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NOAA Technical Memorandum NOS OMA 58

STATUS AND TRENDS IN TOXICANTS AND THE POTENTIAL FOR THEIR BIOLOGICAL EFFECTS IN TAMPA BAY, FLORIDA

Seattle, Washington
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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

National Ocean Service

Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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STATUS AND TRENDS IN TOXICANTS AND THE POTENTIAL FOR THEIR BIOLOGICAL EFFECTS IN TAMPA BAY, FLORIDA

INTRODUCTION

Tampa Bay, Florida has been modified and impacted by a wide variety of human actions and stresses. These stresses have included dredging and filling projects that have resulted in losses of seagrass beds and other habitats that are important for valued marine biological resources (Lewis and Estevez, 1988). The populations of a number of important species have been impacted by the effects of high inputs and concentrations of nutrients, low oxygen content and clarity of the water, and overfishing (Florida Department of Environmental Regulation (FDER), 1988; Lombard and Lewis, 1985; Fanning and Bell, 1985; Estevez, 1989). The abundance of some rare and endangered species has been diminished as a result of a number of stresses (Weigle *et al.*, 1991; Reynolds *et al.*, 1991; Tampa Bay Regional Planning Council (TBRPC), 1990). Inputs of pathogens, radionuclides, and toxic chemicals have resulted in the contamination of sediments and biota in some parts of the system (Wellings, 1985; Upchurch *et al.*, 1985; Doyle *et al.*, 1989). All of these problems have been addressed by a variety of research projects, management strategies, and overview reports (see Treat *et al.*, 1985; Estevez, 1989; Lewis and Estevez, 1988). This report addresses the issue of toxic chemicals and their possible biological effects in Tampa Bay.

Some chemicals, if they occur in sufficiently high concentrations, can cause adverse biological effects in marine and estuarine organisms. In 1984 a technical workshop on contaminants in Florida's coastal zone recommended that research be focused upon quantification of toxicological effects, determination of correlations between contaminants and their effects, and identification of biologically stressed areas along Florida's coast (Delfino *et al.*, 1984). Among the environmental issues listed by the TBRPC (1983) as important in Tampa Bay, were those relating to non-point source discharges, hazardous waste disposal management, improvement of water quality, the poor ability to predict the assimilative capacity of the bay, and the lack of knowledge of the relationships between fishery stocks and a variety of stresses upon these stocks. Dieldrin, DDT and its metabolites, and other pesticides have been detected in Tampa Bay fish and shellfish collected by national and large regional surveys (Mearns *et al.*, 1988). Among the approximately 70 sites sampled along the Gulf Coast for the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program by Brooks *et al.* (1989), some of the sites in Tampa Bay had relatively high concentrations of total aromatic hydrocarbons and some pesticides in the sediments; and, five-ring aromatic hydrocarbons, hexachlorobenzene, total chlordanes, mirex, mercury (Hg), lead (Pb), and zinc (Zn) in oyster tissues. Compared to about 200 sites sampled nationwide by the NS&T Program, oysters from sites in Tampa Bay have had relatively high concentrations of Hg, Zn, and chlordane; and, the sediments from the Tampa Bay sites have had relatively high concentrations of DDT, other chlorinated pesticides, and Pb (NOAA, 1988; 1989).

No single report is available in which the data from chemical analyses of sediments and biota and the data from measurements of adverse effects have been summarized for Tampa Bay. Doyle *et al.* (1989) have prepared a very thorough review of information on the distribution of selected toxicants in sediments in Tampa Bay. There is some evidence that the concentrations of these chemicals differ considerably from place to place in the bay, and that the concentrations of some chemicals have changed over recent years. However, Doyle *et al.* (1989) did not evaluate chemical data from biological tissues, nor did they estimate the potential for biological effects or report data from measures of effects among resident biota.

Some of the toxicants found in the bay may be a threat to plants and animals, especially the sensitive larvae and juveniles of some species. However, thus far, no attempt has been made either to estimate the potential for biological effects attributable to toxicants or to document the present status of knowledge regarding toxicant-related effects in the bay.

The objectives of this report are: (1) to document the status and trends in concentrations of selected toxicants in sediments and biota of Tampa Bay; (2) to compare these toxicant concentrations in Tampa Bay with those observed elsewhere; (3) to estimate the potential for biological effects that may occur as a result of exposure of biota to these toxicants; and (4) to summarize the existing information from measures of toxicant-related effects observed thus far in Tampa Bay. The report is based upon a synthesis and evaluation of existing information from many different surveys and monitoring programs. Much of the data was generated by NOAA's NS&T Program, a nationwide monitoring program for marine environmental quality.

METHODS

The overall approach used in the preparation of this report is similar to that used by NOAA in the preparation of previous regional status and trends reports for San Francisco Bay, southern California, Oregon, and Boston Harbor. Data from the sites sampled in Tampa Bay by the NS&T Program were compared to determine patterns in chemical concentrations. These data also were compared with data from surveys and programs performed by others to determine status and trends within the bay. The NS&T Program data from other sites sampled along the Gulf Coast were compared with the Tampa Bay data to put the data from the bay into perspective. Data from analyses of sediments and biota were included. Chemical data from the quantification of trace metals, polychlorinated biphenyls (PCBs), pesticides, and petroleum hydrocarbons were evaluated. Data published in many different reports in which the concentrations of chemical toxicants in either tissues or sediments were compared with measures of effects were used to estimate the potential for effects occurring in Tampa Bay. Finally, biological data from a variety of measures of adverse effects potentially attributable to the exposure of organisms to toxicants in Tampa Bay were evaluated to determine if adverse effects actually had been observed.

This overall approach of evaluating data from multiple sources provides a larger data base upon which to base conclusions regarding status and trends than would be possible by using data only from one program. However, it has the disadvantage of comparing and evaluating data that may have been collected with different methods. Therefore, caution must be used in the interpretation of the data. In most cases, patterns were determined both by examining data from each study separately and by merging data from the different studies to form a preponderance of evidence.

Spatial patterns in toxicant concentrations were determined by comparing means and standard deviations in chemical concentrations among sites sampled in Tampa Bay. The locations of the sampling sites were described by using a modification of the subdivision nomenclature (Figure 1) proposed by Lewis and Whitman (1985). They segregated the Tampa Bay system into seven subdivisions: subdivision 1 is Old Tampa Bay, subdivision 2 is Hillsborough Bay, subdivision 3 is Middle Tampa Bay, subdivision 4 is Lower Tampa Bay, subdivision 5 is Boca Ciega Bay, subdivision 6 is Terra Ceia Bay, and subdivision 7 is lower Manatee River. In the present report, we have added subdivision 0 for the lower Hillsborough River and subdivision 8 for the Gulf of Mexico beyond the mouth of Tampa Bay.

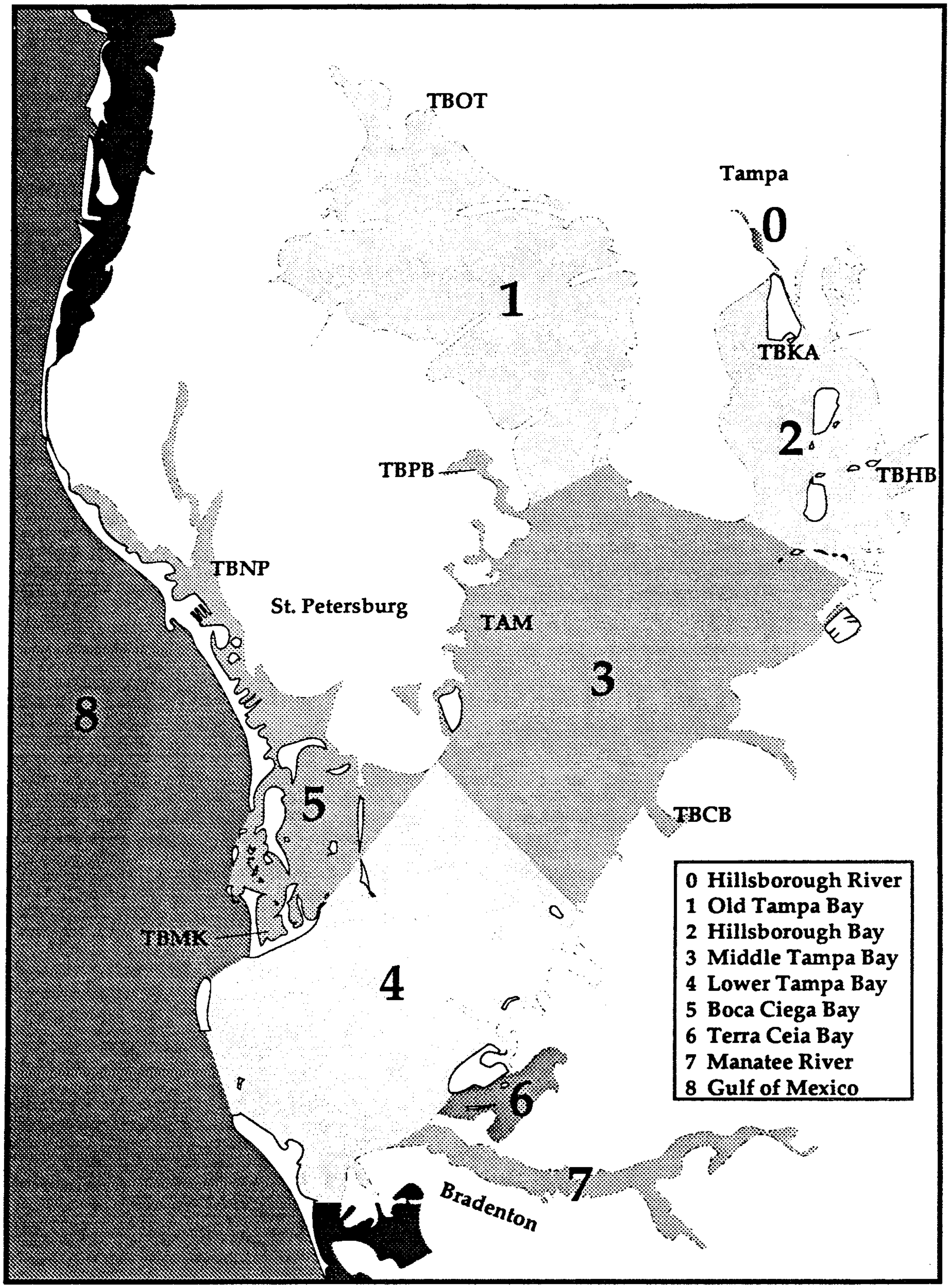

Figure 1. Tampa Bay subdivisions (after Lewis and Whitman, 1985) and locations of NS&T Program sampling sites.

When chemical concentrations below the method detection limits were encountered, mean concentrations were estimated by using one-half of the detection limits. Tissue chemistry data reported in units of wet weight were converted to units of dry weight (dw) to facilitate comparisons among all the data. Tissue moisture content data provided in the source documents were used in the conversions when reported. If moisture content was not reported, an assumed value was used in the conversion. Temporal trends were determined with two different methods: (1) evaluation of the results reported from the analyses of stratified sections of sediment cores; and, (2) comparisons of data collected in different years from the same locations.

Spatial patterns in the incidence of biological effects were determined by comparing data collected at different sites in the major subdivisions of the bay. No data were available for the evaluation of temporal trends in biological effects.

Much of the data evaluated in this report were produced by NOAA's NS&T Program. Samples of oysters and sediments have been collected at seven sites in the Tampa Bay system by the NS&T Program as a part of the nationwide Mussel Watch Project. The seven sites are designated as site TBMK (located at Mullet Key in lower Boca Ciega Bay); site TBPB (located in Bayou Grande, adjoining Middle Tampa Bay); site TBHB (located off the mouth of the Alafia River in lower Hillsborough Bay); site TBCB (located in Cockroach Bay, adjoining Middle Tampa Bay; site TBOT (located in Double Branch Creek, adjoining Old Tampa Bay); site TBKA (located near Knight Airport on the southern tip of Davis Islands in upper Hillsborough Bay); and site TBNP (located near Navarez Park in upper Boca Ciega Bay). Sediments were collected once at each of these sites. Oysters were collected in 1986, 1987, 1988, and 1989 thus far at sites TBMK, TBPB, and TBCB; in 1986, 1987, and 1988 at site TBHB; in 1988 and 1989 at site TBOT; and 1989 at sites TBKA and TBNP. In addition, NOAA has sampled bottom fish and sediments at site TAM (located off St. Petersburg in Middle Tampa Bay) annually since 1984 as a part of the Benthic Surveillance Project. The locations of these sites are illustrated in Figure 1. Three samples of oysters or fish and/or sediments were collected at each site each time the site was sampled.

Data from other sites in southwestern Florida also sampled by the NS&T Program will be described in this report and compared with the data from the Tampa Bay sites. These other sites are located in Naples Bay (site NBNB); Henderson Creek in Rookery Bay (site RBHC); Cedar Key (site CKBP); Everglades, Faka Union Bay (site EVFU); Bird Island, Charlotte Harbor (site CBBI); and central Charlotte Harbor (site LOT).

STATUS AND TRENDS IN CHEMICAL CONCENTRATIONS

Geographic Patterns in the Distribution of Toxicants in Sediments

NS&T Program Site Ranks. NOAA's NS&T Program has analyzed the surficial sediments (upper 1 to 2 cm) sampled at eight sites in Tampa Bay for many trace metals and classes of organic contaminants. The NS&T Program also has analyzed surficial sediments from six other nearby sites along Florida's west coast. The 14 sites were initially ranked (1 most contaminated, 14 least contaminated) for each analyte based on the mean concentrations found in the sediments. Then overall ranks were determined based on the sum of ranks for trace metals, for organics, and for all chemical groups (Table 1). These ranks strictly reflect the level of contaminants found in the sediments and not the degree of loading or the bioavailability of the analytes. Various sediment parameters (i.e., grain size and total organic carbon [TOC]) affect the concentrations of contaminants present in the sediments.

Therefore, the chemical concentrations were normalized to fines (<63µ) for trace metals (chemical concentration in µg/g dw divided by concentration of fines in g/g dw) and to TOC for organics (chemical concentration in µg/g dw divided by concentration of TOC in g/g dw). Means were calculated based on the normalized data and the sites re-ranked based on these normalized means (Table 1).

Based upon the unnormalized data, a Tampa Bay site ranked number 1 (most contaminated) in the concentrations of Ag, Cd, Cu, Pb, Hg, Zn, total DDT (tDDT), chlordane, dieldrin, mirex, total PCBs (tPCBs), and total PAHs (tPAH); while non-Tampa Bay sites were ranked number 1 in concentrations of As, Cr, and Ni (Table 1). However, based on the normalized data, a Tampa Bay site ranked number 1 for all the analytes examined. The overall ranks for metals (Tables 1 and 2) indicated that two of the five most contaminated sites were in Tampa Bay based on the unnormalized data, but when the data were normalized, the top six sites were in Tampa Bay. In the case of organic contaminants, the five most contaminated sites based on unnormalized data were in Tampa Bay; while, the normalized data indicated that only four of the top five were in Tampa Bay (Tables 1 and 2). The overall combined rankings indicated the reverse of the organic rankings with four of the top five sites located in Tampa Bay based on the unnormalized data; while, based on the normalized data, all five of the most contaminated sites were in Tampa Bay.

The Tampa Bay site TBHB either ranked first or was tied for first based on unnormalized and normalized metals, normalized organics, and the combined normalized data (Table 2). TBHB ranked fourth for unnormalized organics and second for the combined unnormalized data (Table 2). At the other extreme, TBOT ranked thirteenth for unnormalized and normalized metals and combined data. However, it ranked eleventh for normalized organics and seventh for unnormalized organics (Table 2). The largest changes in ranks for Tampa Bay sites due to normalization were for TBCB and TBNP, the Tampa Bay sites with lowest and highest percent fines and TOC, respectively (Table 1). TBCB ranked fourteenth, tenth, and fourteenth for unnormalized metals, organics, and combined, respectively. However, it ranked fourth, first (tied with TBHB), and third for normalized metals, organics, and combined, respectively (Table 2). TBNP ranks were lowered by normalization. It was either ranked first or tied for first for unnormalized data but ranked fifth, ninth (tied with RBHC), and eighth for normalized metals, organics, and combined, respectively.

The actual mean concentrations, unnormalized and normalized, for each of the individual analytes at the 14 sites are presented in Table 3 for trace metals and in Table 4 for organic compounds. The highest mean concentration of mirex in a Tampa Bay site (1.2 ppb at site TBNP) exceeded the lowest mean concentration (0.003 ppb at sites NBNB and EVFU) by a factor of 400. The other classes of organic compounds in Tampa Bay were elevated by maximum factors of 19- to 62-fold. The highest concentrations of trace metals in Tampa Bay sediments were 5 to 33 times higher than the lowest concentrations.

Table 1. Relative ranks of southwestern Florida NS&T Program sites based upon mean concentrations. Sites are ranked according to (1) dry weight sediment concentrations and (2) concentrations normalized to fines for metals and to TOC for organics. Overall ranks are based on the sum of individual analyte ranks (for metals, for organics, and for all chemicals). Tampa Bay sites are listed in bold italics.

Site	Site Name	%Fines	METALS Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Overall
TBHB	***Hillsborough Bay***	***18***	***2\1***	***9\5***	***1\1***	***2\1***	***3\1***	***1\1***	***5\2***	***1\1***	***2\1***	***1\1***
TBNP	***Navarez Park***	***58***	***1\3***	***4\9***	***2\2***	***6\9***	***1\3***	***2\6***	***7\13***	***2\4***	***1\4***	***1\5***
CKBP	Cedar Key	41	7\10	1\2	3\8	5\5	9\10	4\5	4\8	6\8	6\9	3\7
NBNB	Naples Bay	45	5\8	3\4	9\11	4\10	2\5	6\7	8\9	9\10	3\5	4\8
RBHC	Rookery Bay, Henderson Creek	72	11\12	2\8	6\13	3\7	7\11	5\10	1\7	11\14	5\12	5\11
TBPB	***Papys Bayou***	***27***	***6\6***	***7\7***	***7\6***	***10\14***	***8\7***	***3\3***	***3\3***	***3\5***	***7\8***	***6\6***
TBKA	***Knight Airport***	***17***	***3\2***	***14\11***	***4\3***	***11\3***	***5\6***	***9\4***	***13\11***	***4\3***	***4\2***	***7\3***
EVFU	Everglades, Faka Union Bay	56	10\13	6\10	10\12	1\4	11\13	7\12	2\6	10\13	10\13	8\12
TBMK	***Mullet Key Bayou***	***14***	***9\4***	***8\1***	***11\5***	***13\13***	***6\2***	***8\2***	***9\1***	***5\2***	***8\3***	***9\2***
TAM	***Tampa Bay***	***19***	***4\5***	***13\13***	***8\9***	***9\6***	***4\8***	***10\9***	***11\10***	***7\7***	***11\11***	***9\10***
CBBI	Charlotte Harbor, Bird Island	24	12\11	5\6	5\7	7\2	10\9	12\13	6\5	12\9	9\7	11\8
LOT	Charlotte Harbor	20	14\14	11\12	12\14	8\11	13\14	11\14	10\14	8\12	13\14	12\14
TBOT	***Old Tampa Bay***	***19***	***8\9***	***10\14***	***13\10***	***12\12***	***14\12***	***13\11***	***12\12***	***13\11***	***12\10***	***13\13***
TBCB	***Cockroach Bay***	***7***	***13\7***	***12\3***	***14\4***	***14\8***	***12\4***	***14\8***	***14\4***	***14\6***	***14\6***	***14\4***

Site	Site Name	%TOC	ORGANICS tPAH	tDDT	Chlordane	Dieldrin	Mirex	tPCB	Overall
TBNP	***Navarez Park***	***5.95***	***2\9***	***1\12***	***1\10***	***2\9***	***1\6***	***2\12***	***1\9***
TBPB	***Papys Bayou***	***0.55***	***4\4***	***3\6***	***2\3***	***5\5***	***4\2***	***1\2***	***2\3***
TBKA	***Knight Airport***	***0.30***	***1\2***	***2\3***	***5\6***	***1\1***	***10\12***	***4\4***	***3\5***
TBHB	***Hillsborough Bay***	***0.11***	***3\1***	***4\1***	***8\5***	***4\6***	***6\4***	***3\1***	***4\1***
TBMK	***Mullet Key Bayou***	***0.62***	***6\6***	***7\5***	***3\4***	***6\7***	***2\3***	***5\9***	***5\6***
NBNB	Naples Bay	0.18	5\3	5\4	4\1	3\2	14\13	6\3	6\4
TBOT	***Old Tampa Bay***	***0.57***	***7\11***	***8\10***	***11\11***	***8\10***	***11\14***	***8\7***	***7\11***
RBHC	Rookery Bay, Henderson Creek	0.45	10\12	9\8	6\8	12\11	8\8	9\11	8\9
LOT	Charlotte Harbor	1.20	13\14	12\14	10\12	10\13	5\10	7\13	9\14
TBCB	***Cockroach Bay***	***0.04***	***14\5***	***6\2***	***7\2***	***14\3***	***3\1***	***14\5***	***10\1***
CKBP	Cedar Key	0.24	12\10	13\11	9\9	9\8	9\7	10\8	11\8
CBBI	Charlotte Harbor, Bird Island	0.13	8\7	11\7	12\7	7\4	12\5	13\6	12\7
TAM	***Tampa Bay***	***0.84***	***9\13***	***10\13***	***13\13***	***13\12***	***7\9***	***12\14***	***13\13***
EVFU	Everglades, Faka Union Bay	0.33	11\8	14\9	14\14	11\14	13\11	11\10	14\12

Site	Combined Overall
TBNP	***1\8***
TBHB	***2\1***
TBPB	***3\5***
NBNB	4\6
TBKA	***5\4***
RBHC	6\10
TBMK	***7\2***
CKBP	8\9
EVFU	9\12
TAM	***9\10***
CBBI	9\7
LOT	12\14
TBOT	***13\13***
TBCB	***14\3***

Table 2. Relative overall ranks of NOAA's southwestern Florida NS&T Program sites based on normalized and unnormalized data for trace elements, organic compounds, and all chemicals combined. The numbers after each site code are the sums of the ranks for the individual analytes which are the basis for the overall ranks. Tampa Bay sites are in bold italics.

	Metals		Organic Compounds		Combined	
Rank	Unnormalized	Normalized	Unnormalized	Normalized	Unnormalized	Normalized
1	***TBHB 26***	***TBHB 14***	***TBNP 9***	***TBCB 18***	***TBNP 35***	***TBHB 32***
2	***TBNP 26***	***TBMK 33***	***TBPB 19***	***TBHB 18***	***TBHB 54***	***TBMK 67***
3	CKBP 45	***TBKA 45***	***TBKA 23***	***TBPB 23***	***TBPB 73***	***TBCB 68***
4	NBNB 49	***TBCB 50***	***TBHB 28***	NBNB 27	NBNB 86	***TBKA 73***
5	RBHC 51	***TBNP 53***	***TBMK 29***	***TBKA 28***	***TBKA 90***	***TBPB 82***
6	***TBPB 54***	***TBPB 59***	NBNB 37	***TBMK 34***	RBHC 105	NBNB 96
7	***TBKA 67***	CKBP 65	TBOT 53	CBBI 36	***TBMK 106***	CBBI 105
8	EVFU 67	CBBI 69	RBHC 54	CKBP 54	CKBP 107	***TBNP 111***
9	***TBMK 77***	NBNB 69	LOT 57	RBHC 58	EVFU 141	CKBP 119
10	***TAM 77***	***TAM 78***	***TBCB 58***	***TBNP 58***	***TAM 141***	RBHC 152
11	CBBI 78	RBHC 94	CKBP 62	***TBOT 64***	CBBI 141	***TAM 152***
13	LOT 100	EVFU 96	CBBI 63	EVFU 67	LOT 157	EVFU 163
13	***TBOT 107***	***TBOT 101***	***TAM 64***	***TAM 74***	***TBOT 160***	***TBOT 165***
14	***TBCB 121***	LOT 119	EVFU 74	LOT 76	***TBCB 179***	LOT 195

Table 3. Mean concentrations (dw) of trace metals at the 14 NS&T Program sites in southwest Florida in µg/g sediment and µg/g fines. The sites are listed in the order of their overall unnormalized trace metals rankings and Tampa Bay sites are listed in bold italics.

DATA REPORTED AS µg/g sediment									
Site	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
TBHB	***0.13***	***1.5***	***0.91***	***59***	***7.9***	***0.11***	***5.3***	***63***	***66***
TBNP	***0.20***	***4.3***	***0.73***	***39***	***21***	***0.09***	***4.8***	***39***	***67***
CKBP	0.04	8.0	0.21	40	3.9	0.06	5.4	6.7	18
NBNB	0.06	5.0	0.14	42	11	0.04	4.6	4.6	27
RBHC	0.03	5.1	0.16	55	4.3	0.05	8.8	4.1	18
TBPB	***0.04***	***2.2***	***0.15***	***17***	***4.2***	***0.06***	***7.5***	***18***	***17***
TBKA	***0.09***	***0.7***	***0.19***	***15***	***4.6***	***0.03***	***1.6***	***13***	***27***
EVFU	0.03	3.1	0.12	75	2.6	0.04	7.8	4.4	12
TBMK	***0.03***	***2.1***	***0.10***	***9.3***	***4.2***	***0.04***	***3.3***	***8.8***	***15***
TAM	***0.08***	***0.90***	***0.15***	***23***	***5.0***	***0.03***	***2.7***	***5.3***	***9.1***
CBBI	0.02	3.1	0.16	35	2.7	0.02	4.9	2.8	13
LOT	0.01	1.4	0.08	28	1.2	0.02	3.3	4.9	7.2
TBOT	***0.04***	***1.4***	***0.08***	***11***	***1.0***	***0.01***	***1.6***	***2.4***	***7.5***
TBCB	***0.01***	***1.2***	***0.07***	***5.3***	***2.3***	***0.01***	***1.4***	***1.9***	***5***

DATA REPORTED AS µg/g fines									
Site	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
TBHB	***0.76***	***12***	***5.8***	***450***	***58***	***0.84***	***28***	***580***	***480***
TBNP	***0.36***	***7.5***	***1.3***	***68***	***35***	***0.15***	***8.4***	***65***	***120***
CKBP	0.10	20	0.52	82	9.9	0.16	12	17	44
NBNB	0.17	15	0.37	67	30	0.11	11	13	79
RBHC	0.04	7.8	0.23	78	6.3	0.08	13	5.9	27
TBPB	***0.26***	***9.8***	***0.77***	***40***	***17***	***0.17***	***28***	***60***	***47***
TBKA	***0.52***	***4.4***	***1.2***	***89***	***28***	***0.16***	***9.5***	***72***	***160***
EVFU	0.02	5.4	0.24	82	5.1	0.06	15	8.0	25
TBMK	***0.30***	***21***	***0.9***	***44***	***50***	***0.20***	***29***	***100***	***130***
TAM	***0.28***	***3.1***	***0.49***	***80***	***16***	***0.09***	***9.6***	***18***	***31***
CBBI	0.09	12	0.74	110	15	0.06	20	17	62
LOT	0.02	3.2	0.19	66	2.4	0.05	7.6	11	16
TBOT	***0.13***	***1.7***	***0.41***	***58***	***5.2***	***0.08***	***8.4***	***12***	***40***
TBCB	***0.19***	***18***	***0.94***	***76***	***32***	***0.11***	***2.0***	***26***	***74***

Table 4. Mean concentrations (dw) of organic analytes at the 14 NS&T Program sites in southwest Florida in ng/g sediment and ng/g TOC. The sites are listed in the order of their overall unnormalized organic rankings and Tampa Bay sites are listed in bold italics. PCB concentrations are given based on both the sum of 8 chlorination levels (Cl) and the sum of 18 congeners (Con).

	DATA REPORTED AS ng/g sediment						
Site	PAH	DDT	Chlordane	Dieldrin	Mirex	PCB Cl	PCB Con
TBNP	***1700***	***13***	***10***	***2.8***	***1.2***	***NA***	***40***
TBPB	***720***	***10***	***3.7***	***0.32***	***0.12***	***140***	***83***
TBKA	***1900***	***12***	***1.8***	***5.7***	***0.02***	***NA***	***22***
TBHB	***1000***	***8.3***	***0.69***	***0.38***	***0.07***	***43***	***35***
TBMK	***150***	***2.1***	***3.0***	***0.2***	***0.76***	***13***	***9.1***
NBNB	300	2.9	2.8	0.56	0.003	15	5.5
TBOT	***110***	***1.2***	***0.34***	***0.11***	***0.01***	***NA***	***6.4***
RBHC	70	1.1	1.0	0.08	0.05	8.4	4.3
LOT	40	0.65	0.40	0.09	0.07	6.1	NA
TBCB	***20***	***2.3***	***0.90***	***0.05***	***0.32***	***1.9***	***2.5***
CKBP	60	0.59	0.53	0.1	0.03	5.7	3.8
CBBI	110	0.74	0.31	0.15	0.01	2.5	2.3
TAM	***90***	***0.78***	***0.22***	***0.07***	***0.06***	***2.0***	***NA***
EVFU	60	0.48	0.16	0.09	0.003	5.5	3.6

	DATA REPORTED AS ng/g TOC						
Site	PAH	DDT	Chlordane	Dieldrin	Mirex	PCB Cl	PCB Con
TBNP	***28000***	***220***	***190***	***48***	***21***	***NA***	***700***
TBPB	***260000***	***2100***	***1200***	***210***	***350***	***30000***	***17000***
TBKA	***670000***	***4000***	***580***	***2000***	***5.4***	***NA***	***7200***
TBHB	***1300000***	***8300***	***620***	***190***	***95***	***46000***	***32000***
TBMK	***76000***	***2400***	***800***	***130***	***120***	***4400***	***780***
NBNB	490000	3900	5200	1100	3.8	33000	2800
TBOT	***23000***	***240***	***70***	***28***	***2.9***	***NA***	***1200***
RBHC	18000	280	250	23	15	2100	720
LOT	4800	69	62	10	7.6	1000	NA
TBCB	***87000***	***8000***	***5100***	***280***	***2300***	***5900***	***6400***
CKBP	27000	240	230	120	16	2200	1300
CBBI	56000	1800	470	260	42	8700	2000
TAM	***12000***	***130***	***38***	***12***	***9.9***	***270***	***NA***
EVFU	33000	270	36	9.1	5.7	4200	610

Distribution of Trace Metals Within Tampa Bay. The unnormalized site means for all but two of the analytes (As, Ni) differed by more than an order of magnitude among the Tampa Bay sites (Table 3). When the data were normalized to fines, only the Ag site means in Tampa Bay had a range of less than an order of magnitude (Table 3). Silver, Cu, and Pb differed by the greatest degree between the least contaminated and the most contaminated sites (factors of 20, 21 and 33, respectively) based on the unnormalized data but the normalized data indicated that Ag had the lowest degree of difference between site means (a factor of 6) while Pb still had the highest (a factor of 48). This observation illustrates the significance of sediment grain size in differences in metals concentrations among sites. Site TBNP had particularly high concentrations of Ag, Cu and Zn, but this may have been partially due to the relatively high percent fines at the site (mean of 58%) (Table 1), since the normalized means indicated only moderate levels of these contaminants at the site. Site TBHB had high concentrations of Cd, Cr, Hg, Pb, and Zn. Based upon the unnormalized data, sites TBOT and TBCB generally had the lowest mean concentrations of all trace metals. The percent fine-grained sediments at both sites also were relatively low (19 and 7%, respectively) (Table 1).

