

NBP-89-22

Water Quality Survey of Narragansett Bay: A Summary of Results

from the SINBADD 1985-1986 125 pp

Pilson & Hunt (URI)

Narragansett Bay Estuary Program

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Narragansett Bay
A Summary of Results from the
SINBADD 1985-1986

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FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1990, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- * management of fisheries
- * nutrients and potential for eutrophication
- * impacts of toxic contaminants
- * health and abundance of living resources
- * health risk to consumers of contaminated seafood
- * land-based impacts on water quality
- * recreational uses

The NBP is taking an ecosystem/watershed approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement #CX812680 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication as a technical report by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

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I. EXECUTIVE SUMMARY

The results are presented from four cruises to sample Narragansett Bay for concentrations of nutrients and trace metals. The objectives of the study were (a) to obtain a view of the whole of Narragansett Bay with respect to the concentrations of nutrients and trace metals, during each time of sampling; (b) to obtain estimates of the inputs of these substances into the bay during the times of the surveys; and (c) to collect these data with associated parameters in such a way as to be of most use to subsequent modeling efforts and to provide a point of reference so that future changes in the chemistry of the bay can be evaluated.

To address these objectives an attempt was made to sample the whole bay in a nearly synoptic fashion, always near the time of high tide, at 20 to 22 stations and at several depths at each station. The four SINBADD cruises took place in October and November of 1985 and April and May of 1986. Each cruise took four days. Substances measured included salinity, oxygen, the several forms of nitrogen and phosphorus nutrients, dissolved silicate, particulate carbon, and dissolved and particulate silver, cadmium, copper, chromium, nickel and lead. On some cruises and at some stations, additional samples were taken for bacteriological work and for analysis of mercury and trace organic substances. Most of the results are incorporated into four cruise and data reports, and are summarized in this report.

At the upper end of the bay, concentrations of nutrients and trace metals were greater in the surface waters than deeper in the water column, due to the association of these substances with inputs of river water and effluent from waste treatment plants. As expected, there was a general decrease in the concentrations of all nutrients and metals from the upper ends of the bay (Providence River and Mt. Hope Bay) down to the lower bay.

Most of the nitrogen in the water column of the bay is in the form of dissolved organic nitrogen. Little is known of the constitution of this material, its rates of turnover or accessibility to the plankton. The inorganic nutrients, both nitrogen and phosphorus, varied seasonally as previously described, being high in the fall and low in the late spring.

The measured inputs of nutrients from rivers and waste treatment plants were sufficient to replace the total mass of nutrients in the water column of the bay in from 40 to 125 days, depending on the season. Inputs from offshore are not yet accounted for, however, nor is atmospheric input or direct land runoff. Residence times of the metals were all much shorter than for the nutrients, ranging from less than 1 day up to

32 days where data were sufficient for the evaluation. These much shorter residence times must be due to the transport of metals to the sediments and their tight binding and burial in the sediments.

Comparisons of metal concentrations in the bay with EPA Chronic Water Quality Criteria for Seawater showed that only copper and nickel exceeded these criteria. Except for one occurrence of high copper in the upper bay, the water quality criteria were exceeded only in the Providence River.

The results of this survey suggest or support recommendations for further studies. Some, but not all, of these were subsequently addressed in the SPRAY series of cruises.

a) The full extent of seasonal effects can only be observed by carrying out observations during the hottest months of the summer and the coldest months of the winter. An argument can be made that the months of July and August are the most stressful times for at least some bay organisms, and observations should be focussed at first on those months, with the months of January and February of lesser importance but needed for contrast.

b) Additional data are needed from rivers and waste water treatment plants not sampled during SINBADD.

c) Attempts to model the whole bay, and especially to obtain information on the significant inputs of particulate matter, trace metals, and nutrients in deep water from offshore will require more intensive sampling near the lower end of the bay and adjacent offshore waters, where gradients are small.

d) Obtaining good average data from the upper ends of the bay, where seasonal and weather-related variability is pronounced and the data inherently noisy will require relatively more intensive monitoring there.

e) Monitoring for a long time at perhaps a very few stations is needed in order to observe secular trends and interannual variability. The long term monitoring is especially needed in order to determine the effectiveness of the regulatory process in reducing pollutant loading to the system or to provide data which will help predict the effects of changing patterns of land use in the watershed on the water quality of the bay.

This set of data will serve as an important point of reference for current and future evaluations of the health of the bay ecosystem, and will be incorporated into many attempts to model the system.

II. INTRODUCTION

Narragansett Bay provides a focus for much of the marine-related economic and recreational activity in the State of Rhode Island. It is a source of great pride for the people of the state, and there is much concern over its status and health. Despite this interest, we lack adequate data for assessing long-term changes in the chemical and biological health and status of the Bay. Until 1985, there had been no survey in which a sampling of the various regions of the bay for trace metals and nutrients was adequate to estimate the total quantities of these substances present at one time in the water of the whole bay. Only from data collected during the 1950's could even the salinity of the whole bay be directly calculated. These deficiencies have made it difficult to formulate and impossible to evaluate models of the behavior of important substances in the bay as a whole.

Limited sampling at several locations has provided a valuable 10-20 year record of nutrients at these few locations, and a less complete record of the concentrations of organics and trace metals. All these substances characteristically show strong gradients down-bay. Analysis of sediment cores has provided a partial historical record. Experimental work at the Marine Ecosystems Research Laboratory (MERL) has provided evidence of the effects of several levels of nutrient addition on the water column plankton and benthic animal components of the ecosystem in the bay. Experiments at MERL have also shown some of the complex behavior of trace metals and a few organic substances in the bay ecosystem.

In order to obtain an assessment of the status of nutrients and metals in Narragansett Bay, the RI Department of Environmental Management (DEM) funded the Marine Ecosystems Research Laboratory (MERL) at the Graduate School of Oceanography, University of Rhode Island, to carry out a series of measurements of the water quality throughout Narragansett Bay. In addition, measurements were made of the concentrations of substances entering the bay at various locations. The primary objective of this effort was to provide a reasonably synoptic picture of water quality throughout the bay (both horizontal and vertical distributions) for a variety of environmentally significant parameters, along with estimates of the inputs of various pollutants at the same time. The information was intended to provide a base line against which to assess future changes, and to assist in the development of ecological, hydrodynamic, and geochemical models so as to develop a better

understanding of the status of the bay, to better predict the transport of contaminants within the system, and ultimately to assist DEM to develop plans for waste load allocation among those legally using Narragansett Bay as a waste receptacle.

A series of four "cruises" was undertaken to sample all parts of the bay at intervals throughout one year. Each "cruise" took several days, with one or more legs each day. Each location was sampled as near to the time of high tide as was practical, given the logistics and resources available, in order that the final results should form a nearly synoptic picture. These cruises comprise the series known as the SINBADD cruises ("Sampling In Narragansett Bay All During the Day").

During each cruise, some 22 stations in the bay were sampled, each at several depths. Samples were also taken from five rivers, ten sewage treatment plants, and from the Narragansett Electric Company discharge in Providence. Water samples were analysed for salinity, oxygen, nutrients, trace metals, total solids, chlorophyll, and sometimes for other parameters. Details of collection and analysis are provided in the cruise reports (Hunt et al. 1987 a,b,c,d) and in Vandal and Fitzgerald (1988). The hydrographic, nutrient and trace metal data are given in Appendix Tables A1 to A8, and the results are summarized in this report.

III. SAMPLING AND ANALYSIS

A. Station locations in Narragansett Bay.

The locations of the stations (Fig. 1 and Table 1) were selected to provide a reasonably complete coverage of the whole bay, within the limits of resources available. There was some small variation from cruise to cruise in the precise locations, as well as some ship drift, but these variations were not significant in the analysis of the data.

B. Locations for measuring input fluxes.

Simultaneously with each cruise on the Bay, five rivers were sampled, representing most of the fresh water input to the Bay. In addition, the effluents from ten sewage treatment plants were sampled, to provide data on direct anthropogenic inputs of the measured substances. The cooling water discharge from the Narragansett Electric Plant in Providence was also sampled (Table 1 and Fig. 1).

C. Sampling and analytical procedures.

At each station in the bay, continuous profiles of temperature and salinity with depth were obtained with in situ probes connected to an onboard computer. In some cases, the turbidity of the water (a measure of the suspended particle content) was also obtained. In-situ probes for oxygen and light were separately lowered and data collected at one-meter intervals. Most water samples were collected, from several depths, by a pumping system with the inlet connected near the salinity-depth sensors. Some samples were obtained with sampling bottles lowered to depth. After the necessary preliminary processing on board, samples were returned to laboratories on shore and analyzed for important constituents (Table 2). Procedures used for nutrients, oxygen and salinity were generally standard; most are given in Lambert and Oviatt (1986). Dissolved and particulate fractions were separated by filtration through 0.45 μM nucleopore filters. Most dissolved metals in saline samples (Ag, Cd, Cu, Ni, Pb), were analysed by APDC-coprecipitation followed by atomic absorption spectrometry after the general procedures of Boyle and Edmond (1975). For non-saline (river) samples the total dissolved metals were analysed by direct injection, as was chromium in both saline and river samples. Particulate metals were all analysed by direct injection after digestion in 3 M HNO_3 . Additional details are given in Hunt

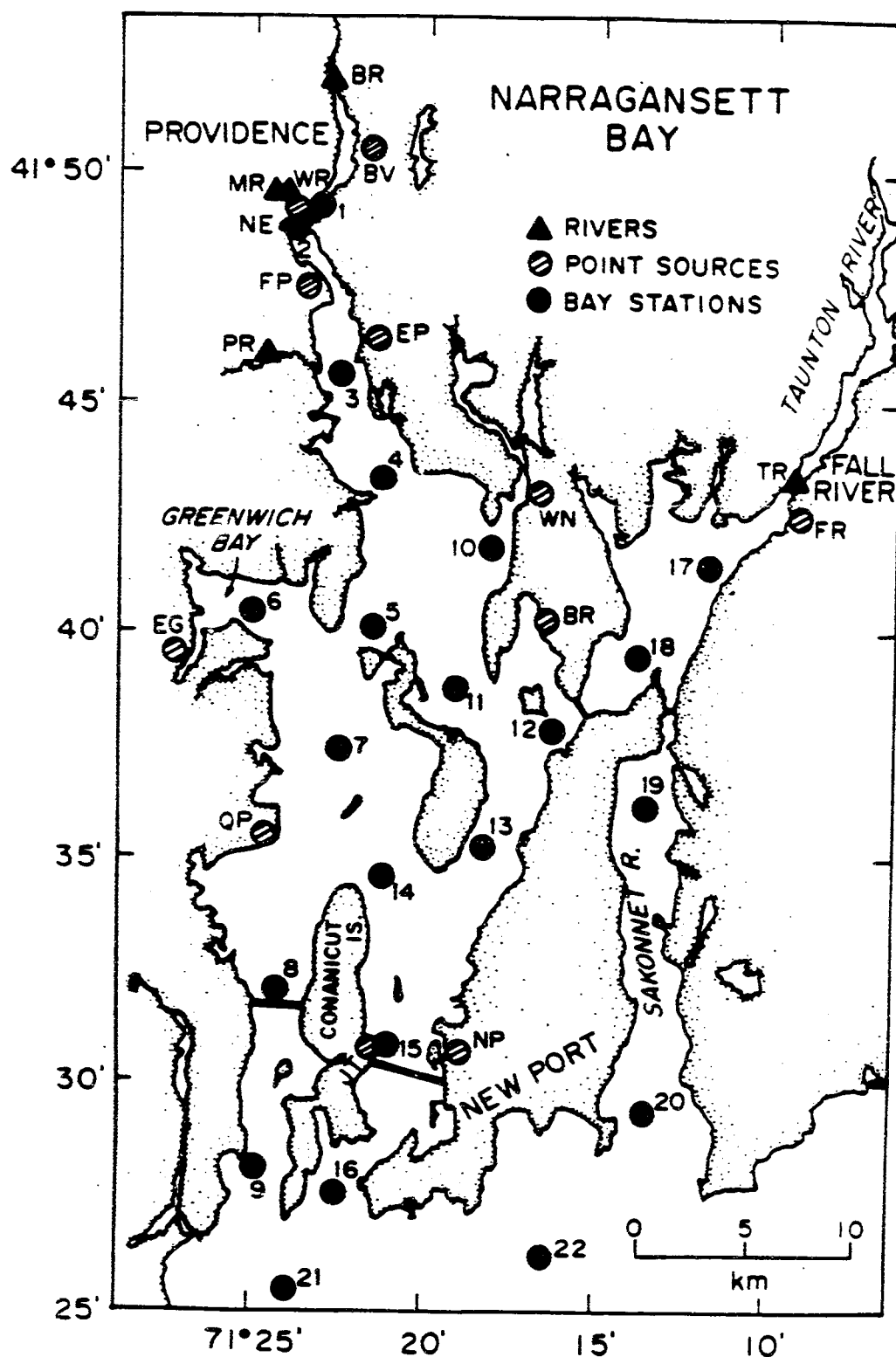


Fig. 1. Sampling locations for the Narragansett Bay Survey.

