

2.0 INTRODUCTION AND BACKGROUND

2.1 Overview

This study was initiated to provide information on the concentrations of heavy metals and organic priority pollutants in edible fish and shellfish from Galveston Bay. Each year, millions of pounds of fish and shellfish caught by commercial and sport fishermen in Galveston Bay are consumed. However, little or no testing of edible tissues for toxic contamination by heavy metals and priority pollutants has been conducted to assess public health risks. This study provides an assessment of the historical data available on contamination concentrations in selected aquatic organisms (Section 2); provides data on the current levels of contamination present in fish and shellfish at selected sites and times from Galveston Bay (Sections 4 and 5); and assesses the potential risk to human health from these contaminants (Section 6).

Fish and shellfish were collected and analyzed from four sites in Galveston Bay (Figure 2.1). The collection sites for these target species were Morgans Point, at the mouth of Houston Ship Channel, Eagle Point, off of San Leon, Carancahua Reef, in the West Bay, and Hanna Reef, in the East Bay. The data produced were used to assess potential risks to human health posed by the consumption of seafood organisms from Galveston Bay. The information obtained should aid resource agencies in formulating management decisions and as a guide to future data collection.

Literature and agency data pertinent to the project topic were reviewed and information related to concentrations of heavy metals and organic pollutants in seafood organisms in Galveston Bay and in the tidal portions of Galveston Bay tributaries are summarized. The Galveston Bay Bibliography was reviewed to identify pertinent literature, followed by identification of other sources not found in the Bibliography. The literature review as well as citations are included in this section and a copy of this report will be supplied to the Galveston Bay Information Center.

Four samplings of aquatic organisms were launched for GBNEP. The first sampling in late May (23-25) 1990 collected oyster and crab samples; however, trawling for fish was not very successful because Trinity River flooding caused low salinity water. A second sampling was undertaken in early June (6-8) 1990 that involved gill netting at the four sites. This sampling had some success in collecting drum, sea catfish, trout and flounder from some of the sites, although not in sufficient quantities for most analyses. Most fish samples were collected from July 30 to August 3, 1990, after the bay had returned to a more normal salinity. However, the Apex Barge spill on July 28, 1990, complicated late July sampling. Because of this spill, few fish were collected near Eagle Point (close to the oil spill site). A final sampling trip on September 4-6, 1990 completed the collection at Eagle Point.

Samples were analyzed for trace contaminants, including heavy metals, PAHs, pesticides, PCBs and other base/neutral priority pollutants. The methods used for this study are those that the Geochemical and Environmental Research Group (GERG) uses as part of the NOAA "National Status and Trend Program" and/or those approved by the U.S. Fish and Wildlife Service (FWS). All the environmental contaminants analyzed as part of the NS&T and FWS programs were also analyzed for this GBNEP study. All methods have undergone extensive intercalibration with NOAA, NIST and FWS. These methods are superior in regards to detection limits and QA when compared to standard EPA methods. For example, in the EPA method 8270 (SW 846) for gas chromatography/mass spectrometry for semi-volatile organics, capillary column techniques give practical quantitation limits for naphthalene in soil/sediment as 660 ng/g wet weight. GERG detection limits are 1 to 10 ng/g. The highest naphthalene concentration for this study was 439 ng/g which was well below the EPA practical quantitation limit for soil/sediment. The practical quantitation limit for tissue using EPA methodologies, if available, would be even higher. Also, the EPA methods require surrogate concentrations of 40 ng/ml while GERG's are 40 ng/μl, or 1000 times lower in concentration. These methods are detailed in the Standard Operating Procedures (SOPs, Appendix C) attached to this document. Final choice of analytical methodologies was subject to approval by the Management Conference and EPA Region 6.

The risks to human health associated with consumption of seafood from Galveston Bay based on measured concentrations of contamination were also assessed. This assessment was based on EPA's risk-based approach as detailed in:

U.S. EPA. 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish: A Guidance Manual.

U.S. EPA (1989) states that a complete risk assessment includes the following:

1. **Hazard Identification:** Qualitative evaluation of the potential for a substance to cause adverse health effects (e.g., birth defects, cancer) in animals or in humans.
2. **Dose-response assessment:** Quantitative estimation of the relationship between the dose of a substance and the probability of an adverse health effect.
3. **Exposure assessment:** Characterization of the populations exposed to the toxic chemicals of concern; the environmental transport and fate pathways; and the magnitude, frequency, and duration of exposure.
4. **Risk characterization:** Integration of qualitative and quantitative information from the first three steps, leading to an estimate of risk for the health effect of concern.

Items 1 and 2 are addressed in the Literature Review. Exposure assessment (Item 3) is accomplished with mathematical models. According to U.S. EPA (1989) the general model to calculate intake from a single-species diet is:

$$E_{ijkm} = \frac{C_{ikm} I_{ijk} X_m}{W} \quad (1)$$

Where:

E_{ijkm} = Effective ingested dose of chemical m from fishery species i for human subpopulation j in area k ($\text{mg kg}^{-1} \text{day}^{-1}$ averaged over a 70-year lifetime).

C_{ikm} = Concentration of chemical m in edible portion of species i in area k (mg/kg).

I_{ijk} = Mean daily consumption rate of species i by subpopulation j in area k (kg/day averaged over 70-year lifetime).

X_m = Relative absorption coefficient, or the ratio of human absorption efficiency to test-animal absorption efficiency for chemical m (dimensionless).

W = Average human weight (kg).

C_{ikm} results from the chemical analyses performed in this project. I_{ijk} is obtained from literature sources, X_m is generally assumed equal to 1.0, and W is usually assumed to be 70 kg (U.S. EPA, 1989). Estimation of chemical exposure from a mixed-species diet, which is complicated by variation in individual diet, is also outlined in U.S. EPA (1989).

Carcinogenic risk can be estimated by:

$$R^*_{ijkm} = q1^*_m E_{ijkm} \quad (2)$$

Where:

R^*_{ijkm} = Plausible-upper-limit risk of cancer associated with chemical m in fishery species i for human subpopulation j in area k (dimensionless).

$q1^*_m$ = Carcinogenic Potency Factor for chemical m [$(\text{mg kg}^{-1} \text{day}^{-1})^{-1}$] estimated as the upper 95% confidence limit of the slope of a linear dose-response curve.

E_{ijkm} = Exposure dose of chemical m from species i for subpopulation j in area k ($\text{mg kg}^{-1} \text{day}^{-1}$).

q1* m values are obtained from the U.S. EPA Integrated Risk Information System (IRIS)(U.S. EPA, 1989).

2.2 Literature Review

Galveston Bay has a surface area of 1600 km² and is one of the largest embayments on the U.S. coast. However, the bay is very shallow, averaging only about 2 m in depth, and is isolated from the Gulf of Mexico by the Bolivar Peninsula and Galveston Island. Tides, which average about 40 cm in height, exchange ocean and bay water primarily through the channel between these two land barriers. Winds, rather than tidal cycles, are often the dominant factor determining bay circulation and water exchange. Exact current patterns in the Bay and the residence time of water in the Bay are not well known.

For many years, this area has been the recipient of various pollutant inputs because of an aggressively growing urban and industrial region. Houston, Deer Park, Baytown, Texas City, and Galveston, surrounding Galveston Bay to the north and west, are some of the most heavily industrialized areas in the United States. Hundreds of industrial plants, including petrochemical complexes and refineries, bordering the Galveston Bay estuarine system are likely to introduce significant amounts of pollutants into the Bay. Early ecological studies showed the damage suffered by different areas in Galveston Bay. Hohn (1959) and Chamber and Sparks (1959) reported significant decreases in diatom species diversity and number of invertebrates and fish in the upper Houston Ship Channel. Fish species diversity indices were also used to assess the health of Galveston Bay (Bechtel and Copeland, 1970). A change in species diversity from sciaenids to anchovy was related to the influx of pollutants into the Bay. In general, these ecological studies suggested that the waters of Galveston Bay contained pollutants in sublethal amounts which caused stress to organisms that resulted in significant changes in the estuarine community structure.

A number of studies on contaminants of environmental concern have been conducted in Galveston Bay. Presented here is a review and summary of the data available for the Galveston Bay system, including the concentrations and distributions of trace metals, polynuclear aromatic hydrocarbons (PAHs) and high molecular weight chlorinated hydrocarbons, e.g. chlorinated pesticides and polychlorinated biphenyls (PCBs), in organisms, water column and sediments. Substantial changes have been made in analytical methods in recent years; for example, the advent of the fused silica capillary columns allows for better resolution of organic contaminants and lower detection limits, and improved graphite furnace AA techniques allow better detection of low concentrations of trace metals. Because of different and improved analytical techniques, comparisons among different studies are generally complicated and should be conducted with caution.