A visual presentation of the unnormalized site means from Table 3 clearly shows how TBHB and TBNP were consistently higher in trace metals concentrations than the other Tampa Bay sites (Figures 2 and 3). TBHB is located in subdivision 2 of Tampa Bay, an area which all the available data suggested had higher concentrations of metals than the other subdivisions. However, TBNP is located in subdivision 5 which, based on all the available data, did not have exceptionally high levels of metals when compared to the other subdivisions. At the other end of the spectrum were TBOT, in subdivision 1, and TBCB, in subdivision 3, which consistently had the lowest unnormalized mean trace metals concentrations (Figures 2 and 3). The mean percent fines at the Tampa Bay sites (except TBNP and TBCB) varied over a fairly narrow range (Figure 3).

To increase the amount of data for each subdivision that could be used to identify spatial patterns in chemical concentrations within the estuary, the data from other programs were merged with the NS&T Program data. Mean concentrations were then determined for each subdivision. Data from grain size analyses were not available from most of these studies. Trace metal concentrations generally are higher in fine-grained sediments than in sand. However, the objective of this evaluation was not to attribute causes to the patterns in contamination, but, rather to simply identify patterns within the system. These patterns may be influenced by differences in grain size or proximity to sources or both factors. If the chemical data could be normalized to grain size, the patterns may look quite different from those depicted here.

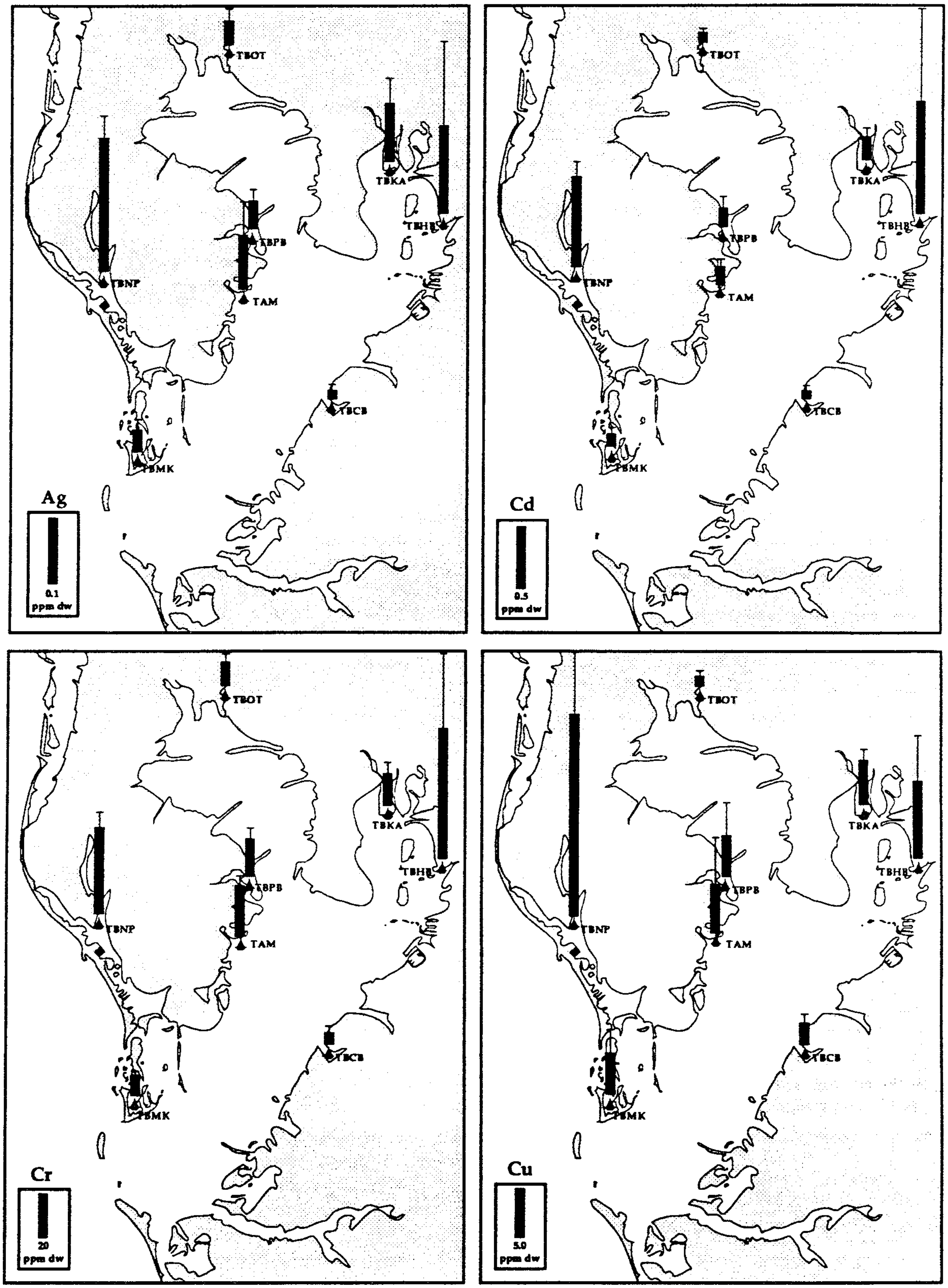

Figure 2. Mean Ag, Cd, Cr, and Cu concentrations (ppm dw) in the surficial sediments NOAA's NS&T Program sites in the Tampa Bay area based on combined data from 1984-88.

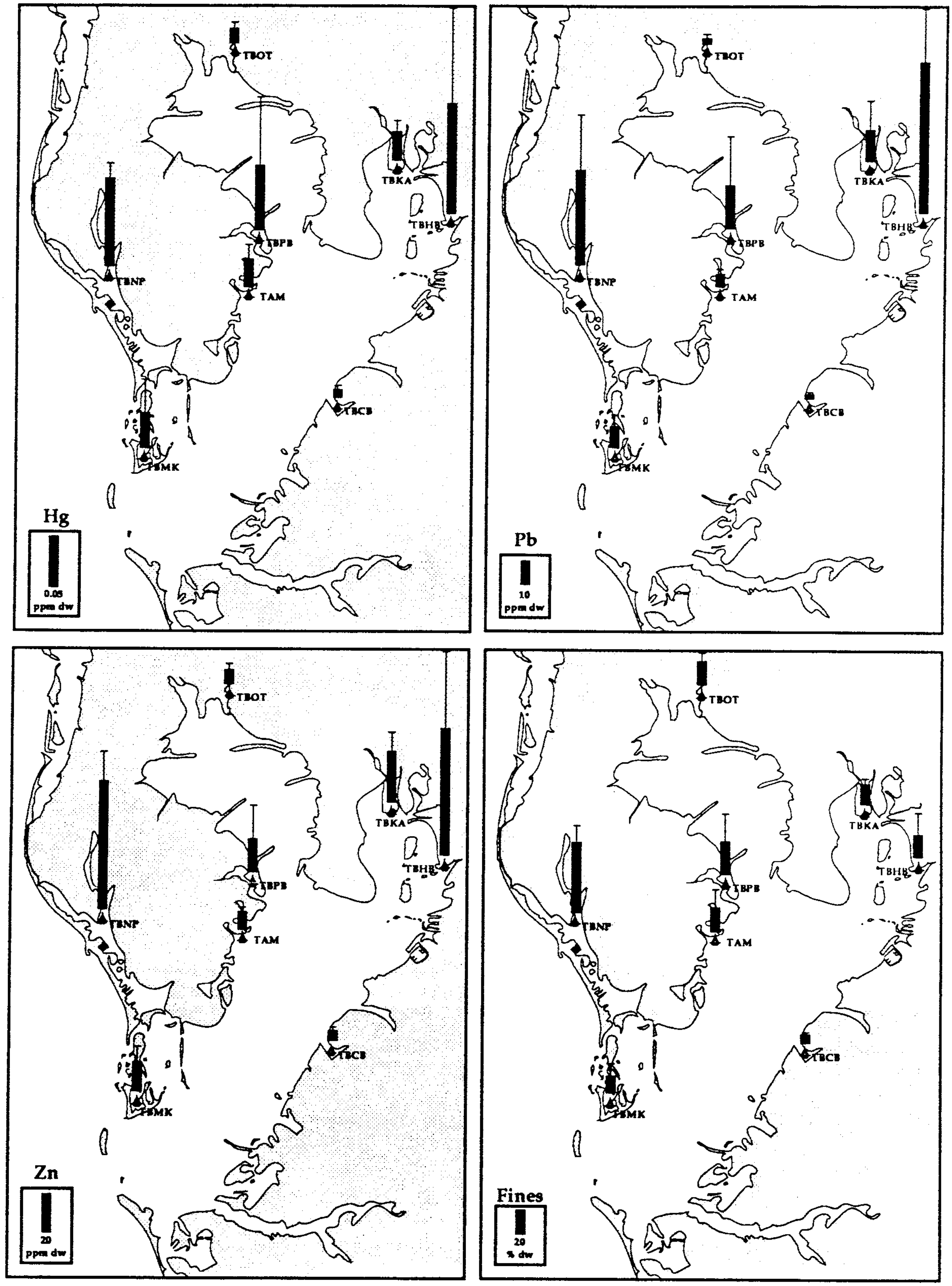

Figure 3. Mean Hg, Pb, and Zn concentrations (ppm dw) and percent fines in the surficial sediments NOAA's NS&T Program sites in the Tampa Bay area based on combined data from 1984-88.

Only four different studies or programs have quantified trace metals in sediment samples from more than one subdivision of Tampa Bay. The four programmatic data sets were: (1) the combined Army Corps of Engineers (ACOE) data set from a number of individual studies (ACOE, 1974; 1979; 1985); (2) data from the FDER (FDER, unpublished); (3) data from several small studies performed by the Savannah Laboratories and Environmental Services (SLES), Inc. (1986 a; b; 1987; 1988); and (4) the NS&T Program's (NOAA, 1988) data set. The mean trace metal concentrations from each of these four programs were calculated for each of the subdivisions and compared in Table 5. The subdivision with the highest mean concentrations for each program is outlined in a box. In each program, sediment samples from subdivision 2 often had the highest mean trace metal concentrations. There generally was no consistent trend in contamination levels among the other subdivisions.

Table 5. Mean metal concentrations (ppm dw) in the surficial sediments of the subdivisions of Tampa Bay determined by four research groups. Outlined values are the highest for each metal analyzed by each group; those in bold are overall means, and the numbers in parentheses are sample sizes.

Data Source	Sub-division	Ag	Cd	Cr	Cu	Hg	Pb	Zn
ACOE:	2	0.222 (18)	1.80 (22)	51.1 (10)	19.3 (22)	0.37 (22)	35.0 (22)	60.0 (22)
	3	•	1.44 (9)	6.2 (9)	4.0 (9)	0.29 (9)	26.3 (9)	8.7 (9)
	4	•	1.60 (5)	5.6 (5)	3.2 (5)	0.17 (5)	26.6 (5)	7.0 (5)
	8	•	2.17 (3)	9.0 (3)	3.3 (3)	0.18 (3)	31.7 (3)	7.7 (3)
	Overall	**0.222 (18)**	**1.72 (39)**	**23.0 (27)**	**12.5 (39)**	**0.31 (39)**	**28.0 (39)**	**37.3 (39)**
FDER:	1	•	0.14 (3)	48.4 (3)	6.4 (3)	0.36 (3)	4.1 (3)	30.4 (3)
	2	•	2.79 (56)	70.2 (52)	204.3 (56)	0.23 (55)	80.7 (56)	86.1 (56)
	3	•	0.60 (20)	51.5 (20)	21.8 (20)	0.19 (20)	9.8 (20)	35.7 (20)
	4	•	0.91 (4)	33.0 (3)	11.1 (4)	0.24 (4)	10.4 (4)	33.1 (4)
	6	•	0.57 (2)	7.6 (2)	2.3 (2)	0.02 (2)	4.2 (2)	7.7 (2)
	Overall		**2.10 (85)**	**61.8 (80)**	**140.5 (85)**	**0.22 (84)**	**56.3 (85)**	**67.9 (85)**
SLES:	2	•	1.24 (18)	89.1 (18)	28.3 (6)	0.08 (6)	49.9 (18)	130.1 (18)
	3	0.192 (6)	0.83 (6)	70.0 (6)	32.8 (6)	0.06 (6)	28.7 (6)	38.0 (6)
	Overall	**0.192 (6)**	**1.14 (24)**	**84.3 (24)**	**30.6 (12)**	**0.07 (12)**	**44.6 (24)**	**107.1 (24)**
NS&T:	1	0.036 (2)	0.08 (3)	11.0 (3)	1.0 (3)	0.01 (3)	2.4 (3)	7.5 (3)
	2	0.117 (9)	0.67 (9)	37.0 (6)	6.8 (9)	0.08 (9)	46.2 (9)	53.3 (9)
	3	0.038 (15)	0.12 (15)	15.0 (9)	3.6 (15)	0.03 (15)	9.0 (15)	10.6 (15)
	5	0.089 (9)	0.31 (9)	24.1 (6)	9.7 (9)	0.05 (9)	19.0 (9)	32.3 (9)
	Overall	**0.071 (35)**	**0.30 (36)**	**22.3 (24)**	**5.7 (36)**	**0.05 (36)**	**20.2 (36)**	**26.4 (36)**

Figure 4 illustrates the patterns in concentrations of nine selected trace metals among the nine subdivisions of Tampa Bay. Mean concentrations (and standard deviations) were based upon all the available data merged from all the studies described above. The data from these different studies were merged despite the likelihood that analytical methods differed among laboratories, that different sediment depths (usually not specified) were sampled, and that the samples were collected in different years. Also, the concentrations were not normalized to percent fine-grained particles, and, therefore, may reflect, in part, the effects of differences in sediment texture as well as proximity to sources.

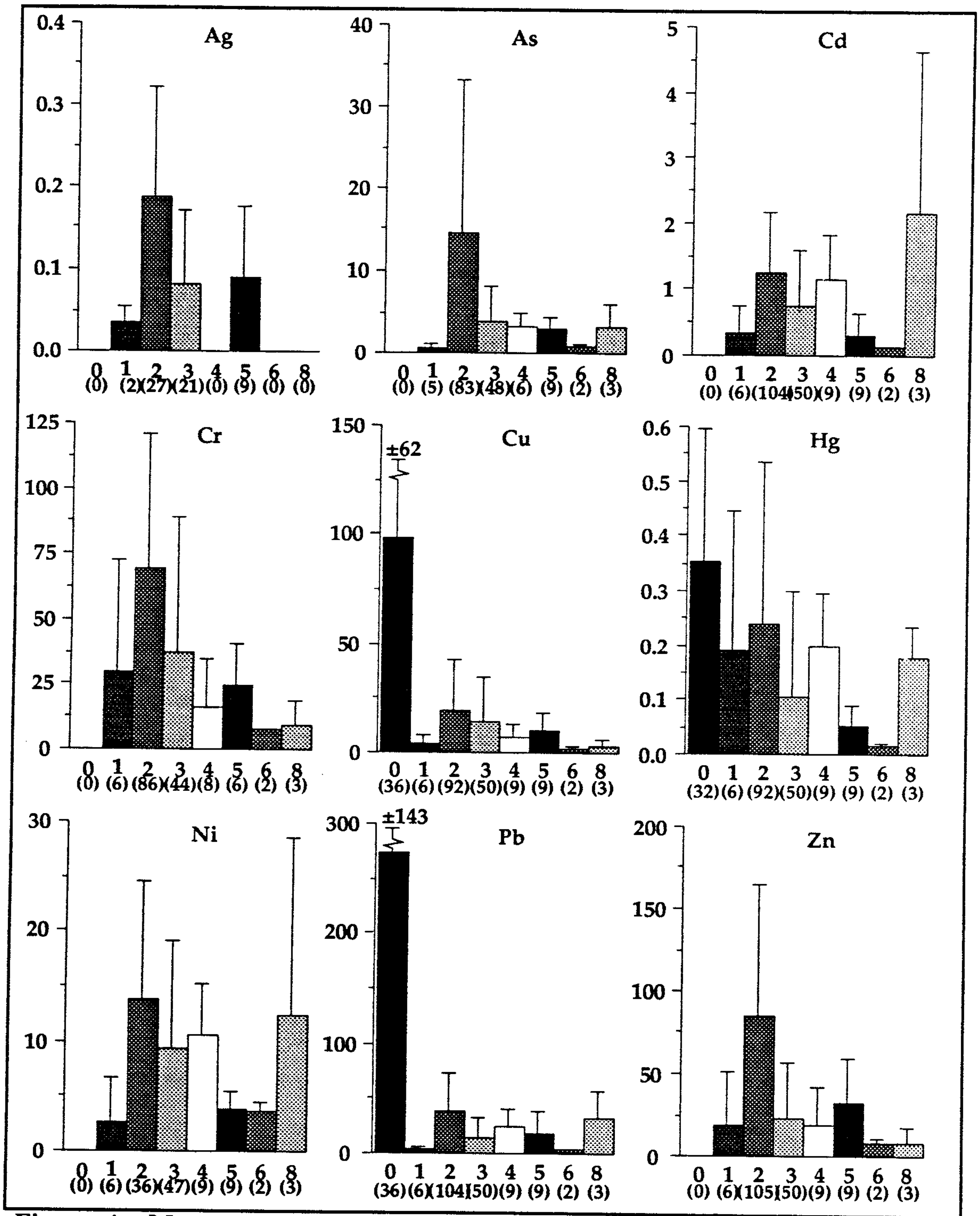

Figure 4. Mean metal concentrations (ppm dw) in the surficial sediments of seven of the eight Tampa Bay subdivisions based on all the available data (numbers in parentheses are sample sizes). Subdivision 0 is the lower Hillsborough River, 1 is Old Tampa Bay, 2 is Hillsborough Bay, 3 is Middle Tampa Bay, 4 is Lower Tampa Bay, 5 is Boca Ciega Bay, 6 is Terra Ceia Bay, and 8 is Gulf of Mexico.

Based upon these merged data, subdivision 0 (the Hillsborough River), had the highest mean concentrations of Cu, Hg, and Pb. These were the only three metals quantified in sediments collected in that subdivision (Figure 4). The remainder of the trace metals were generally found in highest concentrations in subdivision 2 (Hillsborough Bay). Cadmium on the other hand, occurred in highest concentrations in subdivision 8, the Gulf of Mexico; however, this mean was based upon only three samples. Subdivision 2 and subdivision 4 (Lower Tampa Bay), had the second and third highest mean Cd concentrations, respectively. Subdivision 6 (Terra Ceia Bay) had either the lowest or second lowest mean concentrations of trace metals; however, it should be noted that only two samples were analyzed from this subdivision. Also Old Tampa Bay (subdivision 1) often had relatively low concentrations of many trace metals, based upon these data. Generally, there was a pattern of decreasing trace metal concentrations from the head of the Tampa Bay system (Hillsborough Bay) to Old Tampa Bay and the mouth of the system.

Again, these subdivision means based on the merged data set must be viewed with caution, because of the small number of samples analyzed from some of the subdivisions, the possible effects of differences in grain size among the subdivisions, and because of possible differences in sampling and analytical methods used in the different laboratories. Different depths of sediment were sampled in the different studies. Specifically, the data from subdivisions 5, 6, and 8 were derived from only a single data set and may represent differences in methodologies used to analyze samples from the other areas, rather than differences in metal concentrations. A possible example of these differences in analytical procedures is illustrated in the Cd data generated by the ACOE and NS&T Program. The ACOE values were generally an order of magnitude higher than the NS&T Program values.

Schropp *et al.* (1990) determined the statistical relationships between the concentrations of aluminum and seven other metals (As, Cd, Cr, Cu, Ni, Pb, and Zn) in uncontaminated estuarine sediments from Florida and calculated the mean metals-to-aluminum ratios and the ±95 percent confidence limits about those means. They suggested that when metal-to-aluminum ratios from areas of suspected metals enrichment are plotted against the ±95 percent confidence limits and the values fall above the +95 percent prediction limit, these ratios indicate that metal concentrations are higher than in uncontaminated sediments. Using this approach, the metals-to-aluminum ratios for Tampa Bay, based upon the combined, merged data sets described above, were plotted against these upper 95 percent confidence limits (Figures 5 and 6). The resulting plots indicated relatively high enrichment of Cd, Cu, Pb, and Zn, and, to a lesser degree, Cr in the sediments above the concentrations expected in many of the samples. Most of the enrichment was in sediments sampled in the Hillsborough River and Hillsborough Bay (subdivisions 0 and 2).

Table 6 lists the proportions of total numbers of samples tested in each subdivision to the numbers of samples that exceeded the upper 95 percent confidence limits of the metals-to-aluminum ratios provided by Schropp *et al.* (1990). The greatest frequencies of exceedances were in sediments collected from subdivision 2 (Hillsborough Bay), followed by those from subdivisions 3 (Middle Tampa Bay) and 5 (Boca Ciega Bay). Exceedances of these ratios were rare in subdivisions 1, 4, and 6 (Old Tampa Bay, Lower Tampa Bay, and Terra Ceia Bay, respectively).

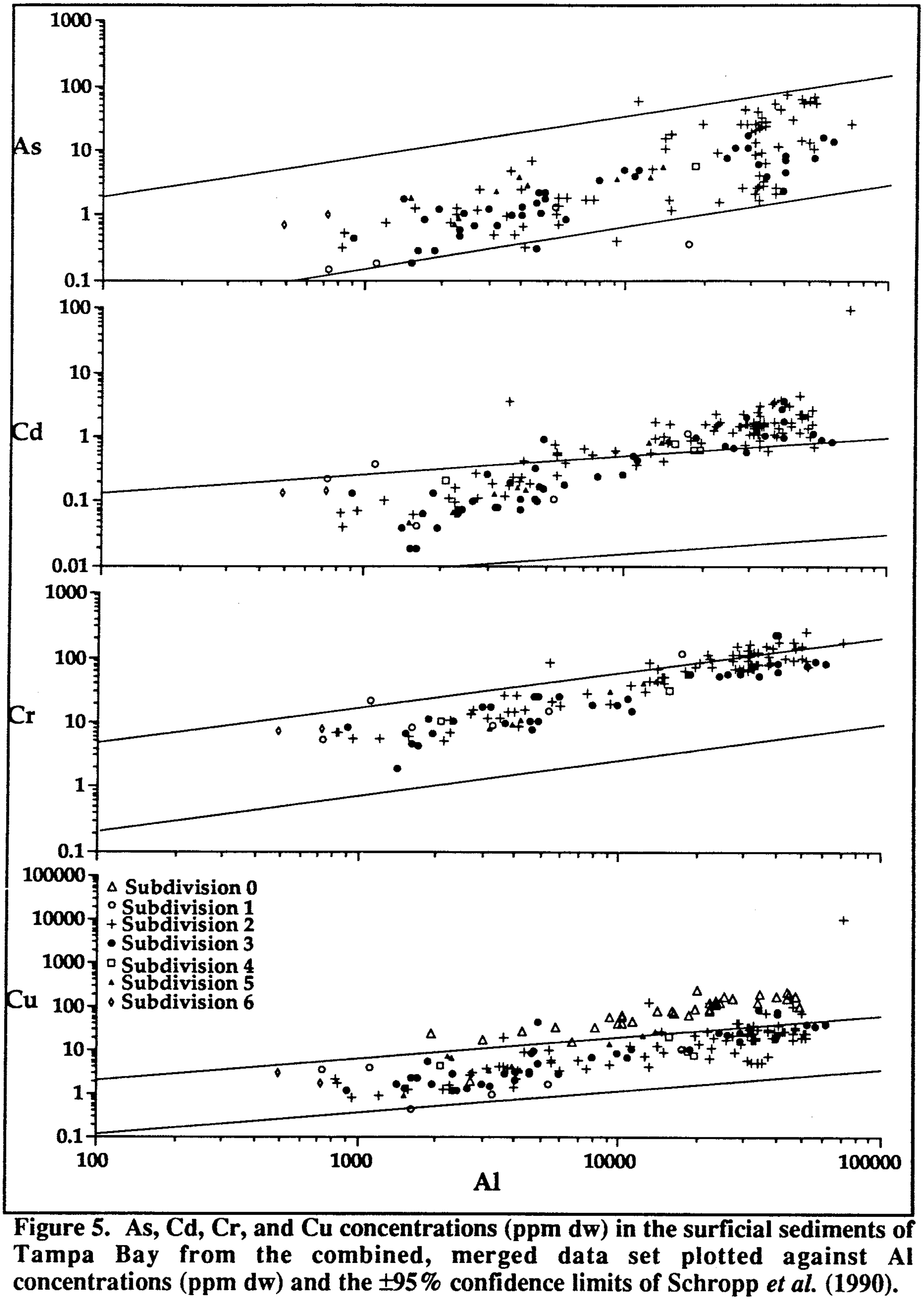

Figure 5. As, Cd, Cr, and Cu concentrations (ppm dw) in the surficial sediments of Tampa Bay from the combined, merged data set plotted against Al concentrations (ppm dw) and the ±95% confidence limits of Schropp *et al.* (1990).

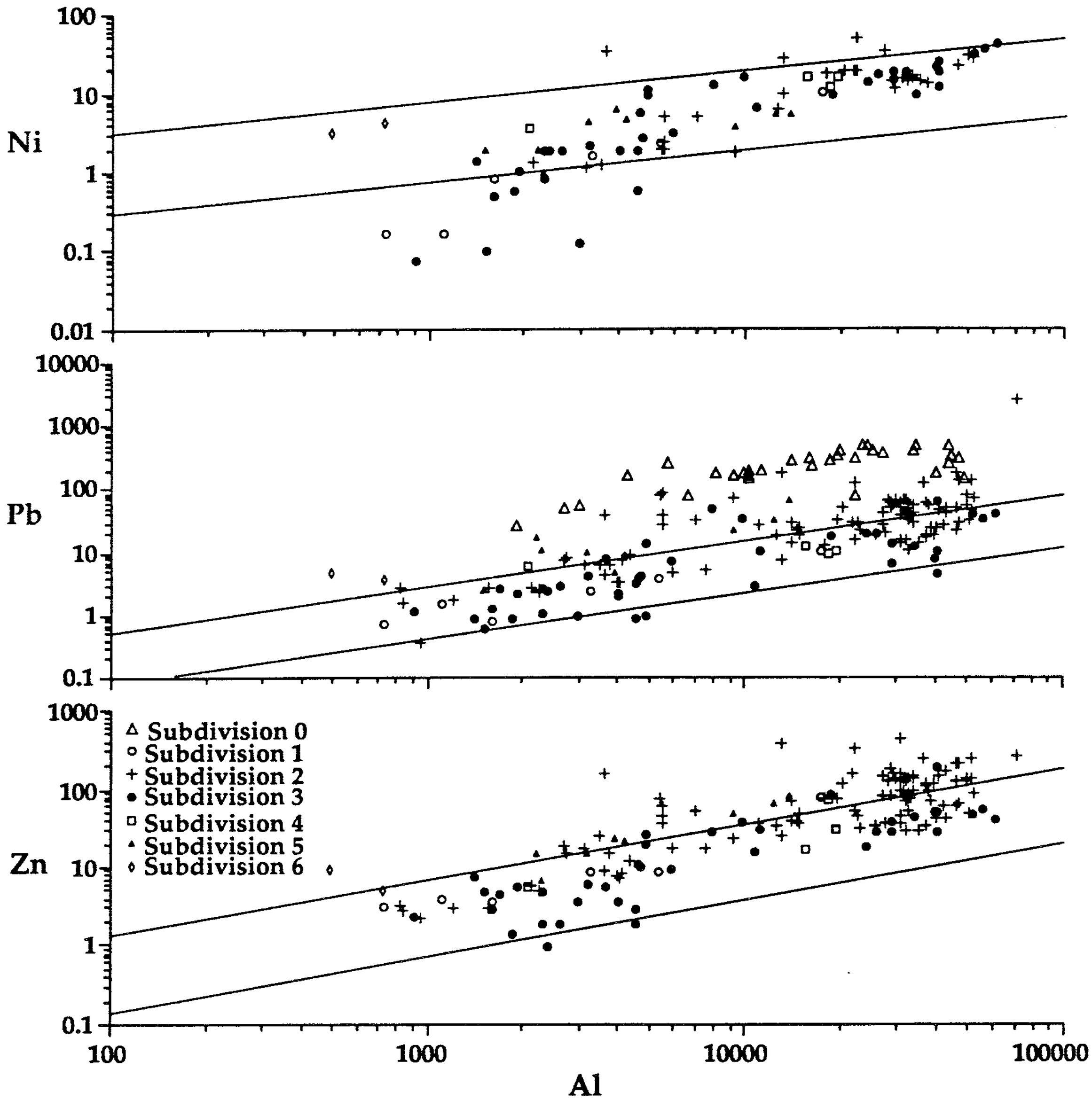

Figure 6. Ni, Pb, and Zn concentrations (ppm dw) in the surficial sediments ofTampa Bay from the combined, merged data set plotted against Al concentrations (ppm dw) and the ±95 confidence limits of Schropp *et al.* (1990).

Table 6. The proportion of samples tested by all groups to samples in which the metals-to-aluminum ratio exceeded the upper 95 percent confidence limits (calculated by Schropp *et al.*, 1990) for each subdivision and metal.

	1	2	3	4	5	6
As	0/4	1/77	0/40	0/1	0/9	0/2
Cd	2/6	77/101	15/26	3/4	3/9	0/2
Cr	2/6	20/82	2/33	0/3	0/6	0/2
Cu	0/6	45/125	4/37	0/4	1/9	0/2
Ni	0/6	4/32	1/37	0/4	0/9	0/2
Pb	0/6	94/137	6/35	1/4	7/9	0/2
Zn	1/6	54/101	6/35	1/4	6/9	1/2

Distributions of Organic Compounds within Tampa Bay. Based upon the NS&T Program data for tPAH (the sums of 18 individual PAHs) at selected sites in southwest Florida, the four top ranking sites and six of the top seven sites were from the Tampa Bay system (Tables 1 and 4). The four most highly contaminated sites had mean concentrations of tPAHs more than an order of magnitude higher than the five sites with the lowest mean tPAH concentrations (Table 4). Figure 7 illustrates the mean tPAH concentrations at the NS&T Program sites in the Tampa Bay area. It indicates that the sites fall into two distinct classes: those with concentrations in excess of 0.7 ppm dw and those with concentrations of 0.15 or less. As with the metals, TBHB and TBNP were among the sites with the highest tPAH concentrations (mean tPAH concentrations of 0.99 and 1.73 ppm dw, respectively), but, the site with the highest tPAH concentrations was TBKA (1.88 ppm dw).