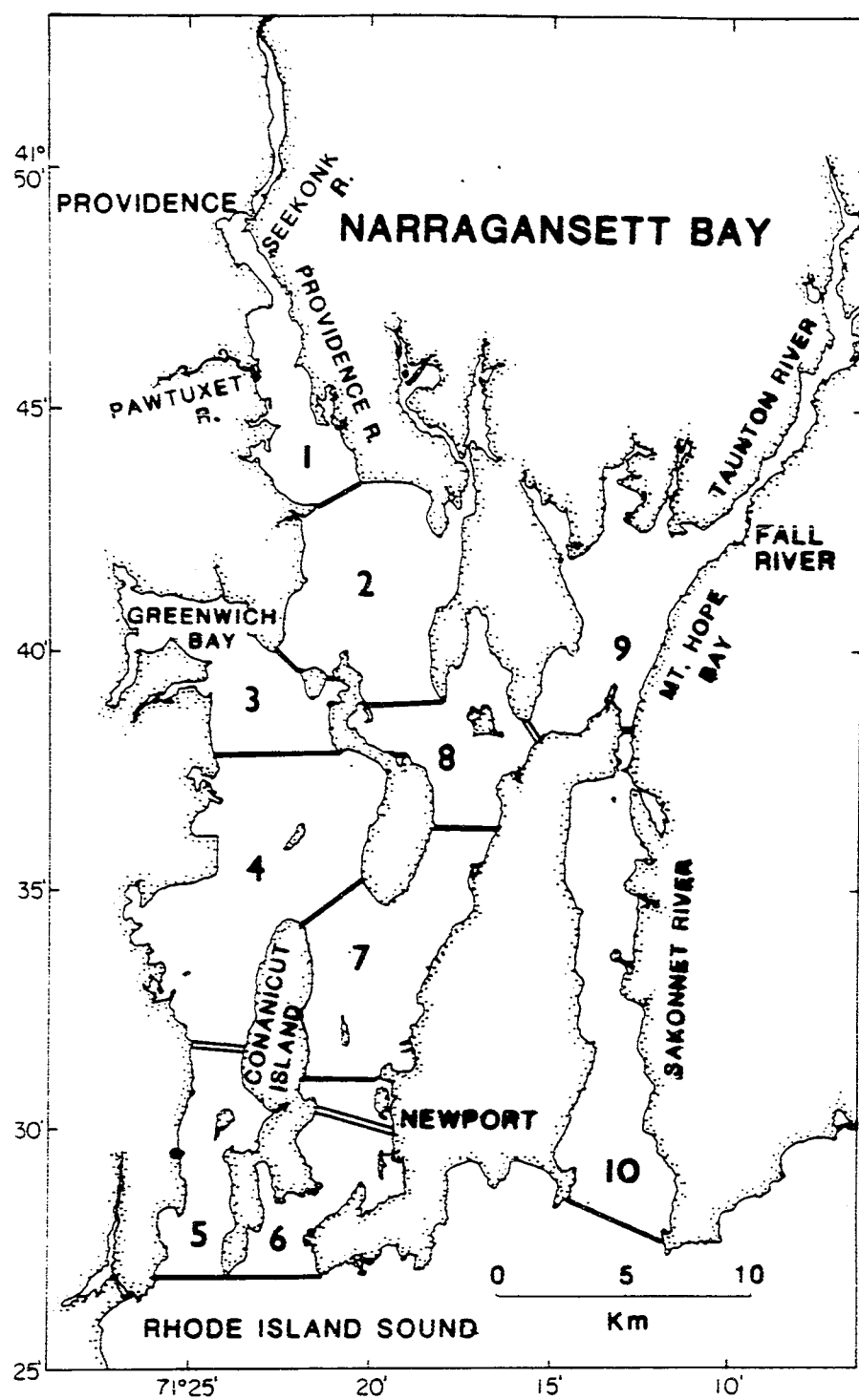


Fig. 2. Segmentation of Narragansett Bay for the purpose of modeling and analysis of bay dynamics. After Kremer and Nixon (1978) and Pilson (1985).

Table 1. Dates and locations of the SINBADD Cruises and other sampling. Locations of cruise stations varied slightly from cruise to cruise; individual cruise reports should be consulted for details.

SINBADD 1: 1985 Oct. 21-24			SINBADD 3: 1986 Apr. 7-10		
SINBADD 2: 1985 Nov. 18-21			SINBADD 4: 1986 May 19-22		
Sta. No.	Lat. (41°xx'N)	Long. (71°xx'W)	Sta. No.	Lat. (41°xx'N)	Long. (71°xx'W)
1	50.1	22.7	12	38.4	15.6
2	48.8	23.9	13	35.5	18.2
3	46.2	22.5	14	34.9	20.8
4	43.6	21.7	15	30.6	21.0
5	40.2	21.5	16	27.4	22.8
6	40.7	25.7	17	41.7	11.2
7	38.0	22.3	18	39.5	14.0
8	31.9	23.8	19	36.2	13.0
9	27.8	24.8	20	29.5	13.1
10	41.9	17.9	21	25.6	23.6
11	38.0	18.6	22	26.0	16.7

River Samples

Blackstone	—	Main St. Bridge
Moshassuck	—	250 m below Smith St. Bridge
Pawtuxet	—	Broad St. Bridge
Taunton	—	Brightman St. Bridge (Cruises 1, 2)
"	—	Berkley Bridge (Cruises 3, 4)
Woonasquatucket	—	Stillman St. Bridge

Sewage Treatment Plants

Blackstone Valley	Fields Point
Bristol	Jamestown
East Providence	Newport
East Greenwich	Quonset
Fall River	Warren

Other

Narragansett Electric Cooling Water Discharge

Table 2. Parameters measured on station or in samples collected during the SINBADD cruises and associated sampling of rivers and point sources. Some parameters were not measured on some samples; consult original reports for details.

<u>Parameter</u>	<u>Symbol or Units</u>
Salinity	S
Temperature	°C
Dissolved oxygen	μM (micromoles/liter = 10^{-6} mol/L)
Total suspended solids (TSM)	mg/kg (milligrams/kg)
Chlorophyll <i>a</i>	μg/L (micrograms/liter)
Nutrients	
-dissolved reactive phosphate	μM (micromoles/liter)
-ammonia	μM
-nitrate plus nitrite	μM
-dissolved silica	μM
-total dissolved phosphorus	μM
-total dissolved nitrogen	μM
-total phosphorus	μM
-total nitrogen	μM
Organics, particulate and dissolved	Special
Particulate carbon	μM
Particulate nitrogen	μM
Metals, dissolved and particulate	
-cadmium, Cd*	*ng/kg (10^{-9} g/kg)
-copper, Cu*	and
-lead, Pb*	*nmol/kg (10^{-9} mol/kg)
-nickel, Ni*	
-chromium, Cr*	
-silver, Ag*	
-mercury, Hg**	**pM, = 10^{-12} mol/L
Microbiological: Bacteria and spores	Special

et al. 1987a and other cruise reports. Most samples were analyzed at MERL. On one cruise, samples were taken for analysis of mercury, which was done at Avery Point, University of Connecticut, under the direction of Professor William Fitzgerald. Organic chemicals in selected samples were analyzed at GSO under the direction of Professor James Quinn. Salinity samples were analyzed by MERL personnel with a conductivity-based instrument at the National Marine Fisheries Service, Narragansett, RI.

Flow data for the rivers that were sampled during SINBADD were obtained from the USGS (1986). Because the flow data were sometimes obtained significantly further upstream than the chemical samples, the flows were adjusted by multiplying by the ratios of the respective drainage areas, for the days of sampling (Table 3).

Table 3. Flow data for rivers during sampling for SINBADD Cruises 1-4. Provisional data from USGS, corrected using a factor for estimated differences between the drainage areas above where the flows were measured and above where the samples were taken.

River (Area factor)	Dates of Sampling Flows, thousands of cubic meters per day			
	85/10/22-24	85/11/18-21	86/4/7-10	86/5/19-22
Blackstone (1259/1077)	1287, 1247, 1218	5491, 4633, 4004, 3575	2431, 2500, 2514, 2317	1067, 835, 847, 1439
Moshassuck (60/60)	19, 18, 17	148, 105, 88, 76	87, 122, 93, 78	37, 42, 149, 142
Woonasquatucket (99/99)	37, 39, 51	291, 250, 232, 220	154, 164, 164, 154	61, 61, 66, 98
Pawtuxet (596/518)	296, 281, 279	2215, 1793, 1436, 1216	994, 777, 721, 673	360, 355, 459, 664
Taunton (1406/668)	649, 600, 575	3684, 3330, 3000, 2840	1629, 1714, 1919, 1914	680, 650, 620, 805

IV. RESULTS

A. Oxygen.

1. *Background:*

Reports of bad smell, and other evidence from the last century and the early years of this century, indicate that even the surface waters of the Providence River sometimes became devoid of oxygen during the summer. There have been no such reports in recent decades, but measurements of oxygen have shown occasional periods of anoxia or near anoxia in the bottom waters of the Providence River. There has been concern whether low oxygen might also be a problem in other parts of Narragansett Bay. During SINBADD we measured the concentration of oxygen at all stations.

2. *Surface water.*

During the SINBADD cruises the oxygen concentration in surface waters was close to saturation with air, or above saturation. Concentrations in marine waters always vary somewhat due to the effects of temperature, salinity, wind, and biological activity. Such variations were observed here, but no examples of especially low concentrations were seen.

3. *Bottom water.*

The deep and bottom water at the upper end of the bay and in the Providence River was somewhat depleted in oxygen at the time of the SINBADD cruises. This feature was observed consistently on every cruise, and appears characteristic of Narragansett Bay (Figs. 3, 4).

The lowest values found, however, in the upper reaches of the ship channel in the Providence River and in the Seekonk River, were around 5 ppm, still quite appreciable concentrations, and not low enough to be damaging to most sea life.

Variations in the middle and lower bay are also interesting. Characteristically, the highest bottom-water values were found in the mid-bay region (Figs. 3,4).

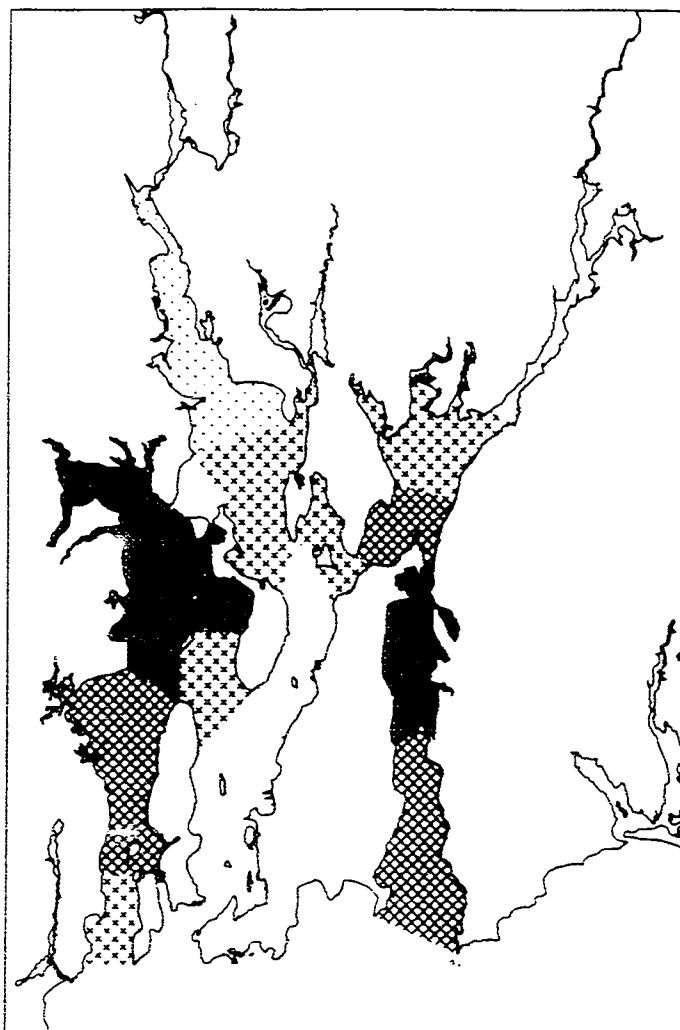


Fig. 3. Areal distribution of oxygen in the bottom waters of Narragansett Bay during SINBADD 1, Oct, 1985.



Figs. 3 to 12 were provided through the courtesy of Steve Hale and of the RI Geographic Information System, Univ. of Rhode Island. The SINBADD data were plotted and contoured, and the maps drawn through the use of the GIS plotting and contouring programs.

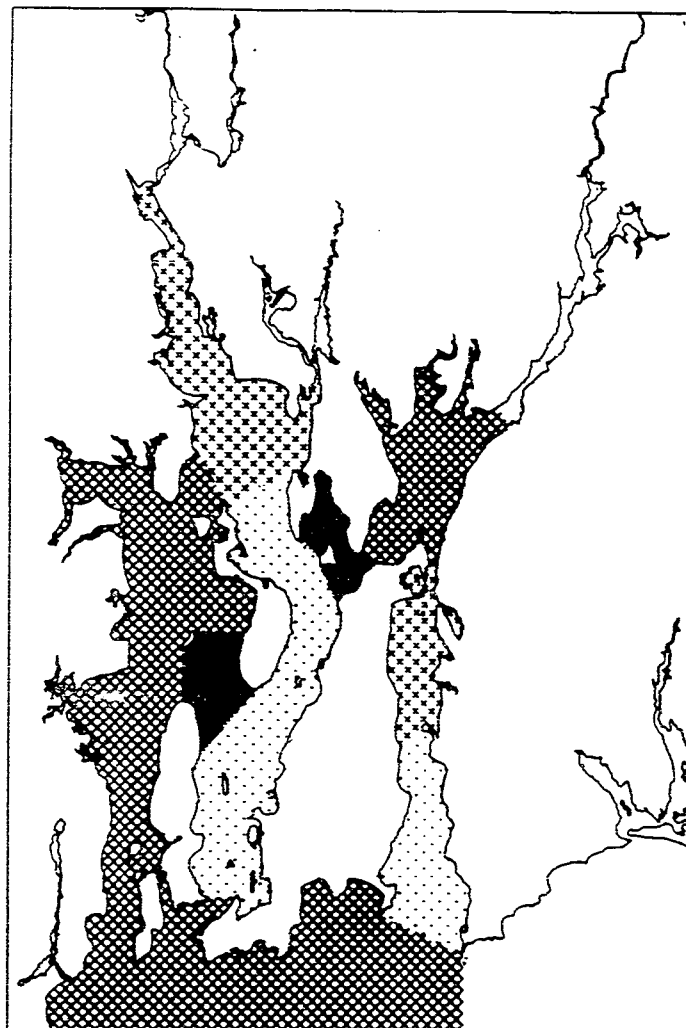


Fig. 4. Areal distribution of oxygen in the bottom waters of Narragansett Bay during SINBADD 4, May, 1986.



