NATIONAL STATUS AND TRENDS PROGRAM FOR MARINE ENVIRONMENTAL QUALITY

TOXIC CONTAMINANTS IN THE GULF OF MAINE

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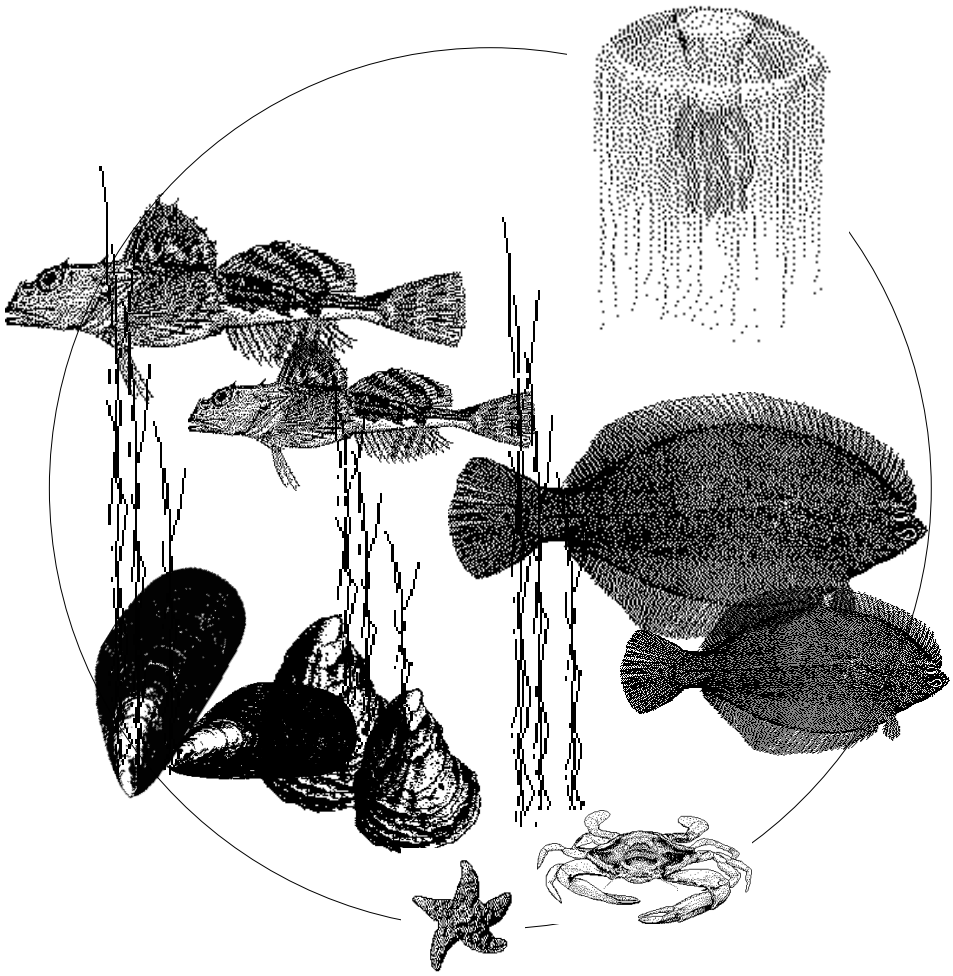

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ABOUT THIS REPORT

This report summarizes results of the National Status and Trends (NS&T) Program from the Gulf of Maine Region. It characterizes the system, its drainage basin, and inputs that influence the concentrations of contaminants and biological responses to those substances. These results are shown in relation to those obtained at all other NS&T sites around the United States. This summary is intended to provide information to assist local and state resource managers in evaluating toxic contaminant conditions in their areas and placing those conditions in perspective to those throughout the Gulf and across the nation.

NATIONAL STATUS AND TRENDS PROGRAM

In response to the need for information assessing the effects of human activities on environmental quality in coastal and estuarine areas, and the need to develop management strategies to deal with these conditions, the National Oceanic and Atmospheric Administration (NOAA) initiated, in 1984, the National Status and Trends (NS&T) Program. The purpose of this program is to determine the current status and detect changes that are occurring in the environmental quality of our nation's estuarine and coastal waters. Because of concern over inputs of contaminants to U.S. coastal waters, the program initially focused on these substances and their effects. The NS&T Program has four major components: the **Benthic Surveillance Project**; the **Mussel Watch Project**; **Biological Effects Surveys and Research**; and **Historical Trends Assessment**.

As part of its nationwide monitoring, the NS&T Program monitors the levels of more than 70 contaminants and certain associated effects in biota and sediments. It provides data for making spatial and temporal comparisons of contaminant levels to determine which regions around our coasts are of greatest concern regarding existing or developing potential for environmental degradation. It includes measurements of concentrations of 24 polycyclic aromatic hydrocarbons, 20 congeners of polychlorinated biphenyls (PCBs), DDT and its breakdown products (DDD and DDE) and 9 other chlorinated pesticides, butyltins,12 toxic trace elements, and 4 major elements in sediments, mussels, and oysters at a network of about 220 regionally representative sites by the **Mussel Watch Project.** Additionally, determinations of the levels and effects of the same chemicals in the livers of bottom-dwelling fish and associated sediments are made by the **Benthic Surveillance Project** at about 75 sites (refer to the map inside back cover). The frequency of external disease and internal tumors are documented in the fish studied. Data from all monitored sites are stored on NOAA national databases, analyzed, and made available to estuarine managers and to the public in a variety of reports (over 200 to date).

Sampling and analyses for the NS&T monitoring projects are performed using well-documented methods and techniques, so that a known level of confidence can be assigned to all data. Analytical procedures adhere to the standards of the NOAA Quality Assurance Program, established for all laboratories participating in the NS&T Program. Selected samples collected as part of the activities of the NS&T Program are preserved in liquid nitrogen and stored at -150 ° C. A specimen archive of these samples has been established at the National Institute of Standards and Technology (formerly the National Bureau of Standards) in Gaithersburg, MD. Specimens from the archive will be available for retrospective analyses as new analytical techniques become available and perceptions of environmental quality issues change.

In 1986, the NS&T Program initiated **Biological Effects Surveys** in those regions where NS&T analyses indicated a potential for substantial environmental degradation, and **Research** on biological effects of contaminants. Most studies focus on living marine resources, especially bottom-dwelling fish. Studies are done on such subjects as reproductive impairment, genetic damage, sediment toxicity, refinement of methodologies, and evaluation of new indicators of contamination (DNA damage and enzymatic activity in fish livers), as well as on the relation of such effects to contaminant concentration gradients.

Historical Trends Assessment studies involve a closer examination of the environmental conditions in individual regions of the United States. The available data and ancillary information pertaining to the status and trends of toxic contaminants and their effects in regions of concern are used to assess the present state of knowledge on the magnitude and extent of degradation to living resources and their habitat. Recently, the NS&T Program added sediment coring to better assess the trends of chemical contaminants.

TOXIC CONTAMINANTS IN THE GULF OF MAINE

GENERAL DESCRIPTION

The Gulf of Maine can be broadly defined as that area encompassing the Bay of Fundy to the north and Georges Bank to the south, including the Gulf proper, and comprising a complex ecosystem. In understanding and interpreting the NS&T contaminant data measurements, the following information on the characteristics of the Gulf region are important.

■ NOAA's National Estuarine Inventory Data Base has characterized 13 estuaries and one subestuary (Figure 1) within the U.S. Gulf of Maine region, ranging from Passamaquoddy Bay southward to Cape Cod Bay. These estuaries make up a total water surface area (length and width) of approximately 2,000 square miles, a total volume of 3.1 trillion cubic feet, and a shoreline perimeter of about 3,039 miles. Semidiurnal tides range from about 8 feet in Cape Cod to about 17 feet in northern Maine (NOAA , 1987).

■ These estuaries have a combined total estuarine drainage area of 22,417 square miles. The most recent (1975) land-use data indicate that 1,382 square miles of this drainage area were urban, 2,467 square miles were agriculture, 167 square miles were rangeland, 16,208 square miles were forested, and 1,153 square miles were in other (wetland and barren land) land- use categories (NOAA, 1987).

■ The states of Maine, New Hampshire, and Massachusetts have a combined total of approximately 1,314,000 acres of coastal wetlands. Of these, 74,200 acres (6%) are salt marsh, 61,900 acres (5%) are fresh marsh, 1,030,000 acres (78%) are forested-scrub/shrub, and 148,000 acres (11%) are tidal flats (Strategic Assessment Branch, 1989).

■ Of the approximately 1,133,000 acres of U.S. classified molluscan shellfishing waters in 1990, about 781,000 acres (69%) were classified approved for harvest, 9,000 acres (1%) were conditional, 11,000 acres (1%) were restricted, and 332,000 acres (29%) were prohibited. Two estuaries have no approved waters: Merrimack River and Boston Bay (Slaughter, pers. comm.).

■ The region supports 20,000 U.S. and Canadian fishermen with landings in 1988 totaling nearly 1.2 billion pounds, and worth approximately $650 million (Konrad et al., 1989).

■ The Massachusetts Bay and Merrimack River are two of the four basins within the U.S. Northeast estuaries that have the largest input of nutrients from Wastewater Treatment Plants. Casco Bay is one of the primary areas of nutrient input from industrial sources in the Northeast (NOAA, 1988).