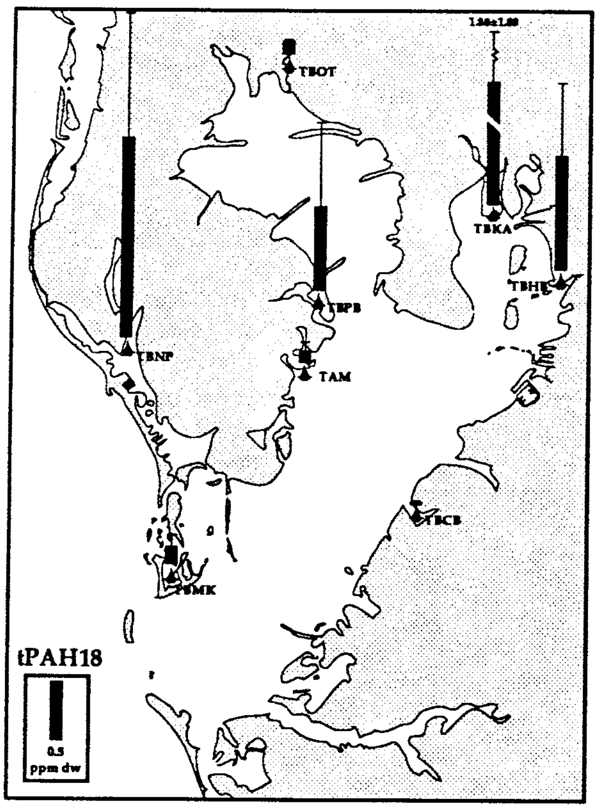

Figure 7. Mean tPAH concentrations (ppm dw) in the surficial sediments collected in 1984-88 at Tampa Bay area NS&T Program sites.

In the early 1980s the FDER, as part of their Deepwater Ports Study, analyzed surficial sediment samples (depths not specified) from 36 sites in Hillsborough Bay for 14 individual PAHs (FDER, unpublished report). The most abundant hydrocarbons were napthalene, fluoranthene, and pyrene. The concentrations of these compounds ranged from below the detection limits (0.05 ppm dw for napthalene and 0.1 ppm dw for fluoranthene and pyrene) to maxima of 84, 4.3, and 18 ppm dw, respectively. The sum of the total concentrations of all the quantified PAHs ranged from 0.80 to 90.8 ppm dw (adding one-half the detection limits of those analytes listed as less than the detection limits).

In 1984 and 1985, Doyle *et al.* (1985) analyzed approximately 100 surficial sediments (0-5 cm) for f1 (aliphatic) and f2 (aromatic and olefinic) fraction hydrocarbons. In addition, 26 samples were analyzed for four families of PAHs (napthalenes, phenanthrenes, pyrenes, and benz(a)anthracenes). These data were summarized by VanVleet *et al.* (1986). There was no clear pattern in f2 fraction contamination levels among the subdivisions of the Tampa Bay system. Samples with high and low concentrations were found in all the sampled subdivisions, although the highest average concentrations generally were found in samples from subdivisions 2, 3, and 5 (Figure 8A). The highest concentrations generally were found in samples collected around the perimeter of the estuary and the lowest concentrations occurred down the axis of the system.

Since the f2 fraction consists of both biogenically and anthropogenically produced hydrocarbons, several samples were analyzed by Doyle *et al.* (1985) for four PAHs and their congeners to better determine the presence and type of anthropogenically produced hydrocarbons. Of the 26 samples analyzed for PAHs, 14 had no detectable levels of any of the PAHs that were quantified; while the other 12 had tPAH levels ranging from 0.35 to 12.8 ppm dw (Figure 8B). Of those samples containing detectable levels of PAHs, five from subdivision 2, one from subdivision 3, and two from subdivision 5 were determined to be of petrogenic origins, while three from subdivision 2 and one from subdivision 7 were determined to be of both petrogenic and pyrogenic origins.

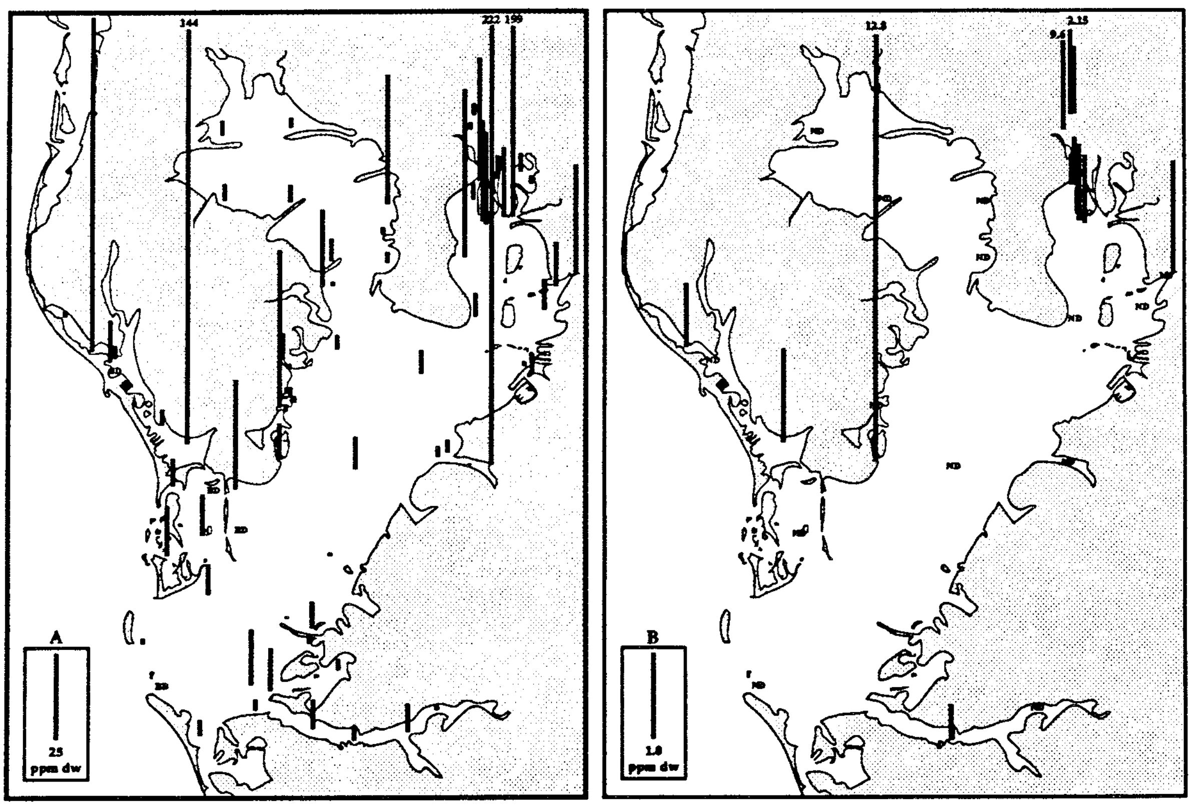

Figure 8. Concentrations (ppm dw) in the surficial sediments of Tampa Bay of the f2 fraction (aromatic and olefinic) hydrocarbons (A) in 1984 and tPAH (B) based on the sum of the concentrations of four families of PAHs (naphthalenes, phenanthrenes, pyrenes, benz(a)anthracenes) in 1984-85 (from Doyle *et al.*, 1985).

Other hydrocarbon data reviewed for this report included those presented by Brown *et al.* (1985) who, in 1983, determined the f2 fraction concentrations in ten surficial sediment samples (0-5 cm) from Hillsborough Bay and two from the Hillsborough River. The concentrations in the Hillsborough Bay samples ranged from 15 to 89 ppm dw and the two samples from the Hillsborough River had concentrations of 26 and 41 ppm dw. Savannah Laboratories (1987) analyzed three samples from four sites in the Alafia River Channel (two in Hillsborough Bay, one at the mouth of the river, and one about 1000 yards upstream of the mouth of the river) for 16 individual PAHs. At the two Hillsborough Bay sites and the river mouth site, only three PAHs were detected (naphthalene, phenanthrene, and pyrene). At the river site, a fourth PAH (fluoranthene) was also detected. Based only on the detected PAHs, the site in the river had a mean tPAH concentration of 1.88±0.04 ppm dw (1.65±0.06 ppm dw if fluoranthene is excluded from the calculations), while the river mouth site had 0.79±0.06 ppm dw and the two Hillsborough Bay sites had 0.63±0.13 and 0.64±0.12 ppm dw.

The U.S. Geological Survey (USGS) in 1988 analyzed four surficial sediment samples from Allen Creek, and one from Old Tampa Bay for concentrations of 16 individual PAHs. At one site in Allen Creek a maximum of 10 PAHs occurred at concentrations above the detection limits; the tPAH concentration was 2.3 ppm dw (USGS, unpublished data).

Among the eight NS&T Program sites sampled in Tampa Bay for surficial sediments, site TBNP generally had the highest, or among the highest, pesticide concentrations. However, the patterns of the concentrations of chlordane, dieldrin, DDT, and mirex among the eight sites were not the same for each group of chemicals. For example, site TBCB had higher mirex concentrations than site TBPB, whereas the chlordane concentrations in site TBPB were higher than those in site TBCB (Figure 9).

Four programs, other than the NS&T Program, included analyses of sediments for pesticides; however, the vast majority of the reported results were below the detection limits. The FDER (unpublished report) analyzed samples from Hillsborough Bay in 1985 for chlordane, heptachlor epoxide, 4,4' DDE, and 4,4' DDT with detection limits of 4.0, 0.2, 0.6, and 1.0 ppb dw, respectively. Out of 32 samples that were analyzed, only one had detectable levels of chlordane (55 ppb dw), 4,4' DDE (5 ppb dw), and 4,4' DDT (11 ppb dw). One other sample had a detectable level of heptachlor epoxide (16 ppb dw).

Savannah Laboratories (1987) analyzed sediments from the Alafia River Channel for chlordane, heptachlor, heptachlor epoxide, 4,4' DDD, 4,4' DDE, and 4,4' DDT. All samples were reported as being below the detection limits that varied from 0.6 to 1.0 ppb dw. The Savannah Laboratories (1986b) analyzed three samples each from two sites in Middle Tampa Bay for the same analytes quantified by the Savannah Laboratories (1987), using the same range of detection limits. Only heptachlor was present in concentrations above the detection limits. The mean heptachlor concentrations at the two sites were 0.63±0.25 and 0.67±0.12 ppb dw.

The USGS analyzed four samples from lower Allen Creek and one from Old Tampa Bay for chlordane, heptachlor, heptachlor epoxide, dieldrin, mirex, DDD, DDE, and DDT using detection limits of 1.0 ppb dw for chlordane and 0.1 ppb dw for the other analytes (USGS, unpublished data). Three of the four Allen Creek sites had chlordane concentrations above the detection limits (1.0, 1.0, and 39 ppb dw). The Tampa Bay site had 3.0 ppb dw chlordane. The same Allen Creek site that had the 39 ppb dw chlordane (the one at the mouth of the creek) was also the only site to have measurable amounts of DDD (0.1 ppb dw). The Old Tampa Bay site also had 0.3 ppb dw dieldrin. All the other sample values were below the detection limits.

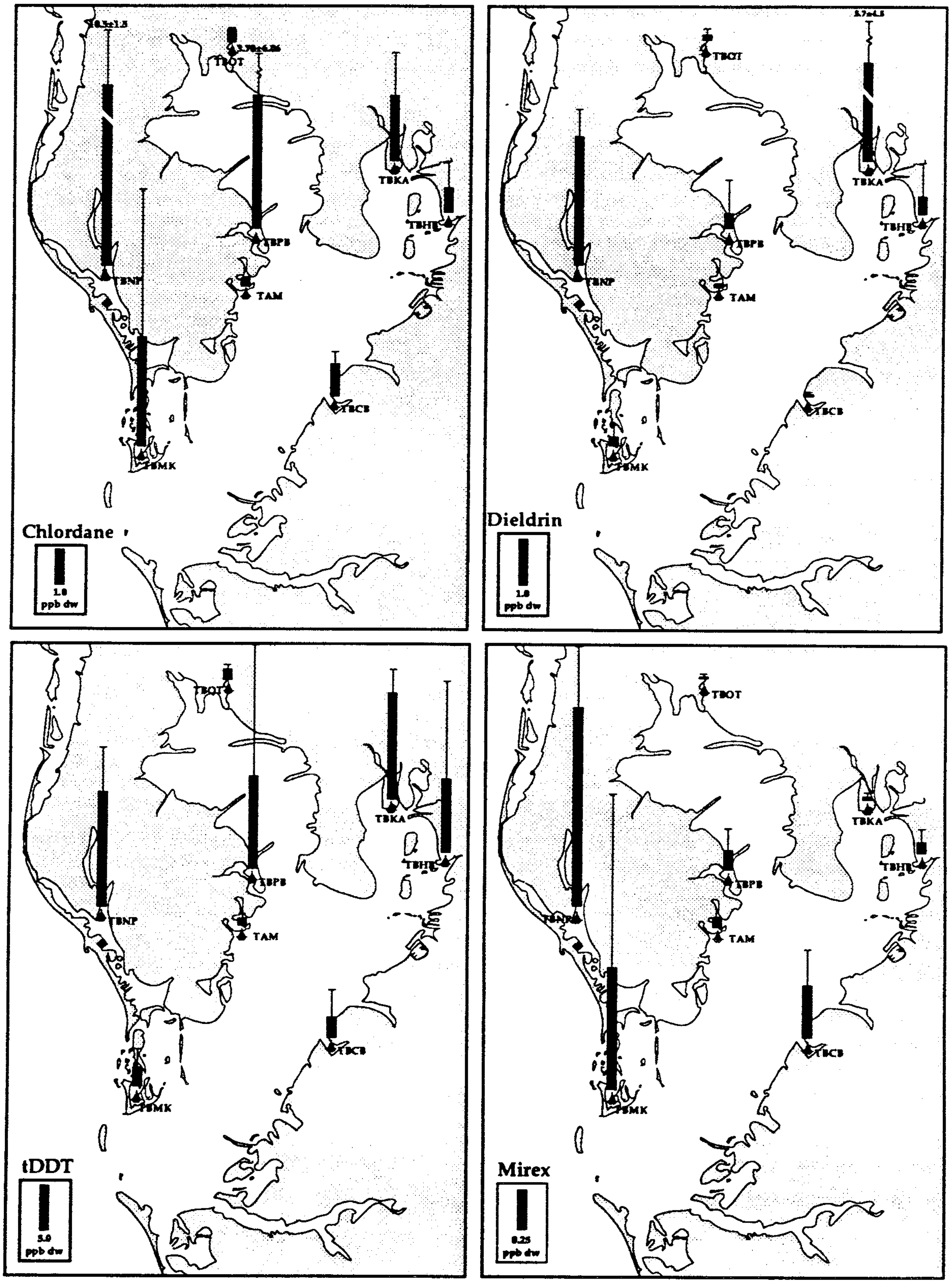

Figure 9. Mean concentrations (ppb dw) and standard deviations of chlordane, dieldrin, tDDT, and mirex in the surficial sediments of the Tampa Bay area NS&T Program sites.

NOAA's NS&T Program initially determined tPCB concentrations by analyzing samples for the concentrations of the eight chlorination level classes of PCBs and then summing the total. In 1987 they began to analyze the samples for the concentrations of 20 individual PCB congeners and summing these. When the southwest Florida NS&T Program sites were compared the top five sites were from the Tampa Bay area as was the fourteenth ranked site (TBCB) (Table 1). Based on the chlorination level data, the top ranked site had over 70 times as much tPCBs as did the least contaminated site; based on congener data the difference was a factor of over 35 (Table 5). When the individual Tampa Bay area sites were compared, site TBPB had the highest mean concentration of tPCBs based on both quantification methods (Table 4). However, when one extraneously high sample from the site was excluded from the calculations it appeared only moderately contaminated (Figure 10 A and B). The chlorination level data indicated that the TBHB site had significantly higher levels of tPCBs than the other four sites for which chlorination data existed (Figure 10A). Based upon the data from the quantification of PCB congeners, sites TBNP, TBHB, and TBKA were relatively highly contaminated with tPCBs compared to the other four sites for which equivalent data were generated (Figure 10B).

In 1985, the FDER analyzed surficial sediment samples from Hillsborough Bay for seven Aroclor mixtures of PCBs (1016, 1221, 1232, 1242, 1248, 1254, and 1260) (FDER, unpublished report). Of the 32 samples for which results were reported, only one sample had no detectable levels of PCBs. When the below-detection values were assumed to be one-half the detection limit (1.0 ppb dw) and the values for the individual mixtures for each site summed, the tPCB concentrations ranged from 3.5 to 560 ppb dw. The mean concentration was 120±140 ppb dw with a median value of 65 ppb dw. Savannah Laboratories (1987) analyzed three samples each from four sites from the Alafia River Channel for the same seven Aroclor mixtures of PCBs. PCB 1254 was found at three of the four sites at mean concentrations of 0.01 ppb dw, and PCB 1260 was found at the site 1000 yards upstream from the mouth at a mean concentration of 0.01 ppb dw. The remainder of the samples had concentrations below the detection limits of 0.005 ppb dw. Savannah Laboratories (1986b) analyzed three samples each from two sites in Middle Tampa Bay for the same PCB mixtures with the same detection limits and no detectable levels of PCBs were found. The USGS data from Allen Creek and Old Tampa Bay indicated no detectable levels of PCBs at a detection limit of 1.0 ppb dw (USGS, unpublished data).

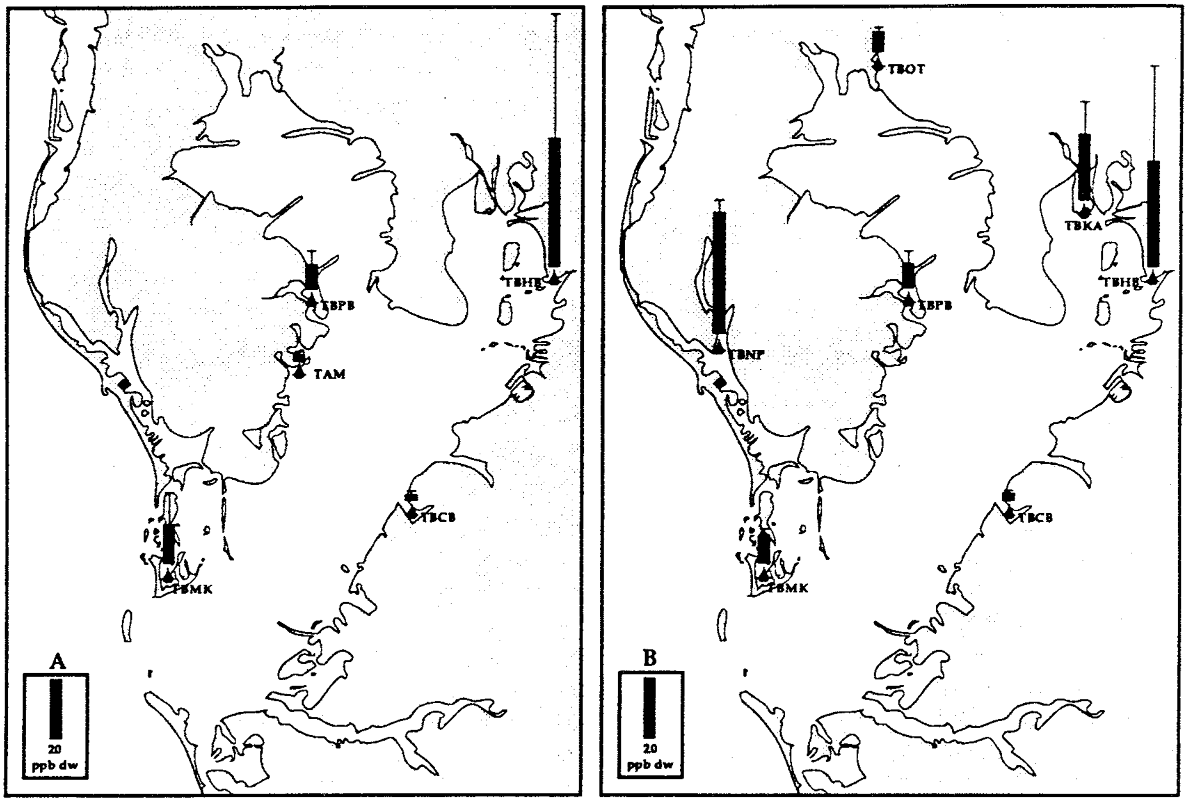

Figure 10. Mean tPCB concentrations (ppb dw) in the surficial sediments of the Tampa Bay area NS&T Program sites based on (A) summed chlorination level concentrations and (B) summed congener concentrations. Excludes single extraneously high sample from TBPB with tPCB concentrations of 230 and 790 ppb dw based on chlorination levels and congener levels, respectively.

<u>Toxicants in Tampa Bay Compared to Other Areas.</u> The mean concentrations (and standard deviations) of selected toxicants in sediments sampled by the NS&T Program in San Francisco Bay (summarized by Long *et al.*, 1988) and Boston Harbor (summarized by MacDonald, 1991) are compared to the equivalent means for Tampa Bay in Figure 11. Both San Francisco Bay and Boston Harbor are known to have anthropogenically enriched toxicants in the sediments. Among the three systems, the Boston Harbor sites had the highest levels of most chemical contaminants, while the Tampa Bay sites often had the lowest concentrations. These higher levels can be partially explained by the higher levels of both fine-grained sediments and TOC found in Boston Harbor. Figure 11 indicates that, except for Cd and Pb, the San Francisco Bay sites had much higher mean concentrations of metals than the Tampa Bay sites. The mean concentrations of Cd and Pb were nearly the same as those in San Francisco Bay. The concentrations of chlordane, dieldrin, mirex, and tPCBs in the Tampa Bay sites were similar to or higher than those in the San Francisco Bay sites, in spite of the presence of higher percent fine materials and higher TOC content in the San Francisco Bay sediments.

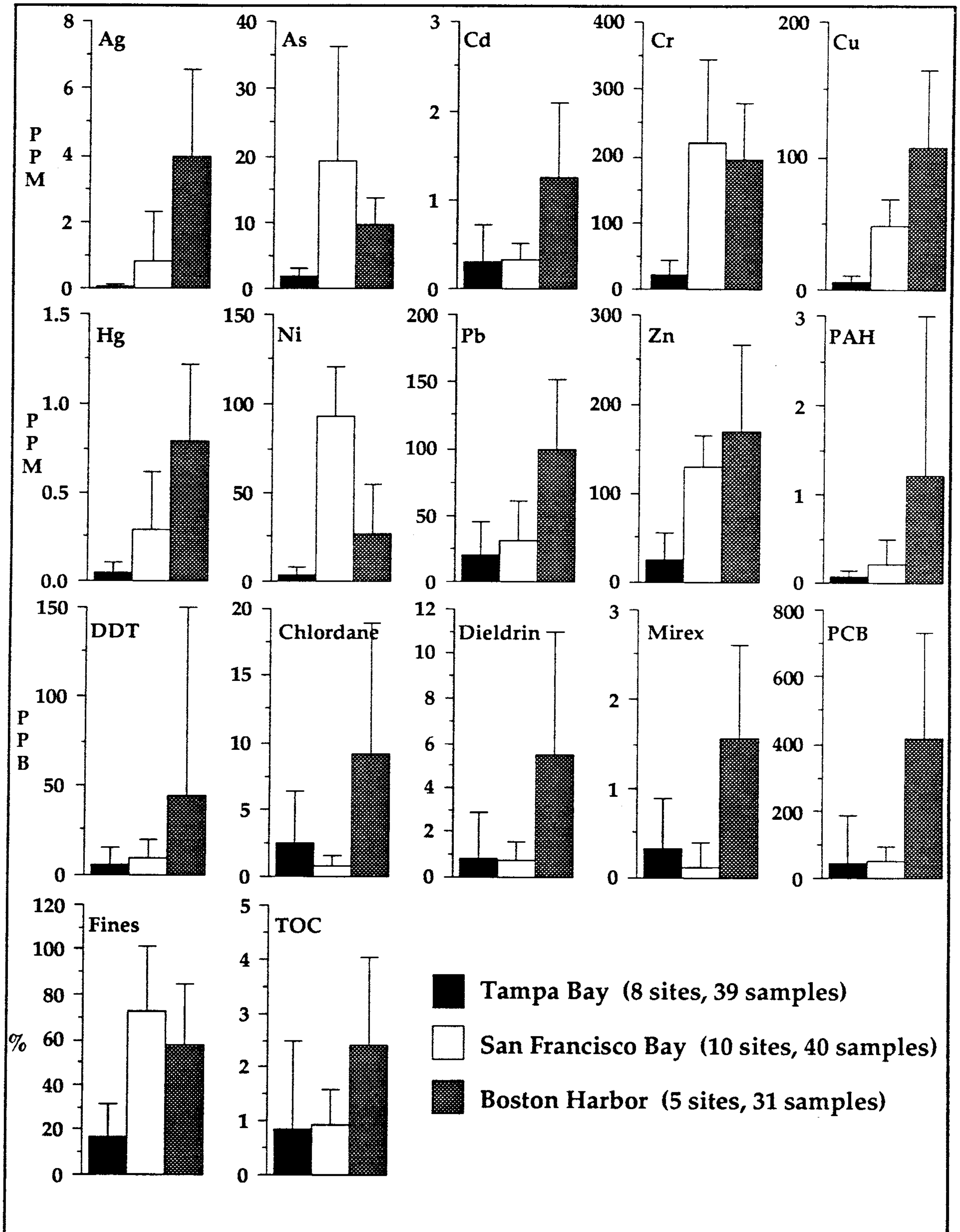

Figure 11. Comparison of the mean concentrations of 15 analytes and 2 normalizers based on the NS&T Program data for Tampa Bay, San Francisco Bay and Boston Harbor (bars represent one standard deviation). The concentrations are in ppm dw for the metals and PAHs, ppb dw for the pesticides and PCBs, and percent for fines and TOC. The PCB means are based solely on the chlorination level data and the Boston Harbor mean excludes one sample which had 51,000 ppb.

Summary. Most of the data from chemical analyses of sediments are available from Hillsborough Bay and the adjacent lower Hillsborough River. The highest concentrations of many chemicals also occur in these two areas. Isolated areas in marinas, blind finger canals, and harbors around the perimeter of the estuary also have very high levels of some chemicals. There is a general pattern of decreasing chemical concentrations from the head of the estuary (Hillsborough Bay) to Old Tampa Bay and the mouth of the estuary and the Gulf of Mexico. This pattern parallels a pattern of increasing distance from the relatively industrialized Tampa area and decreasing percent fine-grained sediments. The concentrations of fine-grained particles and organic carbon in the sediments can markedly influence the concentrations of toxicants. Based upon the rankings of the NS&T Program sites with other sites along the Gulf Coast of Florida, the comparison of the Tampa Bay data with data from San Francisco Bay and Boston Harbor, and the comparisons of the trace metals data to the aluminum-to-metals ratios of Schropp *et al.* (1990), at least some areas of Tampa Bay have elevated levels of some metals (Ag, Cd, Cr, Cu, Hg, Pb, and Zn). The concentrations of Cd and Pb in Tampa Bay were similar to those found in San Francisco Bay. Based on the ranking of southwest Florida NS&T Program sites and the comparison with the other two bay systems, at least some Tampa Bay sites have relatively high concentrations of some organic contaminants (DDTs, PCBs, chlordane, dieldrin, mirex, PAHs).

Temporal Trends In Toxicant Concentrations in Sediments

Very little data were available with which temporal trends in sediment contamination could be determined. None of the NS&T Program sites had been sampled for more than 2 years. No other programs apparently have sampled surficial sediments repeatedly at the same locations over any appreciable period of time.

Data were available, however, from several studies in which different strata of sediment cores were analyzed. If it is assumed that the sediments deep in the cores were deposited, along with associated toxicants, before the sediments at the water-sediment interface were deposited, then trends in the accumulation of toxicants over time can be retrospectively reconstructed by evaluating these data. Changes in chemical concentrations with depth in sediment cores can be influenced by changes in both input rates and sediment grain size.

Wade-Trim, Inc. (1988) analyzed undated cores from the Bradenton Municipal Marina in the lower Manatee River. The Pb concentration increased from bottom to top in four of the five cores (Figure 12). The Pb concentration in core no. 5 increased by about an order of magnitude. The strata of the cores were not dated by radioisotope dating techniques, so it is not possible to estimate the period of time that these data represent. Lead concentrations normalized to the percent fines remained higher in the upper strata of the cores than in the lower strata in cores 1, 4, and 5. This observation suggests that this pattern was not a factor of only changes in grain size over the length of the cores. This pattern was probably influenced by changes in input rates of Pb. Based upon the fine-grain normalized data, it appeared that Pb concentrations in core 2 were lowest in the upper and lower strata and peaked in the middle section; while there was no consistent pattern of change over the length of core 3.

Trefry *et al.* (1989) analyzed four cores from the lower Hillsborough River for Cu, Hg, and Pb concentrations. Grain size data were not reported. As exemplified by the data for Pb (Figure 13), there were no clear trends in trace metal concentrations with depth in these cores. These sediments may have been periodically disturbed by dredging, thereby obscuring any temporal trends in contaminant accumulation. Note that the maximum Pb concentration (about 100 ppm) in the Bradenton Municipal Marina sediments (Figure 12) was roughly equivalent to the lowest Pb concentration reported for the Hillsborough River cores (Figure 13).