4. Discussion

The concentration of oxygen found in any parcel of water will reflect those processes that add and remove oxygen. Oxygen is added by photosynthesis, by diffusive air-sea exchange if the water is undersaturated, and by bubble dissolution if there are white caps or breaking waves. It is removed by diffusive air-sea exchange if the water is supersaturated and by respiratory consumption in the water column and on the bottom. None of these processes were measured during the SINBADD cruises. The depressed oxygen concentrations in the bottom waters of the Providence and Seekonk rivers were certainly expected, but it was reassuring that concentrations never were low enough to prevent fish and bottom forms from living there. The worst conditions would be expected in July through early September, however, and SINBADD did not sample during those times.

The high concentrations of oxygen consistently observed in the mid-bay regions lead to the speculation that this may be due to some combination of high biological production of oxygen by photosynthesis and mixing downward of surface waters. To carry this speculation further would require information on vertical mixing rates in that region.

B. Nutrients.

1. *Background:*

It is characteristic of estuaries to exhibit high nutrient concentrations in the water at their upper or landward ends, compared to the seawater offshore. Factors involved include riverine input, land runoff, atmospheric deposition, direct anthropogenic discharge, and the counter-current concentration mechanism in estuaries. The concentrations are affected by biologically mediated transformations, trapping for short or long times in the sediments, and advective processes.

The relative importance of the above factors varies from estuary to estuary and from time to time. No model has yet fully captured the behaviour of any nutrient in any estuary, because many processes are yet unquantified. In the SINBADD cruises we obtained, at four sampling intervals, and for the first time, nearly synoptic measurements of the total amounts of most forms of the important nutrients in Narragansett Bay, and measurements of the rates of input from major rivers and sewage treatment plants.

2. *Concentrations of nutrients:*

The major nutrient elements are usually considered to include phosphorus, nitrogen and silica. Forms of all three were measured during SINBADD. All three show characteristic patterns of being most concentrated in the upper ends of the bay – in the Providence and Seekonk rivers and in the lower Taunton River. Also characteristic were the higher concentrations exhibited in the surface waters at these locations, compared to the bottom water.

Because of the general and increasing importance of the nitrogen nutrients, these have been selected for demonstrating the general distribution of all the nutrients (Figs. 5-12). In these figures the total fixed nitrogen in the water is plotted. This includes forms NH_3 , NO_2^- , NO_3^- , dissolved organic nitrogen, and particulate nitrogen. In general all individual forms showed the characteristic distribution patterns described, but these are clearer when presented as the totals.

The average distribution of nitrogen between its various forms in the water column is presented in Fig. 13, for the four cruises. Dissolved organic nitrogen is always the predominate form. The easily utilized nutrient forms, ammonia and nitrate

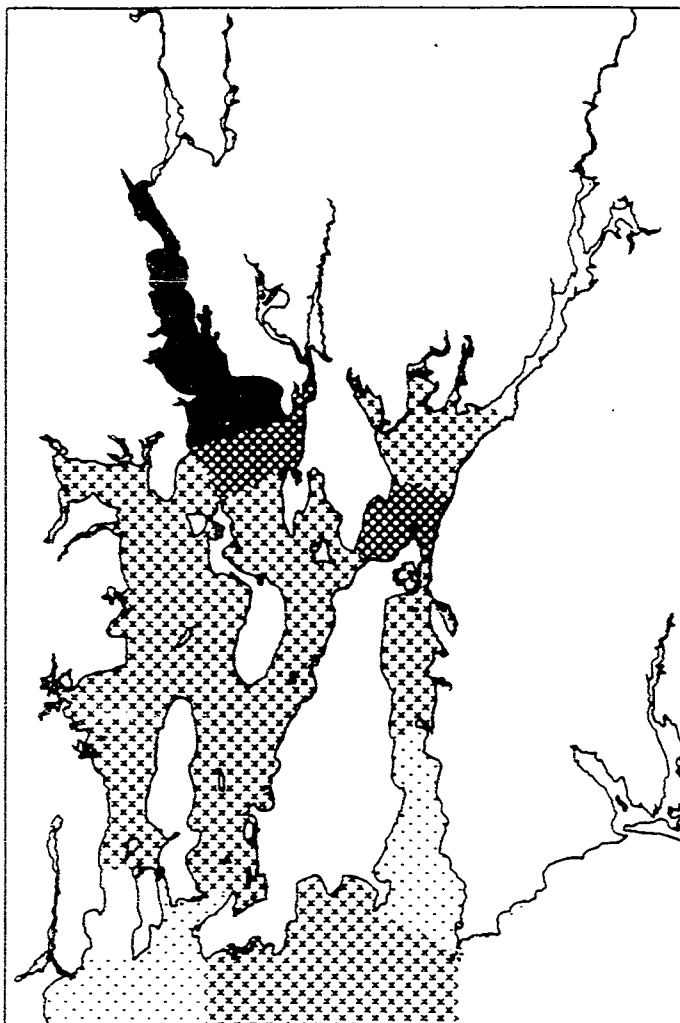


Fig. 5. Areal distribution of total nitrogen in Narragansett Bay surface water during SINBADD 1, October 21-24, 1985.



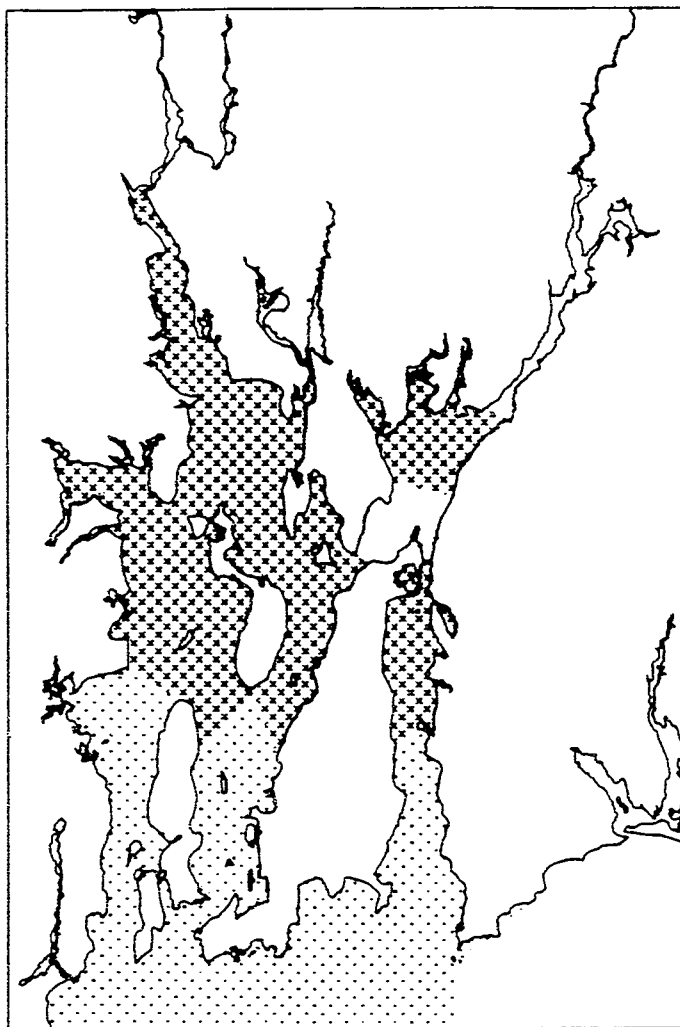


Fig. 6. Areal distribution of total nitrogen in Narragansett Bay deep water during SINBADD 1, October 21-24, 1985.



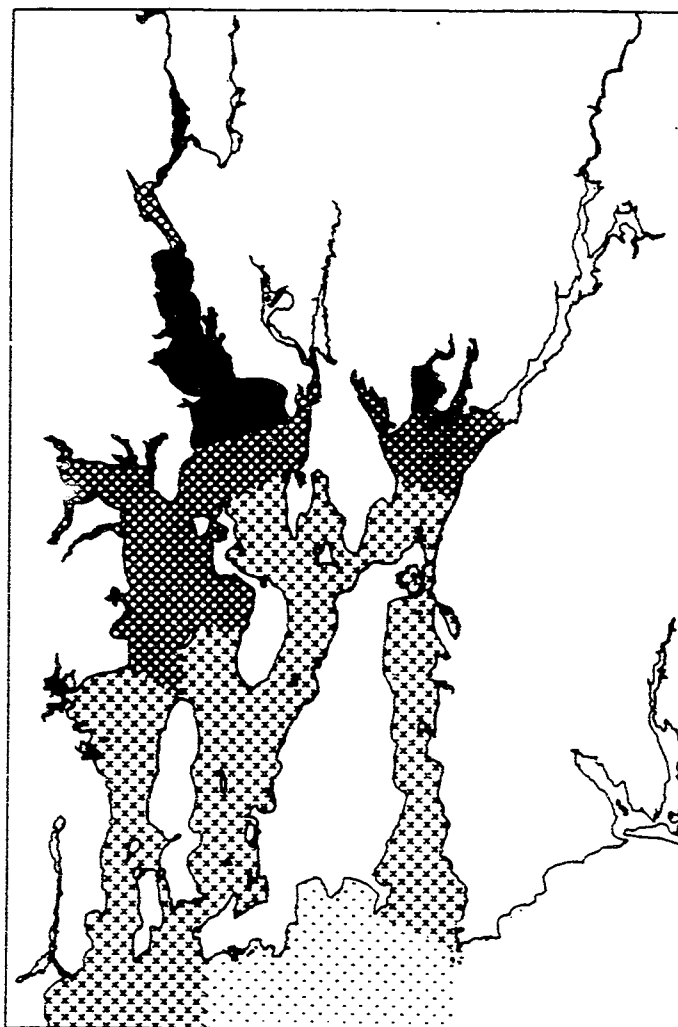


Fig. 7. Areal distribution of total nitrogen in Narragansett Bay surface water during SINBADD 2, Nov. 18-21, 1985.





Fig. 8. Areal distribution of total nitrogen in Narragansett Bay deep water during SINBADD 2, Nov. 18-21, 1985.

□ less than 20 μM ;

■ 40 to 60 μM ;

▣ 20 to 40 μM ;

■ more than 60 μM .

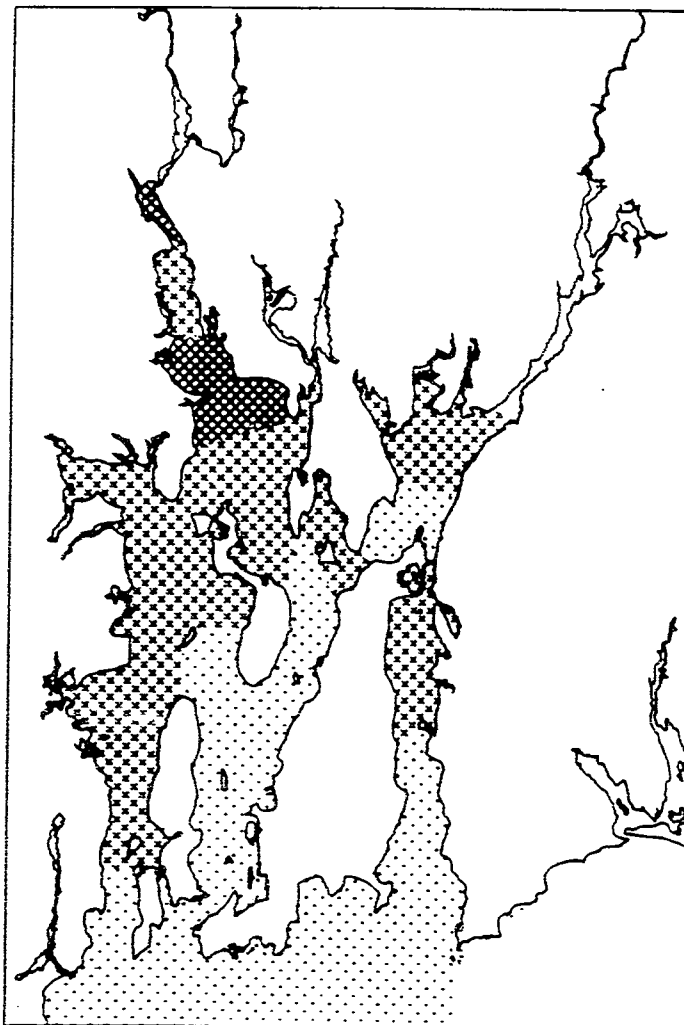


Fig. 9. Areal distribution of total nitrogen in Narragansett Bay surface water during SINBADD 3, April 7-10, 1986.

