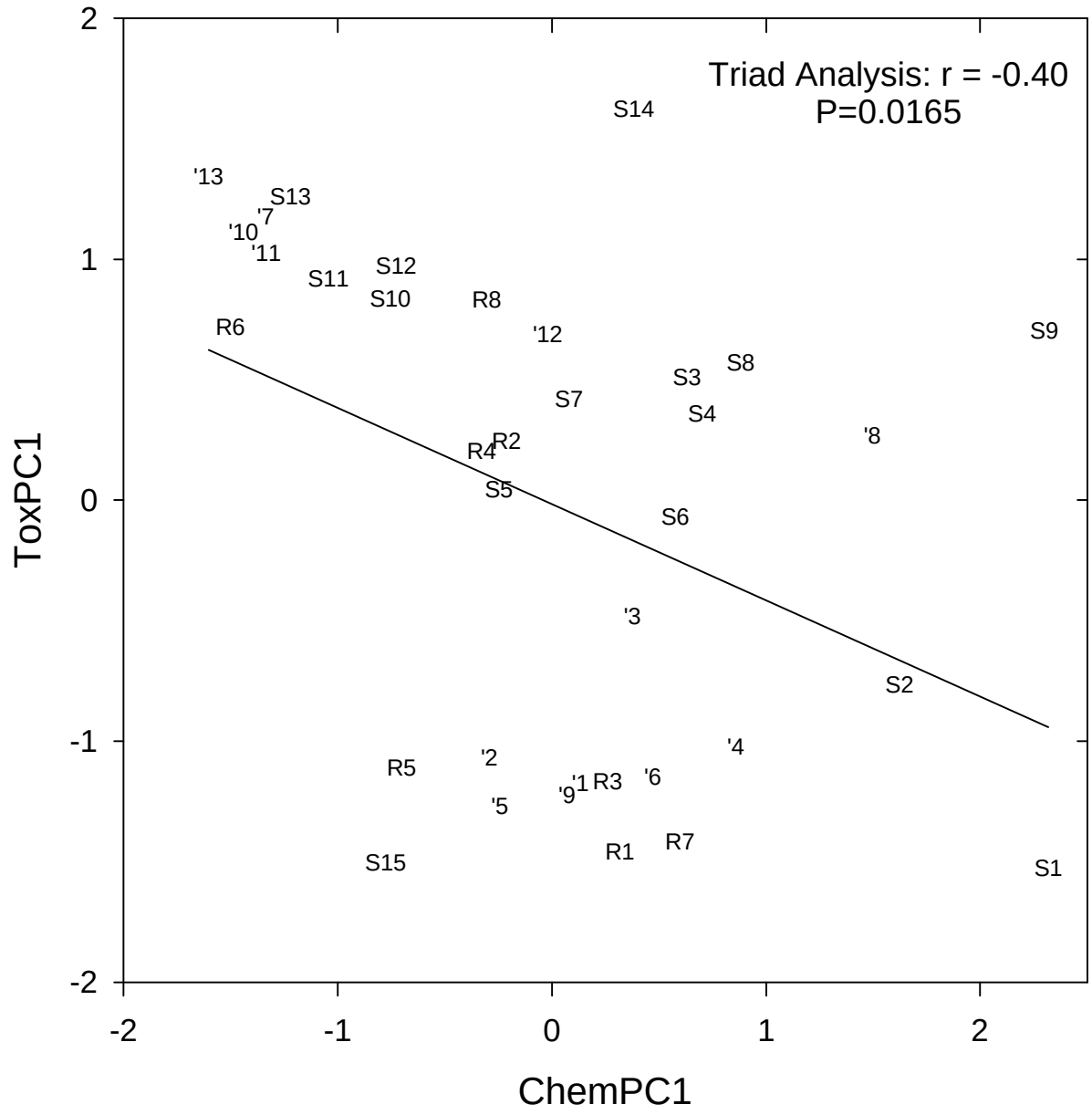


Figure 22. Toxicological (ToxPC1) responses to natural background parameters and metal concentrations (ChemPC2).