2.2.1 Polynuclear Aromatic Hydrocarbons (PAHs)

Hydrocarbons are widely distributed in the environment. Most of the evaluations of environmental concentrations of hydrocarbons are generally based on the

analysis of total or selected individual compounds that are indicative of petroleum pollution, although petroleum is not the only cause of hydrocarbons. Major sources of petroleum hydrocarbons in the coastal marine environment are drilling operations and petroleum production, transportation activities, coastal and/or riverine inputs, combustion of fossil fuels, and atmospheric fallout. Cycloalkanes, branched alkanes, n-alkanes and aromatic compounds are the predominant hydrocarbons present in petroleum. Aromatic hydrocarbons, particularly PAHs, are also introduced into the environment from other sources, e.g. pyrolysis of organic materials, municipal incinerators, natural fires, coal production and burning. Because of the persistent and lipophilic nature of PAHs, it is not surprising that they have been frequently detected in biota, sediment and water samples from a wide variety of polluted and unpolluted habitats. In general, the presence of petroleum hydrocarbons in earlier studies has been inferred from the distribution of normal alkanes and the presence or absence of an unresolved complex mixture (UCM) in the aliphatic fractions. Since most of these studies were conducted before the introduction of capillary columns, identifications of individual aromatic compounds were not confirmed by gas chromatography/mass spectrometry (GC/MS).

2.2.1.1 Organisms

A number of studies have been conducted in the Galveston Bay area to establish baseline concentrations of petroleum hydrocarbons (Table 2.2), although reports of individual aromatic compound concentrations or distributions are limited. Most of these studies were conducted with organisms, particularly bivalves. Oysters collected from several polluted and unpolluted locations in Galveston Bay in November, 1969, and January, 1971, had total PAHs that ranged from 11 to 237 ng/g (Fazio, 1971). The highest PAHs in oyster tissues from contaminated sites were fluoranthene (7.8 ng/g), pyrene (6.5 ng/g), benzo(b)fluoranthene (2.2 ng/g), and benzo(e)pyrene (2.1 ng/g). Benzo(a)pyrene was below detection in samples from both contaminated and uncontaminated stations. Much higher concentrations were reported for oyster samples from a heavily polluted area, Morgans Point, near the entrance of the Houston Ship Channel (Ehrhardt, 1972). Oyster tissues contained a total of 236,000 ng/g hydrocarbons. Concentrations of aromatic hydrocarbons, mainly mono-, di-, and tricyclic aromatics, were higher than those of alkanes (134,000 and 102,000 ng/g, respectively). Anderson (1975) reported similar concentrations, 160,000 ng/g, of total hydrocarbons in oysters collected at the same general location. At Halfway Reef, a few miles farther away from the entrance of the Houston Ship Channel toward the center of Galveston Bay, 26,000 ng/g (wet weight) of total hydrocarbons were detected, while oyster samples collected in the East and West Bays had less than 2000 ng/g of total hydrocarbons in their tissues. Benzo(a)pyrene in oysters collected during May 1979 near Morgans Point ranged from 0.07 to 0.14 ng/g with a mean 0.12 ng/g (Murray *et al.*, 1980).

In 1980, Farrington *et al.* published the hydrocarbon concentrations measured in bivalves collected from 90 to 100 stations around the U.S. coastline during the EPA "Mussel Watch" Program (1976-1978). Oysters collected in the Galveston Bay area during 1977-1978 had concentrations of 940 and 1010 ng/g for fluoranthene and

pyrene, respectively. Fox (1988), in a study designed to examine the spatial and temporal variations in concentrations of selected organic contaminants in Galveston Bay, reported the PAHs concentrations in oysters from three stations at four sites sampled during 1986. Total PAHs were higher in samples from sites located closer to urban areas. Oysters collected in the proximity of the Houston Yacht Club (615 ng/g, range= 319-1020 ng/g) and Confederate Reef (610 ng/g, range= 259-1120 ng/g), near the city of Galveston, had annual average concentrations higher than samples collected from Todd's Dump (134 ng/g, range= 94.7-183 ng/g), located in the middle of Galveston Bay, and Hanna Reef (111 ng/g, range = 21.3-228 ng/g), in the East Bay. Pyrene, fluoranthene, chrysene, phenanthrene and 1-methyl phenanthrene were the most frequently detected analytes.

Although temporal variations of individual PAHs in oysters from the Galveston Bay area did not present an easily recognizable trend during this study, it seemed evident that total PAHs in samples from the most polluted sites, i.e. Houston Yacht Club and Confederate Reef, were lower during the summer. Oysters collected monthly near the entrance to the Houston Ship Channel were analyzed for a number of organic contaminants between December 1988 and June 1989. The maximum total PAHs measured during February (10120 ng/g, range= 9677-10565 ng/g) decreased to 2270 ng/g (range= 1837-2710 ng/g) in May. Pyrene, fluoranthene, chrysene, benzo(a)pyrene and benzo(e)pyrene were the most abundant PAHs detected during this study. Temporal variations of organic contaminants in bivalves were also reported for DDT (Butler, 1973) and PCBs (Farrington *et al.*, 1983).

Various marine organisms collected at San Luis Pass, located in West Galveston Bay, were analyzed for benzo(a)pyrene (Murray *et al.*, 1981a,b). In all cases, concentrations were below the detection limit (<0.01 ng/g).

In 1987, King *et al.* reported the concentrations of selected PAHs in double-crested cormorants, a fish-eating species near the top of an aquatic food web, wintering in the Houston Ship Channel. This species of cormorant is rarely found in the area during summer months. Naphthalene and fluoranthene were the only PAHs present in individuals collected at the beginning of the study. After the three-month winter period, eight aromatic hydrocarbons were detected in bird carcasses (Table 2.2).

2.2.1.2 Sediments and Water

Table 2.2 reports PAHs in sediment and water samples from the Galveston Bay area. In 1979, Armstrong *et al.* reported the results of a study conducted from April, 1974, to December, 1975, to examine the effects of brine effluents on the benthic communities surrounding a platform in Trinity Bay, a part of the Galveston Bay system. Total petroleum hydrocarbons measured in sediment samples collected near the platform were 96,100 ng/g. Approximately one third of this total, 34,200 ng/g, corresponded to aromatic hydrocarbons, primarily dimethyl, trimethyl, and C4-naphthalenes. Bottom water samples collected at the same site contained mostly monoaromatic compounds, e.g. toluene, benzene, and

C₂-benzene, in the 200-3200 ng/l range. Total PAHs in water was 10,500 ng/l. Sedimentary PAHs decreased to near background levels (2000-6000 ng/g) with distance from the platform. There was a definite inverse correlation between sedimentary PAHs and the number of benthic species and individuals present. The Bay bottom was almost completely devoid of organisms within 15 m of the effluent outfall. Stations located 455 m from the platform were unaffected. Sediment samples collected in the San Luis Pass area had an average benzo(a)pyrene concentration of 2.2 ng/g (range= 0.01-6.0 ng/g; Murray *et al.*, 1981a). Benzo(a)pyrene was not detected in water samples from that area.

2.2.2 Chlorinated Hydrocarbons

Chlorinated hydrocarbons comprise a wide range of compounds. Most of the attention in environmental studies has been focused particularly on the high molecular weight chlorinated hydrocarbons, i.e. pesticides and PCBs. Chlorinated pesticides or organochlorines include a well known variety of compounds: DDT and related compounds, DDD and DDE; aldrin, which, under environmental conditions, degrades to dieldrin, a pesticide by itself; heptachlor and its degradation product heptachlor epoxide, which is even more toxic than the parent compound; endrin; and lindane. Because of the tendency of these compounds to bioaccumulate in food chains, their use has been banned or severely restricted in most developed countries.

Since the early 1930s, PCBs, a generic name of 209 possible isomers and congeners, have been used as components in electrical equipment, in the manufacture of paints, plastics and adhesives, in transmission fluids and as dielectrics in transformers and capacitors. After the discovery of their widespread environmental impact in the 1970s, PCB production decreased significantly; however, important quantities of the produced PCBs are still in use in many closed systems, e.g. transformers and capacitors. Therefore, a continuous release of PCBs into the environment is expected for many more years.

2.2.2.1 Organisms

A variety of organochlorine residues have been analyzed in organism (e.g., bivalves and various species of fishes and birds), sediment, and water samples from the Galveston Bay area. The compounds most commonly found were PCBs, DDT metabolites and, occasionally, dieldrin, HCB and chlordane (Table 2.3). In 1973, Butler reported the data corresponding to the analyses of more than 8000 mollusk samples collected between 1965 and 1972 along the coast of fifteen states. Oysters from the Trinity and Galveston Bays were sampled for the 1965-69 and 1965-72 periods, respectively. DDT residues were the most commonly detected organochlorines. Overall averages for the above periods were 6.16 and 23.9 ng/g for Trinity and Galveston oysters, respectively, with similar concentration ranges. Dieldrin was the second most frequently encountered chlorinated pesticide. Concentrations in Galveston Bay samples averaged 14.5 ng/g (range=n.d.-87 ng/g) whereas the average dieldrin concentrations in oysters from Trinity Bay were slightly lower (2.86 ng/g; range=n.d.-20 ng/g). Similar dieldrin

concentrations (6.8-16.6 ng/g) were reported in clams from this bay (Petrocelli *et al.*, 1975).

