**Report**

# Assessment of Sediment Contamination in Casco Bay

**Submitted by**

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## 1.0 Executive Summary

Contaminant concentrations of sediment samples collected approximately 10 years apart are compared in an attempt to establish current status of contaminant concentrations in Casco Bay, to determine whether contaminant concentrations are increasing, decreasing or remain unchanged, and to examine any changes in the geographical distribution of contaminants. This process is complicated by the potential of re-suspension of older sediment back to the surface, the non-homogeneity of sediments, low concentrations for some analytes and variability of different analytical methods. In spite of these complications several trends are observed. As expected, most of the contaminants appear to be decreasing in concentrations. Total PAH concentrations in the sediment are an exception. When comparing total PAH concentration in 1991 and 2001, there is neither an increase nor a decrease when the analytical uncertainties are considered. The continuing increased use of fossil fuels that may add additional PAH to the sediments appears to be balanced by increasing controls that lower PAH inputs. Total pesticides as well as 4,4-DDE, 4,4-DDD and total DDTs indicate a decrease from 1991 to 2000/2001. Total PCB concentrations also suggest a decrease over this time period. Silver is the only trace element increasing in concentration at most sampling sites from 1991 to 2001. The reason for this difference is not clear. Concentrations decreased at the majority of the sampling sites for cadmium, chromium, mercury, nickel, and selenium with no apparent difference for arsenic, copper lead and zinc. Tributyltin and total butyltin concentrations decreased over the time period from 1994 to 2000/2001. The overall indication for dioxin/furans is no change between sampling periods. The planar PCB indicates no change (PCB 77) or decreasing concentrations (PCB 126). With the many complicating factors, the interpretation of these data needs to be done with care. There is no indication from these data that any of the contaminants measured has increased by more than a factor of 2. At most Casco Bay sites and for most analytes there is either no change or a decrease. There are sites where increases are apparent and many of these sites are at the shallow water sites or at the Inner Bay sites where concentrations are higher and new inputs are more likely.

Sediments from the Inner Bay region of Casco Bay; closest to Portland, ME; contain the highest levels of trace metals, PCBs, DDTs, and chlordane. For contaminants other than PAH (and these only at a few locations) and PCBs at one location, the levels of contamination in Casco Bay would not be considered high on a national basis, based on Macauley et al. (1994). The geographical distribution of most contaminants remains similar to those determined in 1991/1994. There are generally higher contaminant concentrations in the vicinity of Portland and other populated and industrial areas. Toxicity tests for selected sites and comparison of contamination concentrations to ERL or ERM indicate the sediments are not toxic. The overall conclusion based on the available data is that the contaminant loading for Casco Bay, as a whole, is decreasing or remaining the same and these concentrations are not likely to adversely affect the biota. The geographic distribution of sediment contaminants is generally confirmed in the analysis of mussel tissue by the Casco Bay Estuary Project and the Maine Department of Environmental Protection (DEP) (Doggett, DEP, personal communication).

# 2.0 Introduction and Background

## 2.1 Overview

Casco Bay is located on the coast of Maine in Cumberland County. The major city on the bay is Portland. The bay serves as a major docking facility and the principal fishing port of Maine (Larsen et al., 1983a). The embayment is over 28 miles long and averages 8 miles in width. It is characterized by numerous islands that are highs between glacial scoured valleys. The rivers provide an average daily inflow to the bay of 60 $m^3$/sec of freshwater. The highest average flow rates (NOAA 1985) are in April (137 $m^3$/sec) and the lowest in September (23 $m^3$/sec). Cumberland County, with a surface area of 3000 $km^2$, accounts for most of the drainage basin for the Casco Bay estuary. The average tidal range for the bay is approximately 2.7 m (NOAA 1985). The geology of this region is controlled by the Paleozoic bedrock structure which was sculpted by glacial ice movements at 70 to 90 degrees to the structural grain. The bedrock in this region is composed of high grade meta-sedimentary rocks (Kelley, 1987). Casco Bay can be subdivided into three depositional regions; an inner, middle, and outer region (Belknap et al., 1987). The outer region is characterized by virtually no sediment cover on bathymetric highs with no major sediment accumulation in bathymetric lows. This region is strongly influenced by wave action resulting in low sediment accumulation rates. This wave action is the dominant factor affecting the coastlines of the outer islands. The middle region has a thicker till, evidence of glacial marine sediment (the Presumpscot formation) and Holocene mud. The inner region characterized by sedimentary accumulation with thick Holocene mud, drowned stratified sands, and only a slightly reworked Pleistocene section (Belknap et al., 1987)

Casco Bay has a wealth of natural resources including marine habitats that support a rich and diverse ecology. Casco Bay's natural beauty, clean water, abundant fish and waterfowl, and its deep and protected waters have made it a sought-after location for residences, business, industry, and recreation. However, these same activities may add contaminants that pose a threat to the environmental integrity of the bay. Casco Bay receives freshwater from rivers that discharge directly into the bay (Fore, Presumpscot, Cousins, and Royal Rivers). It also appears that the Kennebec/Androscoggin River, which discharges just north of Casco Bay, may be a source of water and contaminants to the bay under certain wind and current conditions. The most densely populated portions of the Casco Bay watershed are Portland, the banks of the Fore and Presumpscot Rivers, and Back Cove. These areas may receive higher inputs of selected contaminants compared to other regions of Casco Bay.

Casco Bay can be sub-divided into five areas: Inner Bay, Outer Bay, West Bay, East Bay, and Cape Small. Figure 1 show the Casco Bay sampling region divided into the five geographic areas. The Inner Bay is bounded on the southwest by Portland Harbor, the northwest by the shore, the northeast by Cousins Island and the southeast by the series of islands running in a line from Great Chebeague Island to Cushing Island. West Bay is the area to the north of Cousins Island and west of Highway 24, and includes Maquoit Bay, Merepoint Bay, Middle Bay, and Harpswell Sound. West Bay is bounded to the south by a line extending from Great Chebeague Island to the east to the southern tip of Little Whalebone Island, to the southern tip of Whalebone Island, extending to the east alone the southern tips of the islands from Whalebone to Haskell Island and continuing to the southern tip of Jaquish Island. East Bay is the area bounded to the east by the eastern boundary of West Bay, to the west by the eastern shore of the New Meadows River, extending southward along the eastern shore to the middle of Hermit Island. East Bay is bounded to the south from the southern tip of Jaquish Island eastward to a point approximately 4 miles east of Small Point, then along an arc including the western shore of Mark Island and the southern shore of Wood Island to Hermit Island. The Outer Bay is bounded on the northwest by the islands forming the southeast boundary of the Inner Bay, to the north by the southern boundaries of West and East Bays and an arc from the point approximately 4 miles east of Small Point extending to the east boundary. Cape Small is defined as the area located to the east of the Outer Bay eastern boundary.

Casco Bay has been designated as an Estuary of National Significance and included in the U.S. EPA's National Estuaries Program (NEP). The goal of the Casco Bay NEP is to protect and improve the water quality and enhance living resources by developing a Comprehensive Conservation and Management Plan that works to ensure its ecological integrity. As part of the development of the Plan, an assessment of sediment contamination for trace elements, hydrocarbons (including Polynuclear Aromatic Hydrocarbons (PAH)), chlorinated pesticides and PCB was undertaken in 1991 and results reported (Kennicutt et al., 1992; Kennicutt et al., 1994). Surface sediment samples (top 2 cm) were collected from 65 sites in Casco Bay in 1991. The sites were selected based on depth, circulation, sediment type and historical data. In 1994, 28 of the original sampling sites were sampled in order to assess the contamination of surface sediments for butyltin, dioxin/furan and planar PCB and five additional sampling sites were added. Two of the new sites were analyzed for dioxin/furan and planar PCB while the other three sites were analyzed for butyltins. The results for this assessment were also reported (Wade et al., 1995a; Wade et al., 1995b). Recently, another assessment of sediment contamination in Casco Bay was initiated in 2000/2001 with the collection and analyses of sediments from most of the original sediment sampling sites and selected additional sites.

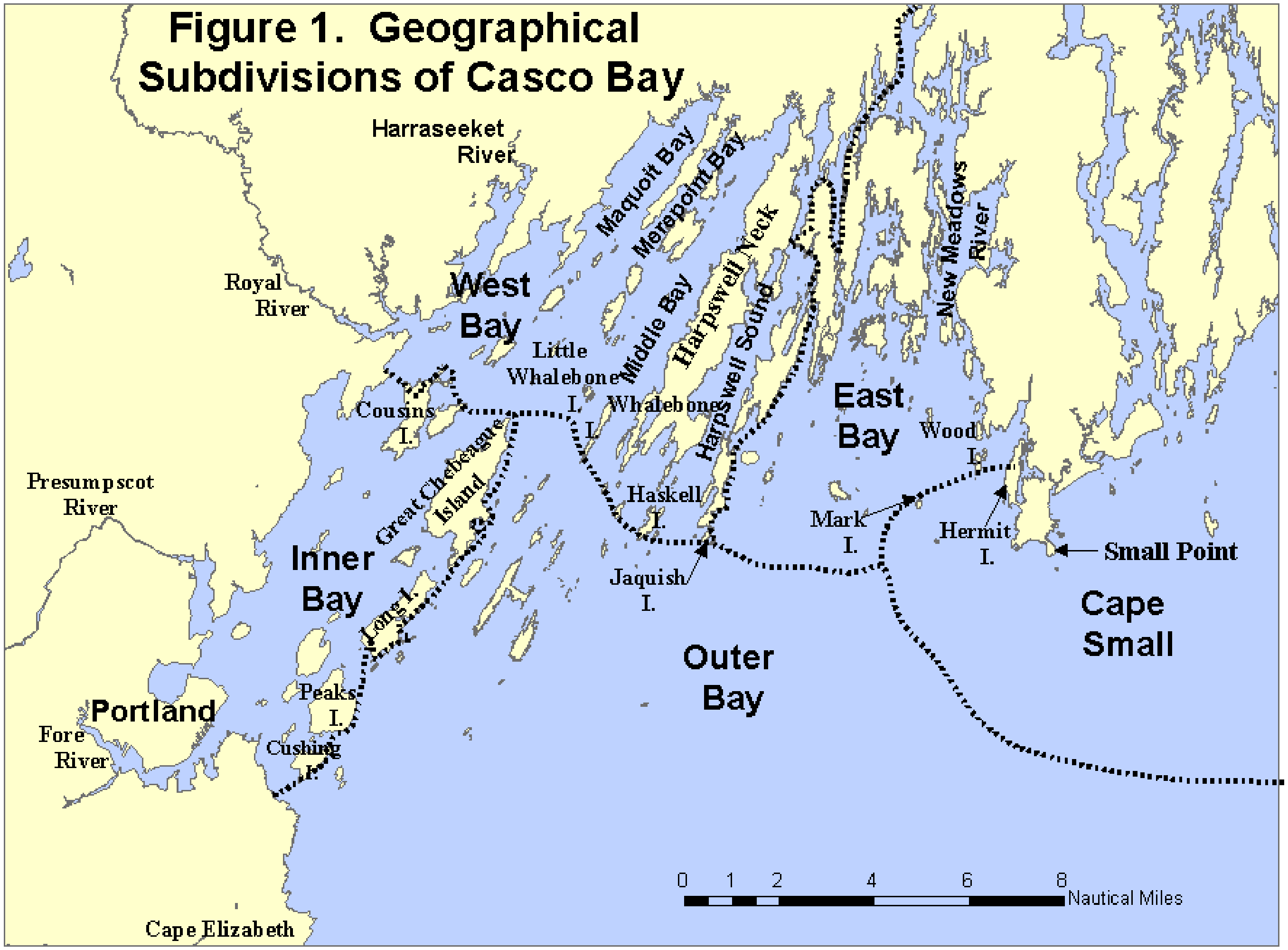


Figure 1. Geographical Subdivisions of Casco Bay

The Casco Bay Environmental Monitoring Program called for the retesting of sediments in the year 2000. Building on the opportunity to partner with EPA's Coastal 2000/National Coastal Assessment (NCA) program, the Casco Bay Estuary Project/NCA re-sampled the sediments at the 70 original stations during the summers of 2000 and 2001. In addition, EPA's Office of Water funded sampling for sediment chemistry (metals, PAHs, pesticides and PCBs, TOC, grain size) and toxicity parameters at 18 new randomly selected sites.

The Casco Bay Estuary Project wishes to develop a sediment contamination assessment report based on the data from the 1990 projects compared to the data from the 2000/2001 project. This assessment report updates the conclusions (Kennicutt et al., 1992; Kennicutt et al., 1994; Wade, et al., 1995a; Wade et al., 1995b) from the previous work. The assessment attempted to determine if there are temporal trends for the contaminant concentrations between sampling periods. The current assessment also considers other recent relevant data and effect range low (ERL) and effects range medium (ERM) criteria and compares concentrations to sediment quality guidelines to determine the potential to cause adverse effects to biota. Sediment toxicity data (based on *Ampelisca* toxicity test significance) collected at 30 sites in Casco Bay by the NCA was also examined in an attempt to assess the toxicity of Casco Bay sediments and compare it to contaminant concentrations. Table 1 shows selected analytes from both sampling periods and their relationship to sediment quality guidelines (SQG) developed for the National Status and Trends Program from work by Long and Morgan (1990), Long et al. (1995), Long et al. (1998), and Field et al. (1999).

## 2.2 Historical Data

In the previous study (Kennicutt et al., 1994), the Casco Bay sediments collected were generally characterized as fine-grained sediments with median total organic carbon (TOC) greater than or equal to 2%, except in the Cape Small area where sandy sediments with a median TOC concentration of 0.2% were found. The shallow water sediments are generally coarser grained and had a median TOC concentration of 1.5%. Coarser grained sediment in the shallow water is expected since tidal and wave activity can transport the finer material away from shore.

In 1991, 65 sites in Casco Bay were sampled and the sediments analyzed for organic and inorganic contaminants. One or more anthropogenic contaminants; trace metals, PCB's, DDT, chlordane, or polycyclic aromatic hydrocarbons (PAH); were detected at all locations sampled. The geographic distribution of contaminants is initially controlled by the frequency of

## Table 1. Summary Data from Casco Bay Regions for Both Sampling Periods with ERL and ERM Guideline Values (From Long et al. 1995).

| | Guidelines | | Percent incidence of Effects | | | Inner Bay | | | | West Bay | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical | Effects Range Low (ERL) | Effects Range Median (ERM) | Less Than ERL | Between ERL and ERM | Greater Than ERM | Minimum Conc. | | Maximum Conc. | | Minimum Conc. | | Maximum Conc. | |
| | | | | | | 1991 | *2000/2001* | 1991 | *2000/2001* | 1991 | *2000/2001* | 1991 | *2000/2001* |
| **Trace Elements (ppm)** | | | | | | | | | | | | | |
| Arsenic | 8.2 | 70 | 5.0 | 11.1 | 63.0 | 1.6 | *1.0* | 16.0 | *16.0* | 4.8 | *4.0* | 19.6 | *16.0* |
| Cadmium | 1.2 | 9.6 | 6.6 | 36.6 | 65.7 | 0.2 | *0.0* | 0.9 | *0.7* | 0.1 | *0.1* | 0.5 | *0.5* |
| Chromium | 81 | 370 | 2.9 | 21.1 | 95.0 | 31.0 | *20.0* | 91.0 | *96.0* | 35.0 | *33.0* | 100.0 | *97.0* |
| Copper | 34 | 270 | 9.4 | 29.1 | 83.7 | 7.9 | *4.0* | 48.4 | *44.0* | 7.0 | *7.0* | 26.2 | *25.0* |
| Lead | 46.7 | 218 | 8.0 | 35.8 | 90.2 | 27.5 | *26.8* | 75.6 | *76.0* | 20.5 | *20.8* | 37.6 | *37.7* |
| Mercury | 0.15 | 0.71 | 8.3 | 23.5 | 42.3 | 0.06 | *0.00* | 0.42 | *0.49* | 0.02 | *0.01* | 0.10 | *0.13* |
| Nickel | 20.9 | 51.6 | 1.9 | 16.7 | 16.9 | 7.8 | *8.0* | 37.8 | *36.0* | 9.7 | *11.0* | 38.6 | *34.0* |
| Silver | 1 | 3.7 | 2.6 | 32.3 | 92.8 | 0.1 | *0.1* | 0.8 | *1.0* | 0.1 | *0.1* | 0.4 | *0.4* |
| Zinc | 150 | 410 | 6.1 | 47.0 | 69.8 | 35 | *19* | 125 | *144* | 34 | *37* | 140 | *107* |
| **Organic Compounds (ppb)** | | | | | | | | | | | | | |
| Acenaphthene | 16 | 500 | 20.0 | 32.4 | 84.2 | 1.2 | *1.2* | 59 | *49* | 0.2 | *0.5* | 2 | 4 |
| Acenaphthylene | 44 | 640 | 14.3 | 17.9 | 100.0 | 3.4 | *9.9* | 113 | *89* | 1.1 | *1.8* | 10 | 15 |
| Antracene | 85.3 | 1100 | 25.0 | 44.2 | 85.2 | 4.5 | *7.9* | 180 | *170* | 1.2 | *2.0* | 13 | 16 |
| Fluorene | 19 | 540 | 27.3 | 36.5 | 86.7 | 2.9 | *4.7* | 125 | *98* | 0.7 | *1.3* | 6 | 10 |
| 2-Methyl naphthalene | 70 | 670 | 12.5 | 73.3 | 100.0 | 3.8 | *3.1* | 63 | *81* | 0.8 | *0.8* | 8 | 10 |
| Naphthalene | 160 | 2100 | 16.0 | 41.0 | 90.3 | 6.1 | *5.2* | 89 | *110* | 1.0 | *1.20* | 10 | 18 |
| Total LMW PAH | 552 | 3160 | 13.0 | 48.1 | 100.0 | 26.7 | *29.5* | 707 | *531* | 6.3 | *8.2* | 55 | 69 |
| Benz(a)anthracene | 261 | 1600 | 21.1 | 43.8 | 92.6 | 26.1 | *31.0* | 446 | *740* | 4.2 | *8.0* | 51 | 62 |
| Benzo(a)pyrene | 430 | 1600 | 10.3 | 63.0 | 80.0 | 36.4 | *44.0* | 658 | *900* | 6.0 | *9.4* | 89 | 77 |
| Chrysene | 384 | 2800 | 19.0 | 45.0 | 88.5 | 38.8 | *52.0* | 523 | *1000* | 6.6 | *12* | 67 | 93 |
| Dibenzo(a,h)anthracene | 63.4 | 260 | 11.5 | 54.5 | 66.7 | 2.8 | *6.7* | 91 | *170* | 1.0 | *1.2* | 37 | 10 |
| Fluoranthene | 600 | 5100 | 20.6 | 63.6 | 92.3 | 73 | *100* | 1018 | *2200* | 13 | *20* | 124 | 170 |
| Pyrene | 665 | 2600 | 17.2 | 53.1 | 87.5 | 66 | *78* | 1094 | *1700* | 12 | *15* | 117 | 140 |
| Total HMW PAH | 1700 | 9600 | 10.5 | 40.0 | 81.2 | 362 | *501* | 5748 | *10314* | 70 | *111* | 904 | 856 |
| Total PAH | 4022 | 44792 | 14.3 | 36.1 | 85.0 | 388 | *530* | 6157 | *10663* | 76 | *119* | 959 | 924 |
| p,p'-DDE | 2.2 | 27 | 5.0 | 50.0 | 50.0 | 0.4 | *0.4* | 3.6 | *3.0* | 0.1 | *0.2* | 0.8 | 1.1 |
| Sum Total DDT | 1.58 | 46.1 | 20.0 | 75.0 | 53.6 | 1.3 | *0.9* | 17.4 | *18.6* | 0.1 | *0.3* | 2.9 | 2.9 |
| Total PCB | 22.7 | 180 | 18.5 | 40.8 | 51.0 | 3.0 | *1.2* | 254 | *26* | 0.7 | *0.1* | 7 | 74 |

**Table 1 (continued). Summary Data from Casco Bay Regions for Both Sampling Periods with ERL and ERM Guideline Values (From Long et al. 1995).**

| | Guidelines | | Percent incidence of Effects | | | East Bay | | | | Cape Small | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical | Effects Range Low (ERL) | Effects Range Median (ERM) | Less Than ERL | Between ERL and ERM | Greater Than ERM | 1991 Minimum Conc. | *2000/2001* Minimum Conc. | 1991 Maximum Conc. | *2000/2001* Maximum Conc. | 1991 Minimum Conc. | *2000/2001* Minimum Conc. | 1991 Maximum Conc. | *2000/2001* Maximum Conc. |
| **Trace Elements (ppm)** | | | | | | | | | | | | | |
| Arsenic | 8.2 | 70 | 5.0 | 11.1 | 63.0 | 3.2 | *6.0* | 19.6 | *17.0* | 5.0 | *3.0* | 13.7 | *10.0* |
| Cadmium | 1.2 | 9.6 | 6.6 | 36.6 | 65.7 | 0.1 | *0.1* | 1.3 | *1.5* | 0.0 | *0.0* | 0.2 | *0.1* |
| Chromium | 81 | 370 | 2.9 | 21.1 | 95.0 | 29.0 | *51.0* | 105.0 | *110.0* | 37.0 | *37.0* | 93.0 | *59.0* |
| Copper | 34 | 270 | 9.4 | 29.1 | 83.7 | 5.6 | *9.0* | 27.9 | *30.0* | 2.5 | *4.0* | 21.6 | *12.0* |
| Lead | 46.7 | 218 | 8.0 | 35.8 | 90.2 | 13.6 | *19.8* | 37.0 | *37.3* | 14.1 | *14.3* | 32.4 | *22.7* |
| Mercury | 0.15 | 0.71 | 8.3 | 23.5 | 42.3 | 0.05 | *0.05* | 0.18 | *0.20* | 0.01 | *0.00* | 0.19 | *0.04* |
| Nickel | 20.9 | 51.6 | 1.9 | 16.7 | 16.9 | 8.4 | *18.0* | 38.4 | *41.0* | 12.9 | *13.0* | 30.6 | *24.0* |
| Silver | 1 | 3.7 | 2.6 | 32.3 | 92.8 | 0.1 | *0.2* | 0.3 | *0.5* | 0.1 | *0.1* | 0.2 | *0.2* |
| Zinc | 150 | 410 | 6.1 | 47.0 | 69.8 | 28 | *60* | 105 | *119* | 31 | *38* | 88 | *66* |
| **Organic Compounds (ppb)** | | | | | | | | | | | | | |
| Acenaphthene | 16 | 500 | 20.0 | 32.4 | 84.2 | 1.4 | *2.2* | 12 | *15* | 0.1 | *0.0* | 7.8 | *2.8* |
| Acenaphthylene | 44 | 640 | 14.3 | 17.9 | 100.0 | 6.6 | *13.0* | 53 | *91* | 0.1 | *0.6* | 35.7 | *12.0* |
| Antracene | 85.3 | 1100 | 25.0 | 44.2 | 85.2 | 7.2 | *16.0* | 97 | *150* | 0.1 | *0.5* | 50.0 | *12.0* |
| Fluorene | 19 | 540 | 27.3 | 36.5 | 86.7 | 4.1 | *5.2* | 59 | *35* | 0.1 | *0.0* | 15.6 | *5.3* |
| 2-Methyl naphthalene | 70 | 670 | 12.5 | 73.3 | 100.0 | 4.0 | *3.6* | 28 | *19* | 0.3 | *0.3* | 14.3 | *4.4* |
| Naphthalene | 160 | 2100 | 16.0 | 41.0 | 90.3 | 5.13 | *7.10* | 35 | *30* | 0.5 | *0.6* | 17.7 | *7.8* |
| Total LMW PAH | 552 | 3160 | 13.0 | 48.1 | 100.0 | 32.7 | *41.0* | 214 | *213* | 2.3 | *1.8* | 121 | *37* |
| Benz(a)anthracene | 261 | 1600 | 21.1 | 43.8 | 92.6 | 31.8 | *67.0* | 326 | *530* | 0.5 | *2.0* | 182 | *53* |
| Benzo(a)pyrene | 430 | 1600 | 10.3 | 63.0 | 80.0 | 46.4 | *94.0* | 359 | *480* | 0.5 | *1.8* | 218 | *60* |
| Chrysene | 384 | 2800 | 19.0 | 45.0 | 88.5 | 43.8 | *81* | 350 | *480* | 0.6 | *1.8* | 201 | *56* |
| Dibenzo(a,h)anthracene | 63.4 | 260 | 11.5 | 54.5 | 66.7 | 6.9 | *11* | 45 | *64* | 0.1 | *0.3* | 32 | *7* |
| Fluoranthene | 600 | 5100 | 20.6 | 63.6 | 92.3 | 78 | *150* | 566 | *580* | 1.4 | *2.8* | 266 | *92* |
| Pyrene | 665 | 2600 | 17.2 | 53.1 | 87.5 | 74 | *140* | 508 | *600* | 1.4 | *2.7* | 286 | *92* |
| Total HMW PAH | 1700 | 9600 | 10.5 | 40.0 | 81.2 | 464 | *890* | 3219 | *4200* | 8.2 | *19.0* | 1826 | *559* |
| Total PAH | 4022 | 44792 | 14.3 | 36.1 | 85.0 | 498 | *931* | 3433 | *4413* | 11.9 | *20.8* | 1948 | *596* |
| p,p'-DDE | 2.2 | 27 | 5.0 | 50.0 | 50.0 | 0.3 | *0.3* | 1.7 | *1.3* | 0.0 | *0.0* | 0.6 | *0.3* |
| Sum Total DDT | 1.58 | 46.1 | 20.0 | 75.0 | 53.6 | 0.7 | *0.6* | 3.8 | *3.5* | 0.0 | *0.0* | 1.3 | *0.6* |
| Total PCB | 22.7 | 180 | 18.5 | 40.8 | 51.0 | 4.1 | *1.1* | 17.9 | *9.1* | 0.2 | *0.2* | 13.8 | *2.5* |

**Table 1. Summary Data from Casco Bay Regions for Both Sampling Periods with ERL and ERM Guideline Values (From Long et al. 1995).**

| | Guidelines | | Percent incidence of Effects | | | Outer Bay | | | |
|---|---|---|---|---|---|---|---|---|---|
| Chemical | Effects Range Low (ERL) | Effects Range Median (ERM) | Less Than ERL | Between ERL and ERM | Greater Than ERM | 1991 | *2000/2001* | 1991 | *2000/2001* |
| | | | | | | Minimum Conc. | | Maximum Conc. | |
| Trace Elements (ppm) | | | | | | | | | |
| Arsenic | 8.2 | 70 | 5.0 | 11.1 | 63.0 | 5.0 | *2.0* | 20.5 | *15.0* |
| Cadmium | 1.2 | 9.6 | 6.6 | 36.6 | 65.7 | 0.0 | *0.0* | 0.6 | *0.3* |
| Chromium | 81 | 370 | 2.9 | 21.1 | 95.0 | 43.0 | *21.0* | 93.0 | *85.0* |
| Copper | 34 | 270 | 9.4 | 29.1 | 83.7 | 6.9 | *4.0* | 26.2 | *20.0* |
| Lead | 46.7 | 218 | 8.0 | 35.8 | 90.2 | 25.5 | *17.3* | 40.7 | *35.1* |
| Mercury | 0.15 | 0.71 | 8.3 | 23.5 | 42.3 | 0.05 | *0.00* | 0.14 | *0.10* |
| Nickel | 20.9 | 51.6 | 1.9 | 16.7 | 16.9 | 14.5 | *8.0* | 39.8 | *33.0* |
| Silver | 1 | 3.7 | 2.6 | 32.3 | 92.8 | 0.1 | *0.1* | 0.3 | *0.3* |
| Zinc | 150 | 410 | 6.1 | 47.0 | 69.8 | 43 | *22.0* | 109 | *99.0* |
| Organic Compounds (ppb) | | | | | | | | | |
| Acenaphthene | 16 | 500 | 20.0 | 32.4 | 84.2 | 2.0 | *0.1* | 5 | *4.6* |
| Acenaphthylene | 44 | 640 | 14.3 | 17.9 | 100.0 | 7.5 | *1.0* | 26 | *24.0* |
| Antracene | 85.3 | 1100 | 25.0 | 44.2 | 85.2 | 10.8 | *1.2* | 41 | *23.0* |
| Fluorene | 19 | 540 | 27.3 | 36.5 | 86.7 | 5.3 | *0.6* | 14 | *9.3* |
| 2-Methyl naphthalene | 70 | 670 | 12.5 | 73.3 | 100.0 | 5.8 | *0.4* | 17 | *7.6* |
| Naphthalene | 160 | 2100 | 16.0 | 41.0 | 90.3 | 8.5 | *2.1* | 18 | *12.0* |
| Total LMW PAH | 552 | 3160 | 13.0 | 48.1 | 100.0 | 45 | *5.8* | 109 | *77.2* |
| Benz(a)anthracene | 261 | 1600 | 21.1 | 43.8 | 92.6 | 42 | *5.8* | 152 | *83.0* |
| Benzo(a)pyrene | 430 | 1600 | 10.3 | 63.0 | 80.0 | 49 | *4.5* | 196 | *88.0* |
| Chrysene | 384 | 2800 | 19.0 | 45.0 | 88.5 | 47 | *6.6* | 168 | *100* |
| Dibenzo(a,h)anthracene | 63.4 | 260 | 11.5 | 54.5 | 66.7 | 8 | *0.6* | 68 | *14* |
| Fluoranthene | 600 | 5100 | 20.6 | 63.6 | 92.3 | 91 | *11* | 239 | *150* |
| Pyrene | 665 | 2600 | 17.2 | 53.1 | 87.5 | 85 | *11* | 247 | *140* |
| Total HMW PAH | 1700 | 9600 | 10.5 | 40.0 | 81.2 | 524 | *60* | 1875 | *889* |
| Total PAH | 4022 | 44792 | 14.3 | 36.1 | 85.0 | 569 | *65* | 1964 | *966* |
| p,p'-DDE | 2.2 | 27 | 5.0 | 50.0 | 50.0 | 0.5 | *0.1* | 1.2 | *0.6* |
| Sum Total DDT | 1.58 | 46.1 | 20.0 | 75.0 | 53.6 | 1.1 | *0.0* | 3.4 | *455.5* |
| Total PCB | 22.7 | 180 | 18.5 | 40.8 | 51.0 | 2.9 | *0.3* | 13.1 | *11.9* |

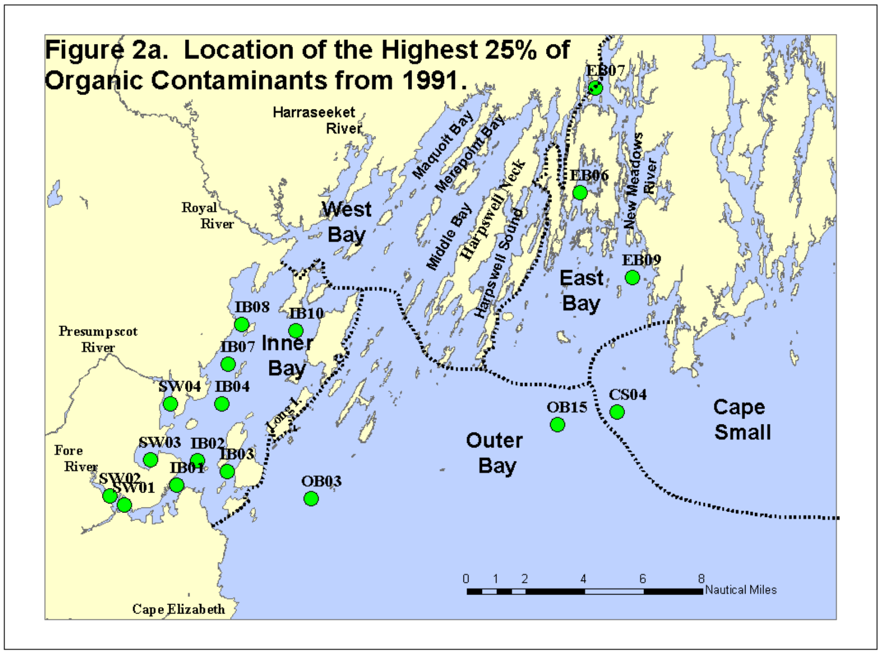
occurrence of sources and secondarily by oceanographic conditions. The most widespread contaminants are associated with the utilization of petroleum and petroleum products. Polycyclic aromatic hydrocarbons (PAH) are the primary agent causing the toxic effects attributed to petroleum. Hydrocarbon contamination decreases in intensity with increasing distance from areas of highest population density. Localized sites of contamination are associated with cities, effluent outfalls and spills. A recent study funded by Casco Bay Estuary Project suggests that atmospheric deposition is also a significant direct contributor of PAHs to the Bay (Golomb et al., 2001). The predominant PAH in sediments adjacent to urban and industrialized locations are combustion-derived (i.e., car exhaust, urban run-off, etc.). Sediments from the Inner Bay region of Casco Bay; closest to Portland, ME; contain the highest levels of trace metals, PCBs, DDTs, and chlordane. For contaminants other than PAH (and these only at a few locations) and PCBs at one location, the levels of contamination in Casco Bay would not be considered high on a national basis. Variations in contaminant concentration with time are difficult to assess based on historical information because of different analytical methods, variations in the contaminants measured, and a lack of common station locations. However, in general, the contaminant concentrations measured in the 1990 studies were within the ranges reported in previous studies (Macauley et al., 1994; USEPA, 1997).

The high PAH concentrations in Inner Bay sediments were similar to other contaminated estuaries (Macauley et al., 1994; USEPA, 1997). Two sites in this region from the 2000/2002 sampling, SW01 and SW02, had PAH sediment concentrations in Inner Bay sediments greater than PAH concentrations thought to produce toxic effects low responses (ERL) in marine benthic organisms, i.e., total PAH $\geq$ 4022 ppb (Long et al., 1995) while five sites (IB01, SW01, SW02, SW03, and IB08) from the 1991 sampling were greater than the ERL. None of these sites from either of the samplings were above the level thought to produce a median toxic response (see Table 1). While historical data on biological effects are useful for qualitative comparisons, it should be noted that toxicity is affected by factors other than concentration (i.e., biological availability). The mode of occurrence of PAH has been shown to vary widely depending on original source. Coal or soot associated combustion PAH are often tightly bound or occur in the interiors of particles. This mode of occurrence renders these PAH largely inert to organisms. In contract, equivalent concentrations of liquid hydrocarbons such as oil or creosote may induct toxicological effects. Biological availability is important in determining whether a contaminant evokes a biological response. A majority of PAH detected in Casco Bay are combustion related and sequestered in fine particulates that may reduce toxicity. The remainder of the PAH are weathered residues of petroleum contributed by spills and runoff. No direct measure of biological effect was done in the 1990 studies. Evidence of toxic effects on organisms is apparent in the inner Fore River between the Casco Bay Bridge and the Veteran's Memorial Bridge (no samples were taken upstream of the Veterans Memorial Bridge). The benthic (bottom-dwelling) infaunal community is altered and, at some sites, greatly reduced in these waters. Many of the animals had oil on their parapodia (legs) (Doggett, DEP, 1989, personal communication).

PCB concentrations above 180 ppb (dry wt.) have been shown to elicit a median toxic response in some benthic organisms. Only one site from Casco Bay was above this threshold, located in the Fore River (SW02, see Figure 2a) and sampled in 1991. DDT concentrations in Casco Bay sediments were also low compared to concentrations known to cause a median toxic response in most benthic organisms with the exception of one site, collected in 2001, located a little north of Cape Elizabeth (ME01-0128). Chlordane concentrations are low on a national basis and should pose little or no threat of toxic biological effects. Again, biological effects are only inferred from previous literature studies and were not directly measured as part of this study. Other organochlorine pesticides including aldrin, HCH, dieldrin, endosulfan (I, II, and sulfate), endrin, endrin aldehyde, heptachlor, heptachlor epoxide, toxaphene, and hexachlorobenzene were found at low concentrations (<~0.25 ppb dry wt.).

While Casco Bay sediments would not be considered "high" in trace metal content, it is important to assess whether these concentrations would be harmful to organisms. The concentrations of metals known to elicit toxic biological responses were much higher than those found in Casco Bay sediments. Metal concentrations in Casco Bay sediments were comparable to uncontaminated sediments. Ag, Cd, Pb, Zn, and Hg concentrations suggest that additions of metals from anthropogenic activities have occurred at a few locations. However, even the few elevated trace metal concentrations in Casco Bay were much lower than those of highly contaminated sediments from Hudson-Raritan, Long Island Sound, Boston Harbor, and urban water bodies. It is unlikely that the trace metals present in the Casco Bay sediments result in measurable toxic effects to marine organisms. As with PAH, biological availability must be considered when estimating the potential toxicity of trace metal contamination.

The highest 25% of organic contaminants in the 1991 study were located at 10 Inner Bay, 2 Outer Bay, 3 East Bay, and 1 Cape Small sites (See Figure 2a). Eight of the ten most highly contaminated stations were located in the Inner Bay region including the six stations with the highest concentrations. The lowest levels of organic contaminants were in the Cape Small and West Bay regions. High levels of organic contaminants tend to co-occur at a single location. Locations with the 25% highest levels of inorganic contamination were at 12 Inner Bay, 3 East



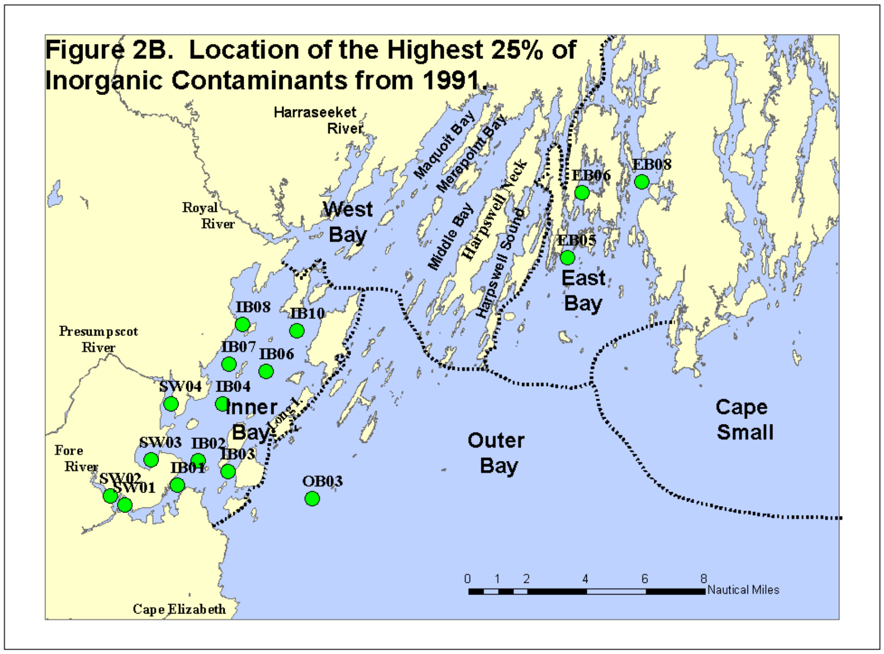


**Figure 2. Location of the Highest 25 % of a) Organic Contaminants and b) Inorganic Contaminants Collected in 1991.**

Bay, and 1 Outer Bay locations (See Figure 2b). Nine of the ten locations with the highest concentrations were in the Inner Bay region including the eight highest stations. The lowest metal concentrations occurred in the Cape Small region. Eleven stations were ranked in the highest 25% for both inorganic and organic contaminants. Nine of the eleven were located in the Inner Bay.

In the 1991 study, contaminants related to human activities were detectable throughout Casco Bay but in most cases occur at exceedingly low concentrations. A variety of processes release contaminants to Casco Bay and these chemicals had accumulated in bay sediments. The focus of contamination in the Inner Bay region was directly associated with population centers and industrialization. Localized contamination by various chemicals is generally far below levels suspected of evoking a toxic biological response.

Several sets of historical data are particularly germane to the present study. Larsen et al. (1983a, 1983b, 1983c) and Larsen et al. (1984) measured trace metals, PAH and PCBs in sediments from Casco Bay collected in 1980. A further study of sediment contaminants in Casco Bay was conducted as part of two multi-year studies by NOAA, the Benthic Surveillance Program, and the Status and Trends Program. Sediments were collected between 1984 and 1988 at a few sites with selected sites occupied more than once. A more extensive suite of individual analytes were measured in the 1991 study compared to the 1980 study. However, the same general suite of contaminants was selected for analysis. Finally, two sediment transects were sampled by the Maine Department of Environmental Protection in 1989 and analyzed for trace metals, PCBs, and PAH (Doggett, DEP, personal communication). A summary of these studies was presented by Kennicutt et al. (1992).

In 1994, 28 of the original sites were re-sampled for the analysis of butyltins, PCDD/PCDF and planar PCB, and 5 additional sites were added. Two of the new sites were analyzed for PCDD/PCDF and planar PCB, while the other three sites were analyzed for butyltins. The additional sites selected in 1994 were along the Presumpscot River, the Royal and Cousins Rivers and a marina at Falmouth Foreside. The other sites selected for re-sampling in 1994 were the sites containing the highest organic contaminant concentrations in 1991. The presence of high concentrations of contaminants in sediments indicate potential source of contaminants to organisms, which may lead to adverse environmental and/or human health effects. For example, the detection of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and dibenzofuran (TCDF) in lobster tomalley has resulted in a human consumption advisory for Casco Bay (Mower 1994).

The 1994 study was conducted for the Casco Bay Estuary Project. . The purpose of this study was to extend a comprehensive evaluation of sediment quality in Casco Bay to include butyltins, 2,3,7,8- polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans (PCDD/PCDF) and planar polychlorinated biphenyls (PCB). Butyltins, PCDD/PCDF and planar PCB were detected in sediments from all areas of Casco Bay. The concentrations were highest near potential input sources. For example, the butyltin concentrations are highest near marinas and boat anchorages while PCDD/PCDF and especially 2,3,7,8-tetrachloro-*p*-dioxin/tetrachloro dibenzofurans (TCDD/TCDF) had higher concentrations near the Presumpscot River sites, 10 miles down stream of a pulp and paper mill. There are also exceptions, for example the higher PCDD/PCDF concentrations in East Bay are not near known point sources, but may be the result of transport into the bay from sources in the Kennebec/Androscoggin River or localized combustion sources (e.g., until recently, Harpswell operated an incinerator). The concentrations of butyltins, PCDD/PCDF and planar PCB found in Casco Bay sediments are in the range expected when compared to similar estuarine areas (Finley et al. 1990, Clarke et al. 1994, Fiedler 1994).

In spite of the low concentration in sediment, detection of 2,3,7,8-TCDD/TCDF in lobster tomalley indicates these compounds are bio-available and have resulted in an advisory regarding consumption of lobster tomalley from Casco Bay and all Maine waters (Mower 1994). The sediment contaminant studies document the presence of contaminants in Casco Bay. Additional studies were conducted by Casco Bay Estuary Project and DEP to determine if PCDD/PCDF isomers including 2,3,7,8-TCDD/TCDF, planar PCB, butyltins and other contaminants (metals, chlorinated pesticides, polycyclic aromatic hydrocarbons and PCB) were bio-available and reach concentrations that pose a human health concern for seafood consumption from Casco Bay. While these contaminants were found in seafood, the state toxicologists have determined that no human health advisory is warranted.

Butyltins found in the environment include tetrabutyltin (4BT), tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT). The only reports of detecting 4BT in sediment are in shipyards, probably from paint chips. TBT is the active ingredient used in marine paints to prevent fouling of marine vessel bottoms by the growth of barnacles and other organisms on solid surfaces immersed in sea water (Wade, et al. 1991). Fouling increases the roughness of the surface of the vessel and increases fuel consumption. Sediments near boating activities are the sites where tributyltin would be expected to be found in the highest concentrations. DBT and MBT are minor components of anti-fouling paints and are also degradation products of TBT.

DBT is also used as a stabilizer in PVC and as a catalyst in the production of polyurethane foams (Muller et al. 1989). Only limited butyltin data was available for Casco Bay before the 1994 study. In 1990, sediments from the Fore River were sampled and analyzed for butyltins. The concentration of TBT ranged from 24 ng Sn/g to 693 ng Sn/g in the surficial sediments. DBT concentrations ranged from 15 ng Sn/g to 453 ng Sn/g. The highest concentrations of butyltins were observed in the sediments collected near shipyards (Ozbal 1992).

No historical PCDD/PCDF data were available for sediments from Casco Bay before the 1994 study; however, there were data for the TCDD/TCDF for Androscoggin and Kennebec River sediments (Mower 1994). The Kennebec/Androscoggin River effluents join in Merrymeeting Bay and enter the Atlantic Ocean via the Kennebec estuary, which is northeast of Cape Small in Phippsburg, on the easternmost point of Casco Bay. Since the average daily flow rate to the Kennebec estuary is more than eight times the flow rate into the Casco Bay estuary, it is possible that effluent from the Kennebec/Androscoggin River containing particulate materials could exit the Kennebec Estuary and enter Casco Bay where they may be deposited (NOAA 1985). Androscoggin River sediments had a median concentration of 2,3,7,8-TCDD of 23.1 and 5.3 pg/g for samples collected in 1985 and 1991, respectively. The median concentration of 2,3,7,8-TCDF in 1991 (the only year it was measured) was 168 pg/g. The analyses did not include the other 2,3,7,8-substituted polychlorinated-*p*-dioxins and furans (Mower 1994). Concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in bass, suckers, and lobster tissues from the Presumpscot River have been reported (Mower 1994). The muscle of the bass had no detectable TCDD, and TCDF concentrations were less than 1 pg/g. Suckers did contain TCDD and TCDF. The 2,3,7,8-TCDD toxicity equivalents (TEQ) were calculated based on the values reported by Safe (1994). Toxicity equivalents are based on the comparison of the relative toxicity of compounds to that of the most toxic known compound 2,3,7,8-TCDD. The toxicity equivalency factors (TEF) are multiplied by the analyte concentration to produce the TEQ for that compound (Safe 1994). The total TEQ is the sum of the TEQ for all compounds. This concept allows for the total TEQ and the relative toxicity that the various compounds contribute to the total TEQ to be determined. The TEQ concept is further discussed by Safe (1994). An average TEQ of 2.3 pg/g was calculated for the suckers. Lobster meat had an average TEQ of 0.8 pg/g; however the tomalley or hepatopancreas of the lobster had an average TEQ of 18.7 pg/g. TEQ at these levels resulted in the Maine Bureau of Health issuing an advisory in 1994 regarding human consumption of lobster tomalley (Mower 1994).

There was no historical data on the concentrations of planar polychlorinated biphenyls (PCB) in Casco Bay sediments prior to the 1994 study. There is heightened environmental concern regarding planar PCB due to their high toxicity. The non-*ortho* chlorine substituted planar PCB (PCB77-3,3',4,4'-tetra, PCB126-3,3',4,4',5,-penta and PCB169-3,3',4,4',5,5'-hexa) are approximate isostereomers of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and these planar PCB produce toxic responses typical of TCDD (Kannan et al. 1987). The planar PCB are minor components of commercial PCB mixtures (aroclors and kaneclors), with PCB77 being the most abundant planar PCB, and PCB126 and PCB169 present at lower concentrations. Brunstrom (1989) observed that the most toxic of the non-*ortho* chlorinated PCBs in chick embryos was PCB126. Toxic equivalency factors (TEF) have been proposed for each planar PCB relative to 2,3,7,8-TCDD (Safe 1992, 1994). The computed toxic equivalents (TEQ) from the concentration of the particular analyte and the appropriate toxic equivalency factor are useful in providing a single number evaluation of the relative toxicity of the sample for comparison. In summary, while the planar PCB are only minor components of PCB mixtures, they have the highest toxicity. Therefore, the planar PCB were measured so that the total TEQ and relative contribution from PCDD, PCDF and planar PCB in Casco Bay sediments could be assessed.

## 3.0 Sampling and Analytical Procedures

Sediment samples (top 2 cm) were collected for all sampling periods. The sampling sites provided good coverage of the entire Bay (Figure 3). The Geochemical and Environmental Research Group (GERG) at Texas A&M University analyzed the 1991 and 1994 sediment samples. The results from these studies have been reported (Kennicutt et al., 1992 and 1994; Wade et al. 1995 a, b and 1997). The 2000/2001 sediment samples were analyzed for trace elements, chlorinated pesticides, PAH and PCB by ICF (formerly Arthur D. Little). The 2000/2001 samples were analyzed for butyltins, planar PCB and dioxin/furan by RPC Chemical and Biotechnical Services. The Casco Bay sample collection and analyses by year are summarized in Table 2. There is a cross reference for samples collected in 1991, 1994, 2000 and 2001 in Table 2. A total of 59 of the original 65 sites collected in 1991 had collection locations close enough to be considered reoccupation of theses sites. A total of 29 of the original 31 sites collected in 1994 had collection locations close enough to be considered reoccupation of theses sites for dioxins and butyltins. Details of the sites sampled and what analyses were performed on these samples is detailed in Table 2. Organochlorine analyses are abbreviated as OC in Table 1 and include both the pesticide and the PCB analyses. Table 3 (See Appendix I) provides a summary of data sources used in this report.

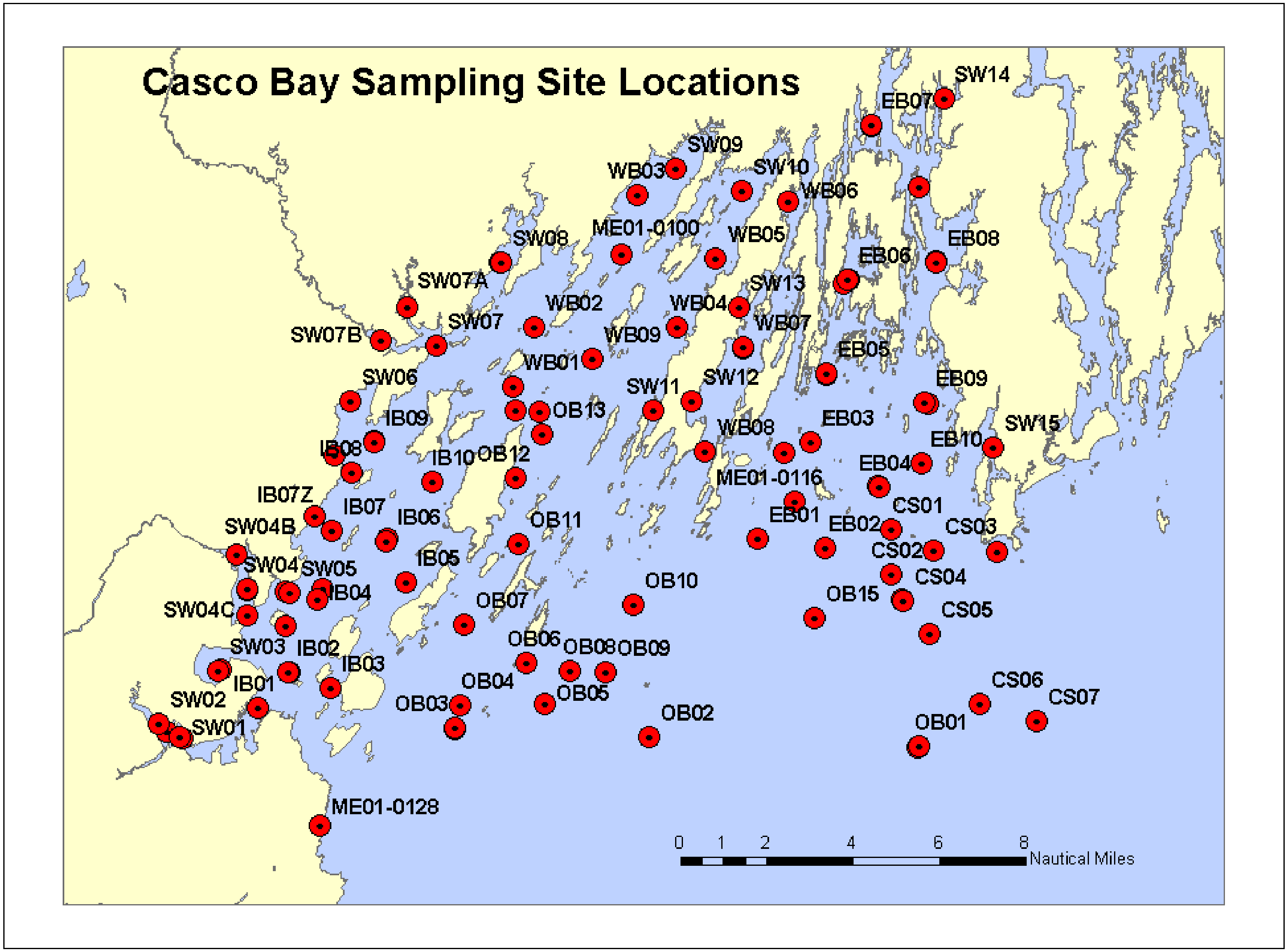


Figure 3. Casco Bay Sampling Site Locations.