■ The Gulf of Maine is the third most densely populated coastal region in the United States. In 1988, 72% of Maine's population resided in coastal counties; 31% of New Hampshire's population resided in coastal counties; and Massachusetts had 75% of its population residing in coastal counties. Even with a projected population growth of 16 percent in this region by the year 2010, making it the second slowest-growing coastal region in the U.S., the ratio of coastal to non-coastal population should remain approximately the same (Culliton et al., 1990).

■ Millions of tourists are attracted each year to the Gulf of Maine coast, having both direct and indirect impacts on its wide variety of freshwater, estuarine, and marine habitats (Konrad et al., 1989).

GULF OF MAINE ACTIVITIES

The NS&T activities in the Gulf of Maine are being carried out through cooperative efforts among states, provinces, and local governments from the U.S. and Canada; the academic community; and private institutions. In December 1989, the Gulf of Maine: Sustaining Our Common Heritage Conference was held in Portland, Maine. More than 250 scientists, policymakers, fishermen, and citizens gathered to discuss how to conserve the Gulf's resources. The conference concluded with the Governors of Maine, Massachusetts, and New Hampshire, together with the Premiers of Nova Scotia and New Brunswick, signing an agreement to cooperatively protect the resources of the Gulf of Maine. Some programs involved in monitoring the environmental status of the Gulf of Maine include: the Boston Harbor Monitoring Program (BHMP); the National Water Quality Data Bank, Environment Canada (NAQUADAT); NOAA's Marine Resources Monitoring, Assessment and Prediction (MARMAP); and the Water Resources Data Program, U.S. Geological Survey (USGS). Additionally, NOAA's NS&T Program has been monitoring the Gulf's coastal waters from northern Maine to Cape Cod with special emphasis on biological effects surveys in Boston Harbor.

BOSTON HARBOR NS&T STUDIES

Because NS&T monitoring has identified sites in Boston Harbor that are high nationally in multiple chemical contaminants (O'Connor, 1990), more intensive surveys on the effects of chemicals on the biota were initiated in 1986. Measures of biological responses to contaminant exposure have been studied in winter flounder from sites in and around Bos-

ton Harbor (Deer Island, off East Boston, the Harbor mouth, and Quincy Bay) since 1987. These studies were conducted by the Northwest Fisheries Center of NOAA's National Marine Fisheries Service (NMFS) in Seattle, WA. Preliminary results indicate elevated levels of aryl hydrocarbon hydroxylase (AHH) activity, bile fluorescent aromatic compounds (FACs), and DNA-adducts in winter flounder from Boston Harbor. Results from a bioassay study on the effects of methylene chloride extracts from sediments taken inside and outside of Boston Harbor suggest that these extracts were toxic to bioluminescent bacteria. From 1986 through 1988, the NMFS Northeast Fisheries Center at Milford, CT, studied egg, embryo, and larval maturation in 200 winter flounder females from six sites in Long Island Sound (LIS) and two in the Boston Harbor area (Deer Island and Long Island). Results showed that the livers of spawned fish from the Boston sites had significantly higher concentrations of PCBs, and that spawned eggs from Boston Harbor winter flounder were consistently smaller than those of the LIS fish (NMFS, 1990).

Since 1988, the NMFS Southeast Fisheries Center Laboratory at Beaufort, NC, has conducted pollutant metal effects surveys studying total dissolved copper and zinc concentrations and copper speciation at 100 northeast coastal sites, including several sites in and near Boston Harbor. Sunda and Huntsman (1989) concluded that free cupric ion concentrations, with a potential for copper toxicity ($\geq 10^{11}$ M), occurred in surface waters of several northeast sites, including Boston Harbor. Currently, direct measurements of toxicity effects are being made on Arbacia punctilata (purple sea urchin) larvae at sites in the Northeast.

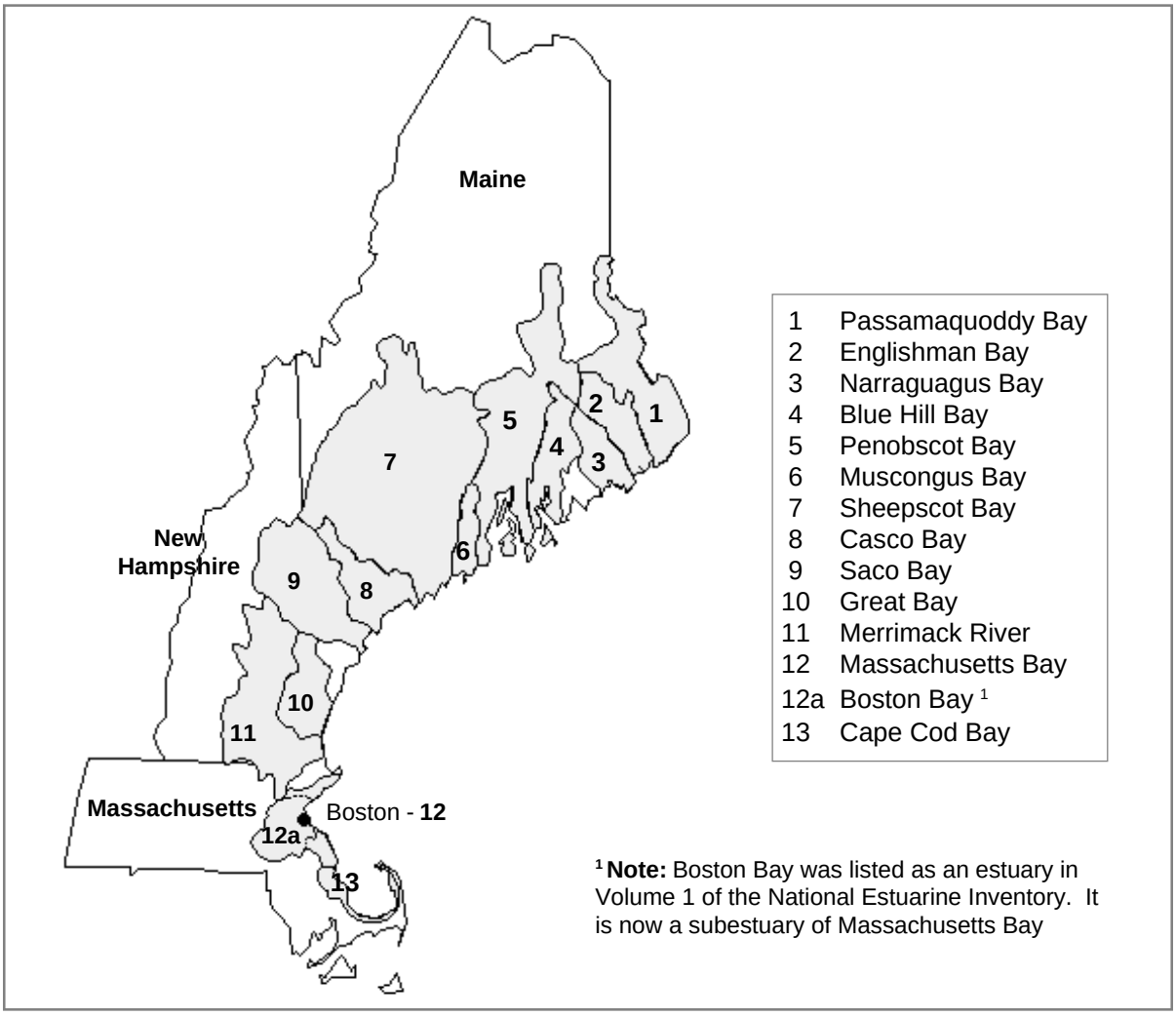

Figure 1. Estuarine drainage areas within the Gulf of Maine (Source: modified from NOAA, 1990a)

In 1990, scientists from the Woods Hole Oceanographic Institution in Woods Hole, MA, began a two-year NS&T study on the effects of lipophilic organic contaminants on the reproductive condition of blue mussels at two Boston Harbor sites (Deer Island and Dorchester Bay).

MacDonald (1991) has documented historical trends in contaminant conditions in Boston Harbor using data from various surveys and research performed by many organizations.