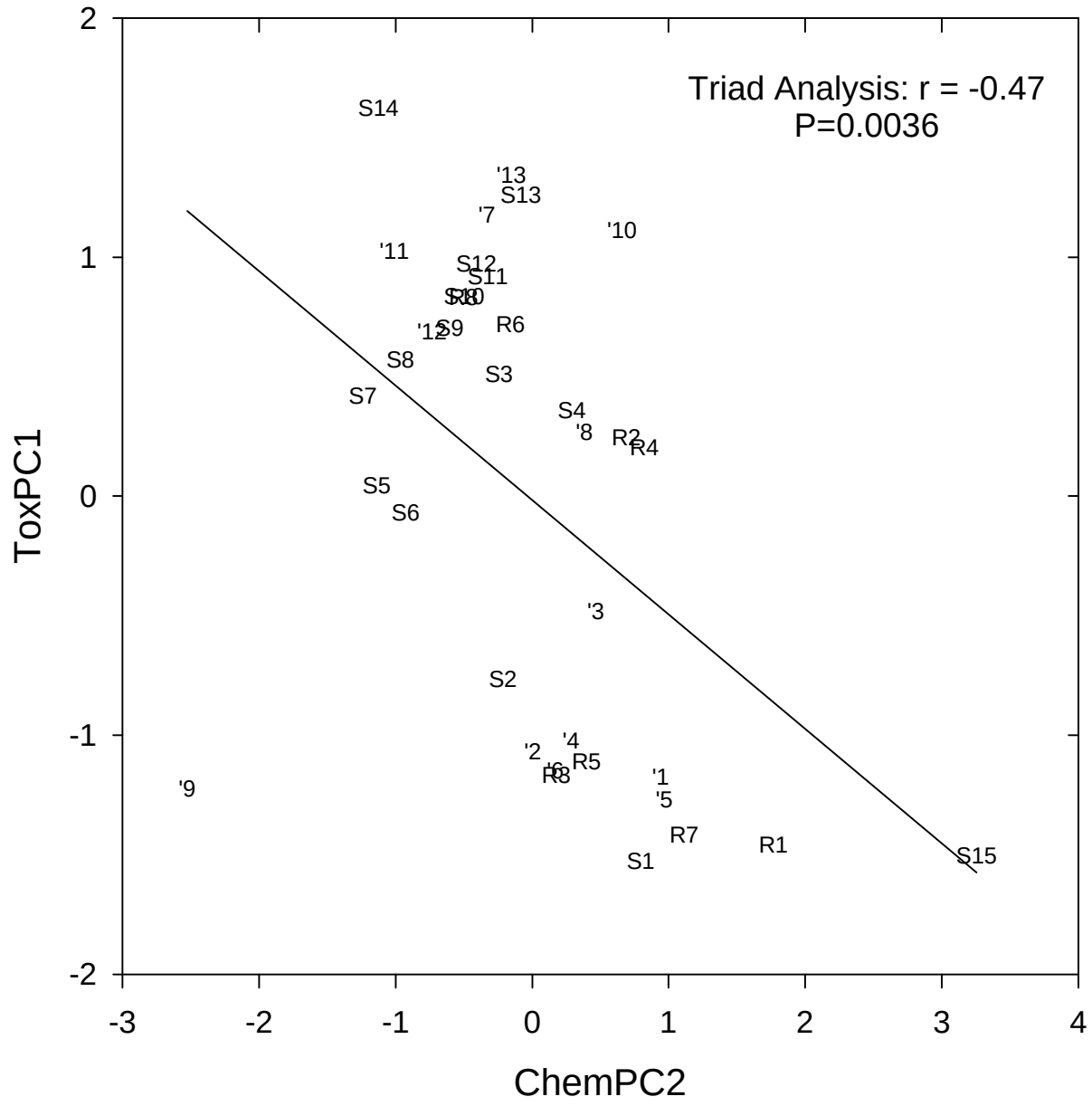


Figure 23. Ecological (EcolPC1) response to chemical concentrations (ChemPC1).

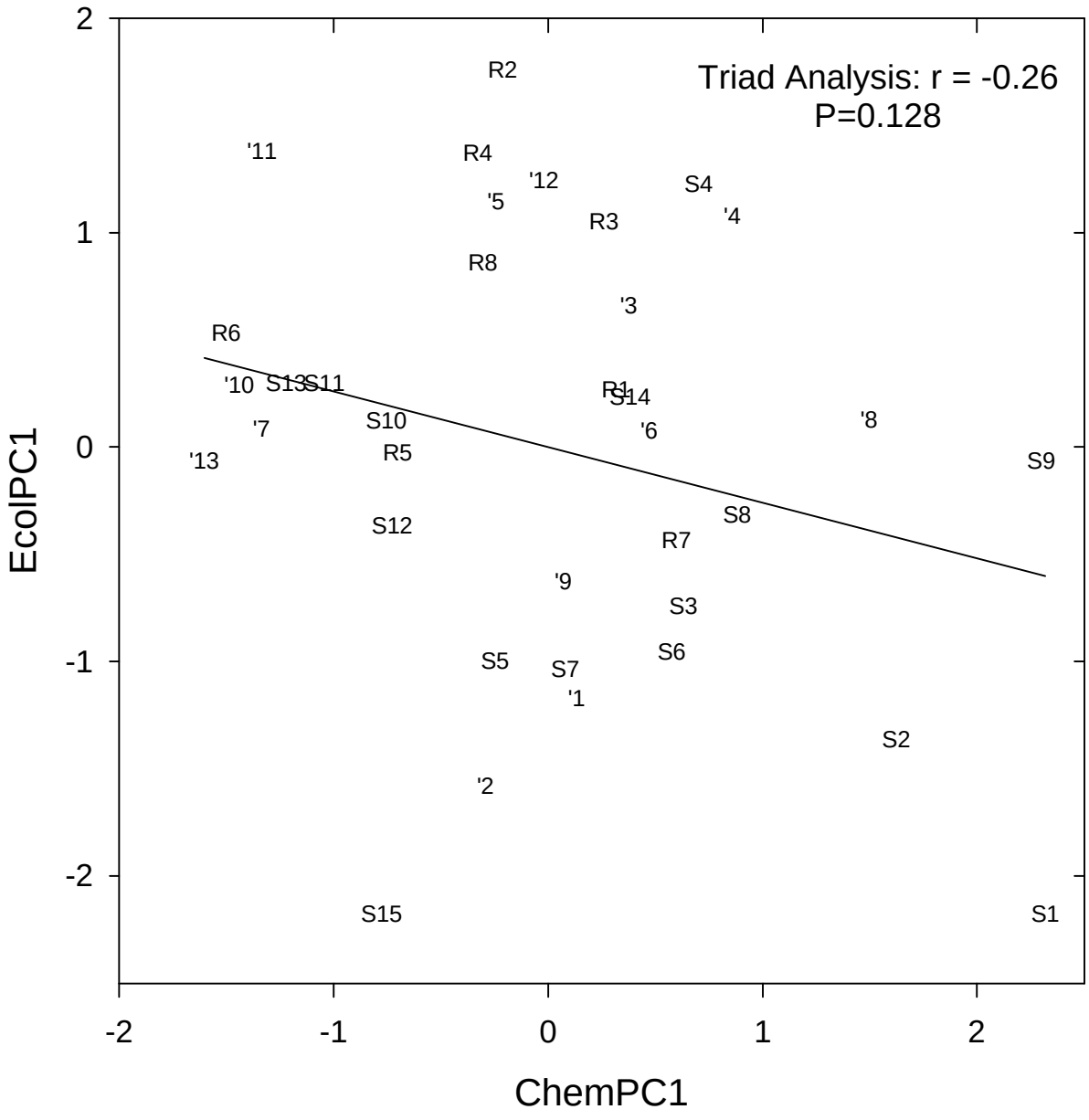


Figure 24. Ecological (EcolPC1) response to toxicity (ToxPC1).