In general the analytical methods used by GERG, ICF and RPC provide valid results based on the quality control information on procedural blank, duplicate, matrix spike and standard reference material analytical results supplied by each laboratory. There were a few cases where differences that might affect the comparison of the data need to be documented. The PAH data for 2000/2001 did not contain concentrations for phenanthrene, benzo(e)pyrene, perylene or alkylated PAHs. These analytes from the 1991 data were not included in the totals so that the data would be compared on an equivalent basis. PCB data were reported as total PCB in the 1991 study. For comparison purposes the total of 18 PCB congeners measured are compared here. The total of the 18 congeners when multiplied by 2 is a good estimate of the total PCB present in a sample. The dioxin/furan data discussion by RPC Chemical and Biotechnical Services notes that "results reported for 2,3,7,8-TCDF represent maximum possible concentrations due to the possibility of overlapping HRGC peaks". The analyses of 2,3,7,8-TCDF by GERG included analyses of a second column to eliminate possible interferences. Therefore the 2,3,7,8-TCDF results are not easily compared. Data tables for the analytes and sum of selected analytes are provided in Appendix I.

Temporal trends can be divided into three categories; increased, unchanged or decreased concentrations. A method of visualizing these trends is to plot the analyte concentration for each site in 1991 or 1994 versus the analyte concentration for 2000/2001 using the same concentration scales. A diagonal line is drawn. Data points plotting above this trend line indicate an increase in concentration between SP1 and 2000/2001, while data points below the line indicates a decrease. Each analyte or the sum of selected analytes is plotted and these plots are evaluated to detect temporal trend for contaminants. The plots for most analytes and sums of selected analytes are presented in Appendix II.  Spatial trends in the data are best visualized by using graduated symbols that representing different concentration ranges on an ArcView GIS map of Casco Bay. All of these figures are provided in Appendix III.

## Table 2. Casco Bay Sampling Summary.

| Station | Dioxin 1994 | Dioxin 2001 | TBT 1994 | TBT 2001 | Grain Size 1991 | Grain Size 2000 | Grain Size 2001 | OC 1991 | OC 2000 | OC 2001 |
|---|---|---|---|---|---|---|---|---|---|---|
| CS01 | | | | | ● | ● | | ● | ● | |
| CS02 | | | | | ● | ● | | ● | ● | |
| CS03 | | | | | ● | ● | ● | ● | ● | ● |
| CS04 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| CS05 | | | | | ● | ● | | ● | ● | |
| CS06 | | | | | ● | ● | | ● | ● | |
| CS07 | | | | | ● | ● | | ● | ● | |
| EB01 | | | | | ● | ● | | ● | | |
| EB02 | | | | | ● | ● | | ● | ● | |
| EB03 | | | | | ● | ● | ● | ● | ● | ● |
| EB04 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| EB05 | | ● | ● | ● | ● | | | ● | | |
| EB06 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| EB07 | ● | ● | ● | ● | ● | | ● | ● | ● | ● |
| EB08 | | ● | ● | ● | ● | | ● | ● | | ● |
| EB09 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| EB10 | | | | | ● | ● | | ● | ● | |
| IB01 | ● | ● | ● | ● | ● | | | ● | | ● |
| IB02 | ● | ● | ● | ● | ● | | ● | ● | | ● ● |
| IB03 | ● | | ● | | ● | | ● | ● | | ● |
| IB04 | ● | ● | ● | ● | ● | | ● | ● | | ● ● |
| IB05 | | | | | ● | ● | | ● | ● | |
| IB06 | ● | ● | ● | ● | ● | | | ● | | ● |
| IB07 | ● | ● | ● | ● | ● | | | ● | | ● |
| IB07Z | ● | ● | ● | ● | | | ● | | | ● |
| IB08 | ● | ● | ● | ● | ● | | ● | ● | | ● ● |
| IB09 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| IB10 | ● | ● | ● | ● | ● | | | ● | | ● |
| OB01 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| OB02 | | | | | ● | ● | | ● | ● | |
| OB03 | ● | | ● | | ● | | | ● | | |
| OB04 | | | | | ● | ● | | ● | ● | |
| OB05 | | | | | ● | ● | | ● | ● | |
| OB06 | | | | | ● | | | ● | | ● |
| OB07 | | | | | ● | ● | | ● | ● | |

## Table 2. Casco Bay Sampling Summary (cont.)

| Station | Dioxin 1994 | Dioxin 2001 | TBT 1994 | TBT 2001 | Grain Size 1991 | Grain Size 2000 | Grain Size 2001 | OC 1991 | OC 2000 | OC 2001 |
|---|---|---|---|---|---|---|---|---|---|---|
| OB08 | | | | | ● | ● | | ● | | |
| OB09 | | | | | ● | | | ● | | |
| OB10 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| OB11 | | | | | ● | | ● | ● | | ● |
| OB12 | | | | | ● | ● | | ● | ● | |
| OB13 | | | | | ● | ● | ● | ● | ● | ● |
| OB15 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| SW01 | ● | ● | ● | ● | ● | | ● | ● | ● | ● |
| SW02 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| SW03 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| SW04 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| SW04B | ● | ● | | ● | | | | | | |
| SW04C | ● | ● | ● | ● | | | ● | | | ● |
| SW05 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| SW06 | | | | | ● | | ● | ● | | ● |
| SW07 | | | | | ● | | | ● | | |
| SW07A | ● | ● | ● | ● | | | ● | | | ● |
| SW07B | ● | ● | ● | ● | | | ● | | | ● |
| SW08 | | ● | ● | ● | ● | ● | | ● | ● | |
| SW09 | | | | | ● | | ● | ● | | ● |
| SW10 | | | | | ● | | ● | ● | | ● |
| SW11 | | | | | ● | | ● | ● | | ● |
| SW12 | | | | | ● | | | ● | | ● |
| SW13 | | | | | ● | | ● | ● | | ● |
| SW14 | | | | | ● | | | ● | | |
| SW15 | | | | | ● | | ● | ● | | ● |
| WB01 | | | | | ● | ● | ● | ● | ● | ● |
| WB02 | | | | | ● | ● | | ● | ● | |
| WB03 | | | | | ● | ● | | ● | ● | |
| WB04 | | | | | ● | ● | | ● | ● | |
| WB05 | | | | | ● | ● | | ● | ● | |
| WB06 | | | | | ● | | | ● | | |
| WB07 | ● | ● | ● | ● | ● | ● | | ● | ● | ● |
| WB08 | | | | | ● | ● | | ● | | ● |
| WB09 | ● | ● | ● | ● | ● | | ● | ● | | ● |
| ME01-0100 | | | | | | | ● | | | ● |
| ME01-0116 | | | | | | ● | ● | | | ● |
| ME01-0128 | | | | | | | | | | ● |
| Number of Stations (Duplicates) | 30 (0) | 31 (1) | 32 | 32 | 65 | 26 | 38 (3) | 65 | 25 | 48 (5) |

## Table 2.  Casco Bay Sampling Summary (cont.)

| Station | PAH 1991 | PAH 2000 | PAH 2001 | TOC 1991 | TOC 2000 | TOC 2001 | Trace Metals 1991 | Trace Metals 2000 | Trace Metals 2001 |
|---|---|---|---|---|---|---|---|---|---|
| CS01 | ● | ● |  | ● | ● |  | ● | ● |  |
| CS02 | ● | ● |  | ● | ● |  | ● | ● |  |
| CS03 | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| CS04 | ● |  | ● | ● |  | ● | ● |  | ● |
| CS05 | ● | ● |  | ● | ● |  | ● | ● |  |
| CS06 | ● | ● |  | ● | ● |  | ● | ● |  |
| CS07 | ● | ● |  | ● | ● |  | ● | ● |  |
| EB01 | ● | ● |  | ● | ● |  | ● | ● |  |
| EB02 | ● | ● |  | ● | ● |  | ● | ● |  |
| EB03 | ● | ● | ● | ● | ● |  | ● | ● | ● |
| EB04 | ● |  | ● | ● |  | ● | ● |  | ● |
| EB05 | ● |  |  | ● |  | ● | ● |  | ● |
| EB06 | ● |  | ● | ● |  | ● | ● |  | ● |
| EB07 | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| EB08 | ● |  | ● | ● |  | ● | ● |  | ● |
| EB09 | ● |  | ● | ● |  | ● | ● |  | ● |
| EB10 | ● | ● |  | ● | ● |  | ● | ● |  |
| IB01 | ● |  | ● |  |  |  | ● |  | ● |
| IB02 | ● |  | ● ● |  |  | ● | ● |  | ● ● |
| IB03 | ● |  | ● | ● |  | ● | ● |  | ● |
| IB04 | ● |  | ● ● | ● |  | ● | ● |  | ● ● |
| IB05 | ● | ● | ● | ● | ● |  | ● | ● |  |
| IB06 | ● |  |  | ● |  |  | ● |  | ● |
| IB07 | ● |  | ● | ● |  |  | ● |  | ● |
| IB07Z |  |  | ● |  |  | ● |  |  | ● |
| IB08 | ● |  | ● ● | ● |  | ● | ● |  | ● ● |
| IB09 | ● |  | ● | ● |  | ● | ● |  | ● |
| IB10 | ● |  | ● | ● |  |  | ● |  | ● |
| OB01 | ● |  | ● | ● |  |  | ● |  | ● |
| OB02 | ● | ● |  | ● | ● |  | ● | ● |  |
| OB03 | ● |  |  | ● |  |  | ● |  |  |
| OB04 | ● | ● |  | ● | ● |  | ● | ● |  |
| OB05 | ● | ● |  | ● | ● |  | ● | ● |  |
| OB06 | ● |  | ● | ● |  |  | ● |  | ● |
| OB07 | ● | ● |  | ● | ● |  | ● | ● |  |

## Table 2. Casco Bay Sampling Summary (cont.)

| Station | PAH 1991 | PAH 2000 | PAH 2001 | TOC 1991 | TOC 2000 | TOC 2001 | Trace Metals 1991 | Trace Metals 2000 | Trace Metals 2001 |
|---|---|---|---|---|---|---|---|---|---|
| OB08 | ● | ● |  | ● | ● |  | ● | ● |  |
| OB09 | ● |  |  | ● |  |  | ● |  |  |
| OB10 | ● |  | ● | ● |  | ● | ● |  | ● |
| OB11 | ● |  | ● | ● |  |  | ● |  | ● |
| OB12 | ● | ● |  | ● | ● |  | ● | ● |  |
| OB13 | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| OB15 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW01 | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| SW02 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW03 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW04 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW04B |  |  |  |  |  |  |  |  |  |
| SW04C |  |  | ● |  |  | ● |  |  | ● |
| SW05 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW06 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW07 | ● |  |  | ● |  |  | ● |  |  |
| SW07A |  |  | ● |  |  | ● |  |  | ● |
| SW07B |  |  | ● |  |  | ● |  |  | ● |
| SW08 | ● | ● |  | ● | ● |  | ● | ● |  |
| SW09 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW10 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW11 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW12 | ● |  | ● | ● |  |  | ● |  | ● |
| SW13 | ● |  | ● | ● |  | ● | ● |  | ● |
| SW14 | ● |  |  | ● |  |  | ● |  |  |
| SW15 | ● |  | ● | ● |  | ● | ● |  | ● |
| WB01 | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| WB02 | ● | ● |  | ● | ● |  | ● | ● |  |
| WB03 | ● | ● |  | ● | ● |  | ● | ● |  |
| WB04 | ● | ● |  | ● | ● |  | ● | ● |  |
| WB05 | ● | ● |  | ● | ● |  | ● | ● |  |
| WB06 | ● |  |  | ● |  |  | ● |  |  |
| WB07 | ● | ● | ● | ● | ● |  | ● | ● | ● |
| WB08 | ● |  | ● | ● |  |  | ● |  | ● |
| WB09 | ● |  | ● | ● |  | ● | ● |  | ● |
| ME01-0100 |  |  | ● |  |  | ● |  |  | ● |
| ME01-0116 |  |  | ● |  |  | ● |  |  | ● |
| ME01-0128 |  |  | ● |  |  | ● |  |  | ● |
| Number of Stations (dups) | 65 | 27 | 48 (5) | 63 | 27 | 36 (3) | 65 | 27 | 48 (4) |

# 4.0 Contaminant Concentrations

## 4.1 Polynuclear Aromatic Hydrocarbons (PAH)

PAH are ubiquitous environmental contaminants. PAH are generated by natural combustion processes, oil seepage and anthropogenic inputs. PAH can enter the environment from oil spills, ship traffic, urban runoff, wastewater and industrial discharges and atmospheric deposition from vehicle exhaust and industrial stack emissions. The environmental concern regarding PAH is due to their carcinogenic and mutagenic potential. PAH, due to their low water solubility, tend to be associated with particles and are deposited in sediments. The sediments are an important reservoir for PAH that may continue to be a source to organisms. PAH sediment and bivalve concentrations are normally higher in proximity to large population centers (Jackson et al. 1994). Casco Bay has high sediment PAH concentrations in near shore sediments (Kennicutt et al. 1994). The Casco Bay Estuary Project and DEP found that the results of analysis of mussels in Casco Bay show, in general, that PAH and other contaminants are more elevated in the Portland Harbor area than in the rest of the bay (Doggett, DEP, personal communication).

The analytical results for each of the PAH compounds from each of the sampling periods measured may be found in Table 4, Appendix I. The individual PAH measured in both sampling periods, 1991 and 2000/2001, are plotted on comparison diagrams, Figures 4 to 28 (Appendix II). Field duplicate samples were averaged before plotting in these diagrams. The 2000/2001 data set did not analyze phenanthrene, benzo(e)pyrene or perylene; therefore no comparison could be made for these compounds. The total PAH is the sum of the PAH reported in both sampling periods. It is important to note that duplicate samples from IB08 had a relative percent difference (RPD) for total PAH of 114%. Other field duplicates had RPD less that 10%, which is within the analytical uncertainty of the analyses. Selected sites were sampled in both 2000 and 2001. One of theses sites, such as CS03 had an RPD for total PAH of 162%, while other sites sampled in both years had RPD values of less than 10%. The variation in RPD indicates the non-homogeneity of in-place sediments complicating interpretation of this data.

The total PAH concentrations for 2000/2001 are compared to 1991 (Figure 4). When only sites with concentrations above 2000 ng/g are considered, 10 sites had higher concentrations in 2000/2001 while 2 sites had higher concentrations in 1991. This suggests that concentration for total PAH in Casco Bay increased at some sites and decreased at other sites. This complicates detection of temporal or spatial trends. For example, low molecular weight PAH (LMW PAH) (defined as the sum of detected concentrations for naphthalene, acenaphthylene, acenaphthene, fluorene, and anthracene) indicate a decrease in concentration between sampling periods (Figure 5). The high molecular weight PAH, where the High molecular weight PAH (defined as the sum of detected concentrations for fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3,-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene) indicate an increase at a majority of the sites (Figure 6). Individual PAH show similar behavior with some analytes having more sites above the line and others with more sites below the line (Figure 8 to 28). Another technique to visualize large data sets for comparison is to plot the data as frequency distributions. Only the 59 sites in common from both sampling periods are plotted in these diagrams. The average concentration is used for duplicate samples from the same site. The data is sorted by ascending concentration and the concentration, on a log scale, is plotted versus the percent occurrence. The frequency distribution for 1991 and 2000/2001 for total PAH, low molecular weight PAH (LMW PAH) and high molecular weight PAH (HMW PAH) are plotted in Figure 29 a, b, and c. These plots have an "S" shaped curve indicating a normal distribution on a log scale. If one sampling period had significantly different concentrations, the curves would be separated from one another. These curves have very similar distributions. There is an indication that total PAH and HMW PAH are slightly separated at higher concentrations. This possible increase of PAH in 2000/2001 compared to 1991 is not large enough to indicate a significant increase. Review of all these graphs and consideration of variability caused by sediment non-homogeneity leads to the conclusion that PAH concentrations in Casco Bay as a whole have remained the same between 1991 and 2001.

Another objective of this report is to examine the geographical distribution of contaminants to see if any changes were apparent between sampling periods. Concentrations of LMW PAH and HMW PAH, for 1991 and 2000/2001, are plotted as circles of graduated size, based on concentration, on a map of Casco Bay (Figure 30). It should be noted that the period for 2000/2001 has 8 addition sites plotted that were not sampled in 1991. The total PAH distributions for both 1991 and 2000/2001 are similar (Figure 31). Thus the distribution described in the previous sections for the 1991 sampling with highest concentration in the vicinity of Portland and others in East Bay are also valid for the 2000/2001 study. Sites having total PAH concentrations over 3,000 ng/g in 2000/2001 but not in 1991 are IB02, IB08 (one of two samples), SW15 and EB10. There were also more samples with total PAH concentrations

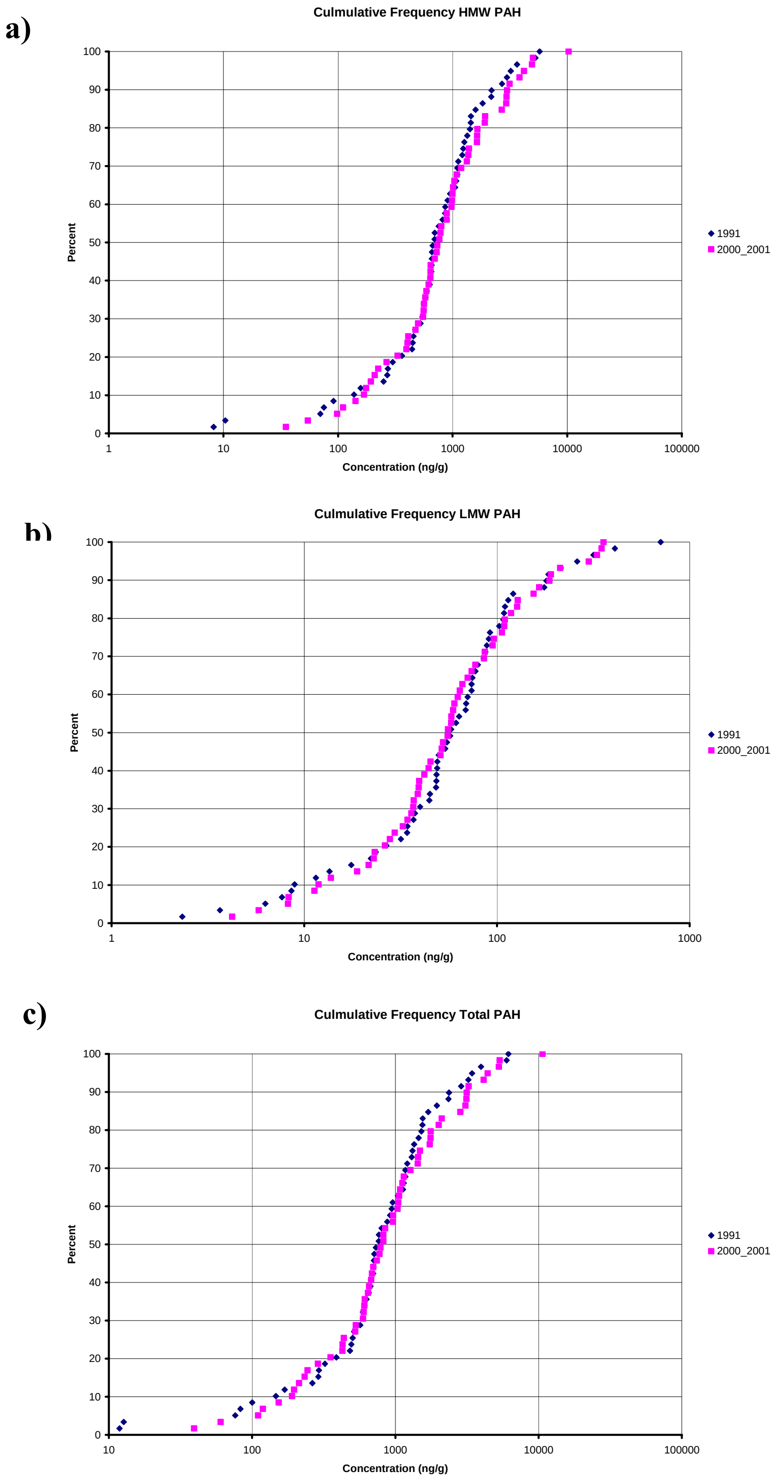


**Figure 29. Cumulative Frequency Distributions of a) HMW PAH, b) LWM PAH, c) Total PAH for Both Sampling Periods.**

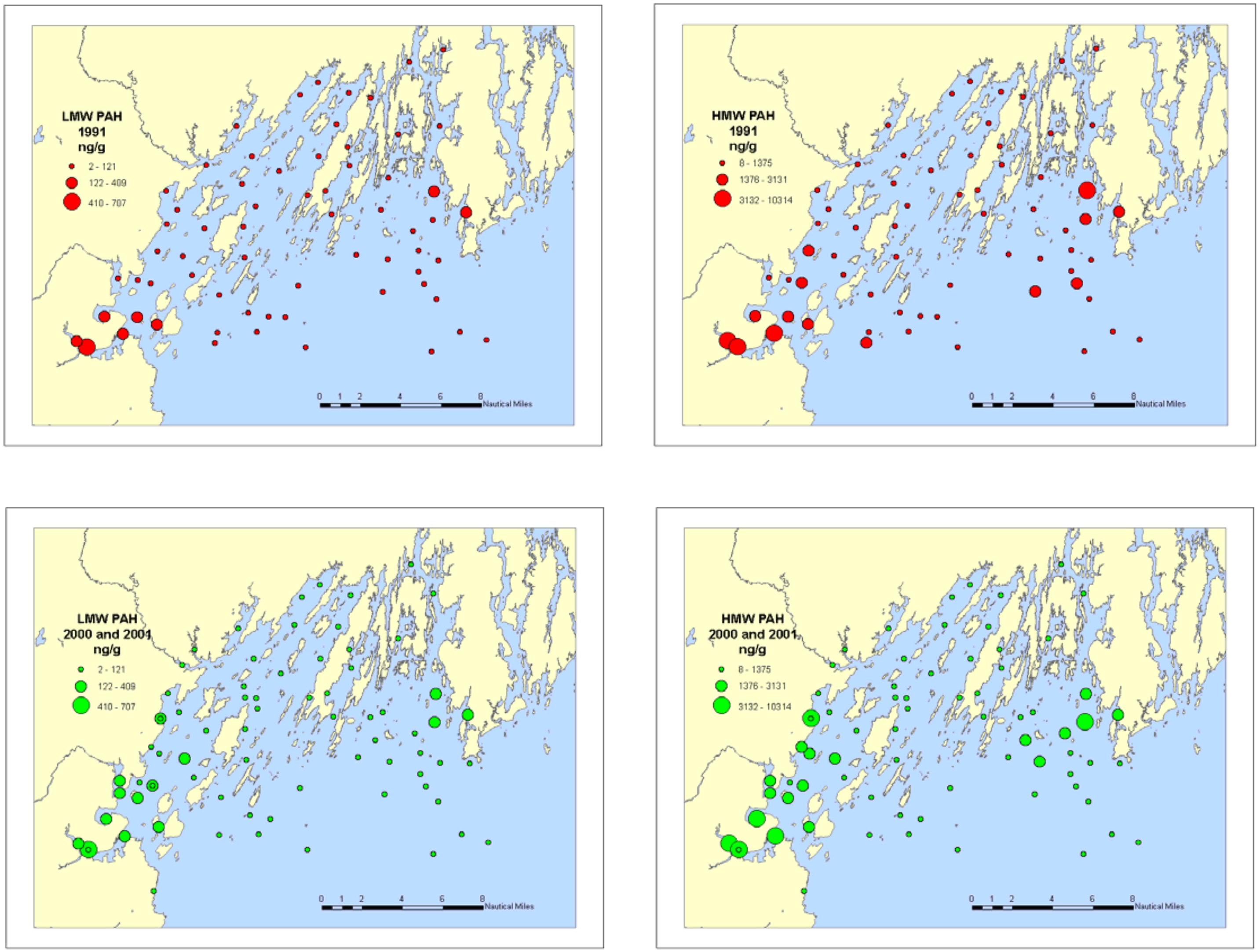


**Figure 30. Geographic Distribution of LMW and HMW PAH from Both Sampling Periods.**

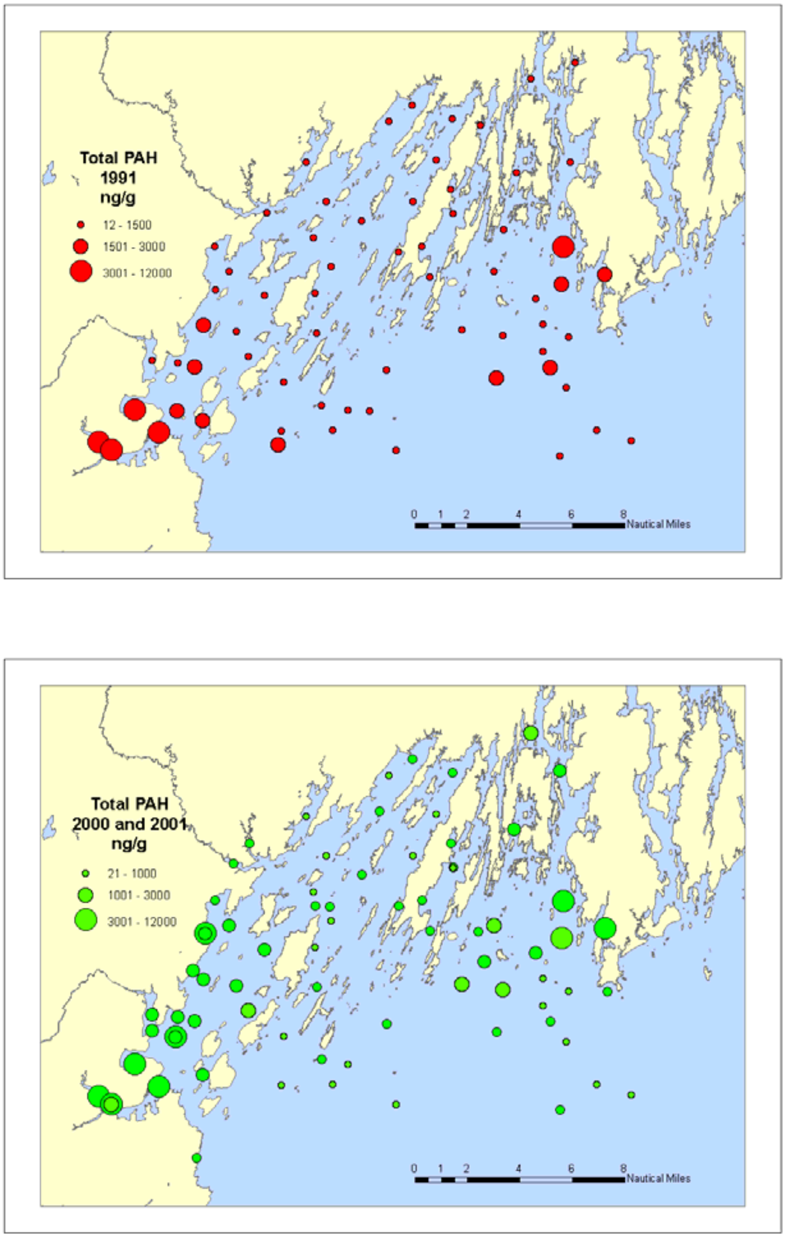


**Figure 31. Geographic Distribution of total PAH from Both Sampling Periods.**

greater than 1500 ng/g in 2000/2001 compared to 1991 in the inner bay (SW04, IB06) and east bay (EB4). However in general even with the addition of the 8 additional sites the 2000/2001 total PAH concentrations appear remarkably similar to the 1991 distributions.

## 4.2 Pesticides and PCB

Pesticides and PCB are ubiquitous environmental contaminants that are found in nature only due to anthropogenic activities as there are no known natural sources. Pesticides and PCB enter ecosystems like Casco Bay from run-off and atmospheric deposition (Jarnberg et al. 1993). The pesticides and PCB reported have been banned from use. It is therefore expected that the concentrations of these contaminants will eventually decrease. However many of these contaminants have long environmental half-lives, on the order of 10 to 20 years, and may continue to be added to the bay from run-off and atmospheric deposition.

The pesticide and PCB data from the 1991 sampling indicated that only PCB were at concentrations expected to adversely effect the sediment biota of Casco Bay at a single station in the study area. These toxic PCB concentrations were only found in the Fore River (SW02) in 1991. Due to the low concentrations (Table 5) of most pesticides, the sum of all pesticide for 1991 versus 2000/2001 was plotted. The total pesticide concentrations for 2000/2001 generally have lower concentrations compared to 1991 (Figure 32a). The most significant component of the total pesticides concentrations were the DDTs. The Total DDT concentrations for 2000/2001, in general, have lower concentration compared to 1991 (Figure 32b). Of the 59 sites only 10 had higher concentrations in 2000/2001. The individual PCB congener concentrations were also low, so only total PCB concentrations are compared. The total PCB concentrations for 2000/2001 generally have lower concentrations compared to 1991 (Figure 32c). Of the 65 sites, only 8 had higher concentrations in 2000/2001. Additional plots for DDD and DDE can be found in Appendix II, Figures 33 through 37.

The geographical distribution of total pesticides and PCB are shown in Figure 38. Total pesticides tend to have elevated concentrations in areas near shore and in the vicinity of Portland in 1991, as described previously. The concentration of total pesticides is lower in 2000/2001 especially in West Bay and Outer Bay. Site ME01-0128, located off Cape Elizabeth, had the highest total pesticide concentration. It had not been sampled as part of earlier project. The high total pesticide concentration was driven by the high concentrations of 2,4 DDD and 4,4 DDD (110 ng/g and 330 ng/g, respectively). It should be noted that total PCB depicted here is the sum of 18 PCB congeners measured in 1991 and 2000/2001. The data previously reported was for total of all PCB estimated by multiplying the total of the 18 PCB by a factor of ~2. The total

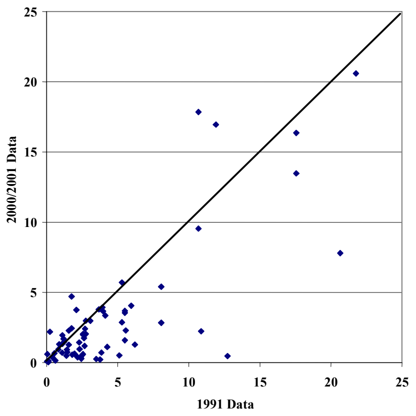


Figure 32a. Total Pesticide

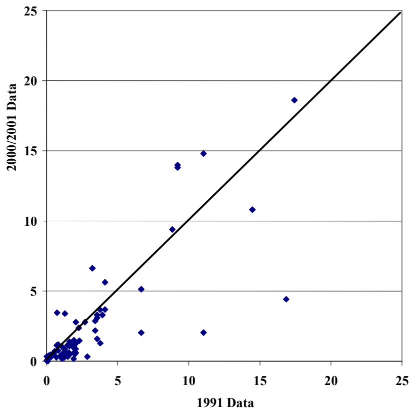


Figure 32b. Total DDT

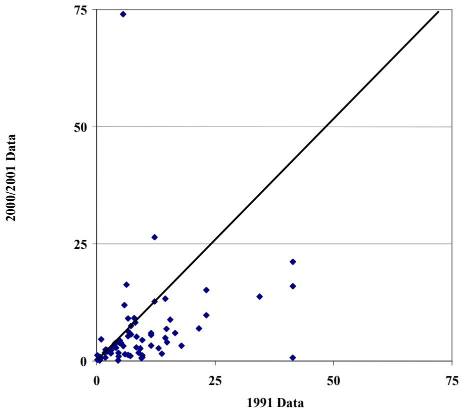


Figure 32c. Total PCB (Except SW1)

Figure 32. Comparison Plots for a) Total Pesticides, b) Total DDT, and c) Total PCB from Both Sampling Periods.

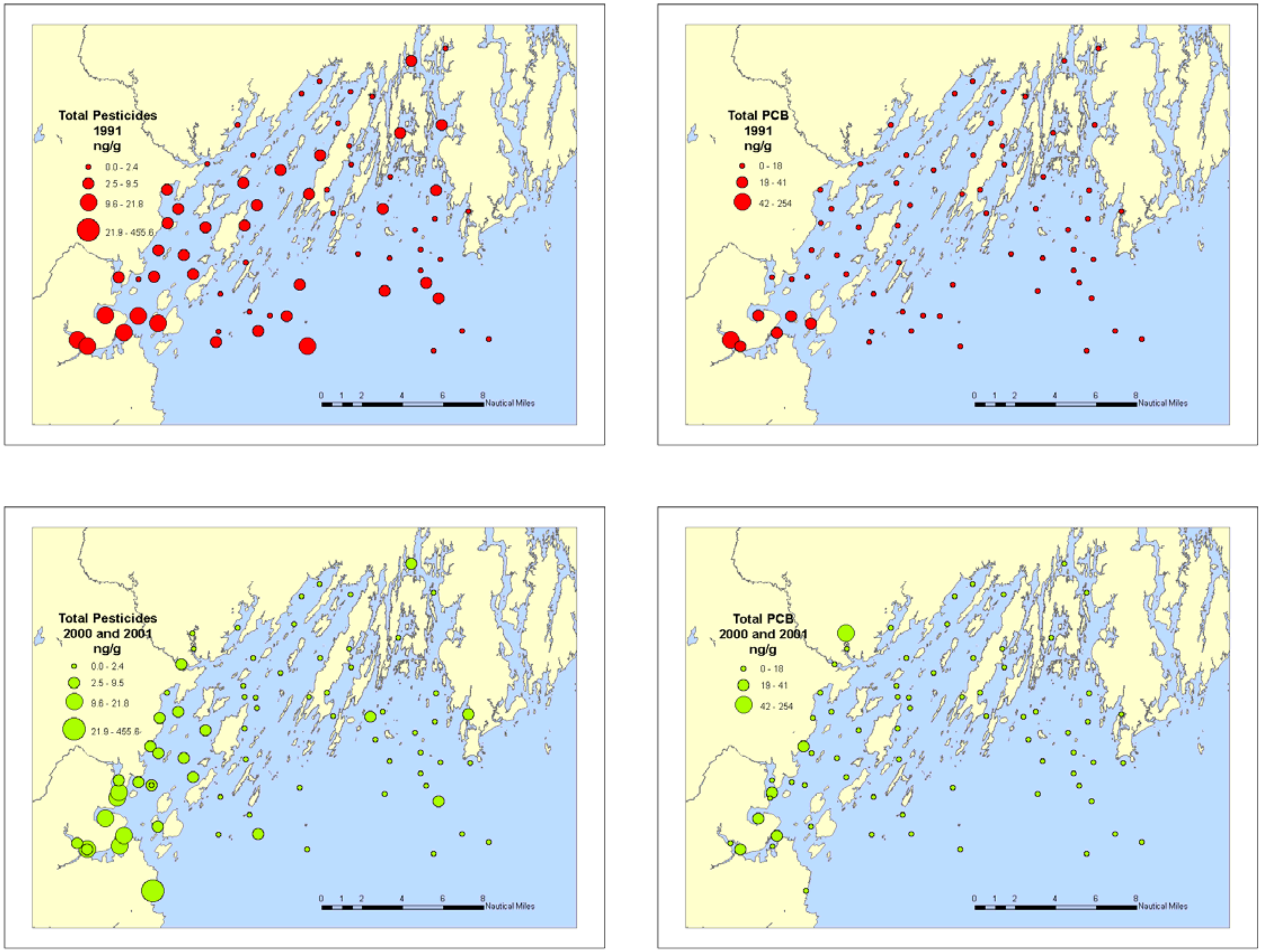


**Figure 38. Geographic Distribution of Total Pesticides and Total PCB from Both Sampling Periods.**

PCB concentrations are low throughout the bay. The highest concentrations of PCB were in the vicinity of Portland for both sampling periods. The high concentration for total PCB of 485 (254 for the 18 congeners) at site SW02 has decreased to less than 40 ng/g total PCB. The concentration of total PCB at SW02 was the only site that exceeded the ERL concentration. expected to adversely affect biota. For the 2000/2001 sampling, the site IB07Z had one of the highest measured total of 18 PCB concentrations (exceeded 19 ng/g). This site was not sampled in 1991. In general, PCB concentrations have decreased at most sites in Casco Bay with time.

## 4.3 Trace Elements

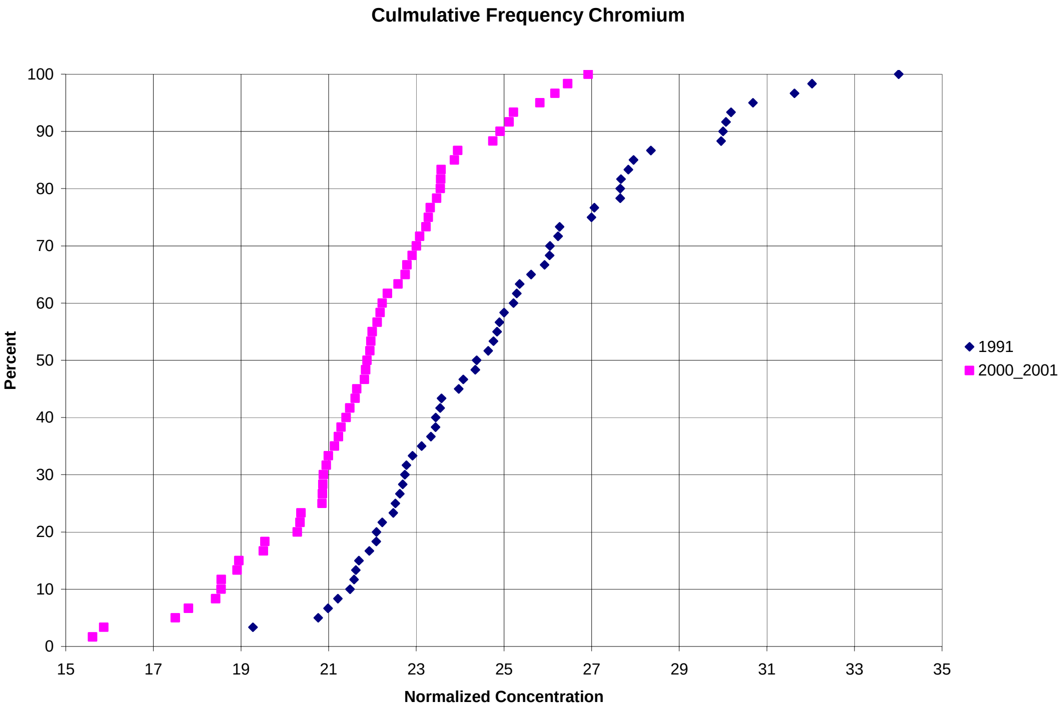
Trace elements are a natural component of sediments. Their concentrations can be increased by the activities of humans and then become a pollution concern. Some trace elements are required for the healthy growth of organisms, but concentrations above a threshold can be toxic. The way environmental chemists account for the natural abundance of these trace elements in sediments is to normalize their concentrations to either iron or aluminum. For this data set iron concentrations were used to normalize trace element data for both 1991 and 2000/2001. The sample concentrations (Table 6, App. I.) for all trace elements were divided by the iron concentration and this "normalized data" for 2000/2001 was plotted versus 1991. The comparisons cross plot diagrams, Figures 39 through 49, are found in Appendix II.

The iron concentrations for 2000/2001 are plotted versus 1991 (Figure 39). There is no consistent trend in the iron concentrations (e.g. many points plotting both above and below the no change line). The variability of iron between sampling periods is indicative of the non-homogeneity of the sediments. The normalized silver concentrations for 2000/2001 are generally higher compared to 1991 (Figure 40). Only 8 of 59 sites had higher concentrations in 1991 (e.g. plotted below the line). The normalized arsenic concentrations for 2000/2001 shows no trend compared to 1991 (Figure 41). The normalized cadmium concentrations for 2000/2001 are generally lower compared to 1991 (Figure 42). The normalized chromium concentrations for 2000/2001 are generally lower compared to 1991 (Figure 43). The normalized copper concentrations for 2000/2001 shows no trend compared to 1991 (Figure 44). The normalized mercury concentration for 2000/2001 was generally lower compared to 1991 (Figure 45). The normalized nickel concentrations for 2000/2001 are generally lower compared to 1991 (Figure 46). The normalized lead concentrations for 2000/2001 shows no trend compared to 1991 (Figure 47). The normalized selenium concentrations for 2000/2001 are generally lower compared to 1991 (Figure 48). The normalized zinc concentrations for 2000/2001 shows no trend compared to 1991 (Figure 49). In summary silver is the only trace element that indicates an increase in concentration at most sampling sites from 1991 to 2001. There were decreasing concentrations at the majority of sites for cadmium, chromium, mercury, nickel, and selenium and no apparent trend for arsenic, copper, lead and zinc. The frequency distribution plots (Figure 50) clearly show the chromium is lower in 2001 compared to 1991 (2001 data to the right of 1991 data) and the silver is higher at most sites in 2001 compared to 1991 (2001 data plots to the left of the 1991 data).

The geographical distributions of trace elements can be found in Figures 51 to 61 (in Appendix III); in general, slightly elevated normalized concentrations are localized in the vicinity of Portland and at many near shore sites. This is due to the overprinting of small anthropogenic trace element concentrations on the natural concentrations from the crustal material of these sediments. This geographic pattern is similar to other contaminants that have sources in highly populated and industrial areas.

### 4.4 Butyltins

Butyltins found in the environment include tetrabutyltin (4BT), tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT). The source of 4BT in sediment is usually from paint chips where 4BT is a minor component. TBT was the active ingredient used in marine paints to prevent fouling of marine vessels bottoms by growth of barnacles and other organisms (Laughlin et al., 1984). Fouling increases roughness of the vessel surface and increases fuel consumption. Sediments sites near boating activities are expected to contain the highest concentrations of TBT. DBT and MBT are minor components of anti-fouling paints and are also degradation products of TBT. DBT is also used as a stabilizer for polyvinylchloride plastics and as a catalyst in the production of polyurethane foams (Laughlin et al., 1984). All butyltin concentrations are reported as ng Sn/g dry sediment weight (Table 7). Three individual butyltin species TBT, MBT and DBT were analyzed during both 1994 and 2000/2001. For 2000/2001 the concentrations of 4BT were not reported. For the 1994 sampling detectable concentrations of 4BT was only found at 8 of 31 sites and only at low concentrations (less than 0.7 ng Sn/g). Concentration plots for TBT (Figure 62a) has 26 of 29 sites (90%) below the trend line indicting lower concentrations for 2000/2001 and 3 of 29 sites (10 %) above the trend line indicating an increase in concentration for 2000/2001. Over half of the sites (16/29, 55%) had detectable TBT concentrations in 1994 but no detectable TBT in 2000/2001. The three sites where TBT did not decrease (SW01, SW02 and IB01) were collected from the Fore River, which contains many



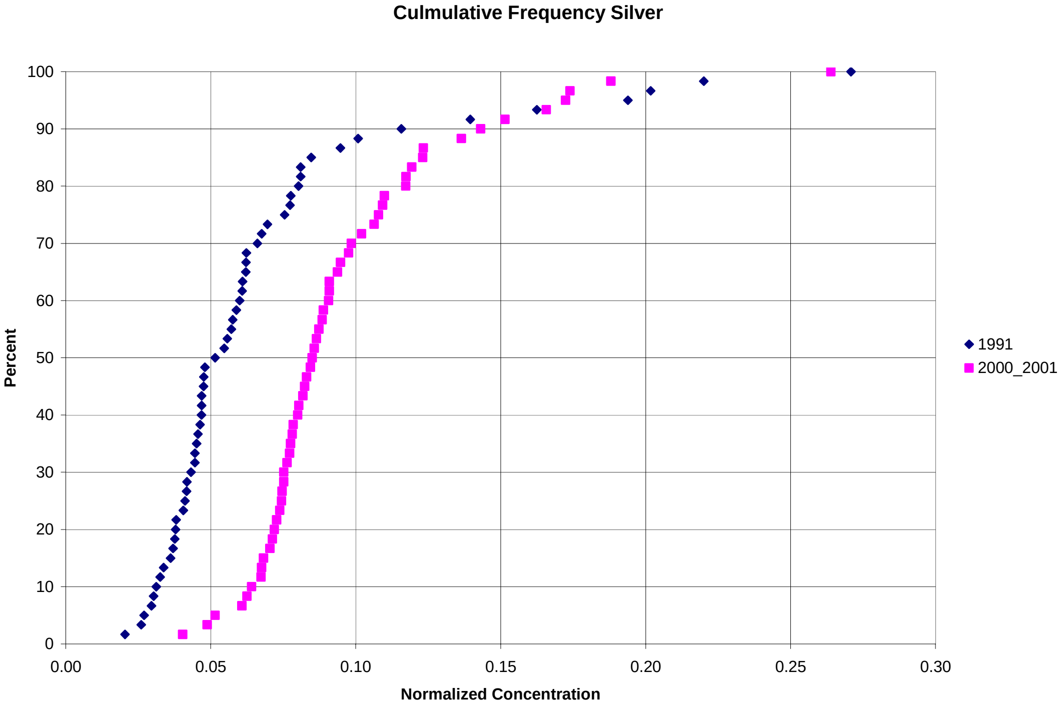


**Figure 50. Cumulative Frequency Distributions of a) Chromium, b) Silver for Both Sampling Periods.**

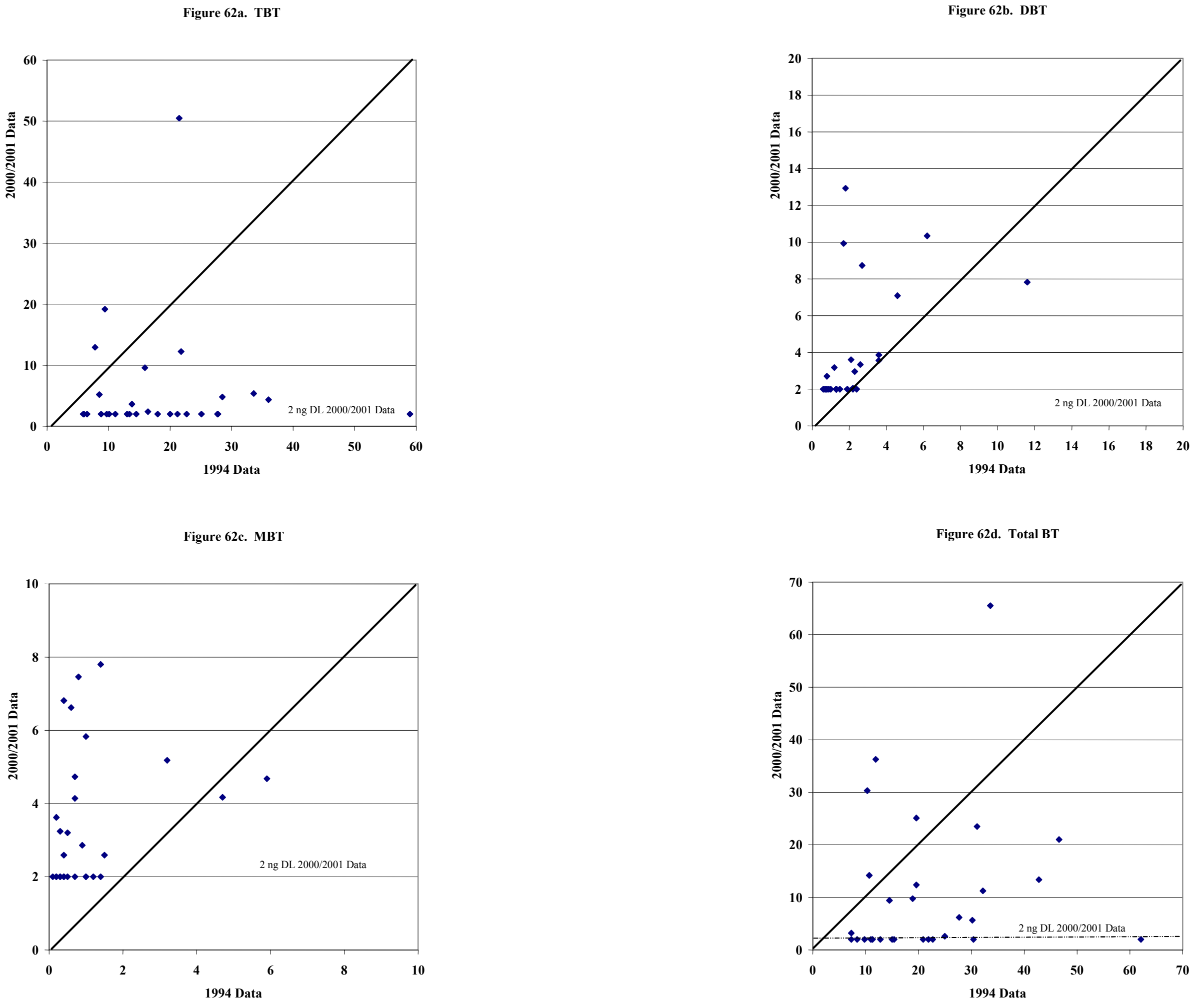


**Figure 62. Comparison Plots for a) TBT, b) DBT, c) MBT, and d) Total BT.**

commercial vessels, including oil tankers, container ships, cruise ships and large fishing vessels. Concentrations of TBT were less than two times greater for these three sites. These results could be due to spatial variability. The interpretation of DBT results is complicated by different method detection limits (MDL) between 1994 and 2000/2001 sampling periods and the low concentrations in the sediments. For samples that had concentrations below the detection limit the concentration was set as equal to the MDL. The detection limit for 2000/2001 was 2 ng Sn/g, while the detection limit for 1994 was 0.1 ng Sn/g. For 2000/2001 only 43% (13 of 29) sites had DBT concentrations greater than the MDL. The concentrations for 1994 were all above the MDL, but 51% (15 of 29) sites were less than 2 ng Sn/g. Only 6 sites in each year had DBT concentrations exceeding 4 ng Sn/g and they were the same 6 sites in both years. For these 6 pairs of sites five had higher concentrations in 2000/2001 and one in 1994 (Figure 62b). The highest DBT concentration for 1994 was 11.6 ng Sn/g at site IB07Z. The highest DBT concentration for 2000/2001 was 12.9 ng Sn/g at site SW01. The five sites where the DBT concentration exceeded 4 ng Sn/g were shallow water (SW01, SW02 and SW03) or inner bay (IB01 and IB07Z) sites. The three sites that had higher concentrations of TBT in 2000/2001 compared to 1994 also had higher concentrations of DBT. DBT is a metabolite of TBT so TBT and DBT typically co-vary. However DBT can also come from other sources making interpretation more tenuous. Considering these caveats, there is no clear indication that DBT has decreased between 1994 and 2000/2001.