GULF OF MAINE MONITORING

In the Gulf of Maine, the NS&T Program's Benthic Surveillance Project began sampling specimens of winter flounder *(Pseudopleuronectes americanus)* and longhorn sculpin *(Myoxcephalus octodecemspinosus)* in 1984 for levels of liver contaminants,

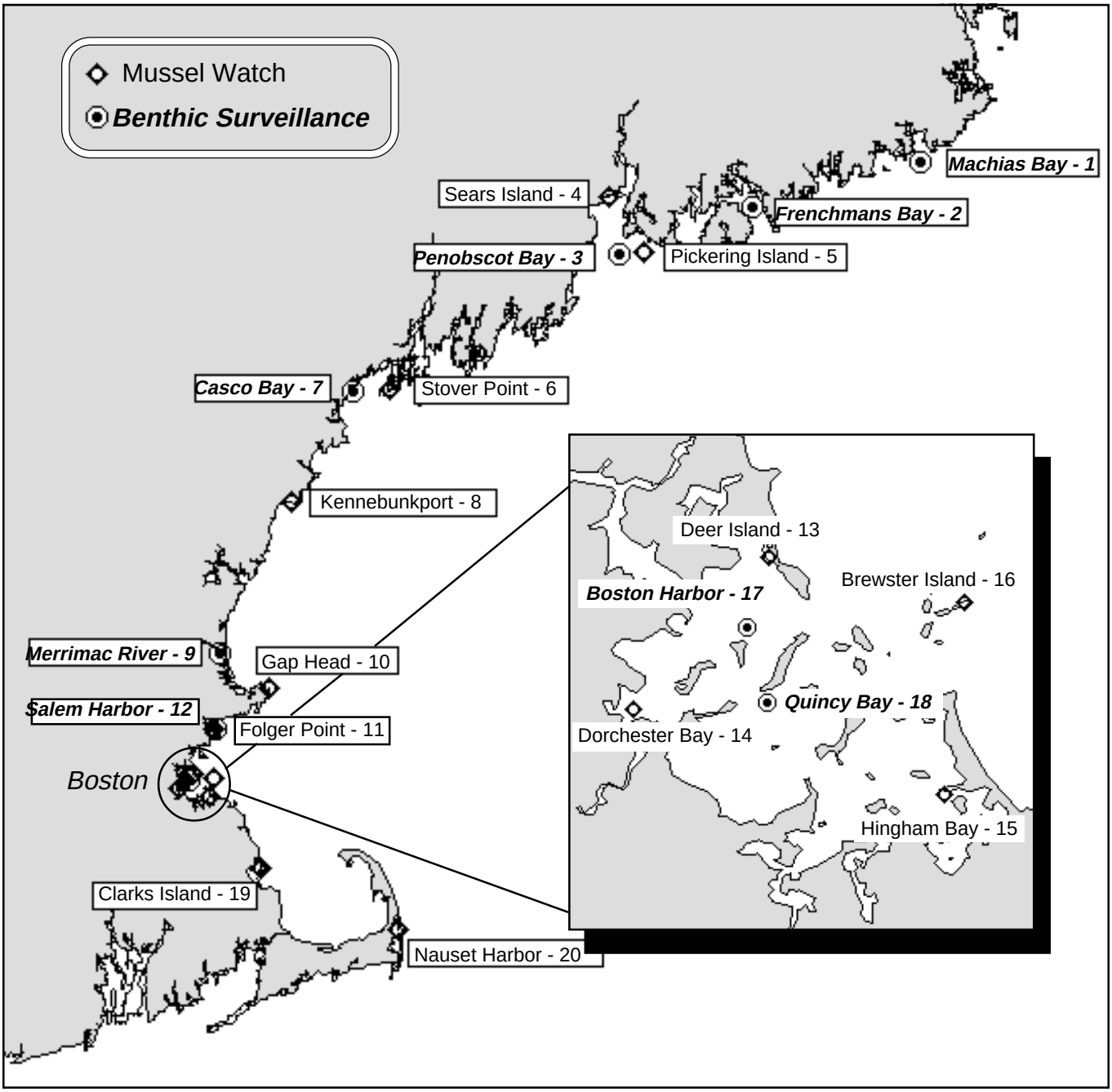

Figure 2. *NS&T Program monitoring sites within the Gulf of Maine*

length, weight, age, and prevalence of tumors and disease. In 1986, the NS&T Program's Mussel Watch Project began monitoring the blue mussel (Mytilus edulis) for the prevalence of disease as well as levels of chemical contaminants. In both programs, sediments (1-3 cm depth) are collected and analyzed for a variety of trace metals, petroleum hydrocarbons, and synthetic organic compounds (refer to Table 2). NS&T selection of monitoring sites is based on collecting samples from areas that are representative of general contamination conditions, avoiding waste discharge points, local dumpsites, and "hot spots." Figure 2 indicates the NS&T monitoring site locations in the Gulf of Maine, which range in depth from intertidal to 45 meters. The laboratories which have collected and analyzed the Benthic Surveillance Gulf of Maine samples are NOAA's NMFS laboratories in Gloucester, MA, Sandy Hook, NJ, and Seattle, WA. The Mussel Watch samples are collected and analyzed by Battelle Ocean Sciences, Duxbury, MA.

NS&T monitoring for prevalence of tumors and general disease conditions in fish and mollusks has found that some sites in the Gulf of Maine are above the U.S. average of 0.7% for neoplasms (tumors) in fish livers. These studies have also found that blue mussel tissues at all sites are generally below West Coast incidences of neoplasms (disseminated sarcomas) (Myers et al., 1987; Rhodes et al., 1987; Varanasi et al., 1989; Zdanowicz et al., 1988; Battelle, 1990). Of the 9,120 fish examined nationwide between 1984 and 1988, 63 had liver neoplasms. Twenty of these fish, or 32%, were winter flounder from the Deer Island site in Boston Harbor. Other cellular disorders, such as vaccuolated cells, have been found at prevalences as high as 70% in the livers of winter flounder from Boston Harbor sites (Bodammer and Murchelano, 1990).

NS&T CHEMICAL DATA

The graphs on this and the following pages (Figures 3 and 4) show the concentrations of contaminants found at Gulf of Maine sites in relation to the concentrations found nationwide at all NS&T sites. Concentrations of contaminants in sediments, mussels, and fish at the Gulf sites are indicated by the vertical lines (concentrations are logarithmic scale); numbers at the top of each vertical concentration line refer to the site locations indicated in Figure 2. The curves are formed by connecting the rank-ordered concentrations of mean chemical contaminants at NS&T sites. The dashed horizontal line on the sediment and mussel graphs indicates the national mean concentrations. The sediment data have been adjusted as follows. First, no data were used in comparisons among sites when the particles in the sample contained more than 80% sand (particles with diameters greater than 64 microns). Second, values for sediment containing less than 80% sand have been adjusted by dividing the analyte concentrations by the fraction of the sediment that was fine-grained (i.e., dividing by a number between 0.20 and 1.00). Values used for the sediment curves include 1984-1986 Benthic Surveillance and 1986-1989 Mussel

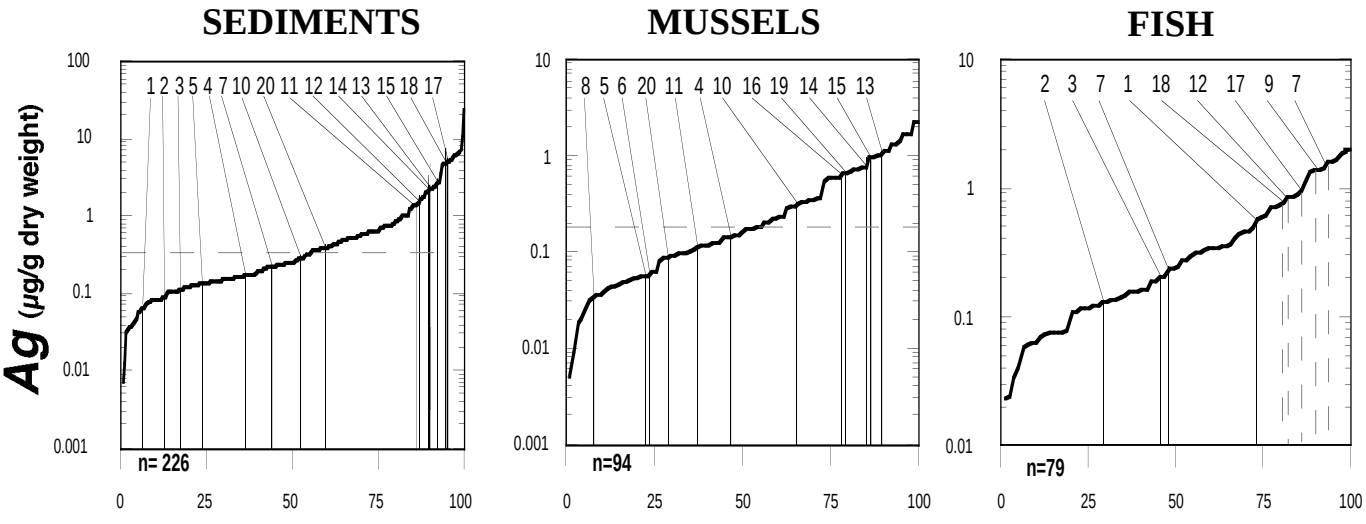

Figure 3. Distributions of metals at Gulf of Maine sites in relation to nationwide (all NS&T sites) concentrations for sediments, mussel tissues, and fish livers (Vertical scale chemical concentrations are logarithmic; the horizontal scale is cumulative percent of national sites.)