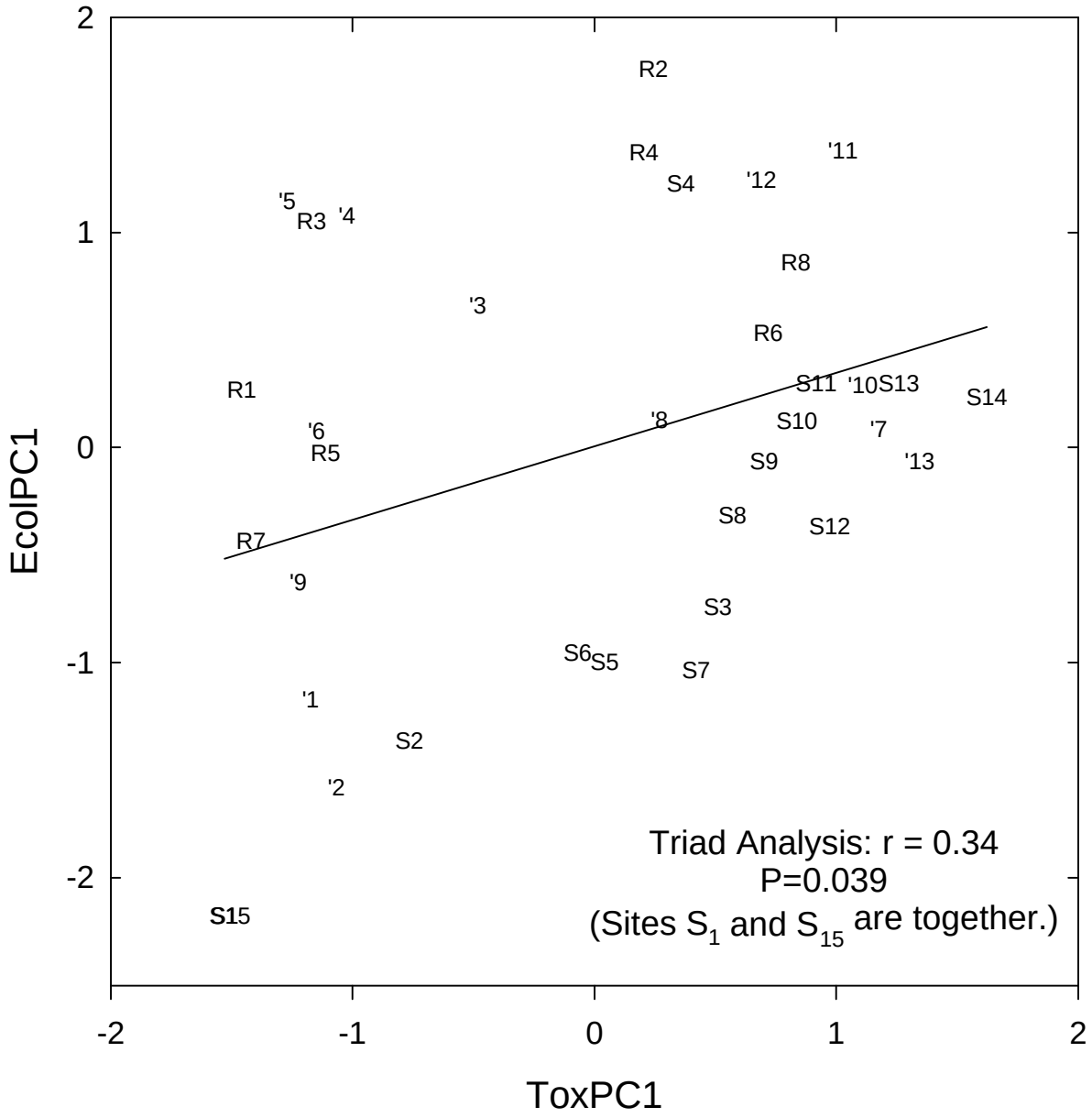
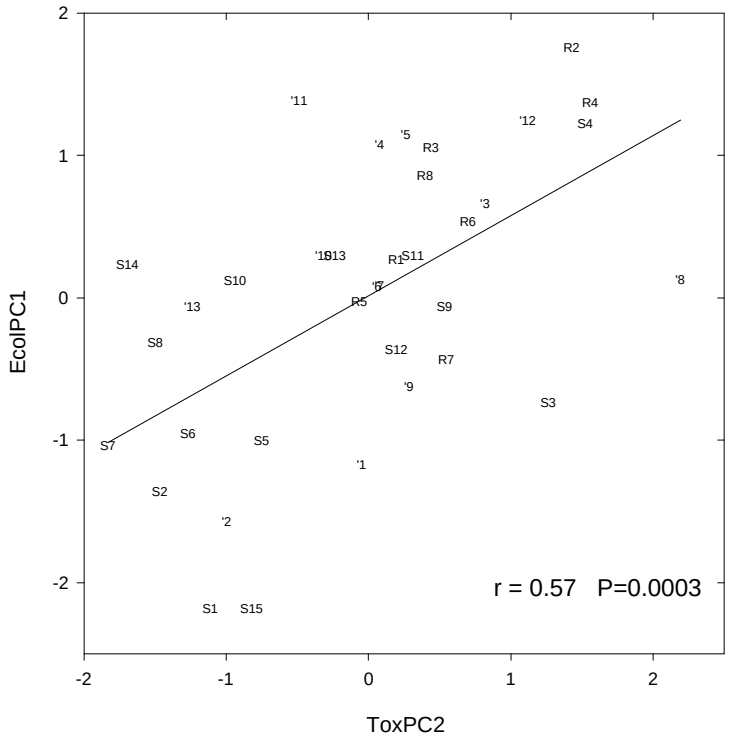


Figure 25. Ecological (EcolPC1 and EcolPC2) response to toxicity (ToxPC2 andToxPC1).



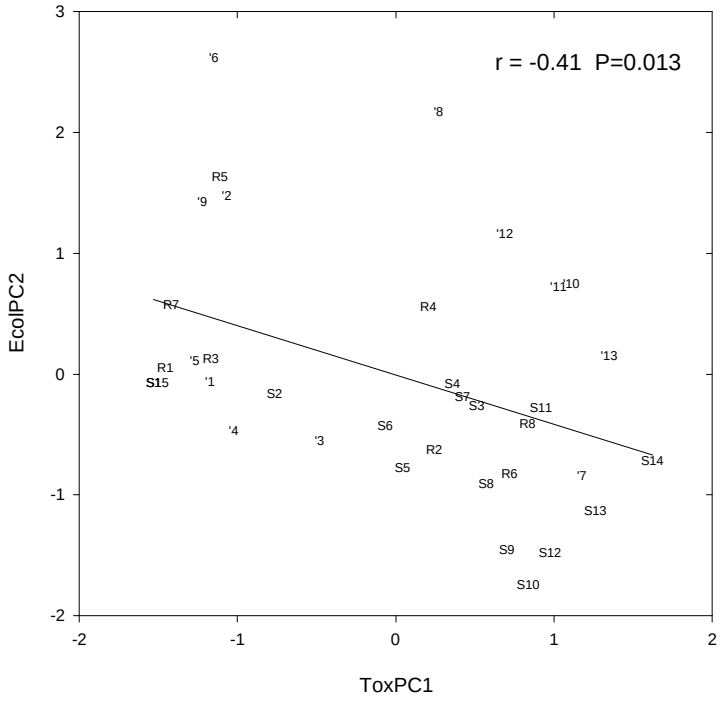


Table 18. Sediment quality triad (SQT) analysis. Pearson product correlations and significance value of the correlation statistic in parentheses for the first (PC1) and second (PC2) principal components for each of the SQT variables for all 36 sites. Significant correlations between parameters are shown in bold ($p \leq 0.05$).