The interpretation of MBT results is also complicated by different method detection limits (MDL) between 1994 and 2000/2001 and the low concentrations encountered. For samples with concentrations below the detection limit, the concentration was set as equal to the MDL. The detection limit for MBT for 2000/2001 was 2 ng Sn/g, while the detection limit for 1994 was 0.1 ng Sn/g. For 2000/2001 only 43% (13 of 29) sites had DBT concentrations greater than the MDL. For 1994 7% (2 of 29) had concentrations of MBT that were below the MDL, but only 10% (3 of 29) sites were greater than 2 ng Sn/g. Only 10 sites in 2000/2001 and 2 sites in 1994 had MBT concentrations exceeding 4 ng Sn/g. Of these 10 sites 80% had higher concentrations in 2000/2001 while 20% had higher concentrations in 1994 (Figure 62c). MBT is metabolite of DBT so MBT and DBT would be expected co-vary. There is an indication that MBT has increased between 1994 and 2000/2001.

Total butyltin is the sum of TBT, DBT and MBT. Concentrations for total butyltin were higher in 1994 for 79% (23 of 29) of the sites (Figure 62d). The five of the six sites that were higher in total butyltin concentration in 2000/2001 were in the Inner Bay area (IB01), including four shallow water sites (SW01, SW02, SW03 and SW04). The other site was in the East Bay region (EB07) and was a relatively low level sample containing only TBT which had no butyltins detected in 1994. The sites include the four that had higher TBT concentration in 2000/2001 and five (all from the Inner Bay) of the six sites that had higher DBT concentrations in 2000/2001. These Shallow Water and Inner Bay sites may have higher concentrations in 2000/2001 due to continued boating activities of boats painted before the ban on butyltin use, mixing of sediments bringing older more contaminated sediment to the surface, transport of more contaminated sediments from other sites, sediment heterogeneity or a combination of all of these. However the trend of decreasing TBT and total butyl tin concentrations at over 75% of the sites strongly supports a decreasing trend for butyltins in most areas of Casco Bay.

The geographic distribution of total butyltin, TBT, DBT and MBT are shown in Figures 63 and 64. The Distribution in 1994 has been described previously. The 2001 samples have very few concentrations above the detection limit. Only two sites have concentrations above 16 ng Sn/g in 2000/2001 (IB01 and OB03). The other geographic distributions for DBT and MBT are hard to interpret due to the low concentrations. It is however apparent from the TBT distributions that TBT decreased between 1994 and 2001 at most sites in Casco Bay.

## 4.5 Dioxins and Furans

Dioxins and furans are toxic unwanted bi-products of industrial chlorination processes and burning of waste (Spiro and Thomas, 1994). They have been called the most toxic man made chemical inadvertently released to the environment. Due to their low toxicity threshold the concentration of dioxins and furans are measured at the pg/g or parts per trillion levels. The method for these analyses requires extensive clean-up of the samples and analyses using a high resolution mass spectrometer. Samples analyzed in both 1994 and 2000/2001 were done using similar methods (modified EPA Method 8290 and EPA Method 1613). The concentrations (Table 7) and graphs of concentrations for 1994 versus 2000/2001 for all 17 toxic (2,3,7,8 substituted) dioxins and furans are provided in Figures 63 to 79 (Appendix II).

The most toxic of the dioxins and furans are ones with four (tetra) chlorines, 2,3,7,8-TCDF and 2,3,7,8-TCDD. The concentration of 2,3,7,8-TCDF for 2000/2001 is higher than 1994 at all sites (Figure 65). However, care must be taken in the interpretation of the 2,3,7,8-TCDF concentrations plots. The 2000/2001 data discussion notes that "results reported for 2,3,7,8-

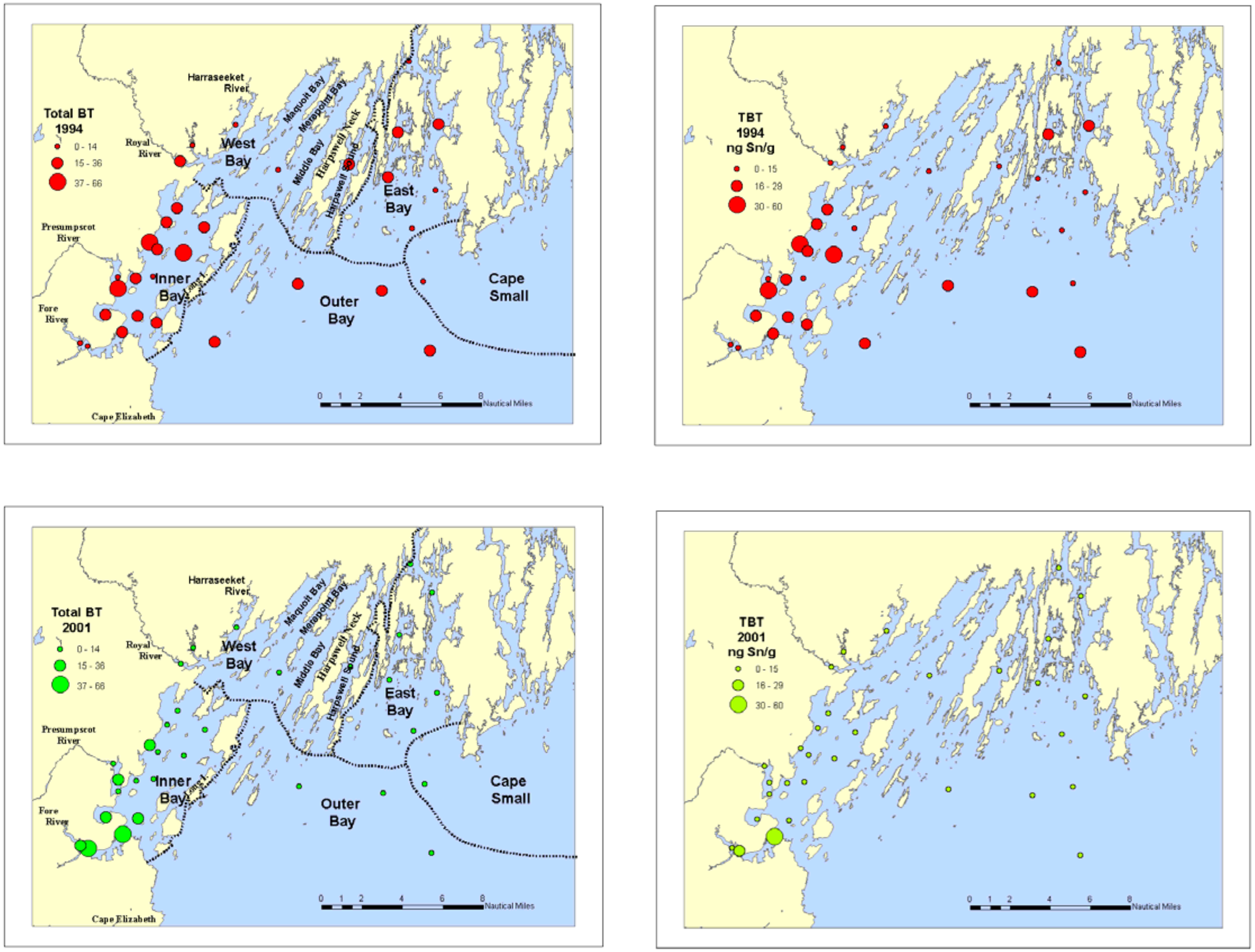


**Figure 63. Geographic Distribution of Total BT and TBT from Both Sampling Periods.**

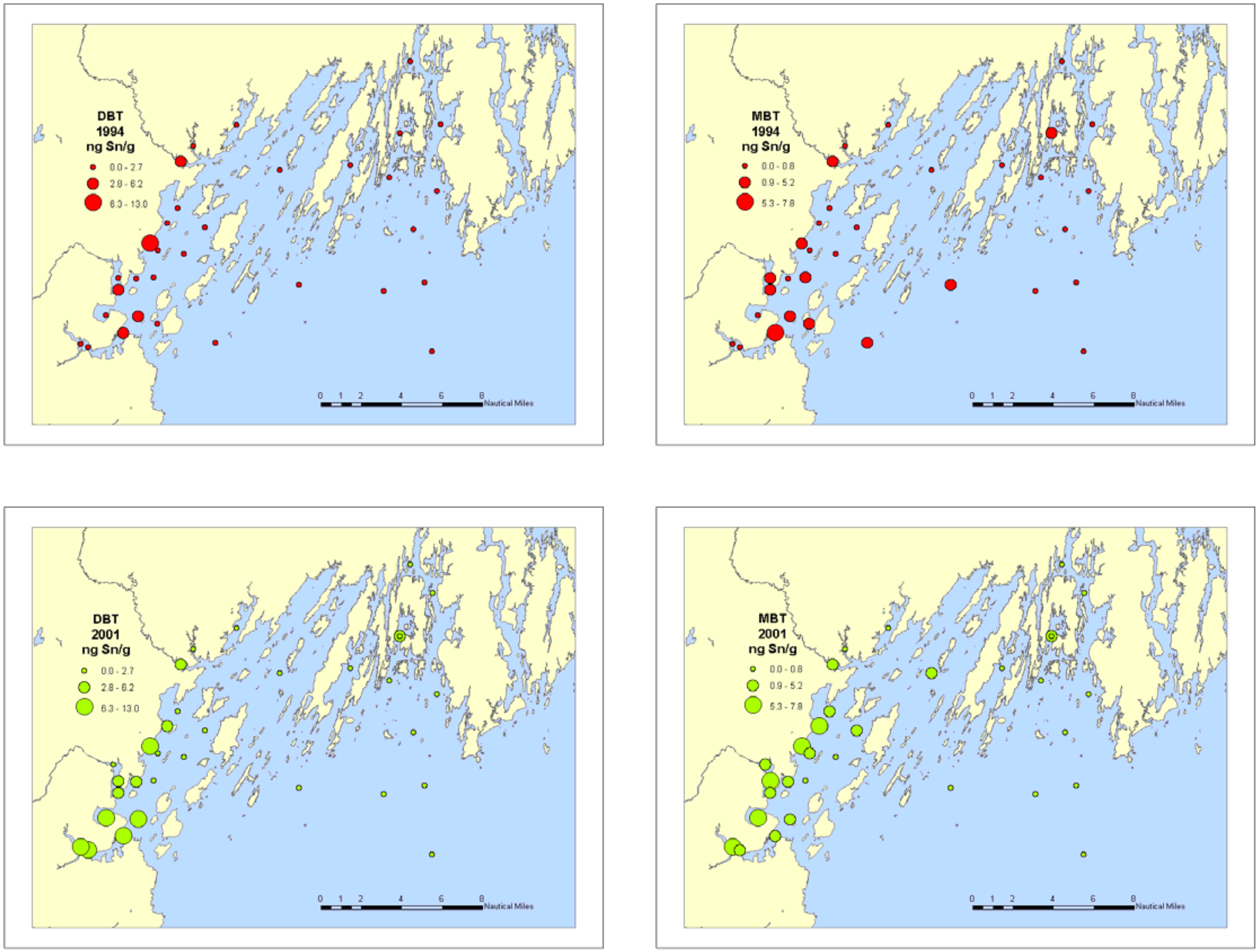


**Figure 64. Geographic Distribution of DBT and MBT from Both Sampling Periods.**

TCDF represent maximum possible concentrations due to the possibility of overlapping HRGC peaks". The analyses of 2,3,7,8-TCDF in 1994 included a second column confirmation, eliminating these interferences. These differences as well as the low concentrations (less than 18 pg/g) makes it difficult to determine if a trend exists at all for 2,3,7,8-TCDF. The concentration of 2,3,7,8-TCDD for 1994 versus 2000/2001 has only 12 of 28 (41%) of the samples that have concentrations above 0.5 pg/g. All 2,3,7,8-TCDD concentration were less than 2 pg/g. Of the 12 samples that have concentrations above 0.5 pg/g, 6 are higher in 2000/2001 and 6 are higher in 1994 (Figure 66). There is no conclusive data that 2,3,7,8-TCDD concentrations are increasing or decreasing based on this data.

The 1,2,3,7,8-PeCDF concentrations indicate generally higher concentrations in 2000/2001 compared to 1994 (Figure 67). Of the 11 sites with concentrations greater than 1 pg/g, 7 had higher concentrations in 2000/2001 while only 4 had higher concentrations in 1994. The 2,3,4,7,8-PeCDF concentrations indicates generally lower concentrations in 2000/2001 compared to 1994 (Figure 68). Of the 12 sites with concentrations greater than 1 pg/g, 4 had higher concentrations in 2000/2001 while 8 had higher concentrations in 1994. The 1,2,3,7,8-PeCDD concentrations indicates generally lower concentrations in 2000/2001 compared to 1994 (Figure 69). Of the 13 sites with concentrations greater than 1 pg/g, 3 had higher concentrations in 2000/2001 while 10 had higher concentrations in 1994.

The 1,2,3,4,7,8-HxCDF concentrations indicates generally higher concentrations in 2000/2001 compared to 1994 (Figure 70). Of the 17 sites with concentrations greater than 1 pg/g, 16 had higher concentrations in 2000/2001 while only 1 had higher concentrations in 1994. The 1,2,3,6,7,8-HxCDF concentrations indicates no trend in concentrations in 2000/2001 compared to 1994 (Figure 71). Of the 17 sites with concentrations greater than 1 pg/g, 8 had higher concentrations in 2000/2001 while 9 had higher concentrations in 1994. The 2,3,4,6,7,8-HxCDF concentrations indicates no trend in concentrations in 2000/2001 compared to 1994 (Figure 72). Of the 23 sites with concentrations greater than 1 pg/g, 9 had higher concentrations in 2000/2001 while 14 had higher concentrations in 1994. The 1,2,3,7,8,9-HxCDF concentrations indicates generally lower concentrations in 2000/2001 compared to 1994 (Figure 73). None of the sites in 2000/2001 had concentrations above 1 pg/g. For 1994 4 sites had concentrations greater than 1 pg/g and thus higher concentrations in 1994.

The 1,2,3,4,7,8-HxCDD concentrations indicates generally higher concentrations in 2000/2001 compared to 1994 (Figure 7). Of the 19 sites with concentrations greater than 1 pg/g, all had higher concentrations in 2000/2001 while no sites had higher concentrations in 1994. The 1,2,3,6,7,8-HxCDD concentrations indicates no trend for concentrations in 2000/2001 compared to 1994 (Figure 75). Of the 21 sites with concentrations greater than 1 pg/g, 11 had higher concentrations in 2000/2001 while 10 sites had higher concentrations in 1994. The 1,2,3,7,8,9-HxCDD concentrations indicates generally higher concentrations in 2000/2001 compared to 1994 (Figure 76). Of the 24 sites with concentrations greater than 1 pg/g, 22 had higher concentrations in 2000/2001 while only 2 sites had higher concentrations in 1994.

The 1,2,3,4,6,7,8-HpCDF concentrations indicates similar concentrations in 2000/2001 compared to 1994 (Figure 77). Of the 24 sites with concentrations greater than 1.5 pg/g, 11 had higher concentrations in 2000/2001 while 13 sites had higher concentrations in 1994. The 1,2,3,4,7,8,9-HpCDF concentrations indicates higher concentrations in 2000/2001 compared to 1994 (Figure 78). Of the 12 sites with concentrations greater than 1.5 pg/g, 9 had higher concentrations in 2000/2001 while 3 sites had higher concentrations in 1994. The 1,2,3,4,6,7,8-HpCDD concentrations indicates no trend in concentrations in 2000/2001 compared to 1994 (Figure 79). Of the 28 sites with concentrations greater than 1.5 pg/g, 15 had higher concentrations in 2000/2001 while 13 sites had higher concentrations in 1994.

The OCDF concentration indicates similar concentrations in 2000/2001 compared to 1994 (Figure 80). Of the 29 sites with concentrations greater than 2 pg/g, 15 had higher concentrations in 2000/2001 while 14 sites had higher concentrations in 1994. The OCDD concentration indicates no difference in concentrations in 2000/2001 compared to 1994 (Figure 81). Of the 28 sites with concentrations greater than 2 pg/g, 18 had higher concentrations in 2000/2001 while 10 sites had higher concentrations in 1994.

It is anticipated that over the long term, dioxin/furan concentration in the environment will decrease in response to regulations lowering their production. Of the 17 dioxin/furan compounds measured, differences between the sampling periods for 16 of them were estimated. There were 6 compounds that suggest higher concentrations in 2000/2001, 7 compounds with no strong trend and 3 compounds that had higher concentrations in 1994. It is therefore not apparent at this time that there is a systematic increase or decrease in dioxin/furan concentrations between 1994 and 2000/2001.

The geographic distribution of dioxins and furans is similar to other contaminants. Figure 82 shows the spatial distribution of total dioxins and total furans from both sampling periods. The spatial distributions of dioxins and furans, by the level of chlorination are found in Appendix III, Figures 83 through 91. In general, the higher concentrations are found in the vicinity of Portland and other near-shore highly populated and industrialized areas. While the geographic distribution is similar, it is apparent that the concentrations in the sediments at many sites have decreased between 1994 and 2001.

## 4.6 Planar PCB

Planar PCB are minor components of the Aroclors used in the U.S., but they have characteristic toxicities similar to the dioxin and furans. In order to accurately determine their concentrations, planar PCB must first be separated from other PCBs in the extract. Sample analyses were comparable in both sampling periods. The planar PCB 77 concentrations (Table 7) indicate no differences in concentrations in 2000/2001 compared to 1994 (Figure 92, see Appendix II). Of the 27 sites with concentrations greater than 1.2 pg/g, 13 had higher concentrations in 2000/2001 while 14 sites had higher concentrations in 1994. The planar PCB 126 concentrations (Table 7) indicate lower concentrations in 2000/2001 compared to 1994 (Figure 93, see Appendix II). Of the 28 sites with concentrations greater than 1 pg/g, 5 had higher concentrations in 2000/2001 while 18 sites had higher concentrations in 1994. There were not enough samples where planar PCB 169 was detected to observe any trends. Planar PCB 81 was not reported for 1994, but is likely at lower concentrations than PCB 77. The lower molecular weight, more volatile, and more water soluble PCB 77 does not indicate a decreasing trend between 1994 and 2000/2001. The higher molecular weight less volatile and less water soluble PCB 126 indicates a possible decrease.

The geographic distribution of planar PCB is similar to other contaminants (see Appendix III, Figures 94 and 95). The higher concentrations are found in the vicinity of Portland and other near-shore highly populated and industrialized areas. While the geographic distribution of concentrations is similar it is apparent that the sediments at many sites have decreased between 1994 and 2001.

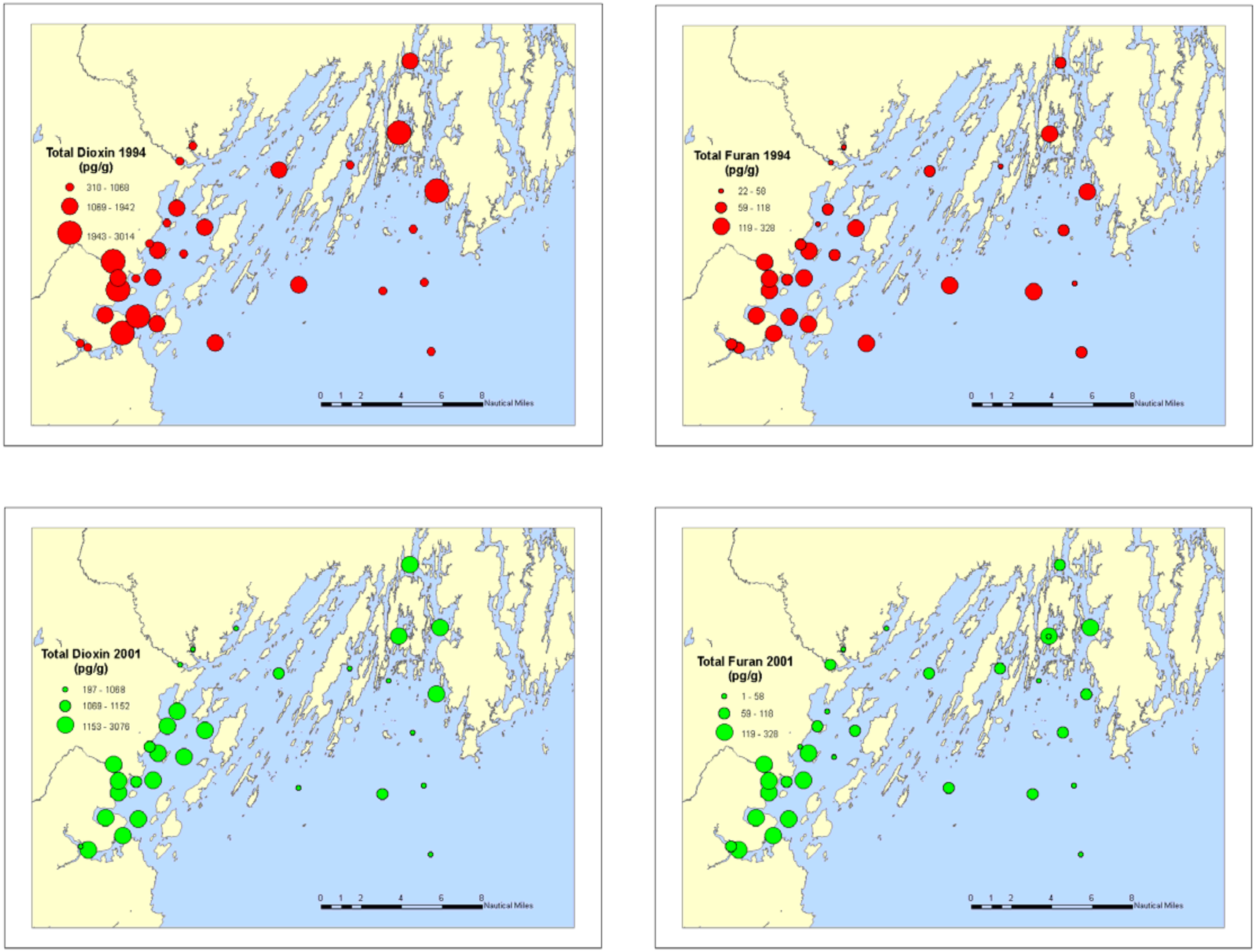
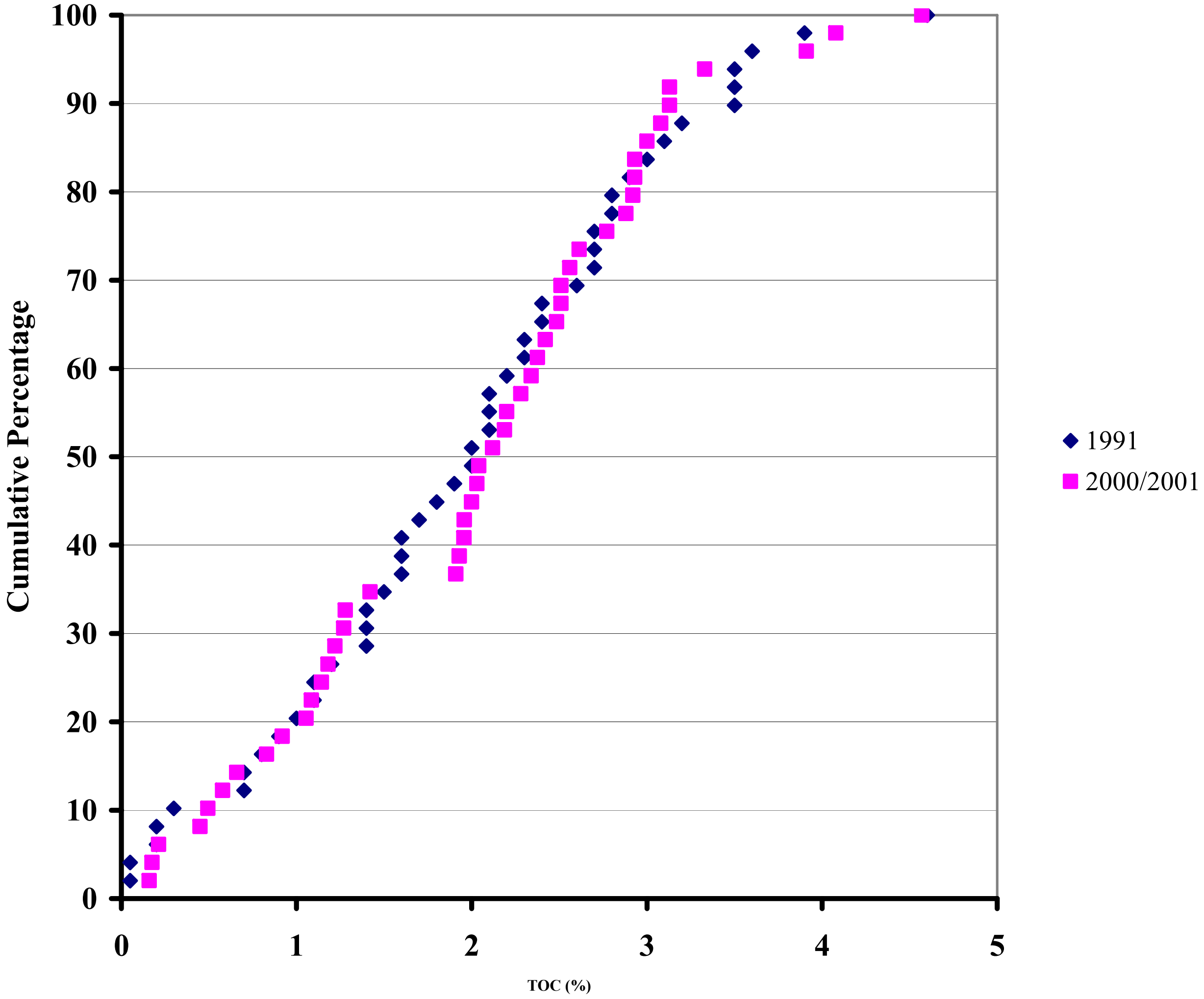


**Figure 82. Geographic Distribution of total dioxins and total furans from both sampling periods.**

## 4.7 TOC and Grain Size

The total organic carbon (TOC) and grain size are measured in sediments as descriptive properties of the sediment. Total organic carbon content of sediments may be related to the contaminant content or to the availability of the contaminant to organisms. The available grain size data from all sources range from four fractions (percent gravel, percent sand, percent silt and percent clay) to two fractions (percent sand and percent silt/clay); we are limiting our discussions to these two fractions (and have converted data as appropriate) in order to incorporate the largest number of sites possible. Grain size is typically related to organic contaminant concentrations with higher concentrations associated with the finer grained (silt and clay) fraction. Many trace elements are also in higher abundance in silt and clay compared to sand. When TOC for 1991 is plotted versus TOC from 2000/2001 (Figure 96, Appendix II) there is no apparent increase or decrease between these sampling periods. The sand fraction or the silt and clay fraction do not exhibit any apparent trend between sampling periods (Figures 97 and 98, Appendix II). A frequency distribution for the two sampling periods indicates TOC (Figure 99) is unchanged when the entire bay is considered. The geographic distribution of TOC and grain size is similar at most sites but there are some changes at specific sites (Figure 100). This is likely due to heterogeneity of the sediments.

## Figure 99. TOC Cumulative Frequency Distribution



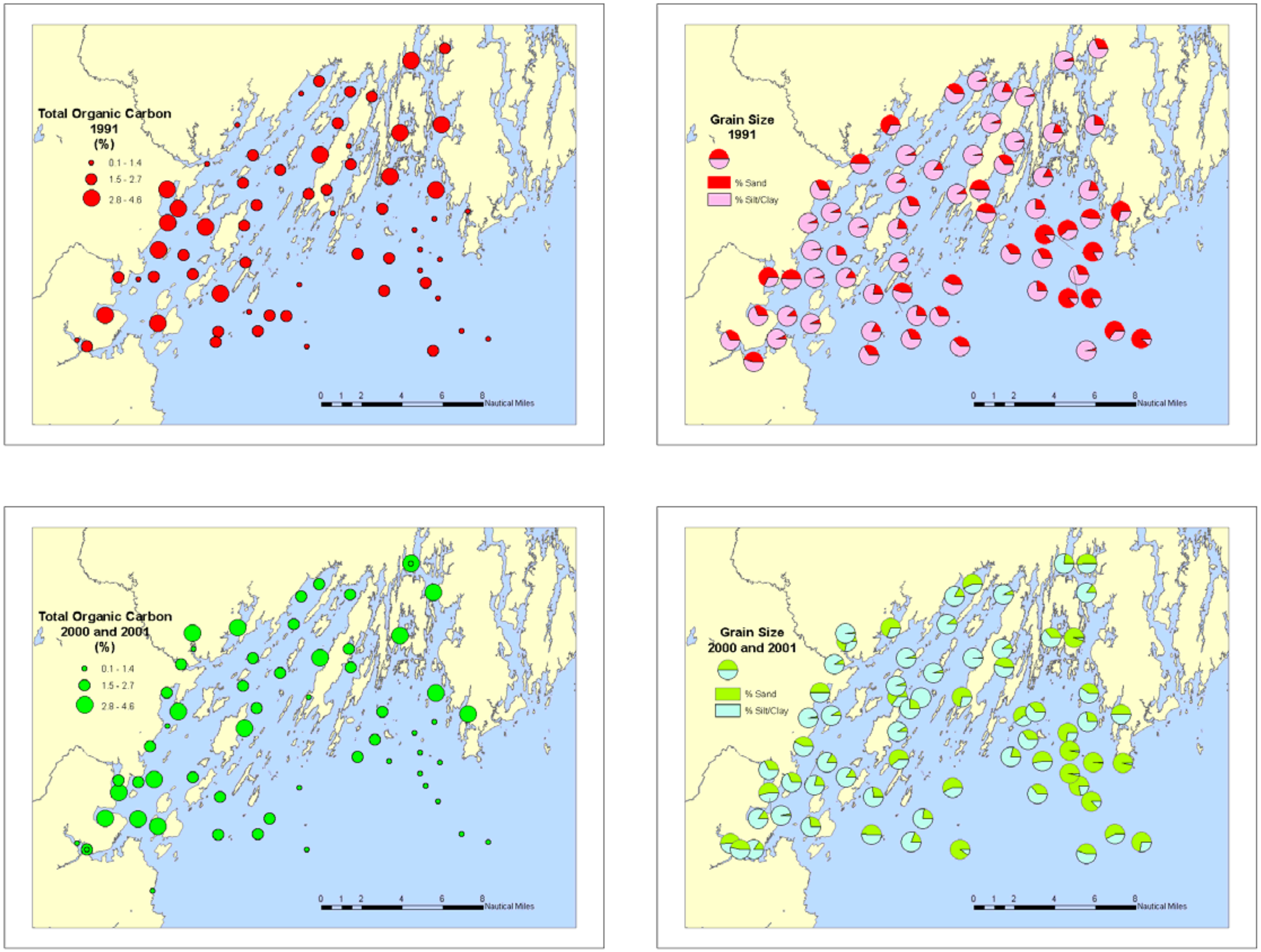


**Figure 100. Geographic Distribution of TOC and Grain Size from Both Sampling Periods.**

## 5.0 Summary and Conclusions

Contaminant concentrations of sediment samples collected approximately 10 years apart are compared in an attempt to establish the current status of contaminant concentrations in Casco Bay and determine the spatial and temporal status and trends as they relate to contaminant concentrations. This process is complicated by the potential of re-suspension of older sediment back to the surface, the non-homogeneity of sediments, low concentrations for some analytes and variability of different analytical methods. The top 2 cm of sediments can reflect different time periods for different locations that have significantly different sedimentation rates. The sediments can also be re-disturbed by natural processes (e.g. storms). Concentrations of many contaminants were low and the lower the measured concentrations of analytes, the greater the uncertainty of their concentrations. Even when differences are apparent at many sites there are also sites that exhibit the opposing differences. It is also important to note that differences were normally of less than a factor of 2 increase or decrease in concentration. However, with greater number of sites analyzed, the overall changes in analytical results observed are given more credibility. In spite of these complications several observations are noteworthy.

The overall trend for PAH is there is no increase or decrease between 1991 and 2000/2001. Low molecular weight PAH (defined as the sum of detected concentrations for naphthalene, acenaphthylene, acenaphthene, fluorene, and anthracene) suggest a temporal decrease in concentration while opposite is true for high molecular weight PAH, (defined as the sum of detected concentrations for fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3,-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene). There are individual PAH that do suggest increasing concentrations (e.g. benzo(b)fluoranthene) or decreasing concentrations (e.g. 2,6-dimethynapthalene) from 1991 to 2000/2001, but most PAH do not indicate any differences. It is not unreasonable that PAH concentrations in sediment may be increasing at selected sites and decreasing at others. There is a continuing increased use of fossil fuels that is balanced by increasing controls that lower PAH inputs as well as small scale oil spills at random sites.

Total pesticides as well as 4,4-DDE, 4,4-DDD and total DDTs indicate a decrease. Total PCBs indicate a decreasing trend. Silver is the only trace element that indicates an increase in concentration at most sampling sites from 1991 to 2001. There were decreasing concentrations at the majority of sites for cadmium, chromium, mercury, nickel, and selenium and no apparent trend for arsenic, copper led and zinc. Tributyltin and total butyl tin indicated decreasing concentrations. The overall indication for dioxin/furans is no change between sampling periods. The planar PCB indicates no change (PCB 77) or decreasing concentrations (PCB 126). As was expected most of the contaminants indicated a decrease in concentrations.

There is no indication from this data that any of the contaminants measured has increased by more than a factor of 2. At most sites and for most analytes the trend is either no change or a decrease between 1991 or 1994 and 2000/2001. The overall conclusion is that the contaminant loading for Casco Bay as a whole is decreasing or remaining static. There are sites where increases are apparent and many of these sites are at the shallow water sites or inner bay sites where concentrations are higher and new inputs are more likely. The geographic distribution of sediment contaminants is generally confirmed in the analyses of mussel tissue by the Casco Bay Estuary Project and Maine DEP (Doggett, DEP, personal communication).

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# APPENDIX I.

# Tables

# Table 3. Casco Bay Data Source Summary

| Station Id for Plotting | 1991 Sampling | 1994 Sampling | 2000 Sampling | 2001 Sampling |
|---|---|---|---|---|
| CS01 | CS01 | | 4073030SO | |
| CS02 | CS02 | | 4096030SO | |
| CS03 | CS03 | | [1]ME00-0007 | [1]ME01-0118 |
| CS04 | CS04 | CS04 | | CS04-ICF Data |
| CS05 | CS05 | | 4097030SO | |
| CS06 | CS06 | | 4098030SO | |
| CS07 | CS07 | | 4085030SO | |
| EB01 | EB01 | | 4092030SO | |
| EB02 | EB02 | | 4095030SO | |
| EB03 | EB03 | | 4203030SO | [1]ME01-0108 |
| EB04 | EB04 | EB04 | | EB04-ICF Data |
| EB05 | EB05 | EB05 (TBT Only) | | |
| EB06 | EB06 | EB06 | | EB06-ICF Data |
| EB06 (DUP) | | | | [1]ME01-0102 |
| EB07 | EB07 | EB07 | [1]ME00-0013 | [1]ME01-0012 |
| EB07 (DUP) | | | | EB07-ICF Data-2 |
| EB08 | EB08 | EB08 (TBT Only) | | [1]ME01-0098 |
| EB09 | EB09 | EB09 | | [1]ME01-0010 |
| EB10 | EB10 | | 4205030SO | |
| IB01 | IB01 | IB01 | | IB01-ICF Data |
| IB02 | IB02 | IB02 | | IB02-ICF Data |
| IB02 (DUP) | | | | [1]ME01-0122 |
| IB03 | IB03 | IB03 | | [1]ME01-0002 |
| IB04 | IB04 | IB04 | | [1]ME01-0004 |
| IB04 (DUP) | | | | [1]ME01-0124 |
| IB05 | IB05 | | 4090030SO | |
| IB06 | IB06 | IB06 | | IB06-ICF Data |
| IB07 | IB07 | IB07 | | IB07-ICF Data |
| IB07Z | | IB07Z | | IB07-Z-ICF Data-2 |
| IB08 | IB08 | IB08 | | IB08-ICF Data |
| IB08 (DUP) | | | | [1]ME01-0112 |
| IB09 | IB09 | IB09 | | [1]ME01-0008 |
| IB10 | IB10 | IB10 | | IB10-ICF Data |
| OB01 | OB01 | OB01 | | OB01-ICF Data |
| OB02 | OB02 | | [1]ME00-0003 | |
| OB03 | OB03 | OB03 | | |
| OB04 | OB04 | | [1]ME00-0005 | |
| OB05 | OB05 | | 4100030SO | |
| OB06 | OB06 | | | OB06-ICF Data |

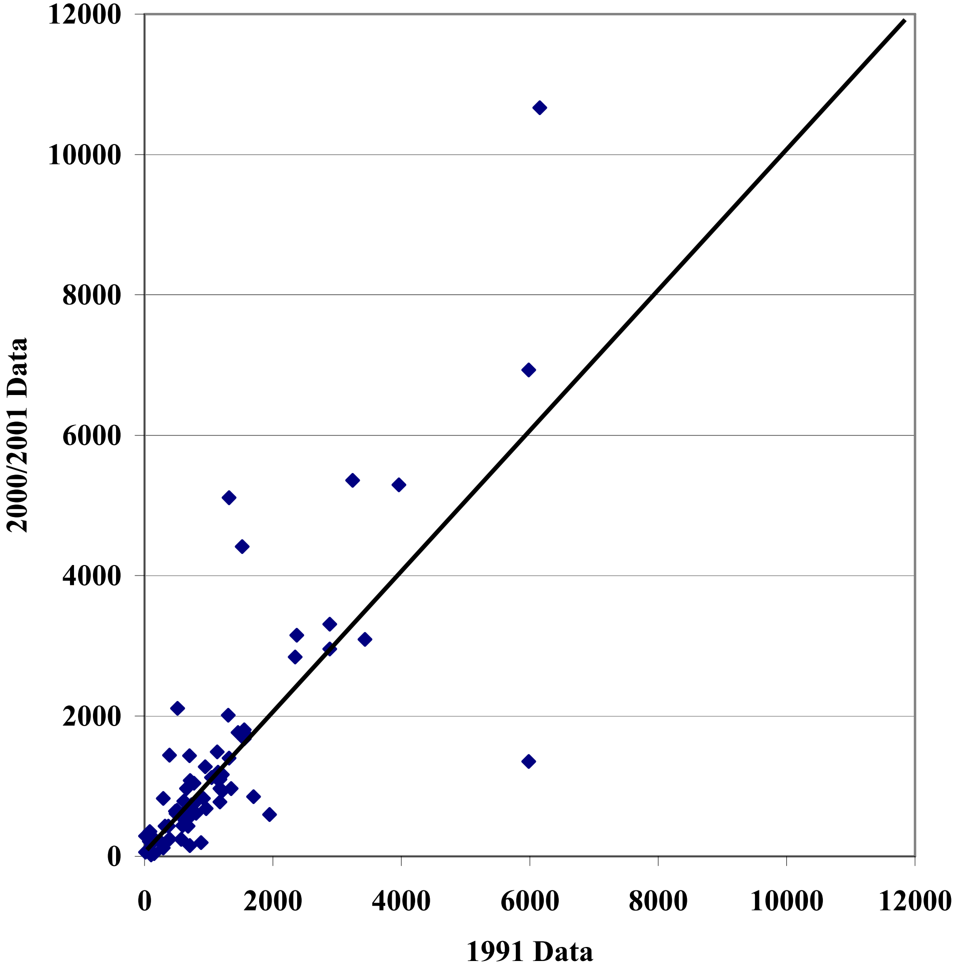
# Table 3. Casco Bay Data Source Summary (cont.)

| Station Id for Plotting | 1991 Sampling | 1994 Sampling | 2000 Sampling | 2001 Sampling |
|---|---|---|---|---|
| OB07 | OB07 | | 4102030SO | |
| OB08 | OB08 | | 4101030SO | |
| OB09 | OB09 | | | |
| OB10 | OB10 | OB10 | | ME01-0006 |
| OB11 | OB11 | | | OB11-ICF Data |
| OB12 | OB12 | | 4099030S0 | |
| OB13 | OB13 | | 4087030SO | ME01-0106 |
| OB15 | OB15 | OB15 | | OB15-ICF Data |
| SW01 | SW01 | SW01 | [1]ME00-0001 | SW01-ICF Data-2 |
| SW02 | SW02 | SW02 | | SW02-ICF Data-2 |
| SW03 | SW03 | SW03 | | SW03-ICF Data-2 |
| SW04 | SW04 | SW04 | | SW04-A-ICF Data-2 |
| SW04B | | SW04B | | SW04-B-ICF Data-2 |
| SW04C | | SW04C | | SW04-C-ICF Data-2 |
| SW05 | SW05 | SW05 | | SW05-ICF Data-2 |
| SW06 | SW06 | | | SW06-ICF Data-2 |
| SW07 | SW07 | | | |
| SW07A | | SW07A | | SW07-A-ICF Data-2 |
| SW07B | | SW07B | | SW07-B-ICF Data-2 |
| SW08 | SW08 | SW08 (TBT) | [1]ME00-0011 | SW08-ICF Data-2 |
| SW09 | SW09 | | | SW09-ICF Data-2 |
| SW10 | SW10 | | | SW10-ICF Data-2 |
| SW11 | SW11 | | | SW11-ICF Data-2 |
| SW12 | SW12 | | | SW12-ICF Data |
| SW13 | SW13 | | | SW13-ICF Data-2 |
| SW14 | SW14 | | | |
| SW15 | SW15 | | | SW15-ICF Data-2 |
| WB01 | WB01 | | 4091030SO | [1]ME01-0114 |
| WB02 | WB02 | | 4089030SO | |
| WB03 | WB03 | | 4088030SO | |
| WB04 | WB04 | | 4093030SO | |
| WB05 | WB05 | | 4094030SO | |
| WB06 | WB06 | | | |
| WB07 | WB07 | WB07 | [1]ME00-0009 | WB07-ICF Data |
| WB08 | WB08 | | | WB08-ICF Data |
| WB09 | WB09 | WB09 | | WB09-ICF Data |
| ME01-0100 | | | | [1]ME01-0100 |
| ME01-0116 | | | | [1]ME01-0116 |
| ME01-0128 | | | | [1]ME01-0128 |

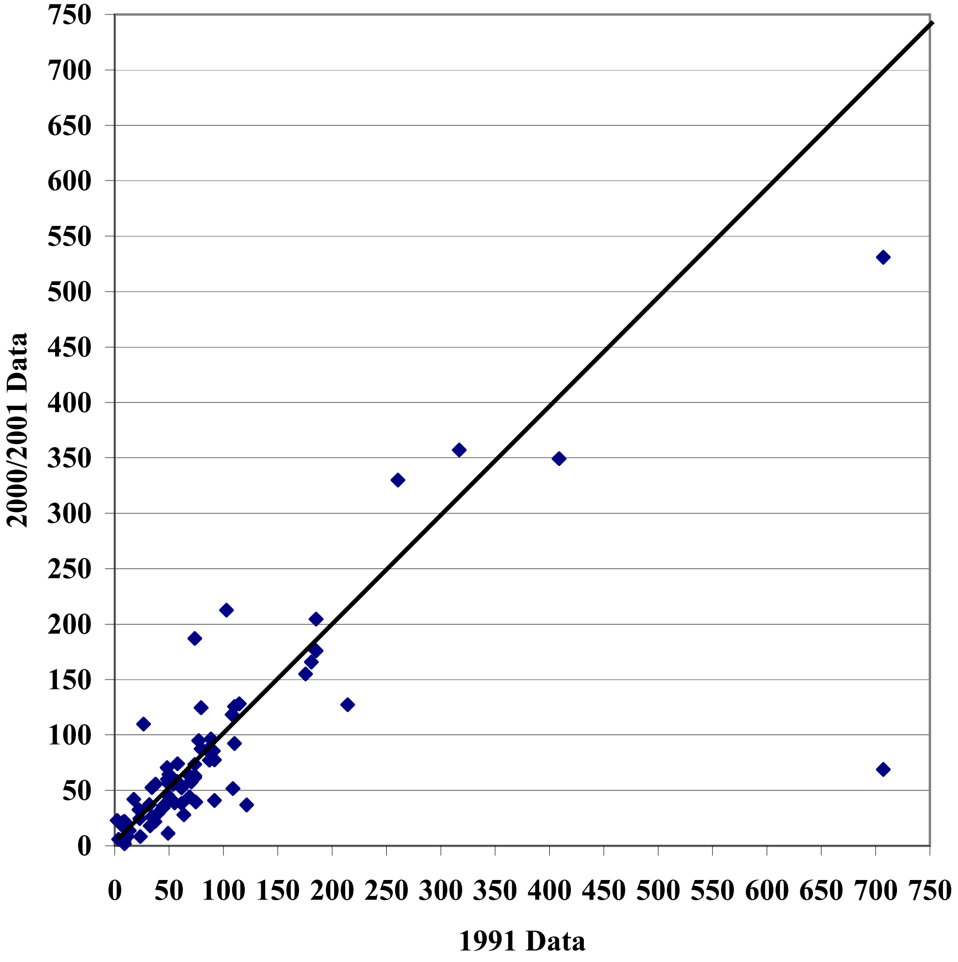
# APPENDIX II

## Data Plots

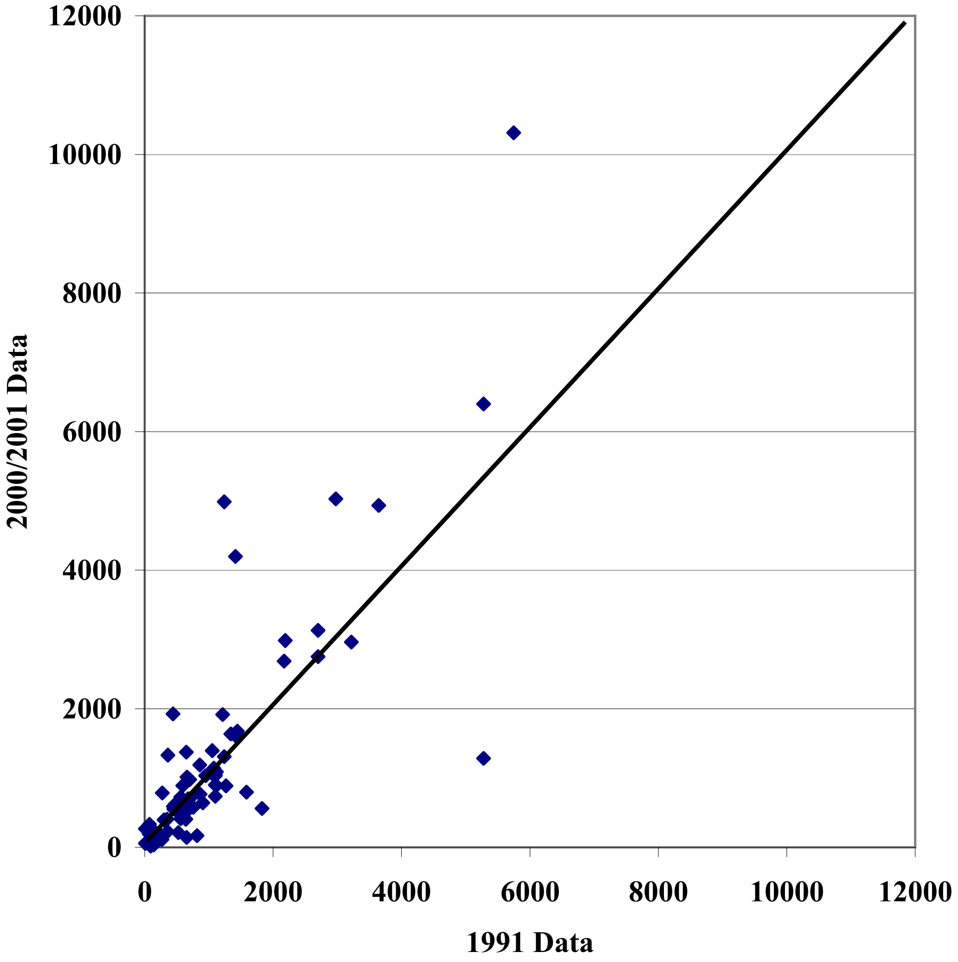
## Figure 4. Total PAH Data Plot of 1991 and 2000/2001



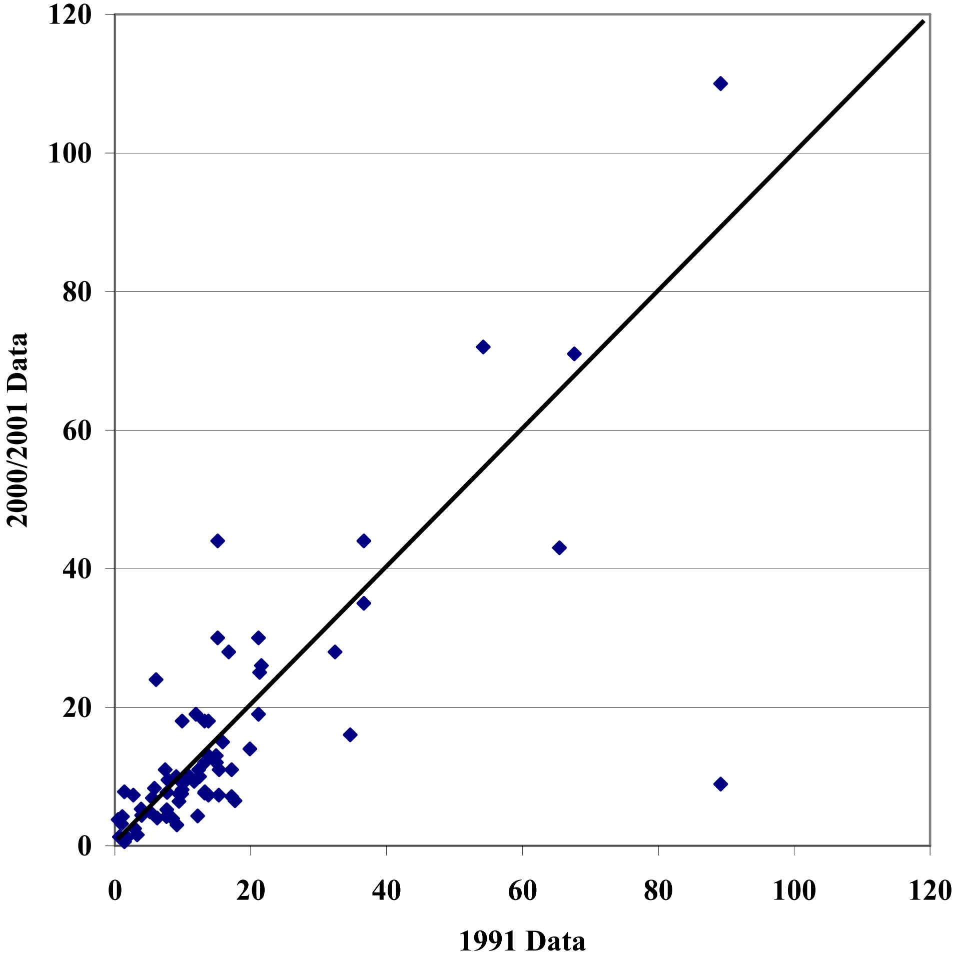
## Figure 5. Total LMW PAH Data Plot of 1991 and 2000/2001