□ less than 20 μM ;

▣ 20 to 40 μM ;

▤ 40 to 60 μM ;

■ more than 60 μM .

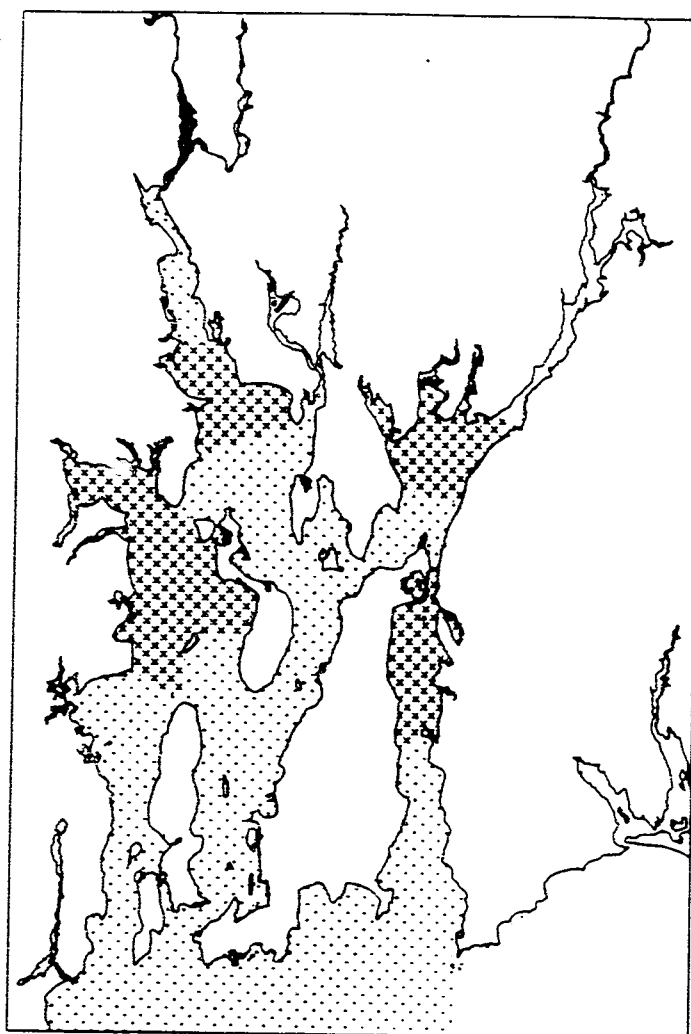


Fig. 10. Areal distribution of total nitrogen in Narragansett Bay deep water during SINBADD 3, April 7-10, 1986.



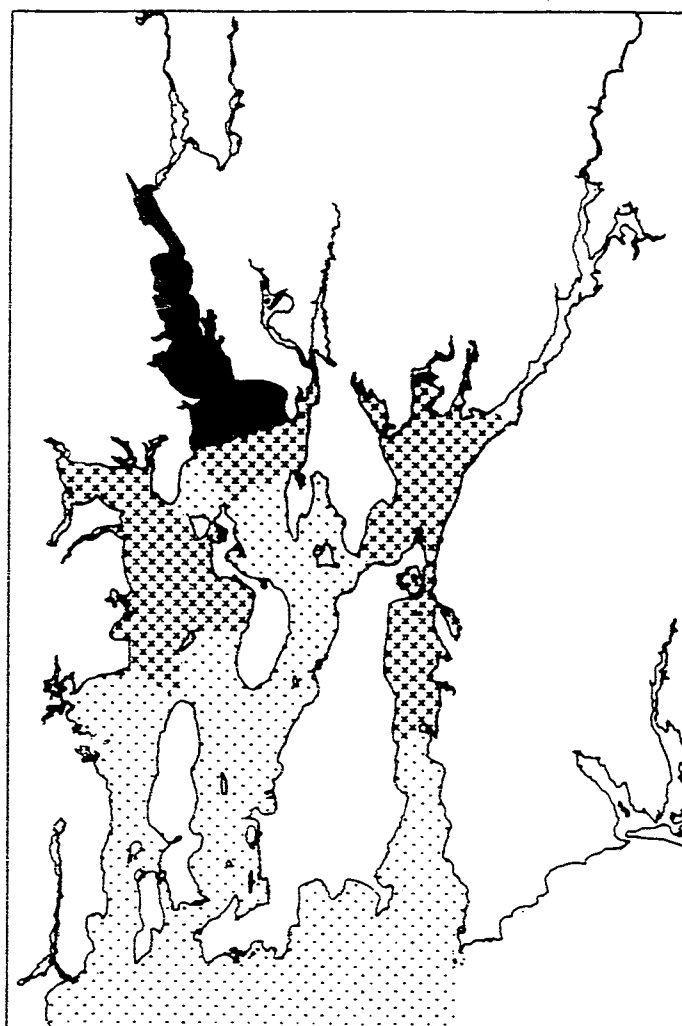


Fig. 11. Areal distribution of total nitrogen in Narragansett Bay surface water during SINBADD 4, May 19-22, 1986.



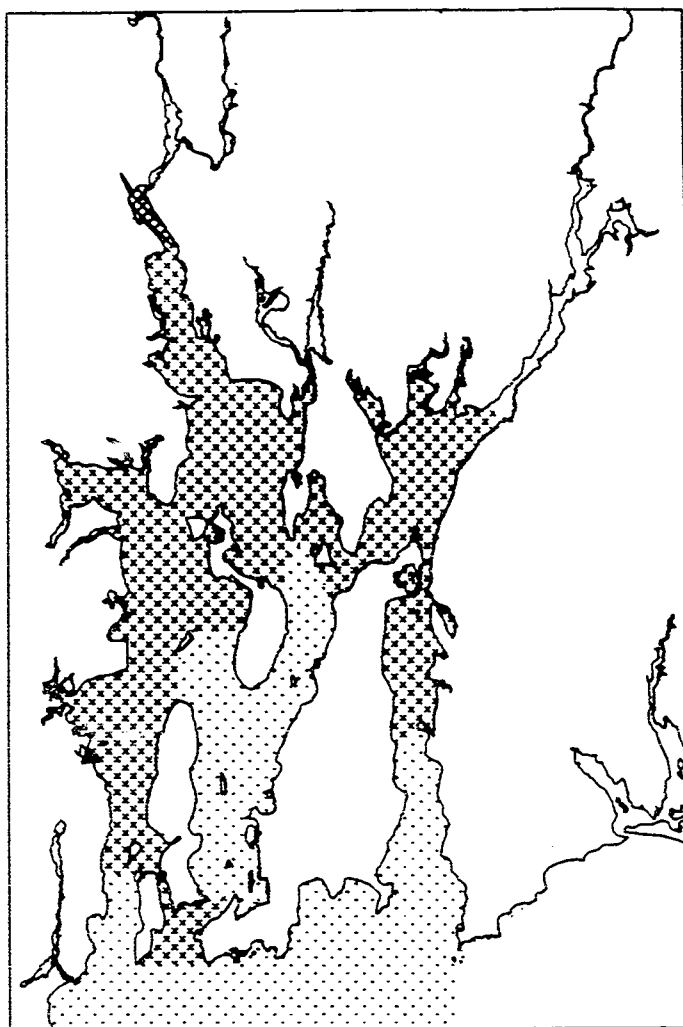


Fig. 12. Areal distribution of total nitrogen in Narragansett Bay deep water during SINBADD 4, May 19-22, 1986.

less than 20 μM ;

20 to 40 μM ;

40 to 60 μM ;

more than 60 μM .

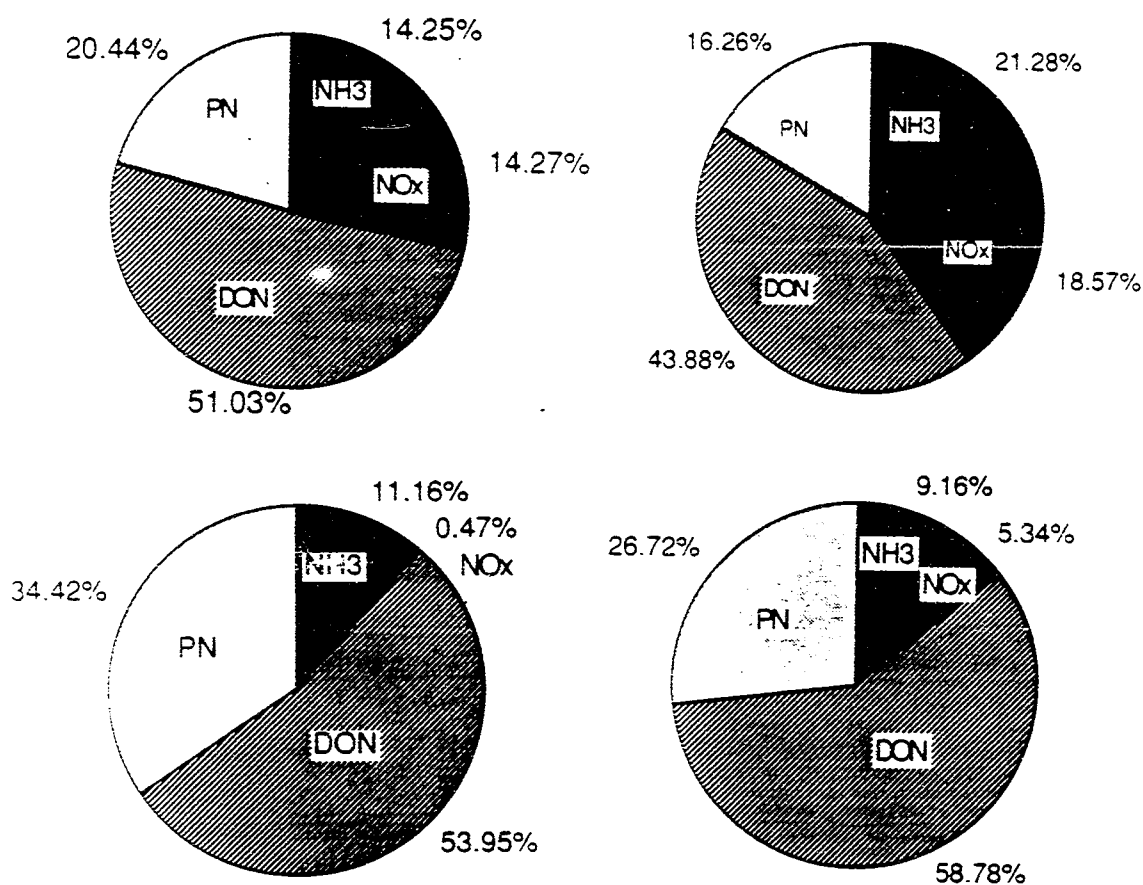


Fig. 13. Diagrams to show the relative distribution of different forms of nitrogen in the water column of Narragansett Bay during SINBADD cruises. These are presented as the simple averages of all the measurements. (NH₃ = Ammonia; NO_x = Nitrate plus Nitrite; DON = Dissolved Organic Nitrogen; PN = Particulate Nitrogen.)

(a) SINBADD 1, Total N = 30 μM ;
 (c) SINBADD 3, Total N = 21 μM ;

(b) SINBADD 2, Total N = 34 μM ;
 (d) SINBADD 4, Total N = 26 μM .

plus nitrite, were reduced in concentration during the spring, in accord with past experience that they must be largely taken up by phytoplankton at this time, and transported in some form to the sediments (Pilson 1985).

3. *Bay totals.*

The total standing stock of nutrients in the bay during SINBADD was estimated as follows: the individual stations were allocated to the standard bay segments as noted in Table 4. The average values for each station were then averaged according to the weighting scheme in Table 4, to obtain an estimate of the average values in each segment. Finally the values were volume-weighted by segment and the bay totals calculated (Tables 5-8). The totals for the bay were computed from segments 1-9 only, because they form a natural hydrologic unit, useful for further modeling and analysis. Segment 10 (Sakonnet Passage) is somewhat separate hydrologically, although it does receive a significant input from Mt. Hope Bay.

4. *River inputs.*

The flow data from Table 3 were combined with concentration data for the days of sampling, averaged, and reported as the river inputs of total nitrogen, total phosphorus, and dissolved silica (Table 9).

5. *Sewage plant inputs.*

Flow data from the wastewater facilities were combined with the measured concentrations of total nitrogen and total phosphorus to estimate the daily inputs of these elements to the bay from the wastewater facilities. The resulting estimates are presented in Table 10. These are probably inexact data, subject to considerable daily and sampling uncertainty. Nevertheless, they provide our only record of inputs from these sources to the bay during the time of the SINBADD cruises.

Table 4. Allocation of SINBADD sampling stations into bay segments as defined by Pilson (1985). Those stations situated in the boundaries between two segments were allocated one-half to each segment. The volumes are in units of 10^6 m^3 .

Segment	Volume	SINBADD stations
1	107	1, 2, 3, 4/2
2	286	4/2, 5/2, 10, 11
3	129	5/2, 6, 7/2
4	448	7/2, 8/2, 14/2
5	193	8/2, 9
6	476	15/2, 16
7	592	13/2, 14/2, 15/2
8	226	11/2, 12, 13/2
9	267	17, 18 (TR*)
10	335	19, 20

* During SINBADD 1 and 2, the Taunton River station consisted of a surface sample in the salt water comprising part of the Mt. Hope Bay segment, so it is included in the bay averages for these two cruises only.

Table 5. Average concentrations of nutrients and salinity in nine segments of Narragansett Bay, and the volume weighted average concentrations and total amounts of nutrients in the bay during SINBADD 1, Oct. 21-24, 1985. Concentrations are in μM ($=\text{mmol m}^{-3}$) and total amounts in units of 10^6 moles, except for chlorophyll, where the units are $\mu\text{g/L}$ and tons/segment, respectively.