	ChemPC1	ChemPC2	ToxPC1	ToxPC2
ToxPC1	**-0.40**	**-0.47**		
	(0.0165)	**(0.0036)**		
ToxPC2	0.06	0.22		
	(0.7259)	(0.1916)		
EcolPC1	-0.26	-0.07	**0.34**	**0.57**
	(0.1278)	(0.6737)	**(0.0394)**	**(0.0003)**
EcolPC2	-0.05	0.10	**-0.41**	0.23
	(0.7448)	(0.5294)	**(0.0134)**	(0.1847)

IV. DISCUSSION

The primary objective of this study was to assess the impacts of storm water outfalls on Corpus Christi Bay as compared with other types of inputs (e.g., industrial and municipal outfalls) and activities (e.g., petroleum production and maintenance dredging) occurring in the CCBNEP study area. The results of this study indicate that contaminant-related impacts are evident at some but not all of the storm drain sites as well as for some of the other sites of concern. It is important to remember that the "reference" sites were primarily selected as "historical reference" sites and not because they were considered to be representative of "clean" or healthy environments. On the contrary, some of these "reference" sites had relatively high concentrations of contaminants and were very toxic in some of the tests. As a group, however, they were located away from local inputs of contaminants, and in that respect are useful as being representative of different regions of the study area.

Chemical Analyses

The sediment quality guidelines (SQGs) that have been developed by Long et al.(1995) and MacDonald et al., (1996), provide a basis for estimating the probability of impacts based on the concentrations of chemicals and classes of chemicals. A number of sites exceeded the threshold effect level (TEL) or effects range low (ER-L) or probable effect level (PEL) or effects range medium (ER-M) values for the chemicals and classes of chemicals for which SQGs are available (Table 19)(Long et al., 1995; MacDonald et al., 1996). The highest number of exceedances for a PEL or ER-M value occurred at site S9, primarily due to the high levels of both low and high molecular weight PAHs. For some reason, these PAHs were not biologically available as evidenced by the lack of toxicity observed in all of the toxicity tests (see Figure 3). The Resort by the Sea Apartments were undergoing major renovation at the time of the sampling and the high levels of PAHs may have been related to the roofing and other construction activities adjacent to

Table 19. Threshold-effects level (TEL), probable effects level (PEL), and the effects range low and median (ER-L and ER-M, respectively) values for key contaminants and sites exceeding those values.

Contaminant	TEL	PEL	ER-L	ER-M	Sites exceeding TEL or ER-L
Pesticides and Polychlorinated Biphenyls (g/kg)					
Chlordane	2.26	4.79	0.5	6	S1, S2, S3, S6, S7, S8, S9**, S14
Dieldrin	0.72	4.3	0.02	8	8, 9, S1, S2, S4, S6, S7, S8, S9
p,p' - DDD	1.22	7.81	2	20	S2, S9
p,p' - DDE	2.07	374	2.2	27	S9
p,p' - DDT	1.19	4.77	1	7	S2
Total DDT	3.89	51.7	1.58	46.1	4, 8, S1, S2, S3, S6, S7, S8, S9, S14, R7
Total PCBs	21.6	189	22.7	180	S1, S9, S14**
Polycyclic Aromatic Hydrocarbons (g/kg)					
Acenaphthene	6.71	88.9	16	500	S1, S2, S9*
Acenaphthylene	5.87	128	44	640	1, 4, 8, S1, S9
Anthracene	46.9	245	85.3	1100	8, S1, S2, S9**
Fluorene	21.2	144	19	540	S2, S9**
Naphthalene	34.6	391	160	2100	S9
2-Methyl Napthalene	20.2	201	70	670	S9
Phenanthrene	86.7	544	240	1500	8, S1, S2, S9**
LMW PAHs[1]	312	1442	552	3160	8, S1, S2, S9**
Benz(a)-anthracene	74.8	693	261	1600	8, S1, S2, S9**
Benzo(a)pyrene	88.8	763	430	1600	8, S1, S2, S9**

Table 19. (continued)

Contaminant	TEL	PEL	ER-L	ER-M	Sites Exceeding Tel or ER-L
Chrysene	108	846	384	2800	8, S1, S2, S9**
Dibenzo(a,h)-anthracene	6.22	135	63.4	260	4, 8, S1, S2, S4, S9**, R1
Fluoranthene	113	1494	600	5100	8, S1, S2, S9**
Pyrene	153	1398	665	2600	8, S1, S2, S9**
HMW PAHs[2]	655	6676	1700	9600	S1, S2, S9**
Total PAHs[3]	1684	16,770	4022	44,792	8, S1, S2, S9**
Trace Elements (mg/kg)					
As	7.24	41.6	8.2	70	S1
Cd	0.68	4.21	1.2	9.6	1, 3, 4, 5, 8, 6, 9, 11, 12, S1, S2, S3, S4, R1, R2, R3, R4, R5, R7, R8
Cr	52.3	160	81	370	-
Cu	18.7	108	34	270	S1
Pb	30.2	112	46.7	218	S1
Hg	0.13	0.7	0.15	0.71	1, 3, 4, 5, S1, R1, R2, R3, R7
Ni	15.9	42.8	20.9	51.6	S1, R3
Zn	124	271	150	410	S1*, R1, R2

[1] Sum of the following low molecular weight PAHs; acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene

[2] Sum of the following high molecular weight PAHs; benz(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h,)anthracene, fluoranthene and pyrene

[3] Sum of high and low molecular weight PAHs described above.