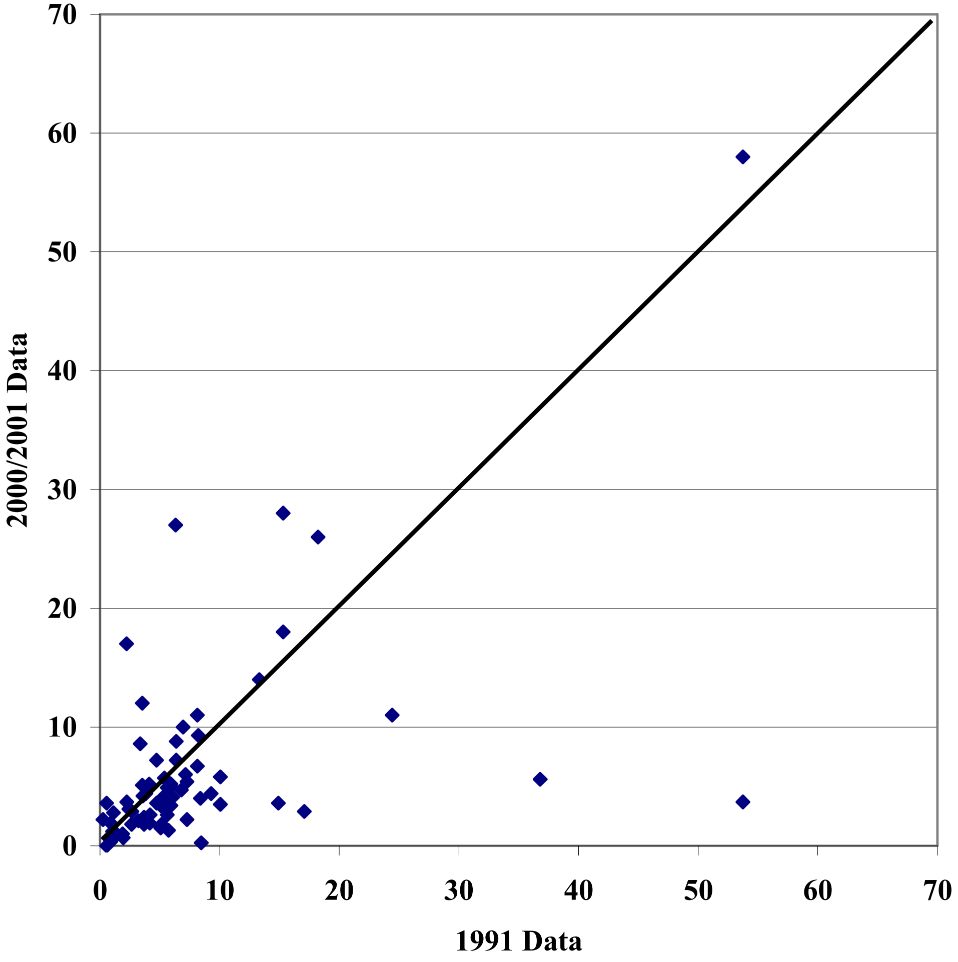
## Figure 6. Total HMW PAH Data Plot of 1991 and 2000/2001



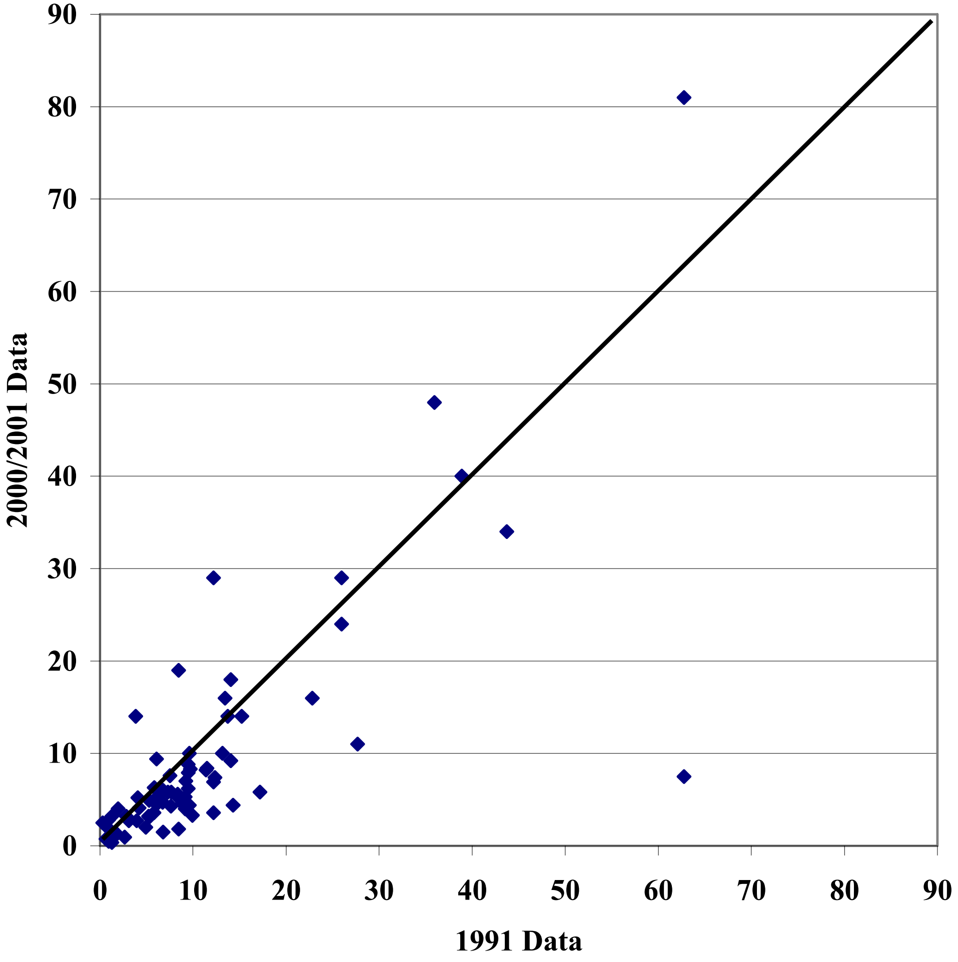
## Figure 7. Naphthalene Data Plot of 1991 and 2000/2001



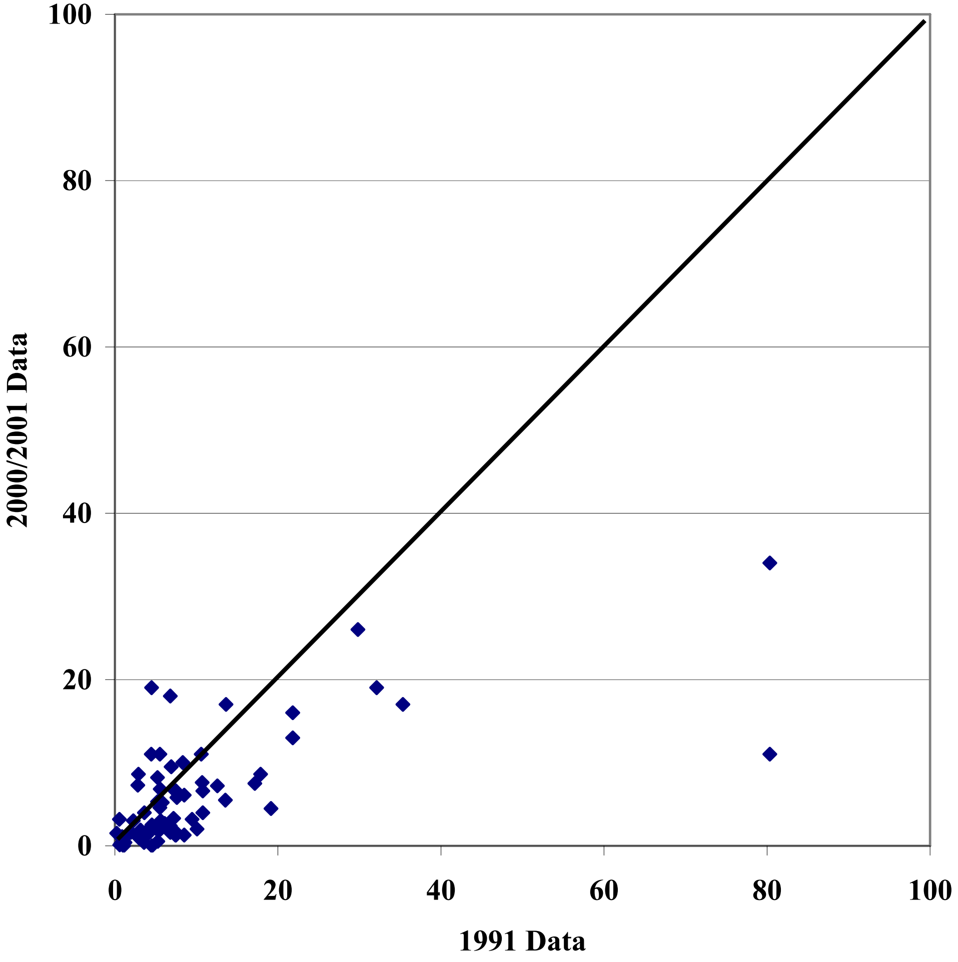
## Figure 8. 1-Methylnaphthalene Data Plot of 1991 and 2000/2001



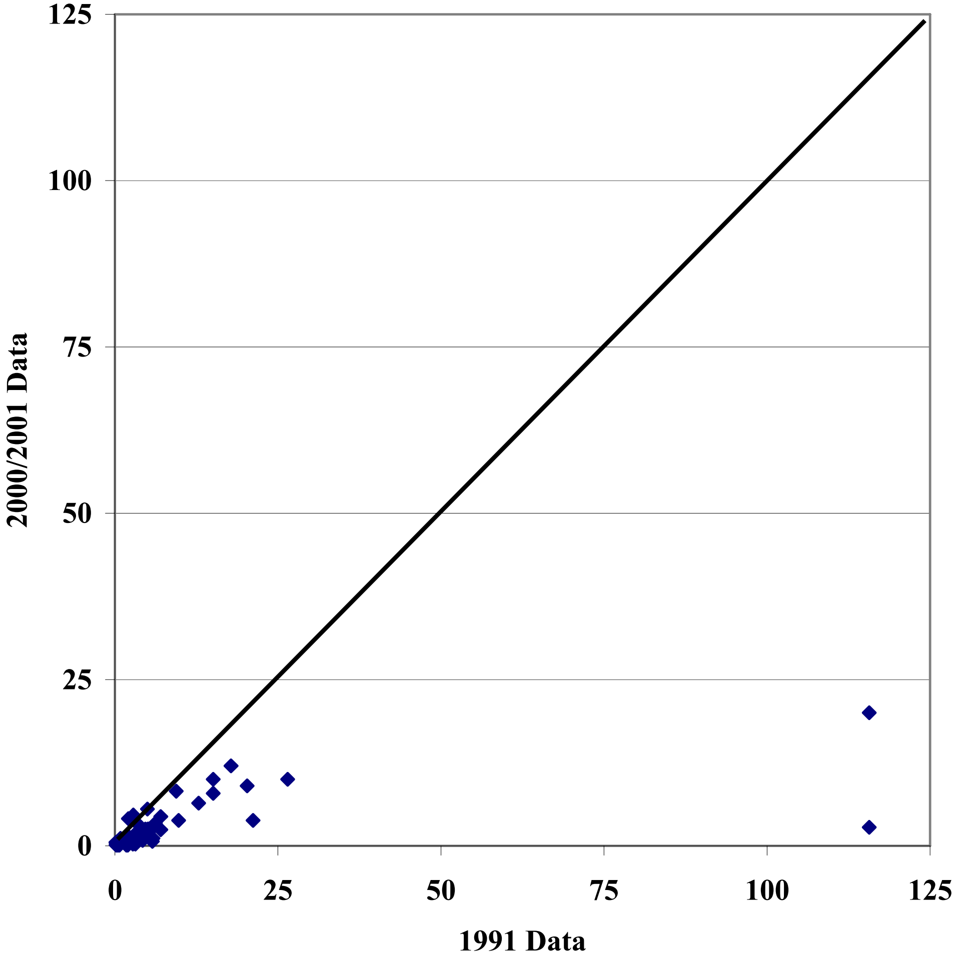
## Figure 9. 2-Methylnaphthalene Data Plot of 1991 and 2000/2001



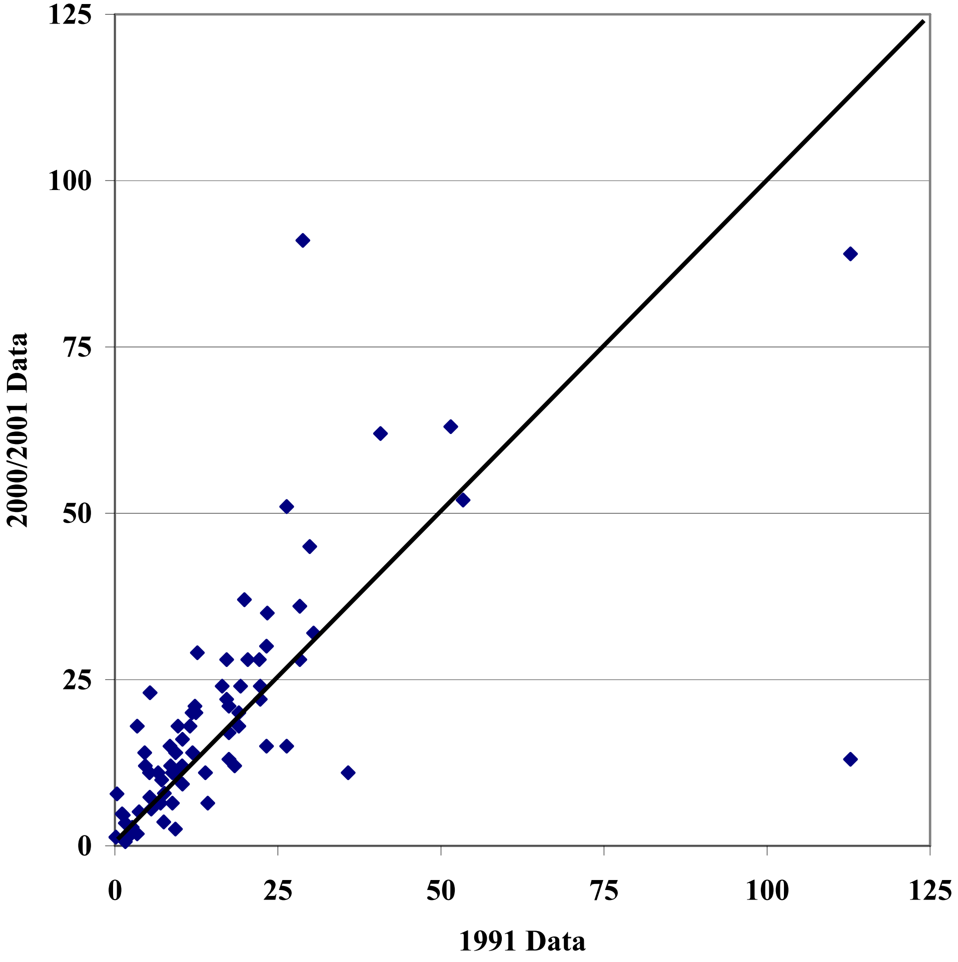
## Figure 10. 2,6 -Dimethylnaphthalene Data Plot of 1991 and 2000/2001



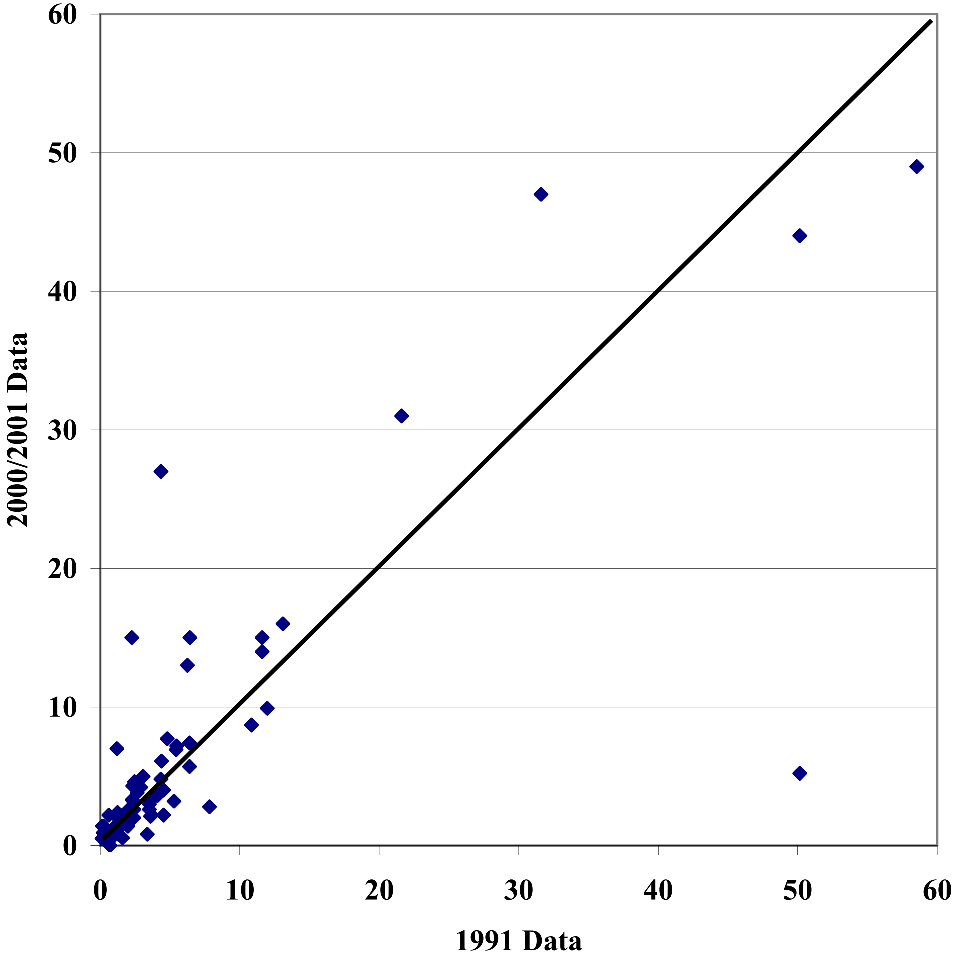
## Figure 11. 1,6,7-Trimethylnaphthalene Data Plot of 1991 and 2000/2001



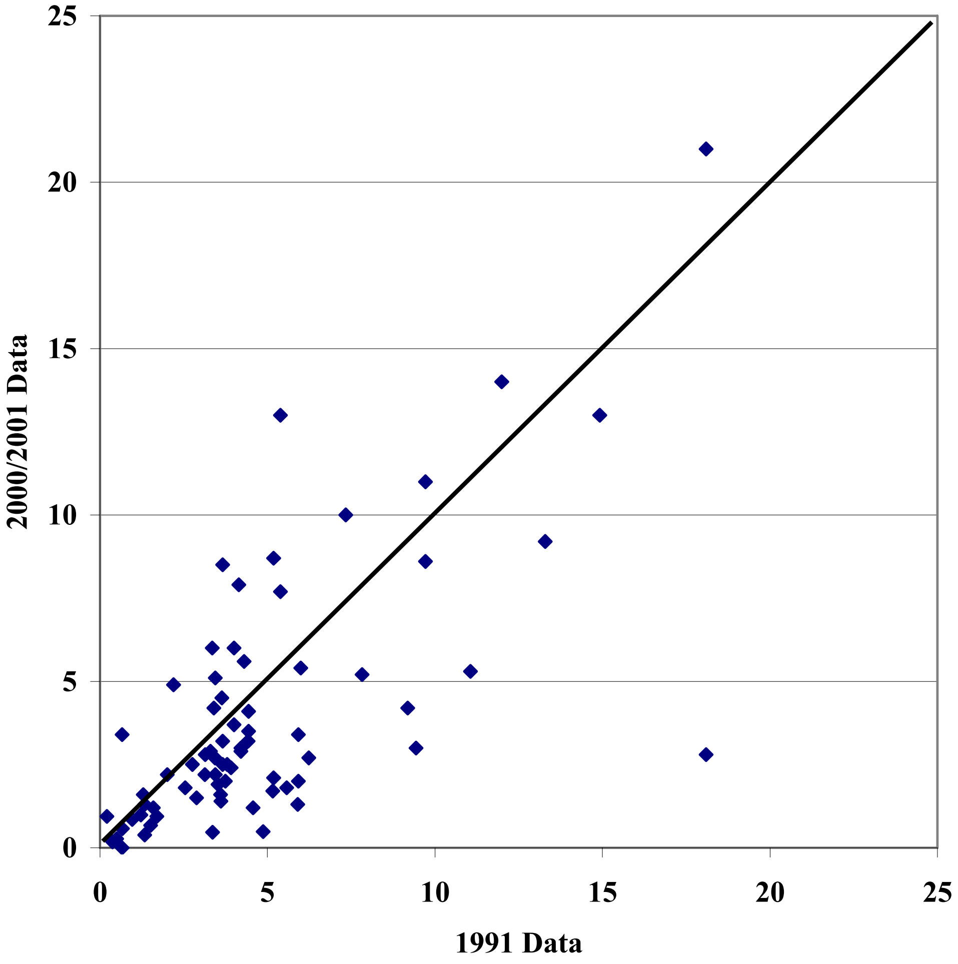
## Figure 12. Acenaphthylene Data Plot of 1991 and 2000/2001



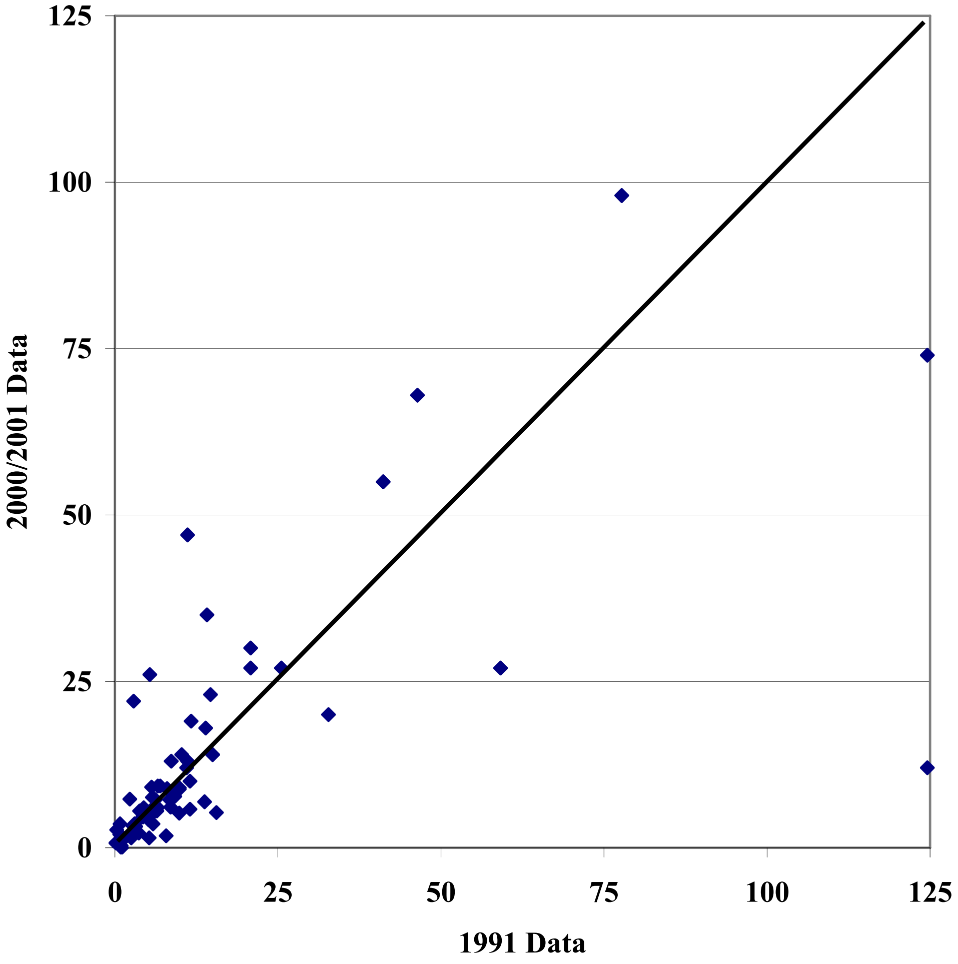
# Figure 13. Acenaphthene Data Plot of 1991 and 2000/2001



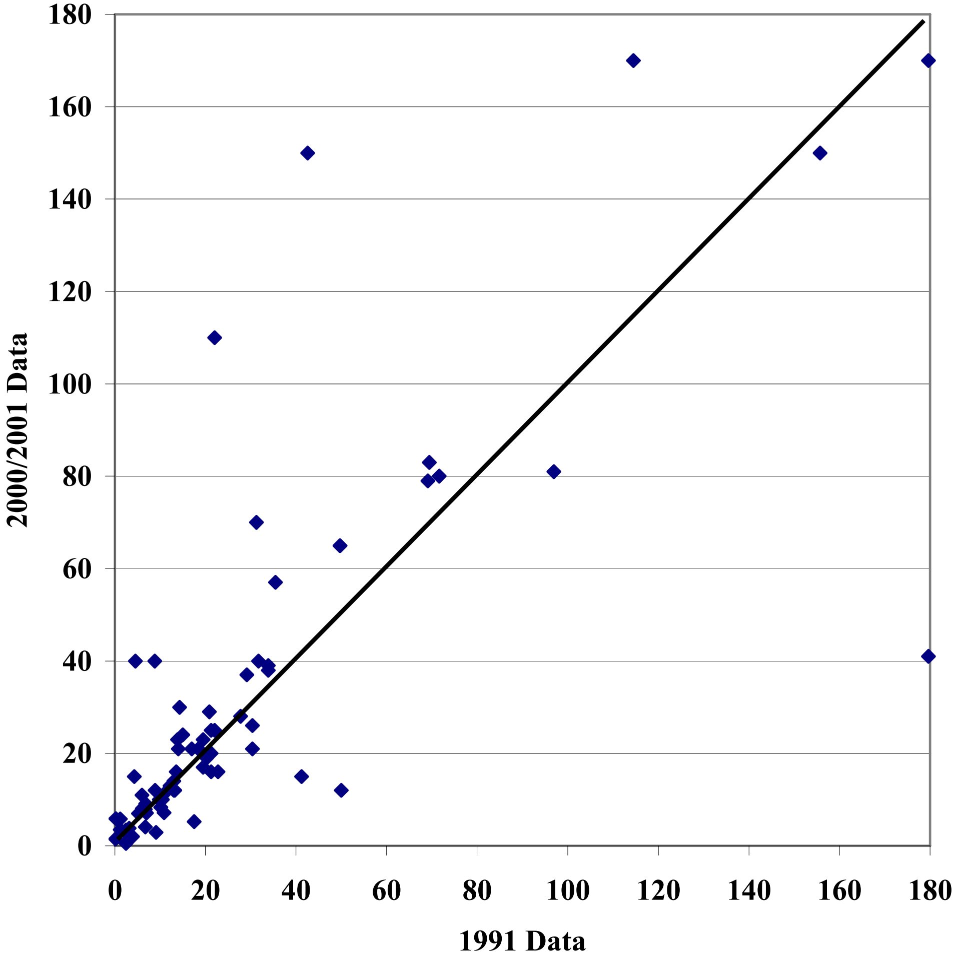
## Figure 14. Biphenyl Data Plot of 1991 and 2000/2001



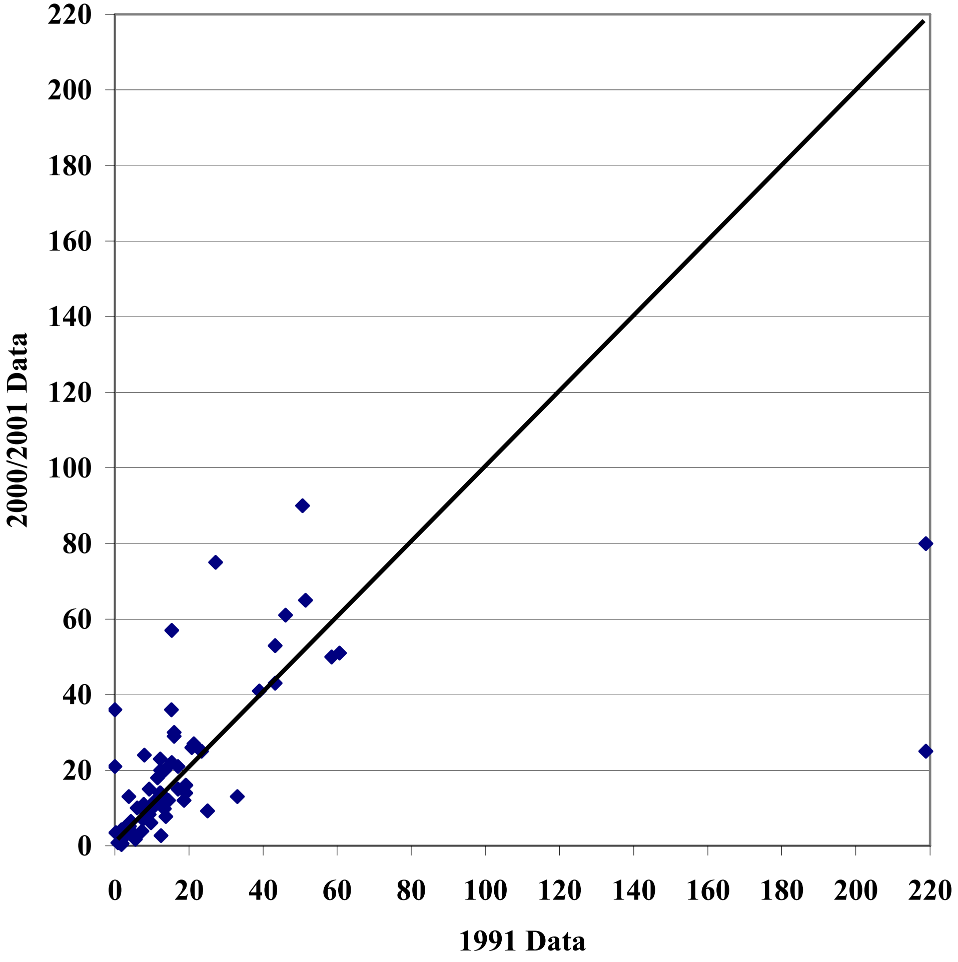
### Figure 15.  Fluorene Data Plot of 1991 and 2000/2001



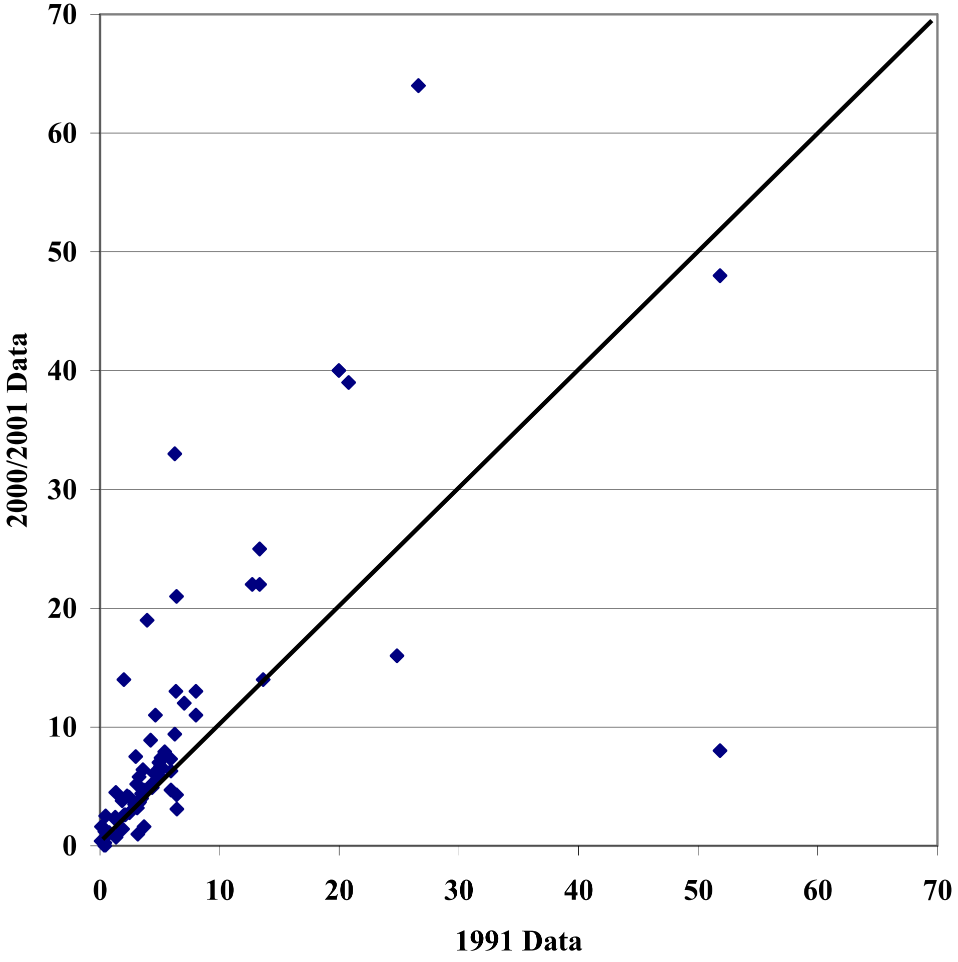
## Figure 16. Anthracene Data Plot of 1991 and 2000/2001



## Figure 17. 1-Methylphenanthrene Data Plot of 1991 and 2000/2001



## Figure 18. Dibenzothiophene Data Plot of 1991 and 2000/2001



## Figure 19. Fluoranthene Data Plot of 1991 and 2000/2001

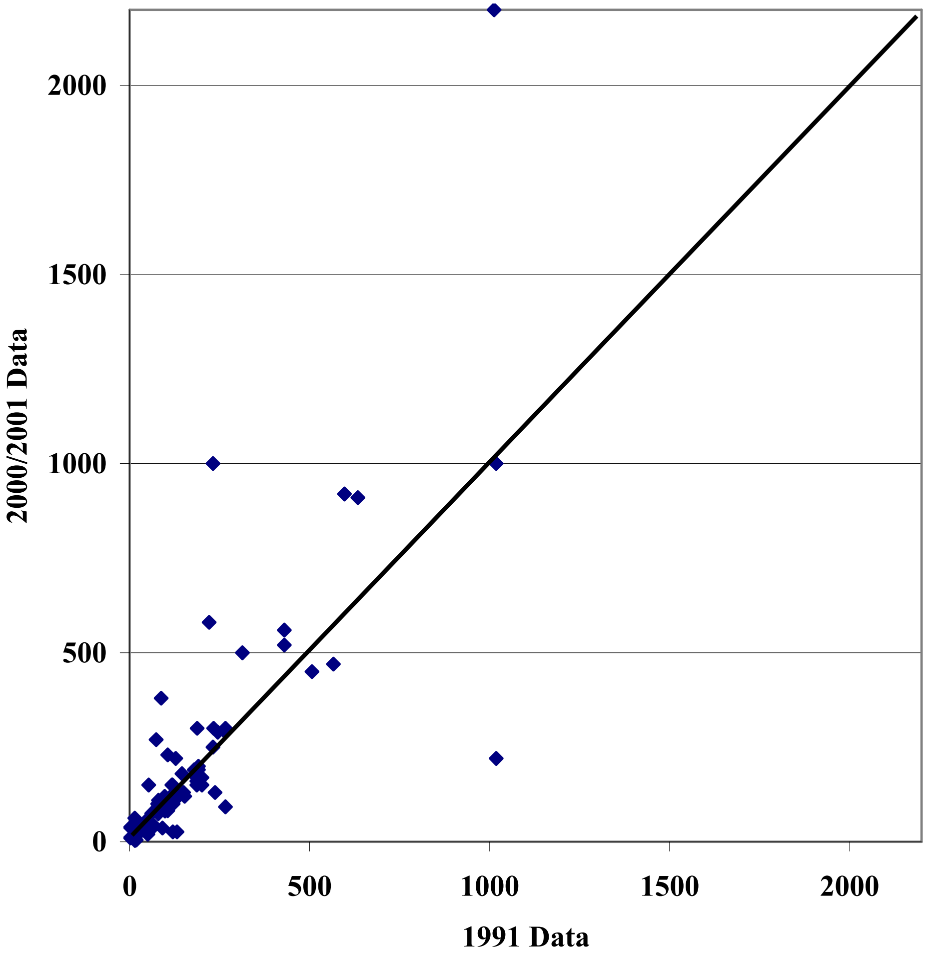
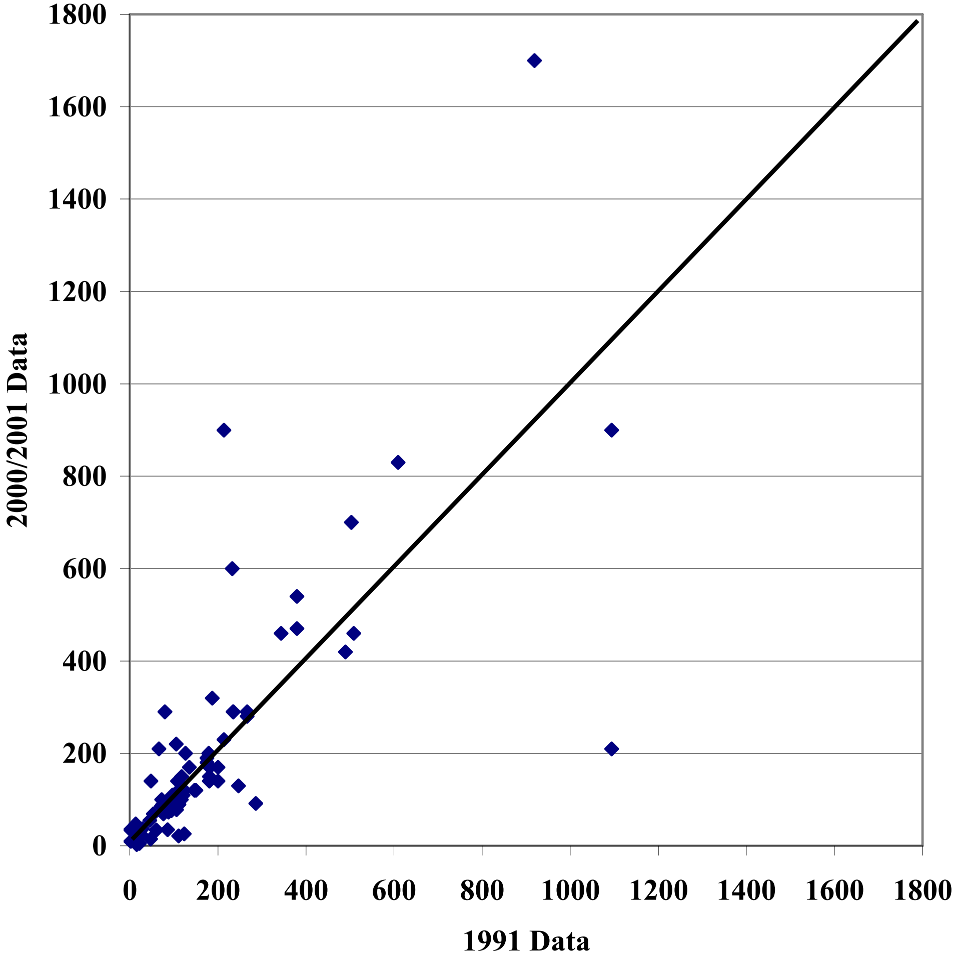
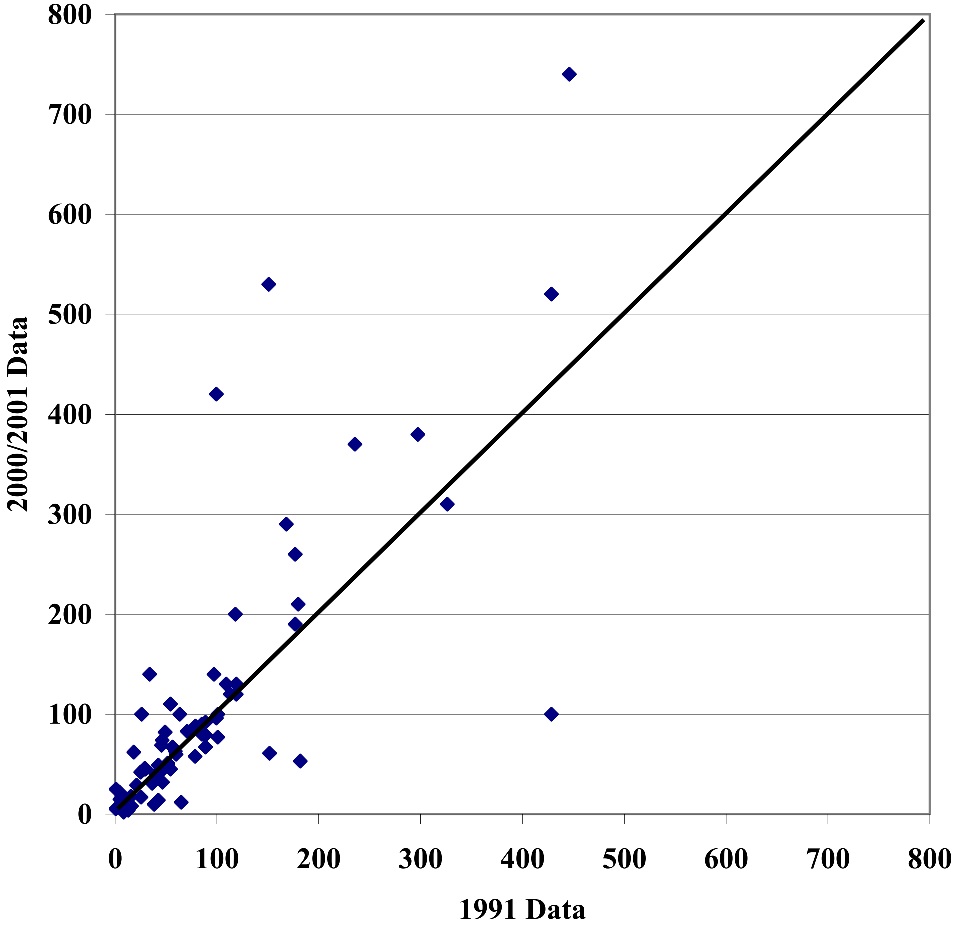


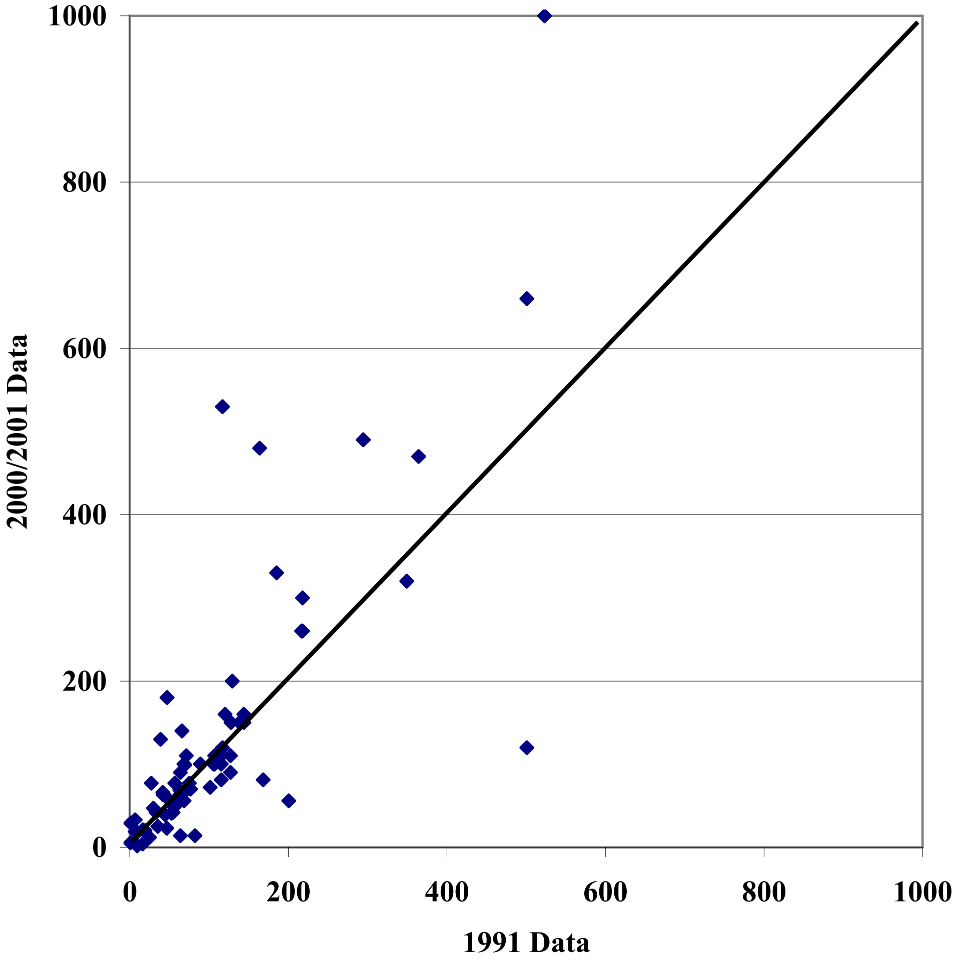
Figure 20.  Pyrene Data Plot of 1991 and 2000/2001



## Figure 21. Benzo[a]anthracene Data Plot of 1991 and 2000/2001



## Figure 22. Chrysene Data Plot of 1991 and 2000/2001



## Figure 23. Benzo[b]fluoranthene Data Plot of 1991 and 2000/2001

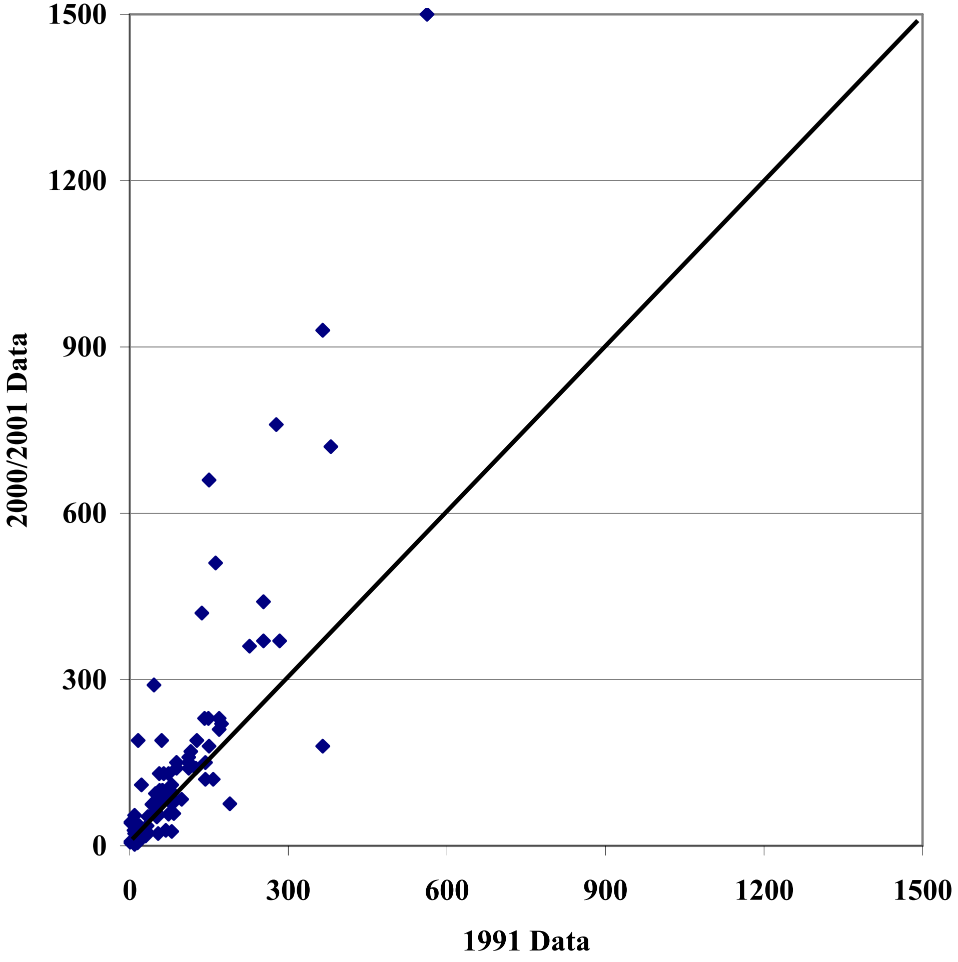
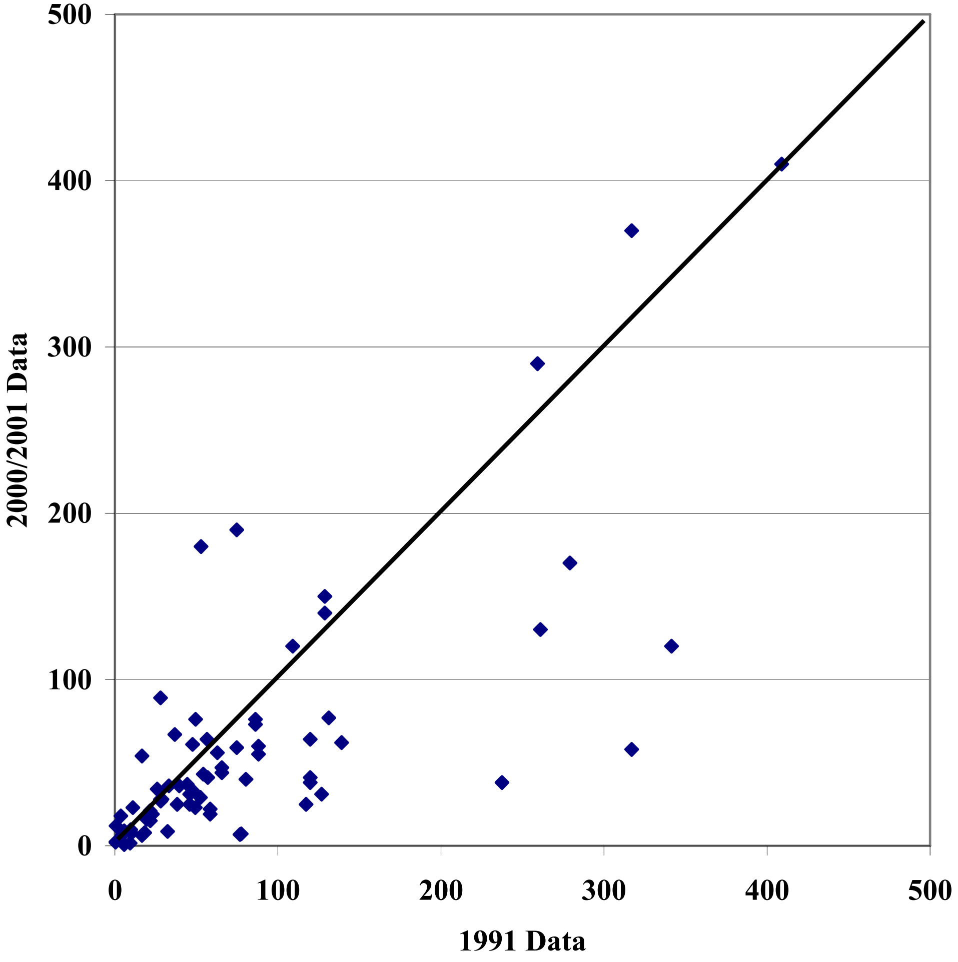
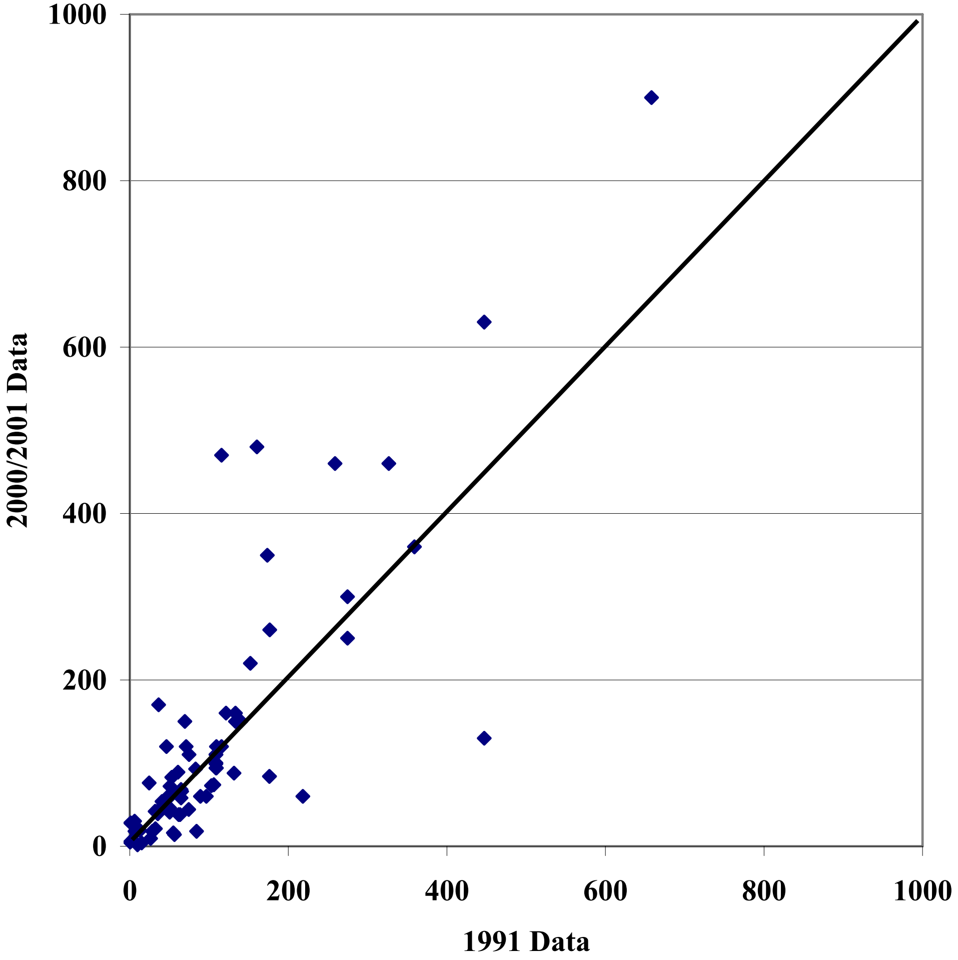