The ubiquity of chlorinated hydrocarbons in Galveston Bay was demonstrated by Fox (1988). Oyster samples were collected at four sites within the bay. PCBs, DDT residues, dieldrin, trans-nonachlor, alpha-chlordane and heptachlor epoxide were detected in every sample analyzed during the study. Organochlorine concentrations measured in oysters collected near the Houston Yacht Club were, in general, significantly higher than the levels encountered in samples from Hanna Reef, Todd's Dump and Confederate Reef which, in spite of the different locations within the bay, had similar annual average organochlorine concentrations. Similar to PAHs, chlorinated hydrocarbons from the vicinity of the Houston Yacht Club had minimum concentrations for samples collected in the summer. Other chlorinated compounds were also detected in oysters collected in the Galveston Bay area. Murray *et al.* (1980) reported the presence of HCB (0.63 ng/g; range= 0.31-1.4 ng/g) and PCP (5.3 ng/g; range= 3.8-8.3 ng/g) in oyster samples from Morgans Point, near the entrance of the Houston Ship Channel to the Galveston Bay.

A number of different species of fish were also analyzed for organochlorine residues. PCB concentrations ranged over two orders of magnitude. Finfishes such as mullet, croaker and Florida pompano, collected near a power plant (Houston Lighting and Power Company) near the upper Trinity Bay, contained PCB concentrations in the range 50-500 ng/g (Strawn *et al.*, 1977). Lower concentrations were reported in juvenile croakers (9-43 ng/g; Stahl, 1980). Similar ranges to those published by Strawn *et al.* (1977) were reported for fishes that represented the black skimmer and olivaceous cormorant food items, mainly tidewater silverside, sheepshead minnow and striped mullet (King, 1989a; 1989b). Total DDT residue concentration in fish tissues were one order of magnitude lower than those reported for PCBs. Typically, DDT concentrations ranged from n.d. to 50 ng/g (King, 1989a; 1989b). Dieldrin (10-20 ng/g), HCB (n.d.-0.63 ng/g), chlordane (n.d.-70 ng/g), heptachlor (20-30 ng/g) and PCP (4.2 ng/g) were some of the other chlorinated hydrocarbons reported for Galveston Bay fishes (Murray *et al.*, 1981a; King, 1989a; 1989b).

Some waterbirds, e.g. olivaceous and double-crested cormorants, laughing gulls and black skimmers, nesting in the upper Galveston Bay were also analyzed for chlorinated hydrocarbons (King and Krynitsky, 1986; King *et al.*, 1987). Average concentrations and concentration ranges encountered in these birds were similar. PCBs, Σ DDT and dieldrin average concentrations ranged from 1580 to 6990, 930 to 4430 and 100 to 160 ng/g, respectively. These concentrations are one to two orders of magnitude higher than concentrations listed on Table 2.3 for Galveston Bay fish samples. Since these fish-eating birds are at the top of an aquatic food chain, a bioaccumulation of organic contaminants is expected. With overall average PCB and Σ DDT concentrations of 4170 and 2270 ng/g, in waterbirds, and 330 and 20 ng/g, in dry weight fish fillets not corrected to % lipid, bioaccumulation factors of 13 and 110 can be calculated for PCB and Σ DDT residues in Galveston Bay waterbirds. Chlordane (100-1200 ng/g), HCB (100-280

ng/g) and heptachlor epoxide (110-140 ng/g) were also found to be present in waterbird tissues (King and Krynitisky, 1986; King *et al.*, 1987).

2.2.2.2 Sediments and Water

Reports of chlorinated hydrocarbon concentrations in sediment and water samples from the Galveston Bay area are limited. In general, PCB concentrations in sediments were in the <0.14 to 7.1 ng/g range (Murray *et al.*, 1981a; 1981b). Stahl (1980) reported a slightly higher concentration range for PCBs in sediments (15-68 ng/g). These concentrations are two to three orders of magnitude lower than those previously reported in dredged sediments from the Houston Ship and Texas City Channels (Saleh and Lee, 1976). The samples collected during Saleh and Lee's study corresponded to sediments disturbed by the construction of underwater pipelines; therefore, they might represent sediments deposited before the restrictions of the use of PCBs in the U.S.A. in the 1970s. Σ DDT residue concentrations (<0.01-1.4 ng/g) in the Galveston Bay sediments were evenly distributed over a wide geographical area (Murray *et al.* 1981a; 1981b). Water samples collected at different locations in Galveston Bay had PCB and Σ DDT concentrations ranging from <0.01 to 70 ng/l and <0.01 to 3.5 ng/l, respectively. The higher PCB concentrations were measured at Texas City whereas the higher DDT residue levels were encountered near Morgans Point. Dieldrin (<0.03 ng/g), HCB (0.49 ng/g), chlordane (<0.03 ng/g) and PCP (0.18 ng/g) were also encountered in sediment samples (Murray *et al.* 1981a; 1981b).

2.2.3 NOAA's National Status and Trends "Mussel Watch" Program

The National Oceanic and Atmospheric Administration's (NOAA) Status and Trends "Mussel Watch" Program is designed to monitor the current status and long-term trends of selected environmental organic and trace metal contaminants, e.g. chlorinated pesticides, PCBs and PAHs along the Atlantic, Pacific and Gulf coasts of the U.S.A. by measuring the concentrations of these contaminants in bivalves. Several overviews of the concentrations and distributions of PAHs and chlorinated hydrocarbons have already been reported (Wade *et al.*, 1988; 1990; Wade and Sericano, 1989; Sericano *et al.*, 1990a; 1990b). In the following paragraphs, the average concentrations in oyster tissues and geographical distributions of PAHs, PCBs and DDT residues in Galveston Bay corresponding to the first three years of this program, i.e., 1986-1988, will be outlined. Then, the overall average concentrations for the Galveston Bay area will be compared to other areas in the Gulf of Mexico. For complete information on site locations as well as for more specific details, refer to the above publications.

Between 1986 and 1988, total PAH average concentrations ranged from 54 to 2400 ng/g (Table 2.4). The higher concentrations were measured in oysters from the upper portion of the Galveston Bay, e.g. Ship Channel and Yacht Club, and near the city of Galveston, e.g. Confederate Reef and Offatts Bayou. Oyster samples from areas further away from urban centers, e.g. Hanna Reef, had average concentrations one to two orders of magnitude lower. In general, these concentrations are in good agreement with those previously encountered during temporal studies in Galveston Bay (Fox, 1988; Sericano, unpublished data). Two

PAHs, pyrene and fluoranthene, generally accounted for >25%, of the total PAHs measured. The predominance of these compounds would suggest that the major source of PAHs in the Galveston Bay area is combustion products.

Average total PCB and DDT concentrations in Galveston Bay oysters were in the 48-1100 and 12-240 ng/g ranges, respectively. Most of the DDT residue is present as metabolites, DDE and DDD. In general, less than 10% of the total contaminant load in oysters is the parent compound, DDT. Samples from the Yacht Club and Ship Channel were the most contaminated while oysters from Hanna Reef had the lowest residue concentrations. These concentrations agree with the ranges reported earlier in Galveston Bay bivalves (Butler, 1973; Fox, 1988).

Total PAH, PCB and DDT concentrations measured in oyster samples from different geographical areas during the period 1986-1988 are presented in Table 2.5. The number of sites sampled in each area during those years are indicated in parentheses. The average PAH, PCB and DDT residue concentrations ranged from 12 to 5200 ng/g, 23 to 520 ng/g and 7.3 to 400 ng/g with overall average values for the entire Gulf of Mexico of 650, 110 and 63 ng/g, respectively. Concentrations in oysters from Galveston Bay, as well as from San Andrew Bay, Panama City and Choctawhatchee Bay, in Florida, Mississippi Sound, in Mississippi, and Mississippi River, in Louisiana, are in the upper quartile of the concentration ranks. Four other Texas locations, i.e. Laguna Madre (PAHs), Aransas Bay (PAHs), Corpus Christi (PAHs) and Brazos River (DDTs), are occasionally listed in the upper 25% range.

2.2.4 Chlorinated Dibenzo-p-dioxin and Dibenzofurans

Recently, there has been much environmental concern over the presence of chlorinated dibenzo-p-dioxin and chlorinated dibenzofurans (CDDs and CDFs) especially the most toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF), because of the possibility for human health effects at low concentrations (ppt). A 1989 study of dioxin and furan compounds in edible tissue for sites in Arkansas, Louisiana, and Texas included sampling two stations on the Houston Ship Channel, with two species collected per station (Crocker and Young 1990). The two sampling stations were situated below a bleached Kraft paper mill, and another facility which treats paper mill discharges. Blue crabs and blue catfish collected at San Jacinto Monument had concentrations of 54.8 parts per trillion (ppt) and 3.2 ppt of 2,3,7,8-TCDD, respectively. However, since the crab concentration included internal organs, dioxin in edible tissue *per se* may have been over-estimated. The concentrations equate to risk levels of about 9.4 and 0.5×10^{-4} (assuming 6.5 g/d consumption), respectively. Tissue concentrations further downstream at Morgans Point were 14.8 ppt for sea catfish (risk level 2.2×10^{-4}) and 6.2 ppt for oysters (1.1×10^{-4}).