* exceeds PEL

** exceeds PEL and ER-M

this site or possibly due to leaks from the hydraulic system in the apartment elevator. There was also a lot of debris from old pier pilings at this site which could also have contributed to the high level of PAHs. Chlordane PEL and ER-M values were also exceeded at S9. The highest levels for metals were observed at site S1 near the Corpus Christi Marina. TEL or ER-L values were exceeded at S1 for seven of the eight metals for which SQGs are available and the PEL was exceeded for zinc. It seems likely that these elevated metal levels are related to marina activities as well as inputs from the storm water outfall. The PEL and ER-M values for total PCBs were exceeded at site S14 which is the newest storm drain included in this study adjacent to Texas A&M University - Corpus Christi. These elevated PCB concentrations are most likely related to the large amount of plumbing and other construction activities which have been occurring at TAMU-CC since this storm drain outfall was installed several years ago.

PEL values, which are the concentration of a chemical above which biological effects are likely to occur, were used to asess 31 chemicals or classes of chemicals. For each site, the bulk sediment chemistry concentration for each chemical or class of chemicals was divided by its PEL value and the resulting quotients were summed, divided by 31 (the number of PEL values used) and multiplied by 100 to calculate a PEL index (Carr et al., 1996b; Figure 2). This index allows the additive effect of the different chemicals and the relative magnitude of a PEL exceedance to be accounted for among the different sites and provides a more informative estimate of probable contaminant effects. The highest indices were observed at S9 and S1 but relatively high values were also observed at four of the eight reference sites and at site 1, 3, 5, 8, S2, S5, S8 and S14 (Figure 2). These elevated PEL indices resulted from elevated concentrations of pesticides and metals as well as PAHs (Table 19).

The sediment chemistry data were also compared with the EPA human health screening values (USEPA, 1996). A number of sites exceeded the screening values for various PAHs and chlorinated pesticides (Table 20). Fourteen sites exceeded the screening value for benzo(a)pyrene, a known carcinogen. Storm water outfall sites S1, S2, and S9 and site 8 (NAS) exceeded the screening values for six or more chemicals.

Toxicity Testing

There was a wide variation in response among the different toxicity tests (Figure 3). The solid-phase tests with amphipods and mysids showed little or no toxicity with the survival end point. The mysid growth test resulted in a wide variety of responses with 13 samples eliciting enhanced growth and 14 samples exhibiting decreased growth. Whether this growth response is related to contaminant effects or the nutritional quality of the sediments is not presently known. The most sensitive test was the sea urchin embryological development test with 18 of the 36 sites exhibiting significant toxicity. The factor analysis (Figure 17) indicated that the sea urchin tests and the mysid growth end point accounted for most of the variability, and hence, useful information in the toxicity data set.

Table 20. Sites which exceeded human health screening values. The values in parentheses after the site designations are the concentration of the chemical measured at that site.

Chemical	Human Health Screening Value (ppb)	Sites Exceeding:
Benzo(a)anthracene	170	**8** (395.0), **S1** (369.9), **S2** (382.1), **S9** (3338.9)
Benzo(b)fluoranthene	170	**8** (557.4), **S1** (900.3), **S2** (487.5), **S9** (3603.7)
Benzo(k)fluoranthene	1700	**S9** (1840.5)
Benzo(a)pyrene	17	**1** (29.6), **3** (27.8), **4** (55.4), **6** (19.0), **8** (427.4), **S1** (529.6), **S2** (363.9), **S3** (25.6), **S4** (33.5), **S6** (31.7), **S8** (23.3), **S9** (3646.9), **R1** (42.4), **R7** (23.0)
Indeno(1,2,3-c,d)pyrene	170	**8** (319.4), **S1** (483.8), **S2** (268.4), **S9** (2497.5)
Dibenzo(a,h) anthracene	17	**8** (69.6), **S1** (98.3), **S2** (64.8), **S9** (437.5)
Total DDT	14	**8** (24.31), **S1** (14.96), **S2** (20.33), **S9** (31.45)
Dieldrin	1.2	**S9** (2.08)

There was a high degree of concordance between the two sea urchin porewater toxicity tests with six of the seven sites exhibiting toxicity in the fertilization test being toxic in both tests. Twelve of the 14 sites in which mysid growth was significantly decreased were also toxic in one or both of the sea urchin tests. Twelve sites exhibited no toxicity for any of the suite of tests (Figure 3). Six adjacent storm drain sites (S9-S14) and two other sites along the southern coast of Corpus Christi Bay (7 and R8) exhibited no toxicity. All of the sites in Nueces Bay and all of the sites near the harbor and marina and storm drain sites S1-S8 (except S3) exhibited toxicity in one or more tests. The transect out from the large storm water outfall at Cole Park (S2-S4) indicated that the toxicity decreased with increasing distance from the outfall (Figure 3).

Microbiological Indicators

Because there are no sediment microbial standards for comparison, it is difficult to interpret the results of the sediment coliform analysis. The highest levels of total coliforms and total fecal coliforms were observed at the two "reference" sites on the backside of Mustang Island (R5 and R6), in Nueces Bay (1 and R1), at a storm water outfall (S7) and near a domestic waste water outfall in Cayo del Oso (9) (Figure 12). The highest fecal coliform values were found at sites far removed from domestic sewage inputs (R6, R5, and 1).

From information obtained from the Corpus Christi-Nueces county Health Department, elevated fecal coliform readings in water samples (200 coliforms/100 ml water is the recreational maximum permissible standard) have been observed at a number of sites during 1996 between the marina and TAMU-CC which would coincide with storm drain sites S2-S14. As these water samples are only taken once a month, the sediment samples may be a better integrator of the actual microbial levels occurring over time. Until more information becomes available for sediment microbiological indicators, these values can be used as benchmarks for future studies which should ideally combine both water and sediment measurements simultaneously.

Benthic Infaunal Communities

Analysis of benthic (i.e., bottom dwelling) invertebrate communities have been widely used in pollution detection and monitoring studies. We expect indicator organisms to do for us today what canaries did for miners in the 18th and 19th century. Indicator organisms should have characteristics that make them useful in applied research (Soule, 1988). 1) They should direct our attention to qualities of the environment. 2) They should give us a sign that some characteristic is present.
3) They should express a generalization about the environment. 4) They should suggest a cause, outcome or remedy. 5) Finally, they should show a need for action.