Segment	Vol.	Sal.	TN	TDN	NH ₃	NO _x	DON	PN	TP	TDP	IPO ₄	DOP	TPP	DSi	Chl	PC
1	107	27.92	47.0	41.1	18.0	10.1	13.0	8.1	4.99	4.37	2.81	1.56	0.62	24.7	4.97	75.1
2	286	29.55	36.6	26.7	4.5	5.6	16.6	10.8	4.06	3.28	1.58	1.70	0.80	21.5	9.63	92.5
3	129	29.52	29.7	19.0	1.1	1.2	16.7	9.4	3.16	2.50	0.92	1.58	0.69	20.2	9.16	86.4
4	448	30.78	23.7	19.6	1.3	1.7	16.6	5.9	2.82	2.28	1.13	1.15	0.54	14.0	5.89	63.0
5	193	31.74	19.3	19.9	2.3	2.6	15.0	3.9	3.40	3.19	1.18	2.01	0.31	11.1	3.34	48.6
6	476	32.07	20.2	22.1	2.3	3.4	16.1	2.3	3.83	3.26	1.18	2.05	0.78	12.5	1.52	36.1
7	592	31.35	24.4	21.1	2.3	3.1	15.8	3.8	3.17	2.89	1.28	1.62	0.33	14.9	3.29	44.7
8	226	30.60	25.9	23.3	2.4	4.4	16.6	5.6	4.07	3.18	1.46	1.73	0.90	17.3	5.33	55.4
9	267	28.44	40.6	35.8	5.4	12.2	19.8	7.3	5.33	4.28	2.88	1.41	1.04	25.6	11.31	65.3
10*	335	31.09	23.6	19.8	2.3	2.7	14.9	6.0	3.66	3.07	1.35	1.71	0.59	12.7	5.35	64.9
Averages		30.65	27.3	23.8	3.2	8.2	16.4	5.6	3.69	3.12	1.48	1.64	0.64	16.7	5.38	57.6
Bay total, 2724 10^6 moles		--	74.4	64.9	8.8	22.2	44.7	15.1	10.05	8.50	4.03	4.47	1.74	45.4	14.66	156.8

* Segment 10 not included in the bay totals or averages.

Table 6. Average concentrations of nutrients and salinity in nine segments of Narragansett Bay, and the volume-weighted average concentrations and total amounts of nutrients in the bay during SINBADD 2, Nov. 18-21, 1985. Concentrations are in μM ($=\text{mmol m}^{-3}$) and total amounts in units of 10^6 moles, except for chlorophyll, where the units are $\mu\text{g/L}$ and tons/segment, respectively.

Segment	Vol.	Sal.	TN	TDN	NH ₃	NO _x	DON	PN	TP	TDP	IPO ₄	DOP	TPP	DSi	Chl	PC
1	107	19.37	63.4	57.6	21.4	18.1	18.8	8.9	6.84	5.68	2.88	2.83	1.16	39.20	0.77	90
2	286	27.47	41.1	35.9	11.3	8.6	17.0	6.7	4.25	3.81	1.77	2.08	0.52	30.60	2.29	68
3	129	27.65	41.4	32.1	8.1	7.2	16.8	6.2	4.04	3.35	1.40	1.95	0.69	30.70	4.26	61
4	448	29.66	31.9	23.4	4.3	4.1	15.0	6.3	3.77	3.26	1.27	1.99	0.56	22.60	4.22	63
5	193	31.08	24.8	17.4	2.5	2.7	12.2	5.5	3.77	3.86	1.10	2.76	0.40	16.60	2.58	55
6	476	31.67	21.3	18.1	2.4	3.2	12.5	3.3	3.68	3.74	1.17	2.58	0.32	13.20	1.84	41
7	592	30.64	26.1	19.6	3.6	4.0	12.0	3.9	3.62	3.32	1.28	2.04	0.42	18.90	2.26	47
8	226	29.92	28.9	23.8	5.7	5.1	13.0	3.4	3.58	3.44	1.46	1.98	0.25	22.20	1.82	40
9	267	24.65	44.9	56.9	9.4	30.0	10.6	4.5	4.41	3.79	2.34	1.28	0.62	41.60	4.20	46
10*	335	30.29	27.6	26.0	5.4	3.9	16.7	5.9	3.625	3.22	1.38	1.83	0.41	19.24	1.98	46
Averages		29.13	32.0	27.6	5.9	7.6	13.6	4.9	3.95	3.62	1.48	2.13	0.48	23.40	2.72	53
Bay totals 2724																
10^6 moles		--	87.1	75.2	16.0	20.7	36.9	13.4	10.77	9.87	4.04	5.80	1.31	63.80	7.42	145

* Segment 10 not included in the bay totals or averages.

Table 7. Average concentrations of nutrients and salinity in nine segments of Narragansett Bay, and the volume-weighted average concentrations and total amounts of nutrients in the bay during SINBADD 3, April 7-10, 1986. Concentrations are in μM ($=\text{mmol m}^{-3}$) and total amounts in units of 10^6 moles, except for chlorophyll, where the units are $\mu\text{g/L}$ and tons/segment, respectively.

Segment	Vol.	Sal.	TN	TDN	NH ₃	NO _x	DON	PN	TP	TDP	IPO ₄	DOP	TPP	DSi	Chl	PC
1	107	22.82	41.9	33.7	12.0	0.5	21.3	11.2	4.30	3.72	1.23	2.49	0.94	11.79	8.66	83
2	286	28.89	24.6	12.8	0.8	0.1	11.9	8.8	2.78	2.26	0.27	1.99	0.52	1.39	4.91	59
3	129	27.92	27.3	13.3	0.8	0.1	12.5	10.7	2.75	1.99	0.22	1.78	0.77	1.18	2.67	70
4	448	29.92	18.2	11.7	0.5	0.0	11.2	6.8	2.63	1.87	0.29	1.57	0.76	0.96	1.12	47
5	193	30.99	16.0	10.8	0.7	0.0	10.1	5.8	2.13	1.57	0.34	1.23	0.58	0.54	1.55	45
6	476	31.75	13.7	8.7	0.4	0.0	8.3	3.1	2.37	2.01	0.39	1.62	0.38	0.44	1.32	28
7	592	30.66	13.9	9.8	0.6	0.0	9.3	4.0	2.93	2.33	0.39	1.95	0.62	1.04	0.92	32
8	226	29.81	18.5	10.1	0.4	0.0	9.7	5.4	2.86	2.11	0.32	1.79	0.76	0.90	1.35	45
9	267	28.90	19.2	10.8	0.4	0.0	10.4	9.0	3.41	2.56	0.35	2.22	0.85	0.62	4.87	64
10*	335	30.45	21.0	12.0	0.6	0.1	11.4	8.0	3.85	2.70	0.45	2.25	1.15	1.40	3.30	51
Averages		29.89	18.5	11.5	1.0	0.0	10.5	6.2	2.80	2.18	0.37	1.81	0.64	1.30	2.30	45
Bay totals 2724																
10^6 moles		--	50.3	31.4	2.7	0.1	28.6	16.8	7.63	5.94	1.01	4.93	1.74	3.54	6.27	124

* Segment 10 not included in the bay totals or averages.

Table 8. Average concentrations of nutrients and salinity in nine segments of Narragansett Bay, and the volume-weighted average concentrations and total amounts of nutrients in the bay during SINBADD 4, May 19-22, 1986. Concentrations are in μM ($=\text{mmol m}^{-3}$) and total amounts in units of 10^6 moles, except for chlorophyll, where the units are $\mu\text{g/L}$ and tons/segment, respectively.

Segment	Vol.	Sal.	TN	TDN	NH ₃	NO _x	DON	PN	TP	TDP	IPO ₄	DOP	TPP	DSi	Chl	PC
1	107	27.37	65.3	44.3	13.6	9.1	21.6	13.0	6.52	4.13	2.65	1.49	2.39	6.64	21.71	111
2	286	30.48	26.6	17.6	1.0	0.6	16.0	9.1	3.39	2.39	0.56	1.83	0.94	3.79	7.63	82
3	129	30.45	27.5	18.4	0.5	0.1	17.8	10.8	3.58	2.42	0.29	2.13	1.17	5.55	8.59	89
4	448	31.40	18.3	15.0	0.6	0.1	14.3	6.1	2.67	1.67	0.47	1.20	1.00	2.50	5.23	55
5	193	31.99	15.2	18.4	0.6	0.1	17.7	5.1	2.56	2.00	0.47	1.53	0.56	1.81	4.96	49
6	476	32.39	17.0	12.8	0.5	0.2	12.1	3.0	3.11	2.00	0.43	1.57	1.11	2.18	1.93	39
7	592	31.89	13.5	11.1	0.6	0.3	10.2	4.7	2.22	1.67	0.42	1.24	0.56	3.05	3.08	43
8	226	31.35	18.2	15.0	0.9	0.3	13.9	6.1	2.83	2.67	0.5	2.17	0.13	3.86	4.50	58
9	267	30.67	25.3	16.3	0.6	0.2	15.5	7.1	3.67	2.67	0.58	2.08	1.00	4.00	9.38	61
10*	335	31.87	16.8	15.0	0.8	0.2	14.1	4.8	2.50	2.50	0.68	1.83	0.00	3.93	2.33	47
Averages		31.35	20.7	15.7	1.2	0.6	14.0	6.1	3.02	2.14	0.55	1.59	0.88	3.22	5.57	57
Bay total	2724															
10^6 moles		--	56.3	42.8	3.1	1.6	38.1	16.6	8.23	5.83	1.45	4.33	2.40	8.77	15.17	154

* Segment 10 not included in the bay totals or averages.

Table 9. River inputs of nutrients into Narragansett Bay. Flows are the averages during the days of sampling, given in 1000's of m³ per day; input fluxes are given in 1000's of moles per day, as weighted averages of the results from the several days of sampling.

<u>River</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>	<u>Diss. Si.</u>
— SINBADD 1 —				
Blackstone	1,218	104.7	7.31	129.1
Taunton*	625	—	—	—
Pawtuxet	280	57.1	7.56	31.6
Woonasquatucket	42	6.0	0.42	3.4
Moshassuck	18	1.8	0.16	2.3
Total measured	2,183	169.7	15.45	166.5
Others (Est'd)*	822	157.6	14.35	154.6
Est'd Totals	3,005	327.2	29.80	321.0
— SINBADD 2 —				
Blackstone	4,070	381.6	41.51	417.6
Taunton*	3,338	—	—	—
Pawtuxet	1,481	181.3	18.81	140.5
Woonasquatucket	234	24.3	2.20	17.4
Moshassuck	90	8.1	.82	10.4
Total measured	9,213	595.1	63.34	585.9
Others (Est'd)*	3,470	689.6	73.40	679.0
Est'd Totals	12,683	1,284.6	136.74	1,264.9

Table 9 (continued)

<u>River</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>	<u>Diss. Si.</u>
— SINBADD 3 —				
Blackstone	2,444	353.4	21.26	156.4
Taunton*	1,671	239.0	16.04	78.5
Pawtuxet	724	155.4	12.89	57.2
Woonasquatucket	161	20.3	1.30	8.1
Moshassuck	98	9.6	.42	6.4
Total measured	5,098	777.7	51.92	306.6
Others (Est'd)*	1,920	292.9	19.55	115.5
Est'd Totals	7,018	1,070.5	71.47	422.0
— SINBADD 4 —				
Blackstone	1,040	245.3	11.02	58.9
Taunton*	665	118.2	9.71	37.0
Pawtuxet	407	161.4	14.78	31.4
Woonasquatucket	75	9.3	.69	2.7
Moshassuck	111	11.4	.74	7.7
Total measured	2,298	545.6	36.94	137.2
Others (Est'd)*	865	205.4	13.91	51.6
Est'd. Totals	3,163	751.0	50.85	188.8

* During SINBADD 1 and 2 the "Taunton River" station was in the salt water part of the estuary, so for those cruises the data were not used here. From the Taunton drainage basin, only the Taunton River flow data were included under Taunton River in this table. The Three-Mile River and similar drainages were included under "Others", which were estimated by ratio of their total drainage areas to the overall total.

Table 10a. Sewage plant inputs into Narragansett Bay during SINBADD 1, Oct. 21-24, 1985. Flows are given in units of 1000 m³/day, and inputs in units of 1000 moles/day.

<u>Facility</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>
East Greenwich	(4.0)*	7.72	1.40
Jamestown	--	--	--
Quonset Point	--	--	--
Newport	43.5	--	--
Fall River	87.1	98.39	10.45
Bristol	(11.7)*	23.17	1.87
Warren	5.3	6.73	0.27
East Providence	18.2	14.63	1.64
Blackstone Valley	(75.7)*	108.25	18.93
Fields Point	196.8	350.38	19.68
Measured Totals	--	609.3	54.24

* Flows not available, values from SINBADD 2 used as estimates.

Table 10b. Sewage plant inputs into Narragansett Bay during E.NBADD 2, Nov. 18-21, 1985. Flows are given in units of 1000 m³/day, and inputs in units of 1000 moles/day.