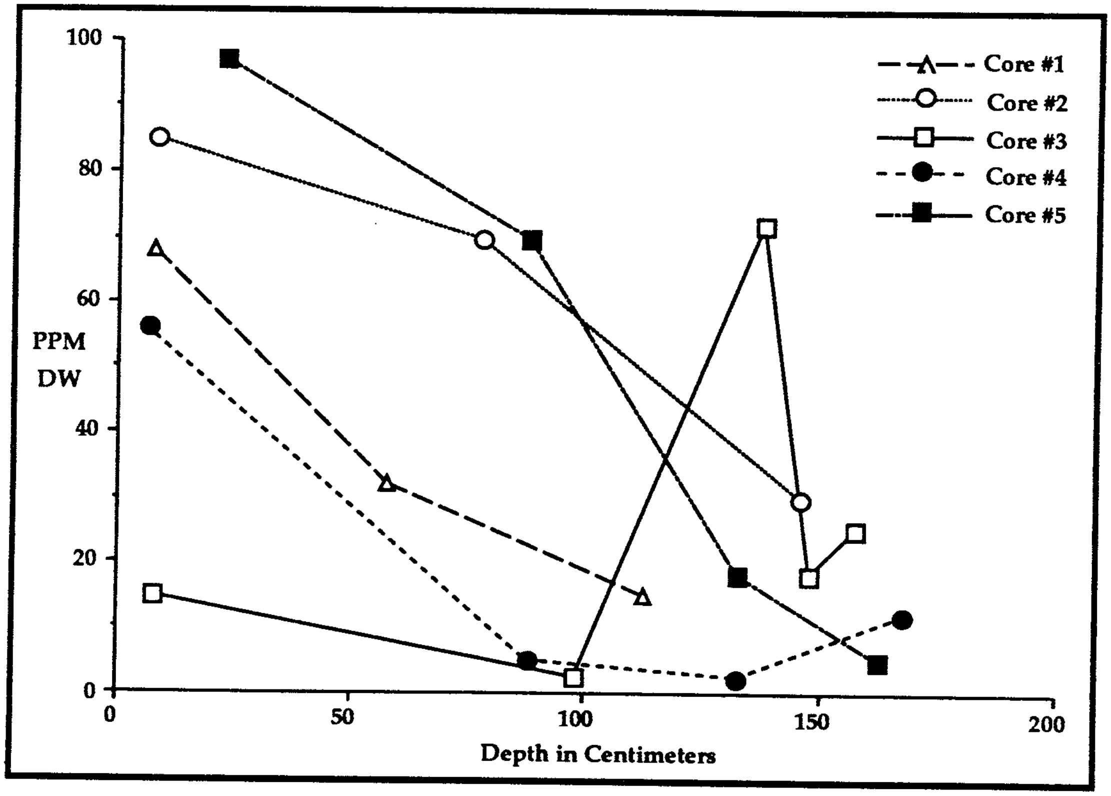

Figure 12. Lead concentrations (ppm dw) in different depth strata below the sediment surface in five cores from the Bradenton Municipal Marina in the lower Manatee River (Wade-Trim, Inc. 1988).

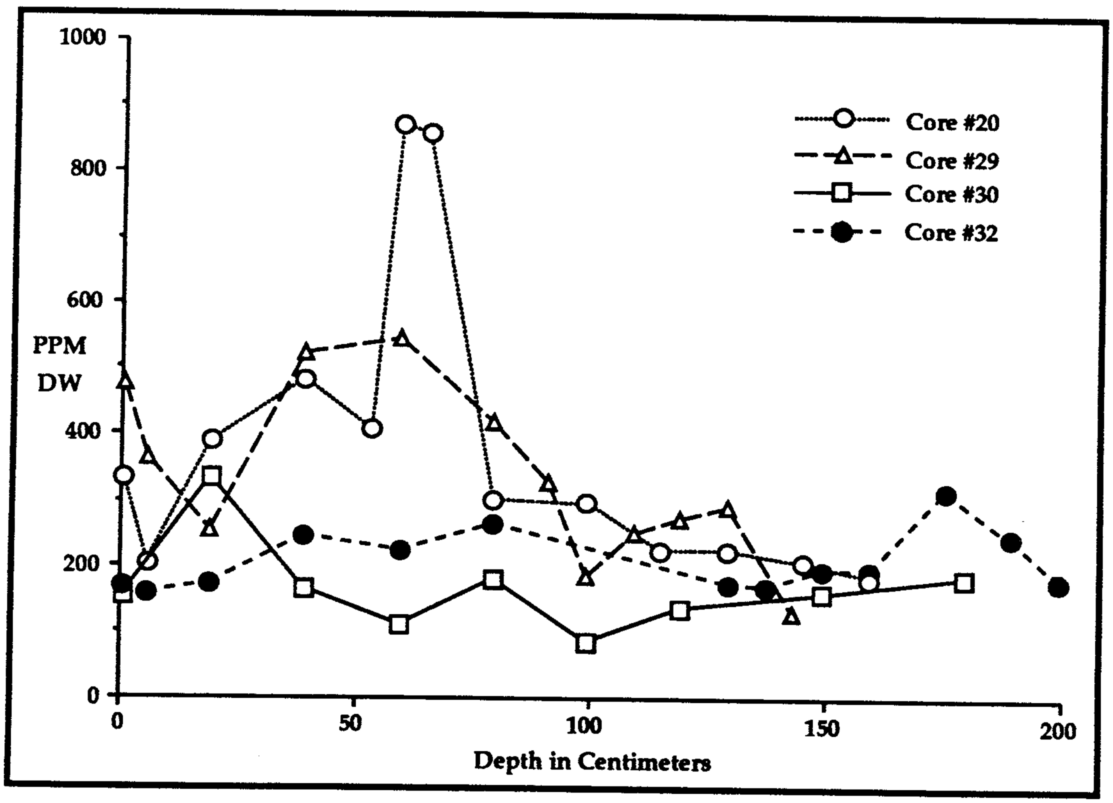

Figure 13. Lead concentrations (ppm dw) in different depth strata below sediment surface in four cores from the lower Hillsborough River (Trefry *et al.*, 1989).

Finally, Doyle *et al.* (1985) measured hydrocarbon concentrations with depth in three cores from Tampa Bay. Core 1 was collected in upper Old Tampa Bay (subdivision 1), core 17 was collected in Hillsborough Bay (subdivision 2), and core 41 was collected in Lower Tampa Bay (subdivision 4). As shown in Table 7, the concentrations of the f1 and f2 fractions and total hydrocarbons generally decreased sharply from the surface segment to the middle segment(s) and then increased in the bottom segment. Core 17 indicated the greatest change in hydrocarbon concentrations (roughly an order of magnitude) with depth in the core. These data suggest that recently deposited sediments generally had higher concentrations of hydrocarbons than those sediments before industrialization of the Tampa Bay area. The cause of the increase in concentrations in the bottom strata of the cores is unknown. However, since these analyses effectively quantify both anthropogenically generated and naturally (biogenically) derived hydrocarbons, it is possible that at least some portion of these hydrocarbons were created by natural processes. Organic peats were observed in the lowest strata of core 17 (Dr. Gregg Brooks, University of South Florida, personal communication). Also, based upon the ages of the strata listed in Table 7, it appears that sedimentation has been very slow or nonexistent and that the sands sampled by the corers have remained relatively unchanged since the sea inundated the Tampa Bay estuary.

Table 7. Concentrations (ppm dw) of F1 (aliphatics) and F2 (aromatics and olefinics) fractions and total extractable hydrocarbons with depth in three sediment cores (Doyle *et al.*, 1985).

Sub division	Core #	Core Depth	Carbon 14 Age B. P.	F1 Fraction	F2 Fraction	Total Hydrocarbons
1	1	0-5 cm		5.0	4.3	9.3
1	1	55-65 cm	1400 yrs			
1	1	100-105 cm		<0.1	<0.1	<0.1
1	1	155-161 cm		<0.1	13.0	13.0
2	17	0-5 cm		36.6	40.3	76.9
2	17	100-105 cm		0.3	4.0	4.3
2	17	200-205 cm		0.1	0.1	0.1
2	17	225-231 cm	3500 yrs	0.1	8.5	8.5
4	41	0-5 cm		5.1	<0.1	5.1
4	41	100-105 cm		<0.1	<0.1	<0.1
4	41	172-177 cm	2800 yrs	2.0	0.5	2.5

Distribution of Toxicants in Bivalve Mollusks

The tissues of oysters and clams from Tampa Bay have been analyzed for toxicant concentrations by both state and federal programs. None of these programs has thus far developed data for a sufficiently long period to use in evaluating long-term temporal trends. The following discussions focus primarily upon geographic distributions of selected chemicals. However, a few preliminary observations were made regarding changes in chemical concentrations from year to year where the data warranted. These observations primarily were based upon the NS&T Program data, which were available for a maximum of only 4 consecutive years at the time the data were evaluated.

A 4-year record is insufficient to determine long-term temporal trends. Additional data are needed to verify or refute patterns observed after only 4 years. The primary utility of these data was to determine if between-site differences in chemical concentrations remained consistent from year to year.

A considerably smaller number of locations have been sampled in Tampa Bay for bivalves than sediments. The relatively small amount of data did not warrant merging of data to determine mean concentrations in the subdivisions of the estuary. Also, an insufficient number of sampling locations within any of the subdivisions have been sampled to determine the degree to which the data from any single site represent conditions within the respective subdivision in which the samples were collected.

PCBs. Bivalve mollusks in Tampa Bay have been analyzed for PCB concentrations by NOAA (1989), Florida Department of Natural Resources (FDNR) (Heil, 1986; David Heil, FDER, personal communication), and the ACOE (1974). With detection limits ranging from 0.01 to 0.50 ppb, neither the FDNR nor the ACOE found quantifiable amounts of PCBs in bivalves from five locations in Tampa Bay. In its NS&T Program, NOAA quantified PCBs in oysters (*Crassostrea virginica*) either by chlorination level in some samples and/or by individual congeners in some samples. The data for tPCBs were generated in 1986 and 1987 by summing the concentrations of 8 chlorination levels of biphenyls; whereas, in 1988 and 1989, they were determined by summing the concentrations of 18 congeners. Total PCB concentrations from the congener analyses were determined with the equation described in NOAA (1989):

$$\Sigma PCBs = 2.30 \times \Sigma \text{ (18 congeners)} + 8.1.$$

The data indicate that mean PCB concentrations were lowest in samples from site TBMK (Mullet Key) and they were highest in samples from site TBKA (Davis Islands) (Table 8, Figures 14 A and B). The samples from site TBHB (the mouth of the Alafia River), site TBNP (Boca Ciega Bay), site TBOT (Double Branch Creek), and site TBPB (Bayou Grande) had moderate PCB concentrations. The highest concentrations in individual samples were 706 and 605 ppb in two samples from the Davis Islands site (TBKA). None of the sites in Tampa Bay ranked in the top 20 in PCB concentrations among the approximately 200 sites sampled for mullusks during 1986, 1987, and 1988 by the NS&T Program (NOAA, 1989).

Data have been generated for an insufficient number of years to determine long-term trends in PCB concentrations. During the years for which data are available, PCB concentrations remained relatively constant in sites TBMK, TBPB, and TBOT (the mean concentrations did not differ by more than a factor of 2). At site TBHB, the PCB concentration in one sample collected in 1988 was much lower than in the samples collected in 1986. At site TBCB there was an apparent increase in PCB concentrations from 1986 to 1987/1988/1989. Additional data are needed to verify any of these observations.

Table 8. Mean concentrations (in ppb dry weight ± standard deviation) of tPCBs in oysters (*C. virginica*) collected from seven sites in Tampa Bay by the NS&T Program (sums of 8 chlorination levels in 1986 and 1987, sums of 18 congeners in 1988 and 1989) and the grand mean for all sites and all years.

Year	Site TBCB	SITE TBHB	Site TBMK	Site TBPB	Site TBOT
1986	45.9±11.2	302.5±111.8	51.0±10.4	175.1±70.7	-
1987	91.5±15.3	121.6±36.0	53.9±15.4	146.8±48.9	-
1988	137±52.5	23.3 (n=1)	53.9±18.3	98.3±24.0	142.5±37.3
1989	133±21.3	-	55.7±20.4	143.1±24.3	147.3±43.2
Mean	101.8±46.6, n=12	186.0±132.9, n=7	53.6±14.3, n=12	140.8±48.8, n=12	144.9±36.2g, n=6

Year	Site TBKA	Site TBNP	All Sites
1986	-	-	
1987	-	-	
1988	588.3±127.5	246.8±87.0	
Mean	-	-	149.6±133.8, n=55

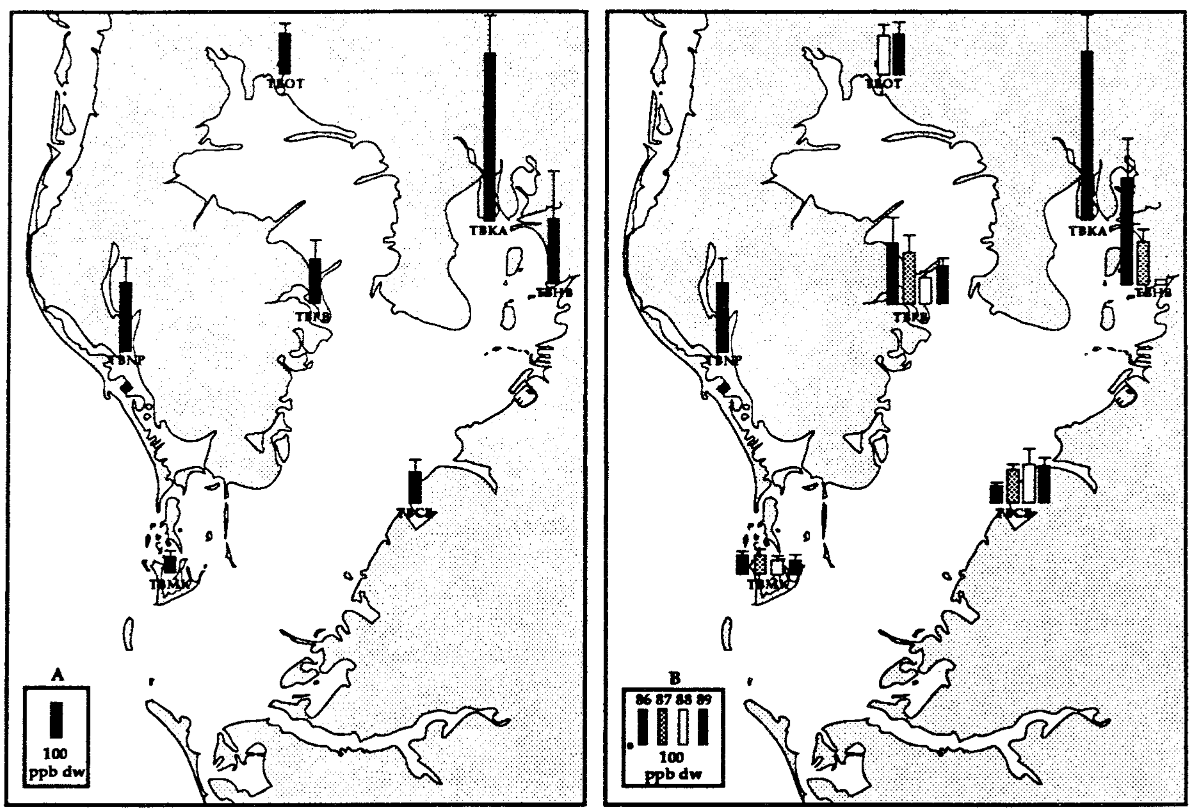

Figure 14. (A) Overall mean and (B) annual mean tPCB concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

PAHs. The concentrations of 25 individual PAHs in oysters (*C. virginica*) were quantified by the NS&T Program (NOAA, 1989). Total PAH concentrations were determined by summing the concentrations of the individual hydrocarbons. The tPAHs concentrations for seven oyster sampling sites in Tampa Bay are summarized in Table 9 and Figures 15 A and B.

Table 9. Mean concentrations (in ppb dw ± standard deviation) of tPAHs in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites in the bay for all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	54.5±0	509.1±44.2	541.1±474.3	144.8±17.2
1987	85.0±11.3	273.3±119.7	120.8±37.9	159.6±57.3
1988	155.3±29.4	115.9 (n=1)	81.5±20.4	338.2±97.4
1989	233.4±42.4	-	296.5±64.6	372.9±14.9
Mean	132.1±77.1, n=12	406.3±154.5, n=7	308.5±312.1, n=9	253.9±117.9, n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	641.2±681.4	-	-	
1989	501.2±134.6	989.1±105.0	758.1±497.0	
Mean	639.0±462.7, n=6			350.3±317.8, n=55

Based upon the data in Table 9 and Figure 15 A, the oysters in site TBCB had the lowest concentrations of PAHs, while the oysters from sites TBOT, TBKA, and TBNP had the highest concentrations. The latter three sites are located in Double Branch Creek below a state highway, near the boat basin on the southern tip of Davis Islands in upper Hillsborough Bay, and in Boca Ciega Bay adjacent to the St. Petersburg urban area, respectively. The sample with the highest single concentration of tPAHs (1428 ppb) was collected at site TBOT. Site TBHB, located in the mouth of the Alafia River, site TBMK, located at Mullet Key, and site TBPB, located in Bayou Grande had intermediate concentrations of PAHs. Greater than two-fold differences in mean tPAH concentrations have occurred from year to year at sites TBCB, TBHB, TBMK, and TBPB. Additional data are needed to determine long-term temporal trends (Table 9, Figure 15B). However, the pattern of decreasing concentrations at site TBMK was statistically significant (NOAA, 1989). None of the Tampa Bay sites sampled in 1986, 1987, and 1988 by the NS&T Program ranked among the top 20 in the nation in either low or high molecular weight aromatic hydrocarbon concentrations (NOAA, 1989).

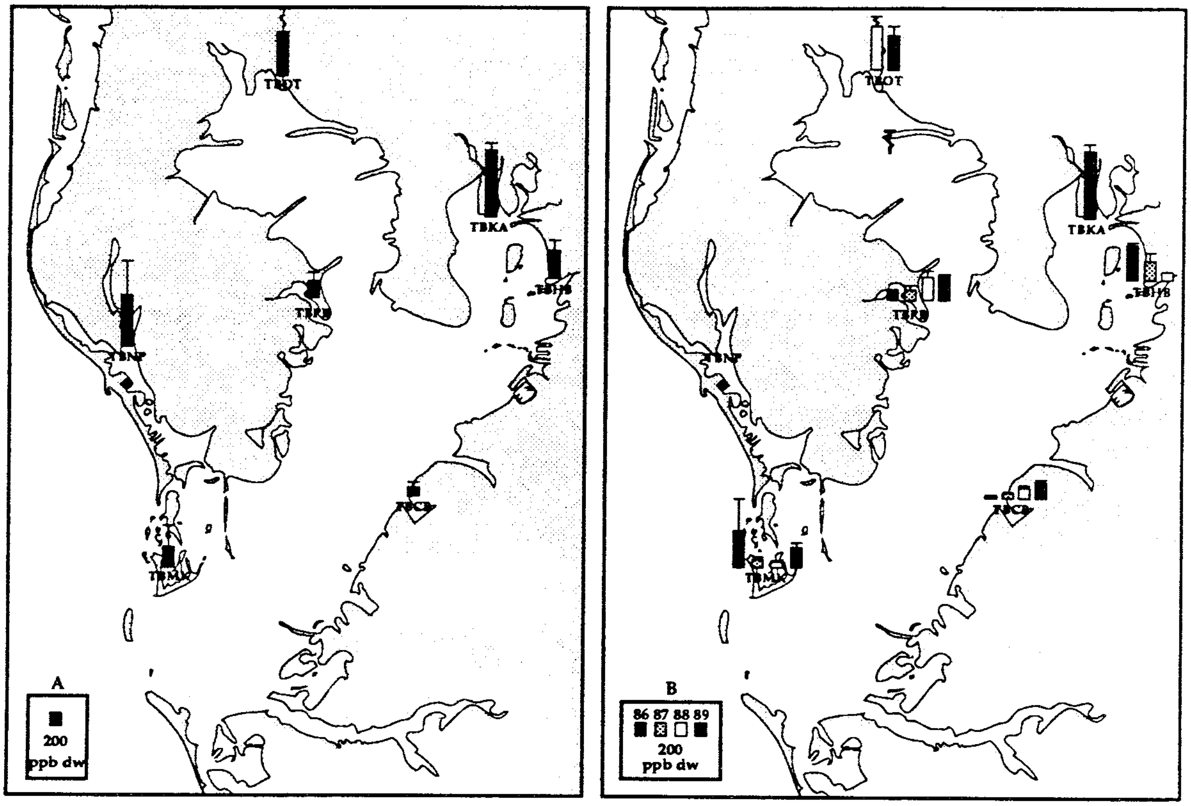

Figure 15. (A) Overall mean and (B) annual mean tPAH concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Doyle *et al.* (1985) presented results of PAH analyses of oysters and other animals collected in different parts of Tampa Bay. The average concentrations of the f2 fraction in oysters for each subdivision that they sampled were: Old Tampa Bay, 22 ppm ww (n=3); upper Tampa Bay proper, 7.1 ppm (n=3); Middle Tampa Bay proper, 4.4 ppm (n=1); Lower Tampa Bay proper, 5.7 ppm (n=1); Boca Ciega Bay, 0.9 ppm (n=4); Anna Maria Sound, 16.9 ppm (n=1); Manatee River, 3.5 ppm (n=2); Little Manatee River, <0.1 ppm (n=2); and the Alafia River, 2 ppm (n=2). The highest concentrations were found in oysters from Old Tampa Bay and Anna Maria Sound. They also determined total hydrocarbon concentrations as the sums of the f1 fraction and the f2 fraction. These data are summarized by subdivision in Table 10, along with data for total hydrocarbon concentrations presented by Van Vleet and Reinhardt (1983). The concentrations presented by Doyle *et al.* (1985) were uniformly much lower than those presented by Van Vleet and Reinhardt (1983), suggesting a difference in the analytical methods used. No distinct patterns emerge from these data and the density of samples in each subdivision was too small to assume that the data represent conditions throughout each subdivision. The highest hydrocarbon concentrations occurred in samples from Old Tampa Bay and Anna Maria Sound. Three samples of the clam *Mercenaria campechiensis* sampled by Doyle *et al.* (1985) ranged in total hydrocarbon concentration from 2.8 to 16.2 ppm ww.

Table 10. Total hydrocarbon concentrations (ppm ww) in oysters (*C. virginica*) in subdivisions of Tampa Bay sampled by Doyle *et al.* (1985) and in clams (*M. campechiensis*) sampled by Van Vleet and Reinhardt (1983).

Geographic Subdivision	Doyle *et al.* (1985)	Van Vleet and Reinhardt (1983)
Old Tampa Bay	22.0±21.3 (n=3)	1365 (n=1)
Lower Hillsborough River	3.7 (n=1)	-
Hillsborough Bay	9.0±2.3 (n=5)	-
Alafia River	2.0±1.3(n=2)	-
Upper Tampa Bay	7.6±8.5 (n=4)	406 (n=1)
Lower Tampa Bay	9.8 (n=1)	1417 (n=1)
Boca Ciega Bay	8.3±5.4 (n=4)	1277±662 (n=2)
Manatee River	7.8±2.8 (n=2)	-
Anna Maria Sound	46.7 (n=1)	-

Pesticides. The concentrations of a variety of pesticides have been measured in bivalves in Tampa Bay. Data were summarized for selected classes of these chemicals.

Dieldrin. Mean dieldrin concentrations measured in oysters from seven sites sampled by the NS&T Program are summarized in Table 11 and Figures 16 A and B. The highest mean concentrations were found in oysters from sites TBPB, TBKA, and TBNP. The highest single concentration (15.7 ppb) was measured in oysters from site TBPB. The lowest mean concentrations occurred in samples from sites TBCB, TBHB, TBMK, and TBOT. Among the approximately 200 sites sampled nationwide by the NS&T Program during 1986, 1987, and 1988, none of the Tampa Bay sites ranked among the top 20 in dieldrin concentrations (NOAA, 1989). In each of the four sites for which data are available for 3 or 4 years, the mean dieldrin concentrations in one of these years was unusually high or low relative to the concentrations in the other years (Table 11, Figure 16B). At site TBCB the unusual year was 1987 (lower concentration than in the other years), at site TBHB it was 1986 (higher), at site TBMK it was 1989 (higher), and at site TBPB it was 1988 (lower).

Table 11. Mean concentrations (in ppb dry weight ± standard deviation) of dieldrin in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites in the bay for all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	2.9±0.4	4.0±0.4	2.2±0.5	7.7±2.1
1987	0.9±0.4	1.1±0.3	2.0±1.8	7.9±7.0
1988	3.1±1.4	0.5, n=1	2.7±2.0	4.1±0.5
1989	2.6±0.9	-	4.7±3.5	8.5±5.3
Mean	2.4±1.2, n=12	2.3±1.7, n=7	2.9±2.2, n=12	7.1±4.3, n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	2.3±1.5	-	-	
1989	1.8±0.8	8.2±4.3	7.0±2.8	
Mean	2.1±1.1, n=6			4.0±3.4, n=55

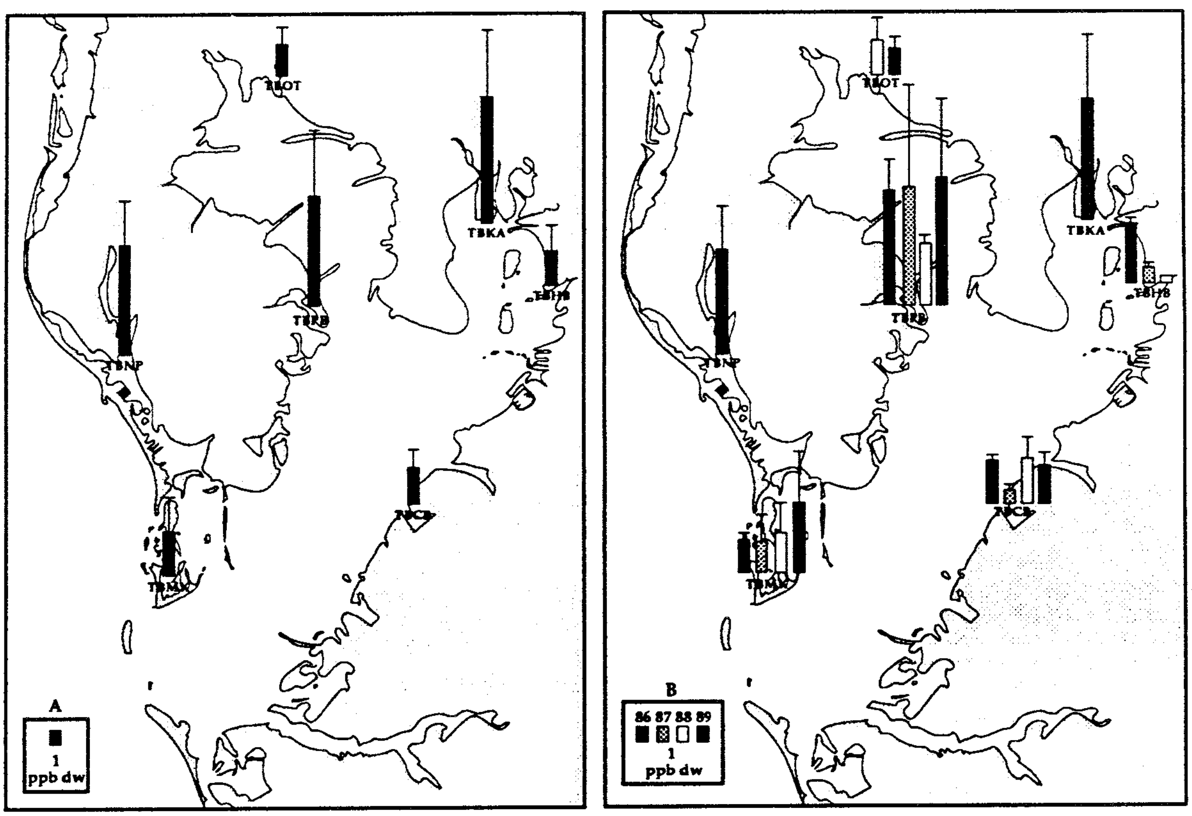

Figure 16. (A) Overall mean and (B) annual mean dieldrin concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

The concentration of dieldrin in clams (*Polymesoda caroliniana*) collected in the Alafia River did not exceed the method detection limit of 12 ppb (Pan *et al.*, 1982). Oysters from Tampa Bay analyzed by Heil (1986) also did not exceed the detection limits for dieldrin (4 ppb). Three oyster samples collected in Tampa Bay by the ACOE (1974) had 0, 0.4, and 0.5 ppb dieldrin in their tissues. Dieldrin concentrations in oysters sampled monthly at the mouth of the Manatee River during 1966-69 did not exceed the detection limit of 10 ppb ww (Butler, 1973).

Chlordane. The NS&T Program data for total chlordane in oysters are summarized in Table 12 and Figures 17 A and B. These data indicate that mean chlordane concentrations were highest in sites TBKA and TBNP (which were sampled only in 1989), intermediate in sites TBCB and TBPB, and lowest in sites TBHB, TBMK, and TBOT. The highest single concentration (193.6 ppb) occurred in a sample from site TBKA. Among the approximately 200 sites sampled for mollusks by the NS&T Program during 1986, 1987, and 1988, site TBCB ranked third in the nation in 1988 in total chlordane concentration and fifteenth overall for the 3-year period. Site TBPB ranked seventeenth overall in the nation in total chlordane concentration during the 3-year period (NOAA, 1989). During the years that samples were collected, mean concentrations increased roughly twofold at site TBCB and either remained unchanged or varied between years in no consistent pattern at the other sites (Table 12; Figure 17B). Data from additional years are needed to determine long-term trends.