The Texas Department of Health (TDH 1990) conducted additional sampling for crabs, oysters, and red drum in upper Galveston Bay during May 1990. Toxicity equivalence concentrations (TECs) ranged from nondetected to 3.97 ppt, equating to risk levels ranging from negligible to 5.75×10^{-5} (assuming 6.5 g/d

consumption). In response to the above data, the TDH decided to issue a fish consumption advisory for the Houston Ship Channel and associated waters.

2.2.5 Trace Metals

The combination of large population, high industrialization, shallow depth and restricted water exchange gives Galveston Bay the potential for serious trace metal pollution problems. Such problems, however, have not been well documented. Hann and Slowey (1972) showed sediments in the upper, confined parts of the Houston Ship Channel to be highly enriched in several trace metals and this has been confirmed by yearly sampling by the Texas Water Quality Board and Texas Water Commission (TWC) since 1974 (Texas Water Commission, 1987). However, sediment from the ship channel where it crosses the open Galveston Bay did not appear to be contaminated in these early studies. TWC analyses for trace metals in sediment in the Houston Ship Channel show a decline in all metals between 1974 and 1986 (Stanley, 1989). Previously published data for dissolved trace metals in open Galveston Bay waters which are considered reliable are thought to be those of Tripp (1988) who determined only As and Sb concentrations. These were both near normal seawater values in the open Bay but As was enriched by up to a factor of 5 in the Houston Ship Channel. Sb was depleted there. Benoit (unpublished data, Texas A&M at Galveston, 409-740-4476) has recently determined concentrations of several trace metals dissolved in Galveston Bay waters and finds them similar to those in other Texas Bays.

The numerous petrochemical plants along the Houston Ship Channel use large quantities of metals such as Cr, Cu, Ni, V and Zn as catalysts in the manufacture of styrene, polyethylene and other products. Metal finishing and plating facilities also produce a variety of metal wastes and metal salts such as zinc chromate and copper sulfate are added to industrial cooling waters to control algae. In addition, surface urban runoff is enriched in Pb from automobile exhaust and in other metals. The Texas Water Quality Board, the USEPA and other agencies have been concerned with trace metal contamination in the Ship Channel and Galveston Bay for at least 30 years.

Since 1974, the TWC has taken quarterly water samples at six Ship Channel locations and at selected locations in the Bay. They have also taken and analyzed bottom sediment samples for trace metals. Much of the data from the late 1960s and early 1970s are reported by Copeland and Fruh (1970) and Hann and Slowey (1972).

Figures 2.2 and 2.3 show plots of all the data collected by the Texas Water Quality Board and Water Commission between 1974 and 1987. Arsenic, chromium, and lead have shown the strongest declines in the water samples. In the 1970s arsenic was frequently greater than 30 µg/liter, but since 1984 almost all the measured concentrations have been below 10 µg/liter, and lead levels have fallen from a maximum of 300 µg/liter in 1974 to a maximum of 100 µg/liter in 1986 (Figure 2.2). Although these declines are reassuring, they must be interpreted with caution. It is almost certain that the values from earlier years, and probably those from latter years too, are in error, due to contamination with sampling

equipment and instrumental limits. Recent data (Presley, unpublished, Dept. of Oceanography, Texas A&M University, 409-845-5136) is hundreds of times lower than these values.

Arsenic, cadmium and lead concentrations in the ship channel sediments appear to be trending downward, but for the other metals, there are no obvious trends (Figure 2.3). Before 1982 about half the arsenic values were above 8 mg/kg sediment; since then they have all been below 8. Average lead levels in the 1984 and 1985 samples were also down by about 50% from those taken a decade earlier. Similarly, cadmium concentrations seem to have declined modestly since the 1970s. In 1986 the maximum was 6 mg/kg sediment, compared to 11 mg/kg sediment in 1974 and 1978. The sediment data is more likely to be reliable than are the water data. This reliability is due to higher concentrations found in sediments and fewer problems with sample contamination.

Both water column and sediment values for a given metal have ranged widely, but there are several factors that could explain this. One is that the highest concentrations are probably very localized because some of the metals are discharged in large quantity by only a few industries. Second, the data plotted in Figure 2.3 are for the whole ship channel (segments 1005-1007). It has been shown by Hann and Slowey (1972) that, in the early 1970s at least, there was a clear trend of decreasing sediment metals concentrations as one moved down the ship channel; the open Bay had little enrichment. This is a reflection of the high concentration of municipal and industrial outfalls along the upper one-third of the channel. Finally, estuarine sediment concentrations of many of the metals are naturally highest in muddy sediments and lowest in sandy sediments and unless data on grain size or Fe or Al is given, trace metal data are hard to interpret.

The Hann and Slowey (1972) report gives trace metal data on sediments taken from a number of locations in Galveston Bay. Except for three stations in the upper bay near Morgans Point and a station in the Texas City Channel, metals were distributed uniformly throughout the Bay with little indication of pollutant inputs. Data from the Texas Water Quality Board and Water Commission since 1974 essentially agree with the Hann and Slowey (1972) data. Shown in Figure 2.4 is data for five stations around Galveston Bay collected by TWQB and TWC from 1974 to 1986. No real trend is apparent in the data; it has not been normalized to Fe or Al and the significance of isolated high values is difficult to interpret. Sediment from Galveston Bay collected at six sites during the NOAA NS&T Programs in 1986-1990 (Brooks *et al.*, 1991) gave few indications of pollutant influences when normalized to Fe or Al.

2.2.5.1 Organisms

Oysters (*Crassostrea virginica*) were collected at six different sites in Galveston Bay during 1986-1990 as part of the National Status and Trends Program (Brooks *et al.*, 1990). Each site was on an identifiable oyster reef. At each site, twenty oysters were taken from each of three stations, which were 100 to 500 m apart. Each site was sampled once each year, except two of the sites (GBOB and GBSC)

which were not sampled the first years. The twenty oysters from each station were combined and analyzed as a single sample each year.

Oysters were usually hand-picked from exposed reefs, but in deeper water were taken by dredge or tongs. In most cases, stations were located hundreds of meters to many kilometers away from any obvious point sources of pollutant inputs in an attempt to characterize large areas of Galveston Bay, rather than to identify specific point sources of pollutant input. The new sites added in year 3 were, however, selected to be closer to industrial areas or population centers than were the original four sites. Stations were revisited as closely as possible each year, both in time and space.

All data reported for the NS&T Program were obtained by atomic absorption spectrophotometry (AAS). Flame AAS was used for Cu, Fe, and Zn, which exhibit high concentrations in oysters; cold vapor AAS for mercury and graphite; furnace AAS (Perkin-Elmer Corp. model 3030 with Zeeman background correction) for the remaining elements. Some samples of freeze-dried oyster tissue were also analyzed for some elements by neutron activation analysis (NAA) which required no sample pre- or post-treatment. Agreement between AAS and NAA was good ($\pm 10\%$) for elements analyzed by both techniques.

The samples were analyzed for Ag, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Si, Sn, and Zn. In addition, temperature, salinity and related environmental parameters were measured as were size, sex, parasite presence and indicators of health of the oysters (see Brooks, 1990).

Trace metal concentrations found in oysters collected along the entire Gulf of Mexico coastline during the first five years of the Status and Trends Program were generally similar to those reported in oysters taken from non-contaminated water in other parts of the world (Presley *et al.*, 1990). Only a few sites (locations) showed obvious trace metal pollution and these were restricted geographically such that nearby sites were usually unaffected. Abnormally high or low values at a site did, however, usually repeat year after year, suggesting local control. Abnormal sites for most metals were just as likely to appear visibly pristine as to be highly industrialized.

The oysters collected in Galveston Bay for the Status and Trends Program were similar in trace metal content to those collected elsewhere along the Gulf coastline, i.e., there is no indication of generalized trace metal pollution in Galveston Bay. This can be seen by comparing the overall averages (Table 2.6) for all years and all sites in Galveston Bay with those for the entire Gulf. The Galveston data includes four sites sampled all five years and two sites sampled for two years. Twenty oysters were taken from each of three stations sampled at each site, resulting in 1560 Galveston oysters being analyzed over the five year period. The Gulf data set includes more than 18,000 oysters, as 50 sites were sampled all five years and an additional 20 sites for three years. Thus, the data are unlikely to be biased by a few abnormal individuals.

The average Cd, Cr, Cu, Mn, and Pb in NS&T Galveston Bay oysters differs by 10% or less from the Gulf-wide average. This difference is about the same as our analytical precision and not significant at the 99% confidence level based on a "t-test". Silver is 23% higher in Galveston Bay, Ni is 16% higher and Se is 14% higher. A "t-test" of the significance of those differences shows that the Ni averages are not significantly different at the 95% confidence level. Although, the Se average for Galveston Bay oysters is significantly higher than the Gulf-wide average, it is not significantly different from the Texas-Louisiana average. It differs from the Gulf-wide average only because of low Se oysters in Mississippi and Florida.