<u>Facility</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>
East Greenwich	4.00	4.45	2.02
Jamestown	4.2	1.00	0.25
Quonset Point	5.7	5.23	0.45
Newport	32.2	44.41	4.67
Fall River	96.5	73.36	14.48
Bristol	11.7	13.49	1.52
Warren	10.6	9.43	0.85
East Providence	28.4	27.25	3.26
Blackstone Valley	75.7	53.75	10.60
Fields Point	204.4	206.4	18.40
Measured Totals	473.4	438.8	56.5

Table 10c. Sewage plant inputs into Narragansett Bay during SINBADD 3, April 7-10, 1986. Flows are given in units of 1000 m³/day, and inputs in units of 1000 moles/day.

<u>Facility</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>
East Greenwich	3.9	5.7	1.44
Jamestown	1.9	0.42	0.13
Quonset Point	1.8	0.79	0.12
Newport	45.4	59.0	4.05
Fall River	94.6	76.6	12.30
Bristol	7.7	12.8	0.21
Warren	8.7	4.9	0.17
East Providence	32.2	13.9	1.93
Blackstone Valley	87.1	27.0	7.40
Fields Point	230.9	80.8	9.24
Measured Totals	514.2	281.9	37.0

Table 10d. Sewage plant inputs into Narragansett Bay during SINBADD 4, May 19-22, 1986. Flows are given in units of 1000 m³/day, and inputs in units of 1000 moles/day.

<u>Facility</u>	<u>Flow</u>	<u>Total N</u>	<u>Total P</u>
East Greenwich	3.90	4.91	0.88
Jamestown	1.14	0.29	0.15
Quonset Point	2.76	2.35	0.20
Newport	26.50	61.48	0.53
Fall River	85.17	89.43	12.35
Bristol	4.85	7.61	0.07
Warren	5.98	5.80	0.42
East Providence	30.28	17.26	0.91
Blackstone Valley	94.26	50.90	0.57
Fields Point	348.26	393.53	(45.0)*
Estimated Totals	603.1	633.6	(61.1)*

* Total phosphorus not available. The ratio to total N observed in SINBADD 3 was applied here to yield an estimated value.

6. *Inputs and Inventories.*

Known and estimated river inputs from Table 9 and the known and estimated inputs from wastewater facilities from Table 10 were combined to yield preliminary estimates of the total inputs of these nutrients to the Bay during the times of the SINBADD cruises. These are compared with the estimates of the total inventory in the water column of the bay (Table 11).

If the input of some substance is divided into the inventory, the result is an estimate of the replacement time (also called the residence time) of the substance. The data here provide a provisional estimate of the replacement times of the nutrients in the bay, and the values range from 23 to 124 days.

The estimates are provisional, because they do not take account of several inputs not directly measured. The largest unmeasured input is that entering in seawater from R.I. Sound. No direct measurement of this is now possible, but estimates can be obtained by further modeling of the available data. Additional inputs are from runoff after rains, unmeasured waste-water facilities, and direct input from the atmosphere.

Certain general trends are evident. Nutrient concentrations in the water column decrease in the spring time, as has been shown before (Kremer and Nixon 1978; Pilson 1985). The decrease is proportionately greater for nitrogen than phosphorus, because the bay maintains a proportion of nitrogen to phosphorus less than the so-called Redfield ratio typical of plankton organisms. This means that the bay is closer to being nitrogen limited than phosphorus limited. The relative changes in the calculated replacement times also reflect this situation.

7. *Comparison with experiments.*

An experiment to evaluate the effects of nutrient additions to the bay ecosystem was carried out at MERL during 1981-1983 (Frithsen *et al.* 1985).

Figures 14 and 15 show summary plots of the nutrient concentrations maintained under different regimes of nutrient addition. The comparable concentrations from Segment 1 in Narragansett Bay during the SINBADD cruises plot on the graph near the level observed in the 2x nutrient addition experiment.

Table 11. Comparison of total bay inventories of nitrogen and phosphorus with the observed daily inputs. Inventories and inputs in units of 10^6 moles per day; provisional replacement times in days.

Cruise	Source	Known inputs		Bay Inventories		Replacement times	
		Total N	Total P	Total N	Total P	Total N	Total P
SINBADD 1							
	Rivers	0.327	0.0298	--	--	--	--
	Sew. Plants	0.609	0.0542	--	--	--	--
	Totals	0.936	0.084	75.6	10.2	124	121
SINBADD 2							
	Rivers	1.285	0.137	--	--	--	--
	Sew. Plants	0.439	0.0565	--	--	--	--
	Totals	1.724	0.194	87.1	10.8	51	56
SINBADD 3							
	Rivers	1.071	0.0715	--	--	--	--
	Sew. Plants	0.282	0.037	--	--	--	--
	Totals	1.353	0.109	31.4	7.63	23	70
SINBADD 4							
	Rivers	0.751	0.0508	--	--	--	--
	Sew. Plants	0.634	0.061	--	--	--	--
	Totals	1.385	0.112	56.3	8.23	41	69

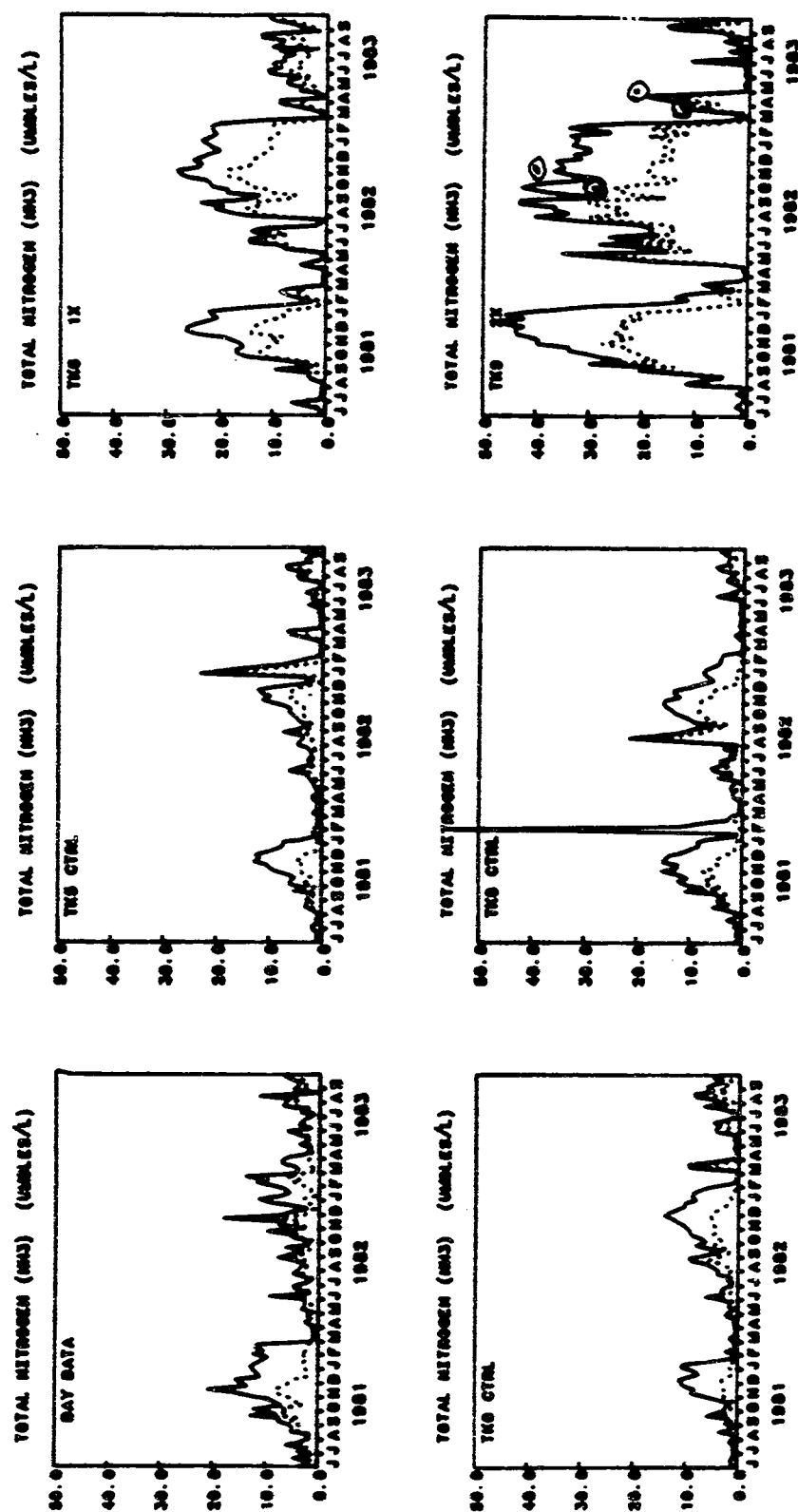


Fig. 14. Total inorganic nitrogen ($\text{DIN} = \text{NH}_3 + \text{NO}_x$) in MERL tanks during the nutrient addition experiment (Frithsen *et al.* 1985). Average concentrations of DIN in Segment 1 (Providence River) from the SINBADD cruises are plotted on the graph for Tank 9, the 2x treatment level.

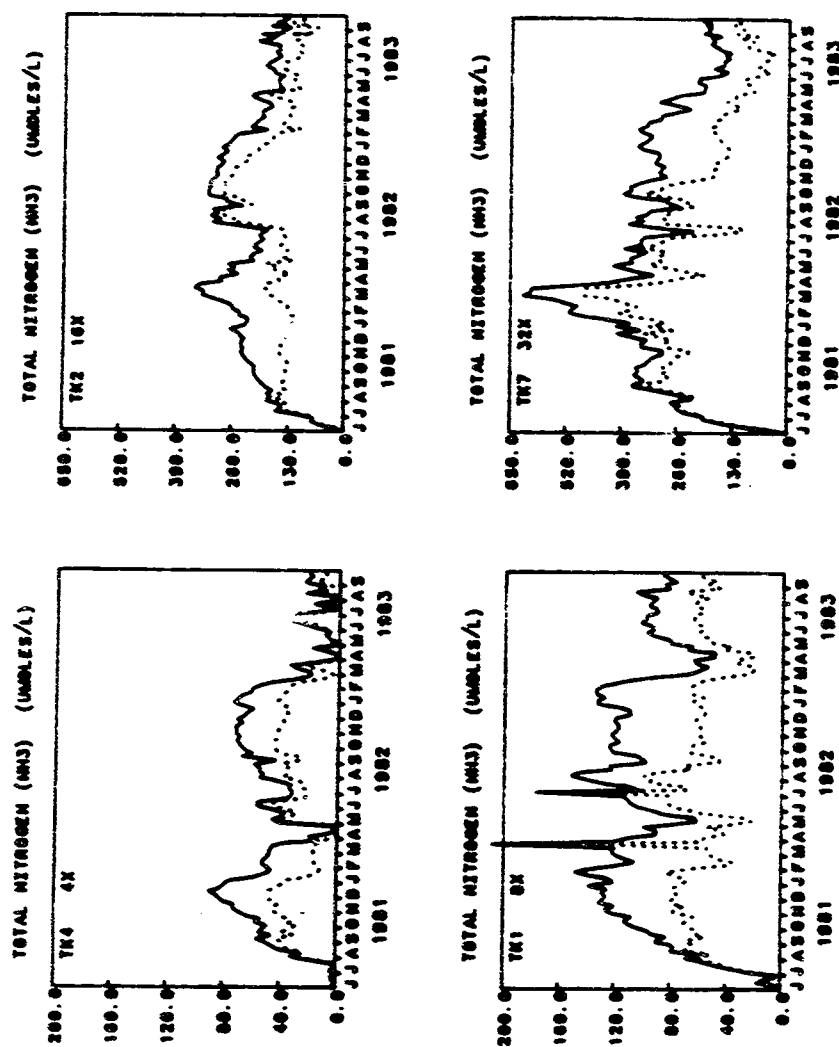


Fig. 14, continued.