Table 12. Mean concentrations (in ppb dw ± standard deviation) of total chlordane (alpha chlordane + trans nonachlor + heptachlor + heptachlor epoxide) in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	73.7±13.5	21.8±3.6	23.6±3.4	58.0±10.9
1987	45.1±6.9	18.1±0.8	21.0±2.9	98.9±54.5
1988	107.3±38.5	1.8, n=1	30.3±9.4	60.0±16.4
1989	127.2±22.3	-	18.1±6.5	81.4±3.2
Mean	88.3±41.0, n=12	17.3±7.6, n=7	23.2±8.0, n=12	74.5±33.5, n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	34.8±4.7	-	-	
1989	28.0±9.7	113.0±41.5	117.0±54.2	
Mean	31.4±9.1, n=6			85.2±214.9, n=55

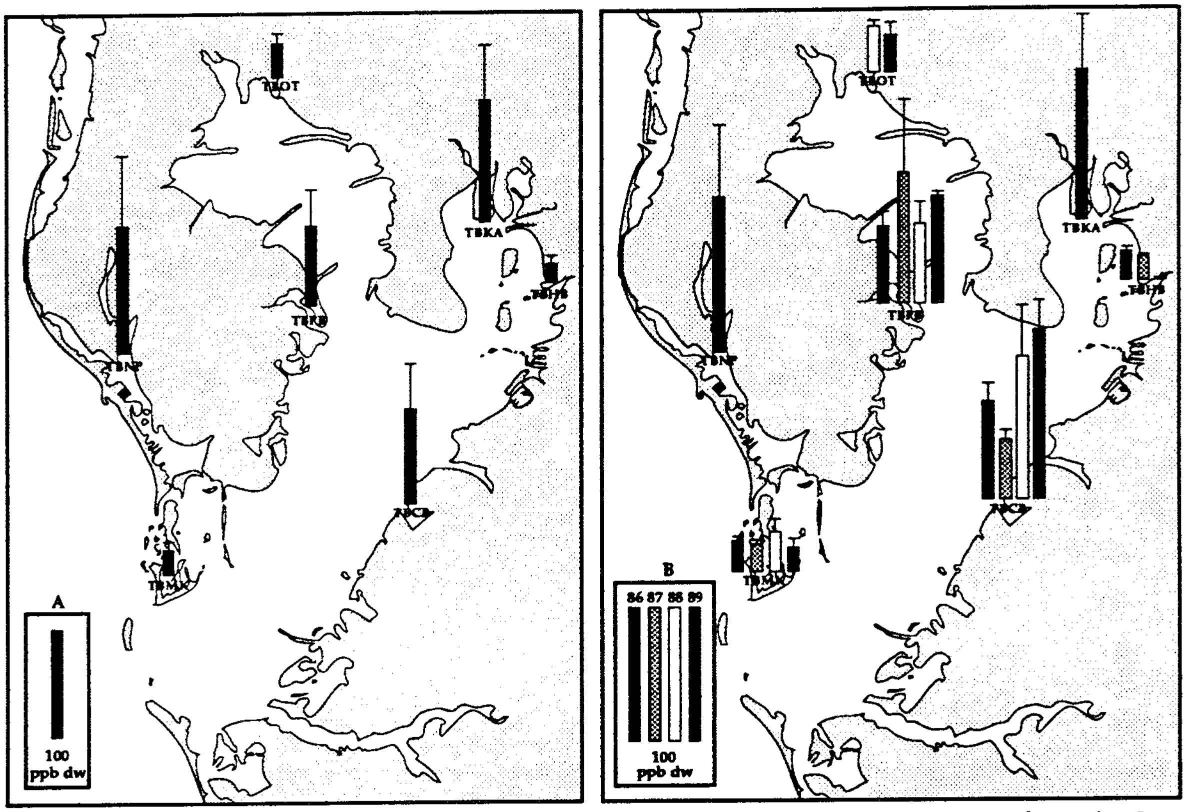

Figure 17. (A) Overall mean and (B) annual mean chlordane concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

The average concentration of total chlordane (alpha chlordane + heptachlor epoxide) in three samples of oysters collected in or near the Tampa Bay navigation channel by the ACOE (1974) was 4.5 ppb (s.d. ±1.7 ppb). This concentration was considerably lower than those determined by the NS&T Program. Oysters sampled in 1985, 1986, and 1987 by the FDNR (Heil, 1986) in Tampa Bay had concentrations of chlordane isomers that were always below the detection limits (the detection limits ranged from 1 to 50 ppb). Chlordane concentrations in clams (*Polymesoda caroliniana*) sampled in the Alafia River by Pan *et al.* (1982) did not exceed the detection limits (4 to 145 ppb for the different isomers).

Total DDT. The mean concentrations of tDDT (the sums of the o,p'- and p,p'-isomers of DDT, DDD and DDE) in oysters sampled by the NS&T Program at seven sites in the bay are summarized in Table 13 and Figures 18 A and B. The highest tDDT concentrations occurred at site TBKA in 1989, at site TBCB in 1988 and 1989, and at site TBPB in 1987. The overall mean concentration was highest at site TBKA, which was sampled only in 1989. The individual sample with the highest tDDT concentration (219.9 ppb) was collected at site TBPB in 1987. Since the other two samples from site TBPB analyzed that year had considerably less DDT, the variability in the data was very high. None of the Tampa Bay sites ranked among the top 20 in tDDT concentration among the approximately 200 sites sampled nationwide for mollusks by the NS&T Program (NOAA, 1989). During the 4-year sampling period, mean tDDT concentrations increased roughly twofold at site TBCB, remained relatively constant (except for 1988) at site TBMK, varied in no consistent pattern from year to year at site TBPB, and appeared to decrease over 3 years at site TBHB (Table 13, Figure 18B). Data from additional years are needed to determine long-term trends.

Table 13. Mean concentrations (in ppb dw ± standard deviation) of tDDT in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	45.7±15.6	50.4±12.9	27.0±18.4	21.3±4.3
1987	75.3±23.7	27.6±4.0	28.8±4.0	103.1±104.3
1988	117.4±50.3	3.5, n=1	10.2±4.7	61.1±9.6
1989	94.7±16.1		28.1±8.0	30.4±8.6
Mean	83.3±37.5	33.9±19.2	23.5±4.8	54.0±55.9
	n=12	n=7	n=12	n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	26.2±12.3	-	-	
1989	38.6±17.7	157.4±32.5	42.7±9.7	
Mean	32.4±15.2			53.8±46.5
	n=6			n=55

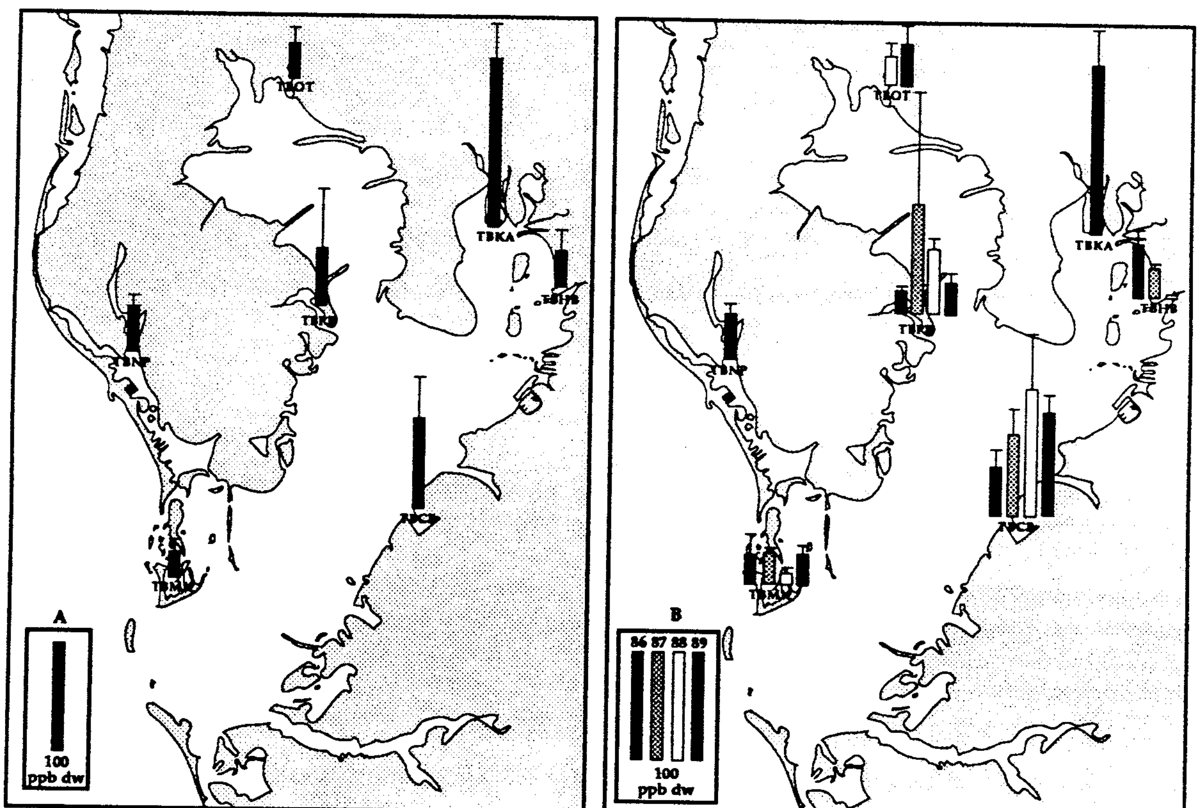

Figure 18. (A) Overall mean and (B) annual mean tDDT concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Butler (1973) collected one sample of oysters (*C. virginica*) each month for 32 consecutive months from the mouth of the Manatee River during 1966-69 and analyzed them for DDT concentrations. The overall mean concentration of tDDT for all 32 samples was 70.8 (±31.3 standard deviation) ppb ww (equivalent to 480 ±212 ppb dw, assuming a moisture content of 14.76%). The individual sample with the highest tDDT concentration (159 ppb ww, equivalent to 1077 ppb dw) was collected during July 1968. The annual mean concentrations in samples collected during 1966, 1967, 1968, and 1969 were 63.6, 70.0, 74.9 and 69.2 ww, respectively, equivalent to 431, 475, 508, and 469 ppb dw (Figure 19). No trends of increasing or decreasing DDT concentrations during the 32 months were apparent. If Butler's data from the mouth of the Manatee River are representative of conditions in Tampa Bay in the late 1960s and the NS&T Program data from seven sites are representative of conditions in the late 1980s, then it would appear that DDT concentrations have diminished appreciably over the intervening 20 years. That is, they have decreased from 400-500 ppb dw to 54 ± 47 ppb dw. However, the samples were collected in different parts of the Tampa Bay system by the two programs and the analytical methods were different; therefore, the data may not be comparable.

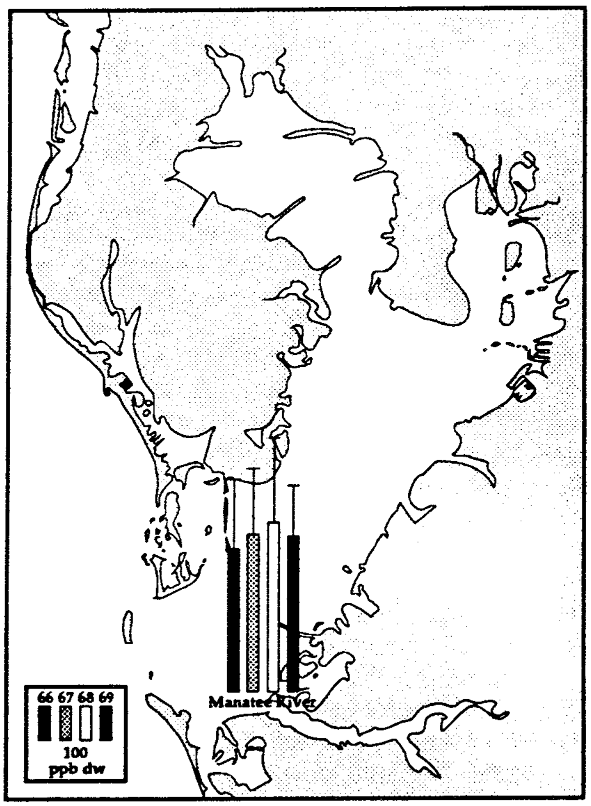

Figure 19. Mean tDDT concentrations (ppb dw) in oysters from the Manatee River site sampled by Butler (1973) during 1966-69 (bars represent one standard deviation).

Total DDT concentrations reported by the ACOE (1974) in oysters from three locations in Tampa Bay were 5.9, 12.4, and 23.5 ppb (whether the data were listed on a wet weight or dry weight basis was not explained). With detection limits ranging from 1 to 12 ppb for individual isomers, both Pan *et al.* (1982) and Heil (1986) reported DDT as below detection limits in bivalves collected in Tampa Bay.

Mirex. The mean concentrations of mirex in oysters sampled at Tampa Bay NS&T Program sites are presented in Table 14 and Figures 20 A, B. The concentrations of mirex were highest at sites TBCB and TBPB. Compared to these two sites, the concentrations of mirex at the other five sites, were considerably lower. Sites TBCB and TBPB ranked either first, second, or third in mirex concentration in oysters among the about 50 to 60 sites sampled annually along the Gulf Coast (Brooks *et al.*, 1989). Among the approximately 200 NS&T Program mollusk sampling sites nationwide, mirex concentrations equivalent to those observed at sites TBCB and TBPB were reported for only three other sites (NOAA, 1989). The individual sample with the highest mirex concentration (25.7 ppb) was collected at site TBCB in 1989. The annual mean concentration in 1987 at site TBCB also was the highest observed thus far. During the 4 years that the samples were collected, there was no consistent pattern of increasing or decreasing concentrations at any of the sites. Data from additional years are needed to determine long-term trends.

Table 14. Mean concentrations (in ppb dw ± standard deviation.) of mirex in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	11.7±4.3	1.9±1.6	1.8±0.3	12.0±0.4
1987	9.2±4.3	1.3±1.1	3.6±1.9	6.3±5.1
1988	6.3±4.2	0.4, n=1	2.2±2.3	5.0±2.5
1989	20.9±4.5	-	1.0±0.9	6.0±2.8
Mean	12.0±6.8 n=12	1.4±1.3 n=7	2.1±1.7 n=12	7.4±3.9 n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	1.1±1.7	-	-	
1989	0.8±0.3	4.2±1.8	3.6±1.3	
Mean	1.0±1.1 n=6			5.4±5.6 n=55

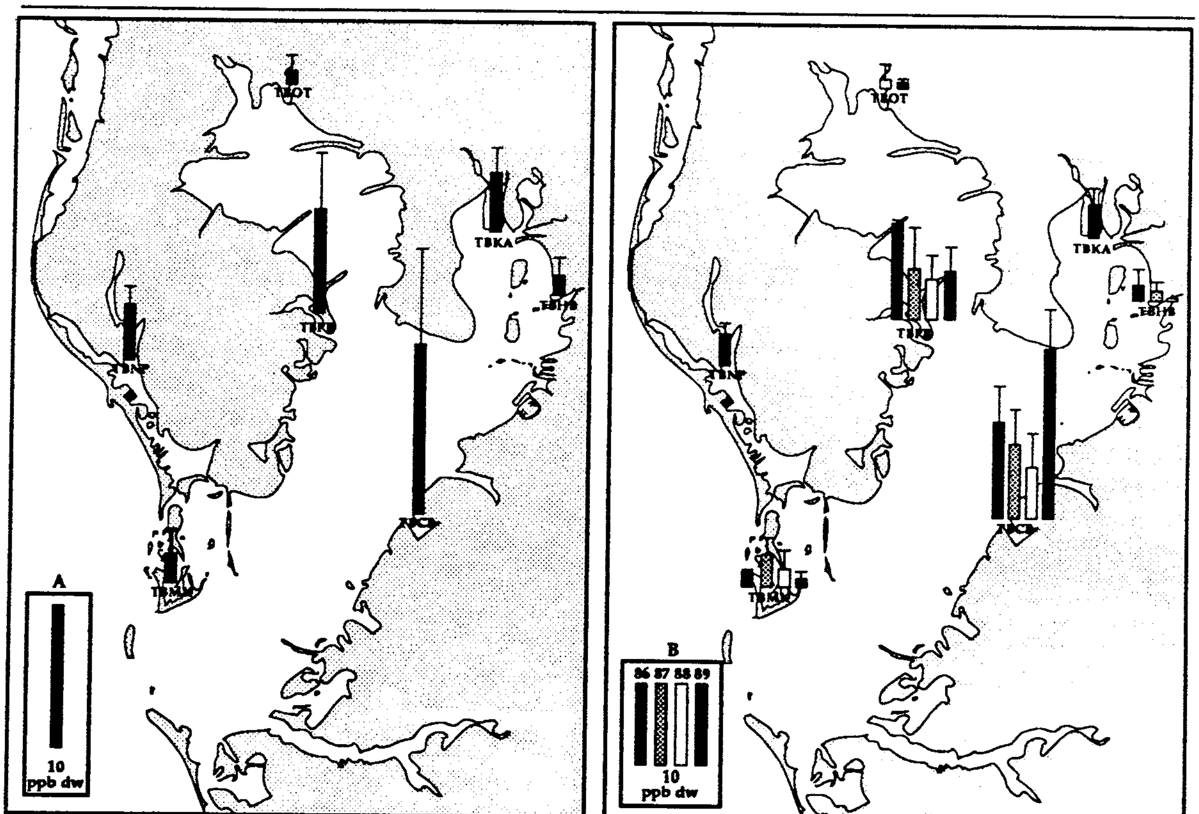

Figure 20. (A) Overall mean and (B) annual mean mirex concentrations (ppb dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Trace Metals. The concentrations of a number of trace metals have been determined in bivalves from Tampa Bay. The data for selected trace metals are summarized in this report.

Mercury. Among the seven sites in Tampa Bay sampled by the NS&T Program, Hg concentrations were highest in sites TBOT and TBPB and lowest in site TBHB (Table 15, Figures 21 A and B). The individual sample with the highest Hg concentration (0.72 ppm) was collected at site TBOT. Sites TBOT and TBPB ranked second and fifth, respectively, in Hg concentrations among the approximately 200 sites sampled for mollusks nationwide by the NS&T Program in 1988 (NOAA, 1989). In 1986 site TBPB ranked first in the nation and in 1988 site TBOT ranked first (NOAA, 1989). The Hg concentrations did not change appreciably between years at most of the sites that were sampled over the 4-year period; however, there was a small decrease in concentrations from 1986-89 at site TBMK (Table 15, Figure 21 B). Data from additional years are needed to determine long-term trends

Table 15. Mean concentrations (in ppm dw ± standard deviation) of Hg in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	0.24±0.03	0.11±0.02	0.23±0.11	0.48±0.10
1987	0.39±0.14	0.07±0.03	0.19±0.01	0.30±0.04
1988	0.27±0.06	0.09, n=1	0.12±0.01	0.44±0.06
1989	0.22±0.01	-	0.14±0.01	0.30±0.05
Mean	0.28±0.09, n=12	0.09±0.03, n=7	0.17±0.06, n=12	0.38±0.10, n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	0.64±0.10	-	-	
1989	0.53±0.09	0.16±0.07	0.12±0.03	
Mean	0.58±0.10 n=6			0.27±0.17 n=55

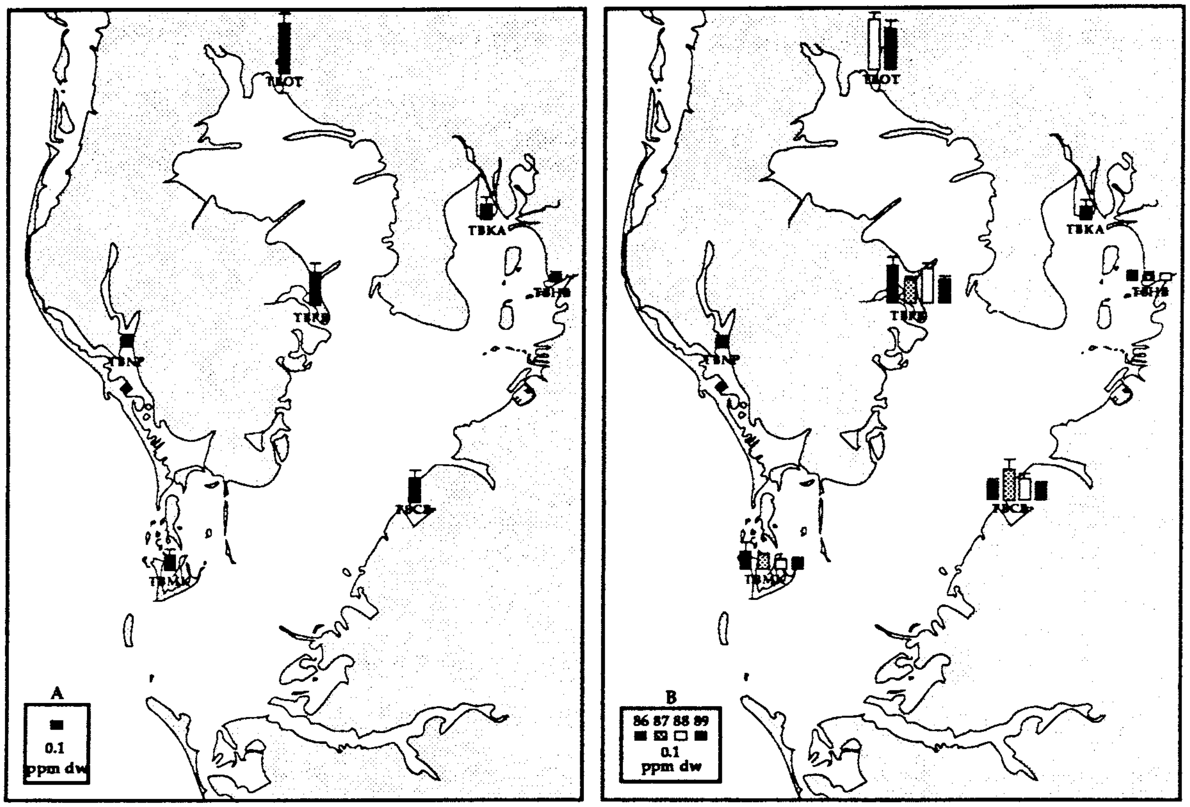

Figure 21. (A) Overall mean and (B) annual mean mercury concentrations (ppm dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Three oyster samples analyzed by the ACOE (1974) had 0.07, 0.0, and 0.18 ppm Hg in the tissues (whether the data were expressed on a wet weight or a dry weight basis was not explained). Pan *et al.* (1982) reported a Hg concentration of 0.02 ppm ww (equivalent to 0.10 ppm dw, assuming a moisture content of 20%) in clams (*P. caroliniana*) sampled in the Alafia River. Heil (1986) reported Hg concentrations in oysters sampled at three Tampa Bay sites in 1984, 1986, and 1987; the overall mean concentration in 18 samples was 0.0018±0.0174 ww (0.012±0.118 dw), considerably lower than the concentrations reported by the NS&T Program. The mean Hg concentrations at the three sites were: 0.16 ppm dw (Little Cockroach Bay, site 11); 0.14 ppm dw (Mullet Key Bayou, site 12); and 0.06 ppm dw (Manatee River, site\ 13). Hg concentrations at all three sites ranged from 3 to 10 times higher in oysters collected in March than in those collected in August.

Lead. The mean concentrations of Pb in oysters sampled at seven sites in the bay are summarized in Table 16 and Figures 22 A and B. Based upon these data, Pb concentrations were highest in sites TBHB, TBPB, and TBKA and lowest in site TBCB. The two individual samples with the highest Pb concentrations (both 2 ppm) were collected at sites TBHB and TBPB. None of the Tampa Bay sites ranked in the top 20 among the approximately 200 NS&T Program sites sampled for mollusks nationwide in 1986, 1987, and 1988 (NOAA, 1989). During the 4-year sampling period, mean Pb concentrations increased slightly at site TBCB and either remained relatively constant or varied from year to year in no consistent pattern at the other sites. At site TBHB, the mean concentrations observed in 1986 and 1987 were similar and the concentration reported for one sample collected in 1988 was slightly lower than in the previous 2 years. Data from additional years are needed to determine long-term trends.

Table 16. Mean concentrations (in ppm dw ± standard deviation) of Pb in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	0.15±0.06	1.37±0.06	0.51±0.24	0.95±0.15
1987	0.44±0.07	1.47±0.20	0.52±0.26	1.36±0.56
1988	0.31±0.05	0.84, n=1	0.42±0.02	1.81±0.29
1989	0.54±0.07	-	0.48±0.13	1.18±0.25
Mean	0.36±0.16, n=12	1.34±0.41, n=7	0.48±0.16, n=12	1.33±0.44, n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	0.53±0.04	-	-	
1989	0.60±0.12	1.17±0.31	0.76±0.07	
Mean	0.57±0.09 n=6			0.81±0.51, n=55

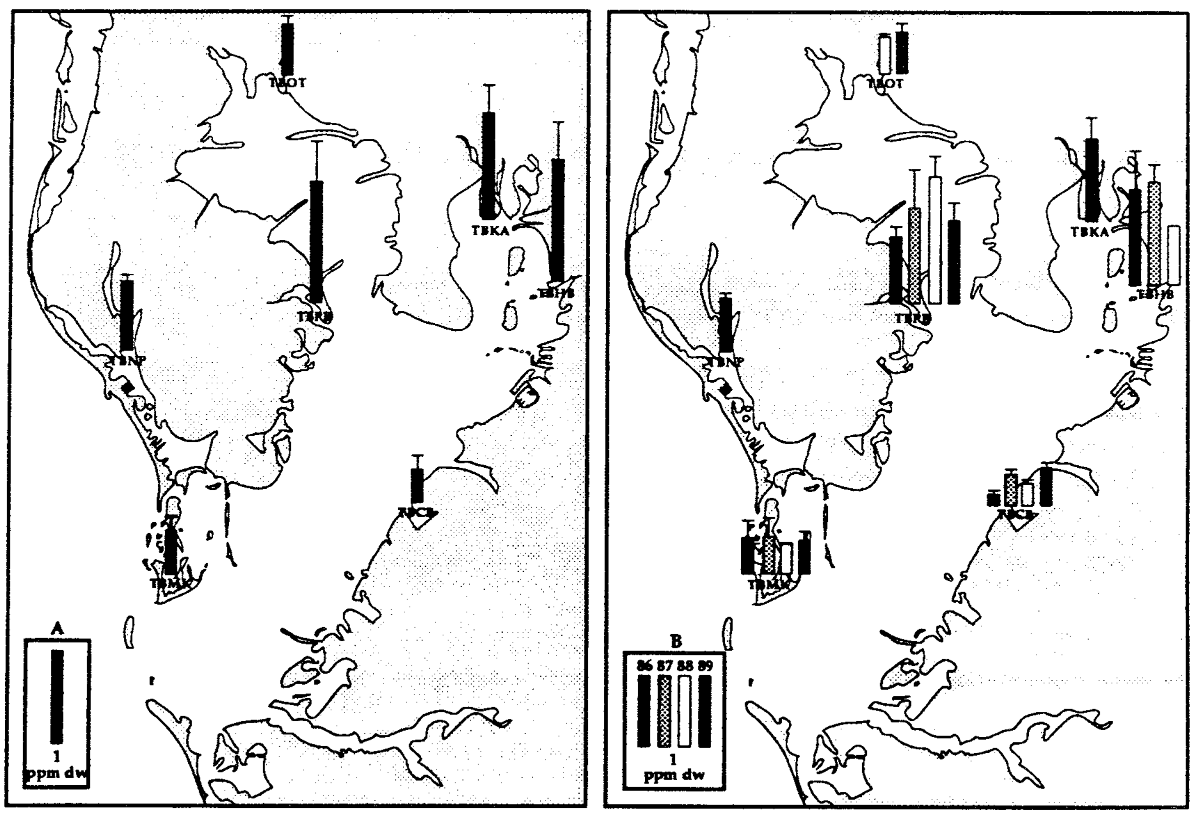

Figure 22. (A) Overall mean and (B) annual mean lead concentrations (ppm dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Heil (1986) analyzed 18 oyster samples from three sites in Tampa Bay collected in 1984, 1986, and 1987; the overall mean Pb concentration was 0.28±0.23 ppm ww (1.90±1.56 dw, assuming 14.76% moisture content), roughly twice the mean concentration observed in the NS&T Program samples. Mean Pb concentrations in oysters from the three sites were: 0.59 ppm dw (Little Cockroach Bay, site 11); 2.48 ppm dw (Mullet Key Bayou, site 12); and 2.68 ppm dw (Manatee River). The detection limits of 0.2 ww (equivalent to 1.36 ppm dw, assuming a moisture content of 14.76%) achieved by Heil (1986) were higher than that used by the NS&T Program, and may have contributed to the higher values. Pan *et al.* (1982) reported a Pb concentration of <0.86 ppm ww (<4.3 ppm dw, assuming a moisure content of 20%) in clams (*P caroliniana*) collected in the Alafia River. The ACOE (1974) reported Pb concentrations of 9, 15, and <7 ppm in three oyster samples from Tampa Bay.

Arsenic. Mean As concentrations in oysters sampled by the NS&T Program are summarized in Table 17 and Figures 23 A and B. The highest mean concentration (34.7 ppm) occurred in oysters sampled in 1989 at site TBNP and the lowest concentrations were in samples from site TBOT. The three individual samples with the highest As concentrations were collected at site TBNP. Among the approximately 200 sites sampled nationwide for mollusks by the NS&T Program during 1986-88, site TBMK tied for twelfth in mean As concentration in 1986 and site TBHB tied for thirteenth in 1988. During the 4 years in which the Tampa Bay samples were collected, mean As concentrations did not change appreciably at any of the sites (Table 17 and Figure 23B). The As concentration in one sample analyzed in 1988 from site TBHB was considerably higher than in the samples collected in the previous 2 years. Additional data are needed to determine long-term trends.