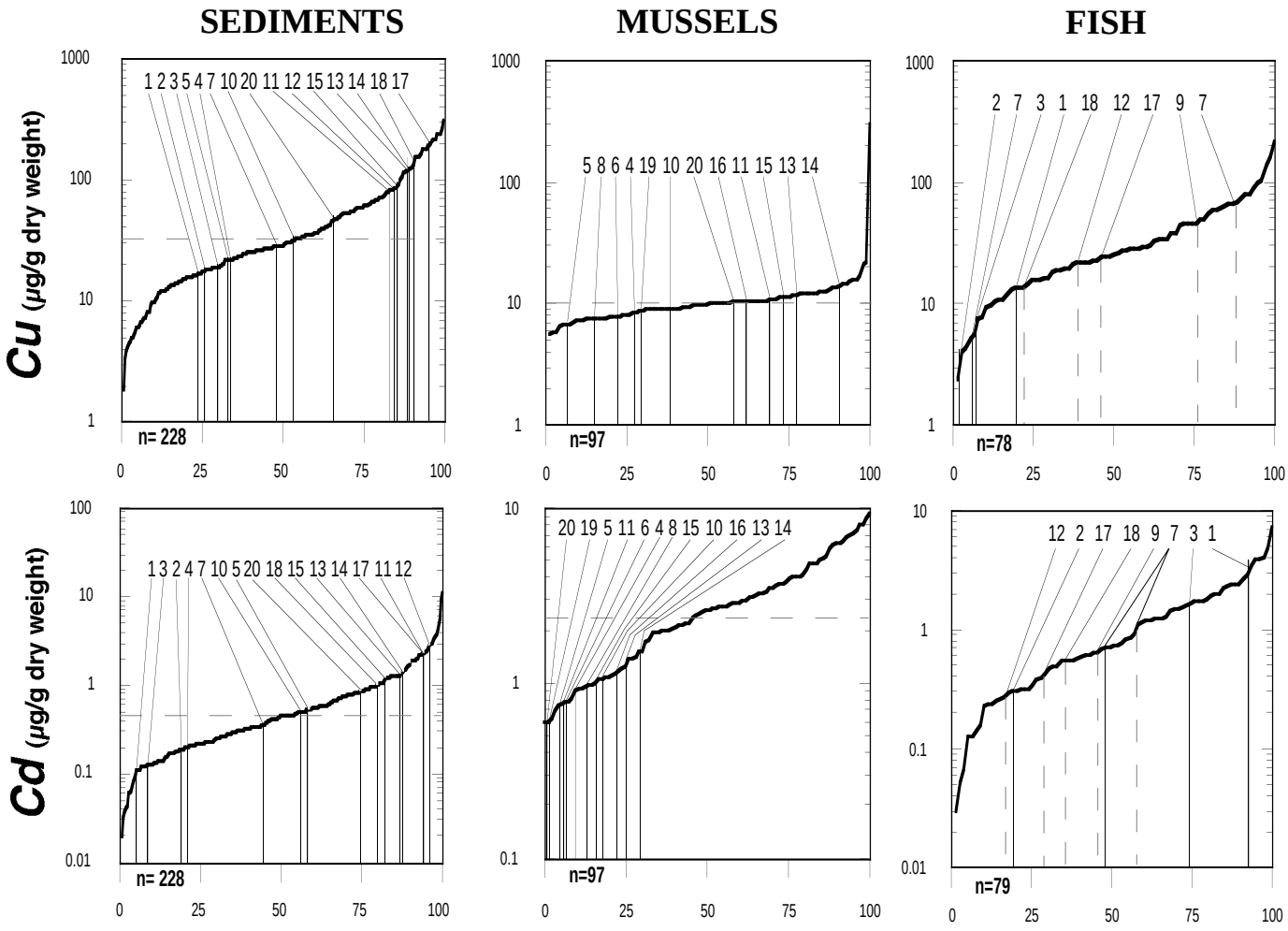

Figure 3. Continued.

Watch data.

The curves for mussels were derived from four-year means (1986-1989) of tissue data. The fish curves are derived from three-year means (1984-1986) of analyses from the livers of various species of fish nationwide (the solid vertical lines represent longhorn sculpin, while the dashed vertical lines represent winter flounder). (Note: both species were sampled in Casco Bay in 1984 with the winter flounder site located just south of the Kennebec River.) Metal concentrations are in µg/g dry weight and organic compounds are expressed in ng/g dry weight. The "n" at the bottom of each graph represents the number of sites used to create the curve.

The data summarized in this paper were collected from sites considered "representative" of conditions in the particular areas sampled (i.e., no sites were knowingly selected near waste discharge or disposal points). As with any data, they are subject to different sources of variability, such as sampling, analytical methods, and environmental factors. Because two different species of fish were sampled in the Gulf of Maine area, no comparisons are made between them since concentration levels have been shown to vary among species. Where a high concentration was >10 times higher than the next highest value (out of 3 or more detectable concentrations), that value was excluded from the mean value. This occurred at only one site, Casco Bay.

RESULTS TO DATE: METALS

The sediment data indicate that the five Boston Harbor area sites (13, 14, 15, 17, 18) have mean silver concentrations that are within the 15 highest nationally. Except for Salem Harbor, the rest of the Gulf sites are at or below the national mean. The mussel tissue data indicate that the four Boston Harbor area sites, along with the Clarks Island site, have mean silver concentrations that rank within the

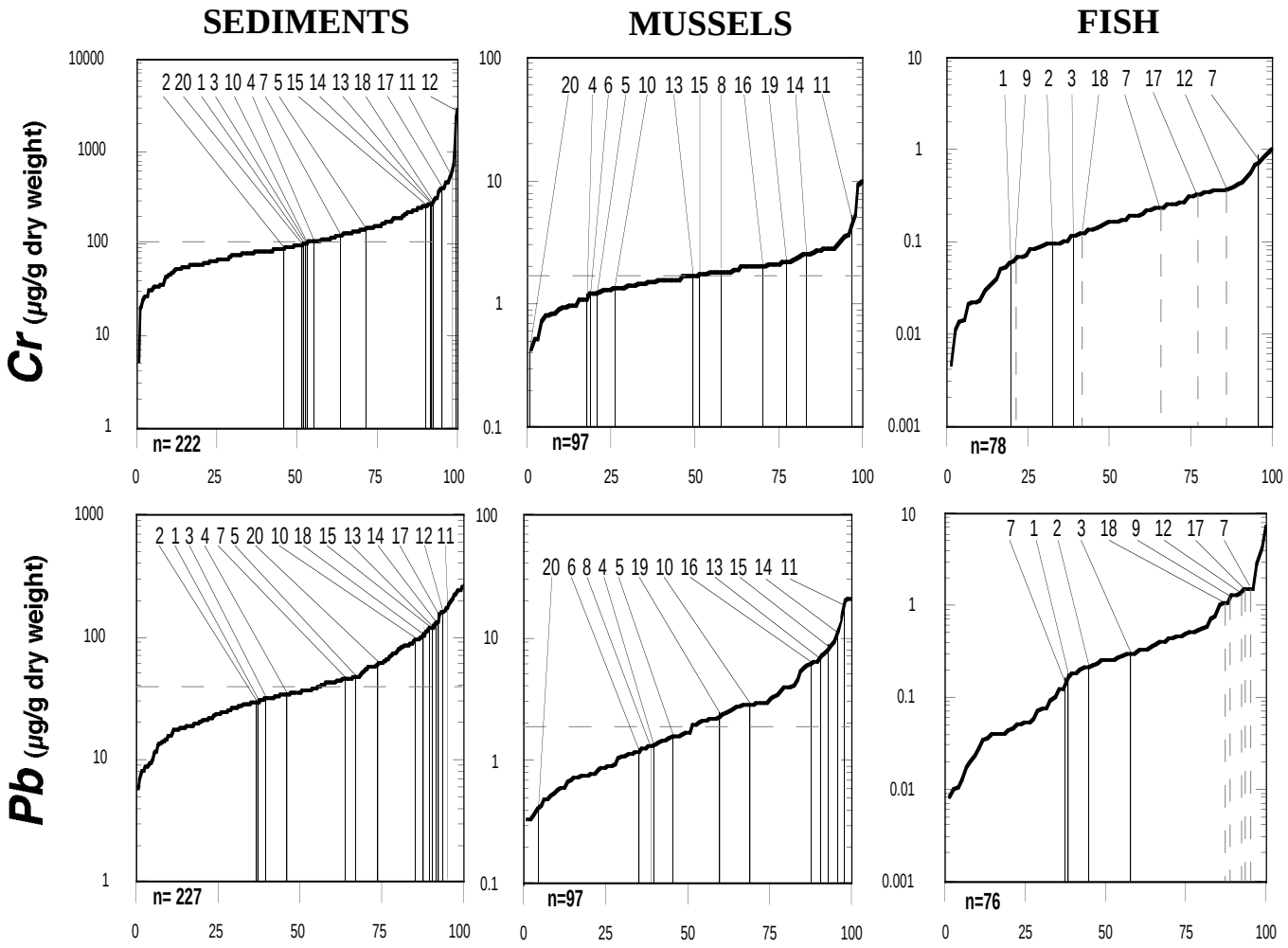

Figure 3. Continued.

20 highest nationally. The remaining Gulf sites, with the exception of Gap Head, are below the national mean. The data for winter flounder livers range from a mean low concentration of 0.9 ppm at Quincy Bay to a high of 1.6 ppm at Casco Bay. When compared to other NS&T winter flounder sites, Casco Bay and Boston Harbor have moderate concentrations of silver. Levels of silver in winter flounder were consistently higher than levels in longhorn sculpin.

Mean concentration levels of copper in the Salem and Boston Harbor area sediments are substantially higher than the mean concentrations for all other Gulf sites. Site 17 in Boston Harbor had a mean concentration of 250 ppm and was fifth highest nationally. The remaining Gulf sites are at or below the national mean. There is little variation in mean concentration levels of copper in mussel tissue throughout the Gulf area. Levels range from a low of 6.8 ppm at Pickering Island to a high of 15 ppm at Dorchester Bay. Boston Harbor sites have moderate levels of copper contamination in mussel tissues; all are above the national mean. Winter flounder liver concentrations of copper range from a low of 15 ppm at Quincy Bay to a high of 69 ppm at Casco Bay. Of all the NS&T sites where winter flounder are collected, Quincy Bay had the lowest mean concentration level of copper. As with silver, mean concentrations of copper in winter flounder were consistently higher than in longhorn sculpin.