Benthic organisms have been especially useful in applied research. Benthos are usually the first organisms affected by pollution. There are several reasons why these organisms are good indicators of environmental stress. 1) Because of gravity, everything ends up in bottom sediments. Even pollutants in freshwater will be transported to the coastal sea bottoms. 2) Everything dies and ends up in the detrital food chain, which is utilized by the benthos. Pollutants are usually tightly coupled to organic matrices, therefore benthos have maximal exposure through their niche (food) and habitat (living spaces) to pollutants. 3) Benthos are relatively long-lived and sessile, so they integrate pollutants effects over long temporal and spatial scales. 4) Benthic invertebrates are sensitive to pollutants. 5) Bioturbation and irrigation of sediments by benthos effect the mobilization and burial of xenobiotic materials.

There are also ecological models that provide a scientific basis for interpreting the data generated in benthic monitoring and detection studies. These approaches utilize many single species, community studies, and statistical models. One of the most important concepts is the succession model proposed by Rhoads et al. (1978). They applied

scientific theories of ecological succession and its relation to productivity to suggest ways that dredge-spoil could be managed to enhance productivity. The theory is based on the assumption that "...healthy benthic communities can be characterized by high biomass estimates dominated by long-lived, often deep-dwelling, species and high species richness" (Dauer 1993). The theory predicts that a healthy community which is exposed to stress, such as low dissolved oxygen or contaminated sediments (in this case stress is a synonym of disturbance) is altered. Characteristics of the altered, or early succession community, compared to the healthy community include lowered biomass, decreased diversity, a lower percentage of biomass representing deep-dwelling and equilibrium species, and a greater percentage of biomass representing fast growing opportunistic species.

The characteristic early succession communities, is dominated by opportunistic species, e.g., *Streblospio benedicti*, *Capitella capitata*, and *Mulinia lateralis* (Dauer, 1993; Weisberg et al., 1997). These are three of the dominant species in the current study and represent 49% of all individuals found (Table 13). This was true even at some of the reference sites (Table 13). Whereas, *Streblospio benedicti* was never found at storm outfall sites, it was replaced by the paronid, *Paraonis fulgens* (Table 13). This change in the community is due to the larger grain size that characterize outfall sediments (Figures 15 and 16). *Paraonis fulgens* and *Mulinia lateralis* appeared to prefer sandy, high energy environments. The other dominant spionid, *Polydoroa caulleryi*, which is known to be an early succession species in Corpus Christi Bay (Montagna and Kalke, 1992), had a distribution similar to *Streblospio benedicti* occurring in only one storm outfall site (Table 13).

Other characteristics of early succession communities include lower biomass and diversity compared to a climax community and fewer deeper dwelling organisms (Dauer, 1993). Except for S4, all storm drain sites had low biomass (Figure 7) and diversity (Figure 11). Whereas there was a great deal of difference in the average vertical distribution of density among sites, there was no clear trend among the site types or with respect to average density (Figure 8). However, biomass was higher at most sites in the deeper sediment fractions (Figure 7). On average, there were more (6,140 m^{-2}) animals and less biomass (0.87 g m^{-2}) in the surface 0 to 3 cm of sediment, than in the deeper 3 to 10 cm fraction (2810 animals m^{-2} and 2.24 g m^{-2}), which is consistent with the early succession model. Overall, it is fair to ascertain that during the time of this particular sampling, the entire system could be characterized as an early succession community. This observation is consistent with a previous study that included five of the reference and three of the sites of concern (Martin and Montagna, 1995).

The results of the benthic ecology study indicate that most of the storm drain outfalls have similar communities due to the similar habitat, which for the majority of the storm drain outfall sites was sandy and high energy (Figure 15). However, these sites are not uniformly contaminated (Figure 16). Therefore, there is a lack of clear trend in the PCA analysis (Figure 16). The best example is site S15 (Padre Isles canal), which was very toxic and had no living organisms, but this site was hypoxic and not contaminated. Site 2 (CP&L outfall) was also unusual because of low contaminants, but high toxicity and very low benthic biomass and abundance, which is probably due to the very high temperatures of the cooling water effluent. Another confounded site was 9 in Oso Bay at the sewage treatment plant outfall. This site had the highest benthic density (Figure 6), but it had by

far the highest density of both *Streblospio benedicti* and *Capitella capitata* (Table 13) which is a classic example of an indicator of organic enrichment. Site 9 also had a dense diatom bloom which is also indicative of organic enrichment. So even though site 9 was not heavily contaminated by chemicals of concern, it was obviously impacted by anthropogenic influences.

The study conducted by the Bureau of Economic Geology (BEG, 1983) in the mid-1970s, provides historical data for comparison with the present study. The dominant macrobenthic invertebrates in the bay margin habitats of Corpus Christi Bay in the BEG study were three bivalves (*Mulinia lateralis*, *Lyonsia hyalina floridana* and *Nuculana acuta*), the polychaete *Paraprionospio pinnata*, and the amphipod *Lepidactylus* sp. In the present study, *Mulinia lateralis* represented 97.5% of bivalves observed with only one individual each of *Nuculana acuta* and *Lyonsia hyalina floridana* observed at only 1 and 3 sites, respectively. The polychaete *Paraprionospio pinnata* was rarely observed in the present study with the opportunistic *Streblospio benedicti* and *Mediomastus ambiseta* now dominating. The amphipod *Lepidactylus* sp., which accounted for over 50% of the crustaceans observed in the BEG study, was not observed at any of the 36 sites in the present study. Thirty-nine species of amphipods were observed in Corpus Christi Bay in the BEG study as compared with 13 in the present study. Amphipods are known to be pollution sensitive species and are often the first species to disappear from a disturbed ecosystem. In the BEG study, the open-bay species assemblages were less diverse and depauperate in comparison with the sandy bay-margin assemblages. In the present study, the reverse appears to be true with the open-bay sites (e.g., 5, R3 and S4) exhibiting the highest species diversity, biomass and abundance (Figure 4) as compared with the bay-margin sites. In the recent REMAP study conducted by the USEPA in 1994 in which benthic communities at 52 sites were examined, approximately 50% of Corpus Christi Bay was determined to be degraded based on their benthic index (Engle and Summers, 1998). Benthic abundance, biomass and diversity at the long-term reference sites (R1 - R5) during the present study were in the lower third of the range reported since 1987 (Montagna et al., 1997). The low benthic characteristics recorded during the present study are due, in part, to high salinities at the time of sampling.