The high average Ag in Galveston Bay oysters is caused by a 300% enrichment found at one site in 1990. The enrichment appears to be real because it was found in all three of 20 pooled oyster samples collected at that site. No cause for the enrichment can be suggested, and without it NS&T Galveston Bay oysters would be average in silver content. Arsenic and mercury in Galveston Bay oysters are less than one-half the Gulf-wide average but the Gulf-wide averages are greatly influenced by several sites in southern Florida that produce oysters greatly enriched in As and Hg and by a site in Lavaca Bay, Texas which is enriched in Hg. Oysters from other Texas and Louisiana bays are similar in As and Hg content to those in Galveston Bay. Tin seems to be about 24% higher in Galveston Bay than Gulf averages, but all Sn values are near the detection limit of the method used and a 24% difference is probably not significant. Finally, Zn is 35% higher in Galveston Bay oysters collected for NS&T than in Gulf-wide average oysters. This difference is highly significant statistically because the high Zn found in all oysters leads to precise analytical determination and few analytical artifacts.

Zinc in Galveston Bay oysters showed an interesting pattern in that three of the six NS&T sites sampled had oysters with near Gulf-wide average Zn, whereas the other three had much higher and more variable Zn. Two of the high Zn sites were in extreme northeastern Galveston Bay near industrial wastewater discharge sites and boat harbors. The third high Zn site was in Offatts Bayou on Galveston Island and was surrounded by residential development and small boat harbors. Thus, zinc, and zinc alone, shows a clear correlation with the activities of man when the five year NS&T trace metals in the oyster data set is examined.

Table 2.1 GBNEP Sampling Summary

Dates	Activity	Comment
May 23-25, 1990	Sampled oysters and crabs at all four sites.	Trawling terminated due to poor fish recoveries.
June 6-8, 1990	Gill netting at all four sites. Fish Analyzed: MP - 10 fish EP - 7 fish	Gill netting terminated due to extremely low salinity at MP.
June 26-27, 1990	Gill netting at HR and CR.	Salinity still low in Bay. No samples analyzed.
July 30-Aug. 3, 1990	Gill netting at all four sites. Fish Analyzed: HR - 30 fish CR - 27 fish MP - 20 fish EP - 3 fish	Salinity near normal, catch good at all sites except Eagle and Morgan Points. Apex barge spill occurred on July 28th. Spill appeared to impact collections at Eagle Point.
Sept. 4-6, 1990	Gill netting and hook-and-line at Eagle Point. Fish Analyzed: EP -20 fish	Resampling Eagle Point after Apex barge spill.

Table 2.2 Hydrocarbon concentrations in samples from the Galveston Bay area. Except where indicated, concentrations in organisms are expressed in ng/g on a wet-weight basis. Concentrations in sediment and water samples are expressed in ng/g, on a dry-weight basis, and in ng/l, respectively.

Location	Sample	Total HCs	Total Aromatic HCs	Individual PAHs	Reference
Galveston Bay	oysters		11-237	fluoranthene= 7.8 pyrene= 6.5 benzo(b)fluoranthene= 2.2 benzo(e)pyrene= 2.1 benzo(a)pyrene= n.d.	Fazio, 1971
Houston Ship Channel	oysters	236000	134000		Ehrhardt, 1972
Morgans Point Reef	oysters	160000			Anderson, 1975
Halfway Reef	oysters	26000			Anderson, 1975
East Bay	oysters	<2000			Anderson, 1975
West Bay	oyster	<2000			Anderson, 1975
Galveston Bay	oysters			pyrene= 1010 fluoranthene= 940 benzo(a)pyrene= 0.12 pyrene= 212; 55-481 fluoranthene= 112; 55-219 chrysene= 97; <20-146 pyrene= 31; <20-63	Farrington <i>et al.</i> , 1980
Morgans Point Reef	oysters		615	fluoranthene= 12; <20-57 chrysene= <20; <20-36 pyrene= 146; 40-293	Murray <i>et al.</i> , 1980
Yacht Club	oysters		319-1020	fluoranthene= 112; 55-219 chrysene= 97; <20-146 pyrene= 31; <20-63	Fox, 1988 ⁽¹⁾
Todd's Dump	oysters		134	fluoranthene= 12; <20-57 chrysene= <20; <20-36 pyrene= 146; 40-293	Fox, 1988 ⁽¹⁾
			94.7-183	fluoranthene= 12; <20-57 chrysene= <20; <20-36 pyrene= 146; 40-293	
Confederate Reef	oysters		610	fluoranthene= 210; 55-404 chrysene= 61; 28-87 pyrene= <20; <20-25	Fox, 1988 ⁽¹⁾
			259-1120	fluoranthene= <20; <20-37 chrysene= <20 pyrene= 2170; 669-3910	
Hanna Reef	oysters		111	fluoranthene= 738; 317-1120 chrysene= 632; 260-1090 benzo(a)pyrene= <0.01 naphthalene= 20-40	Fox, 1988 ⁽¹⁾
			21.3-228	fluoranthene= n.d.-70 pyrene= 20-240 benzo(a)pyrene= 40-110 chrysene= 130	
Morgans Point Reef	oysters		5783	benzo(g,h,i)perylene= 590 benzo(k)fluoranthene= 40 1,2,4,5 dibenzoanthracene= 20 dimethyl naphthalenes= 8000 trimethyl naphthalenes= 10000 C ₄ - naphthalenes= 9000 dimethyl biphenyls= 800	Sericano ⁽¹⁾ (unpublished data)
			2270-10120	benzo(a)pyrene= 2.2; 0.01-6.0 benzene= 1500 toluene= 3200 C ₂ - benzene= 3100 C ₃ - benzene= 800 dimethyl naphthalenes= 700	
San Luis Pass	Fish, crab, shrimp			benzo(a)pyrene= n.d.	Murray <i>et al.</i> , 1981a
Houston Ship Channel	Cormorants				King <i>et al.</i> , 1987 ⁽²⁾
Houston Ship Channel	Cormorants				King <i>et al.</i> , 1987 ⁽²⁾
Trinity Bay	sediments	96100	34200		Armstrong <i>et al.</i> , 1979
San Luis Pass	sediments				Murray <i>et al.</i> , 1981a
Trinity Bay	water	10500	10500		Armstrong <i>et al.</i> , 1979
San Luis Pass	water				Murray <i>et al.</i> , 1981a

n.d.= not detected;⁽¹⁾ ng/g on a dry-weight basis; ⁽²⁾ geometric mean

Table 2.3 Chlorinated hydrocarbon concentrations in samples from the Galveston Bay area. Except where indicated, concentrations in organisms are expressed in ng/g on a wet-weight basis. Concentrations in sediment and water samples are expressed in ng/g, on a dry-weight basis, and in ng/l, respectively.

Location	Sample	PCBs	SDDT	Dieldrin	Others	Reference
Trinity Bay	oysters		6.16 n.d.-51	2.86 n.d.-20		Butler, 1973
Galveston Bay	oysters		23.9 n.d.-88	14.5 n.d.-87		Butler, 1973
Morgans Point	oysters				HCB= 0.63; 0.31-1.4 PCP= 5.3; 3.4-8.3	Murray <i>et al.</i> , 1980
Yacht Club	oysters	966 120-4025	83.9 13.6-167	23.3 4.91-51.6	HEp= 1.30-27.3 a-Chlor= 5.35-73.5 TNon= 4.31-58.8	Fox, 1988 ⁽¹⁾
Todd's Dump	oysters	155 47.4-283	28.5 6.14-67.5	11.1 1.46-26.7	HEp= 0.34-18.1 a-Chlor= 1.49-24.4 TNon= 1.61-19.6	Fox, 1988 ⁽¹⁾
Confederate Reef	oysters	131 94.7-171	15.4 8.09-24.4	5.37 1.64-10.1	HEp= 0.27-5.19 a-Chlor= 1.54-6.68 TNon= 1.51-5.19	Fox, 1988 ⁽¹⁾
Hanna Reef	oysters	59.4 32.5-107	11.8 3.28-30.7	7.64 2.09-13.1	HEp= 0.41-5.40 a-Chlor= 0.79-13.4 TNon= 0.69-5.76	Fox, 1988 ⁽¹⁾
Trinity Bay	clams			6.8-16.6		Petrocelli <i>et al.</i> , 1975
Trinity Bay	fish	50-160				Strawn <i>et al.</i> , 1977
	fish	50-500				Strawn <i>et al.</i> , 1977
	fish	60-150				Strawn <i>et al.</i> , 1977
Galveston Bay	fish	9-43				Stahl, 1980
	crab	18-42				
San Luis Pass	fish, crab shrimp				HCB= 2.5; 0.49-9.6 PCP= 4.2; 2.6-7.5	Murray <i>et al.</i> , 1981a
Galveston Bay	fish	310 70-540	10 n.d.-10		Chlordane= n.d.	King, 1989a ⁽²⁾
Galveston Bay	fish	350 100-620	30 10-50	- 10-20	HCB= n.d. Chlordane= 20-70 Heptachlor= 20-30	King, 1989b ⁽²⁾
Galveston Bay	cormorants	6990 2600-24000	1730 200-20000	100 100-600	Chlordane= 100	King & Krynitsky, 1986 ⁽²⁾
	gulls	4210 1500-11000	2000 700-5500	160 100-400	Chlordane= 100-1200	
	skimmers	3880 800-11000	4430 900-30000	- 100-300	Chlordane= 100-1000	
Galveston Bay	cormorants	1580 1100-3300	930 400-2300	120 130-250	HCB= 100-280 HEp= 110-140	King <i>et al.</i> , 1987 ⁽²⁾
Houston Ship Channel	sediments	3250				Saleh & Lee, 1976
Texas City Channel	sediments	2860				Saleh & Lee, 1976
Galveston Bay	sediments	15-68				Stahl, 1980
San Luis Pass	sediments	0.52 0.25-0.78	<0.03	<0.03	HCB= 0.49; 0.05-1.5 PCP= 0.18 Chlordane= <0.03	Murray <i>et al.</i> , 1981a