Sediment concentrations of cadmium at NS&T sites between Salem and Nauset Harbors (sites 11-20) are considerably above the national mean for all NS&T sites. The Salem Harbor site had the second highest mean concentration (9 ppm) in the nation. Mean concentrations of cadmium in mussel tissue vary little among Gulf sites. Mean concentrations range from a low of 0.6 ppm at Nauset Harbor to a high of 1.5 ppm at Dorchester Bay. The data show that even though the Boston Harbor sites have the highest mean cadmium levels in the Gulf, when

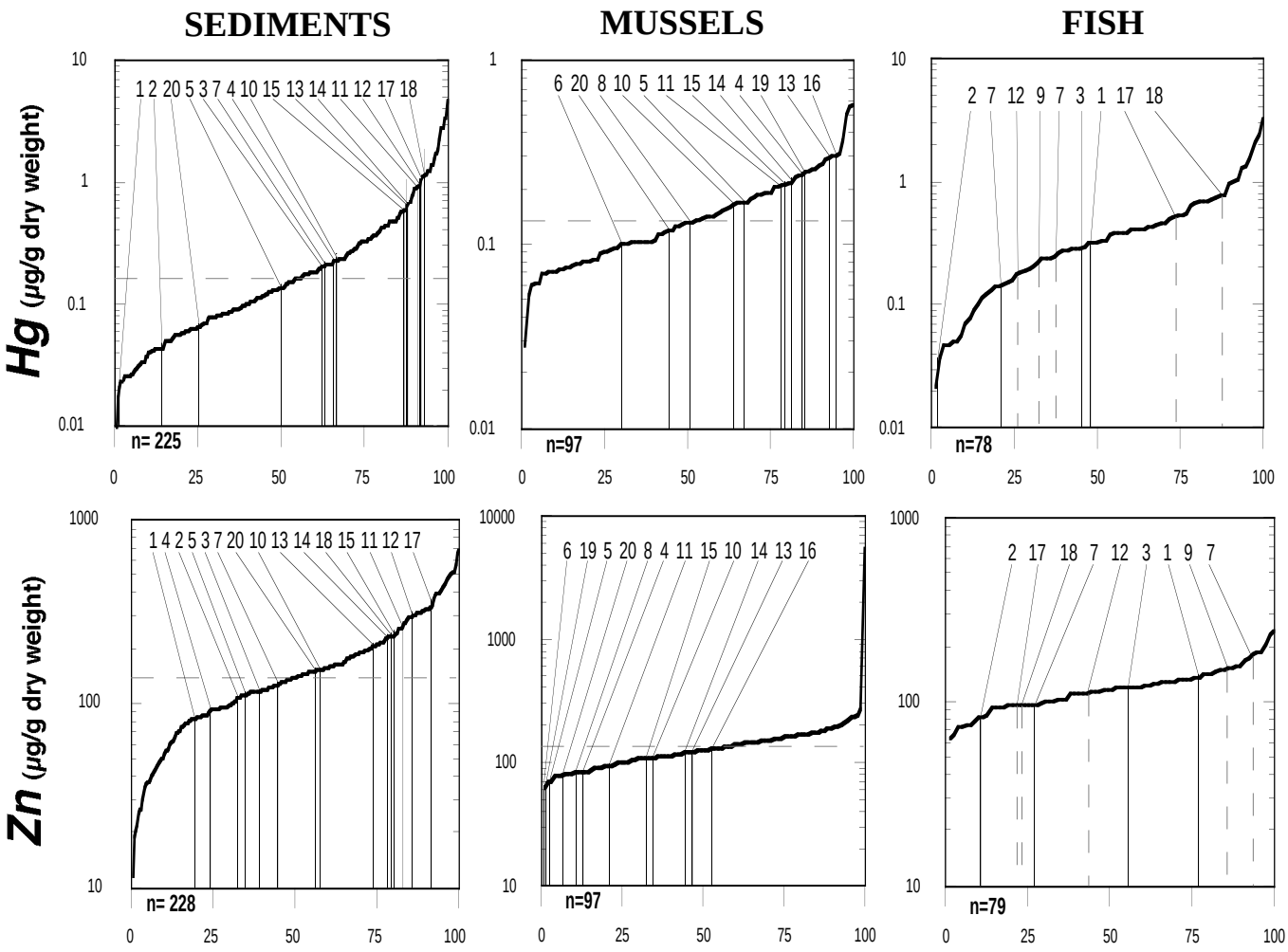

Figure 3. Continued.

compared nationally they are only in the lower third. Concentrations of cadmium in winter flounder livers range from a low of 0.3 ppm at Salem Harbor to a high of 1.1 ppm at Casco Bay. Except for Frenchmans Bay, all sites in the Gulf are at or above the national mean for chromium. Four of the five Boston Harbor area sites are within the 20 highest concentrations nationally. Salem Harbor sediments had a mean concentration of 2,800 ppm, ranking first nationally. The mean concentrations of chromium in mussel tissues ranged from a low of 0.4 ppm at Nauset Harbor to a high of 5.3 ppm at Folger Point. The data for winter flounder livers indicate that the Salem Harbor and Boston Harbor sites have mean chromium concentrations three times higher than the Quincy Bay site. The mean chromium concentration for Casco Bay longhorn sculpin is over seven times higher than Penobscot Bay, the next highest site.

Mean concentrations of lead in Salem and Boston Harbor sediments are in the upper 10 percent nationally. Mean concentrations of lead in mussel tissue at sites in Salem and the Boston Harbor area indicate high levels of contamination. All four sites in the Boston Harbor area are within the highest 12 mean concentrations nationally, while Folger Point has the second highest mean lead concentration (21 ppm) in the nation. Concentrations of lead in winter flounder livers range from a low of 1.1 ppm at Quincy Bay to a high of 7.4 ppm at Casco Bay, which ranks it second, behind Raritan Bay, for all NS&T winter flounder sites. Mean lead concentrations were considerably higher in the NS&T Gulf of Maine winter flounder sites than the longhorn sculpin sites.

The sediment data indicate that mean concentrations of mercury are substantially higher at sites in the Boston and Salem Harbor areas than anywhere else in the Gulf. Mean concentrations of mercury in mussel tissue are above the national mean for many Gulf sites. Sites in Boston Harbor, Sears Island, and Clarks Island are within the 20 highest concentra-

tions nationally. The winter flounder liver data indicate that the sites in Quincy Bay and Boston Harbor had the highest mean concentrations of mercury in the Gulf. Mean concentrations of zinc at Gulf sites are at or below the national mean; however, at Salem and Boston Harbor sites, levels of zinc are substantially higher than mean concentrations for other Gulf sites. Mean concentrations of zinc in mussel tissue vary little among Gulf area sites, with values ranging from a low of 63 ppm at Stover Point to a high of 130 ppm at Brewster Island. Concentrations of zinc in winter flounder livers range from 95 ppm at Boston Harbor to a high of 180 ppm Casco Bay.

RESULTS TO DATE: ORGANICS

Mean concentrations in sediments of total DDT (tDDT), an aggregated value of DDT and the metabolites DDD and DDE, are higher in the Salem and Boston Harbor area than at other Gulf sites. While tDDT concentrations in mussels from Salem and Boston Harbor area sites cluster around the 75th percentile, the remaining Gulf sites are below the national mean. Mean concentrations of tDDT in mussel tissue from the Folger Point and the Boston Harbor area sites are higher than other Gulf sites. The winter flounder livers collected from the Boston Harbor area sites have higher mean concentrations of tDDT than other Gulf area sites. Among NS&T winter flounder sites, Boston Harbor had the highest mean tDDT concentration (780 ppb).