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Sediment Quality Triad Analysis

The power of the triad approach lies in the ability to incorporate the information gained from the independent measurements into an integrated assessment of the potential for contaminant-induced ecological impacts. One of the ways to integrate the three components of the triad into a relative index for among site comparisons is the use of scaled ranking factors (Carr et al., 1996b). For this exercise, the PEL indices were used as a measure of the relative contamination at each site. The mean rank of mysid growth test, sea urchin fertilization and embryological development toxicity data were used as the best measure of toxicity. The benthic index of biotic integrity (BIBI) was used as a measure of benthic community "health". Each site was ranked for each of the three triad components and a scaled ranking value calculated as follows: scaled value = ((initial value-minimum value)/maximum value-minimum value)) X 99. The scaled values for the three components were then summed and a scaled rank sum calculated for each site (Table 21). The scaled rank sums were then ranked amongst the 36 sites. The site with

the lowest rank sum (most degraded) based on all three triad components was S1 followed by S2 and S15. Site S9 and site 2 at the CPL outfall in Nueces Bay ranked fourth and fifth, respectively. The least degraded sites based on this relative ranking were 11, 12, S4, and R4.

Chapman (1990) has provided some possible explanations based on the integration of the different triad components. For this exercise, we used the results from the principal component analysis to differentiate among the sites for the three different components of the triad (Figures 16, 18 and 20). Using a conservative estimate which favored making a type I error (false positive) rather than a type II error (false negative), only sites which were classified in category C were considered to be significantly impacted for each parameter and received a plus (-) designation. Each site was then categorized on the basis of their PCA score for the three components (Table 22). Using these criteria, two sites (S1 and S2) were significantly affected for all three components of the triad which is indicative of contaminant-induced degradation. Fourteen sites (7, 10, 11, 12, 13, S4, S10, S11, S13, S14, R2, R4, R6 and R8) were high or medium quality for all three components which suggests that there is no contaminant-induced degradation. The remaining sites were low quality for toxicity, chemistry or benthic alterations but not all three which indicates that contaminants may be stressing the system or that unmeasured contaminants or other conditions are causing degradation. Figure 26 shows this data presented graphically using the three different groups identified in the PCA analyses for each component of the triad (Figures 16, 18, and 20). It is apparent from the preponderance of red and yellow segments that the sites in Nueces Bay and near the harbor and downtown areas have been most impacted by anthropogenic influences.

Table 21. Site ranks and scaled rank sums for benthic index of biotic integrity (BIBI), toxicity (mean rank of mysid growth, sea urchin fertilization and embryological development), and bulk sediment chemistry (PEL Index) for the Corpus Christi Bay study. The higher the sum of the scaled values, the less degraded the site, compared with the other sites.

Site	Scaled Values[1]			Sum of Scaled Values	Relative Ranking
	BIBI	Toxicity	PEL Index[2]		
1	30	33	84	147	6
2	11	27	95	133	5
3	72	50	88	210	19
4	85	39	82	206	18
5	94	33	86	213	23
6	47	35	87	169	10
7	50	85	98	233	23
8	66	65	46	177	12
9	39	34	94	167	7
10	58	81	98	237	27
11	99	75	97	271	36
12	96	74	94	264	35
13	47	89	99	235	25
S1	0	5	1	6	1
S2	25	38	35	98	2
S3	39	71	91	201	17
S4	96	67	86	249	34
S5	33	61	97	191	16
S6	22	56	92	170	11
S7	25	68	95	188	14
S8	30	67	88	185	13
S9	47	75	0	122	4
S10	61	75	98	235	25
S11	61	78	99	238	27
S12	44	80	98	222	22
S13	63	85	99	247	32
S14	58	95	87	240	29
S15	0	9	95	104	3
R1	63	22	78	163	9
R2	94	65	85	244	31
R3	74	35	82	191	16
R4	96	65	89	250	33
R5	58	36	96	190	15
R6	61	75	96	232	24
R7	47	27	86	160	8
R8	74	75	95	243	30

[1] All values were scaled to a 0-99 range using the following formula: scaled value = ((initial value-minimum value)/(maximum value-minimum value)) × 99.

[2] PEL Index scaled value calculated as the inverse by subtracting from 99. Site S9 was not used in the scaling calculation but was assigned a value of 0 because it skewed the rest of data such that most of the other sites could not be differentiated from one another for this parameter.

Table 22. Summary of Sediment Quality Triad data. A minus sign for chemistry, toxicity or benthos indicates a principal component analysis (PCA) score in the low quality category for that parameter.

Chemistry	Toxicity	Benthos	Sites (Station Number)	Possible Conclusion
-	-	-	SWO near the L-head in Corpus Christi marina **(S_1)**, Cole Park SWO **(S_2)**	Evidence of contaminant-induced degradation
+	+	+	NAS effluent outfall **(7)**, Shamrock Island **(10)**, La Quinta channel south **(11)**, La Quinta channel north **(12)**, mitigation site near JFK bridge **(13)**, Cole Park SWO - 500 m station **(S_4)**, Airline SWO **(S_{10})**, Swantner Park SWO **(S_{11})**, Ennis Joslin SWO **(S_{13})**, TAMU-CC SWO **(S_{14})**, eastern Nueces Bay **(R_2)**, NE Corpus Christi Bay **(R_4)**, SE Corpus Christi Bay - Fish Pass **(R_6)**, Southern Corpus Christi Bay **(R_8)**	No evidence of contaminant-induced degradation
-	+	+	NAS boat basin breakwater **(8)**	Contaminants are not bioavailable
+	-	+	Corpus Christi Inner Harbor **(3)**, ship channel dredge spoil site **(5)**, Oso Pass in Corpus Christi Bay **(6)**, western Nueces Bay **(R_1)**, NW Corpus Christi Bay **(R_3)**, Eastern Corpus Christi Bay **(R_5)**	Unmeasured chemicals or conditions exist with the potential to cause degradation
+	+	-	Cole Park SWO - 200 m station **(S_3)**, South Cole Park **(S_5)**, First Baptist Church SWO **(S_6)**, Ocean Drive SWO **(S_7)**, Dodderidge Park SWO **(S_8)**, Poenish Park SWO **(S_{12})**	Benthic response probably not due to contaminants
+	-	-	West Whites Point **(1)**, CP&L cooling water discharge site in Nueces Bay **(2)**, Texas State Aquarium **(4)**, Oso Wastewater Treatment Plant outfall **(9)**, Padre Island SWO **(S_{15})**, The Boat Hole near NAS **(R_7)**	Unmeasured contaminants or other conditions are causing degradation of benthos
-	+	-	Resort by the Sea Apartments SWO **(S_9)**	Contaminants are not bioavailable or benthic response not due to contaminants