Table 2.3 continued

Location	Sample	PCBs	SDDT	Dieldrin	Others	Reference
Morgans Point	sediments	1.5 <0.14-3.3	0.09 <0.01-1.4			Murray <i>et al.</i> , 1981b
Trinity Bay	sediments	1.2 <0.14-7.1	0.3 <0.01-1.4			Murray <i>et al.</i> , 1981b
Texas City Channel	sediments	2.8 <0.14-5.6	0.23 <0.01-0.53			Murray <i>et al.</i> , 1981b
Galveston Bay	water	45				Saleh & Lee, 1976
Galveston Bay	water	2-15				Stahl, 1980
San Luis Pass	water				PCP= 8.0; 4.3-11	Murray <i>et al.</i> , 1981a
Morgans Point	water	1.1 <0.01-4.6	1.8 0.04-3.5			Murray <i>et al.</i> , 1981b
Trinity Bay	water	1.8 <0.01-4.1	0.03 <0.01-0.16			Murray <i>et al.</i> , 1981b
Texas City Channel	water	18 <0.01-70	0.2 <0.01-0.16			Murray <i>et al.</i> , 1981b

n.d.= not detected; ⁽¹⁾ ng/g on a dry-weight basis; ⁽²⁾ geometric mean; HEp= heptachlor epoxide; TNon= trans-nonachlor; a-Chlor= alpha-chlordane; HCB= hexachlorobenzene; PCP= pentachlorophenol.

Table 2.4 Selected organic contaminant concentrations (ng/g, dry weight) in oyster samples from NOAA's S&T Program sites in the Galveston Bay area.

Site	Σ PAHs	Site	Σ PCBs	Site	Σ DDTs
Houston Ship Channel	2400	Yacht Club	1100	Houston Ship Channel	240
Confederate Reef	710	Houston Ship Channel	420	Yacht Club	120
Yacht Club	620	Todd's Dump	120	Offatts Bayou	70
Offatts Bayou	540	Offatts Bayou	110	Todd's Dump	29
Todd's Dump	81	Confederate Reef	100	Confederate Reef	18
Hanna Reef	54	Hanna Reef	48	Hanna Reef	12
AVERAGE	730		320		82

Table 2.5 Selected organic contaminant concentrations (ng/g, dry weight) in oyster samples from NOAA's S&T Program locations on the Gulf of Mexico coast. Numbers of stations sampled at each location are given in parenthesis.

State-Location	ΣPAHs	State-Location	ΣPCBs	State-Location	ΣDDTs
FL-Saint Andrew Bay (1)	5200	FL-Saint Andrew Bay (1)	520	AL-Mobile Bay (2)	400
FL-Panama City (1)	5100	FL-Pensacola Bay (2)	340	TX-Brazos River (1)	190
TX-Laguna Madre (2)	1400	TX-Galveston Bay (6)	320	FL-Choctawhatchee Bay(2)	190
FL-Choctawhatchee Bay (2)	980	AL- Mobile Bay (2)	210	FL-Saint Andrew Bay(1)	170
TX-Aransas Bay (2)	820	FL-Choctawhatchee Bay (2)	190	LA-Mississippi River (2)	150
MS-Mississippi Sound (3)	820	MS-Mississippi Sound (3)	180	FL-Panama City (1)	100
LA-Mississippi River (2)	750	LA-Mississippi River (2)	170	TX-Galveston Bay (6)	82
TX-Corpus Christi (3)	740	FL-Panama City (1)	130	FL-Charlotte Harbor (2)	71
TX-Galveston Bay (6)	730	LA-Vermillon Bay (1)	120	MS-Mississippi Sound (3)	68
AL-Mobile Bay (2)	690	LA-Breton Sound (2)	110	LA-Vermillon Bay (1)	67
TX-Brazos River (1)	640	FL-Apalachicola Bay (2)	97	LA-Atchafalaya Bay (1)	66
TX-Copano Bay (1)	530	TX-Brazos River (1)	95	FL-Apalachicola Bay (2)	64
FL-Apalachicola Bay (2)	500	LA-Calcacieu Lake (2)	94	TX-Matagorda Bay (6)	58
LA-Calcacieu Lake (2)	440	FL-Atchafalaya Bay (1)	86	FL-Pensacola Bay (2)	55
LA-Barataria Bay (3)	430	FL-Charlotte Harbor (2)	86	FL-Tampa Bay (5)	43
FL-Pensacola Bay (2)	340	TX-Sabine Lake (1)	82	LA-Calcacieu Lake (2)	39
LA-Atchafalaya Bay (1)	330	FL-Tampa Bay (5)	82	LA-Joseph Harbor Bayou (1)	38
LA-Terrebone Bay (2)	270	TX-Laguna Madre (2)	76	TX-Copano Bay (1)	36
FL-Tampa Bay (5)	220	FL-Naples Bay (1)	75	TX-Corpus Christi (3)	32
FL-Suwanee River (1)	210	TX-Corpus Christi (3)	73	LA-Breton Sound (2)	32
FL-Cedar Key (1)	210	LA-Joseph Harbor Bayou (1)	67	FL-Naples Bay (1)	32
LA-Breton Sound (2)	190	FL-Suwanee River (1)	62	FL-Cedar Key (1)	27
FL-Charlotte Harbor (2)	190	TX-Matagorda Bay (6)	56	TX-Espiritu Santo Bay (2)	25
FL-Naples Bay (1)	160	LA-Barataria Bay (3)	56	TX-Sabine Lake (1)	20
TX-Sabine Lake (1)	150	FL-Cedar Key (1)	46	TX-Mesquite Bay (1)	18
FL-Everglades (1)	100	TX-Copano Bay (1)	44	FL-Suwanee River (1)	18
TX-Matagorda Bay (6)	96	LA-Caillou Lake (1)	44	TX-Laguna Madre (2)	16
LA-Lake Borgne (2)	75	TX-Mesquite Bay (1)	39	LA-Barataria Bay (3)	16
LA-Joseph Harbor Bayou (1)	73	LA-Lake Borgne (2)	39	TX-Aransas Bay (2)	15
TX-San Antonio Bay (2)	65	LA-Terrebone Bay (2)	38	TX-San Antonio Bay (2)	14
LA-Vermillon Bay (1)	63	FL-Everglades (1)	29	LA-Caillou Lake (1)	12
TX-Espiritu Santo Bay (2)	29	FL-Rookery Bay (1)	28	FL-Everglades (1)	9.6
FL-Rookery Bay (1)	26	TX-Aransas Bay (2)	27	LA- Lake Borgne (2)	8.8
TX-Mesquite Bay (1)	19	TX-San Antonio Bay (2)	26	FL-Rookery Bay (1)	8.4
LA-Caillou Lake (1)	12	TX-Espiritu Santo Bay (2)	23	LA-Terrebone Bay (2)	7.3
AVERAGE	650		110		63

Table 2.6 Summary Statistics for Trace Metals in Galveston Bay and U.S. Gulf of Mexico Oysters Collected in 1986-1990 and 1976-1978. All values in ppm dry weight.

	Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Sn	Zn
Galveston Bay													
1986-1990 ⁽¹⁾	2.77	4.50	4.33	0.53	165.	275.	0.078	15.9	1.89	0.71	3.42	0.29	3263.
std. dev.	2.42	1.08	1.58	0.44	61.	142.	0.066	8.1	0.64	0.45	0.88	0.22	1648.
U.S. Gulf of Mexico													
1986-1990 ⁽¹⁾	2.24	9.69	4.20	0.55	156.	320.	0.142	14.8	1.64	0.69	2.99	0.23	2417.
std. dev.	1.59	7.00	2.46	0.42	107.	243.	0.156	8.8	1.29	0.93	1.33	0.16	1753.
GB/GOM	1.23	0.46	1.03	0.96	1.06	0.86	0.55	1.08	1.16	1.03	1.14	1.24	1.35
Significance of t-test of means	< 0.01	< 0.01	0.64	0.63	0.44	0.11	< 0.01	0.29	0.08	0.86	< 0.01	< 0.01	< 0.01
U.S. Gulf of Mexico													
1976-1978 ⁽²⁾	1.8	-	4.6	-	162	-	-	-	2.7	0.9	-	-	1940
std. dev.	1.5	-	2.6	-	138	-	-	-	1.4	0.9	-	-	1480

(1) *Crassostrea virginica*: For Galveston Bay, n = 78 pooled samples of 20 oysters each; for GOM, n = 874 pooled samples of 20 oysters each.