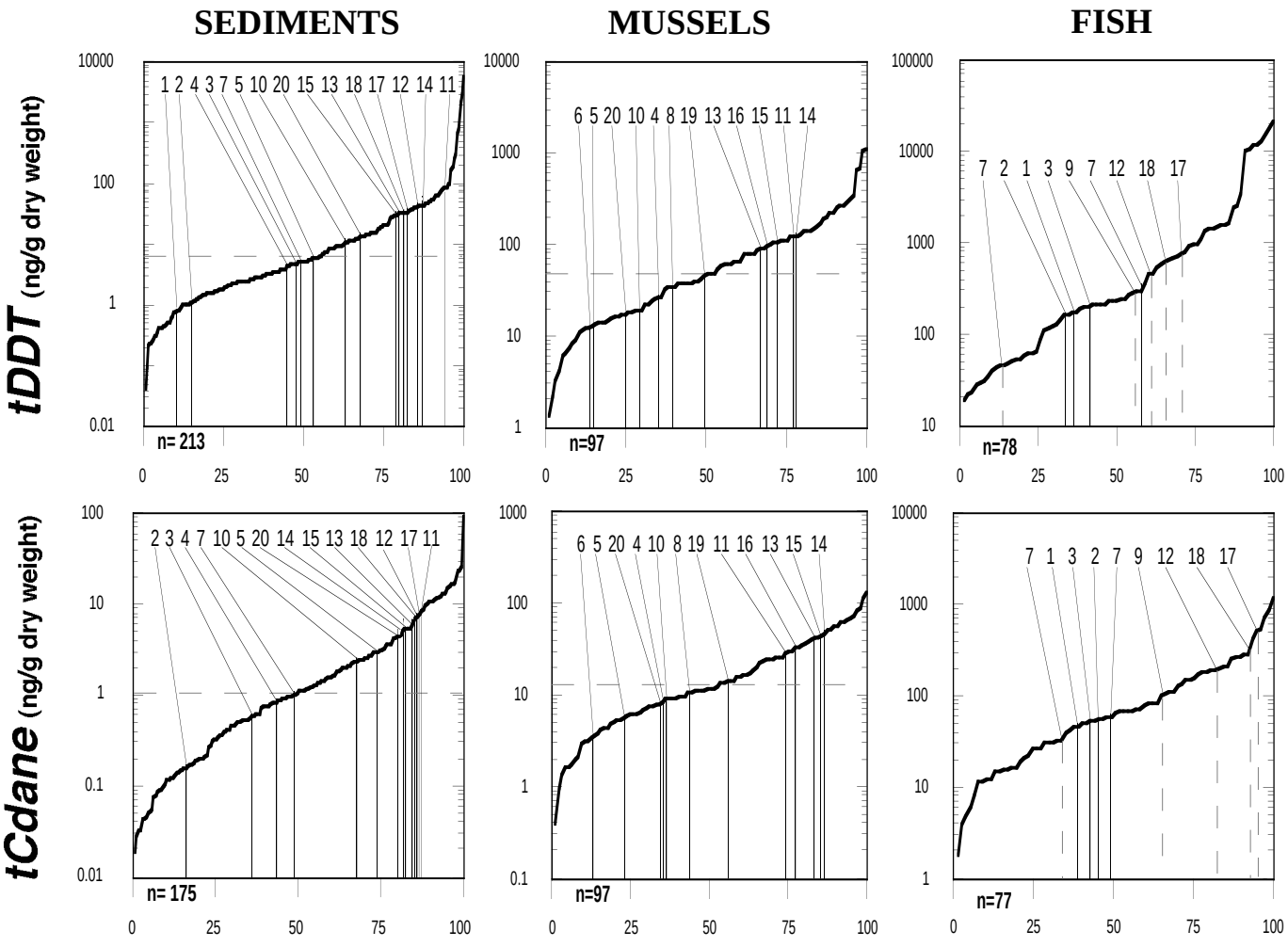

Figure 4. Distributions of organics at Gulf of Maine sites in relation to nationwide (all NS&T sites) concentrations for sediments, mussel tissues, and fish livers (Vertical scale chemical concentrations are logarithmic; the horizontal scale is cumulative percent of national sites).

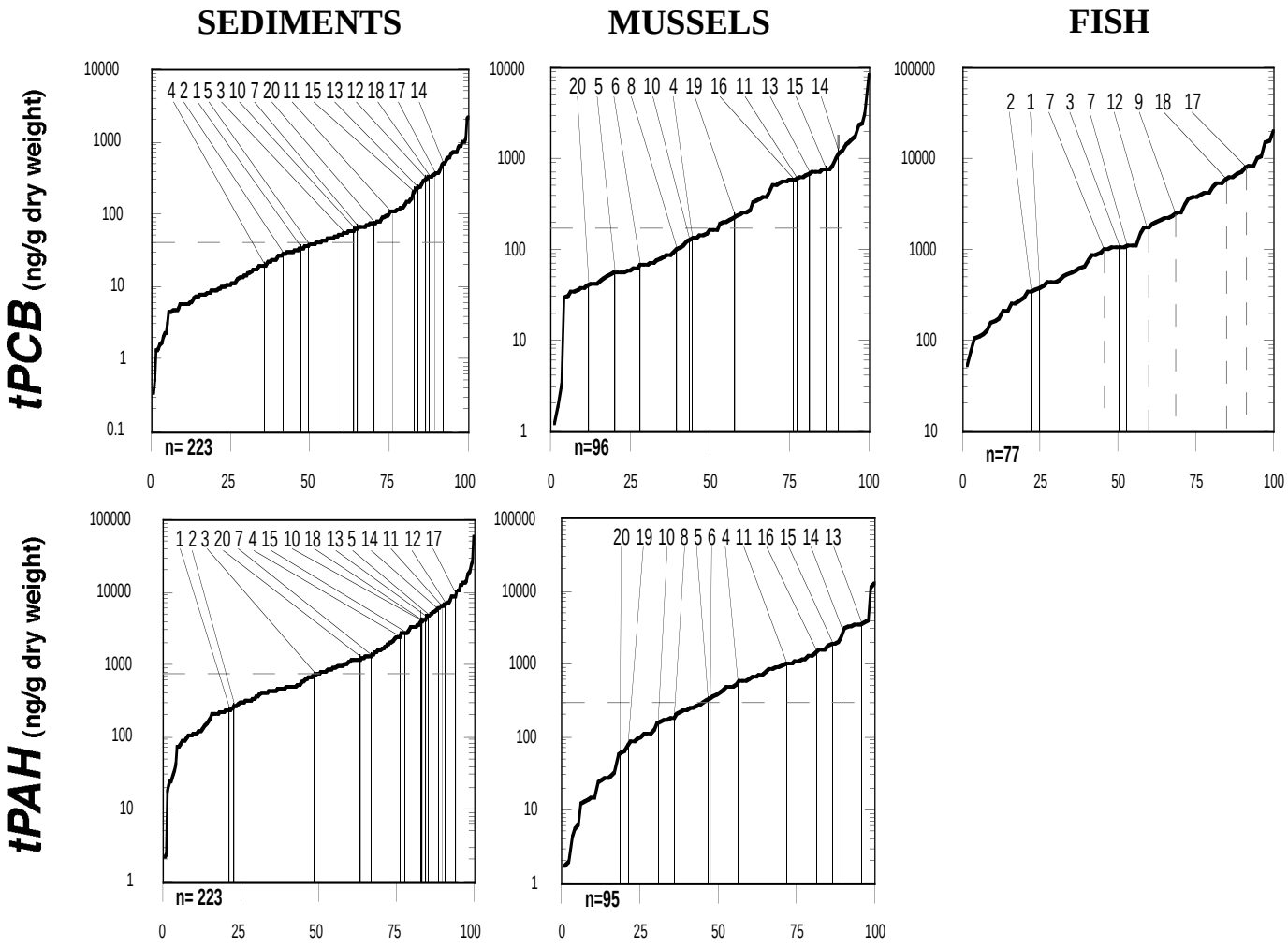

Figure 4. Continued.

Mean concentrations in sediments of total Chlordane (tCdane), the sum of concentrations of alpha-chlordane, trans-nonachlor, heptachlor, and heptachlor epoxide, are higher at the Salem and Boston Harbor area sites than for other Gulf sites. Mean concentrations of tCdane in mussel tissue from the Boston Harbor vicinity sites are above the national mean; other Gulf sites are below. Mussel tissue concentrations measured from the Boston Harbor sites are among the 20 highest nationwide. Likewise, Boston Harbor and Quincy Bay sites have higher mean concentrations of tCdane in winter flounder livers than other Gulf sites.

Sediments from sites in the Salem and the Boston Harbor area have substantially higher mean concentrations of total PCB (tPCB), an aggregate of 20 PCB congeners, than other Gulf sites. Four of the five Boston Harbor area sites rank within the 25 highest mean concentrations nationally. Folger Point and Boston Harbor area sites have higher tPCB mean concentrations in mussel tissue than found at other Gulf sites. Nationally, these sites are within the upper 25 percent. The Dorchester Bay site has a mean tPCB concentration of 1,400 ppm, over 10 times higher than the highest Maine site, Sears Island. The Boston Harbor and Quincy Bay sites have high mean concentrations of tPCB in winter flounder livers, and are within the 10 highest nationally.

Mean concentrations in sediments of total PAH (tPAH), the sum of concentrations of the 24 individual polycyclic aromatic hydrocarbons, for the Boston Harbor site are the second highest in the nation and exceed the highest Maine site, Pickering Island, by more than four times. With the exception of the two northernmost Gulf sites, all sites are above the national mean. Mean concentrations of tPAH are substantially higher in mussel tissue from sites in the Boston Harbor area than from other Gulf sites. Nationally, these sites are in the upper 20 percent, with the Deer Island site having the fourth highest mean tPAH concentration (3,600 ppb). Because

PAHs in fish livers rapidly metabolize and thereby maintain relatively low levels in their tissue (Krahn et al., 1986), tPAHs are not measured in fish livers by the NS&T Program. PAH metabolite levels are measured in fish bile; nationwide findings will be reported soon (Krahn et al., 1986).

CONCLUSIONS

Pollution Sources. In general, higher levels of contamination are characteristic of urban estuaries. However, although the Gulf is the third most densely populated coastal region in the nation and has several highly urbanized areas, it has fewer point sources (major wastewater treatment plants [MWTPs], industrial facilities, and steam-generated electric power plants) of pollution than any other region based on data from NOAA's National Coastal Pollutant Discharge Inventory. Figure 5 shows the location of point sources in the Gulf of Maine region. Boston is the only major city in the U.S. that does not treat its sewage beyond the primary level (separation of sewage into effluent and sludge) (Connor and Gibson,1990). The greatest number of point sources are located in the Boston Bay area, where industrial sources are four times higher than municipal point sources. However, Connor and Gibson, (1990), state that "the major sources of contamination to the harbor are effluent, sludge, combined sewer overflows (CSOs), river stormwater, and the atmosphere... Industrial discharges that go directly into the harbor (or to a river that feeds into the harbor) are relatively unimportant compared to these other sources."