Table 17. Mean concentrations (in ppm dw ± standard deviation) of As in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	4.2±0.3	4.8±0.3	21.3±4.0	6.7±2.1
1987	5.1±0.6	4.0±0	15.5±0.6	6.2±0.4
1988	4.2±1.0	21.9, n=1	12.7±2.1	8.9±1.6
1989	4.7±1.0	-	11.8±1.0	4.6±0.3
Mean	4.6±0.8, n=12	6.9±6.6, n=7	15.4±4.4, n=12	6.6±2.0 n=12
Year	**Site TBOT**	**Site TBKA**	**Site TBNP**	**All Sites**
1986	-	-	-	
1987	-	-	-	
1988	4.7±1.7	-	-	
1989	3.4±0.6	5.0±0.6	34.7±2.8	
Mean	4.0±1.3 n=6			9.3±8.1, n=55

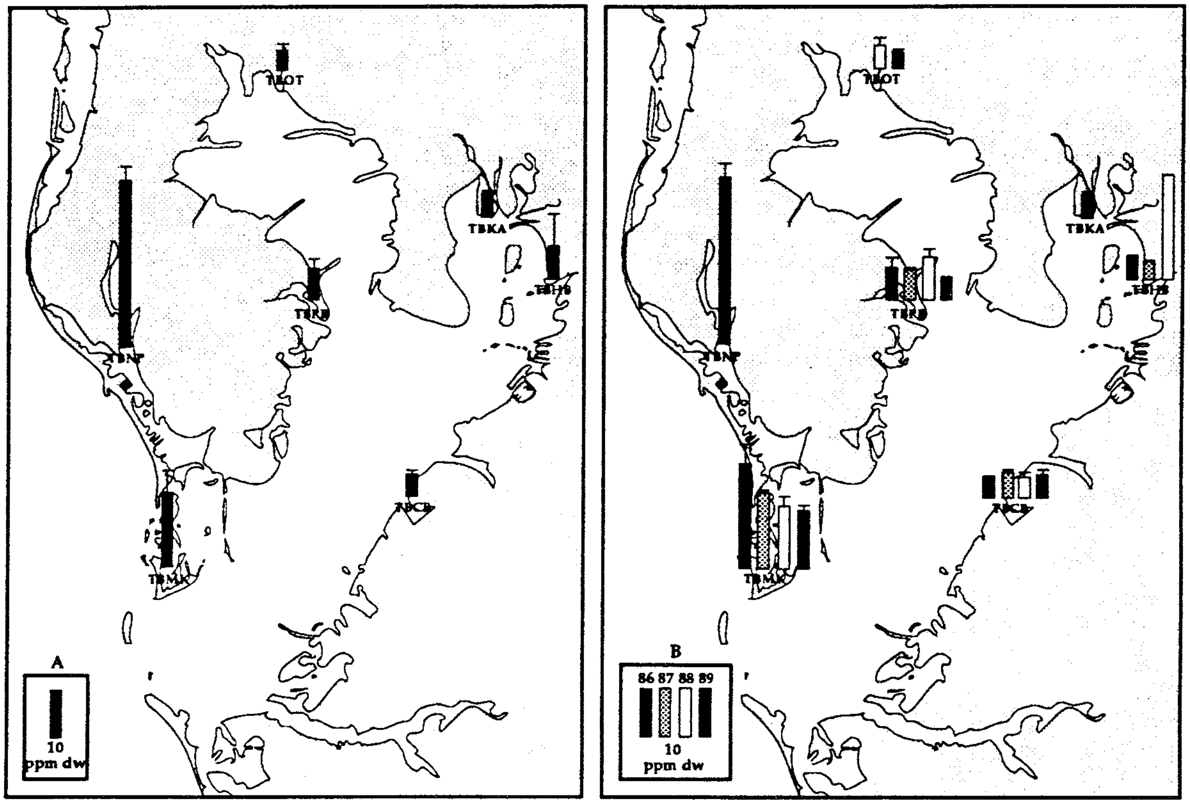

Figure 23. (A) Overall mean and (B) annual mean arsenic concentrations (ppm dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

The ACOE (1974) reported As concentrations in oysters of 1.0, 0.0 and 0.0 ppm. Pan *et al.* (1982) reported an As concentration of 0.31 ppm ww (1.6 ppm dw, assuming a moisture content of 20%) in the clam *P. caroliniana*. Heil (1986) analyzed 18 oyster samples collected at three sites in 1984, 1986, and 1987 and found an overall mean As concentration of 2.68±1.81 ww (18.16 ±12.3 ppm dw, assuming a moisture content of 14.76%), roughly twice the overall mean concentration observed in the NS&T Program samples. The mean concentrations determined at each of the three sites were: 4.67 dw (Little Cockroach Bay, site 11); 24.05 ppm dw (Mullet Key Bayou, site 12); and 6.77 ppm dw (Manatee River), based upon six samples each and assuming a moisture content of 14.76 percent.

Zinc. The overall mean concentration of Zn in 55 oyster samples analyzed by the NS&T Program was 2463.8 ppm dw. Oysters collected at site TBOT had the highest Zn concentrations, followed by those from sites TBKA and TBHB (Table 18; Figures 24 A and B). The individual sample with the highest Zn concentration (8571 ppm) was collected at site TBOT in Double Branch Creek. The lowest concentrations were those in the oysters from site TBMK. Among the approximately 200 sites sampled nationwide for mollusks by the NS&T Program during 1986-88, site TBHB ranked sixteenth in mean Zn concentration in 1986, and site TBOT ranked second in 1988 (NOAA, 1989). During the 4 years that samples were collected, mean Zn concentrations remained relatively constant at sites TBCB, TBMK, and TBPB with no consistent year-to-year changes. At site TBHB, the mean concentration in 1986 was higher than the concentrations observed in 1987 and 1988. Additional data are needed to determine long-term trends.

Table 18. Mean concentrations (in ppm dw ± standard deviation) of Zn in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	1266.7±208.2	3600.0±200.0	650.0±132.3	2600.0±264.6
1987	1545.0±485.9	1923.3±80.8	466.3±34.5	1554.0±12.2
1988	2285.7±704.9	1625, n=1	240.7±37.5	2990.3±584.7
1989	1279.6±61.6		363.1±50.4	2560.4±259.8
Mean	1594.2±573.7 n=12	2599.3±950.2 n=7	430.0±169.3 n=12	2426.2±628.2 n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	8309.0±338.4	-	-	
1989	6673.6±1164.1	4285.7±1118.1	2035.0±412.7	
Mean	7491.3±1179.1 n=6			2463.8±2127.9 n=55

Huggett *et al.* (1975) demonstrated that zinc concentrations in oyster tissues sampled in estuaries generally decreased with increasing salinities. The salinities over which the Zn concentrations varied the greatest were in the 8 to 14 ppt range. Among the seven NS&T Program sites in Tampa Bay, the highest Zn concentrations occurred in sites TBOT and TBKA. Site TBOT is located in lower Double Branch Creek and highly influenced by freshwater discharge; the salinity there in 1988 was 10 ppt. Site TBKA is located within the influence of the lower Hillsborough River and the Hookers Point sewage treatment plant; the salinity there in 1989 was 20 ppt. In contrast, the salinity of site TBMK, where Zn concentrations were the lowest among the seven sites, was 34, 37, and 32 in 1987, 1988, and 1989, respectively. Sites with intermediate Zn concentrations had intermediate salinities (20 to 30 ppt). Salinity data are not available from all of the sites for all the sampling years. However, based upon the data available, there appears to be an inverse relationship between Zn concentrations in oyster tissues and salinity, similar to that observed by Huggett *et al.* (1975)

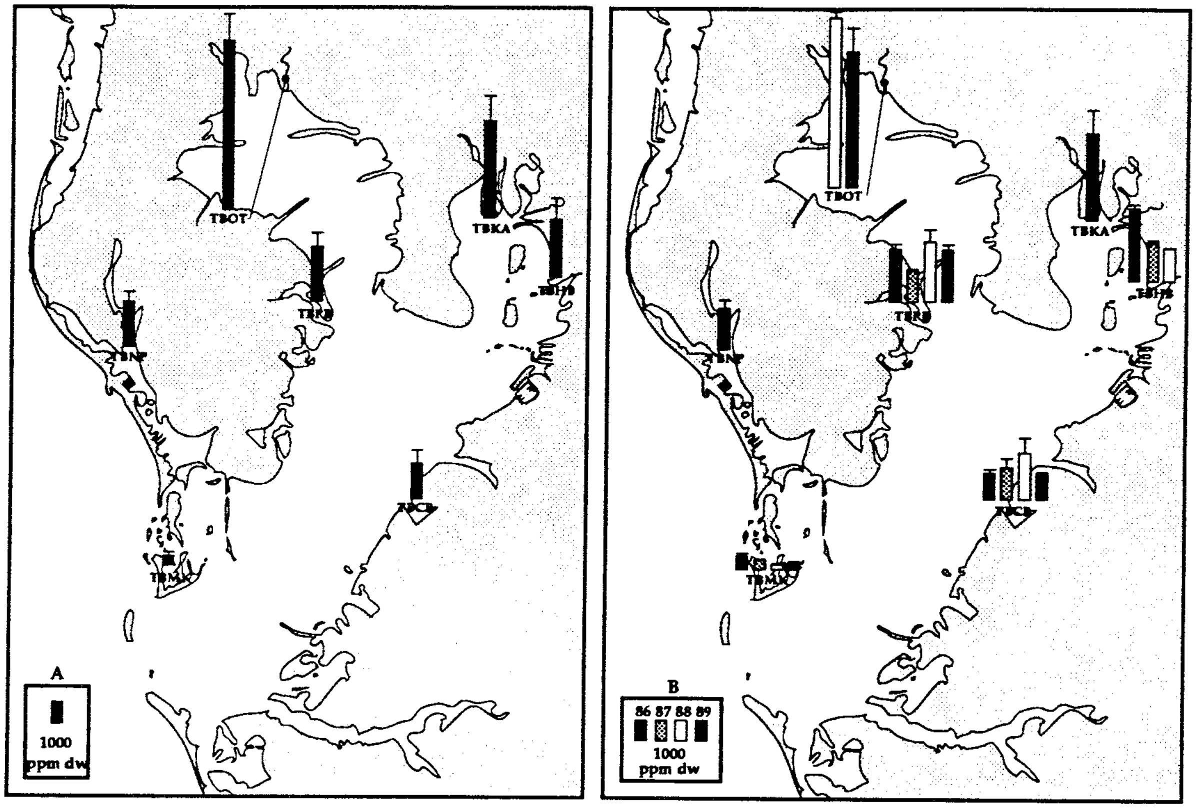

Figure 24. (A) Overall mean and (B) annual mean zinc concentrations (ppm dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

Heil (1986) analyzed 18 oyster samples collected in 1984, 1986, and 1987 from three sites; the overall mean concentration of Zn in the oysters was 79.8±101.6 ppm ww (540.6±688 ppm dw) Mean concentrations determined at each site were: 1184.3 ppm dw (Little Cockroach Bay, site 11); 389.6 ppm dw (Mullet Key Bayou, site 12); 47.8 ppm dw (Manatee River, site 13), based upon six samples from each site, and assuming a moisture content of 14.76%. Pan *et al.* (1982) reported a Zn concentration of 26.9 ppm ww (134.5 ppm dw, assuming a moisture content of 20%) in the clam *P. caroliniana* collected in the Alafia River. The ACOE (1974) reported Zn concentrations of 1600, 3100, and 1900 ppm in three oyster samples collected in the bay. Magley (1978) collected 199 oyster samples from four sites in Tampa Bay and analyzed the tissues for Zn concentrations. The four sites were located in: (1) the mouth of the Alafia River, (2) the effluent channel of Tampa Electric Company's Big Bend power plant near Apollo Beach, (3) Cockroach Bay, and (4) the outfall of a municipal sewage treatment plant off St. Petersburg. The mean Zn concentrations determined on a dry weight basis in 40 to 53 samples per site were 5287.9±2111.9 (site 1), 3957.7±3198.6 ppm (site 2), 2140±1554.5 ppm (site 3), and 13,143.5±5986.8 ppm (site 4). The oysters from the St. Petersburg site had considerably higher Zn concentrations (mean of 13,143 ppm) than those tested by the NS&T Program (overall mean of 2464 ppm for all sites). The individual sample with the highest Zn concentration had 27,350 ppm dw and was collected at the St. Petersburg site.

Copper. The overall mean Cu concentration in oysters was highest at site TBKA among the NS&T Program sites in Tampa Bay (Table 19, Figures 25 A and B). Also, the individual sample with the highest Cu concentration (223.6 ppm) was collected at site TBKA. Copper concentrations in oysters were relatively high at sites TBCB and TBOT; and, they were lowest at site TBMK. None of the Tampa Bay sites ranked among the top 20 in the nation with regard to Cu concentrations (NOAA, 1989). During the 4 years in which samples were collected, no consistent large changes in Cu concentrations occurred at any of the sites (Table 19; Figure 25B).

Table 19. Mean concentrations (in ppm dw ± standard deviation) of Cu in oysters for individual sampling years, the grand mean for each of seven sites sampled by the NS&T Program, and the overall grand mean for all the sites and all the years.

Year	Site TBCB	Site TBHB	Site TBMK	Site TBPB
1986	91.7±7.6	81.7±17.6	43.0±13.1	66.7±12.6
1987	112.7±19.0	54.3±4.7	22.3±0.6	57.0±1.0
1988	138.3±16.3	60, n=1	9.7±3.1	89.7±10.0
1989	102.8±8.1		21.0±9.3	56.3±5.1
Mean	111.4±21.5 n=12	66.9±17.5 n=7	24.0±14.4 n=12	67.4±15.8 n=12

Year	Site TBOT	Site TBKA	Site TBNP	All Sites
1986	-	-	-	
1987	-	-	-	
1988	192.3±3.8	-	-	
1989	112.6±15.7	192.0±48.3	64.4±17.0	
Mean	152.4±44.9 n=6			83.3±52.4 n=55

In addition to the inverse relationship between Zn concentrations and salinity, Huggett *et al.* (1975) recorded a similar relationship for Cu. This relationship appears to pertain to Tampa Bay. Sites TBOT and TBKA had the highest Cu concentrations and salinities of 10 ppt in 1988 and 20 ppt in 1989, respectively. The lowest Cu concentrations occurred in site TBMK (where salinities were 34, 37, and 32 ppt in 1987, 1988, and 1989, respectively) and site TBNP (where the salinity was 31 ppt in 1989). Intermediate Cu concentrations occurred at sites with intermediate salinities (20 to 30 ppt).

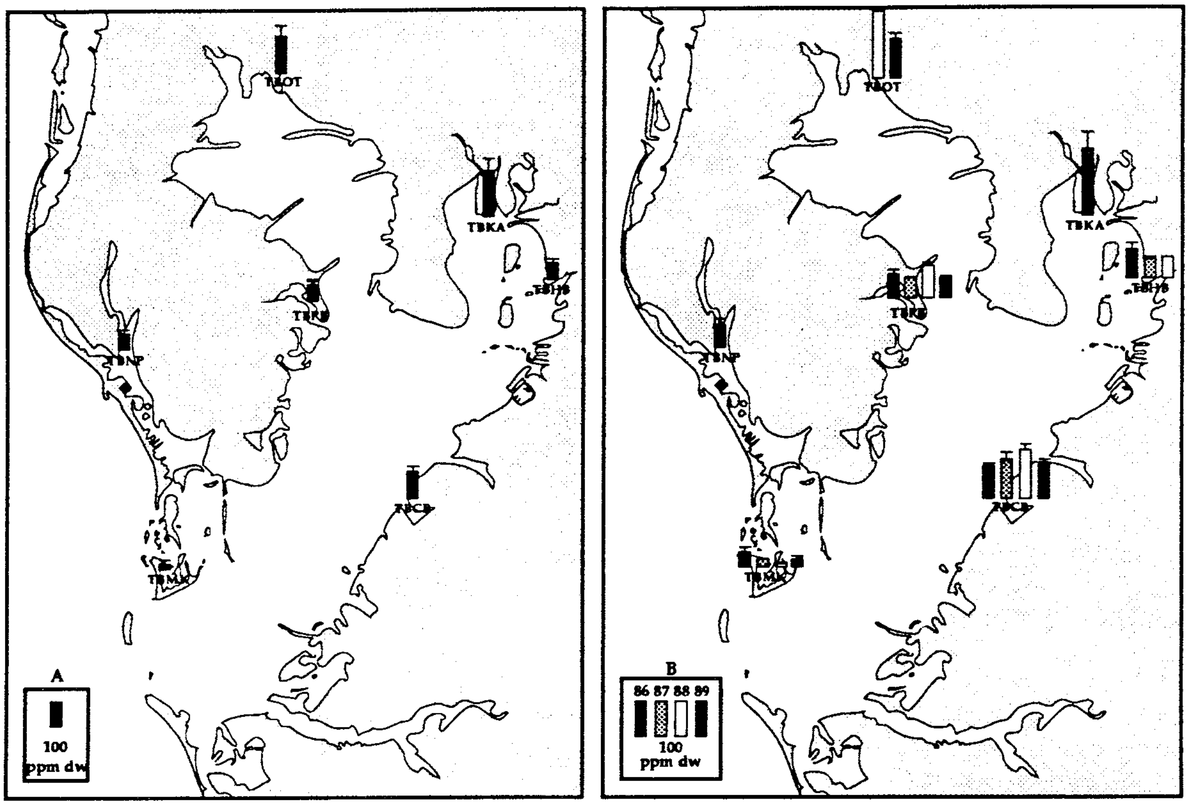

Figure 25 (A) Overall mean and (B) annual mean copper concentrations (ppm dw) in oysters from the Tampa Bay area NS&T Program sites for 1986-89 (bars represent one standard deviation).

The mean Cu concentrations in oysters from the three sites sampled by Heil (1986) were 44.0±18.6 ppm dw (Little Cockroach Bay), 10.2 ±10.2 ppm dw (Mullet Key), and 8.8±5.4 ppm dw (Manatee River); generally lower than the concentrations reported by the NS&T Program. Pan *et al.* (1982) observed a Cu concentration of 1.96 ppm ww (9.8 ppm dw, assuming a moisture content of 20%) in clams (*P. caroliniana*) from their site in the Alafia River. Magley (1978) found mean Cu concentrations in oysters of 181.7±134.4 ppm dw at his Big Bend power plant site; 234.2±109.4 ppm in Cockroach Bay; 1039.4±397.6 ppm off a St. Petersburg sewer outfall; and 171.7±46.5 ppm in the Alafia River (all values converted from wet weight to dry weight, assuming a moisture content of 14.76%).

Relative Ranks of NS&T Program Tampa Bay Sites. The seven NS&T Program sites in Tampa Bay were compared to each other and ranked with regards to the mean concentrations of selected organic compounds and trace elements in oyster tissues. Numerical ranks were assigned to each site for the chemicals or chemical groups discussed above, where one point was awarded for the site with the highest mean concentration for each analyte, two points awarded for the second highest concentration, etc. The individual ranks and the cumulative ranks are listed in Table 20. Based upon these selected data, site TBKA, located on the southern tip of Davis Islands, had the highest degree of overall contamination, mainly as a result of having the highest concentrations of organic compounds. It had the highest mean concentrations of tPCBs, tPAHs, dieldrin, tDDT, and Cu and the second highest concentrations of total chlordane and Zn. Site TBKA ranked first, second, or third for all chemicals but Hg and As. Hg, Zn, and Cu were relatively highly concentrated in site TBOT, where salinity was lowest. It was sampled only once (in

1989); the relative ranks could change with analyses of additional samples. Site TBPB, located in Bayou Grande, ranked second in cumulative degree of contamination; it had high concentrations of dieldrin, mirex, Hg, and Pb. Ranked third was site TBNP, located in Boca Ciega Bay; PCBs, PAH, chlordane, and As were relatively highly concentrated there. Both sites TBKA and TBNP are located near major municipal/ industrial areas (Tampa and St. Petersburg, respectively) and, therefore, are subject to exposure to contaminants from multiple nearby sources. However, site TBPB is surrounded by either mangroves or residential areas. Site TBMK, located south of the I-75 bridge near the mouth of Tampa Bay, was ranked last in cumulative degree of contamination. Site TBCB, located in Cockroach Bay, a rural area surrounded mainly by mangroves and agricultural fields, had relatively low concentrations of most contaminants. However, it had the highest mirex concentration and the second highest tDDT concentration, possibly reflecting the influence of the use of pesticides nearby.

Some of the classes of organic chemicals had similar distribution patterns. Many were most highly concentrated in site TBKA, intermediate in sites TBPB and TBOT, and lowest in sites TBHB and TBMK. In contrast, As was most highly concentrated in sites TBNP, TBMK, and TBHB, intermediate in site TBKA, and lowest in site TBOT. Three of four of the pesticide groups were relatively highly concentrated in site TBCB, where many other organics and most trace metals occurred in relatively low concentrations. These data suggest that some chemicals co-vary with each other and, therefore, may enter the estuary from the same or nearby sources.

Table 20. Individual ranks for each chemical analyte and cumulative ranks for all of the selected analytes, based upon overall mean concentrations at each of the NS&T Program sites sampled in Tampa Bay.

Analyte	TBCB	TBHB	TBMK	TBPB	TBOT	TBKA	TBNP
tPCB	6	3	7	4	5	1	2
tPAH	7	4	5	6	3	1	2
Dieldrin	5	6	4	2	7	1	3
tChlordane	3	7	6	4	5	2	1
tDDT	2	5	7	3	6	1	4
Mirex	1	6	5	2	7	3	4
Hg	3	7	4	2	1	5	6
Pb	7	1	6	2	5	3	4
As	6	3	2	4	7	5	1
Zn	6	3	7	4	1	2	5
Cu	3	5	7	4	2	1	6
Total points	47	50	60	37	49	25	38
Overall ranks	4	6	7	2	5	1	3

Comparisons Between Tampa Bay Sites and Other NS&T Program Sites. To put the data from the Tampa Bay NS&T Program sites in perspective with similar data from other areas along the Gulf Coast, the mean concentrations of selected chemicals in oysters sampled each year at all of the Gulf Coast sites (Brooks *et al.*, 1989) were ranked and compared. A total of about 70 sites have been sampled along the Gulf Coast; about 50 to 60 were sampled each year. In Table 21, the relative ranks for each Tampa Bay site among those sampled each year, based upon the annual mean chemical concentrations, are listed. Sites that had the highest concentrations of a chemical in a particular year were ranked number one. Sites ranking lower than twentieth, an arbitrary threshold previously used in NOAA (1989), were listed as >20. Based upon these data, many of the Tampa Bay sites ranked relatively low for some of the chemicals (e.g., Cu, tDDT, tPCBs, dieldrin, tPAHs). However, there were a number of notable exceptions. The highest concentrations of Hg, Zn, chlordane, and mirex were observed in oysters from the Tampa Bay sites. The oysters from site TBCB had the second highest concentrations of mirex in 3 consecutive years (1986-88) and the highest concentration in 1989. The mirex concentrations in oysters from all of the Tampa Bay sites rarely ranked lower than twentieth.

Table 21. Relative ranks of Tampa Bay sites among approximately 50 Gulf Coast sites for selected chemicals in oysters sampled in 1986, 1987, and 1988 by the NS&T Program.

Chemical				Site			
and Year	TBMK	TBPB	TBOT	TBHB	TBCB	TBKA	TBNP
Arsenic							
1986	4	>20	-	>20	>20	-	-
1987	7	>20	-	>20	>20	-	-
1988	12	>20	>20	3	>20	-	-
1989	11	>20	>20	-	>20	>20	1
Copper							
1986	>20	>20	-	>20	>20	-	-
1987	>20	>20	-	>20	>20	-	-
1988	>20	>20	23	>20	>20	-	-
1989	>20	>20	>20	-	>20	>20	>20
Mercury							
1986	10	1	-	>20	8	-	-
1987	12	5	-	>20	2	-	-
1988	>20	2	1	>20	4	-	-
1989	>20	4	3	-	7	17	>20
Lead							
1986	>20	5	-	2	>20	-	-
1987	>20	5	-	4	>20	-	-
1988	>20	3	>20	10	>20	-	-
1989	>20	2	>20	-	>20	3	9
Zinc							
1986	>20	10	-	6	>20	-	-
1987	>20	>20	-	>20	>20	-	-
1988	>20	20	1	>20	>20	-	-
1989	>20	>20	1	-	>20	11	>20
Total PCBs							
1986	>20	8	-	6	>20	-	-
1987	>20	10	-	15	19	-	-
1988	>20	>20	>20	>20	>20	-	-
1989	>20	>20	>20	-	>20	3	13

Table 21. Continued.

Chemical and Year	TBMK	TBPB	TBOT	Site TBHB	TBCB	TBKA	TBNP
Total DDT							
1986	>20	>20	-	>20	9	-	-
1987	>20	6	-	>20	10	-	-
1988	>20	21	>20	>20	>20	-	-
1989	>20	>20	>20	-	11	8	>20
Dieldrin							
1986	>20	16	-	>20	>20	-	-
1987	>20	13	-	>20	>20	-	-
1988	>20	>20	>20	>20	>20	-	-
1989	20	9	>20	-	>20	11	16
Mirex							
1986	10	1	-	9	2	-	-
1987	5	3	-	12	2	-	-
1988	9	3	>20	>20	2	-	-
1989	15	3	17	-	1	6	7
alpha Chlordane							
1986	11	7	-	13	5	-	-
1987	19	4	-	16	8	-	-
1988	>20	8	12	-	3	-	-
1989	20	9	13	-	5	2	3
Total PAHs							
1986	10	>20	-	11	>20	-	-
1987	>20	>20	-	>20	>20	-	-
1988	>20	>20	>20	>20	>20	-	-
1989	>20	17	>20	-	>20	12	14

Among the 62 sites sampled in 1989, site TBNP oysters had the highest mean As concentration and the third highest mean alpha chlordane concentration. Also, in 1989 site TBKA had the third highest mean concentrations of Pb and tPCBs and the second highest concentration of alpha chlordane.

The concentrations of selected contaminants in the Tampa Bay NS&T Program sites and those determined for other sites along the Gulf Coast of Florida near Tampa Bay were compared by evaluating the data listed in NOAA (1989). The overall mean concentrations were determined for selected chemicals, and the overall site ranks were determined and compared based upon these means (Table 22). Four sites chosen for the comparison outside Tampa Bay were those presumed to represent relatively rural and uncontaminated conditions: Site CBBI in lower Charlotte Harbor, site CKBP at Cedar Key, site EVFU off the Everglades, and site RBHC in Rookery Bay. Based upon the overall ranks from the analyses of five organic chemical classes and eight trace metals, the oysters from site TBKA ranked the highest in cumulative degree of contamination. The concentrations of four of the six organic classes and two of the eight metals were the highest at this site. Site TBPB ranked second highest in the overall index. Sites TBNP and TBOT in Tampa Bay ranked fourth and fifth, respectively, following site CBBI in lower Charlotte Harbor. Site CKBP at Cedar Key, site EVFU off the Everglades, and site TBMK in Lower Tampa Bay had the lowest overall degree of contamination. This analysis (based upon selected data) suggests that some of the Tampa Bay sites located nearest anthropogenic sources of contaminants had chemical concentrations elevated above the levels measured at other nearby sites outside Tampa Bay. In addition, sites in areas relatively removed from anthropogenic sources

Table 22. Overall mean concentrations of selected chemicals in oysters at selected NS&T Program sites in and near Tampa Bay and site ranks based upon the mean concentrations.

				Site	Code	Names					
Chemical	EVFU	RBHC	CBBI	CKBP	TBCB	TBHB	TBMK	TBPB	TBOT	TBKA	TBNP
				Mean Concentrations							
Total PCB(ppb)	44	44	95	79	102	186	54	141	145	588	247
Total DDT(ppb)	9.6	9.3	29	27	83	34	24	54	32	157	43
Total chlordane(ppb)	10	8.9	15	16	88	17	23	75	31	113	117
Dieldrin(ppb)	2.8	1.2	3	2.8	2.4	2.3	2.9	7.1	2.1	8.2	7
Total PAH(ppb)	413	370	525	711	132	406	308	254	639	989	758
Mirex(ppb)	0.25	0.13	0.46	0.68	12	1.4	2.1	7.4	1	4.2	3.6
As(ppm)	8	28	35	18	4.6	6.9	15.4	6.6	4	5	34.7
Cd(ppm)	2.4	2	4	2.4	2.6	2.6	1.8	2.5	5.1	2	1.3
Cr(ppm)	0.74	1.7	0.85	0.49	0.64	0.69	0.59	0.71	0.34	0.57	0.34
Cu(ppm)	44	120	120	23	110	67	25	71	190	192	64
Pb(ppm)	0.2	0.33	0.34	0.27	0.36	1.34	0.48	1.33	0.57	1.17	0.76
Hg(ppm)	0.2	0.23	0.3	0.14	0.28	0.09	0.17	0.38	0.58	0.16	0.12
Ag(ppm)	0.95	2.1	2.5	0.51	1	1.3	0.4	2.1	1.3	2.7	1.3
Zn(ppm)	990	1100	1500	730	1594	2599	430	2426	7491	4286	2035
				Site Ranks							
Total PCB	10	10	7	8	6	3	9	5	4	1	2
Total DDT	10	11	7	8	2	5	9	3	6	1	4
Total chlordane	10	11	9	8	3	7	6	4	5	2	1
Dieldrin	6	11	4	6	8	9	5	2	10	1	3
Total PAH	6	8	5	3	11	7	9	10	4	1	2
Mirex	10	11	9	8	1	6	5	2	7	3	4
As	6	3	1	4	10	7	5	8	11	9	2
Cd	6	8	2	6	3	3	10	5	1	8	11
Cr	3	1	2	9	6	5	7	4	10	8	10
Cu	9	3	3	11	5	7	10	6	2	1	7
Pb	11	9	8	10	7	1	6	2	5	3	4
Hg	6	5	3	9	4	11	7	2	1	8	10
Ag	9	3	2	10	8	6	11	3	6	1	6
Zn	9	8	7	10	6	3	11	4	1	2	5
Sum of Ranks	111	102	69	110	80	80	110	60	73	49	71
Overall Rank	11	8	3	9	6	6	9	2	5	1	4

(e.g., TBMK and TBCB) had relatively low levels of toxicants, often below those concentrations observed in other nearby areas along the Gulf Coast. Site TBMK appeared to have consistently low levels of contaminants in oysters, and, therefore, may serve as a very good reference site.

As discussed earlier, some of the differences in trace metal concentrations among sites may be due in part , to differences in salinity. However, this paradigm may not apply to all sites. For example, 14 ppt salinity was measured at site CKBP, but trace metals concentrations there were very low compared to other sites such as sites RBHC and CBBI where the salinity was 34 ppt.

Relative to other sites in Tampa Bay, site TBMK appeared to rank lowest in overall degree of contamination in oysters. Relative to other selected locations along the Gulf Coast, it remains relatively low in chemical concentrations.

Summary. Compared with the amount of data available for evaluation in San Francisco Bay (Long *et al.*, 1988), southern California (Mearns *et al.*, unpublished), and Boston Harbor (MacDonald, 1991); there is a small amount available for Tampa Bay. Most of the data for Tampa Bay pertaining to toxicants in bivalve tissues have been acquired by the NS&T Program.

Because the amount of data available for each subdivision of the bay is small, it is not possible to develop many general conclusions regarding large-scale toxicant distributions in bivalves within the bay. However, based upon the data available, it appears that toxicant concentrations generally diminish from the head of Tampa Bay toward the mouth of the bay. For example, site TBKA, located in upper Hillsborough Bay, had the highest overall degree of contamination among the NS&T Program sites in the bay and site TBMK, located below the I-75 bridge, had the lowest contaminant levels. Also, site TBNP, located in Boca Ciega Bay near the St. Petersburg municipal/industrial area, had relatively high levels of some toxicants. Data published by Magley (1978) indicated that very high concentrations of selected trace metals occurred near the outfall of a municipal sewage treatment plant. His data also suggested that intermediate concentrations of trace metals occurred in the mouth of the Alafia River and low levels occurred in Cockroach Bay. The NS&T Program data generally confirmed both of the latter observations. Data presented by Doyle *et al.* (1985) suggest that relatively high levels of petroleum hydrocarbons occurred in oysters collected in Hillsborough Bay, Boca Ciega Bay, the lower Manatee River, and Old Tampa Bay relative to other subdivisions; but, the concentration observed in one sample from Lower Tampa Bay was not among the lowest observed. Also, surprisingly, one sample from Anna Maria Sound had a very high concentration of hydrocarbons.

The concentrations of some toxicants (i.e., mirex, chlordane, Hg, and Zn) in oysters collected in Tampa Bay were relatively high as compared with those in oysters from the other Gulf Coast Florida sites. Site TBKA ranked highest in overall contamination among the NS&T Program sites within the Tampa Bay system and located nearby in other Flordia bays. The organic compounds generally were elevated above background or reference levels more than the trace metals. The pesticide mirex was particularly highly concentrated in oysters collected in Cockroach Bay, compared to the concentrations in oysters collected outside Tampa Bay. On the other hand, the concentrations of some chemicals (e.g., As, Cu, Cr, tPAHs, tPCBs, tDDT) generally were higher at sites located outside of Tampa Bay than at sites within the bay. Also, sites TBMK and TBCB had among the lowest concentrations of most chemicals.