(2) *Crassostrea virginica*: Mean \pm 1 std. dev.; EPA Gulf Mussel Watch; Goldberg *et al.* (1983)

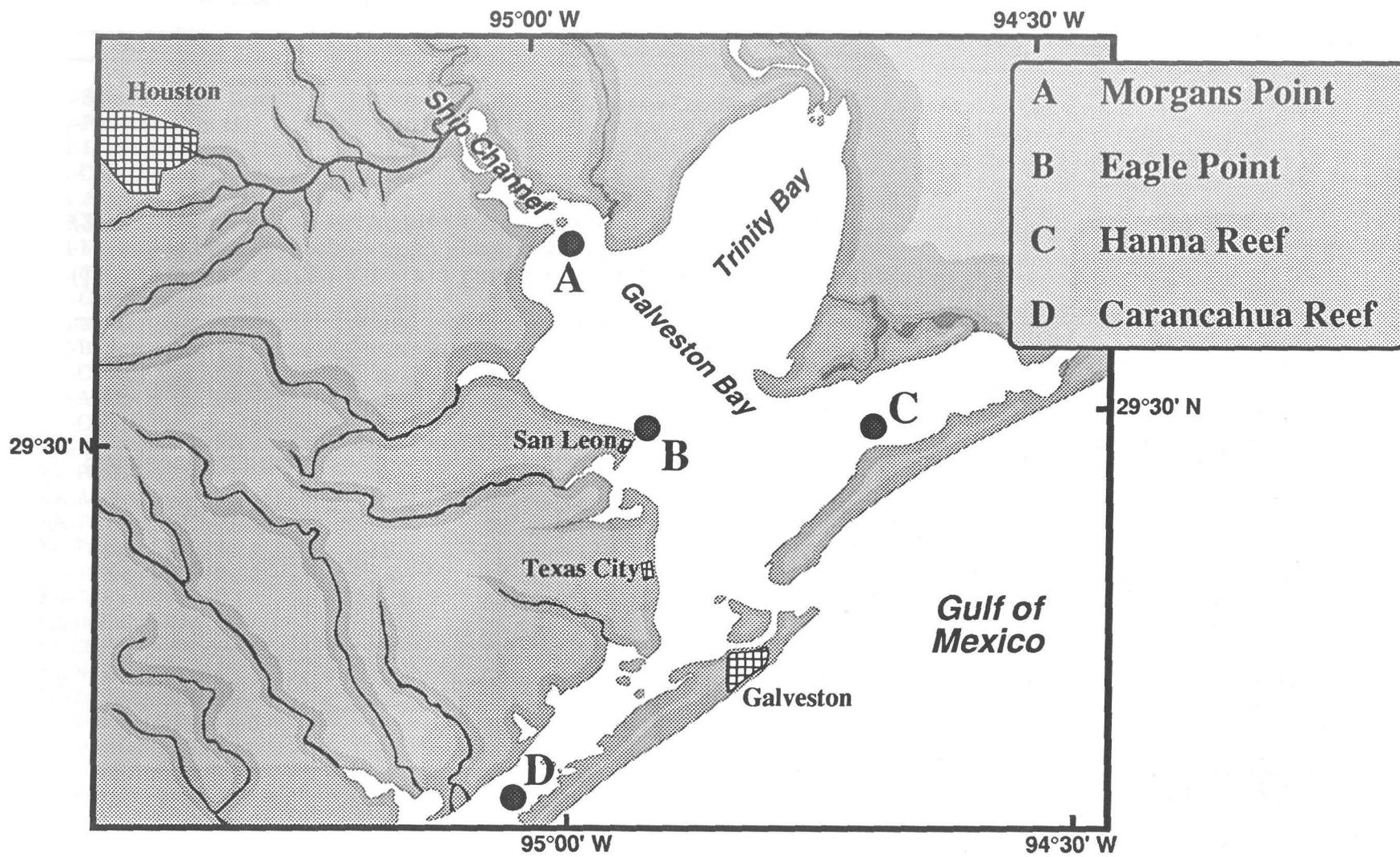


Figure 2.1 Collection Sites for GBNEP Samples.

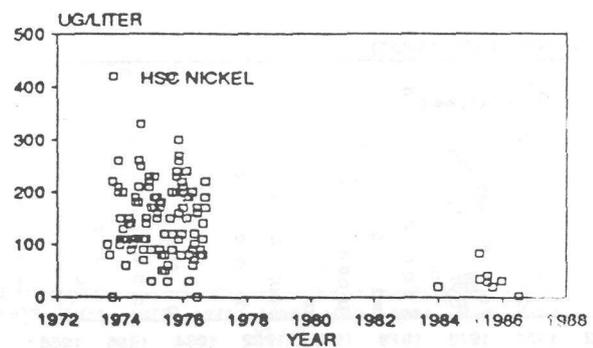
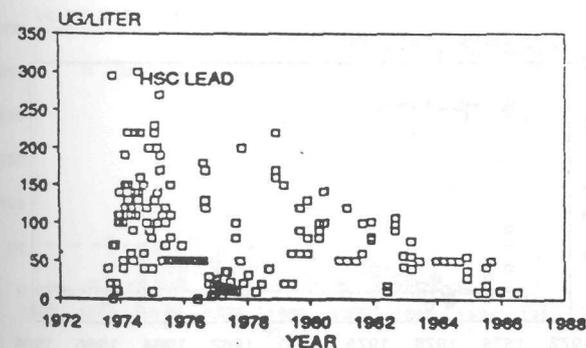
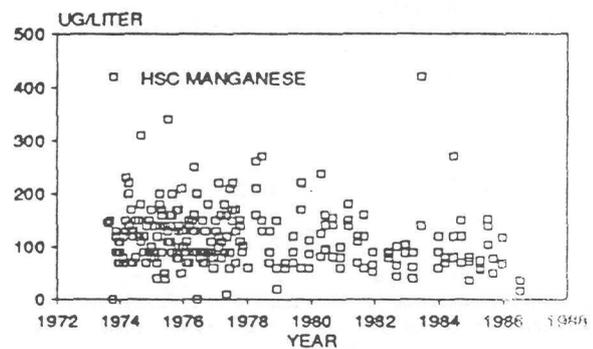
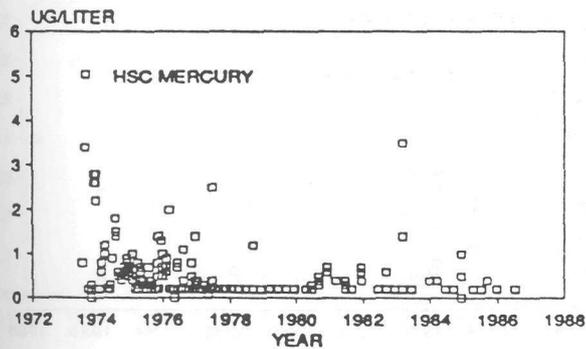
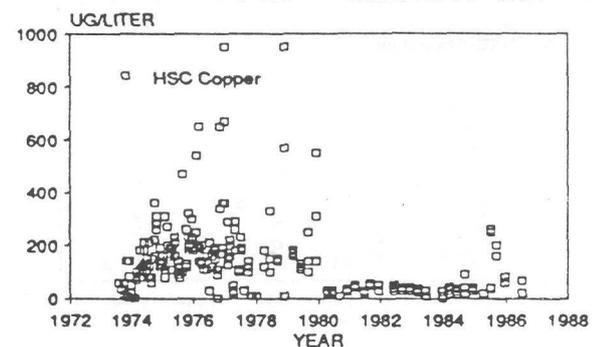
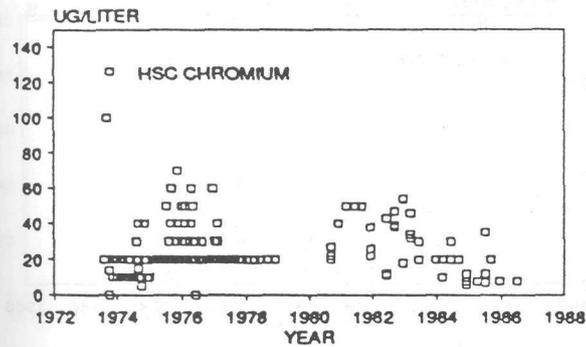
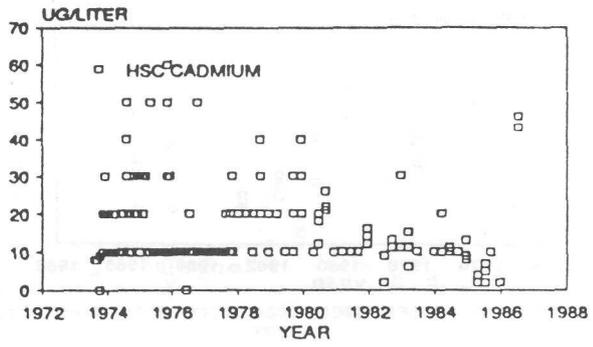
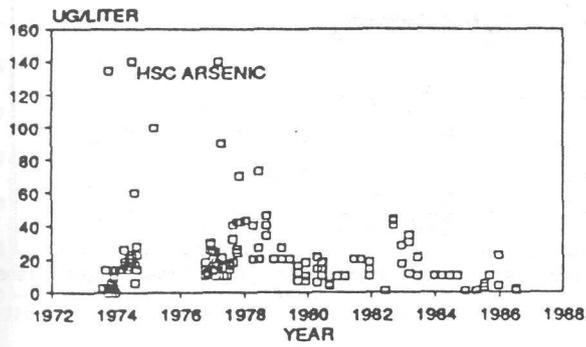


Figure 2.2 Metals concentrations in Houston Ship Channel water, 1974-1986. Data are for Texas Water Commission Segments 1005, 1006, and 1007.