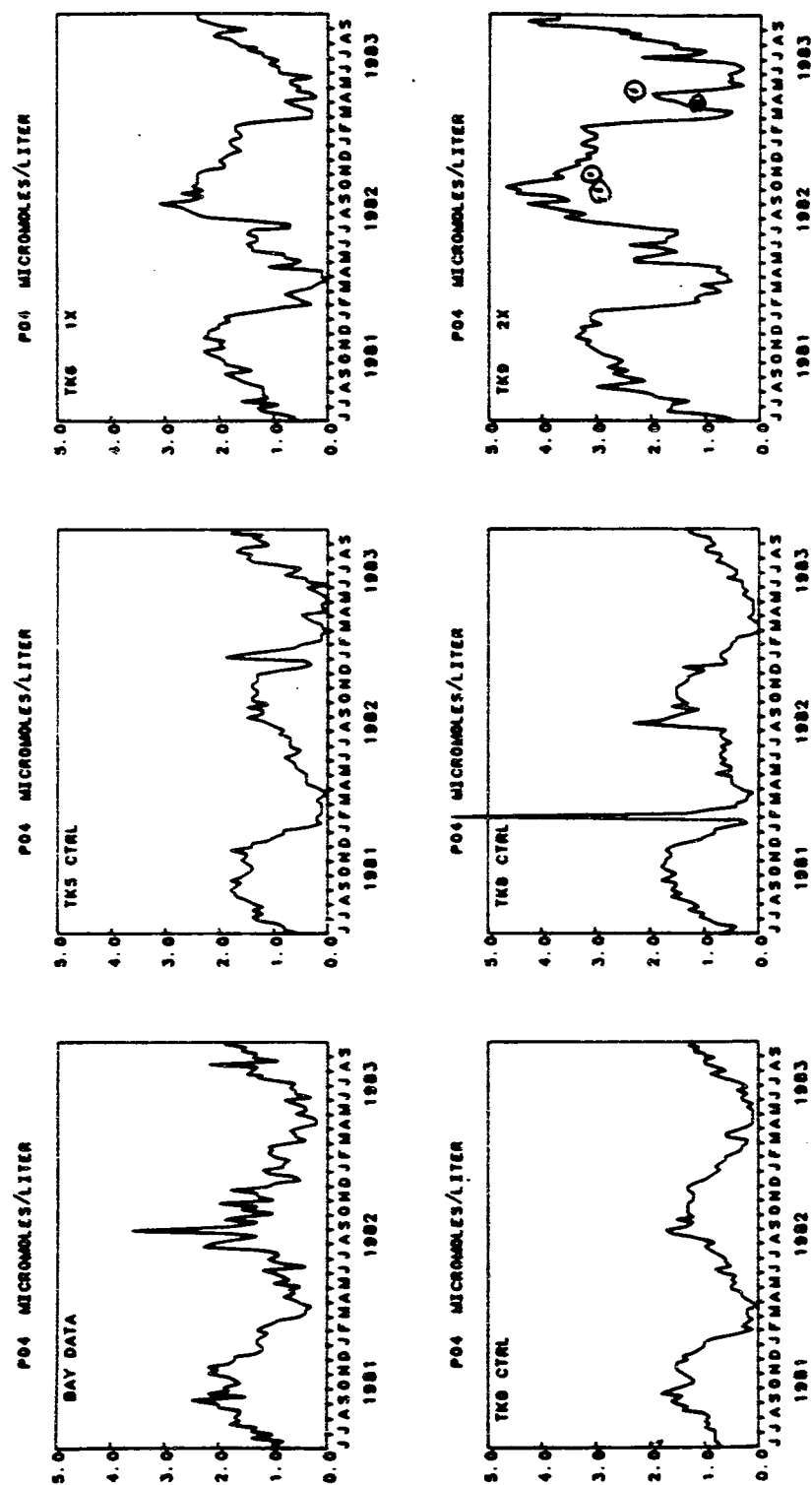


Fig. 15. Dissolved inorganic phosphate concentrations in MERL tanks during the nutrient addition experiment (Frithsen *et al.* 1985). Average concentrations of dissolved inorganic phosphate in Segment 1 (Providence River) from the SINBADD cruises are plotted on the graph for tank 9, the 2x treatment level.

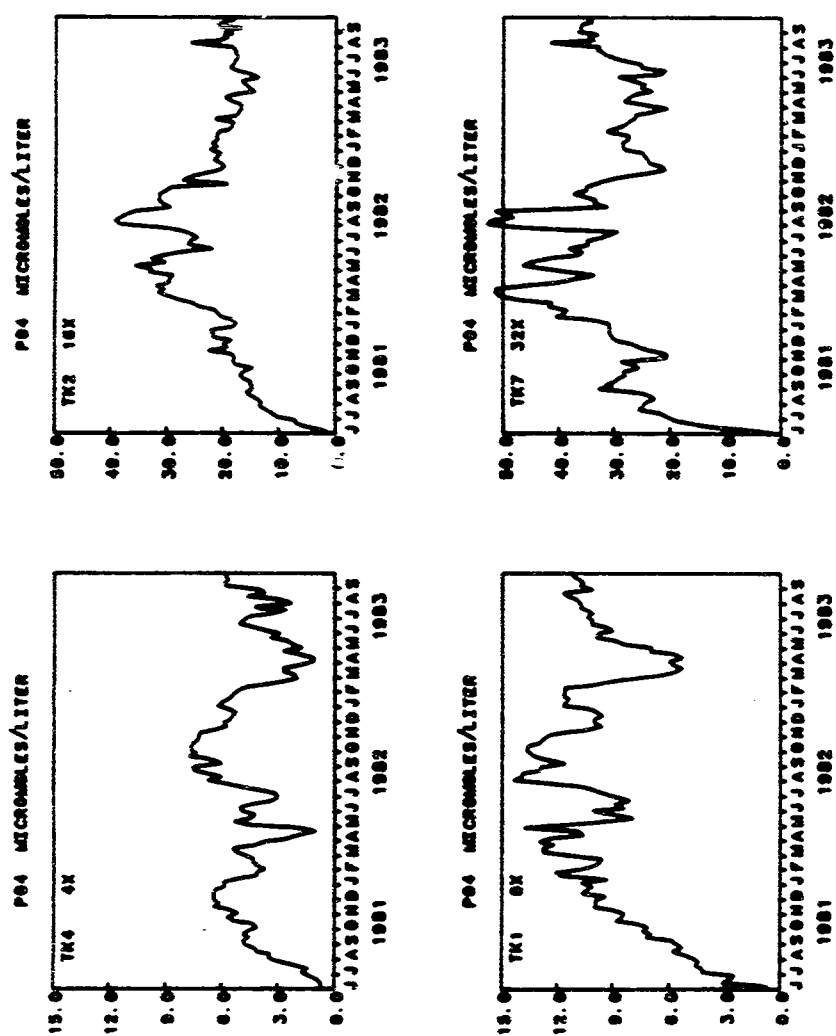


Fig. 15, continued.

Examination of the graphs shows that this level most closely approximates what was observed in the Providence River segment.

On the basis of the area-weighted nutrient addition rates in the experiment above, it would have been expected that the concentrations in the Providence River would have been closer to those achieved in the 16x treatment. Modeling efforts to date have not yet explored the reasons for these differences, which might involve various aspects of internal recycling or differences in flushing rates. While the latter rates are well known for the MERL tanks, published evidence on the Providence River is yet unsatisfactory.

8. *Summary.*

During the SINBADD cruises the concentrations of nutrients were highest in the Providence River and Mt. Hope Bay and decrease through the bay towards the ocean. This is the situation that is nearly always found. Concentrations of nutrients were highest in the surface waters of the upper bay, consistent with their inputs dissolved in fresh water which lays on the surface and only mixes downwards relatively slowly.

Concentrations were highest in the fall, as this is a time when plankton production is low and release from the benthos is still continuing. Concentrations drop in the spring as plankton take up nutrients and are themselves carried down to the benthic system.

The detailed coverage provided by these four cruises has produced the most complete record of nutrient concentrations in the Bay so far available. Although coverage is lacking for the important summer months, these data nevertheless provide an excellent base upon which to build further efforts at modeling the bay ecosystems, for both physical and nutrient dynamics.

C. Metals

1. Background

Over the past ten years several studies, both published and unpublished, have presented data on concentrations of trace metals in the water of Narragansett Bay, although no data were available for Mount Hope Bay and the Sakonnet River. Until the SINBADD surveys no study was conducted such that the entire bay was sampled systematically over short time periods and repeatedly within a given year.

A comprehensive historical trace metals database, which includes the SINBADD data, was compiled during the second year of the Narragansett Bay Project (Kester *et al.* 1987). Comparisons of metal results from the SINBADD surveys to historical information is here limited to a general description of metal distributions within the bay as understood prior to the SINBADD surveys.

2. Historical distribution of metals

The distribution of selected trace metals in Narragansett Bay determined during three surveys conducted in the Providence River, upper bay, and west passage of the bay in 1980 (Oviatt, undated) is presented to provide background information against which results of the SINBADD cruises can be compared.

Data gathered during the 1980 water quality monitoring study (Oviatt, undated), and other studies (Olsen and Lee 1979), indicated that sewage treatment plants were the major entry point for most metals discharged into Narragansett Bay, while the rivers were also found to contribute significantly to the total trace metal load entering the bay. Most significantly, most of the cadmium appeared to come from the Blackstone River. (Hunt, C.D. Unpublished. Metal Inputs to Upper Narragansett Bay Via Point and Non-point Sources. Graduate school of Oceanography, University of Rhode Island, Narragansett, 30p).

The 1980 surveys demonstrated that metal concentrations in the surface waters of the bay are highest in the Providence River (Fig. 16). This region also has the lowest salinity in the bay, excluding the Seekonk River, due to its proximity to the major sources of fresh water entering the bay. Because the 1980 surveys were restricted to the surface samples (1 meter depth) no information on metal concentrations in bottom water was collected.

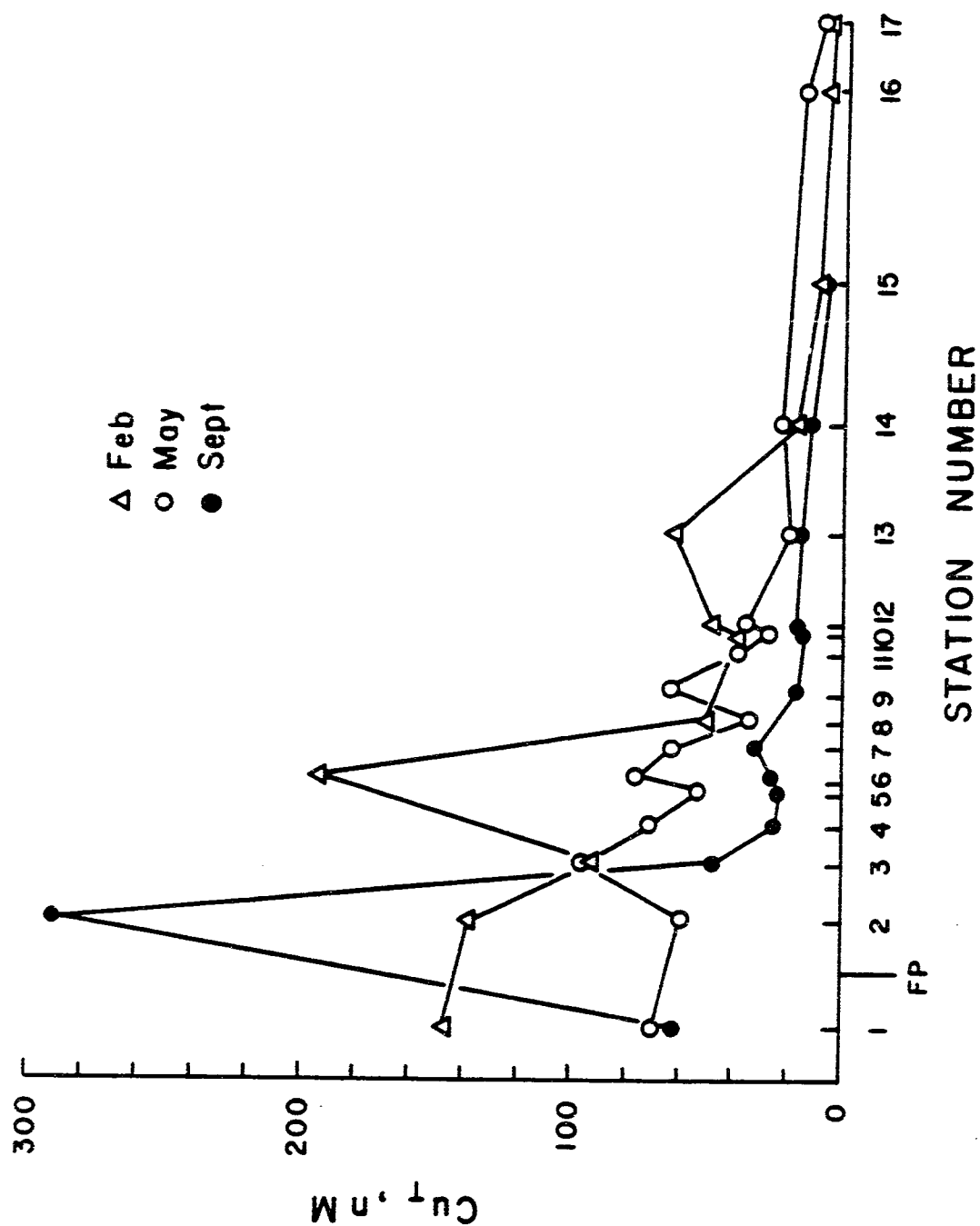


Fig. 16a. Distribution of total copper in the surface waters of Narragansett Bay during three surveys in 1980 (Oviatt, undated). The copper distribution is representative of other metals (Cu, Pb, Cd, Mn) measured during these surveys. The station locations are given in Fig. 16b; 'FP' refers to the location of the Fields Point Sewage Treatment Plant.