High loads of toxic contaminants to an estuary can result in the accumulation of these materials in bottom sediments and estuarine organisms such as fish and shellfish. An estuary's susceptibility to dissolved contaminants can be measured by its ability to flush and/or dilute pollutants. NOAA has developed a relative classification index to approximate the ability of an estuary to retain dissolved and particulate-attached pollutants. This susceptibility is based on two features. "Dissolved Concentration Potential" (DCP) characterizes the effect of flushing and estuarine dilution on a load of dissolved pollutant. A high DCP value indicates that an estuary is likely to retain or concentrate a dissolved pollutant. "Particle Retention Efficiency" (PRE) is an estimate of the relative ability of an estuary to retain or "trap" suspended particulates along with attached pollutants (Klein et al., 1988). In general, the lower an estuary's flushing rate to the open ocean and the smaller its volume for diluting pollutants, the greater its susceptibility to retain dissolved pollutants. Table 1 presents estuarine characteristics taken from NOAA's National Estuarine Inventory.

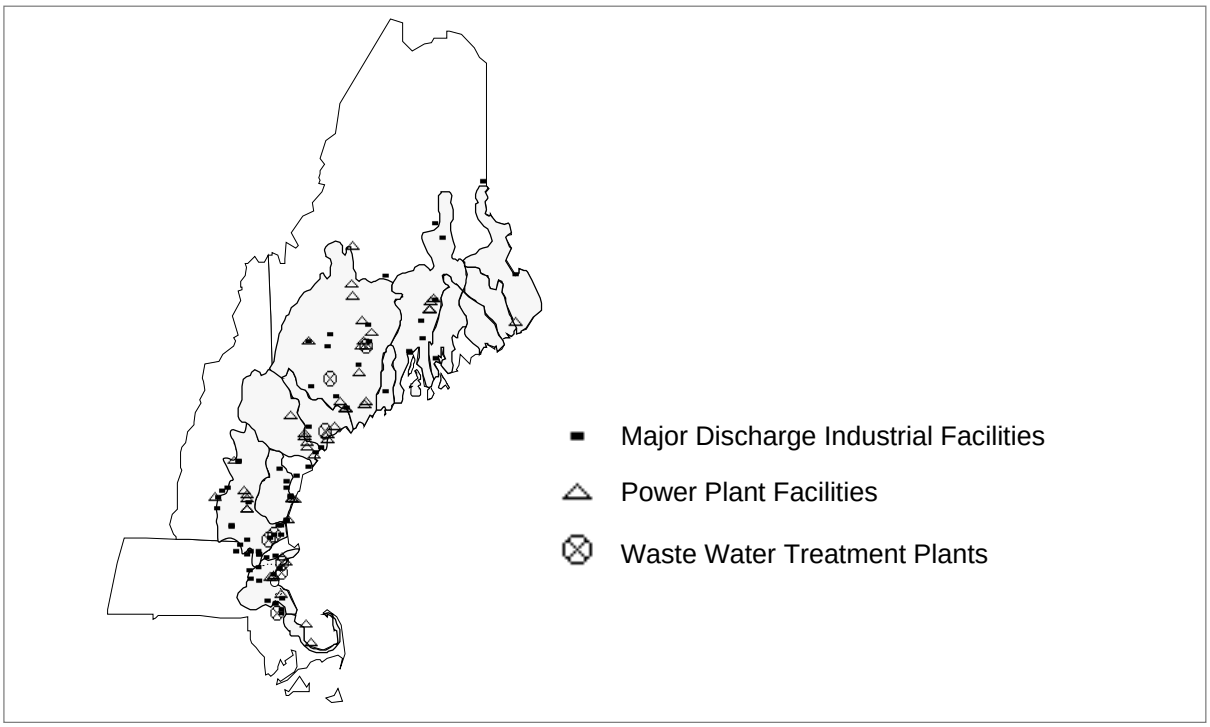

Figure 5. Sources of pollutant discharge (Source: modified from NOAA, 1990b)

As stated earlier, the Gulf of Maine estuaries are primarily tidally flushed, with extremely low freshwater inflow. Sheepscot Bay and Penobscot Bay have the greatest freshwater inflows. However, these volumes are lower than the mean for all U.S. estuaries. This, and other attributes, such as the predominantly high PRE values, contribute to Gulf estuaries exhibiting the highest sensitivities to both dissolved and particulate-attached pollutants in the nation (Basta et al., 1990).

Natural Variability. In any sampling program, areas can be found which are relatively restricted, have little circulation, and where contaminant levels are higher than those in surrounding areas. The Gulf of Maine exhibits some of these features with its many enclosed harbors and embayments.

Variations in precipitation can have a marked influence on the inputs of contaminants. The Massachusetts Division of Marine Fisheries has determined that levels of pathogens in Boston Harbor's shellfish beds are directly related to rainfall, and utilize this information in the management of shellfish resources (Connor and Gibson, 1990). On the other hand, in other areas, large amounts of precipitation can decrease contaminant concentrations near mussel beds by diluting the inputs from point sources. Strong tides and storms also have a marked effect on contaminant levels in coastal waters by exposing and resuspending sediments, causing the resuspension of sediment-associated contaminants within the water column.

NS&T Findings. Metal concentrations found in sediments from the NS&T sites in the Gulf of Maine region show that the five Boston Harbor area sites, along with the Salem Harbor and Folger Point sites, are highest. Nationally, the Salem Harbor site had the highest mean concentration for Cr and the second highest mean concentration for Cd. Boston Harbor Site 17 had the second highest mean concentration for Ag. Among Gulf of Maine sites, concentrations of metals in mussel tissue from the four Boston Harbor sites are in the top five for five metals (Ag, Cu, Cd, Pb, and Zn). Three of the four sites rank in the top five for Hg and two sites rank in the top five for Cr. Nationally, the Folger Point site has the second highest mean concentration level for Pb and the third highest for Cr. Comparison among Gulf of Maine sites shows that for mean concentrations of metals in winter flounder livers, the Casco Bay site ranks highest in four metals (Ag, Cu, Pb, and Zn) and has the third highest mean concentration level for Pb among the 11 NS&T sites sampled for winter flounder. Casco Bay ranked significantly higher than either of the two heavily industrialized sites in the Gulf, Salem and Boston Harbors, for all metal concentrations except Cr and Hg. More focused work is indicated for Casco Bay. There may be sites in Casco Bay with higher concentrations of metals in sediments where these fish have been exposed. However, there is also evidence that the livers of fish from NS&T sites with high organic concentrations may actually have lower than predicted levels of metals, implying a potentially complex physiological response in fish.

In the Gulf, mean concentrations of organics in sediments from four of the five Boston Harbor area sites rank in the top five for three organics (tDDT, tCdane, and tPCB) and three of the five are in the top

Table 1. Selected Estuarine Characteristics (Source: modified from NOAA, 1990a)

ESTUARY	Estuarine Drainage Area (100 sq. mi.)	Total Drainage Area (100 sq. mi.)	Water Surface Area (sq. mi.)	Avg. Depth (ft.)	Avg. Daily Freshwater Inflow (100 cfs)	Volume (billion cu. ft.)	Point Pollution Industrial	Sources of (1982-87 data) MWTP	Susceptibility to Pollution DCP	PRE
Passamaquoddy Bay	32	32	157	72	62	315	8	5	M	H
Englishman Bay	9	9	76	38	16	80	9	4	M	H
Narraguagus Bay	4	4	70	32	9	63	2	1	H	H
Blue Hill Bay	8	8	115	75	13	241	15	8	H	H
Penobscot Bay	32	94	361	72	161	725	29	16	M	H
Muscongus Bay	3	3	72	43	6	85	1	7	H	H
Sheepscot Bay	62	101	103	41	176	118	8	12	L	M
Casco Bay	12	12	164	42	21	191	40	10	M	H
Saco Bay	18	18	17	32	36	15	8	9	M	M
Great Bay	10	10	15	11	20	5	29	30	H	L
Merrimack River	23	50	6	12	84	2	29	7	H	L
Massachusetts Bay	12	12	364	77	29	786	56	16	M	H
Boston Bay	7	7	69	26	18	50	55	14	H	M
Cape Cod Bay	8	8	548	77	18	1178	4	4	M	H
Total	**233**	**361**	**2068**	**48**	**651**	**3804**	**238**	**129**		

five for tPAH. The Boston Harbor site had the second highest mean concentration for tPAH nationally. In general, the data indicate a gradient decrease in tPAH concentrations as the site distance increases from the highly urbanized Greater Boston area. Comparison of the Gulf of Maine sites for organic levels in mussel tissues shows that the four Boston Harbor area sites ranked highest in tCdane and tPAH, and ranked in the top five for tDDT and tPCB along with the Folger Point site. Sears Island, Stover Point, and Pickering Island exhibit moderately high levels of tPAH. Comparison of the