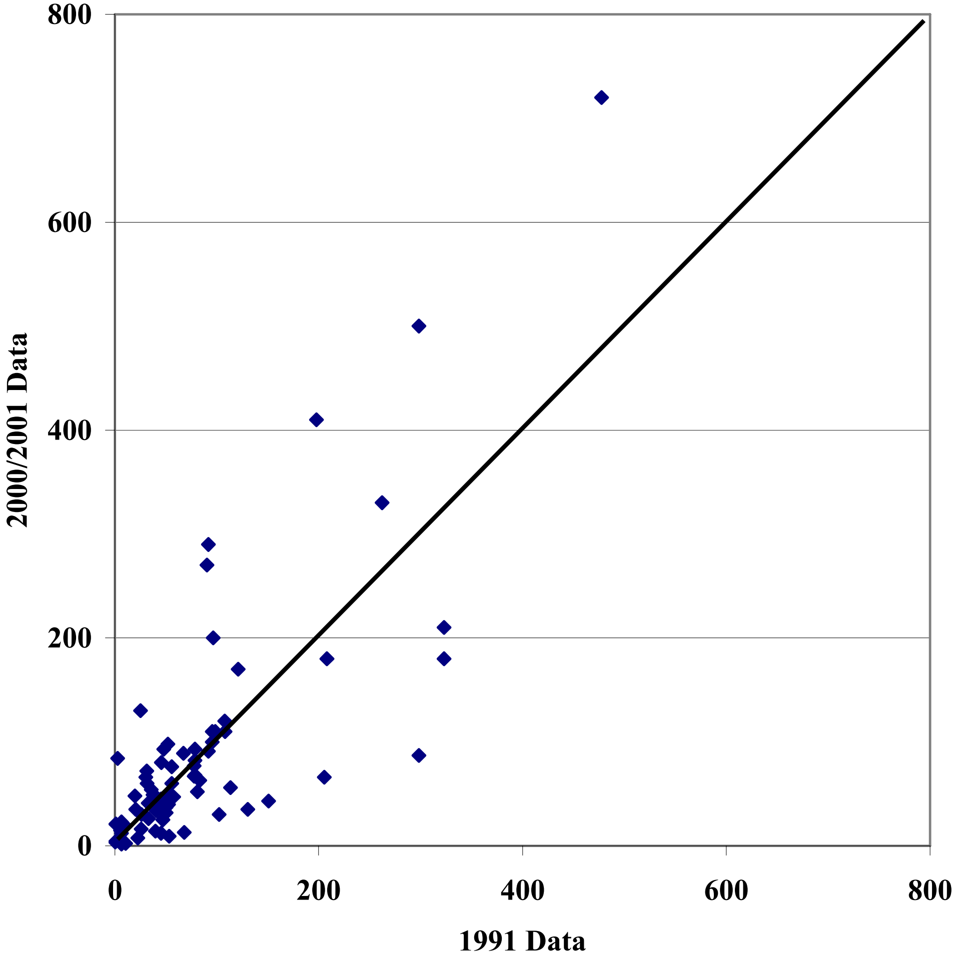
Figure 24. Benzo[k]fluoranthene Data Plot of 1991 and 2000/2001



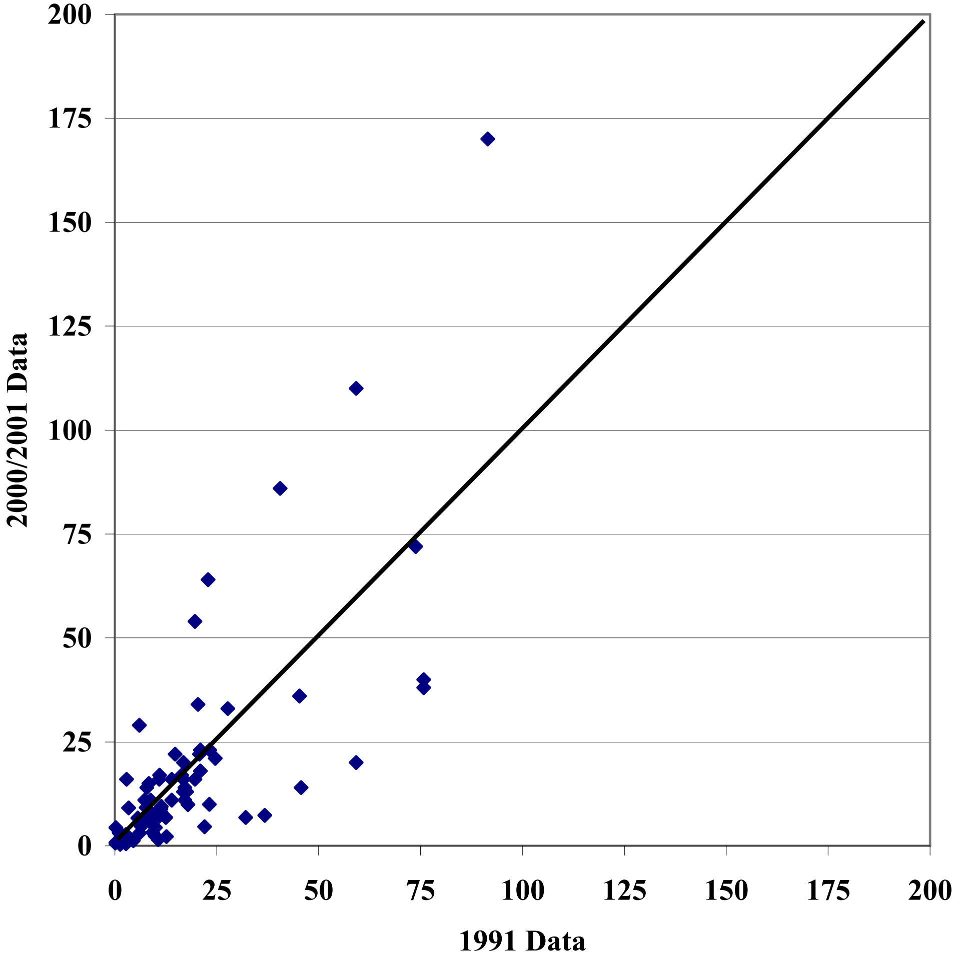
## Figure 25. Benzo[a]pyrene Data Plot of 1991 and 2000/2001



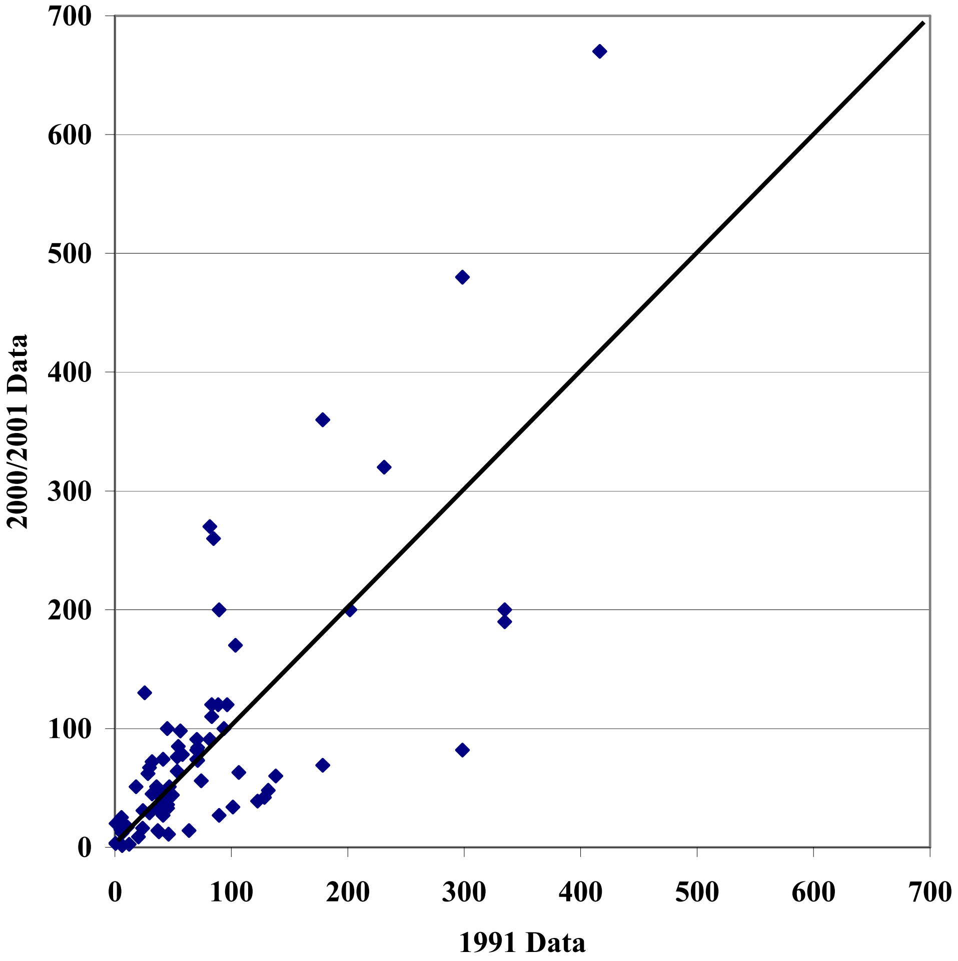
## Figure 26. Indeno[1,2,3,-c,d]pyrene Data Plot of 1991 and 2000/2001



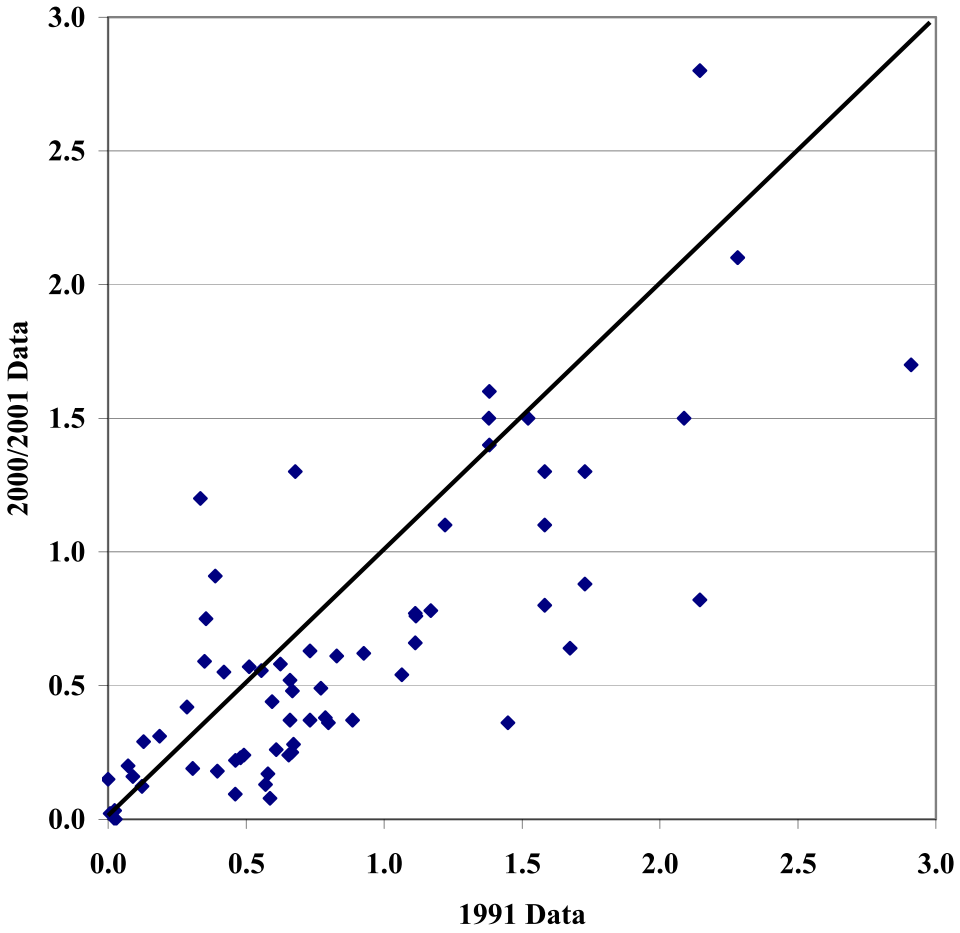
## Figure 27. Dibenzo[a,h]anthracene Data Plot of 1991 and 2000/2001



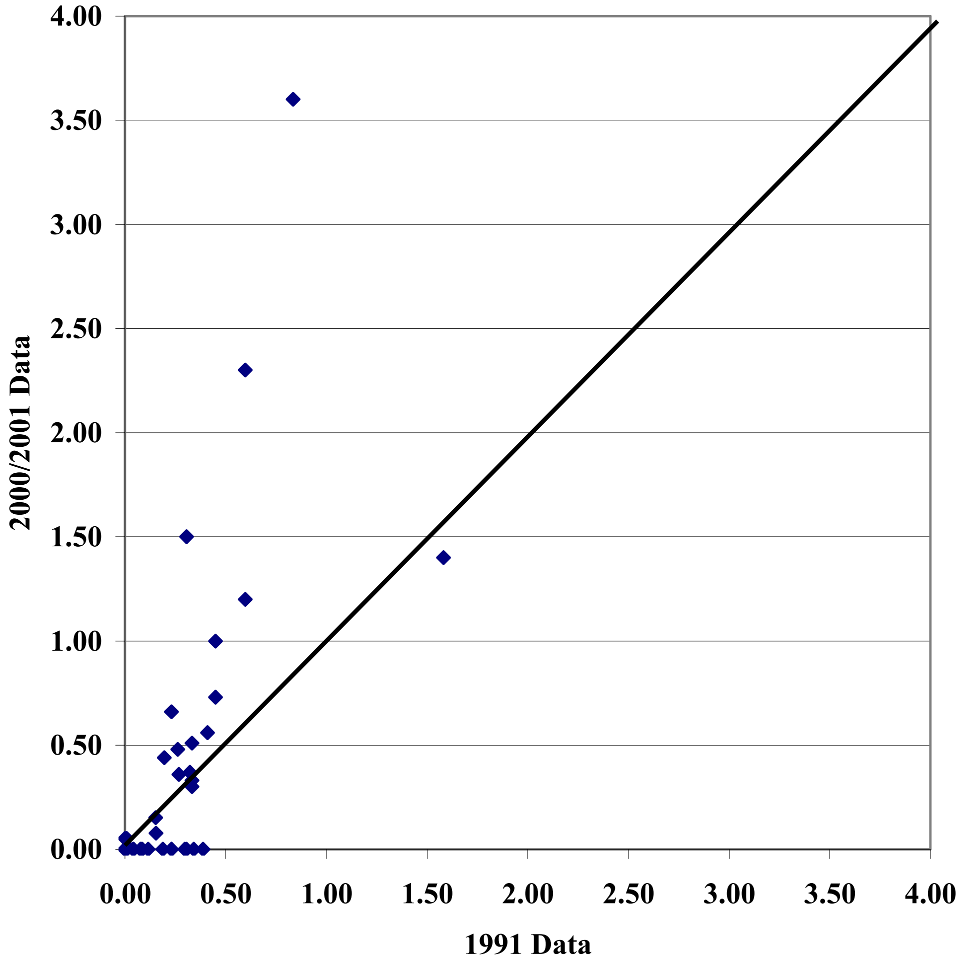
## Figure 28. Benzo[g,h,i]perylene Data Plot of 1991 and 2000/2001



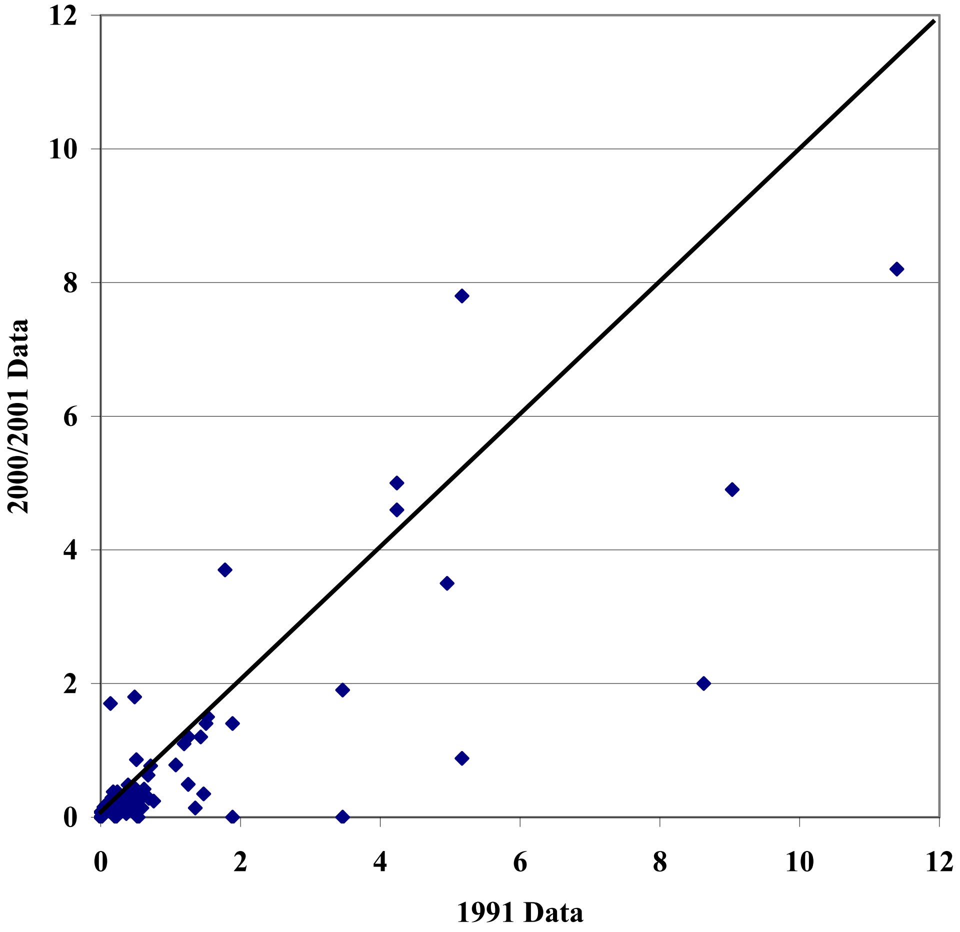
## Figure 33.  4,4'-DDE Data Plot of 1991 and 2000/2001



## Figure 34. 2,4'-DDD Data Plot of 1991 and 2000/2001



## Figure 35. 4,4'-DDD Data Plot of 1991 and 2000/2001



## Figure 36. 4,4'-DDT Data Plot of 1991 and 2000/2001

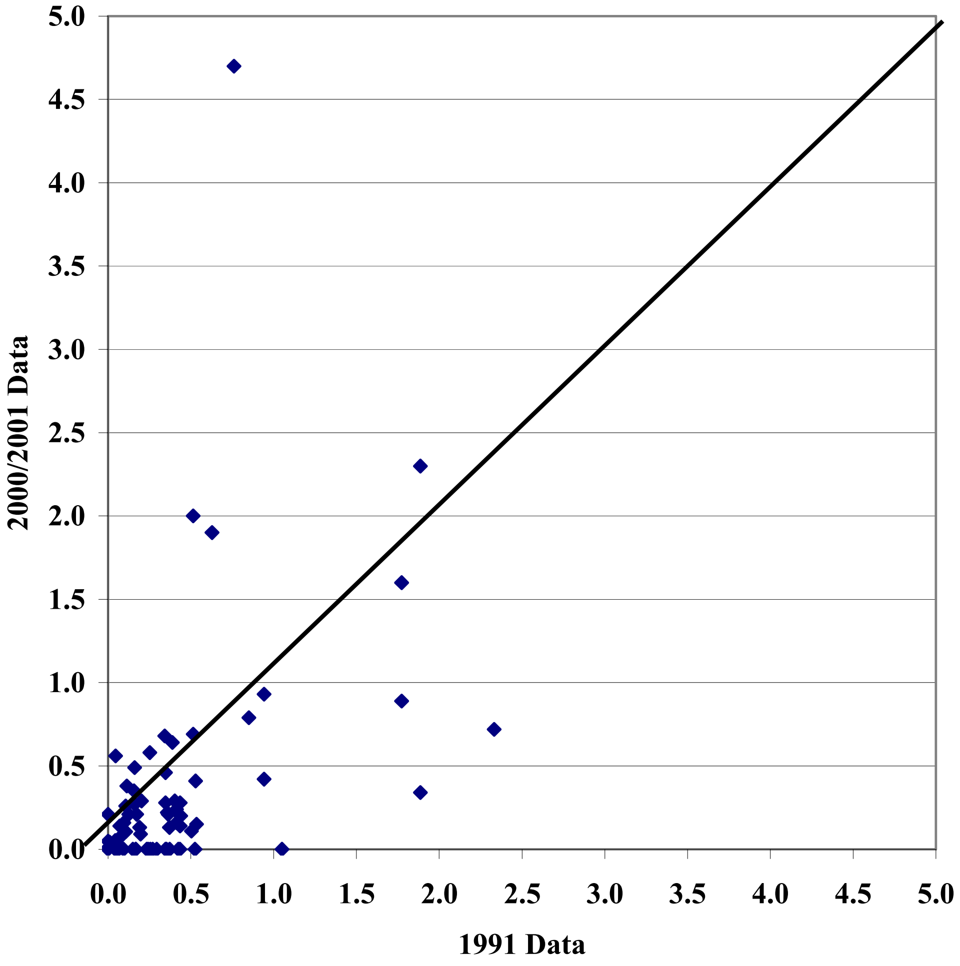
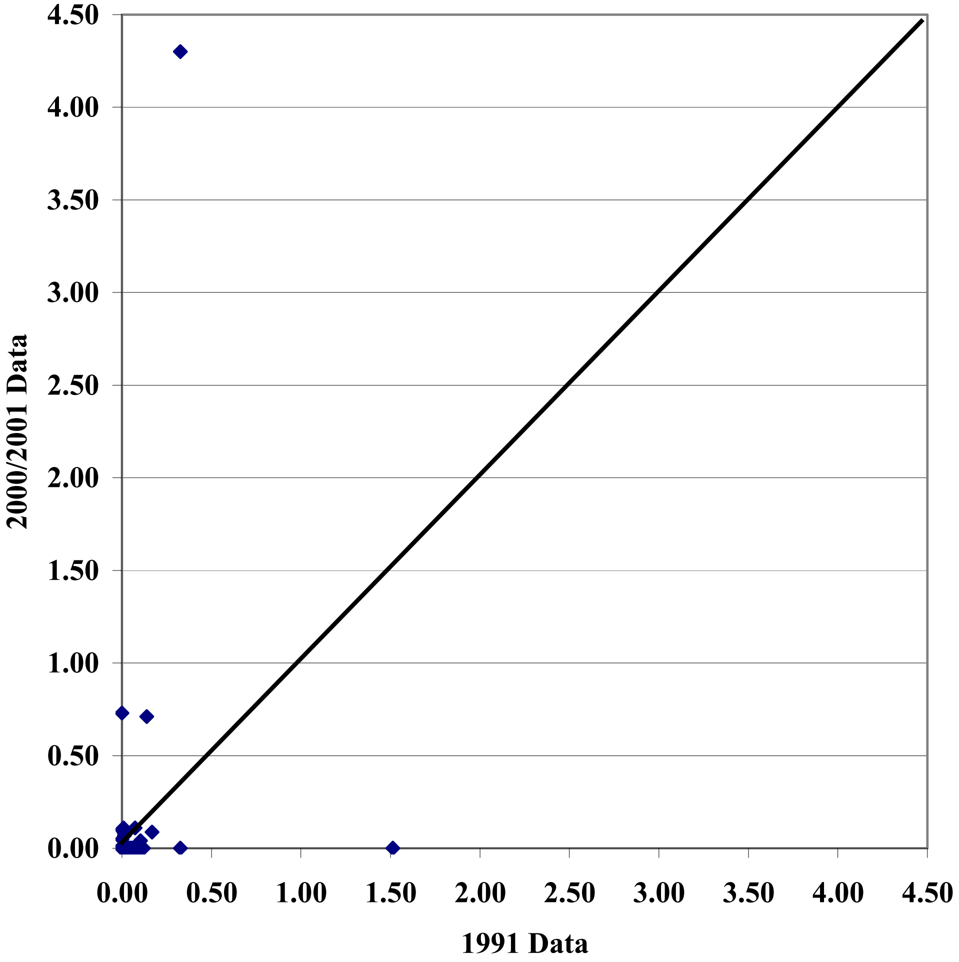


Figure 37. 2,4'-DDT Data Plot of 1991 and 2000/2001



## Figure 39. Iron Data Plot of 1991 and 2000/2001

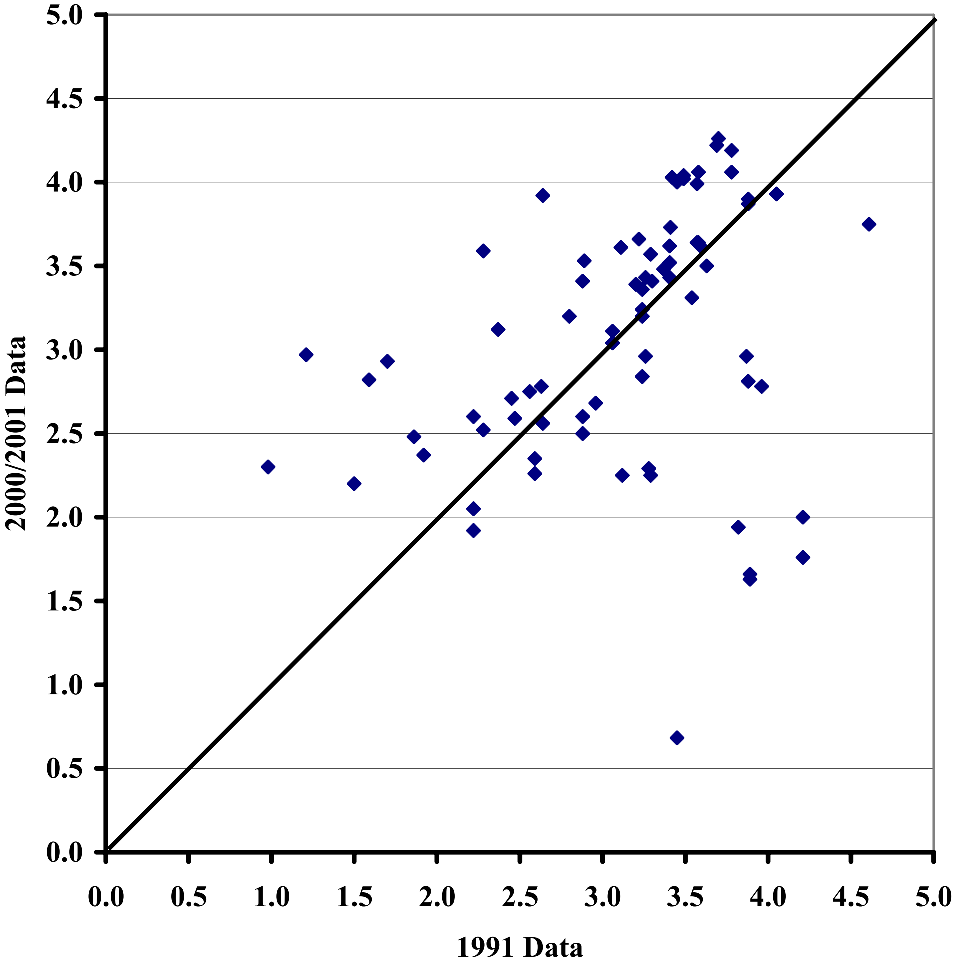
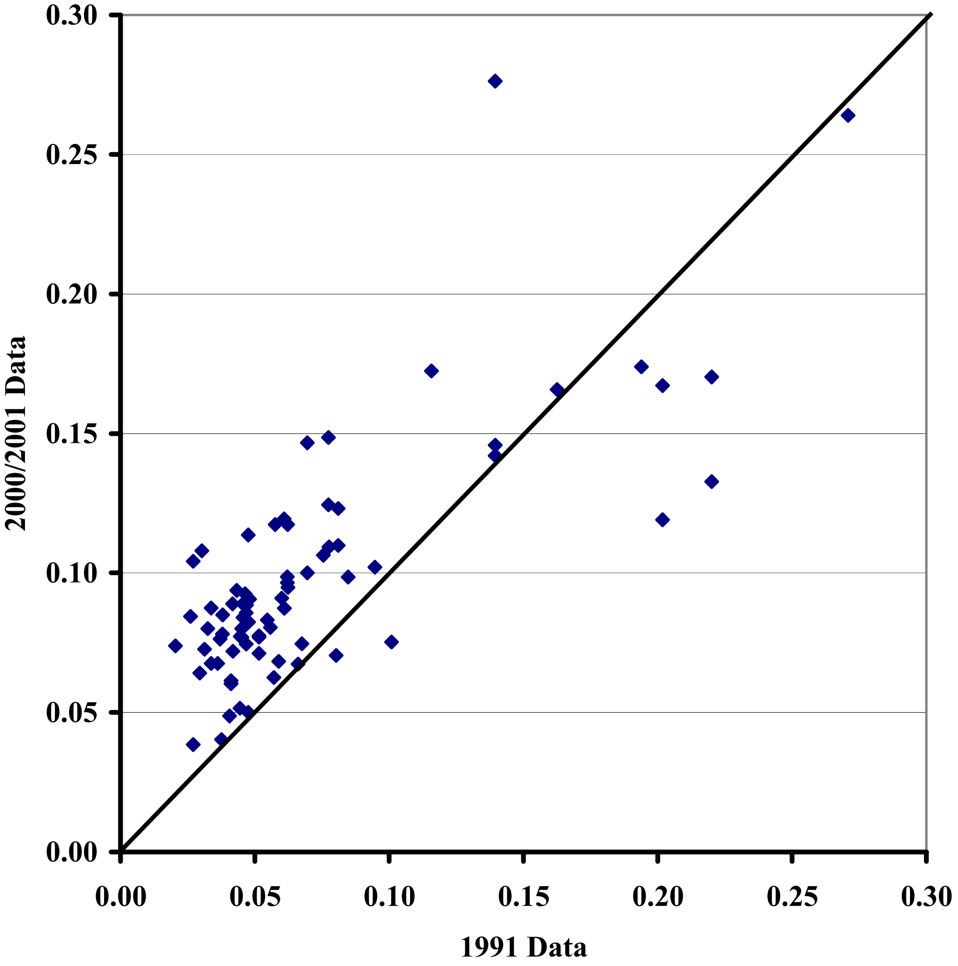
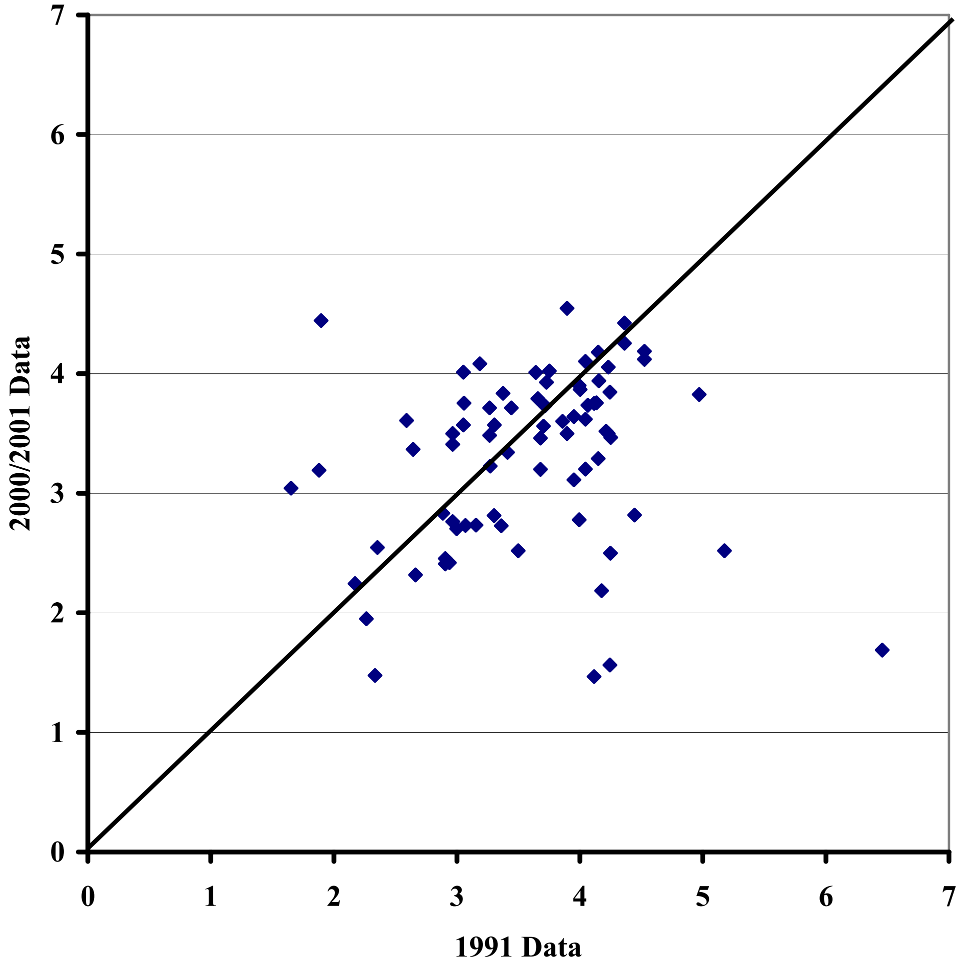


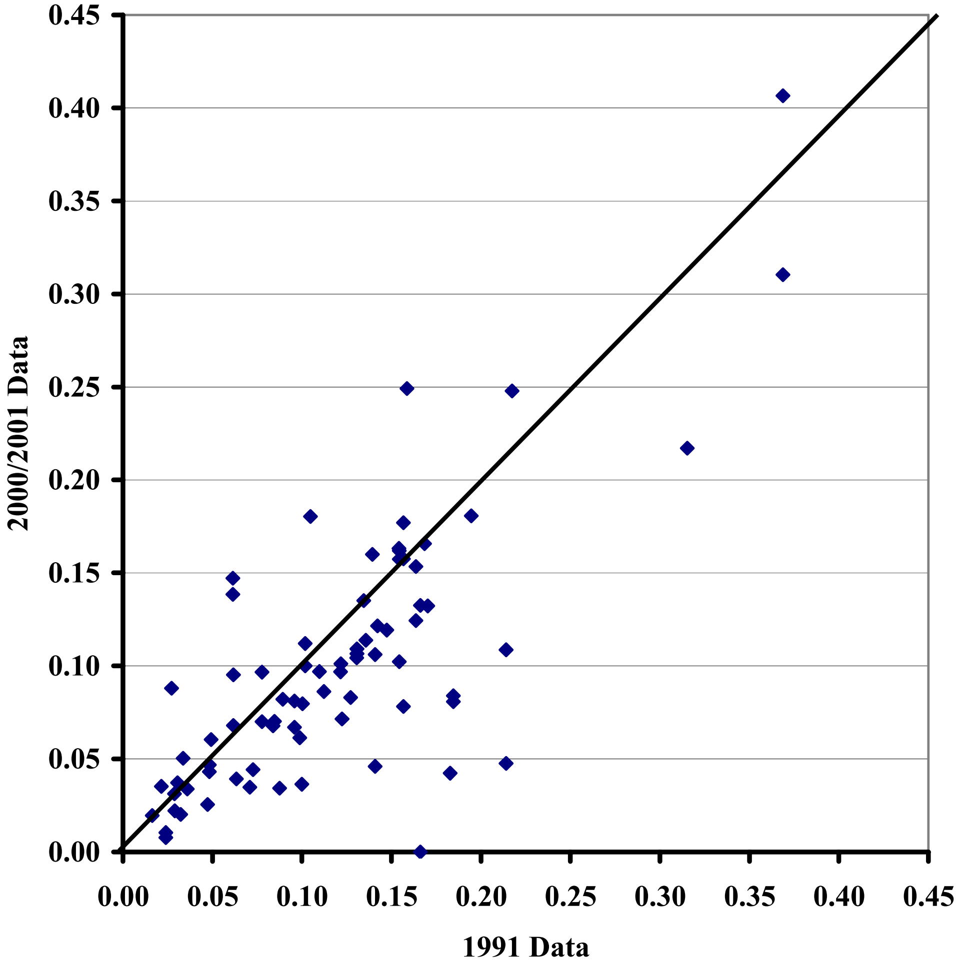
Figure 40. Normalized Silver Data Plot of 1991 and 2000/2001



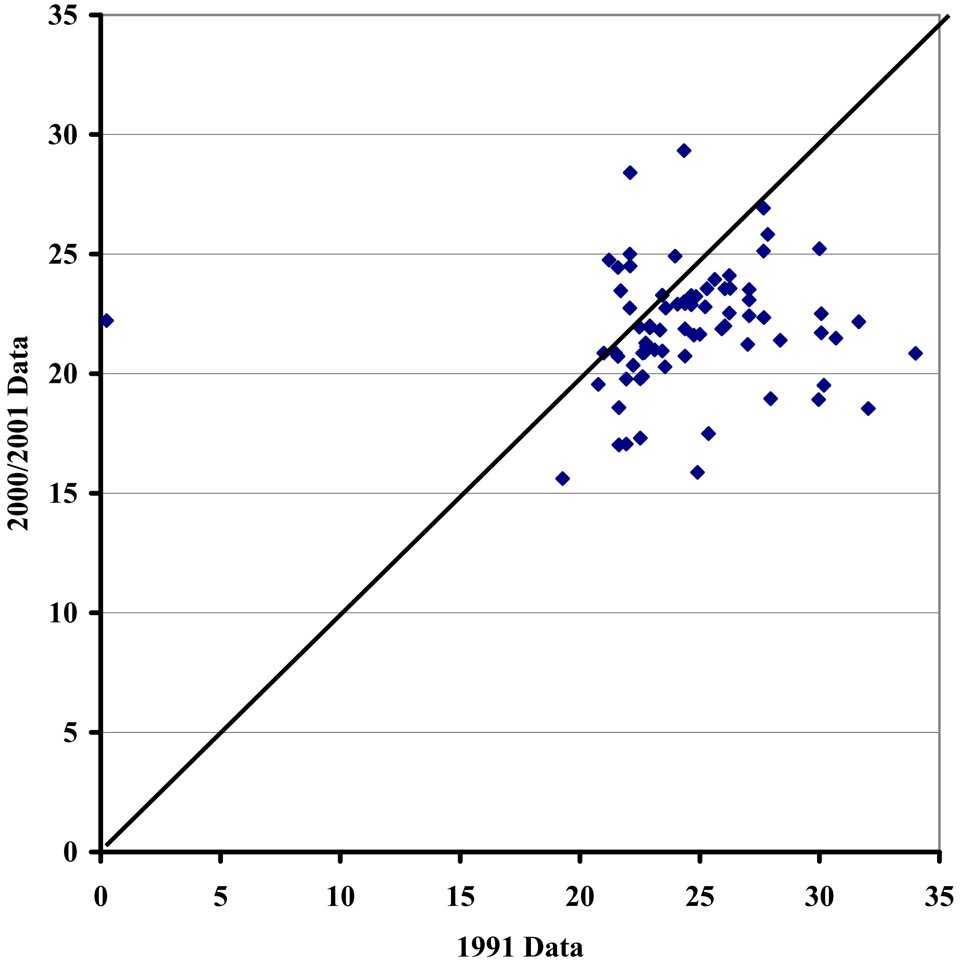
### Figure 41. Normalized Arsenic Data Plot of 1991 and 2000/2001



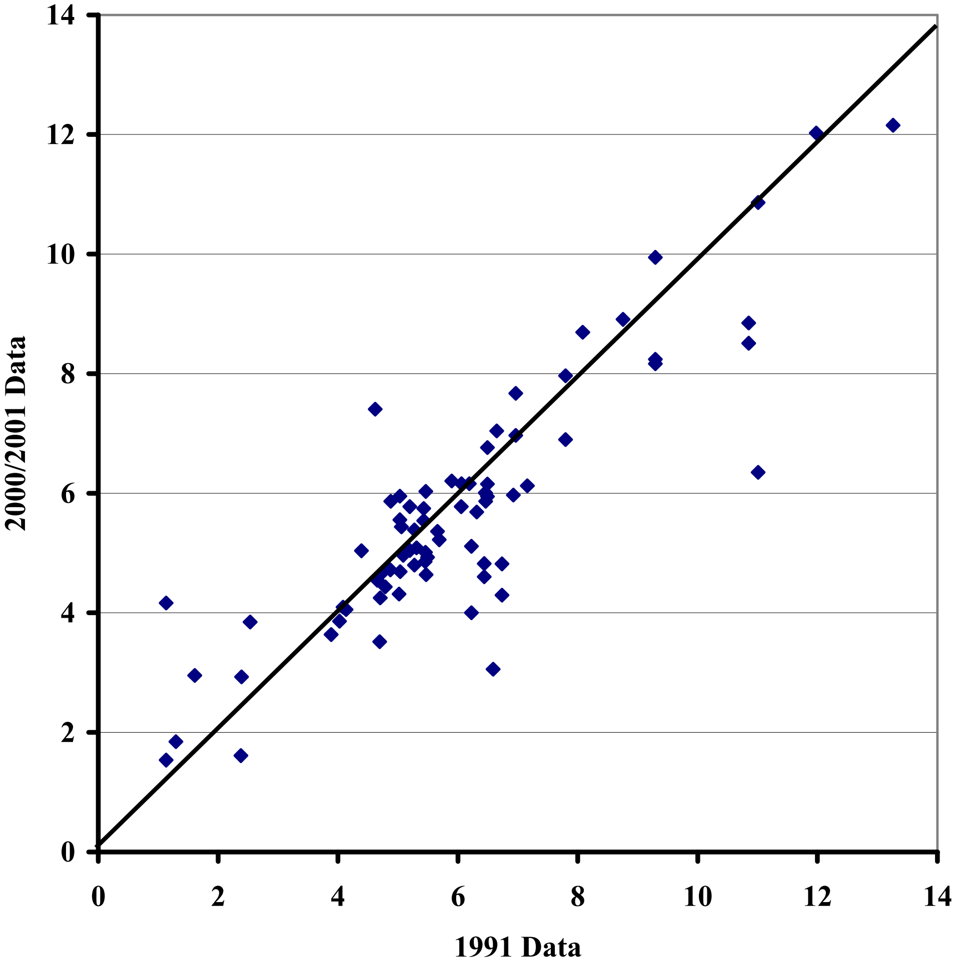
## Figure 42. Normalized Cadmium Data Plot of 1991 and 2000/2001