Compared to the other sites sampled nationwide by the NS&T Program, oysters from Tampa Bay had relatively high concentrations of chlordane, mirex, Hg, and Zn. Oysters were sampled at some sites around the nation, while mussels were sampled at other locations.

During the 4 years that measurements have been made at NS&T Program sites, the concentrations of some toxicants have changed while others have remained stable or shown no consistent pattern in changing concentrations Because of the short time series of data available thus far, it is premature to attempt to identify long-term temporal trends in chemical concentrations. However, a few patterns should be examined as additional data from subsequent years become available. The concentrations of a number of organic compounds and metals have increased over the years at site TBCB. Conversely, a number of toxicants have decreased in concentration during the 3 years of monitoring at site TBHB and over the four years at site TBMK. Most chemical concentrations remained similar from year to year at site TBPB.

Data acquired by FDNR (Heil, 1986) indicate that the concentrations of some chemicals have varied between years at all three sites that have been monitored, but no unidirectional trends have been observed thus far. The DDT data published by Butler (1973) indicated no patterns of changing concentrations during the period that samples were collected (1966-69), but the concentrations he reported for the late 1960s were considerably higher than those reported for other sites by the NS&T Program for the late 1980's. No other data from bivalve tissues are available to determine temporal trends in toxicant concentrations.

The data available from the NS&T Program and Heil (1986) should not be construed as representing long-term trends. They were developed over only a three or four year period. Data from additional years are needed to verify or determine long term trends in concentrations of the chemical analytes.

ESTIMATES OF THE POTENTIAL FOR BIOLOGICAL EFFECTS

Sediments.

Approach. The concentrations of toxicants in sediments usually associated with toxicity or with altered benthic communities were identified by Long and Morgan (1990) for use as guidelines in the NS&T Program. These guidelines were based upon a preponderance of evidence assembled from many different approaches and geographic areas. Data from three basic approaches were used to develop the guidelines: (1) the equilibrium partitioning approach; (2) the spiked-sediment bioassay approach; and (3) various approaches to the use of matching chemistry/biology data collected in the field. The field-collected data were gathered by different investigators in many different geographic areas. Two guidelines were developed by Long and Morgan (1990) for each analyte: effects range-low (ERL) values, the concentrations at which effects begin, and effects range-median (ERM), the concentrations at which effects usually occurred. The chemical concentrations determined in many studies performed in each subdivision of the bay were compared to these guidelines to determine the potential for sediment-associated effects. The potential for effects was assumed to be relatively high in those subdivisions in which the most chemicals either equalled or exceeded the guidelines by the greatest degree. The number of samples tested in the Tampa Bay studies for each analyte was compared with the number of samples in which the guidelines were exceeded.

There are several potential weaknesses in using this approach. First, none of the data assembled by Long and Morgan (1990) were derived from studies performed in Tampa Bay or other nearshore eastern Gulf of Mexico areas dominated by quartz sand sediments. Therefore, it is uncertain whether the guidelines developed by Long and Morgan (1990) are applicable to Tampa Bay. Second, the data evaluated by Long and Morgan (1990) and available from Tampa Bay were not normalized to factors that may strongly influence bioavailability. Therefore, the estimates of potential effects may exaggerate or underestimate reality. Also, most of the data assembled by Long and Morgan (1990) did not address subtle or chronic toxicity end-points that may be associated with exposure to toxicants, and, therefore their guidelines may underestimate toxicity thresholds. Nevertheless, in the absence of other effects-based guidelines, the values derived by Long and Morgan (1990) were used.

Analysis by Individual Study. Trefry *et al.* (1989) analyzed 36 surficial sediment samples and 117 subsurface samples from stations in the lower Hillsborough River for Cu, Pb, and Hg. Of the 36 surface samples for Cu, 22 exceeded the ERL (70 ppm) and none exceeded the ERM (390 ppm). Out of the 36 samples, 35 exceeded the ERL (35 ppm) and 31 exceeded the ERM (110 ppm) for Pb. Out of 32 samples analyzed for Hg, 25 exceeded the ERL (0.15 ppm) and none exceeded the ERM (1 ppm). Out of the 117 subsurface samples analyzed, 86 exceeded the ERL and 1 exceeded the ERM for Cu, while 112 exceeded the ERL and 111 exceeded the ERM for Pb. Out of 52 subsurface samples analyzed, 38 exceeded the ERL for Hg and none exceeded the ERM for Hg. From these data, it appears that Pb could be a toxicological problem in the lower Hillsborough River. A maximum concentration of 1424 ppm Pb was observed in one of the samples, a concentration that exceeded the ERM by a factor of 13.

Six sediment core samples were collected in the Port Sutton Channel (ACOE, 1985). The concentrations of As, Cd, Cr, Cu, Pb, Ni, Ag, and Zn did not exceed the repective ERM values. One of the samples exceeded the ERM for Hg (1 ppm) and all of the samples exceeded the ERL concentration for Hg (0.15 ppm). Three out of the six samples exceeded the respective ERL values for Cr, Pb, and Zn; none of the samples exceeded the ERL concentrations for the other trace metals.

Near Bradenton, 19 core samples were collected in the lower Manatee River (Wade-Trim, Inc., 1988) and analyzed for As, Cd, Cr, Cu, Pb, Hg, and Zn. The respective ERL and ERM concentrations for As, Cd, and Cu were not exceeded in any of the samples. The Hg concentration in one sample and the Zn concentration in two samples exceeded the respective ERM values. Out of the 19 samples, 7 exceeded the ERL concentration for Pb. The maximum Zn concentration was 540 ppm, which exceeded the ERM value by a factor of 2.

Van Vleet and Reinhardt (1983) analyzed ten samples for total extractable hydrocarbon content. Five samples were collected in Middle Tampa Bay, two in Hillsborough Bay, two in Lower Tampa Bay, and one in Old Tampa Bay. Out of these ten samples, the hydrocarbon content of only the two from Hillsborough Bay exceeded the ERL for tPAHs (4 ppm). Neither of these samples exceeded the ERM for tPAHs (35 ppm).

The ACOE (1974) analyzed three samples from the Gulf of Mexico, five from Lower Tampa Bay, nine from Middle Tampa Bay, and two from Hillsborough Bay for trace metals. One sample from Hillsborough Bay exceeded the ERM for Pb; no other ERM concentrations were exceeeded. The ERL value for Hg was exceeded in the majority of the samples from all subdivisions. Otherwise, most of the ERL values were not exceeded in the majority of the samples.

The ACOE (1979) also analyzed five samples each from locations near Wolf Creek, Gadsden Point, and Bullfrog Creek for trace metals (As, Cd, Cr, Cu, Pb, Hg, Ni, and Zn). None of the metals exceeded any of the ERL and ERM values.

Doyle *et al.* (1985) collected 106 sediment samples throughout the Tampa Bay system and analyzed them for hydrocarbons. They reported concentrations of the f1 fraction, the f2 fraction, and the total concentrations of both fractions. Samples were collected in Old Tampa Bay (15), Hillsborough Bay (25), lower Hillsborough River (4), Middle Tampa Bay (21), Lower Tampa Bay (13), Boca Ciega Bay (4), Tiera Ciea Bay (3), Manatee River (8), and Anna Maria Sound (2). The data from the quantification of the f2 fraction were compared with the ERL and ERM concentrations (4 and 35 ppm, respectively) for tPAHs. ERL and ERM values were based upon data from studies in which different hydrocarbons were quantified and, in some cases, in which total hydrocarbons were quantified. Therefore, those data are not exactly comparable with those data from studies performed in Tampa Bay. In Old Tampa Bay, 1 out of 15 samples exceeded the ERM value, a sample taken in Culbreath Bayou. In Hillsborough Bay, 4 out of 15 samples exceeded the ERM value; they were collected near Davis Islands, in East Bay, off Ballast Point, and in the Alafia River. The sediment from station 16 in East Bay had an f2 fraction concentration of 198.7 ppm, over fivefold higher than the ERM for tPAHs. Sediments from two stations in Middle Tampa Bay, one in the Manatee River and one in Bayboro Harbor, exceeded the ERM value. The Manatee River station had the highest f2 fraction concentration (222 ppm) of all of the 106 samples, exceeding the ERM for tPAHs by more than 6. Of the 15 samples taken in Boca Ciega Bay, 2 exceeded the ERM value for tPAHs; both collected in marinas. None of the samples collected in lower Hillsborough River, Lower Tampa Bay, Tiera Ceia Bay, lower Manatee River, or Anna Maria Sound exceeded the ERM concentration for tPAHs.

Brown *et al.* (1985) quantified total aromatic hydrocarbons (f2 fraction) in 12 samples taken in the lower Hillsborough River and upper Hillsborough Bay. The concentration of aromatic hydrocarbons exceeded the ERL value for tPAHs (4 ppm) in all samples. One of the three samples from the upper Hillsborough Bay exceeded the ERM value (35 ppm), whereas, 6 out of 9 samples from the lower Hillsborough River exceeded the ERM value.

The USGS (unpublished data) sampled five locations in lower Allen Creek and eastern Old Tampa Bay and analyzed the sediments for aromatic hydrocarbons, PCBs, and pesticides. Most of the analytes did not exceed the respective ERL and ERM values. One sample at the mouth of Allen Creek exceeded the ERM value for chlordane (6 ppb), the only ERM value that was exceeded. The ERL concentrations for anthracene, pyrene, dibenzo (a,h)anthracene, and dieldrin were exceeded at one station each, either at the mouth of Allen Creek or in Old Tampa Bay. In addition, four of the five samples exceeded the ERL value for chlordane (0.5 ppb).

Savannah Laboratories and Environmental Services, Inc. (1986a; 1988) collected 18 samples in upper Hillsborough Bay and analyzed them for trace metals. An ERM value was exceeded in only one of the samples; the ERM value of 270 ppm for Zn was exceeded in a sample from the East Bay region. Out of the 18 samples, 16 exceeded the ERL value (35 ppm) for Pb and 9 exceeded the ERL value (120 ppm) for Zn.

Savannah Laboratories and Environmental Services, Inc. (1986b) also analyzed six samples from Middle Tampa Bay for trace metals, PCBs, and pesticides. None of the analytes exceeded their respective ERM values. Out of the six samples, three exceeded the ERL values for both Pb (35 ppm) and Ni (30) and two of exceeded the ERL value for Cr (80 ppm).

NOAA (1988) sampled sediments in Middle Tampa Bay, Boca Ciega Bay, Old Tampa Bay, and Hillsborough Bay and analyzed them for trace metals, PCBs, pesticides, and aromatic hydrocarbons. None of the analytes exceeded the ERM values in any of the samples. In the samples from Middle Tampa Bay, the only ERL values that were exceeded were those for Pb, Hg, dieldrin, and benzo(a)anthracene (in 1 sample each out of 18). Concentrations of Pb in the Hillsborough Bay sediments exceeded the ERL value in five of the six samples. At least one of the six samples from Hillsborough Bay exceeded the respective ERL values for Cr, Pb, Hg, Zn, dieldrin, DDT, DDD, DDE, and pyrene. Five samples out of six from Boca Ciega Bay exceeded the ERL value for dieldrin and one sample exceeded the ERL value for benzo(a)anthracene. In three samples from Double Branch Creek in Old Tampa Bay, two of them exceeded the dieldrin ERL value.

FDER (unpublished) analyzed three samples each from numerous stations in Tampa Bay, mostly in Hillsborough Bay, for trace metals. Out of 246 samples from Hillsborough Bay, the ERM values were exceeded in 29 samples for Hg, 16 samples for Pb, 13 samples for Cr, 8 samples for Zn, and 2 samples each for Cd and Ni. None of the samples exceeded the ERM values for Cu, Ag, or As. A sample taken near Ballast Point had a Pb concentration of 2800 ppm, which exceeded the ERM value for Pb by 25. Two samples collected in the same area had Cd concentrations of 89 and 96 ppm, respectively, which exceeded the ERM value for Cd (9 ppm) by about ten. None of the six samples from lower Old Tampa Bay exceeded any of the ERM values, but all six exceeded the ERL value for Hg. Of the 63 samples from Middle Tampa Bay, 6 exceeded the ERM value for Cr and 2 exceeded the ERM value for Hg. None of the 27 samples taken in Lower Tampa Bay exceeded any ERM values, but 11 of the 27 exceeded or equalled the ERL value for Hg. None of the nine samples from Terra Ceia Bay exceeded any ERL or ERM values.

Driggers Engineering Services, Inc. (1986) analyzed two vertical sections each of two cores collected in the East Bay area of Hillsborough Bay for PCB and trace metals. The ERL value for Pb was exceeded in two of the four samples and the ERL and ERM values for Zn were exceeded in one of the samples.

Exceedances of ERL Values Among Merged Data. Table 23 summarizes the ratios of the samples tested from each subidivision of the bay to the number of samples that equalled or exceeded the respective ERL values for each chemical analyte. Chemical concentrations equal to or above the ERL values have been associated with toxic effects in sediments in some studies (Long and Morgan, 1990); sediments with chemicals that equal or exceed the ERL values may cause some types of subtle or sublethal effects or effects among very sensitive species and/or life stages.

The data from the Tampa Bay studies discussed above were merged and the ambient concentrations published in those studies were compared with the respective ERL values. These data suggest a strong geographic pattern in contamination of sediments (Table 23). A higher proportion of the samples collected in the lower Hillsborough River and Hillsborough Bay equalled or exceeded the ERL values for many of the analytes than the samples collected in other subdivisions of the bay. Specifically, a relatively high proportion of the samples from these two adjacent areas had elevated levels of Pb, Hg, and tPAHs. A total of 147 samples out of 153 from the lower Hillsborough River that were tested had Pb concentrations that equalled or exceeded the ERL value (35 ppm). The proportion of the samples that had elevated contaminant concentrations was much smaller in Lower Tampa Bay and was intermediate in Middle Tampa Bay and the lower Manatee River. None of the nine samples from Terra Ceia Bay and none of the three samples from Boca Ciega Bay equalled or exceeded any of the ERL values for trace metals. Mercury was relatively highly concentrated in 6 of the 9 samples tested from Old Tampa Bay and 14 of 32 samples from Lower Tampa Bay.

Relatively high proportions of samples tested for mercury exceeded the ERL concentration in five subdivisions of the estuary. Lead and tPAHs also were relatively highly concentrated in many of the samples. Both Pb and tPAHs are probably indicative of inputs from stormwater runoff, as would be expected in the Hillsborough River/Hillsborough Bay area. Among the chemicals that appeared to be least elevated were As, Cd, Ni, and Ag. Only 21 samples have been tested for antimony (Sb), and none exceeded the ERL concentration (2 ppm). None of the 24 samples tested for PCB exceeded the ERL value (50 ppb) for tPCBs.

Table 23. Ratio of the number of samples that equalled or exceeded an ERL value to the total number of samples tested for each subdivision and each chemical analyte, based upon data merged from many different studies performed in Tampa Bay.

	Subdivision								
	0	1	2	3	4	5	6	7	8
Sb	-	-	0/6	0/15	-	-	-	-	-
As	-	0/9	21/280	0/96	0/32	0/3	0/9	0/19	0/3
Cd	-	0/9	2/284	1/96	0/32	0/3	0/9	0/19	1/3
Cr	-	3/9	51/280	12/96	0/32	0/3	0/9	1/19	0/3
Cu	108/153	0/9	10/276	5/96	0/32	0/3	0/9	0/19	0/3
Pb	147/153	0/9	68/284	13/96	2/32	0/3	0/9	7/19	1/3
Hg	57/84	6/9	100/272	33/96	14/32	0/3	0/9	4/19	2/3
Ni	-	0/9	7/260	4/93	0/32	0/3	0/9	-	1/3
Ag	-	0/9	3/258	12/87	0/27	0/3	0/9	-	0/3
Zn	-	1/9	56/284	4/93	0/32	0/3	0/9	4/19	0/3
tPAH	10/13	7/16	17/30	10/26	3/15	9/15	1/3	4/8	-
Chlordane	4/5	-	0/6	-	-	-	-	-	
pp,DDT	0/8	1/3	0/15	-	0/3	-	-	-	
Dieldrin	3/8	1/3	5/24	-	2/3	-	-	-	
tPCB	0/5	0/4	0/15	-		-			

Subdivision 0, lower Hillsborough River; 1, Old Tampa Bay; 2, Hillsborough Bay; 3, Middle Tampa Bay; 4, Lower Tampa Bay; 5, Boca Ciega Bay; 6, Terra Ceia Bay; 7, lower Manatee River; and 8, the Gulf of Mexico.

Exceedances of ERM Values Among Merged Data. Table 24 summarizes the ratio of the samples tested versus the number that equalled or exceeded the respective ERM values for each subdivision and each chemical analyte. Chemical concentrations equal to or in excess of ERM values often have been associated with toxic effects in many studies (Long and Morgan, 1990). Generally, for most chemicals, a very small proportion of the samples tested equalled or exceeded any of the ERM values, suggesting that toxic effects are unlikely. Either none or very few of the samples equalled or exceeded ERM values for Sb, As, Cd, Cu, Ni, Ag, chlordane, pp'-DDT, and tPCBs. A relatively high proportion of the samples from the lower Hillsborough River and Hillsborough Bay equalled or exceeded the ERM value for Pb; 13 of the 96 samples from Middle Tampa Bay also equalled or exceeded the ERM concentration for Pb. In some of the Hillsborough Bay samples, Hg and Zn were relatively highly concentrated. In the lower Hillsborough River, Hillsborough Bay, and other scattered locations, concentrations of tPAH were elevated.

Given that a relatively high proportion of samples tested in the lower Hillsborough River and upper Hillosborough Bay equalled or exceeded the ERM values for one or more chemicals, the likelihood is highest that parts of these subdivisions would be toxic. The potential for toxicity is lower in Middle Tampa Bay and the lower Manatee River and lowest in Old Tampa Bay and the remaining subdivisions lower in the estuary. None of the samples from both Lower Tampa Bay and the Gulf of Mexico equalled or exceeded any ERM values, suggesting that toxicity is least likely in those areas.

Table 24. Ratios of the numbers of samples that equalled or exceeded an ERM value to the total numbers of samples tested for each subdivision and each chemical analyte, based upon data merged from many different studies performed in Tampa Bay.

	Subdivision								
	0	1	2	3	4	5	6	7	8
Sb	-	-	-	0/15	-	-	-	-	-
As	-	0/9	0/280	0/96	0/32	0/3	0/9	0/19	0/3
Cd	-	0/9	2/284	0/96	0/32	0/3	0/9	0/19	0/3
Cr	-	0/9	13/280	6/96	0/32	0/3	0/9	0/19	0/3
Cu	1/153	0/9	0/276	0/96	0/32	0/3	0/9	0/19	0/3
Pb	142/153	0/9	17/284	13/96	0/32	0/3	0/9	0/19	0/3
Hg	0/84	0/9	33/272	2/96	0/32	0/3	0/9	1/19	0/3
Ni	-	0/9	2/260	0/93	0/32	0/3	0/9	-	0/3
Ag	-	0/9	0/258	0/87	0/27	0/3	0/9	-	-
Zn	-	0/9	10/284	0/93	0/32	0/3	0/9	2/19	0/3
tPAH	6/13	1/16	5/30	2/26	0/15	2/15	1/3	0/8	-
Chlordane	1/5	-	0/6	-	-	-	-	-	
pp'-DDT	0/8	0/3	0/15	-	-	-	-	-	
Dieldrin	0/8	0/3	5/24	-	0/3	-	-	-	
tPCB	-	0/5	0/4	0/15	-	-	-		- -

Subdivision 0, lower Hillsborough River; 1, Old Tampa Bay; 2, Hillsborough Bay; 3, Middle Tampa Bay; 4, Lower Tampa Bay; 5, Boca Ciega Bay; 6, Terra Ceia Bay; 7, lower Manatee River; and 8, the Gulf of Mexico.

Summary. There are no effects-based standards for Florida or the Southeastern United States with which to assess the biological significance of chemical contaminants in sediments. Lacking these standards, the informal guidelines developed for the NS&T Program were used to evaluate the available Tampa Bay data to determine the relative potential for effects. None of the data used to develop these informal guidelines were collected in Tampa Bay or Florida, and, therefore, their applicability to Tampa Bay is unknown.

Generally, the maximum trace metal concentrations identified in the aluminum-to-metal ratios developed by Schropp *et al.* (1990) approximated the respective ERL values or occurred within the ERL/ERM range (Long and Morgan, 1990), but at the low end of the effects range. For example, the ERL and ERM values for Cd were 5.0 and 9.0 ppm, respectively, and the maximum Cd concentrations reported in the Cd-to-Al ratios were about 1 ppm. The ERL and ERM for Cu were 70 and 90 ppm, respectively, and the maximum Cu concentrations reported in the Cu-to-Al ratios were about 80 ppm. This relationship between the aluminum-to-trace metal ratios and the effects ranges was expected since the data used by Schropp *et al.* (1990) were collected in relatively uncontaminated areas where toxic effects would not be expected. In contrast, the data reviewed by Long and Morgan (1990) invariably included samples sufficiently contaminated to cause toxic responses.

Sampling sites with trace metal concentrations that exceed both the aluminum-to-trace metal ratios and the effects range values are doubly significant: (1) these sediments have toxicant concentrations that are elevated due to anthropogenic inputs; and (2) the sediments have a potential for being toxic. Some sediments in Tampa Bay have had metal concentrations that exceeded both the levels predicted by the aluminum content and the concentrations known to be associated with toxicity.

Overall, based upon effects-based guidelines, there appears to be a moderate potential for adverse effects of sediment-associated toxicants in Tampa Bay. The potential is greatest in the lower Hillsborough River and in Hillsborough Bay, followed by Middle Tampa Bay. Old Tampa Bay and the other subdivisions of the system located nearer the Gulf of Mexico generally have the lowest potential for effects. Compared to the other chemicals, the potential for effects appears to be highest for Pb, Hg, tPAHs, and Cr. The potential for effects attributable to sediment-associated As, Cu, chlordane, and dieldrin appear to be moderate. The potential for effects appears to be lowest for Sb, Cd, Ni, Ag, DDT, and PCBs.

Bivalve Mollusks

Approach. Matching tissue chemistry and biological effects data from studies performed elsewhere with bivalve mollusks were evaluated to determine the ranges in concentrations of selected toxicants often associated with adverse effects and the ranges in concentrations never or rarely associated with effects. The data were produced in many different laboratory and field studies, using clams, oysters, scallops, and mussels. Measures of effects included mortality, reduced fecundity, reduced scope for growth (SFG), lysosomal disorders, histopathological disorders, increased enzymatic activity, and other sublethal effects. The concentrations of toxicants in bivalve tissues commonly associated with effects were compared with the concentrations in Tampa Bay bivalves. Also, the chemical concentrations observed in Tampa Bay oysters were compared with the proposed criteria for fish and shellfish intended to protect predatory wildlife (National Academy of Sciences (NAS), 1974).

Comparisons of Effects Ranges with Tampa Bay Tissue Data. Data were evaluated for six classes of organic compounds and five trace metals for which there were matching measures of adverse biologic effects and tissue concentrations of toxicants. Sites in which chemical concentrations in bivalve tissues equalled or exceeded the concentrations previously associated with effects were identified.

PCBs. Total PCB concentrations of 27 to 180 ppb dw in mussels have been associated with observations of no adverse biological effects in many different studies. These observations included relatively high SFG in field studies performed in California (Martin *et al.*, 1984) and Norway (Widdows and Johnson, 1988); no lysosomal effects (Moore, 1988), low cytochrome P-450 activity (Livingstone, 1988), and no gametogenic effects (Lowe, 1988) in mussels studied in Norway; and no histopathological disorders in mussels collected at numerous United States locations (Battelle Memorial Institute, 1990). Measures of adverse effects have been associated with tissue concentrations of 180 to 1433 ppb dw in mussels. The measures of effects included lysosomal disorders (Moore, 1988), high cytochrome P-450 induction (Livingstone, 1988), and gametogenic effects (Lowe, 1988) in Norwegian mussels; significantly reduced SFG in California mussels (Martin *et al.*, 1984) and Norway mussels (Widdows and Johnson, 1988); and some incidence of histopathological disorders in mussels collected in the United States (Battelle Memorial Institute, 1990). Based upon these data, adverse biological effects may be expected where the concentrations of PCBs in bivalve tissues reach or exceed about 180 ppb. All of these data were collected, however, in mussels; and it is not known how well they apply to the oysters that are sampled and analyzed in Tampa Bay. Also, all of these data were collected in studies where a mixture of toxicants was present and the effects that were recorded could have been caused, in part, by other chemicals accompanying the PCBs. The NS&T Program analyzed 55 samples of oysters for PCB concentrations in Tampa Bay. A tPCB concentration of 180 ppb or greater occurred in 11 of the 55 samples, including oysters from sites TBNP, TBKA, TBOT, TBPB, and TBHB. Based upon these data, it appears that at least some of the oysters sampled in Tampa Bay may have sufficiently high PCB concentrations to create some potential for adverse biological effects. On the other hand, the NAS proposed warning criteria for tissue concentrations in fish and shellfish intended to protect predatory wildlife (NAS, 1974) was much higher than 180 ppb. The criterion proposed for tPCBs was 0.5 ppm ww (roughly equivalent to 2.5 ppm or 2500 ppb dw, assuming 20% moisture content). None of the oyster samples from Tampa Bay approached this concentration.

PAHs. In reports from many different laboratory and field studies, adverse biological effects were rare in bivalves with between 93.5 and 3700 ppb dw tPAHs. Measures of enzyme induction, SFG, lysosomal disorders, histopathological disorders, and mortality were low or at background levels in bivalves with these PAH concentrations in their tissues. Adverse biological effects were relatively common in bivalves with about 4000 ppb dw of tPAHs or more. These effects included high mortality (Fossato and Canzonier, 1976), reduced SFG (Widdows and Johnson, 1988; Phelps *et al.*, 1981), elevated enzyme induction (Livingstone, 1988; Suteau *et al.*, 1988), altered enzyme ratios (Neff and Haenslyh, 1982), high incidences of histopathological disorders (Lowe and Clark, 1988; Battelle Memorial Institute, 1990; Mix *et al.*, 1981), and reduced condition index (Fossato and Canzonier, 1976). More data from carefully designed experiments are needed to verify that a tissue concentration of about 4000 ppb represents a threshold in the toxicity of PAH to mollusks. None of the oysters sampled thus far by the NS&T Program in Tampa Bay have equalled or exceeded this concentration. The highest concentration observed, 1428 ppb dw was about one-third of this value, suggesting that the potential for biological effects may be relatively low.

Chlordane. Schimmel *et al.* (1976) observed 8434 ppb and 242,548 ppb dw of total chlordane in oyster tissues (*C. virginica*) associated with moderate and significant reductions, respectively, in shell deposition following 10-day exposures to chlordane, compared with 325 ppb in controls. The proposed criterion for chlordane in marine fish and shellfish tissue intended to protect predatory wildlife was 0.05 ppm ww (roughly equivalent to 250 ppb dw). The highest chlordane concentration observed thus far in the NS&T Program oyster samples from Tampa Bay, 193 ppb dw, did not equal or exceed any of these levels. Martin *et al.* (1984) reported a mean concentration of 70.6±14.1 ppb dw total chlordane in mussels (*M. edulis*) associated with signficantly lowered SFG following deployment of bagged mussels in San Francisco Bay; the mean total chlordane concentration in reference mussels was 4 ppb dw Martin *et al.* (1984) reported elevated concentrations of a number of other chemicals along with the chlordane in the mussels that had low measures of SFG. Of the 55 NS&T Program oyster samples from Tampa Bay analyzed thus far, 20 equalled or exceeded 70 ppb dw total chlordane, and none equalled either 250 ppm or 8434 ppm. Based upon these data, there appears to be a relatively small potential for effects in Tampa Bay oysters that could be attributed to chlordane residues.

Dieldrin. Martin *et al.* (1984) reported mean dieldrin concentrations of 40.3±9.7 ppb dw in mussels (*M. edulis*) with significantly lowered SFG, following transplantation in San Francisco Bay, compared with 4.7 ppb dieldrin in reference mussels. The proposed criterion for dieldrin in freshwater fish and shellfish tissue intended to protect predatory wildlife was 0.10 ppm ww (roughly equivalent to 500 ppb dw) The highest dieldrin concentration observed thus far in the NS&T Program samples, 16 ppb dw, did not equal or exceed these levels.

DDT. Following chronic exposures to DDT, the tDDT residues in oysters (*C. virginica*) with reduced body weights were 91 ppm ww (616,395 ppb dw) (Lowe *et al.*, 1971). Among several experiments performed by Lowe *et al.* (1971), the highest concentrations associated with no observable effects upon growth following chronic exposures were 81,300 ppb DDE, 5420 ppb DDD, and 426,829 ppb DDT. The proposed criterion (NAS, 1974) for DDE in marine fish and shellfish tissue intended to protect predatory wildlife was 0.05 ppm ww (roughly equivalent to 250 ppb dw) The highest DDE, DDD, and DDT concentrations observed thus far in Tampa Bay samples analyzed by the NS&T Program (138 ppb, 174 ppb, and 88 ppb dw, respectively) did not equal or exceed any of these levels. Of the 32 samples analyzed by Butler (1973), 4 equalled or exceeded the proposed criterion of 250 ppb dw Based upon these data, there appears to be relatively little potential for biological effects among bivalves that could be attributable to DDT residues.

Mirex. We were unable to locate any data with which to compare the concentrations of mirex in bivalve tissues with measures of effects. Mirex has been detected at relatively high concentrations in Tampa Bay oysters.

Copper. Most of the data that are available with which Cu concentrations in bivalve tissues can be compared with observations of effects have been developed in research performed with mussels. Generally, adverse effects have not been observed in association with Cu concentrations of 36 ppm dw or less in mussels. At concentrations of 40 ppm or greater, a wide variety of effects have been observed in mussels: lysosomal proliferation and disorders (Moore, 1988; Harrison and Berger, 1982); high mortality (Harrison and Berger, 1982; Kaitala, 1988); enzymatic conditions symptomatic of stressed conditions (Viarengo *et al.*, 1980; 1981); significantly elevated lysosomal lipofuscin content (Moore, 1988); significantly reduced lysosomal stability (Viarengo *et al.*, 1981) and elevated metallothionein binding of Cu (Viarengo *et al.*, 1988). The observations of effects performed in previous studies with mussels may not be comparable with the analytical results with Tampa Bay oysters. Oysters are known to accumulate much higher concentrations of Cu than mussels (NOAA, 1989). So, estimates of the potential for effects of Cu probably should be based upon data collected in studies of oysters, not mussels.