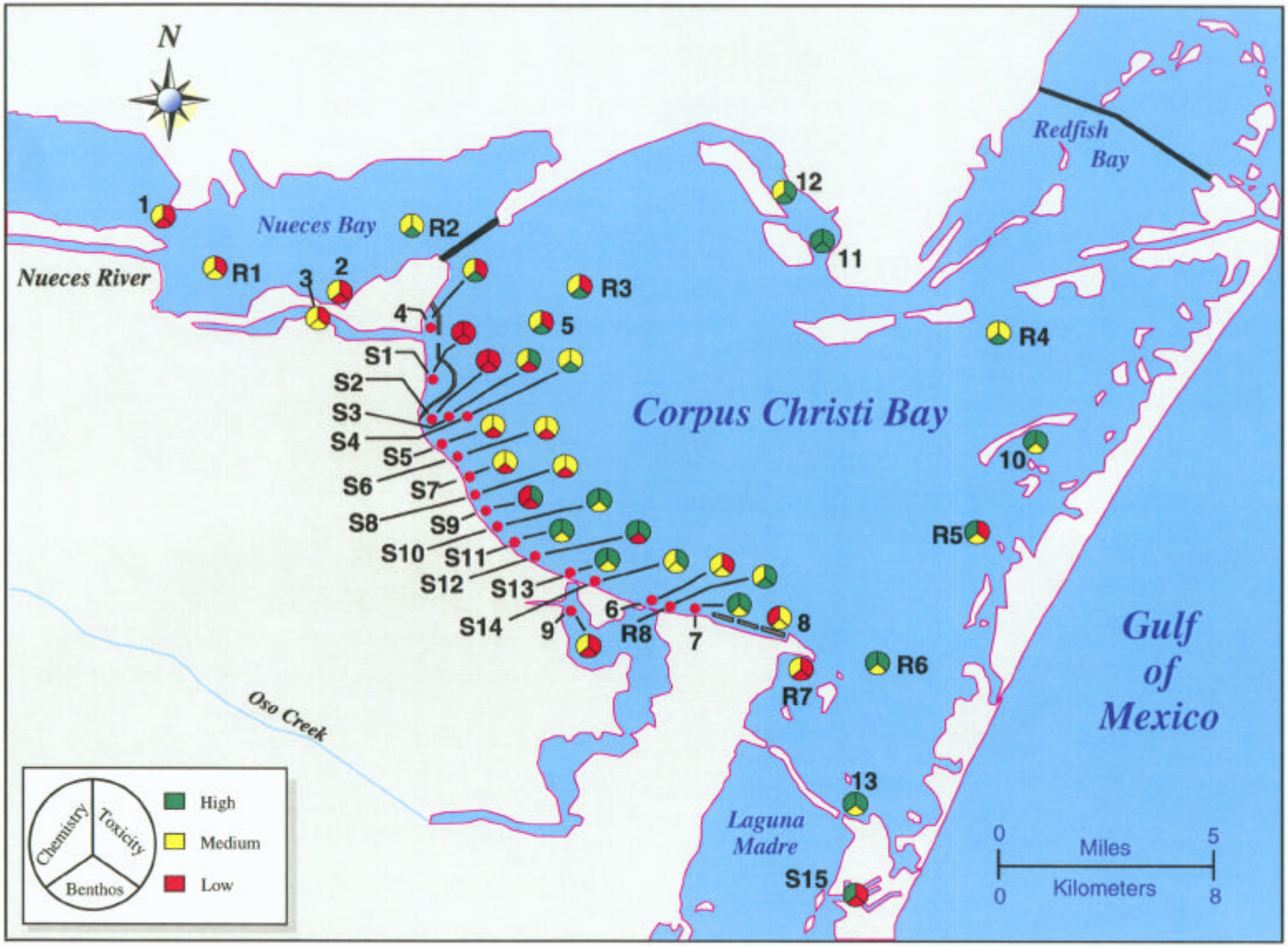

Figure 26. Summary of Sediment Quality Triad (SQT) data for sites in the CCBNEP study. Relative ranking of high, medium or low for each component based on principal component analysis of chemistry, toxicity, and benthic index of biotic integrity (BIBI) data among the sites.

V. CONCLUSIONS

It is apparent that several of the sites included in this study have been impacted by anthropogenic influences. While the more severe effects appear to be localized, this study has served to identify some specific areas of concern where more comprehensive monitoring should be conducted. Some specific storm drains, for example, appear to have high levels of particular types of contaminants or exhibited toxicity. Similar to the Galveston Bay system, which is the other highly urbanized barrier island bay on the Texas coast, the benthic community in the CCBNEP study area is dominated by early colonizer, opportunistic species which are characteristic of highly disturbed environments (Rhoads et al., 1978; Carr et al., 1996a). This is not the case for the other large bay systems on the Texas coast, (e.g., Matagorda Bay, Aransas Bay and Copano Bay) which are not heavily urbanized (BEG, 1983; Montagna and Kalke, 1995).

In comparison with the best historical information that is available (BEG, 1983), it appears that there has been a noticeable change in the composition of the benthic community since the last major survey was conducted approximately 25 years ago. Many of the species which characterized particular regions of Corpus Christi Bay are now rare or absent. Only one-third of the 39 species of amphipods which were observed in the 1970s were observed in the present study. While the low benthic community characteristics recorded by the present study may be due, in part, to higher than normal salinities, other insults related to contaminants and physical disturbances associated with altered circulation, and sediment resuspension or nutrient declines, may impose additional stresses on this naturally stressful ecosystem.

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