## Figure 43. Normalized Chromium Data Plot of 1991 and 2000/2001



## Figure 44. Normalized Copper Data Plot of 1991 and 2000/2001



### Figure 45. Normalized Mercury Data Plot of 1991 and 2000/2001

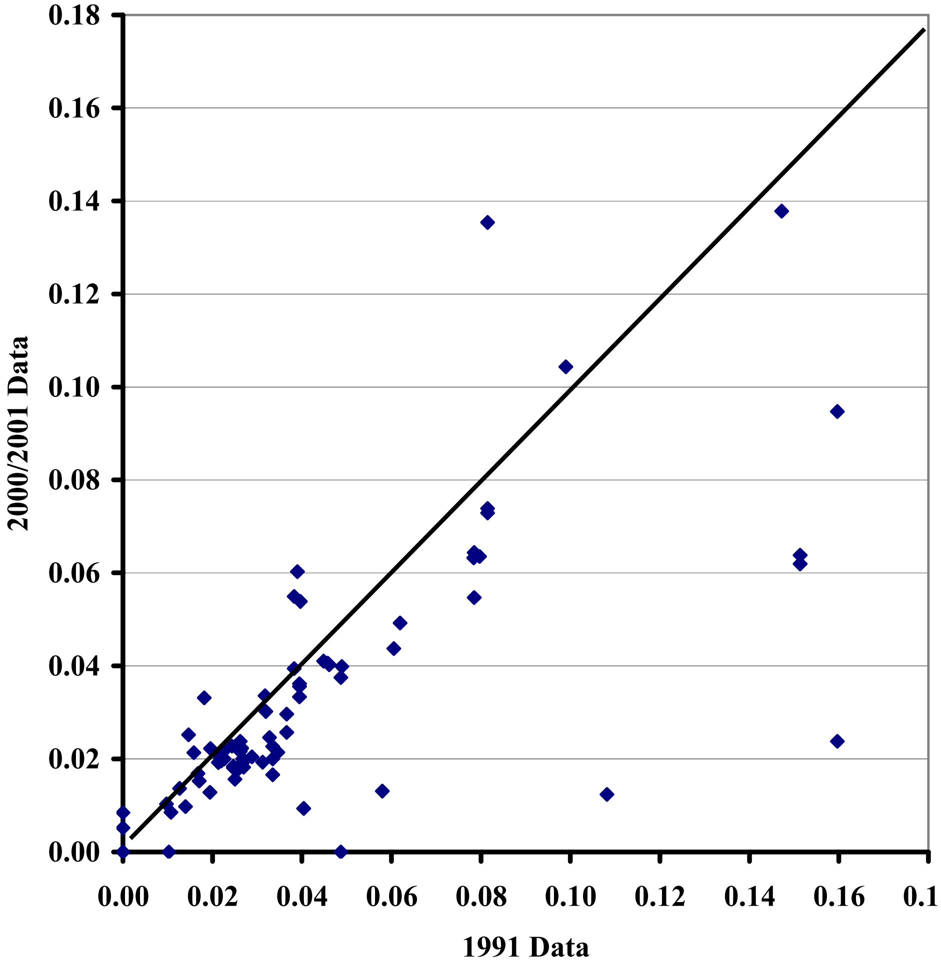


Figure 46. Normalized Nickel Data Plot of 1991 and 2000/2001

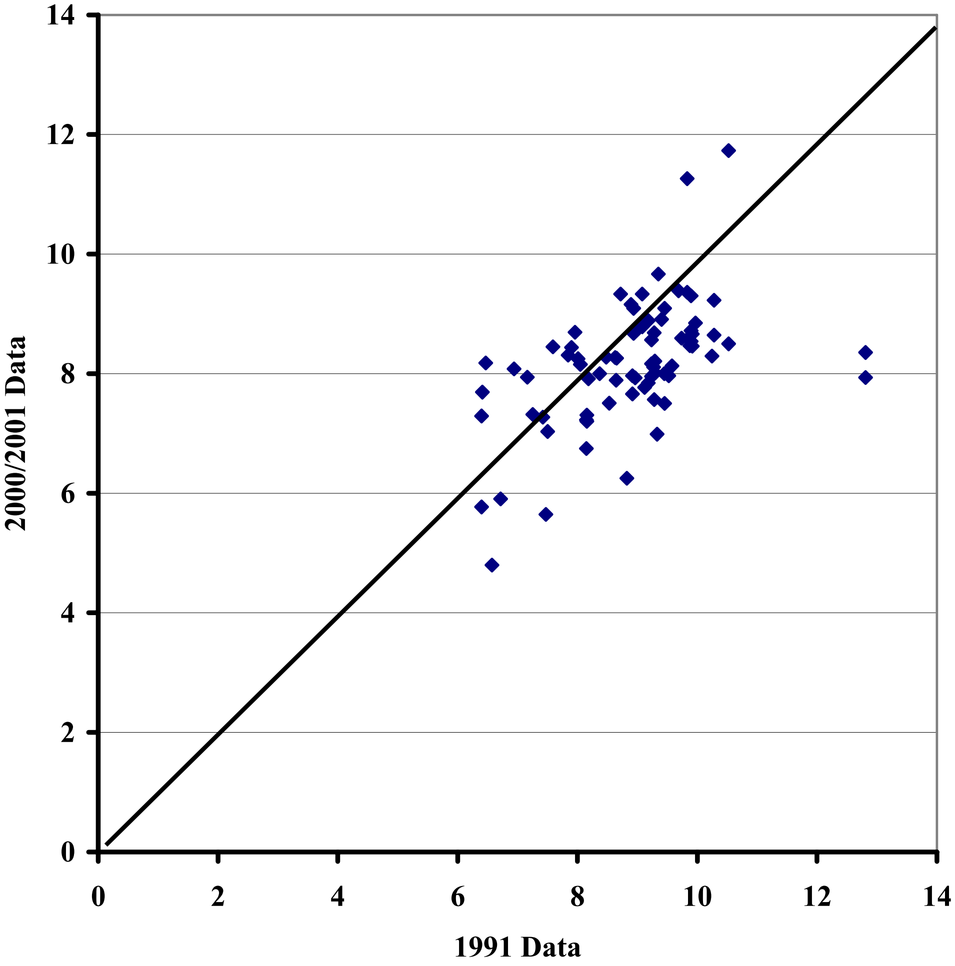


Figure 47. Normalized Lead Data Plot of 1991 and 2000/2001

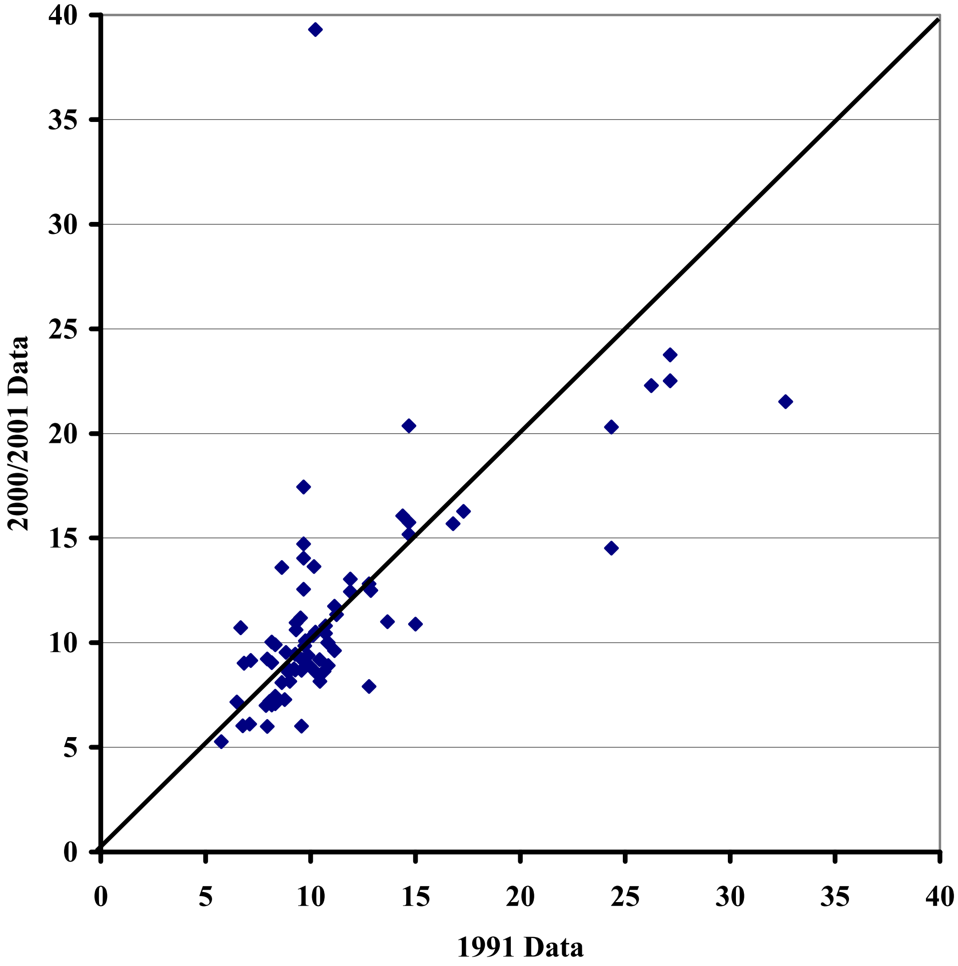


Figure 48.  Normalized Selenium Data Plot of 1991 and 2000/2001

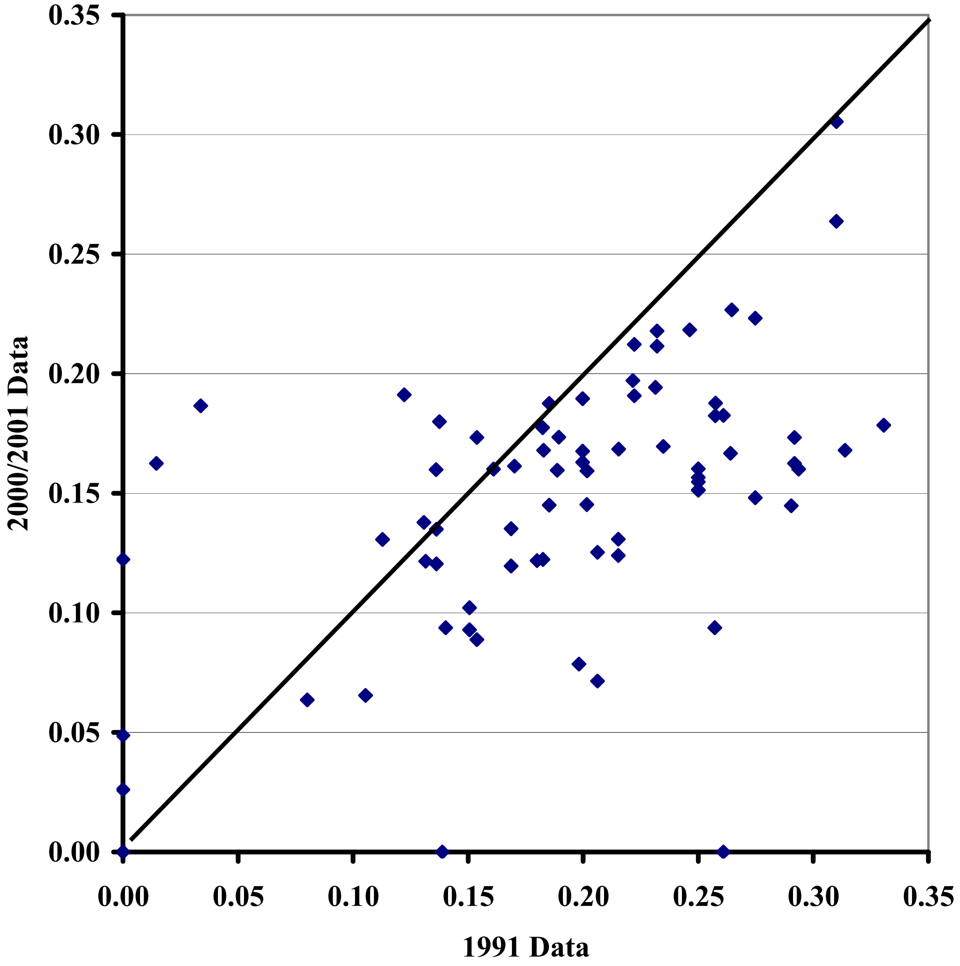


Figure 49.  Normalized Zinc Data Plot of 1991 and 2000/2001

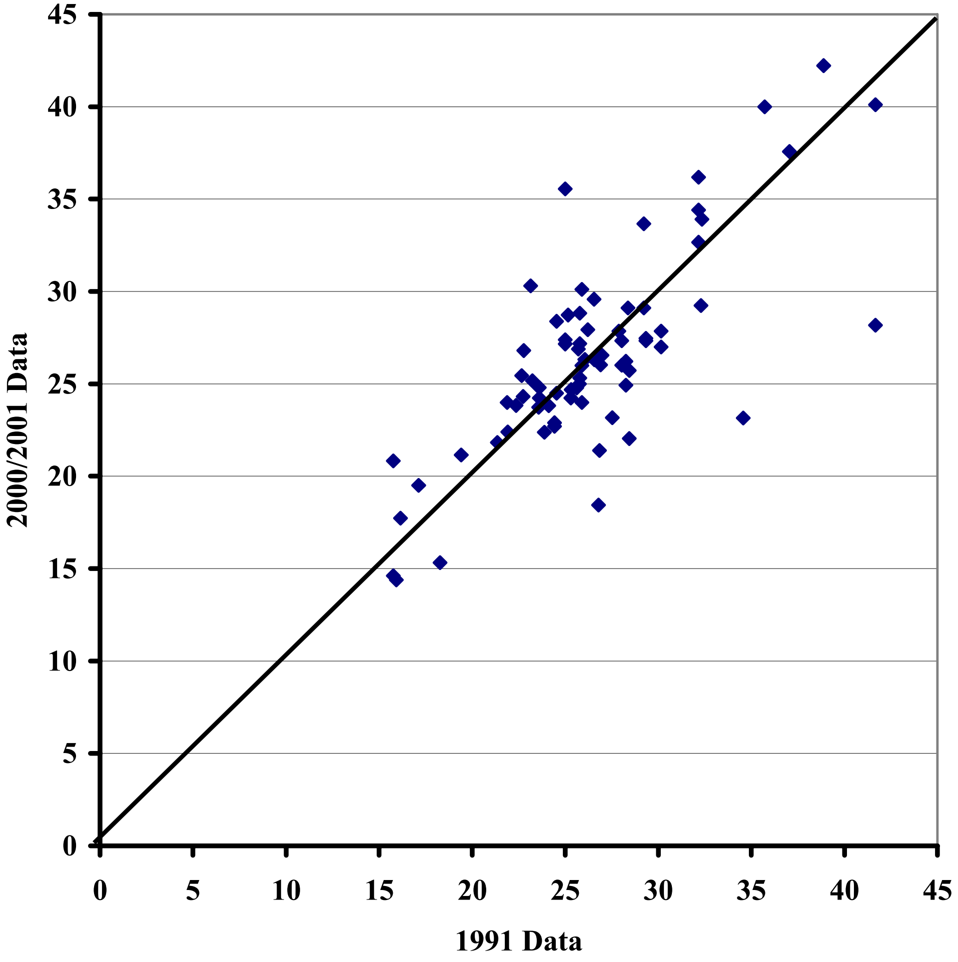


**Figure 65. 2,3,7,8 TCDF Data Plot of 1991 and 2000/2001**

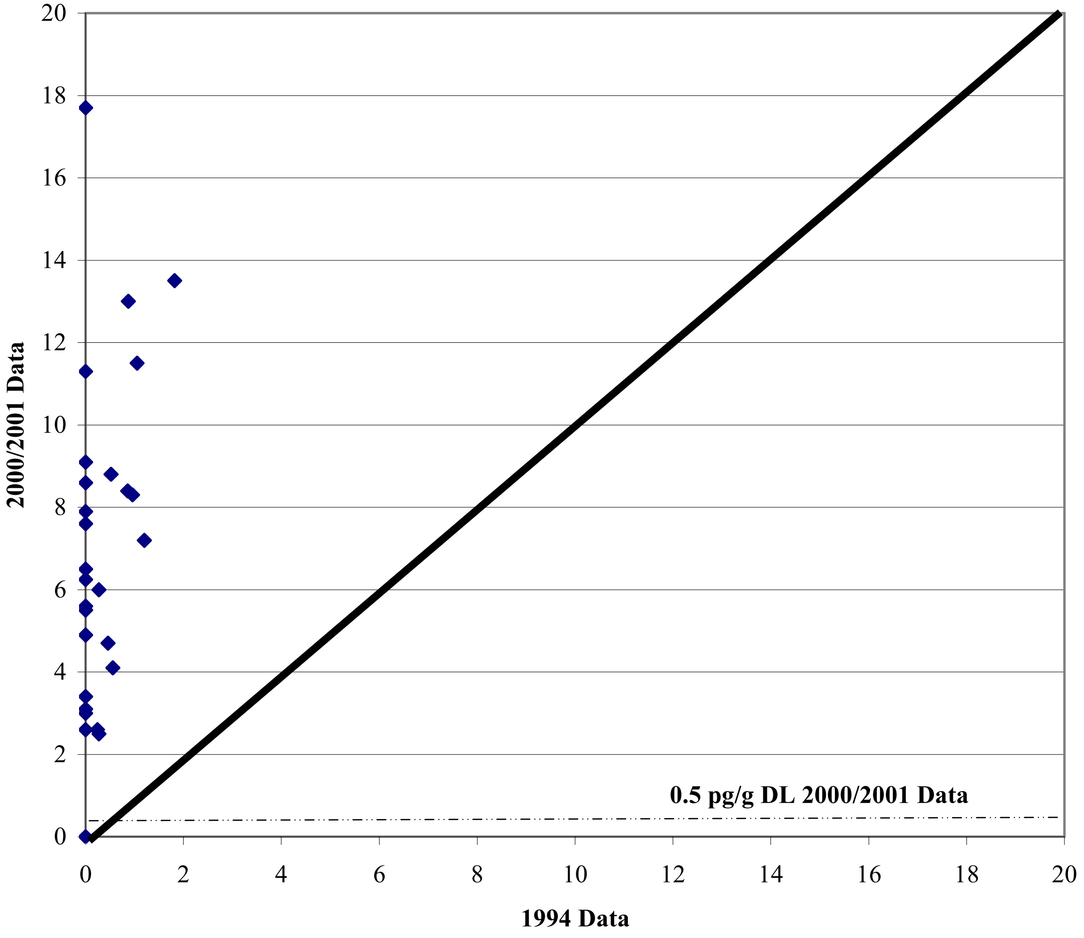
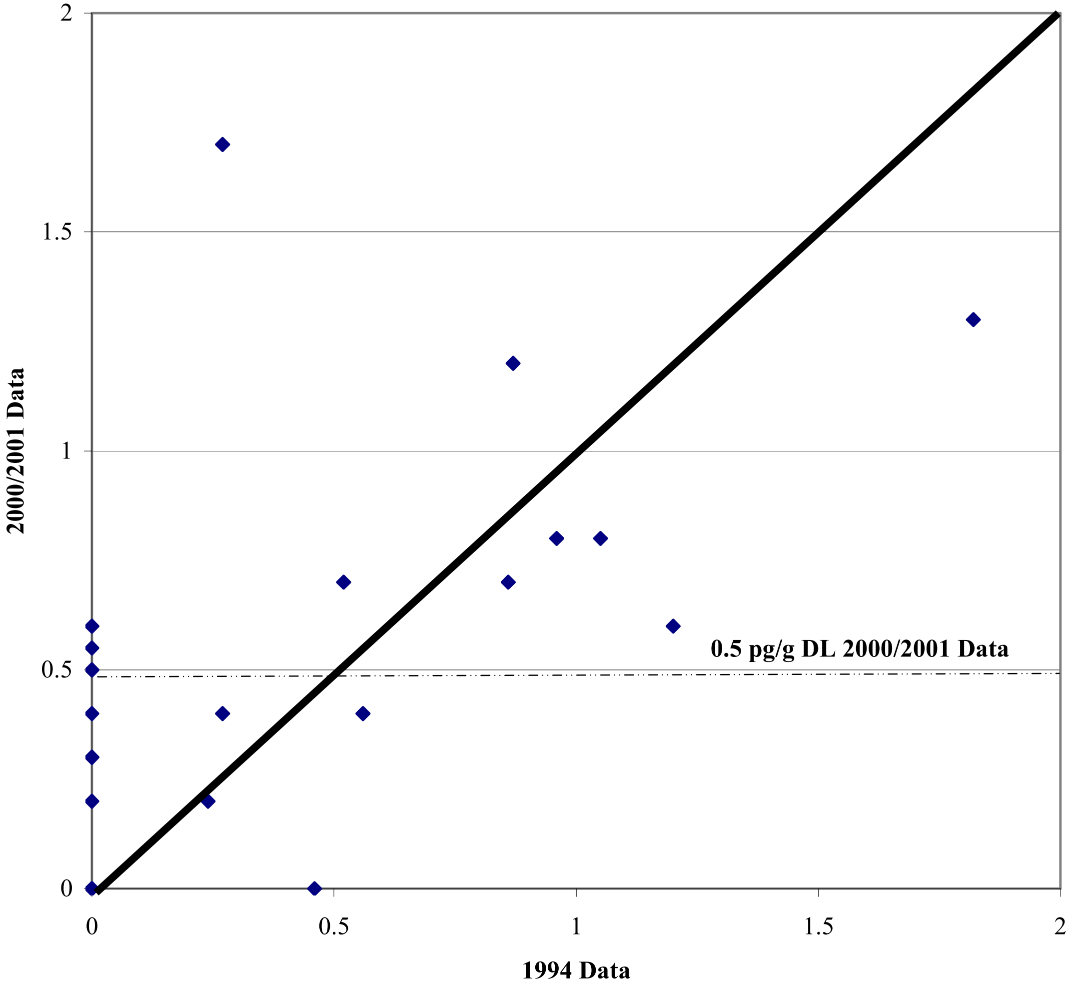
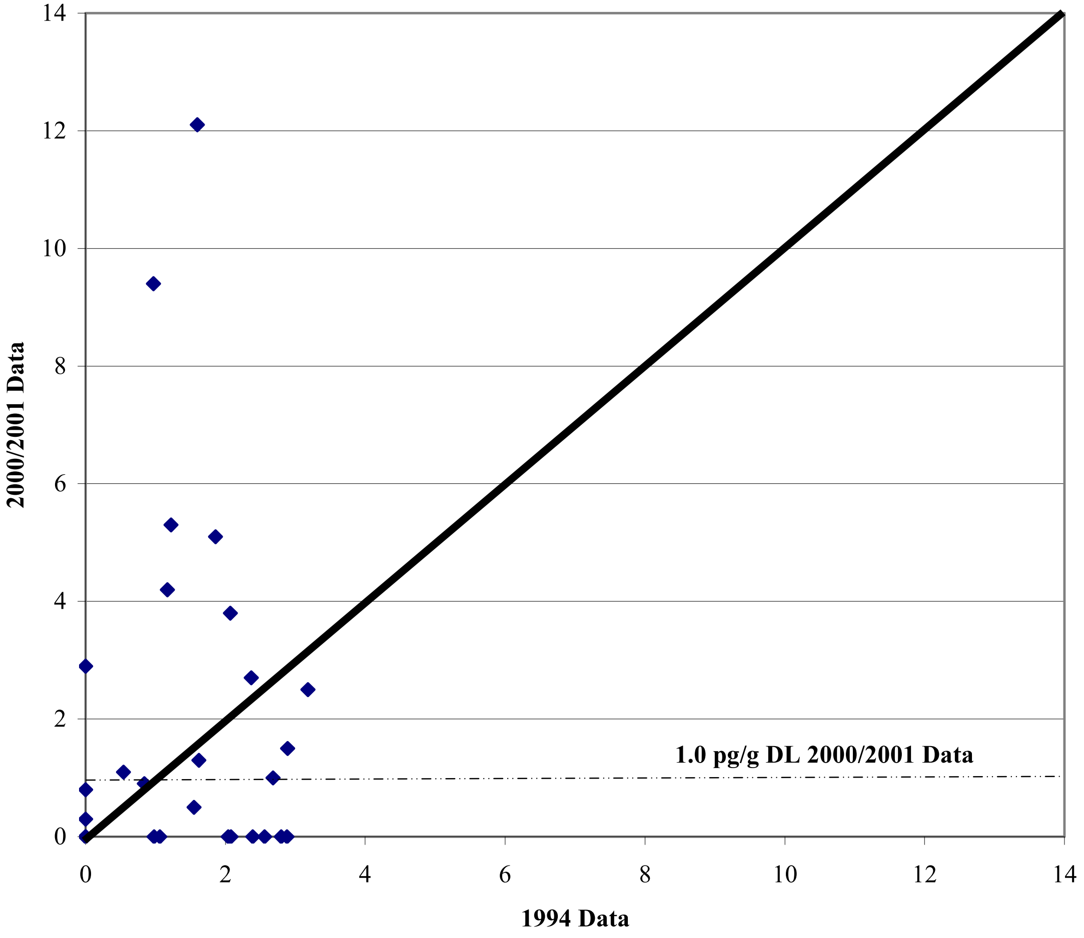


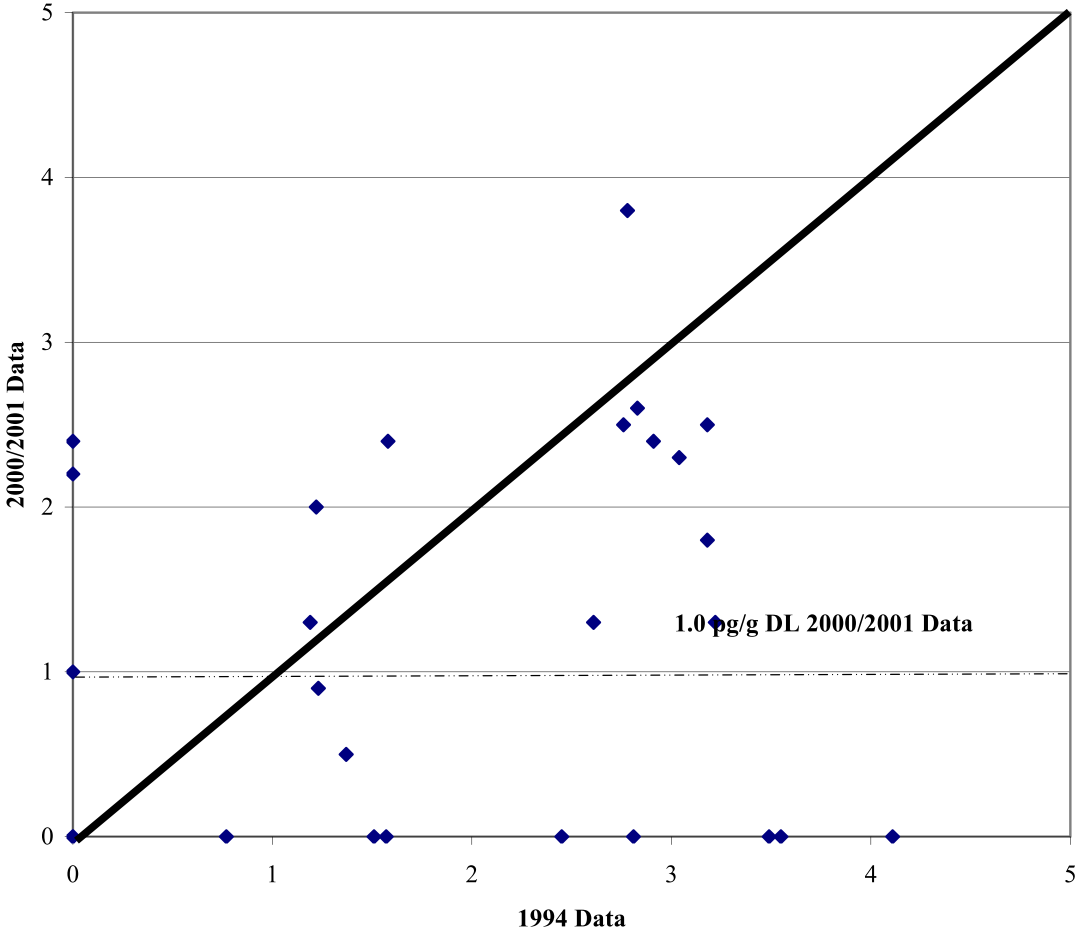
Figure 66.   2,3,7,8-TCDD Data Plot of 1991 and 2000/2001



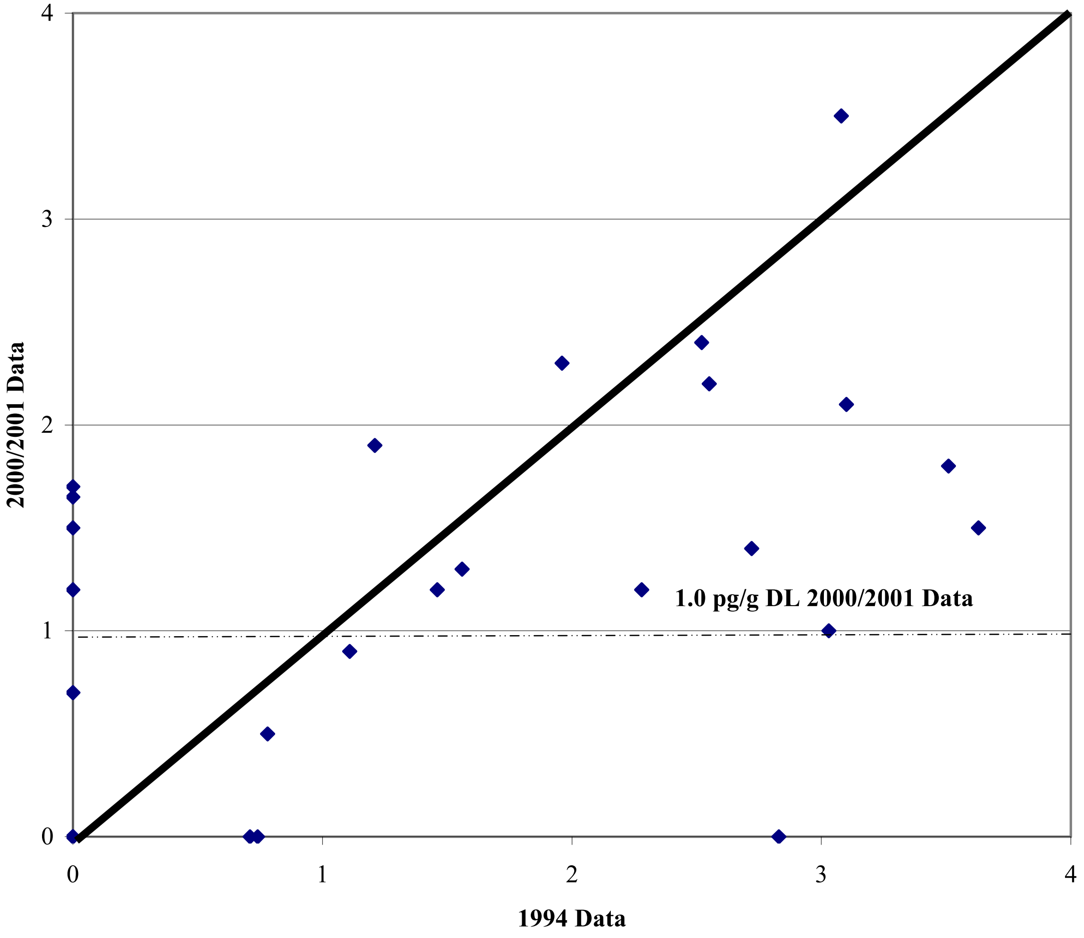
## Figure 67. 1,2,3,7,8-PeCDF Data Plot of 1991 and 2000/2001



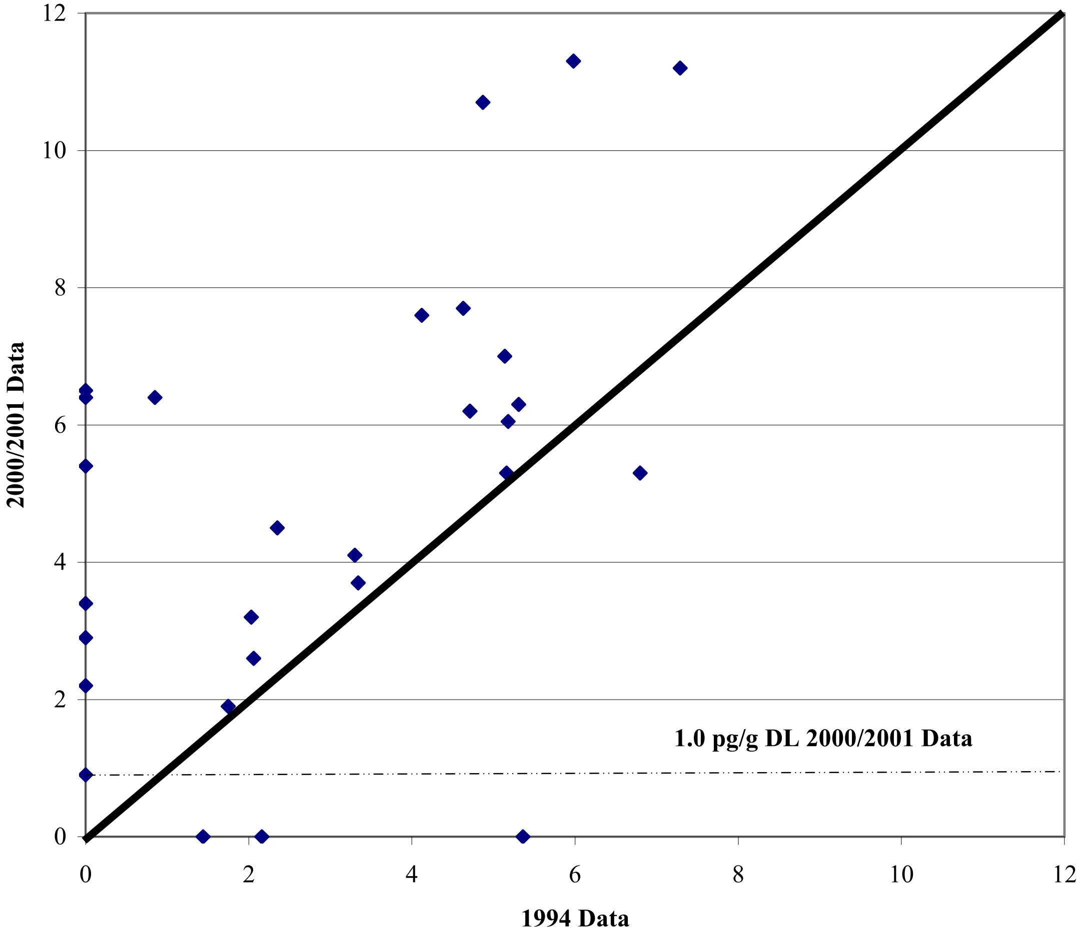
# Figure 68. 2,3,4,7,8-PeCDF Data Plot of 1991 and 2000/2001



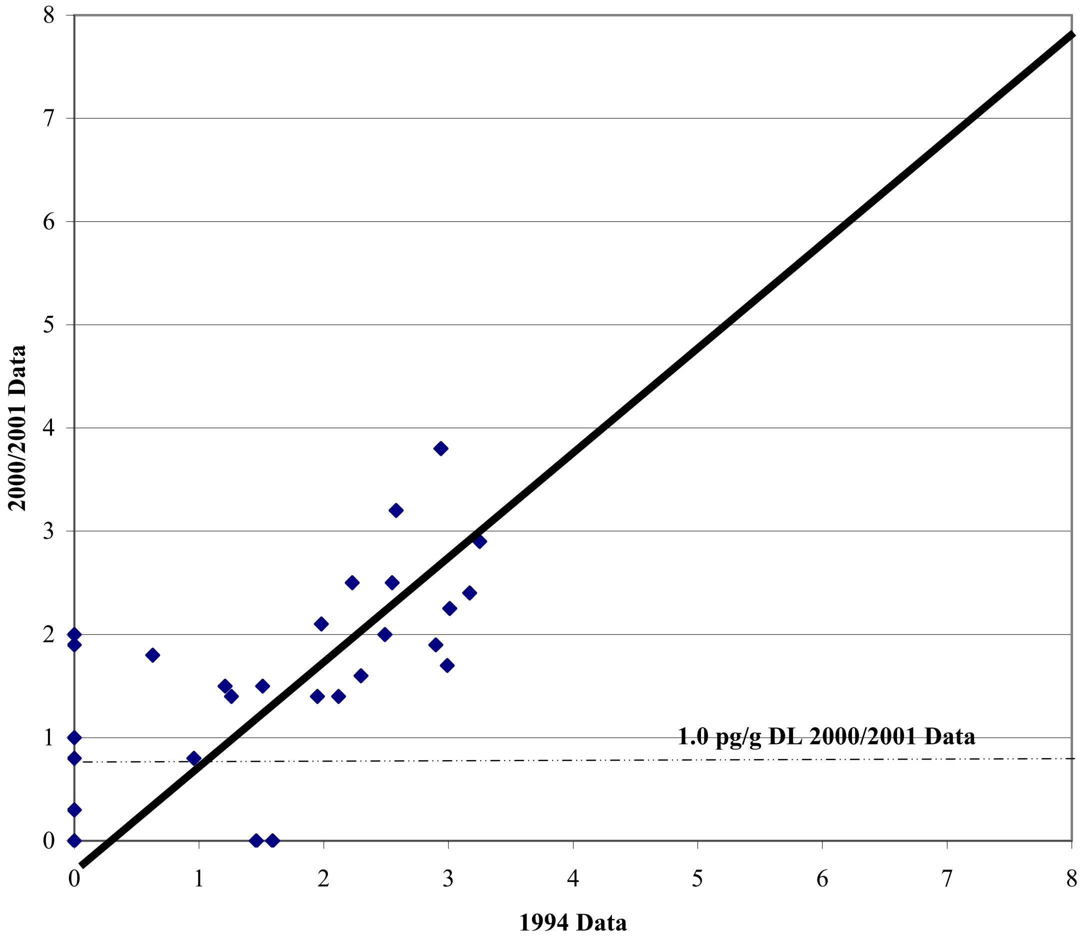
## Figure 69. 1,2,3,7,8-PeCDD Data Plot of 1991 and 2000/2001



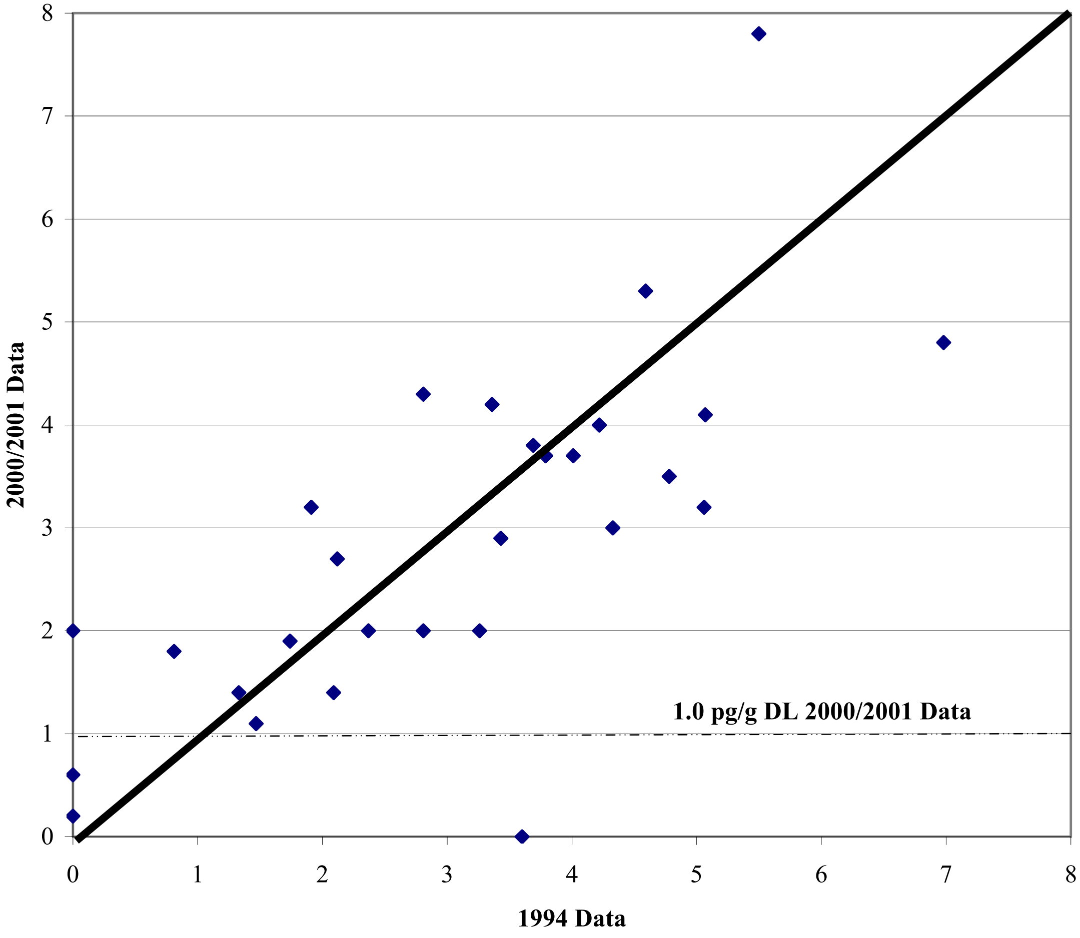
## Figure 70. 1,2,3,4,7,8-HxCDF Data Plot of 1991 and 2000/2001



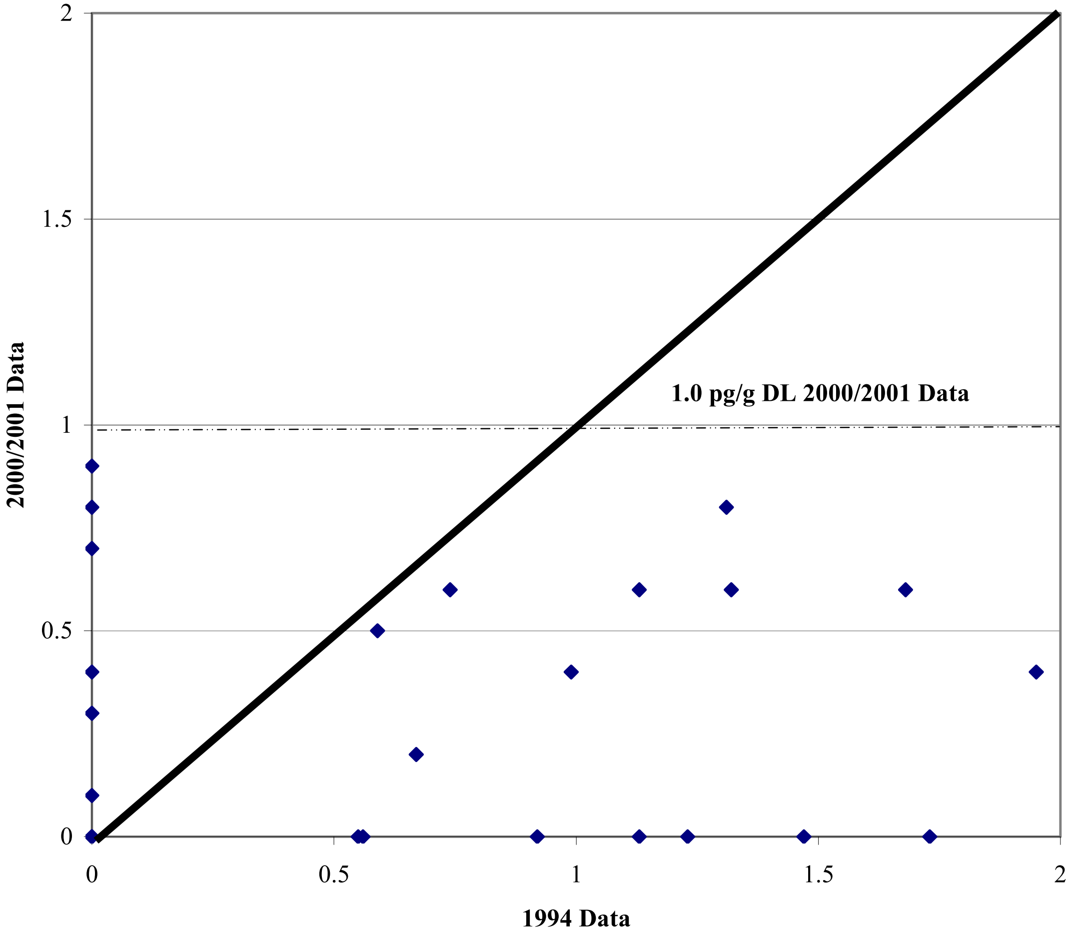
## Figure 71. 1,2,3,6,7,8-HxCDF Data Plot of 1991 and 2000/2001



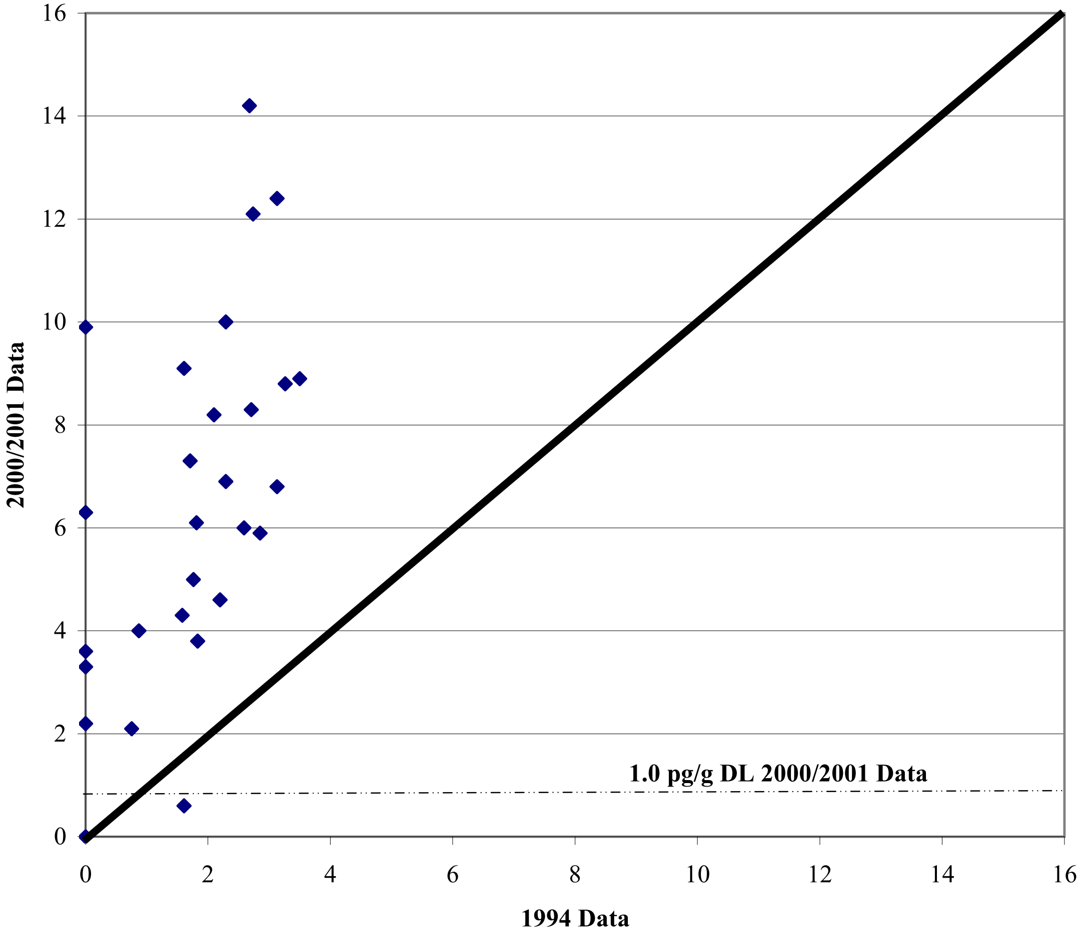
## Figure 72.  2,3,4,6,7,8-HxCDF Data Plot of 1991 and 2000/2001



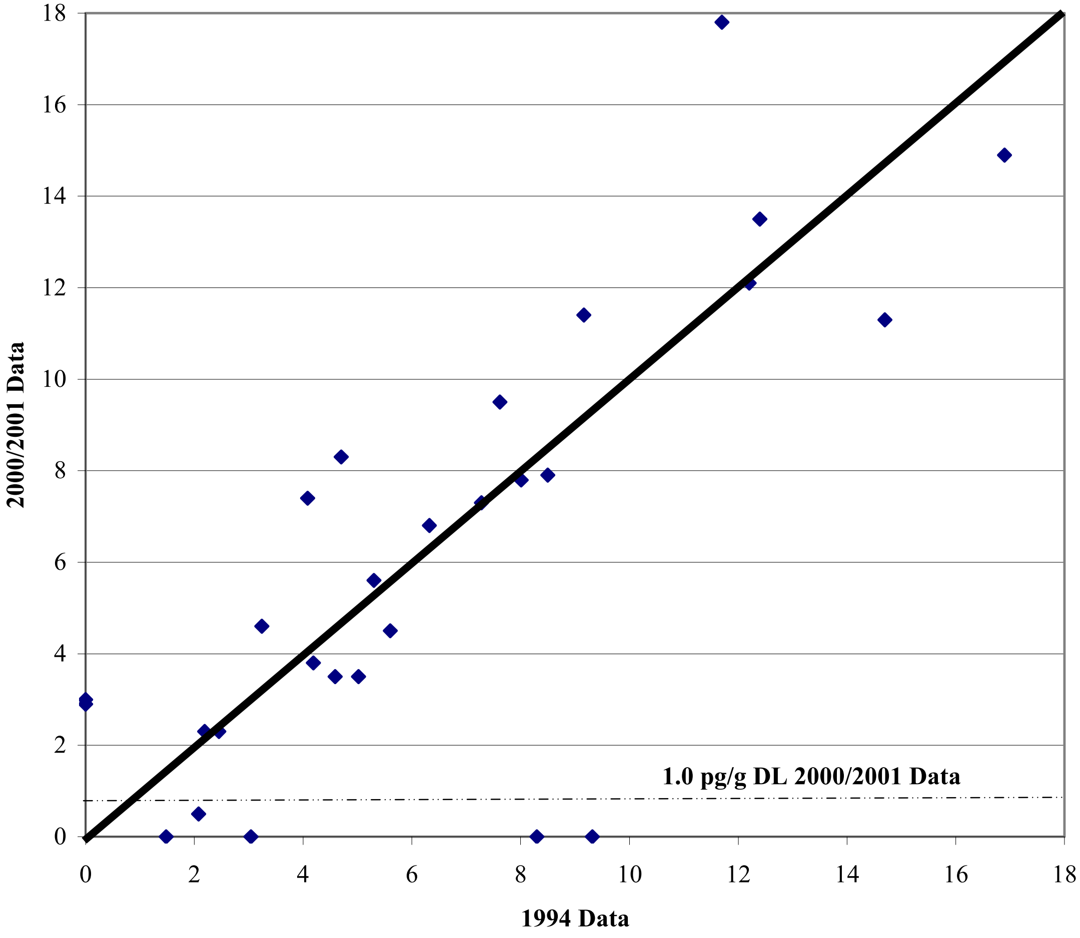
## Figure 73. 1,2,3,7,8,9-HxCDF Data Plot of 1991 and 2000/2001



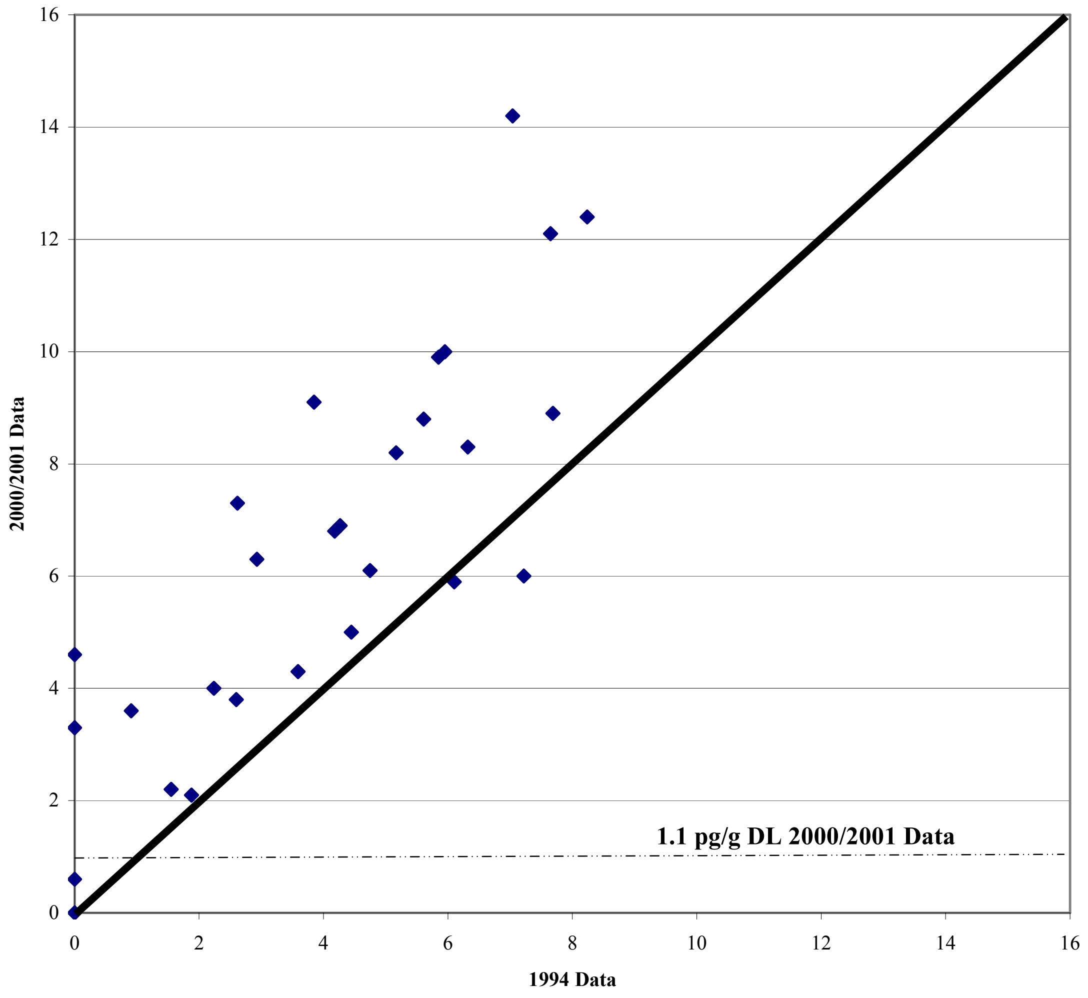
## Figure 74. 1,2,3,4,7,8-HxCDD Data Plot of 1991 and 2000/2001