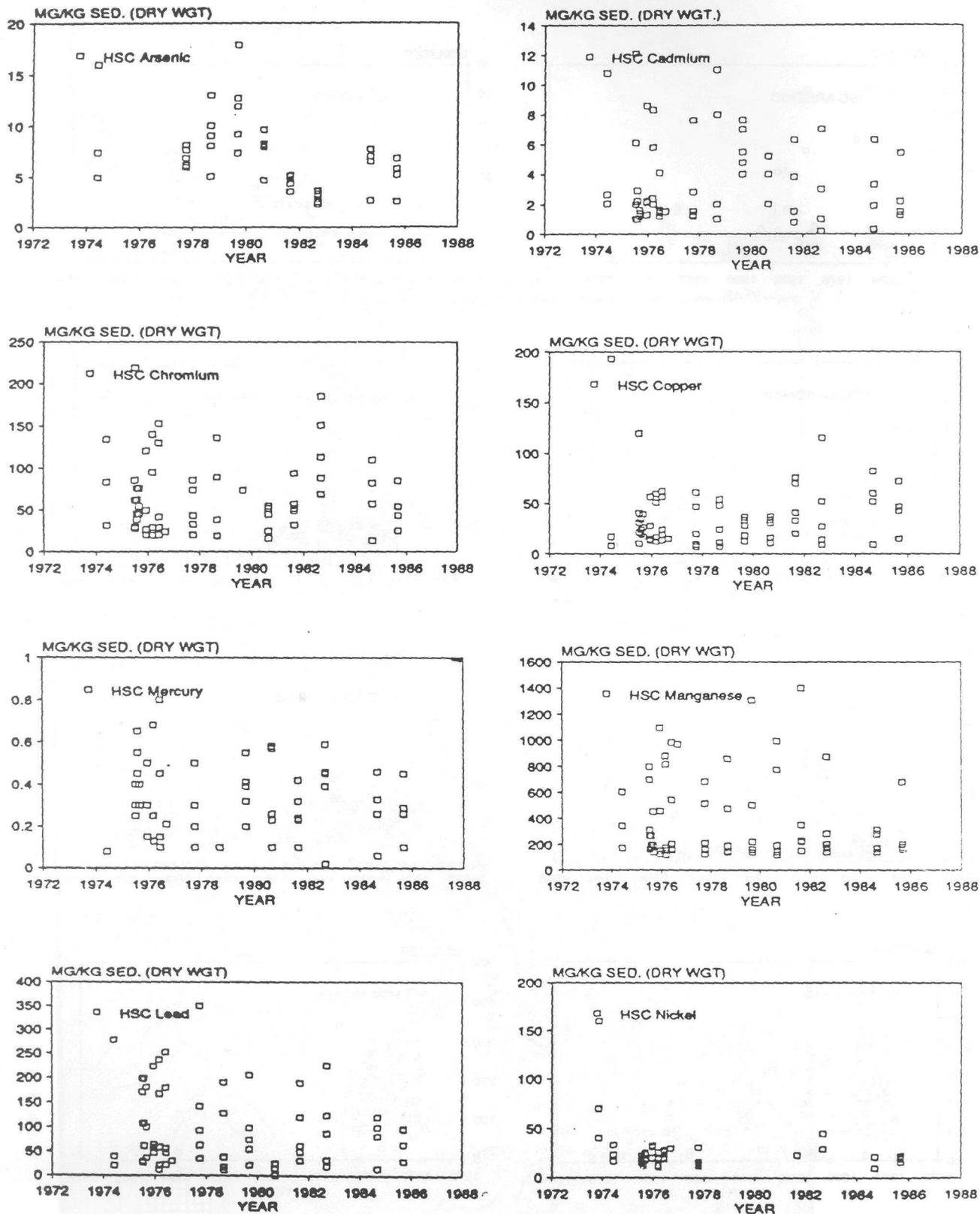


Figure 2.3 Surface sediment metals concentrations in the Houston Ship Channel, 1974-1986. Data are for Texas Water Commission Segments 1005, 1006, and 1007.

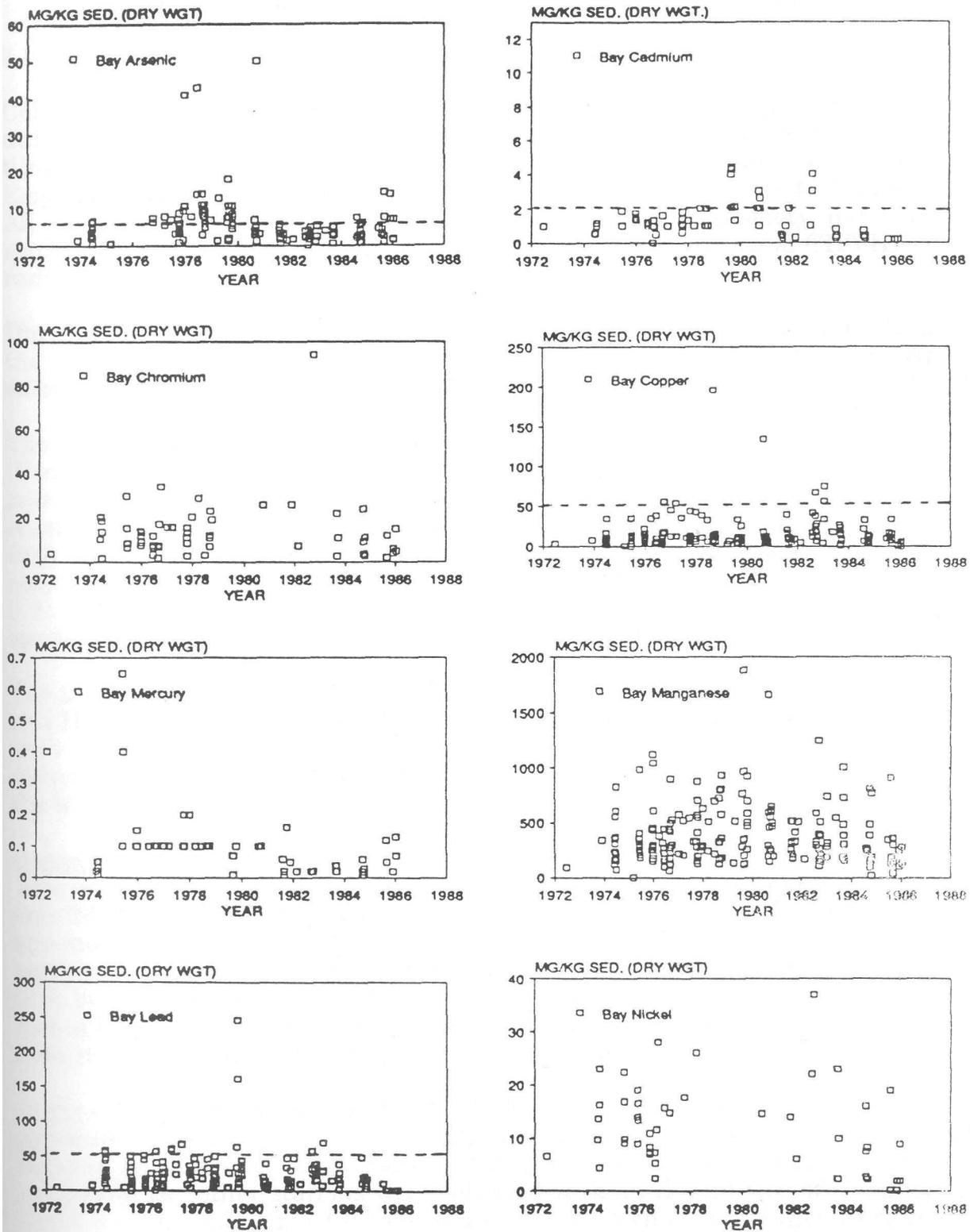


Figure 2.4 Surface sediment metals concentrations in Galveston Bay, 1974-1986. Horizontal lines denote screening levels proposed by the U.S. EPA (1974) for dredged sediment disposal in the Galveston Bay region.