Considerably less data are available for oysters with which to compare observations of tissue residues and effects. Reduced thickness of oyster shells was observed in association with Cu concentrations of 450 ppm, as compared to 60 ppm in controls with normal shell thickness (Frazier, 1976). In another study, mortality increased from 6 percent to 10 and 14 percent as tissue concentrations of Cu in oysters increased from 607 ppm dw to 1458 ppm and 2672 ppm, respectively (Shuster and Pringle, 1969). Significant increases in oxygen consumption co-occurred with Cu concentrations of 800 ppm in oysters as compared to 500 ppm in oysters with no effects (Engel and Fowler, 1979). None of the Tampa Bay oysters analyzed by the NS&T Program equalled or exceeded 270 ppm Cu; the tissue concentration associated with elevated incidences of abnormal larvae. The maximum Cu level was 224 ppm in a sample collected at site TBKA. The mean concentration of Cu (1039 ppm) in samples collected near a St. Petersburg sewer outfall and analyzed by Magley (1978), exceeded 270 ppm. None of the samples analyzed by either Pan *et al.* (1982) or by Heil (1986) equalled or exceeded 270 ppm Cu, If mussels and oysters have similar tolerances for Cu, then the potential for effects in Tampa Bay oysters could be very high. However, it is likely that oysters accumulate and tolerate much higher levels of Cu than mussels. Based upon these data, it appears that the potential for effects attributable to Cu in oyster tissues would be relatively small throughout much of Tampa Bay; but, perhaps, relatively high near sewage outfalls.

Lead. The mean Pb concentration associated with reduced SFG in mussels exposed to San Francisco Bay was 3±0.7 ppm dw as compared to reference mussels with 0.8 ppm dw and normal SFG (Martin *et al.*, 1984). However, the Pb concentrations associated with reduced SFG in mussels exposed to a Norway fjord were 6.5±0.1 ppm, as compared to 3.5±0.7 ppm in reference mussels with normal SFG (Widdows and Johnson, 1988). Also, in the same experiment, the lowest Pb concentration associated with digestive cell lysosomal effects was 6.5 ppm (Moore, 1988). No mortality in *Mya arenaria* was associated with Pb concentrations of 6.7 ppm, as compared to relatively low mortality associated with a Pb concentration of 24.2 ppm and relatively high mortality associated with 174 ppm (Eisler, 1977). None of these data involving measures of effects were developed with oysters, so it is not clear that the data are applicable to estimates of the potential for effects in oysters. None of the 55 NS&T Program oyster samples exceeded a Pb concentration of 3 ppm, the lowest concentration associated with adverse effects. However, a number of samples from Tampa Bay analyzed by other investigators equalled or exceeded this concentration. The highest Pb concentration observed in Tampa Bay (15 ppm) exceeded 3 ppm by fivefold. Based upon these data, there appears to be a relatively small potential for effects in bivalves attributable to Pb.

Zinc. In an experiment performed with *Crassostrea virginica* from the Rhode River, Maryland, exposed to seawater with salinities of 2 to 13 ppt, reduced shell thickness was observed in association with Zn concentrations of 4100 ppm, as compared to 1700 ppm in reference oysters with normal shell thickness (Frazier, 1976). *C. virginica* mortality in seawater with 31 ppt salinity increased from 6 percent to 10 and 14 percent as Zn concentration in the oysters increased from 8540 ppm to 10,164 ppm and 11,531 ppm, respectively (Shuster and Pringle, 1969). A total of 8 of the 55 samples analyzed by the NS&T Program exceeded 4100 ppm Zn. Many of the samples from the Alafia River and near a St. Petersburg sewage outfall analyzed by Magley (1978) also exceeded 4100 ppm Zn. Based upon these data, there may be some potential for effects in oysters in Tampa Bay attributable to Zn. The differences in the salinities of the seawater in these two experiments may have influenced the results.

Arsenic. There are no data with which As concentrations in bivalve tissues can be related to measures of effects. Reductions in SFG in San Francisco Bay mussels (Martin *et al.*, 1984) were associated with a very small gradient in As (5 ppm to 7 ppm), suggesting that other factors were more important than As. Significant differences in growth rates of Chesapeake Bay oysters (Sanders *et al.*, 1987) also were associated with a small gradient in As (5 ppm to 8 ppm). Therefore, it is not possible at this time to estimate the potential for effects in oysters attributable to As.

Mercury. A host of pathological and enzymatic responses in mussels were associated with Hg concentrations of 0.4±0.5 ppm in the tissues, as compared to controls with 0.1±0.01 ppm and none of these responses (Viarengo *et al.*, 1982). The mussel samples with the lowest SFG in San Francisco Bay contained 0.5±0.1 ppm of Hg, as compared to mussels from a reference area with 0.17 ppm and higher SFG (Martin *et al.*, 1984). A total of 13 of the 55 Tampa Bay oyster samples analyzed by the NS&T Program had 0.4 ppm of Hg of more. All six of the samples from site TBOT had Hg concentrations that equalled or exceeded 0.4 ppm. None of the bivalve samples analyzed by either Heil (1986) or Pan *et al.* (1982) equalled or exceeded 0.4 ppm of Hg. The amount of data available with which to estimate the potential for effects of Hg is very small. Based upon this small amount of data, it appears that the potential for effects in Tampa Bay oysters attributable to Hg is moderate.

Summary. The tools with which one can estimate the potential for effects in oysters attributable to chemicals in the tissues are crude or lacking. Very few studies have been performed in which measures of effects and measures of tissue concentrations have been performed on the same organisms. Moreover, most of the studies in which matching bioeffects and tissue chemistry data have been generated have been performed with mussels, not the oysters that occur in Tampa Bay. Nevertheless, a rough estimate of the potential for effects was made with the information that exists. Overall, based upon the limited data available, there appears to be relatively little potential for biological effects in Tampa Bay oysters attributable to the concentrations of toxicants in the tissues. The potential for effects likely would be relatively low as a result of contamination by PAHs, DDT, chlordane, dieldrin, Cu, and Pb. The potential for effects probably would be moderate as a result of contamination by PCBs, Hg, and Zn. Matching effects and tissue chemistry data were not found for As and Hg that occur in Tampa Bay in relatively high concentrations compared to other Gulf Coast areas. As expected, the potential for effects would be highest near point sources, storm drains, etc. and in the industrial harbors around the perimeter of Tampa Bay.

OBSERVATIONS OF EFFECTS

The annual catch of fish and shellfish is a traditional barometer of the relative health of a nearshore or estuarine system. Commercial fishing is an economically important industry in the Tampa Bay area. However, long-term declines in the abundance and commercial landings of a variety of finfish and shellfish in the Tampa Bay area have been documented in recent years (Lombardo and Lewis, 1985). These decreases in fish abundance have been attributed, at least in part, to losses of habitats important to the survival of the fish (Comp, 1985). The linkage between the decreases in fish abundance and exposures of the fish to toxicants in Tampa Bay is not known. Very few quantitative measures of adverse biological effects associated with toxicants have been made in Tampa Bay. Given the lack of available data on toxicant-associated effects upon commercially important populations, a variety of more subtle indicators of the biological health of the system must be examined.

Benthic Infaunal Community Structure

Alterations of soft-bottom benthic communities often can be used as an indication of the adverse effects of toxicants in estuaries and embayments. However, the structure of the communities can be affected by shifts in sediment texture, depth, exposure to waves and sunlight, salinity, and predation, among other factors. Therefore, generally only major alterations in the benthos can be unequivocally attributed to the occurrence of toxicants in the sediments.

Numerous surveys of benthic communities have been performed at different times and in different parts of Tampa Bay by many investigators. Simon and Mahadevan (1985) identified 70 publications on benthic communities in Tampa Bay and reviewed the data from these reports. In addition, Doyle *et al.* (1985) and Lewis and Estevez (1988) summarized and reviewed the data from many of the previous benthic suveys in Tampa Bay. This document will not attempt to duplicate the data syntheses reported in these three publications.

The authors of these three review documents prepared a number of overall conclusions regarding the benthos of Tampa Bay. (1) About 1200 infaunal and epifaunal benthic species inhabit Tampa Bay, indicative of a very diverse and abundant benthic community. (2) Abundance of benthic organisms can fluctuate between 0 and 200,000/$m^2$and the number of species can range between 0 and 30 during different seasons, indicative of extreme seasonal fluctuations and defaunation events in the benthos. (3) Long-term cyclic defaunation appears to occur on about a 5-year cycle. (4) Seagrass beds support relatively rich benthic assemblages and as seagrass beds have declined, so has the diversity of the associated benthos. (5) Opportunistic and "pollution indicator" species are abundant in certain areas, such as Hillsborough Bay, that are stressed by pollutants and/or bottom water anoxia and some valued marine species are absent or depauperate in these areas. (6) Sediment types vary from organically enriched soft muds to relatively coarse quartz sand and they are important controlling factors in determining faunal distributions within the bay. (7) There is a general trend of increasing species richness and decreasing abundance from the head of the bay to the mouth, possibly due, in part, to gradients in factors such as sediment texture, salinity, and proximity to the Gulf of Mexico.

Among the most exhaustive studies of Tampa Bay benthic communities was that of Hall (1972), in which he reported results from 1963 and 1969 for Old Tampa Bay and Hillsborough Bay. He reported species richness, species diversity, and feeding types for sampling stations in both bays, and he classified stations as "unhealthy" where no live mollusks were observed. None of the 71 stations sampled in 1963 and none of the 14 stations sampled in 1969 in Old Tampa Bay were classified as "unhealthy", i.e., none were devoid of live mollusks. Species richness and species diversity indices generally improved at the same stations between 1963 and 1969. In contrast, in Hillsborough Bay 13 of the 35 stations sampled in 1963 and 1 of the 14 stations sampled in 1969 were devoid of live mollusks. These "unhealthy" stations were scattered throughout Hillsborough Bay in 1963. The single "unhealthy" station in 1969 was located in the Cut D Channel east of Davis Islands. Again, indices of species richness and diversity generally improved from 1963 to 1969. Hall (1972) observed very clear relationships between the composition and "health" of the benthic infaunal mollusk assemblages and the sediment texture. He concluded that the differences in the assemblages in the two bays could be attributable to these differences in sediment types. No analyses of toxicants accompanied the analyses of benthic communities.

Attributing changes in benthic communities to toxicants is usually a difficult task, since a large number of natural environmental factors can exert very important influences upon the benthos. It appears that a number of investigators have identified alterations of these communities in association with the occurrence of "pollution" in Tampa Bay. However, it is not clear if these alterations were attributable to toxicants alone or in combination with enrichment with nutrients and organic matter, near-bottom anoxia, and/or differences in substrate types. Science Applications International Corporation (1987) identified patterns in sediment quality in Hillsborough Bay that could influence oxygen content of the sediments and the benthic community composition. Long and Chapman (1985) argued that the availability of sediment toxicity data, along with sediment chemistry and benthic community data, provided a more comprehensive basis for assessing sediment quality. It appears that no surveys have been performed thus far in Tampa Bay in which this triad of measures has been performed.

Biological Measures of the Health of Oysters

No quantitative survey of the incidence of histopathological disorders of bivalves has been performed in Tampa Bay. Dr. Norm Blake at the University of South Florida (personal communication) has, however, observed a number of conditions in oysters suggestive of the poor health of these animals. He has observed parasitism, amoebocitic infestations, gonadal resorption, castration, gonadal neoplasms, dwarfism, and low fecundity in oysters (*C. virginica*) in the bay.

As a part of the Mussel Watch Project of the NS&T Program, Texas A & M University has measured a number of biological parameters in oysters collected annually along the Gulf of Mexico (Brooks *et al.*, 1989). Four sites in Tampa Bay were sampled in 1986, 1987, and 1988, along with an additional site that was added in 1988. Along with the chemical analyses of the tissues, a variety of biological measures were performed as aids in the evaluation of the chemical data. Condition indices were not markedly different in oysters from Tampa Bay than in oysters from other sites along the Gulf coast; however, oysters collected at Mullet Key and Cockroach Bay in 1986 were at the low end of the range Shell length was negatively correlated with salinity ($P = 0.04$, Spearman's Rank) and positively correlated with the prevalence of *Perkinsus marinus* prevalence ($P = 0.03$, Spearman's Rank). Larger oysters were collected in areas with lower salinities.

Brooks *et al.* (1989) reported that the prevalence of the parasite *P. marinus* was high at almost all of the sites along the Gulf Coast. Prevalence was below 50 percent at only 1 of the 70 sites in 1986, 14 sites in 1987, and 17 sites in 1988. However, there appeared to be a focus of relatively high infection in all 3 years in the Charlotte Harbor/Tampa Bay/Naples Bay area. Prevalence was 100 percent in oysters collected at Mullet Key, Bayou Grande, and Cockroach Bay in 1986, and in the mouth of the Alafia River in both 1986 and 1988. The average median infection intensity in oysters collected in 1986 at the Bayou Grande site was among the four highest of the 70 sites along the Gulf Coast. The infection prevalence was determined to be positively correlated with agricultural and industrial land use along the Gulf Coast, and, unexpectedly, not with water temperature at the time of sampling. The authors concluded that the prevalence of *P. marinus* was a reliable indicator of poor water quality.

Biological Measures of the Health of Fish

Fish that have been exposed to toxicants may form neoplasms or other histopathological disorders in their livers and other organs, may have elevated incidences of cellular or subcellular disorders, may indicate elevated levels of oxidative enzyme activities, and/or may have impaired reproductive success. Apparently, no quantitative surveys of the occurrence of these types of toxicant effects in fish have been performed in Tampa Bay. No records or reports of tumors in fish or invertebrates collected in Tampa Bay are on file at the Registry of Tumors in Lower Animals, National Museum of Natural History (Dr. John Harshbarger, personal communication).

As a component of the NS&T Program, the National Marine Fisheries Service (NMFS) of NOAA has examined nearshore fish and determined the incidence of certain histopathological disorders at many locations around the nation, but has not reported data from Tampa Bay. NOAA collected marine catfish at four sites in Tampa Bay in 1990 to determine the incidence of a variety of physiological and histopathological disorders. The data from the analyses are not available thus far (Dr. Bruce McCain, NOAA/NMFS, Seattle, personal communication).

Relative to other subdivisions of the bay, Hillsborough Bay has had lower fish abundance and species richness (see Lewis and Estevez, 1988). These differences in the fish communities could be attributable to loss of habitat and/or exposure to pollutants, but no corroborative evidence was offered.

Because of the lack of data, it is impossible to assess the degree to which the relative health of fish in Tampa Bay has been impaired by exposure to toxicants. Given the mixtures and concentrations of toxicants in parts of Tampa Bay, it is possible that resident fish have suffered adverse effects as a result of exposure to the chemicals, but there are no data available with which to support this speculation.

Sediment Toxicity

Sediment toxicity data from a total of only 10 sampling sites in Tampa Bay were located in our search for information. Three small studies (Environmental Science and Engineering, Inc., 1979; Jones, Edmunds and Associates, Inc., 1979; 1980) of the toxicity of surficial sediments were performed as prerequisites to dredging operations. In these studies, sediment samples were collected at selected sites and transported to a laboratory for testing. A variety of animals were exposed to the samples and percent survival was determined using standardized procedures. Solid phase (unaltered) sediments were tested with the mollusk *Mercenaria mercenaria*, the shrimps *Penaeus duorarum* and *Paleomonetes pugio*, and the polychaete worms *Nereis virens* and *Neanthes arenaceodentata*. The suspended particulate phase of the sediments was tested with *P. pugio* larvae, the minnow *Menidia menidia*, the mysid *Mysidopsis bahia*, the pinfish *Lagodon rhomboides*, and the copepod *Acartia tonsa*. *P. pugio, M. menidia, and M. bahia* were also used in tests of the liquid phase of a few samples (filtered suspended particulate material). Three samples were collected in Bayboro Harbor near St. Petersburg, two in Lower Tampa Bay and five in Middle Tampa Bay (Figure 26). Three samples from a reference site located off Mullet Key in the Gulf of Mexico also were tested.

The results of the tests with solid phase sediments and suspended phase material are summarized in Table 25. Average percent survival (± standard deviations) and the ratio of the number of samples that were significantly toxic (statistically significantly different from controls) to the number of samples tested are compared among four areas: Bayboro Harbor, Lower Tampa Bay, Middle Tampa Bay, and Mullet Key. None of the samples was significantly toxic to *M. mercenaria, P. pugio, P. duorarum*, or *N. virens* in the solid phase tests. The average percent survival was similar among all areas tested with these species. Significant toxicity was observed in all three Bayboro Harbor sediments initially tested with *N. arenaceodentata*, prompting the investigators to test the sediments again. In the subsequent tests, none of the samples was significantly different than controls, probably since the percent survival in the controls decreased. In the suspended phase bioassays, significant toxicity was observed in samples tested with all species but *L. rhomboides*. Four of five samples from Middle Tampa Bay were significantly toxic to *M. bahia* compared to only one of three from both Bayboro Harbor and the Lower Tampa Bay. Also, average percent survival was lower in *M. bahia* exposed to Middle Tampa Bay samples compared to the others.

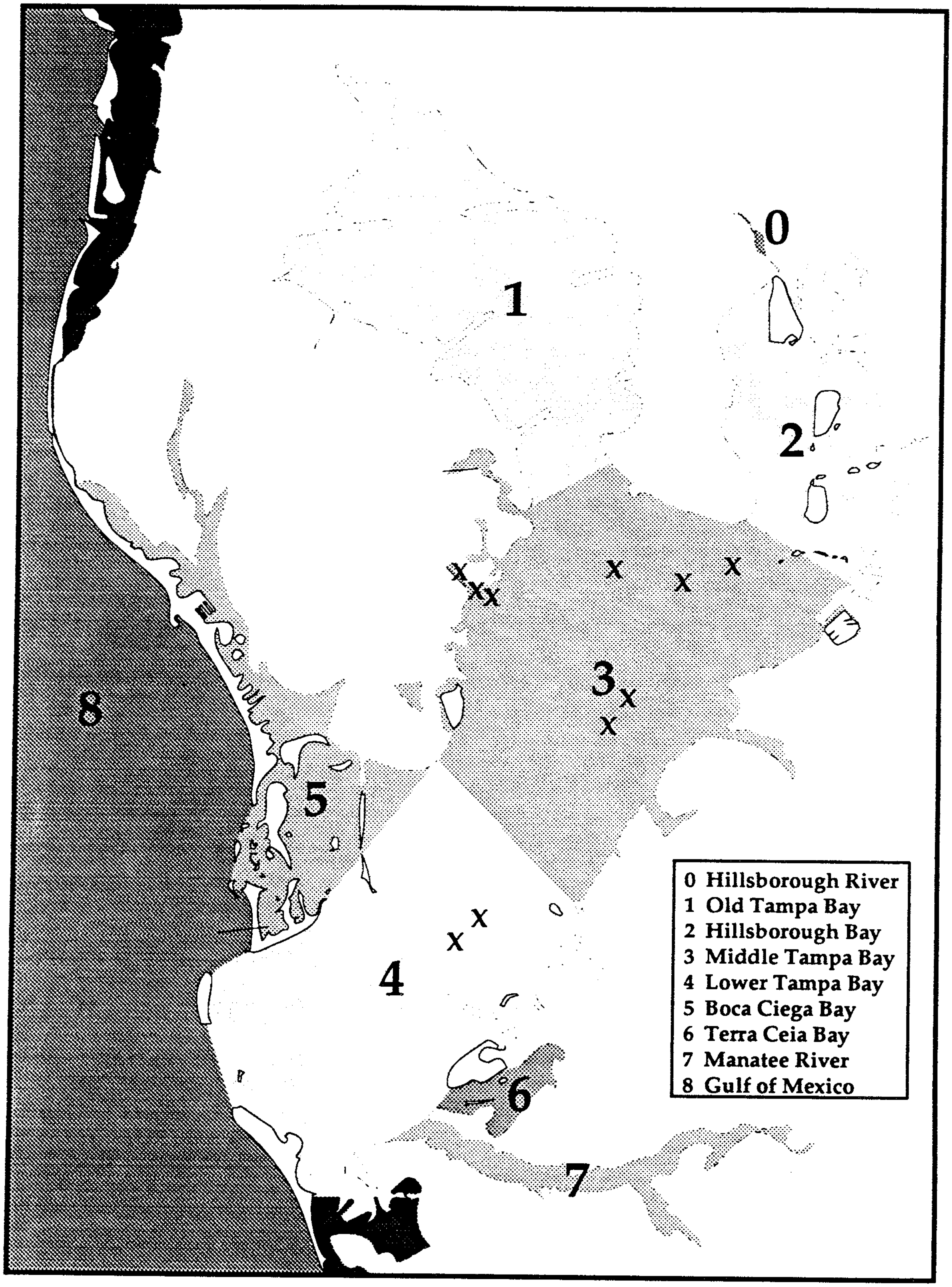

Figure 26. Sediment toxicity sampling locations in Tampa Bay (from Environmental Science and Engineering, 1979; Jones, Edmunds and Associates, 1979, 1980).

Table 25. Average (±standard deviation) percent survival for individual species tested with solid phase and suspended phase sediments from four areas and (in parentheses) the ratio of the number of samples that were significantly toxic versus the total number of samples tested in each area.

SOLID PHASE

Areas	*M. mercenaria*	*P. pugio*	*P. duorarum*	*N. arenaceodentata*	*N. virens*
Bayboro Hbr.	100±0%	95±7%	-	88±4%	-
	(0/3)	(0/3)	-	(3/6)	-
Lower Bay	99±0%	95±2%	-	94±1%	-
	(0/2)	(0/2)	-	(0/2)	-
Middle Bay	99±1.5%	87%	85±4%	70%	84±9%
	(0/5)	-	(0/4)	-	(0/4)
Mullet Key	100%	-	90%	-	73%

SUSPENDED PHASE

	M. menidia	P. pugio	L. rhomboides	M. bahia	A. tonsa
Bayboro Hbr.	67±58%	85±4%	-	78±16%	-
	(1/3)	(1/3)	-	(1/3)	-
Lower Bay	95±3%	99±2%	-	84±9%	-
	(0/2)	(0/2)	-	(0/2)	-
Middle Bay	0%	100%	100±0%	63±20%	81±16%
	(1/1)	(0/1)	(0/4)	(4/5)	(1/4)
Mullet Key	-	-	100%	100%	100%

In Table 26, the results of the solid phase tests with all six of the different species are merged to determine if there are any geographic patterns apparent among all the data. Also, the results of the suspended phase tests with all five of the different species, and the liquid phase tests with all three species are summarized. The proportion of the samples that were significantly toxic (relative to respective controls) is listed for three areas: Bayboro Harbor, Lower Tampa Bay, and Middle Tampa Bay.

Table 26. Ratio of the number of samples that were significantly toxic (reported as significantly different from controls) to several different species versus the total number of tests performed with sediment samples from three areas in Tampa Bay.

Type of Test	Bayboro Harbor	Lower Tampa Bay	Middle Tampa Bay
Solid Phase	3/12	0/6	0/15
Suspended Phase	3/9	0/6	6/15
Liquid Phase	3/9	-	-

In three of the tests performed with Bayboro Harbor sediments, survival was significantly lower than in the respective controls, whereas none of the tests of Lower Tampa Bay sediments were significantly toxic. Significant toxicity was observed in 6 of the 15 suspended phase tests performed with Middle Tampa Bay sediments. There was a relatively high degree of variability among the results from Bayboro Harbor; sediments from one of the sites was frequently more toxic than the other two. Some of the sediment from the Upper Tampa Bay area was reported as having a distinct sulfurous odor; indicative of an anoxic condition. Anoxia, high sulfur content, and high ammonia content could affect the results of sediment toxicity tests.

There are too little data to warrant any general conclusions about spatial patterns in sediment toxicity in Tampa Bay. Toxicity tests of many more samples from many more sampling sites are needed to determine spatial patterns. Also, some recently developed tests are probably more sensitive to toxicants in sediments than the standardized tests used in the three studies summarized here. Given that some of these relatively resistant tests indicated toxicity, it would be interesting to see the results of tests using more sensitive species and end-points.

Since Bayboro Harbor is situated nearer potential sources of toxicants than the other areas, the sediments there would be expected to have a higher likelihood of being toxic than those from the other areas. Two sediment samples from Bayboro Harbor analyzed by Doyle *et al.* (1985) had relatively high hydrocarbon concentrations. The total f2 fraction hydrocarbon concentrations in one sample exceeded the ERL value for tPAH and the other sample exceeded the tPAH ERM value by a factor of about 3. The proportion of samples that exceeded ERM and ERL values was relatively low in Lower Tampa Bay and intermediate in Middle Tampa Bay (Tables 23 and 24). The data available, however, do not suggest such a pattern. There are no clear patterns in the data as determined by examining the results from the individual tests.

Summary

There is a very small amount of data available upon which any general conclusions can be drawn regarding the occurrence of toxicant-associated biological effects in Tampa Bay. There is evidence that benthic communities have been stressed by low-oxygen and anoxic events, but the relative importance of toxicants in causing stress among the benthos is unknown. There is anecdotal evidence of histopathological disorders among oysters in the bay, but no data from a quantitative, systematic survey have been published. Thus far, no reports of histopathological disorders among resident fish have been published. It appears that a total of 10 sediment samples have been tested for toxicity in laboratory bioassays and a few have been toxic to some of the test animals. A general decline in commercial finfish and shellfish landings in the Tampa Bay area has occurred in the past 20 years (Lombardo and Lewis, 1985). Comp (1985) identified a relationship between the loss of habitat in the Tampa Bay system and declines in fish populations. However, neither report attempted to attribute declines in fish abundance to the effects of toxicants.

CONCLUSIONS

Relative to other estuarine systems of comparable size for which we have prepared regional status and trends reports (San Francisco Bay, Boston Harbor, and Southern California Bight), there is a much smaller amount of data available for Tampa Bay. There are essentially no data with which to evaluate spatial patterns in measures of biological effects. The chemical data available from the analyses of sediments and oyster tissues indicate that toxicant concentrations generally are highest in the lower Hillsborough River and parts of Hillsborough Bay and they are lowest in Lower Tampa Bay nearest the Gulf of Mexico. Intermediate concentrations occur in parts of Old Tampa Bay, upper Boca Ciega Bay, and Middle Tampa Bay. Toxicant hotspots have been reported near point sources and storm drains, in marinas, ship canals, and other nearshore confined areas throughout the Tampa Bay system. Toxicant concentrations generally are lowest down the axis of the system and near the mouth of the bay.

Compared with other sediment and oyster sampling sites along the Gulf Coast, some of the sites in Tampa Bay are more contaminated with some toxicants and some are less contaminated. The concentrations of mirex, dieldrin, chlordane, tDDT, tPCBs, Ag, Cu, and Pb in sediments were considerably higher in some Tampa Bay sites than in other Gulf Coast sites in Florida. The concentrations of Cd, Cu, Pb, and Zn exceed the concentrations expected in relatively clean sediments, based upon aluminum-to-trace metal models. The relatively low concentrations of some chemicals in sediments may be explained, at least in part, by the low percent composition of sediments by fine-grained, organically enriched sediments in Tampa Bay. The concentrations of toxicants in Tampa Bay sediments is strongly influenced by sediment grain size and organic carbon content, especially at extremely high and low levels of both parameters. Compared to the oysters from the other 70 NS&T Program sites along the Gulf Coast, those in Tampa Bay have had relatively high concentrations of mirex, chlordane, Hg, and Zn. Among the approximately 200 sites at which bivalve mollusks were sampled nationwide by the NS&T Program, very few in Tampa Bay have ranked in the top 20 in toxicant concentrations. However, among these nationwide sampling sites, the concentrations of total chlordane, mirex, Hg, As, and Zn have been relatively high in oysters from Tampa Bay. There may be an inverse relationship between Zn concentrations in oyster tissues and water salinity at the sampling sites.

Based upon comparisons of the chemical concentrations previously associated with biological effects and the concentrations observed in Tampa Bay, there appears to be, overall, a relatively small to moderate potential for adverse effects among Tampa Bay biota that would be attributable to exposure to toxicants. The potential for toxic effects among resident oysters likely would be relatively low as a result of accumulation of PAHs, DDT, chlordane, dieldrin, Cu, and Pb in their tissues and moderate as a result of contamination by PCBs, Hg, and Zn.

Overall, there appears to be a moderate potential for adverse effects of sediment-associated toxicants in Tampa Bay. The potential is greatest in the lower Hillsborough River and Hillsborough Bay, followed by (in descending order) Middle Tampa Bay and lower Manatee River. Old Tampa Bay and the other subdivisions of the system located nearer the Gulf of Mexico generally have the lowest potential for effects. Compared to the other chemicals, the potential for effects in sediments from these three subdivisions appears to be highest for Pb, Hg, and tPAHs. The potential for effects attributable to sediment-associated As, Cu, Cr, chlordane, and dieldrin appear to be moderate. The potential for effects appears to be lowest for Sb, Cd, Ni, Ag, DDT, and PCBs in sediments. However, none of the data used to estimate the potential for effects in sediments or oysters were generated in studies performed in Tampa Bay or nearby; the data and informal guidelines used to estimate the potential for effects should be verified with data collected locally.

Very little data exist with which estimates can be made of the temporal trends in the accumulation of toxicants in Tampa Bay. The concentrations of some chemicals have apparently increased at some locations over recent years, while others have not changed appreciably or have decreased. The concentrations of some pesticides and other organic compounds have increased at some sites over the 4-year period that analyses of oysters have been performed by the NS&T Program, e.g., a site located in Cockroach Bay. The concentrations of DDT in oysters collected in the 1980s at many sites in the bay are considerably lower than they were in another location sampled in the late 1960s. The concentration of Pb in three of five sediment cores from the lower Manatee River suggested a pattern of increasing concentrations in recent years. Lead concentrations in cores collected in the lower Hillsborough River were very high, but temporal trends in accumulations were not clear.

Very few studies have been performed in which actual measures of biological effects were made. Only anectodal observations have been made of a variety of histopathological disorders and dysfunctions in resident oysters. No observations of toxicant-associated effects in resident fish have been reported. Alterations in benthic communities have been observed, but they are, at least in part, attributable to changes in factors other than toxicants. A few of the 10 sediment samples tested for toxicity have been toxic to relatively resistant species. Beyond these data, there is not much else to report regarding the incidence of toxicant-associated biological effects. Therefore, it is difficult to verify or refute the estimates of the potential for effects attributable to toxicants.

It is the hope of the authors, that this report will serve as a catalyst for further research on the status and trends in toxicants and their effects in Tampa Bay. Much more information is needed for Tampa Bay, an important system that supports an abundance of marine resources.

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