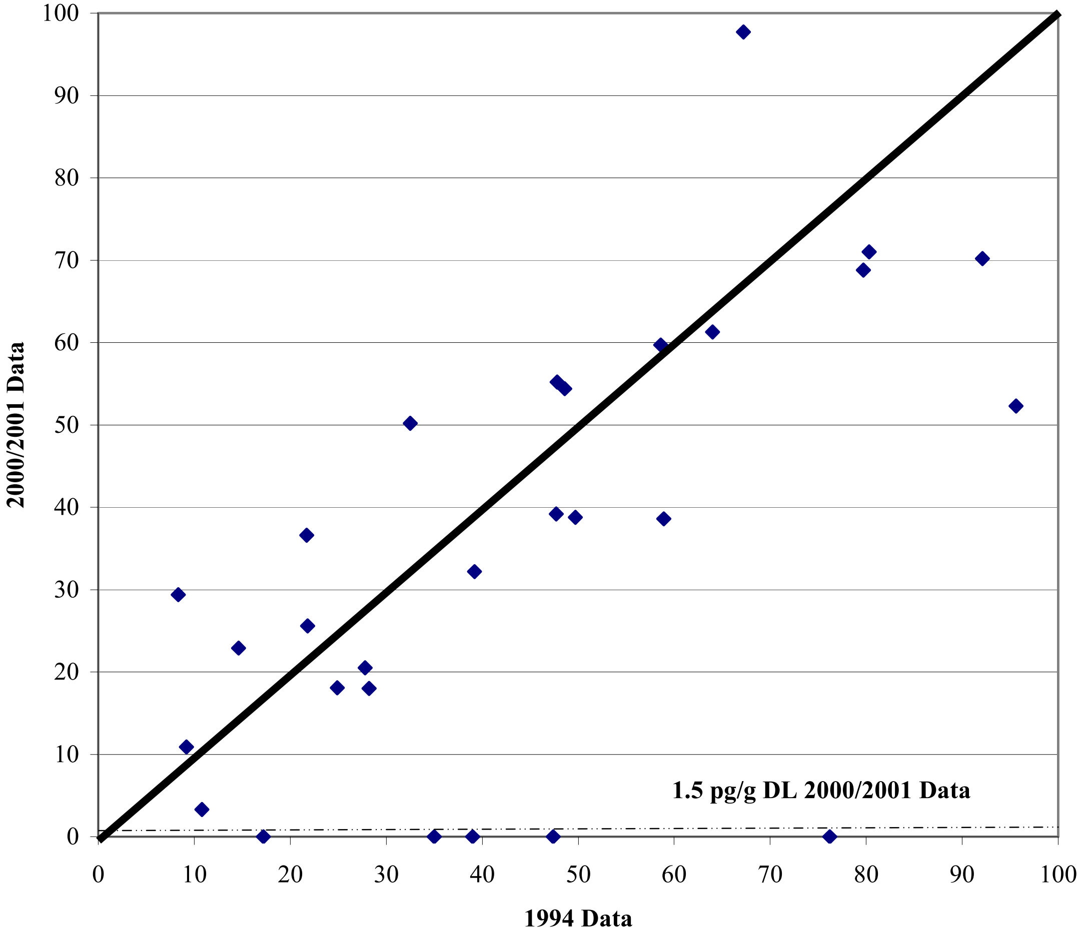
### Figure 75. 1,2,3,6,7,8-HxCDD Data Plot of 1991 and 2000/2001



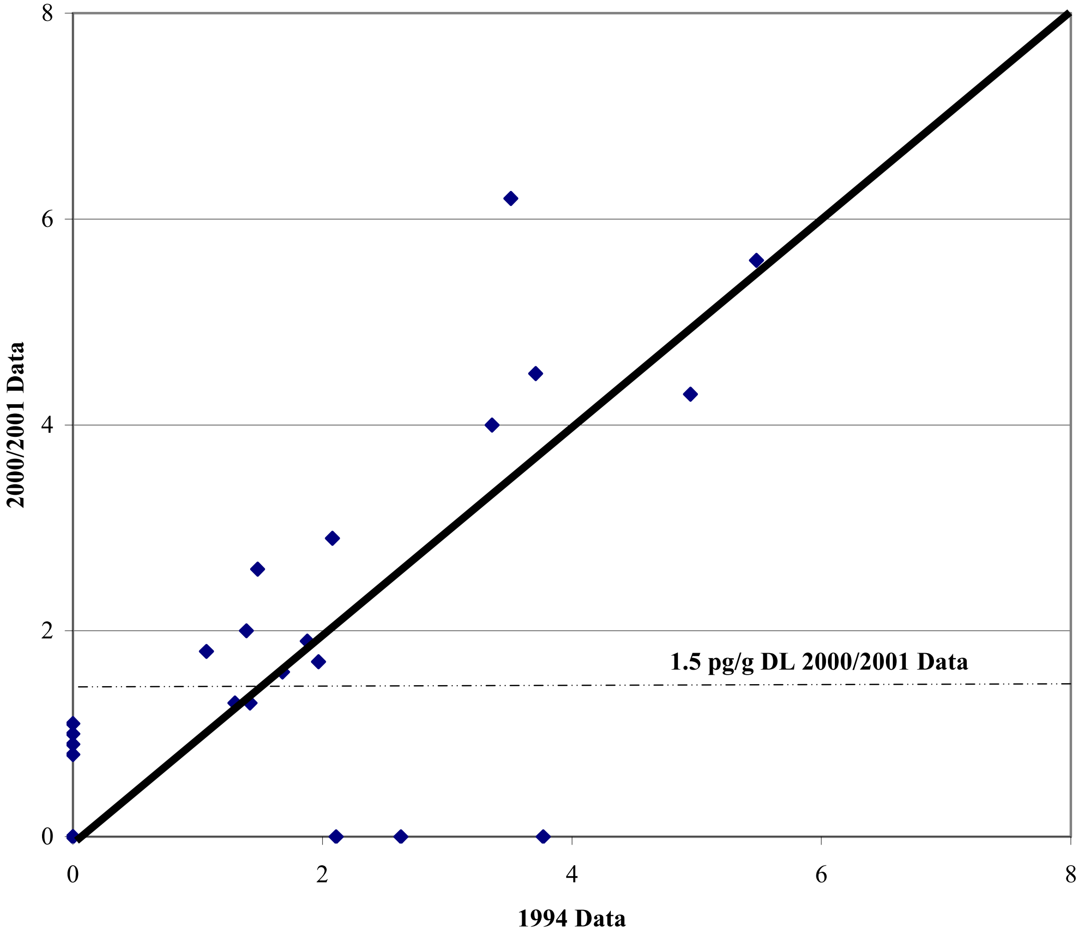
## Figure 76. 1,2,3,7,8,9-HxCDD Data Plot of 1991 and 2000/2001



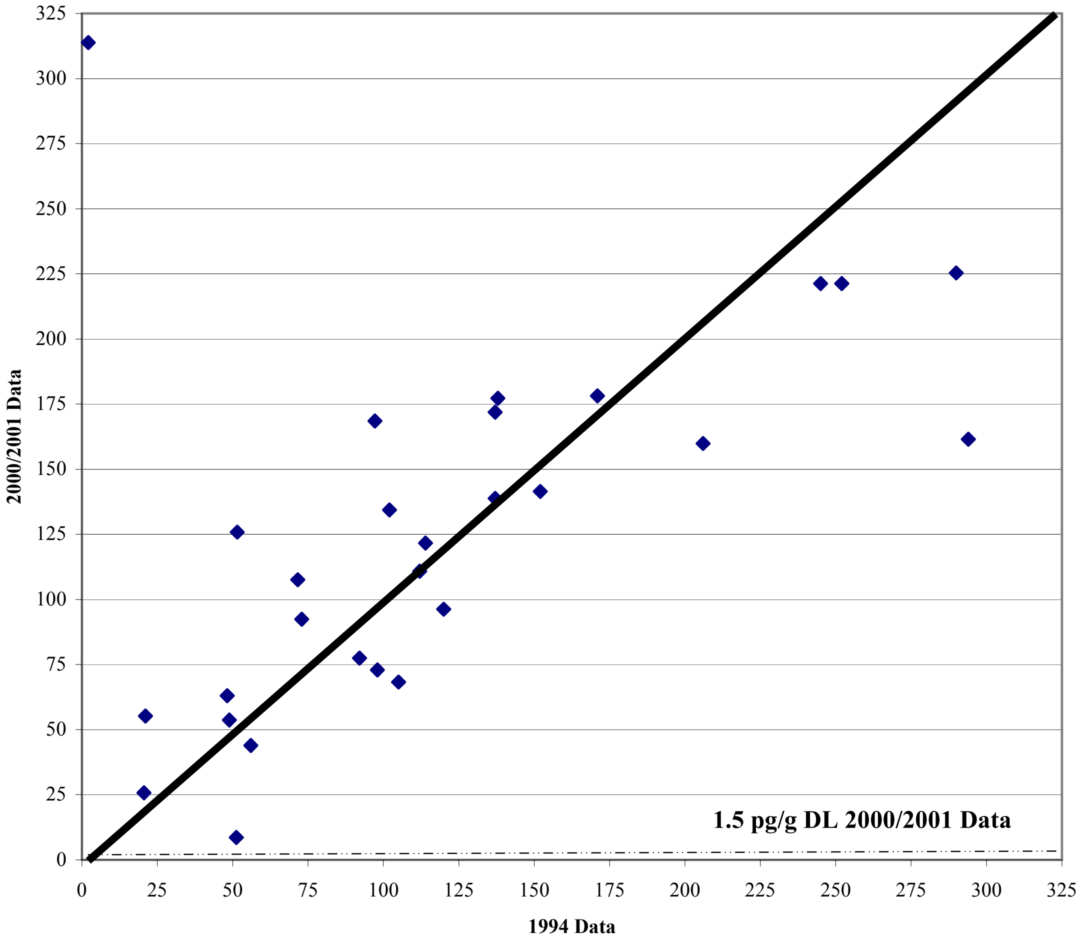
## Figure 77. 1,2,3,4,6,7,8-HpCDF Data Plot of 1991 and 2000/2001



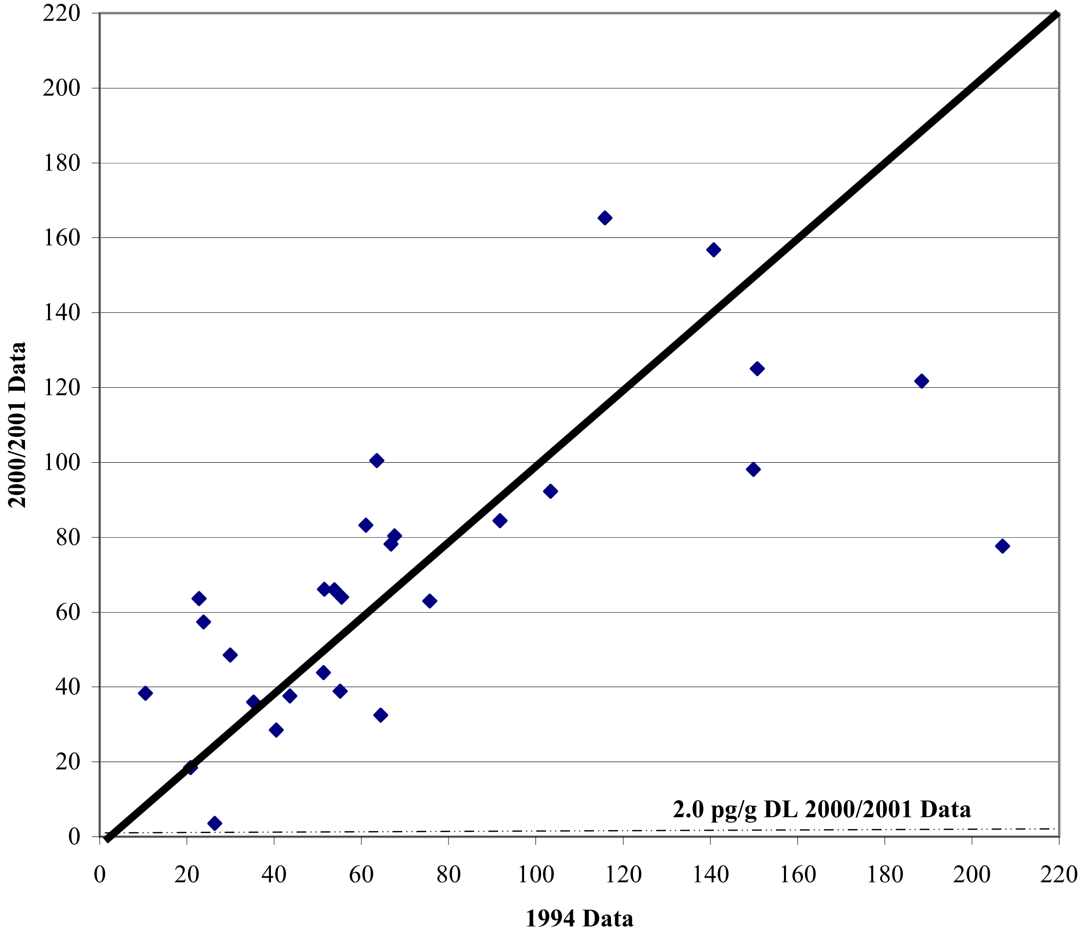
## Figure 78. 1,2,3,4,7,8,9-HpCDF Data Plot of 1991 and 2000/2001



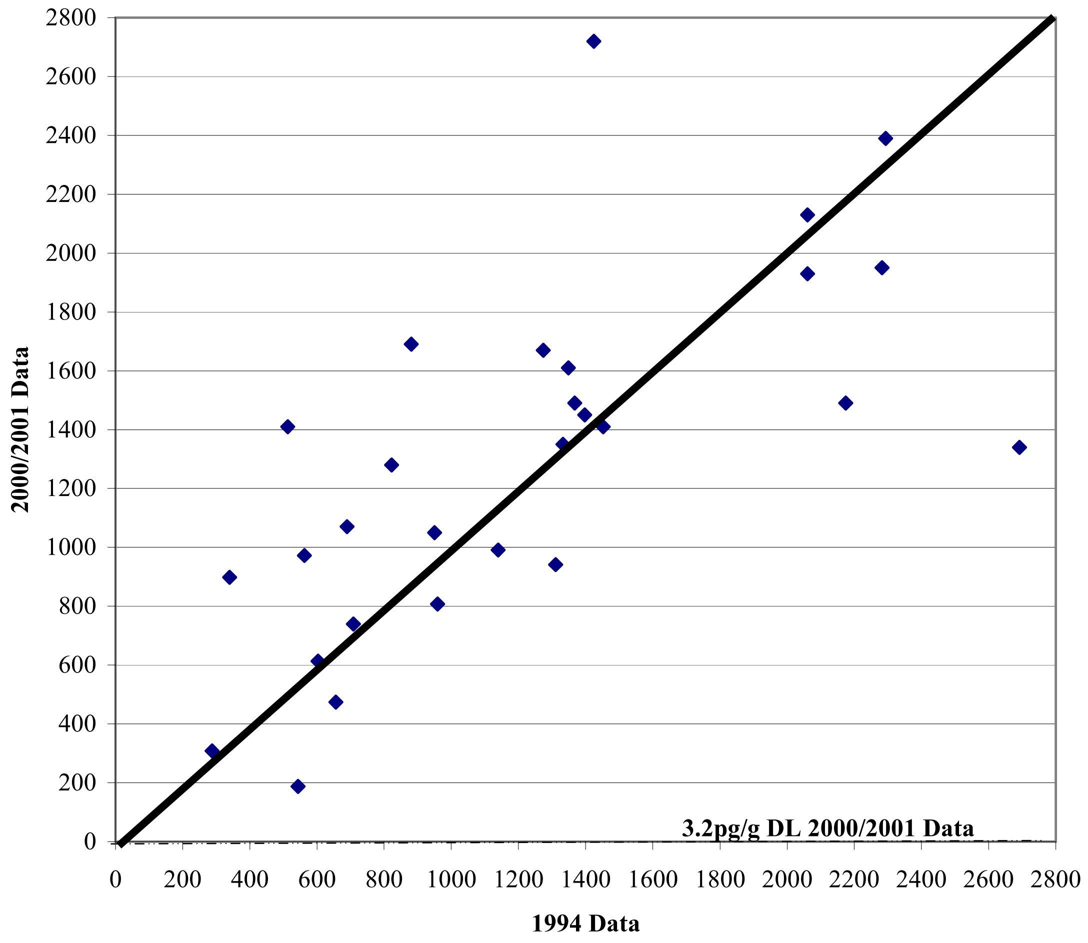
# Figure 79. 1,2,3,4,6,7,8-HpCDD Data Plot of 1991 and 2000/2001



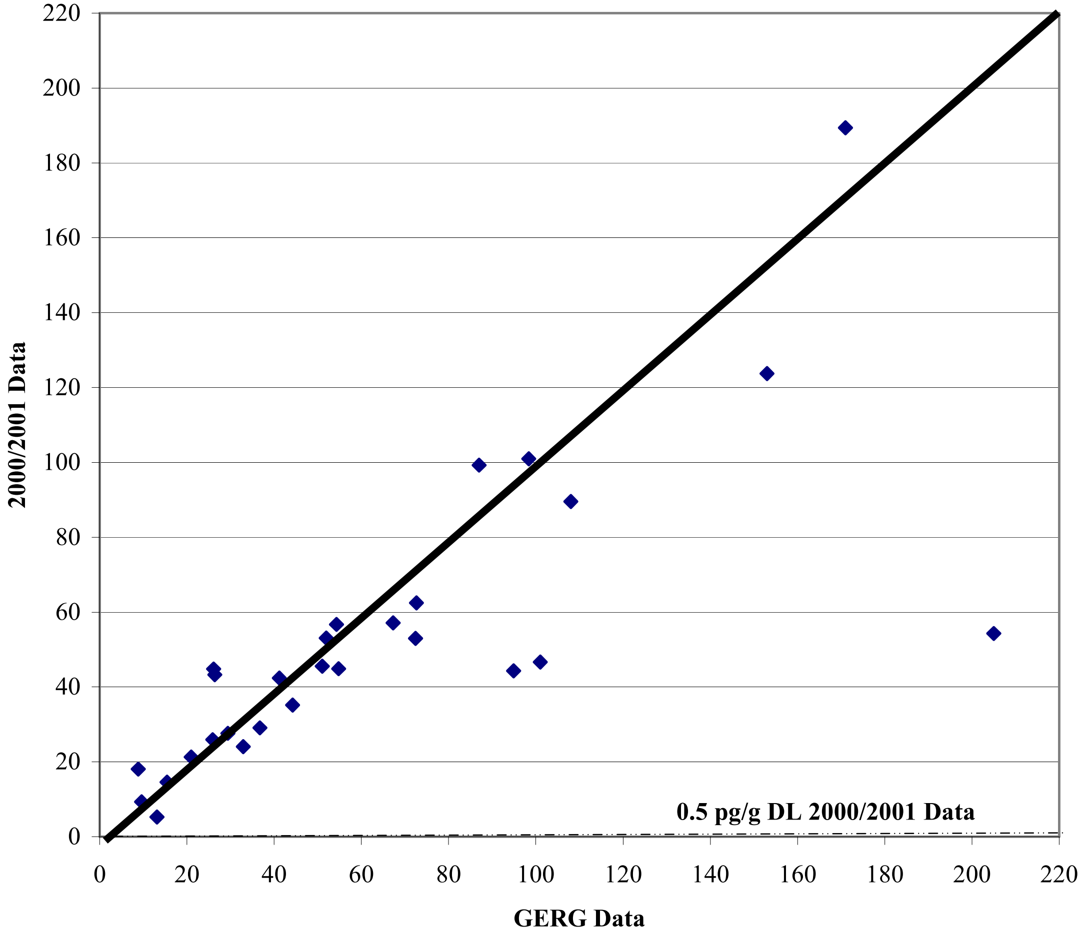
# Figure 80. OCDF Data Plot of 1991 and 2000/2001



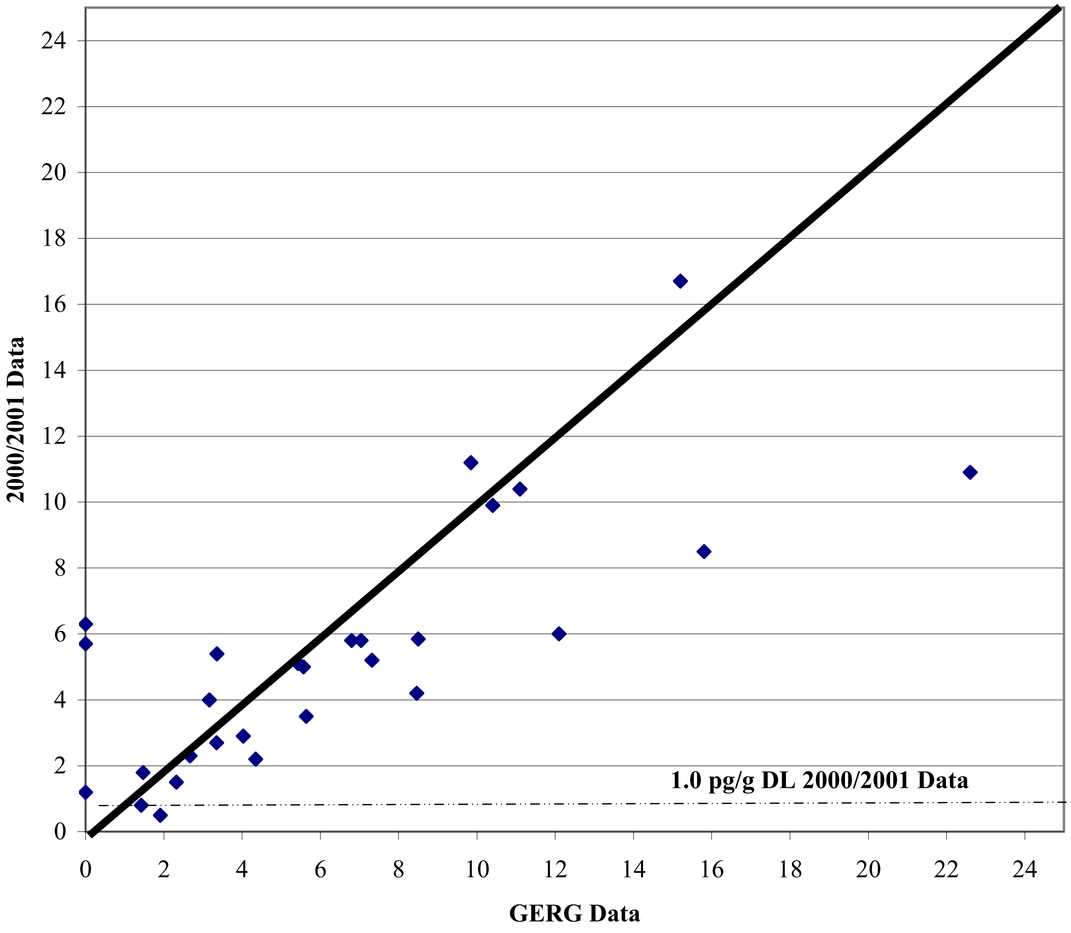
# Figure 81.  OCDD



## Figure 92. PCB 77 Data Plot of 1991 and 2000/2001



## Figure 93. PCB 126 Data Plot of 1991 and 2000/2001



## Figure 96. TOC Data Plot from 1991 and 2000/2001

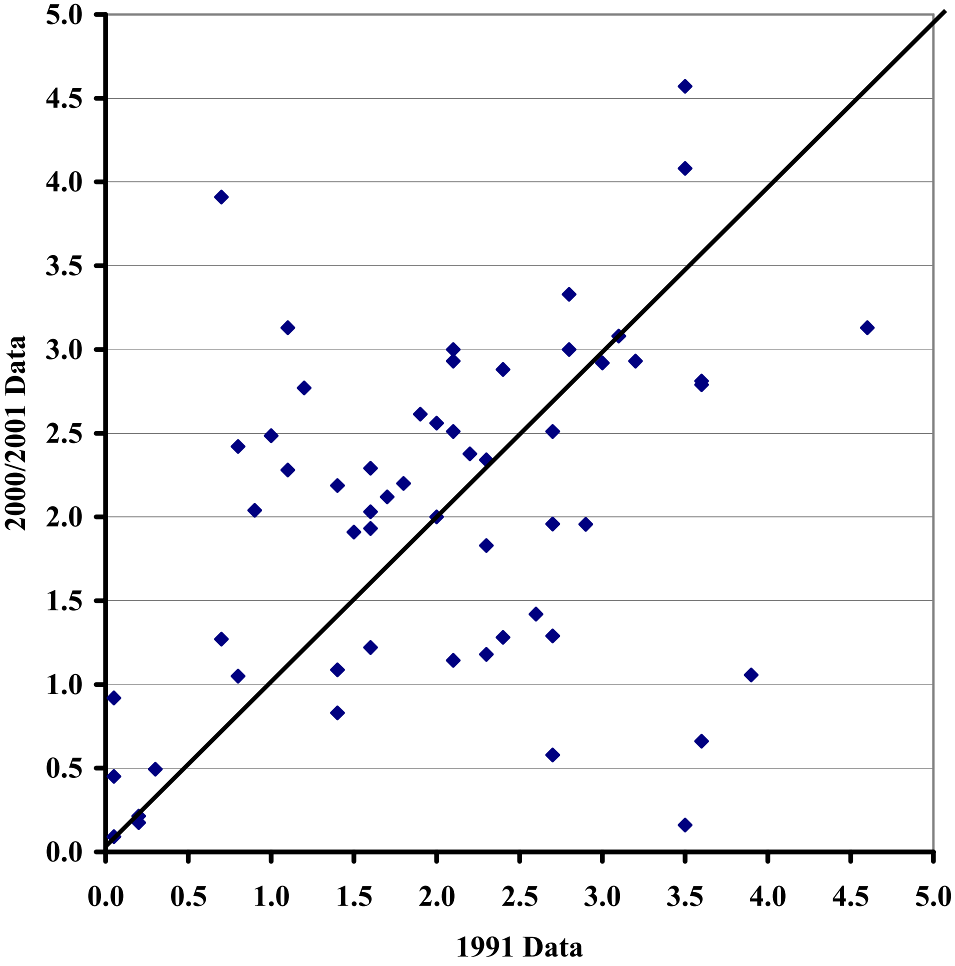


**Figure 97. Grain Size Data Plot from 1991 and 2000/2001 - Sand Fraction**

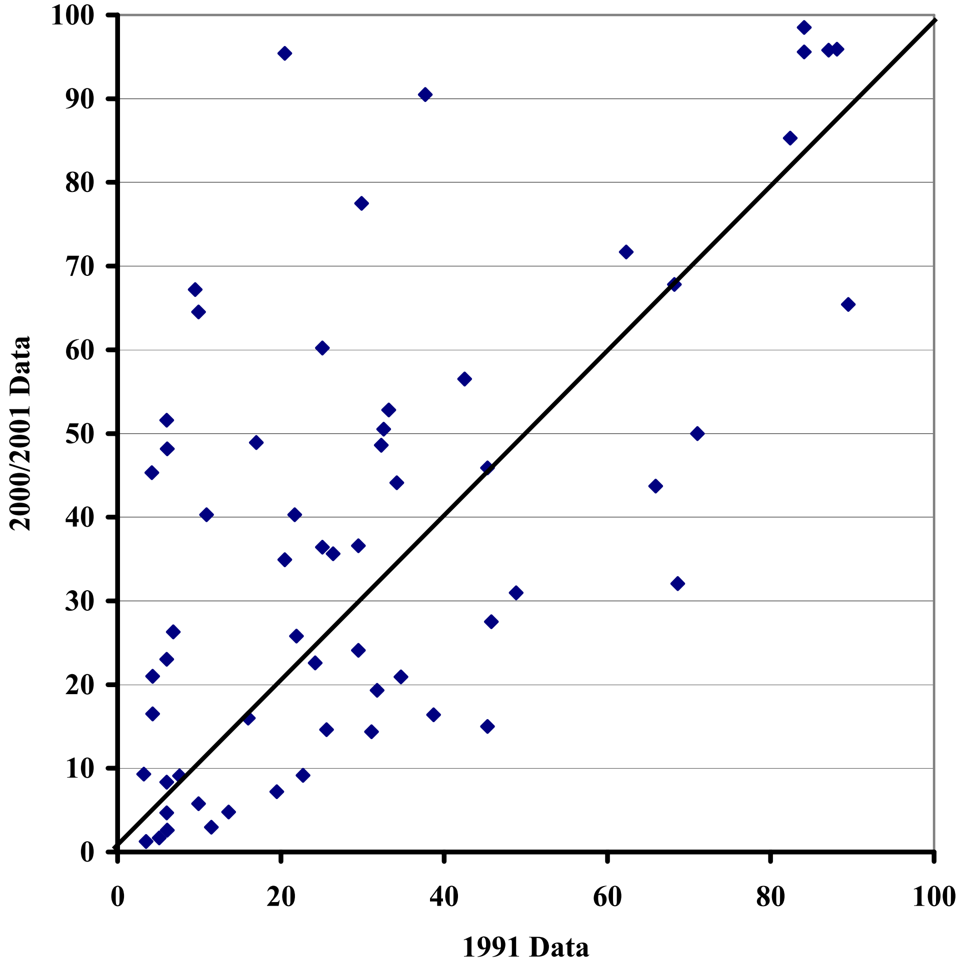
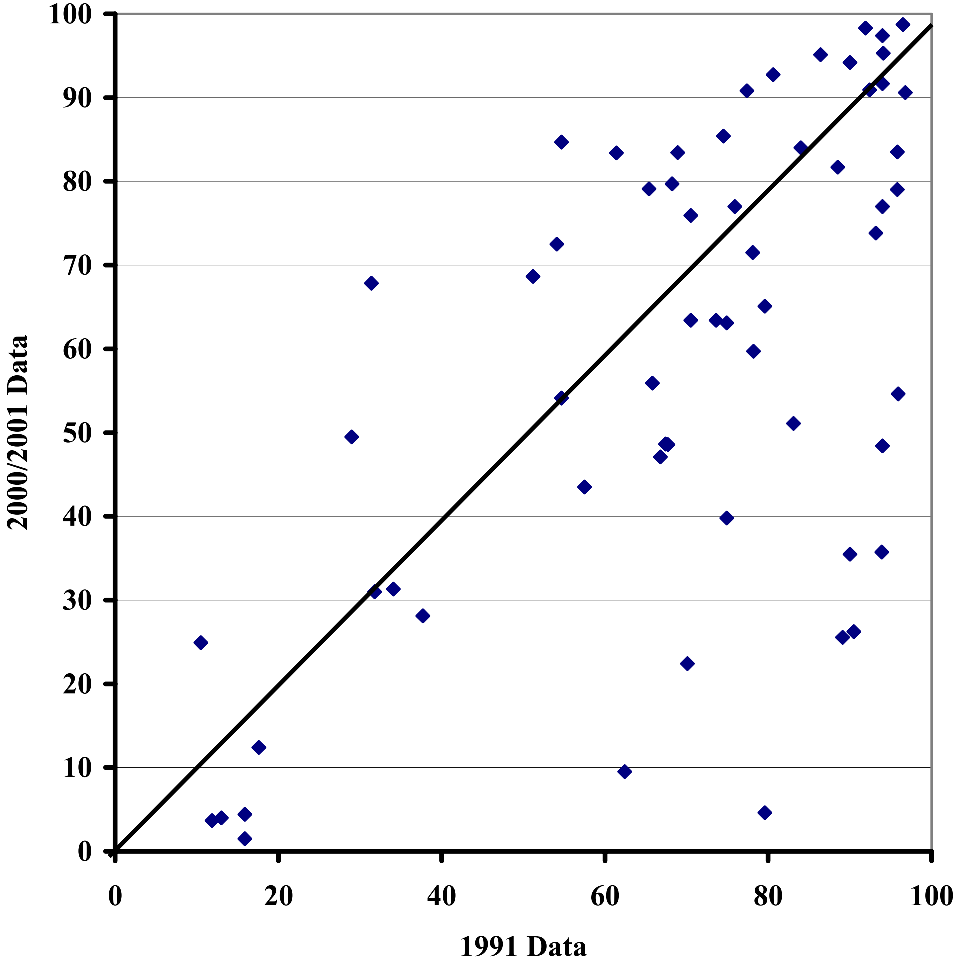


Figure 98. Grain Size Data Plot from 1991 and 2000/2001 - Silt and Clay Fractions



# APPENDIX III

# ArcMap Figures

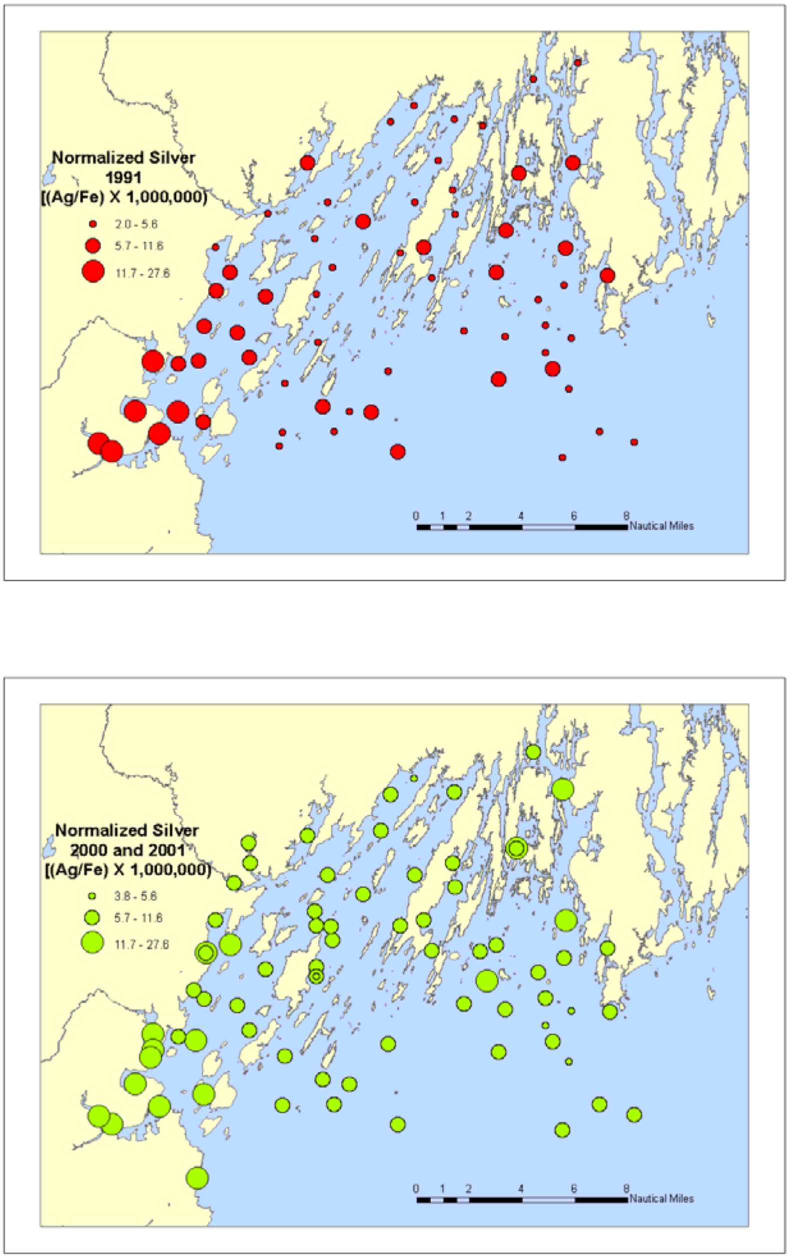


**Figure 51. Geographic Distribution of Silver from Both Sampling Periods.**

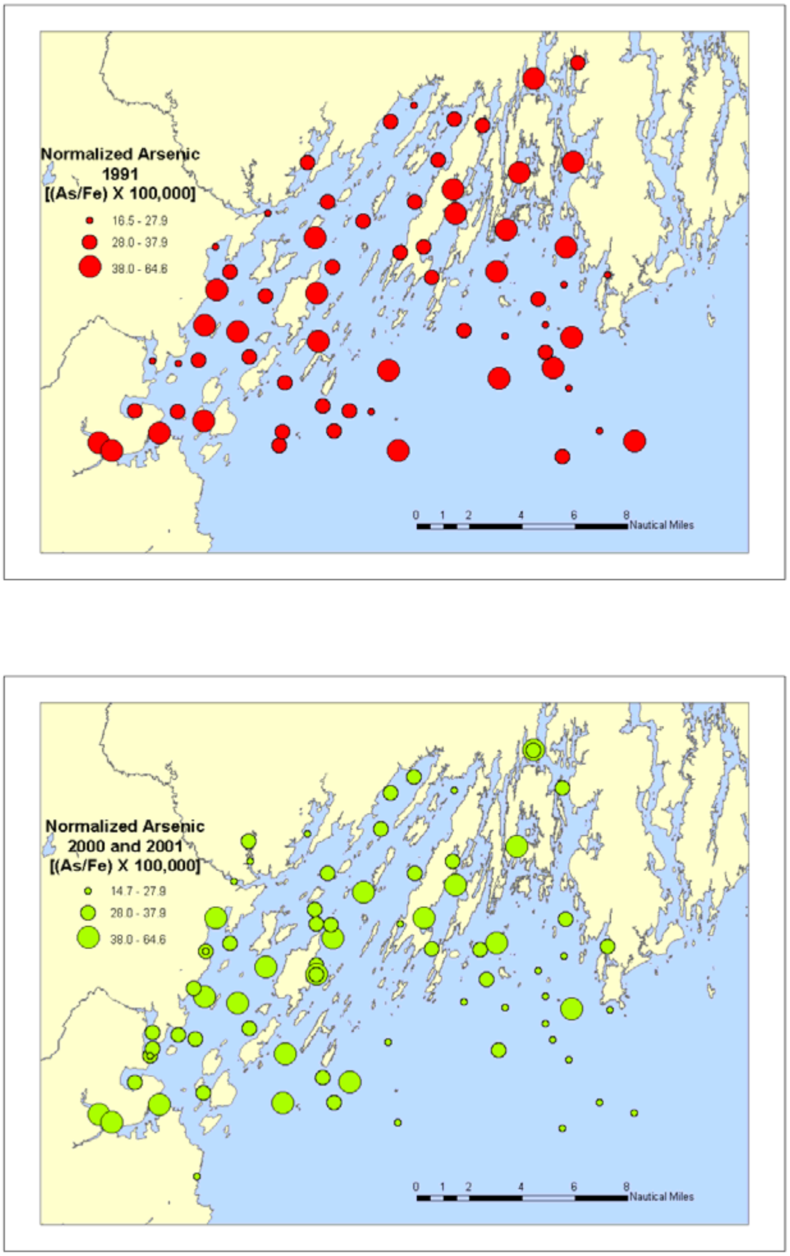
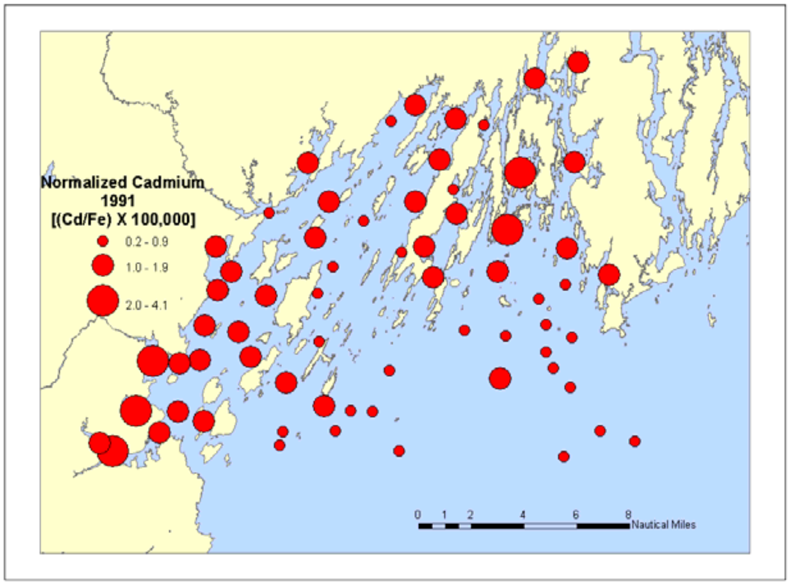