DDT and its metabolites	Polycyclic aromatic hydrocarbons	Major elements
2,4'-DDD	2-ring	Al*
4,4'-DDD	Biphenyl	Fe
2,4'-DDE	Naphthalene	Mn
4,4'-DDE	1-Methylnaphthalene	Si
2,4'-DDT	2-Methylnaphthalene	
4,4'-DDT	2,6-Dimethylnaphthalene	
	1,6,7-Trimethylnaphthalene	
tetra-, tri-, di-, and monobutyltins	3-ring	**Trace elements**
	Fluorene	
	Phenanthrene	Sb
	1-Methylphenanthrene	As
Chlorinated pesticides other than DDT	Anthracene	Cd
	Acenapthene	Cr
	Acenaphthylene	Cu
Aldrin		Pb
cis-Chlordane	4-ring	Hg
trans-Nonachlor	Fluoranthene	Ni
Dieldrin	Pyrene	Se
Heptachlor	Benz(a)anthracene	Ag
Heptachlor epoxide	Chrysene	Sn
Hexachlorobenzene		Zn
Lindane (gamma-HCH)	5-ring	
Mirex	Benzo(a)pyrene	
	Benzo(e)pyrene	
	Perylene	
Polychlorinated biphenyls	Dibenz(a, h)anthracene	
	Benzo(b)fluoranthene	
PCB congeners 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 126, 128, 138, 153, 179, 180, 187, 195, 206, 209	Benzo(k)fluoranthene	
	6-ring	
	Benzo(ghi)perylene	
	Indeno(1,2,3-cd)pyrene	
Toxaphene at some sites	**Related parameters**	
	Grain Size	
	Total Organic Carbon (TOC)	

*Symbols are Al (aluminum), Fe (iron), Mn (manganese), Si (silicon), Sb (antimony), As (arsenic), Cd (cadmium), Cr (chromium), Cu (copper), Pb (lead), Hg (mercury), Ni (nickel), Se (selenium), Ag (silver), Sn (tin), Zn (zinc)

Table 2. List of NS&T chemicals

Gulf sites for organic concentration levels in winter flounder livers shows that Boston Harbor Site 17 and the Quincy Bay site are the top two for tDDT, tCdane, and tPCB. Nationally, Boston Harbor Site 17 has the third highest mean concentration level of tCdane.

In comparison to many of the nation's coastal waters, the Gulf of Maine NS&T sites are in relatively good condition with respect to toxic contaminants except in the vicinity of the highly urbanized areas around Boston and Salem. Increased demands on the Gulf's resources, such as population growth, land usage, and discharge from urban, industrial, and agricultural activities may exert increasing adverse effects on its ecosystem. The NS&T Program is continuing to sample and monitor temporal trends and to determine the effects of selected contaminants (Table 2) on marine organisms.

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APPENDIX

The appendix lists the Gulf of Maine NS&T sites sampled in the Benthic Surveillance Program from 1984-1986 and the Mussel Watch Program from 1986-1989. Benthic Surveillance sites are listed in bold italic with only a general site name. Mussel Watch sites are given both a general and specific site designation. If all sediment samples from a site contained more than 80% sand-sized particles, that site is indicated to be sandy and chemical data from it have not been used when comparing among sites. The last columns indicate which chemical concentrations, if any, at a site exceeded concentrations that are 'high' [•] (more than the mean plus one standard deviation of the log-normal distribution for all sites) or 'very high' [• •] (more than the mean plus two standard deviations of the log-normal distribution for all sites).

NS&T Sediment Data

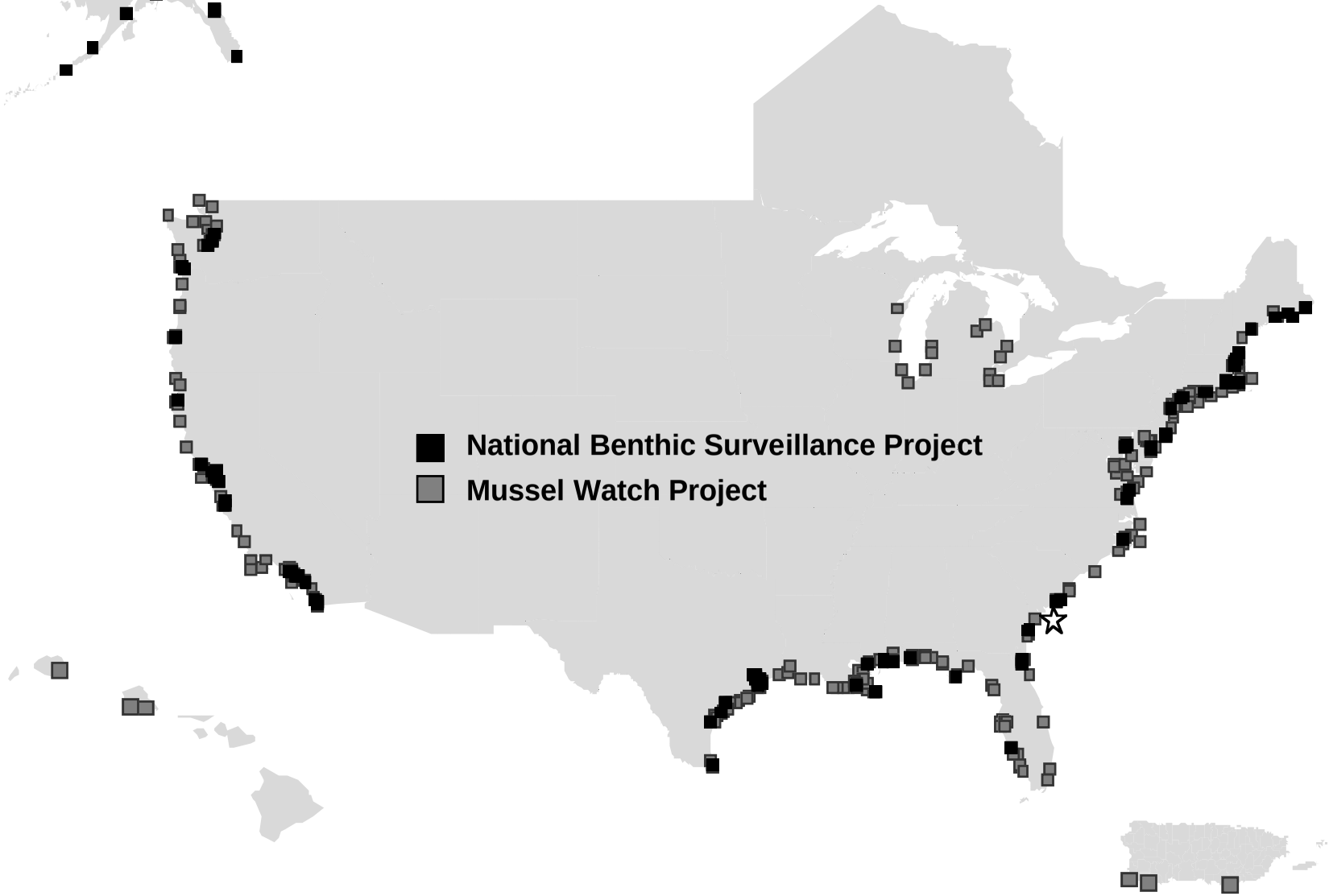
General Site	Specific Site	Type	Cd	Cr	Cu	Pb	Hg	Ag	Zn	tDDT	tCdane	tPCB	tPAH
Maine													
Machias Bay													
Frenchmans Bay													
Penobscot Bay													
Penobscot Bay	Sears Island												
Penobscot Bay	Pickering Island												•
Merriconeag Sound	Stover Point					•					•		
Casco Bay													
Cape Arundel	Kennebunkport	Sandy											
Massachusetts													
Merrimac River		Sandy											
Cape Ann	Gap Head					•							•
Salem Harbor	Folger Point		• •	• •	•	• •	•	•	•	•			•
Salem Harbor			• •	• •	•	• •	• •	•	•	•	•	•	•
Boston Harbor	Deer Island		•	•	•	•	•	• •				•	•
Boston Harbor	Dorchester Bay		•	•	•	•	•	• •		•	•	•	•
Boston Harbor	Hingham Bay		•	•	•	•	•	• •				•	
Boston Harbor	Brewster Island	Sandy											
Boston Harbor			• •	•	• •	• •	• •	• •	•	•		•	• •
Quincy Bay				•	•	•	• •	• •		•	•	•	•
Duxbury Bay	Clarks Island	Sandy											
Cape Cod	Nauset Harbor												

NS&T Mussel Watch Data

General Site	Specific Site	Cd	Cr	Cu	Pb	Hg	Ag	Zn	tDDT	tCdane	tPCB	tPAH
Maine												
Penobscot Bay	Sears Island											
Penobscot Bay	Pickering Island					•						
Merriconeag Sound	Stover Point											
Cape Arundel	Kennebunkport											
Cape Ann	Gap Head											
Massachusetts												
Salem Harbor	Folger Point		• •		• •							
Boston Harbor	Deer Island				•	•	•			•		•
Boston Harbor	Dorchester Bay				• •	•	•			•	•	•
Boston Harbor	Hingham Bay				•		•			•	•	
Boston Harbor	Brewster Island				•	•						
Duxbury Bay	Clarks Island					•						
Cape Cod	Nauset Harbor											

National Status and Trends Program

National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean Resources Conservation and Assessment
Coastal Monitoring and Bioeffects Assessment Division



NOAA ship Ferrel

January 1992