**Figure 52. Geographic Distribution of Arsenic from Both Sampling Periods.**



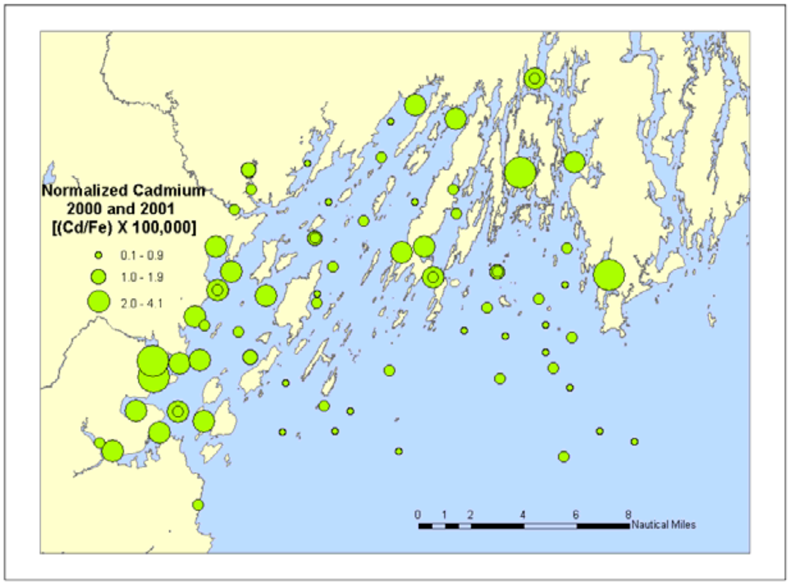


**Figure 53. Geographic Distribution of Cadmium from Both Sampling Periods.**

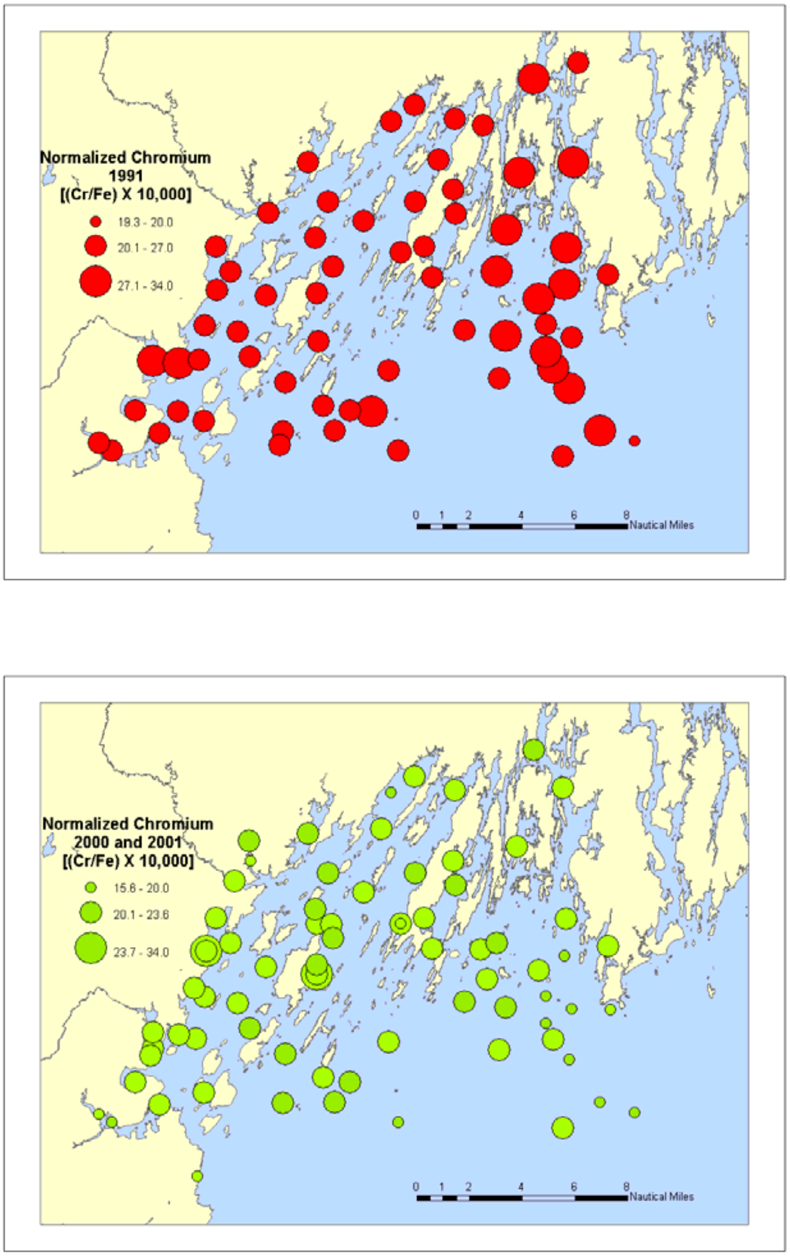


**Figure 54. Geographic Distribution of Chromium from Both Sampling Periods.**

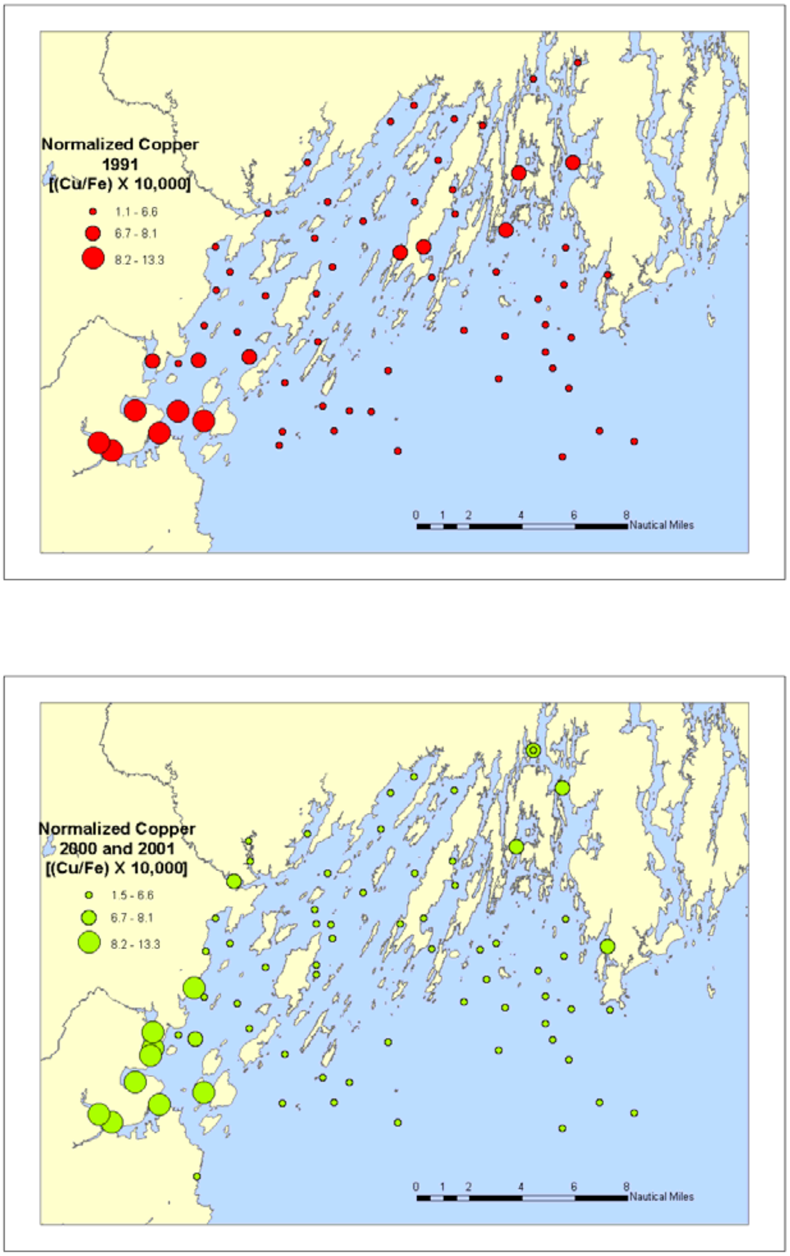


**Figure 55. Geographic Distribution of Copper from Both Sampling Periods.**

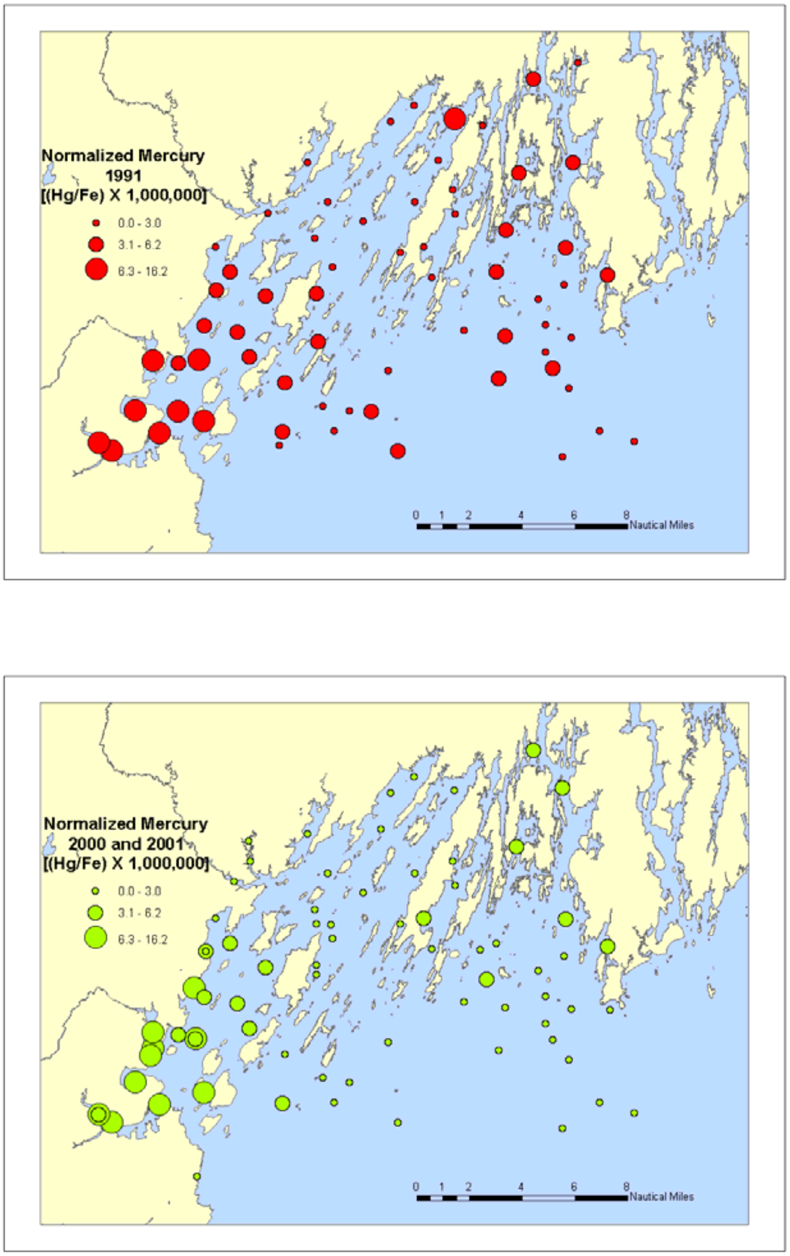


**Figure 56. Geographic Distribution of Mercury from Both Sampling Periods.**

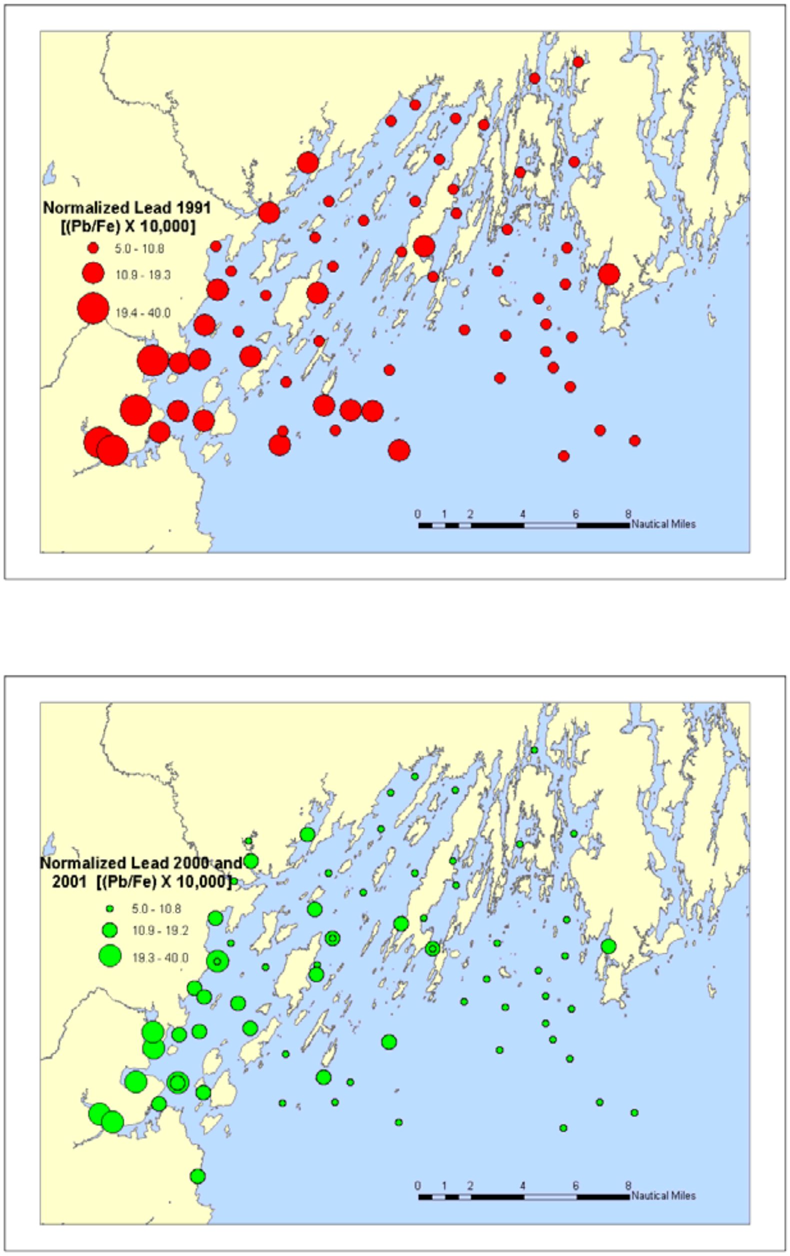


**Figure 57. Geographic Distribution of Lead from Both Sampling Periods.**

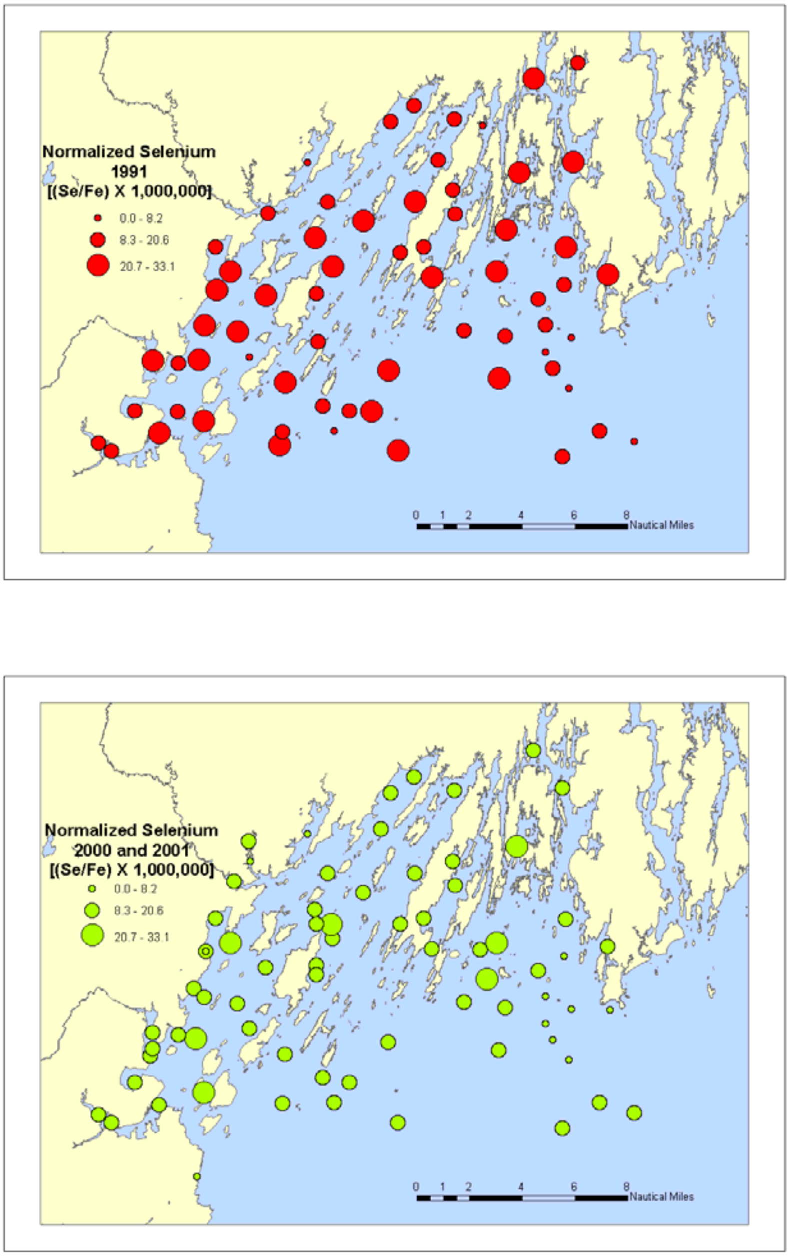


**Figure 58. Geographic Distribution of Selenium from Both Sampling Periods.**

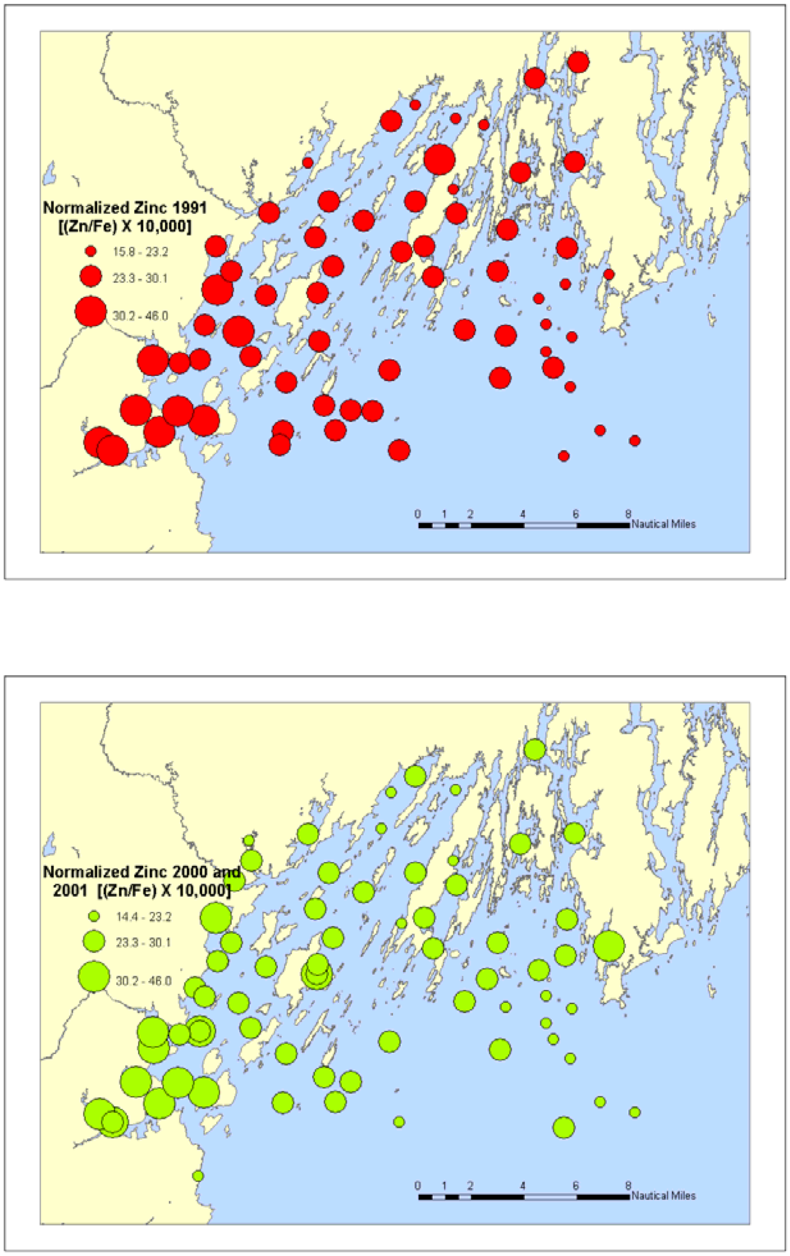


Figure 59. Geographic Distribution of Zinc from Both Sampling Periods.

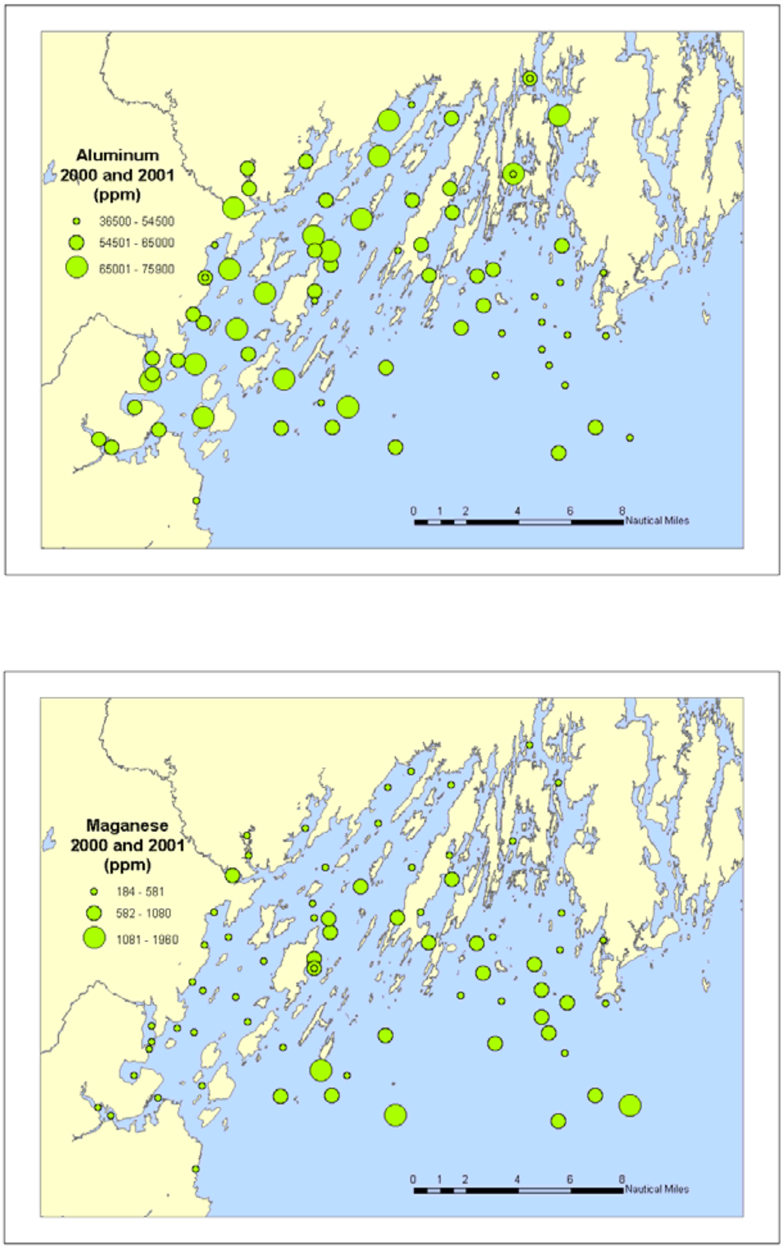


**Figure 60. Geographic Distribution of Aluminum and Manganese from 2000 and 2001.**

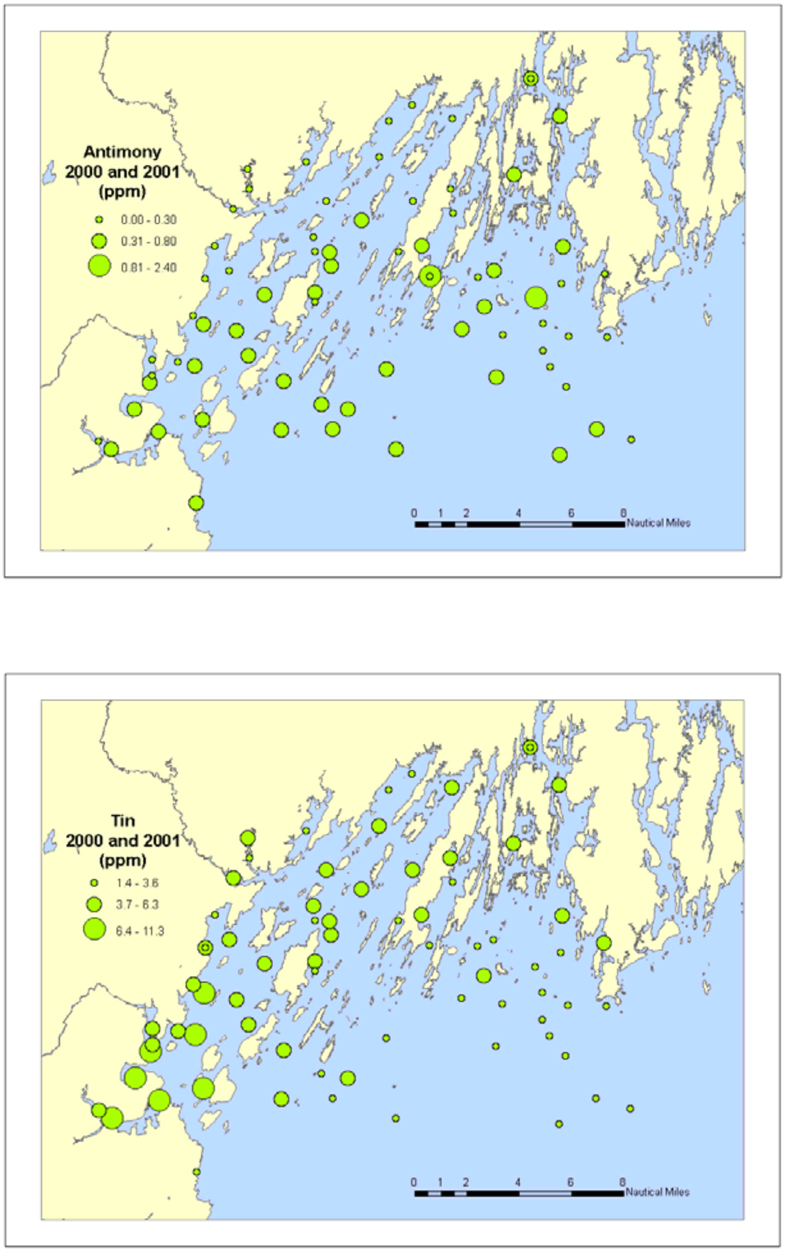


**Figure 61. Geographic Distribution of Antimony and Tin from 2000 and 2001.**

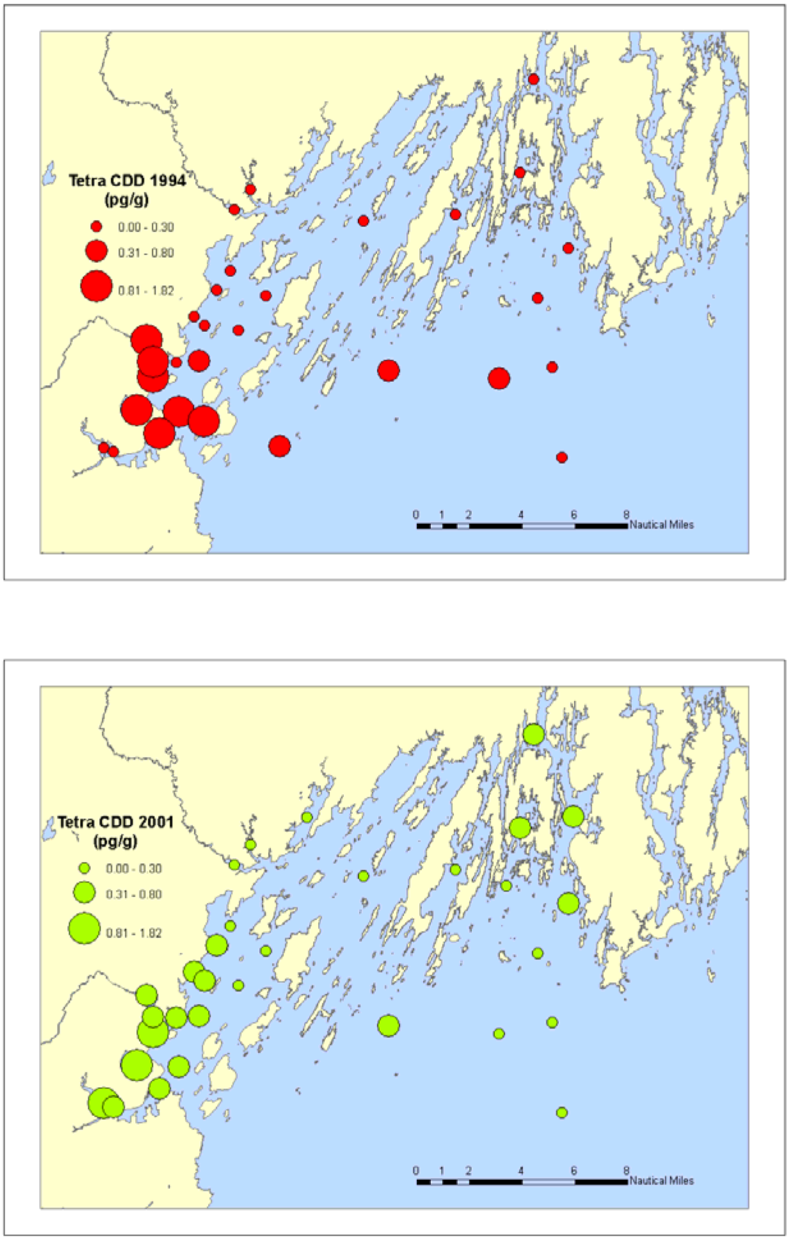


**Figure 83. Geographic Distribution of Tetra CDD from Both Sampling Periods.**

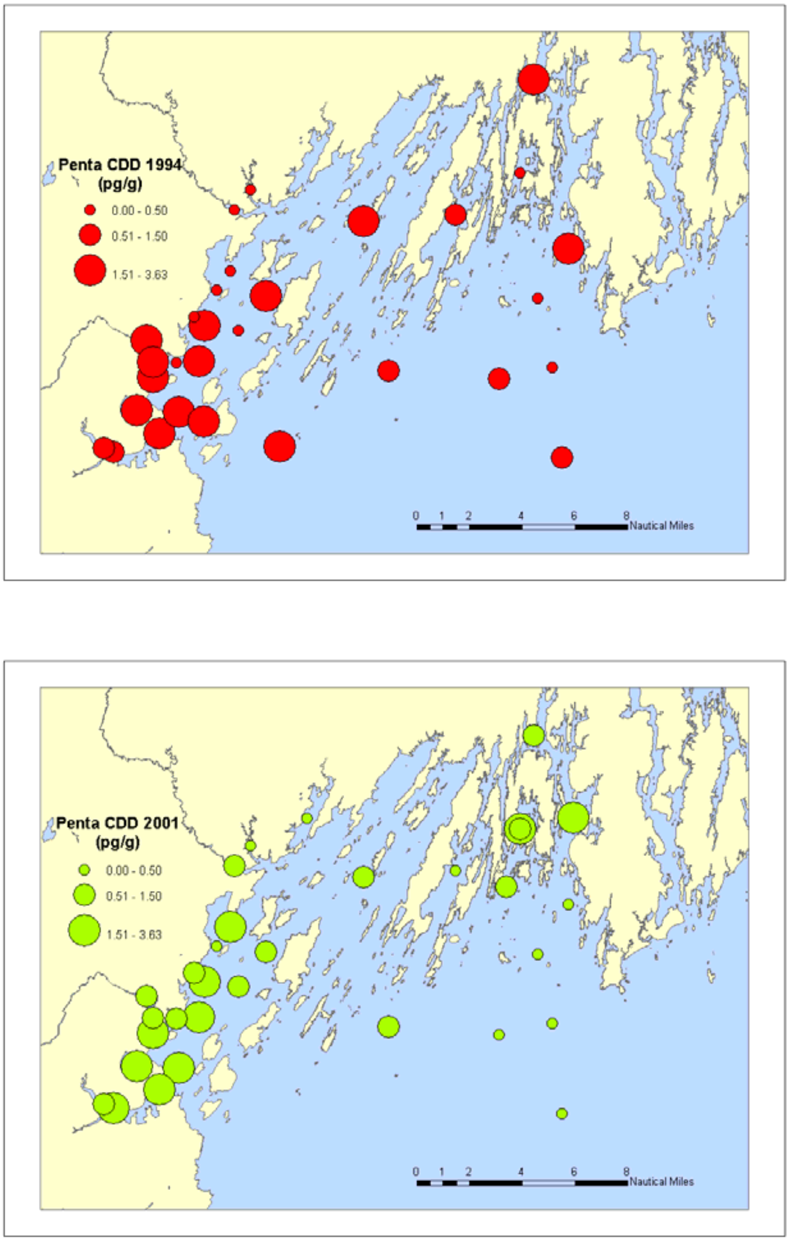


**Figure 84. Geographic Distribution of Penta CDD from Both Sampling Periods.**

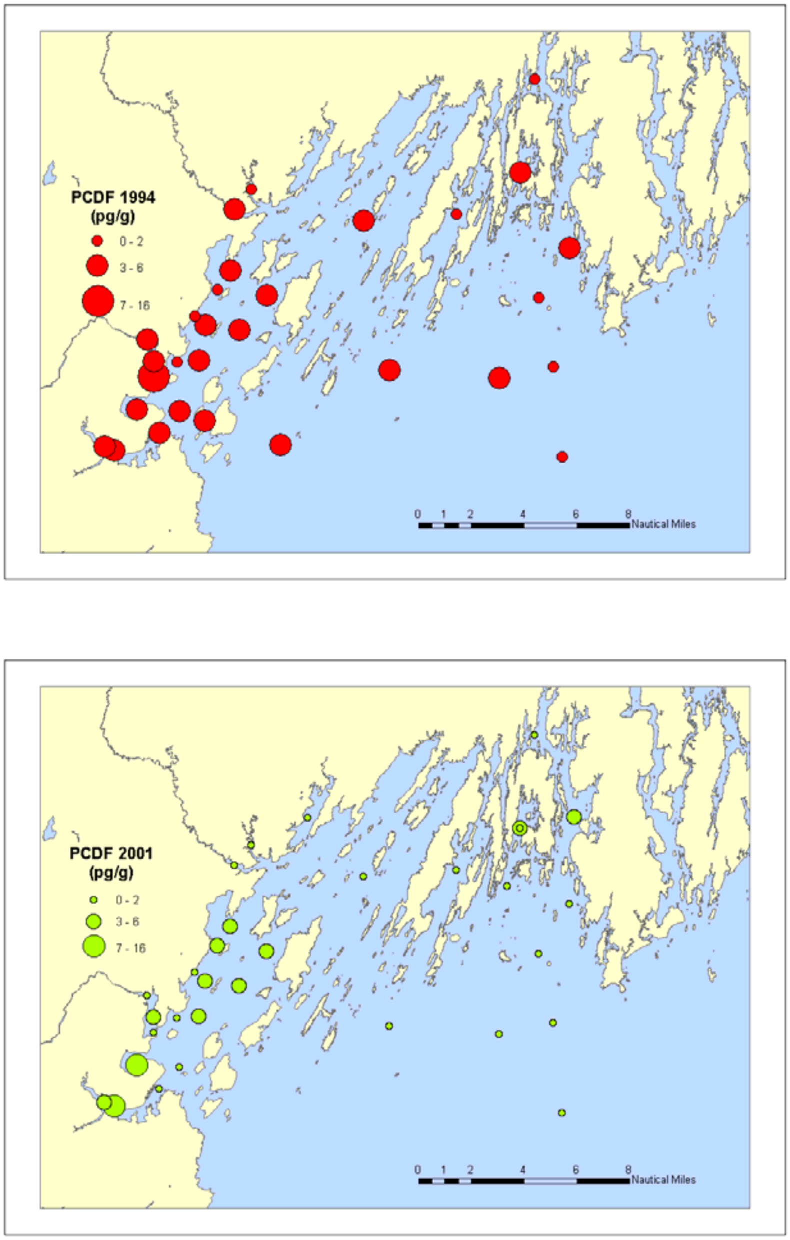
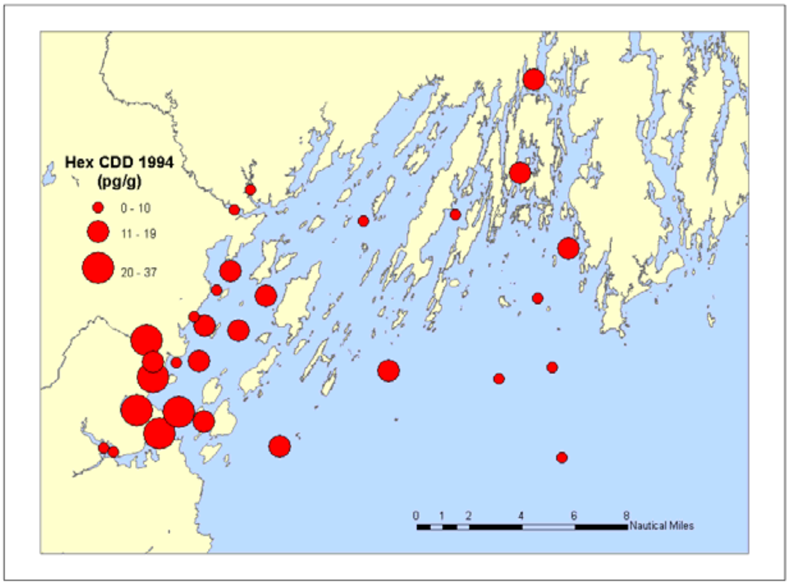


Figure 85. Geographic Distribution of Penta CDF from Both Sampling Periods.



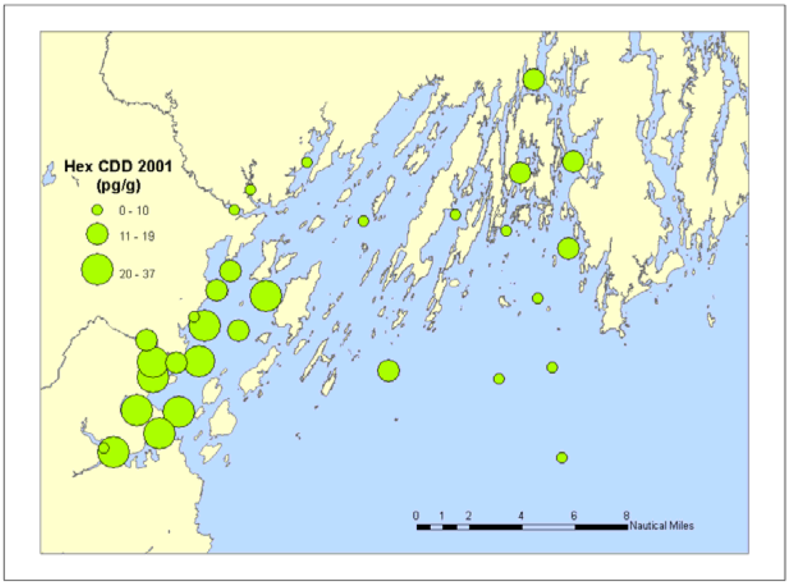


**Figure 86. Geographic Distribution of Hexa CDD from Both Sampling Periods.**

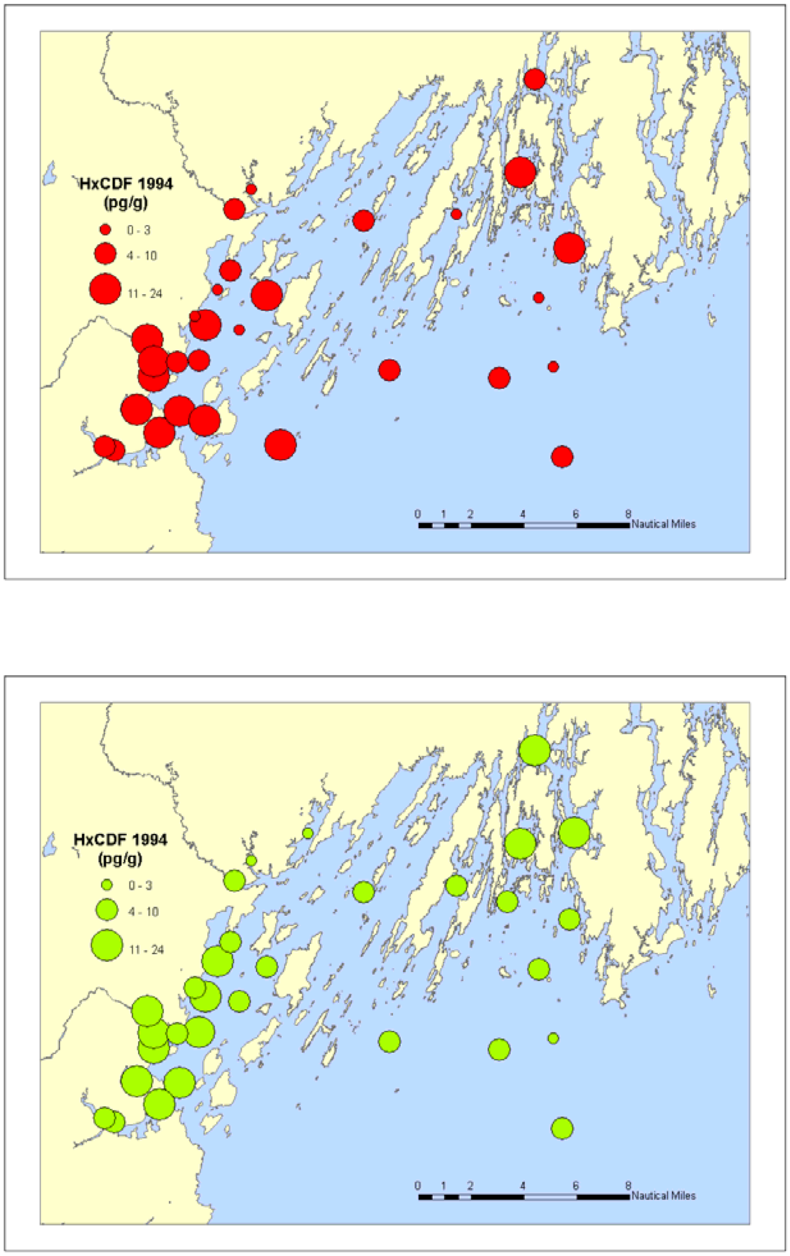


**Figure 87. Geographic Distribution of Hexa CDF from Both Sampling Periods.**

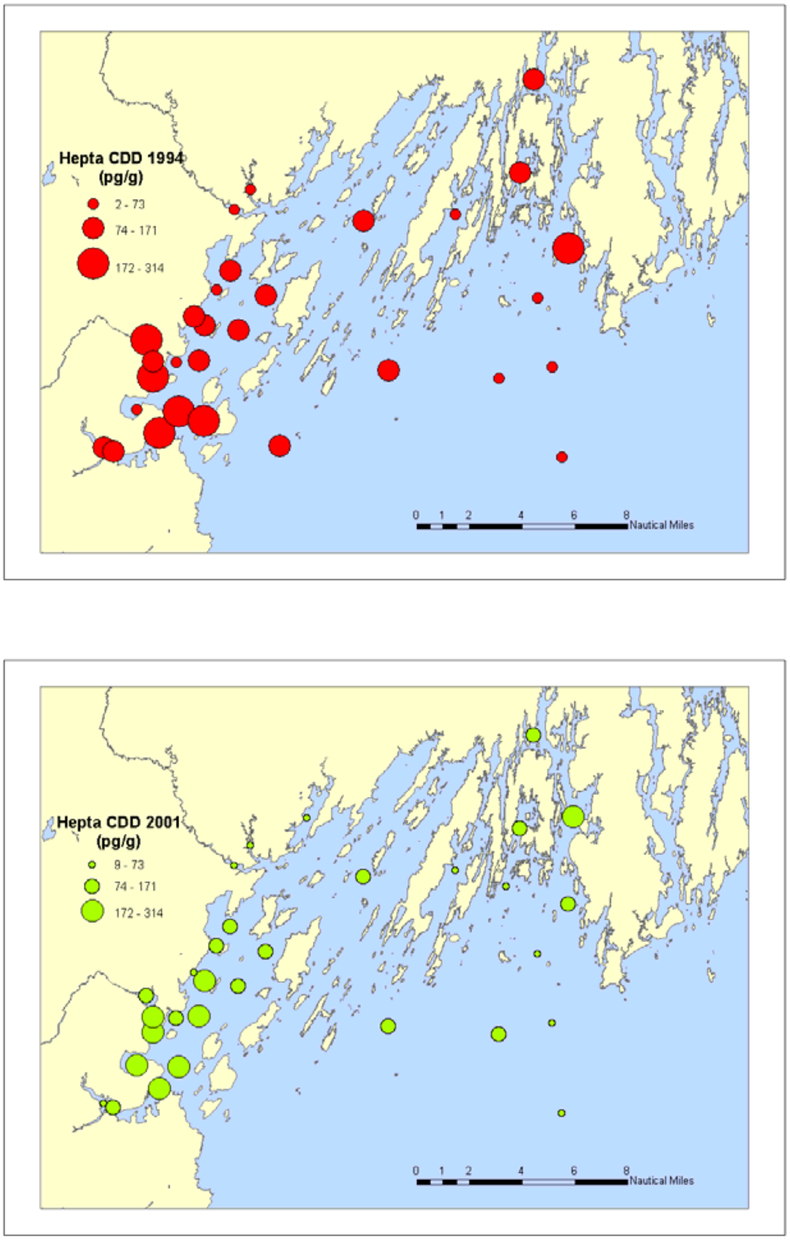
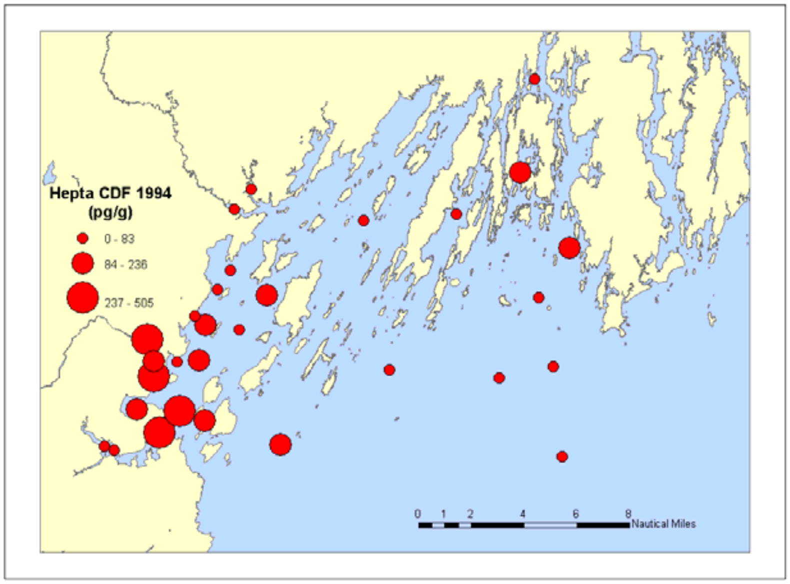


**Figure 88. Geographic Distribution of Hepta CDD from Both Sampling Periods.**



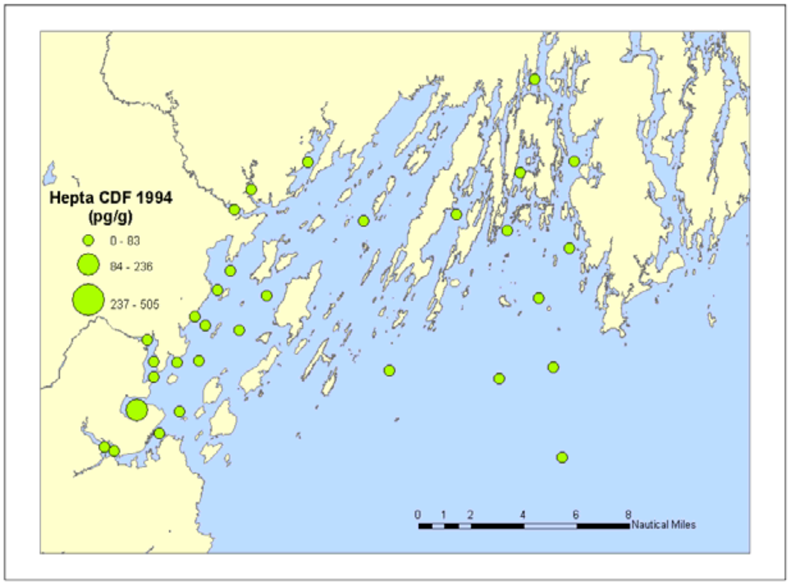


**Figure 89. Geographic Distribution of Hepta CDF from Both Sampling Periods.**

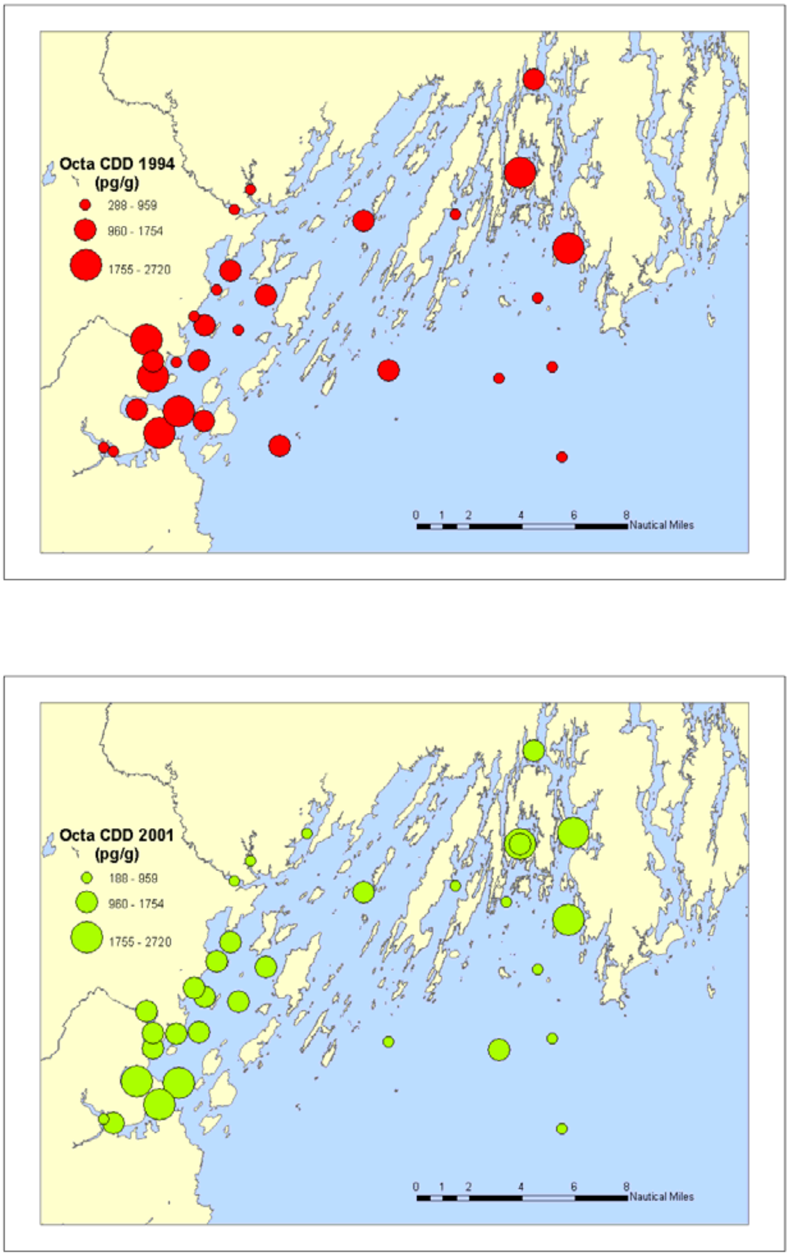


Figure 90. Geographic Distribution of Octa CDD from Both Sampling Periods.

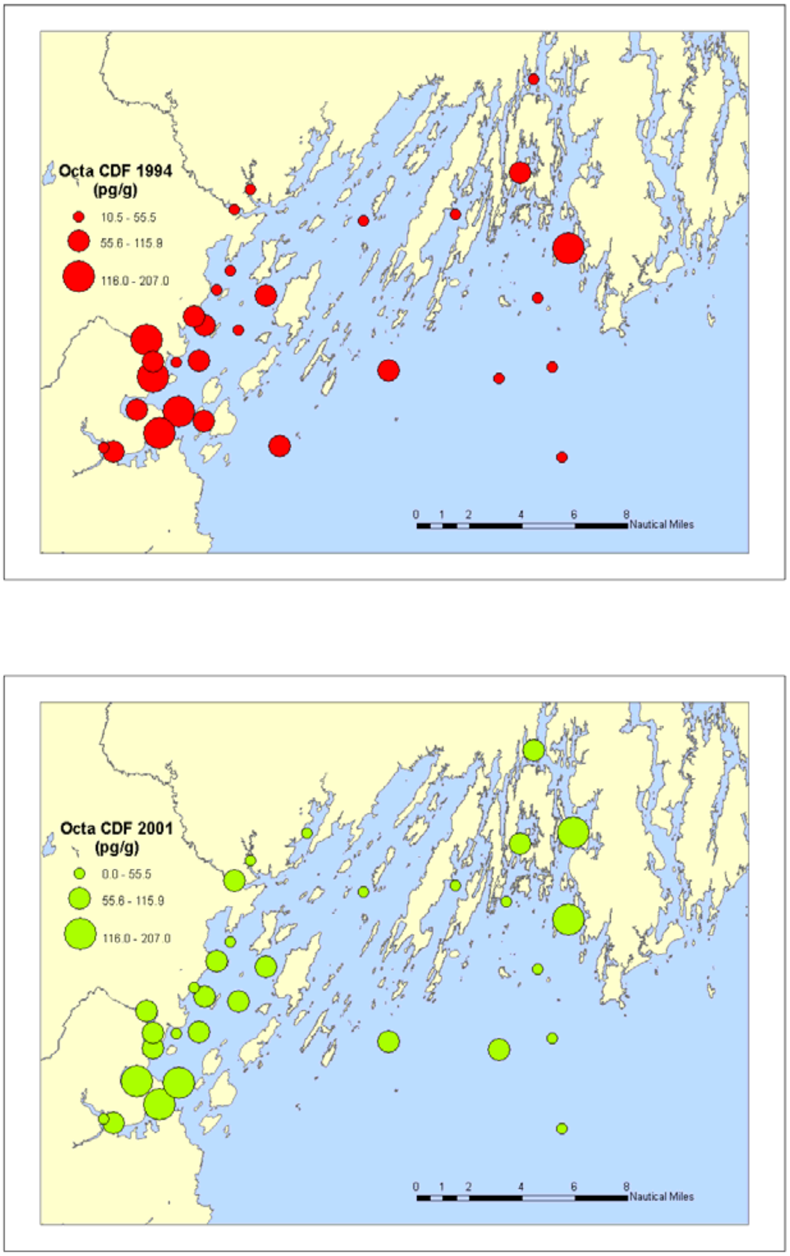


**Figure 91. Geographic Distribution of Octa CDF from Both Sampling Periods.**

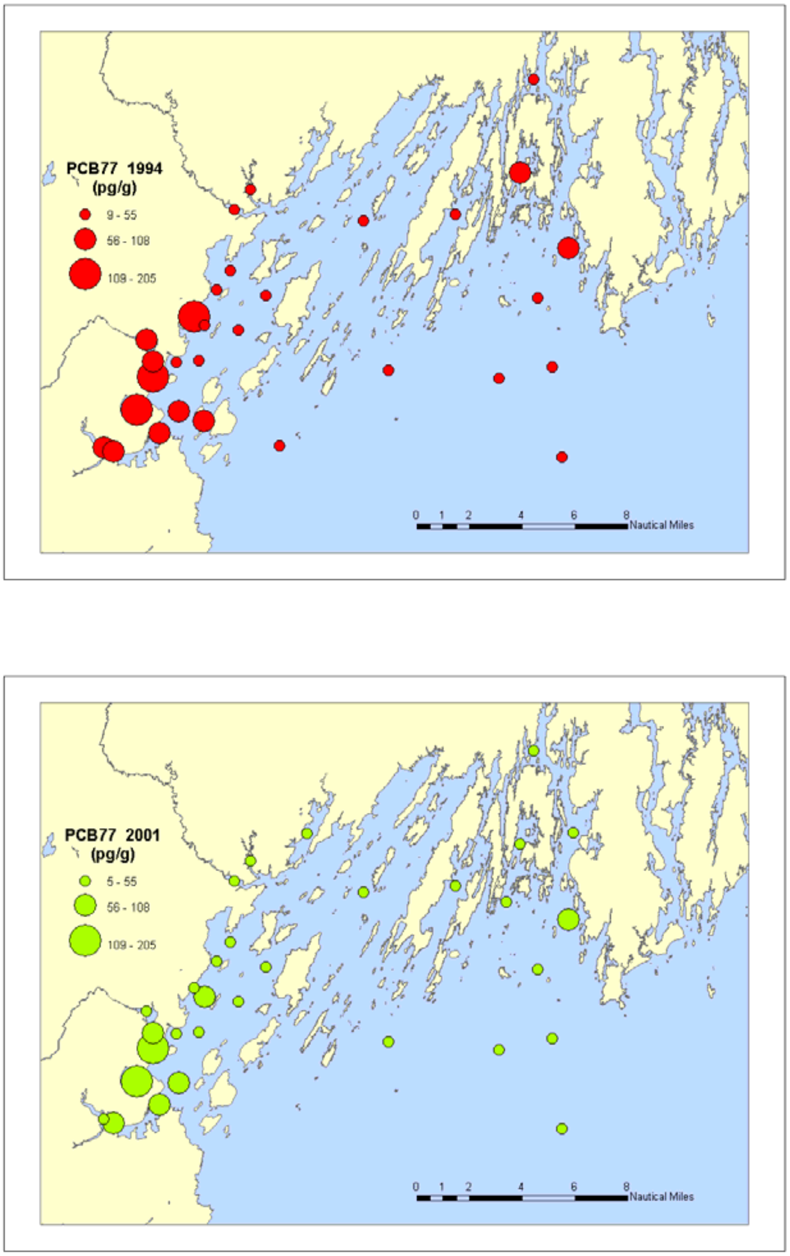


**Figure 94. Geographic Distribution of PCB 77 from Both Sampling Periods.**

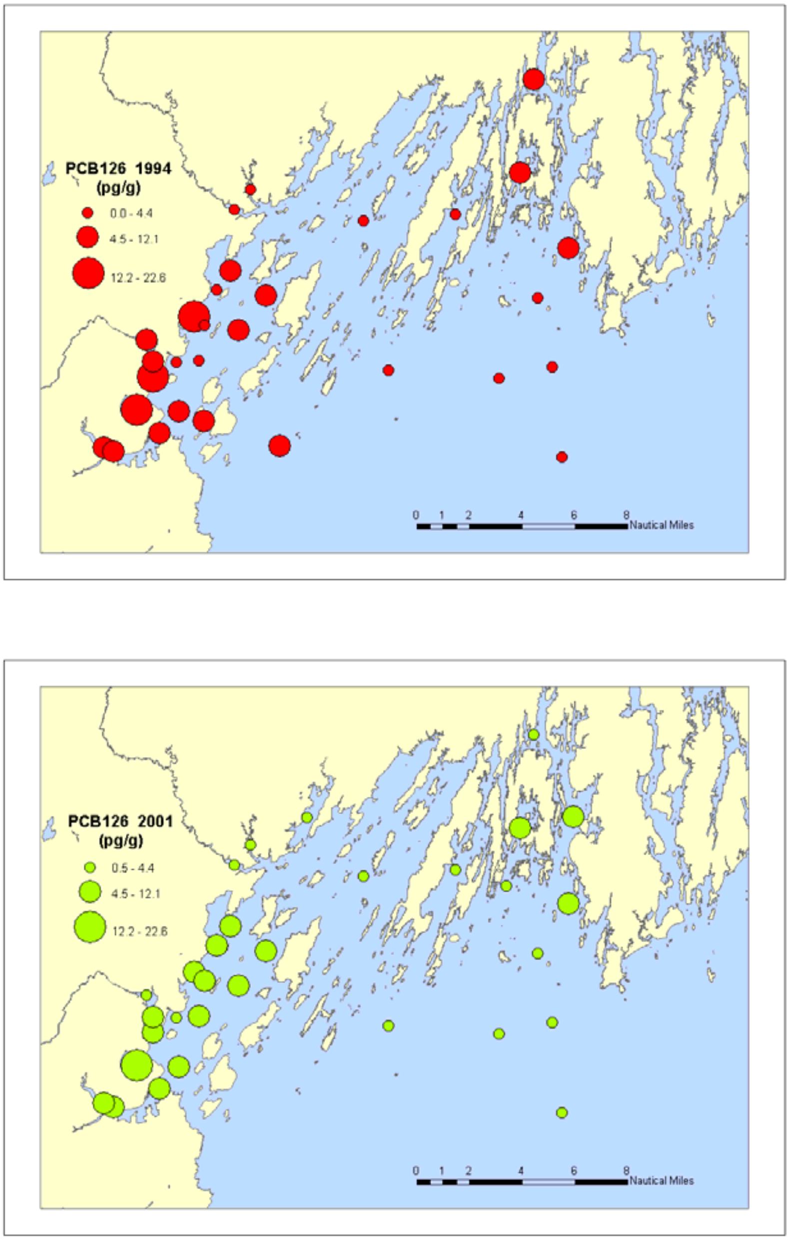


**Figure 95. Geographic Distribution of PCB 126 from Both Sampling Periods.**