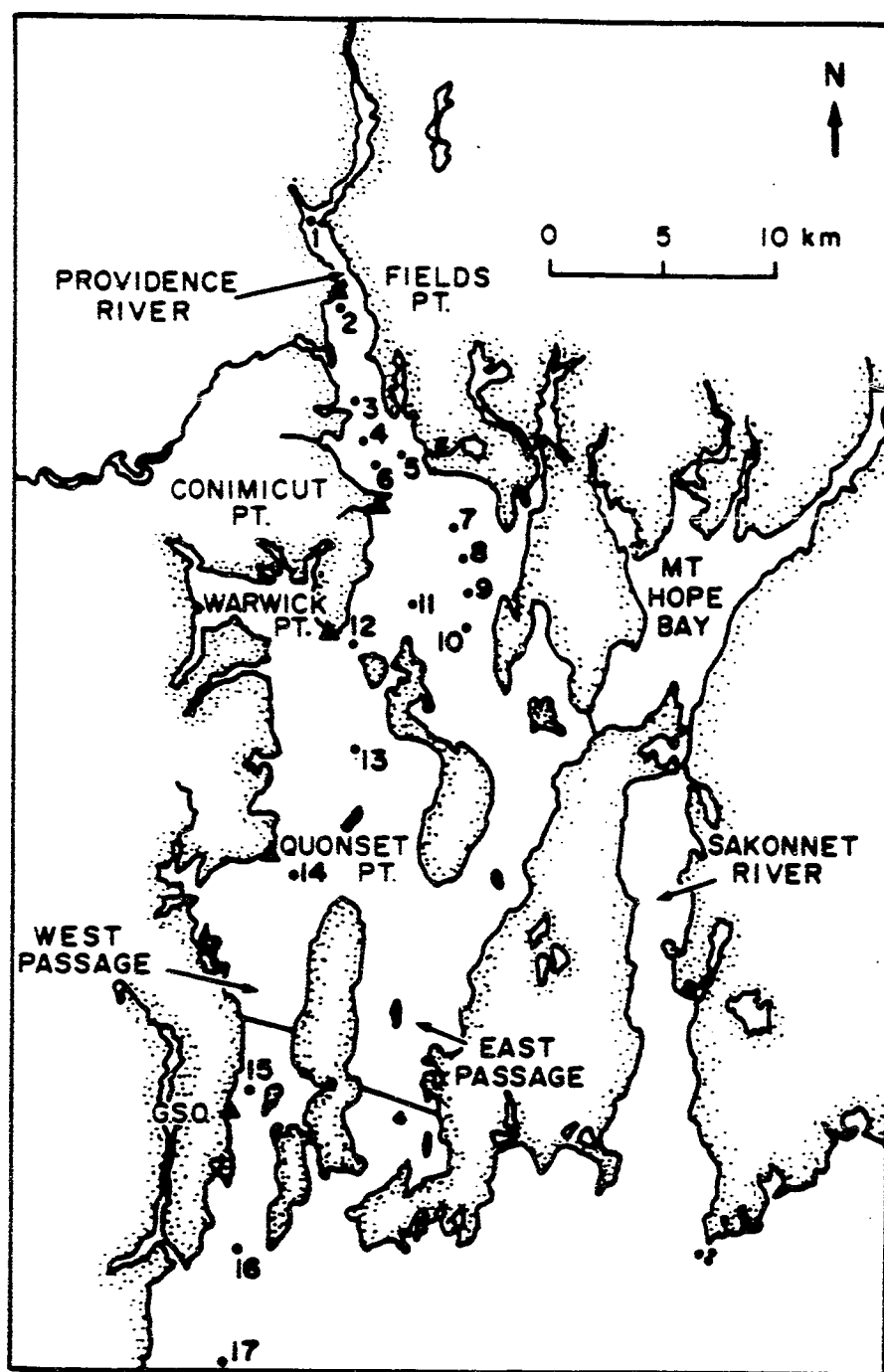


Fig. 16b. Station locations for the 1979-80 survey (from Oviatt, undated).

Generally, total metal concentrations rapidly decrease downbay as mixing and depositional processes act to dilute or deposit the metals. This trend, as demonstrated by the distribution of total copper concentrations in the bay (Fig. 16) is representative of most metals, including lead, cadmium, iron, and manganese. Others metals that may significantly affect the water quality of this estuary but not measured during the 1980 surveys can be expected to follow this general pattern. However, differences in the concentrations of individual metals within the bay, especially within the Providence River, may develop depending on the metal, its loading rate, major point of entry, and biogeochemical behavior (see, for instance, Nixon *et al.* 1986).

Relatively constant total metal concentrations were found in the west passage below the northern tip of Prudence Island (stations 13 to 17 in Fig. 16). It seems likely that low and constant concentrations will be found in the east passage except in areas close to point sources. The slight differences that were observed seasonally in the west passage are related to differences in the salinity of the samples at each station at the time of collection.

The largest spatial and seasonal variability in total copper concentrations within any segment of the bay is found in the Providence River region. This variability must result from the proximity of this region to the major point sources, non-point source urban runoff, and variability in freshwater inputs.

In estuarine systems trace metals are partitioned between dissolved and particulate phases. Understanding this partitioning is important for both geochemical and biological reasons. Geochemically, the depositional pathways and rates of metal removal from the water column are strongly related to the affinity of a metal for particles (Santschi *et al.* 1983). The phase in which a metal is found also influences its uptake by organisms, thus metal toxicity and biological response are related to metal partitioning between the dissolved and particulate phases.

During the 1980 bay surveys, each metal measured was found to partition differently between the dissolved and particulate phases, even though distribution patterns for total metal were similar. For example, copper was found primarily in the dissolved phase (80%) in the surface waters (Fig. 17). Cadmium was also found primarily in the dissolved phase (>95%), while lead was found predominately in the particulate phase (20 to 40 % dissolved).

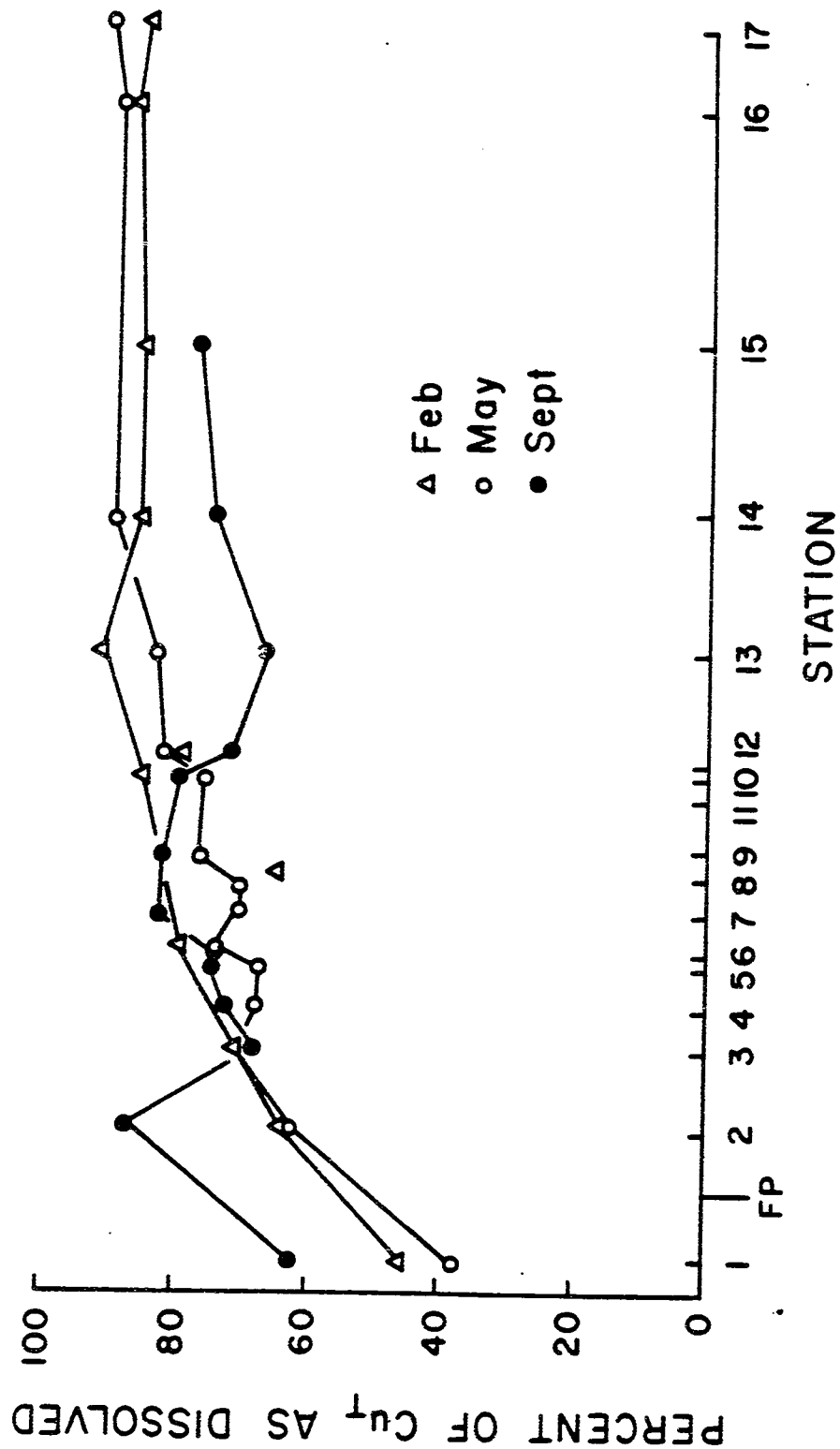


Fig. 17. Partitioning of copper between dissolved and particulate phases in the surface waters of Narragansett Bay during the 1980 water quality surveys. Data from Hunt (unpublished).

In addition, the fraction of copper in the dissolved phase was clearly lower in the Providence River (Stations 1-6, Fig. 17), indicating either a higher concentration of suspended solids in the water or higher concentrations of metal in the particulate phase. The latter explanation is suggested by the fact that the total suspended solid concentration does not vary greatly throughout the bay (Fig. 18), and clearly demonstrated by the distribution pattern for copper in the particulate phase (Fig. 19).

These data showed that the greatest variability in total metal concentration within the water column and also metal concentrations within the particulate matter are found in the Providence River and upper bay. Thus, more frequent and intensive monitoring is required to describe and understand the behavior of metals in this area. Because of this variability, the SINBADD surveys monitored stations at a higher density in this region than in other regions of the bay. In addition, samples from multiple depths within the water column were collected from throughout the bay to determine the vertical distribution of metals in the water column. Intensive spatial and seasonal surveys in this region of the bay were the focus of the monitoring program (SPRAY cruises) in the second year of the Narragansett Bay Project.

3. Metal distributions, 1985-1986

Discussion of the distribution patterns for multi-station, multi-depth metal data is simplified by presenting dissolved and particulate metals results as the sum of these phases (total metal) from the surface and bottom sample depths at each station. Mid-depth concentrations (Appendix tables 5-8) always fell between the values found in the surface and bottom layers and are not discussed. The data set was subdivided on the basis of the bay segments defined by Kremer and Nixon (1978) and Pilson (1985) and several segments grouped together into the geographic regions represented in Table 12. A simple mean and standard deviation for each parameter of interest was calculated for the surface samples and the bottom samples collected within each geographic region. This condensed data set was graphically represented to facilitate comparison of either regional differences within each survey or seasonal differences within a region. Except for Mount Hope Bay which was sampled at only 2 stations, at least three data points were used to obtain the average metal concentrations for the surface and bottom waters of each region. Station 12, at the boundary of Mount Hope Bay and the upper east passage, was not included in the calculations of average concentrations, station 6 in Greenwich Bay, station 19 in the

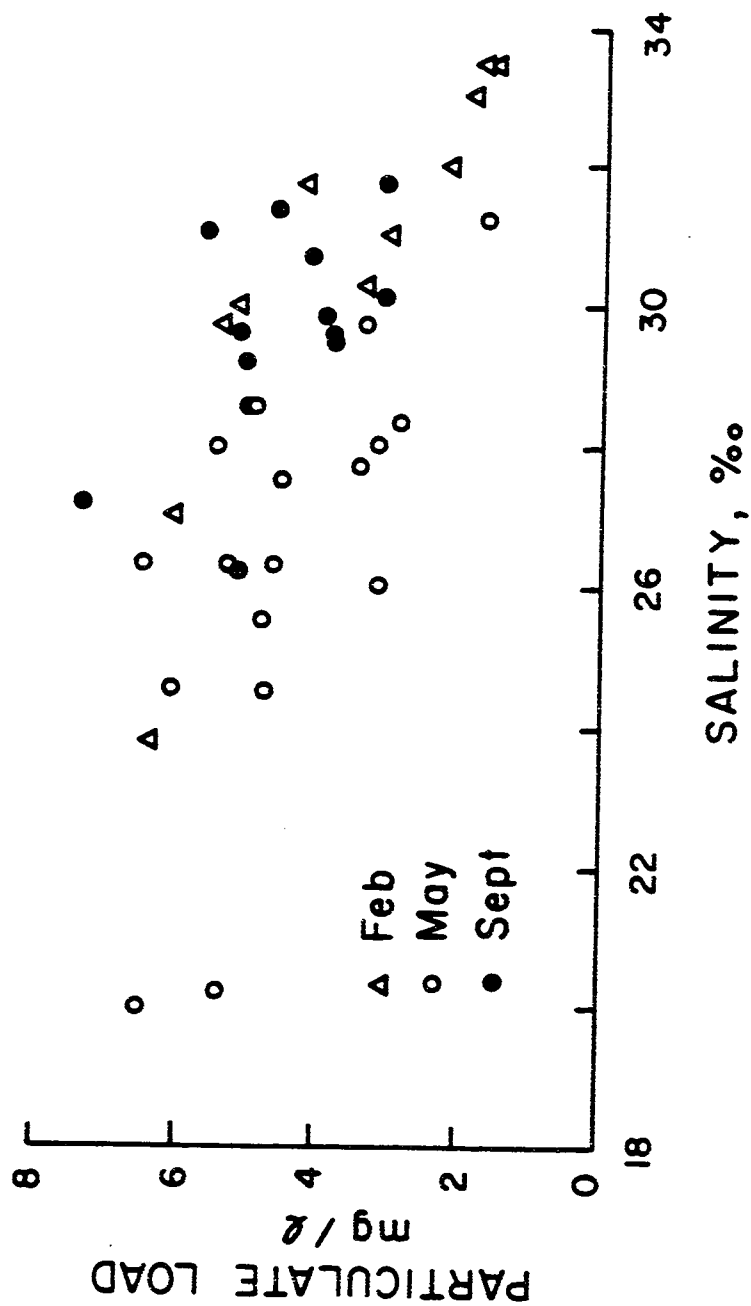


Fig. 18. Total suspended solids (particulate load) in the surface waters of Narragansett Bay during the 1980 water quality surveys as a function of salinity. Lowest salinities are in the Providence River; highest are in the lower west passage.

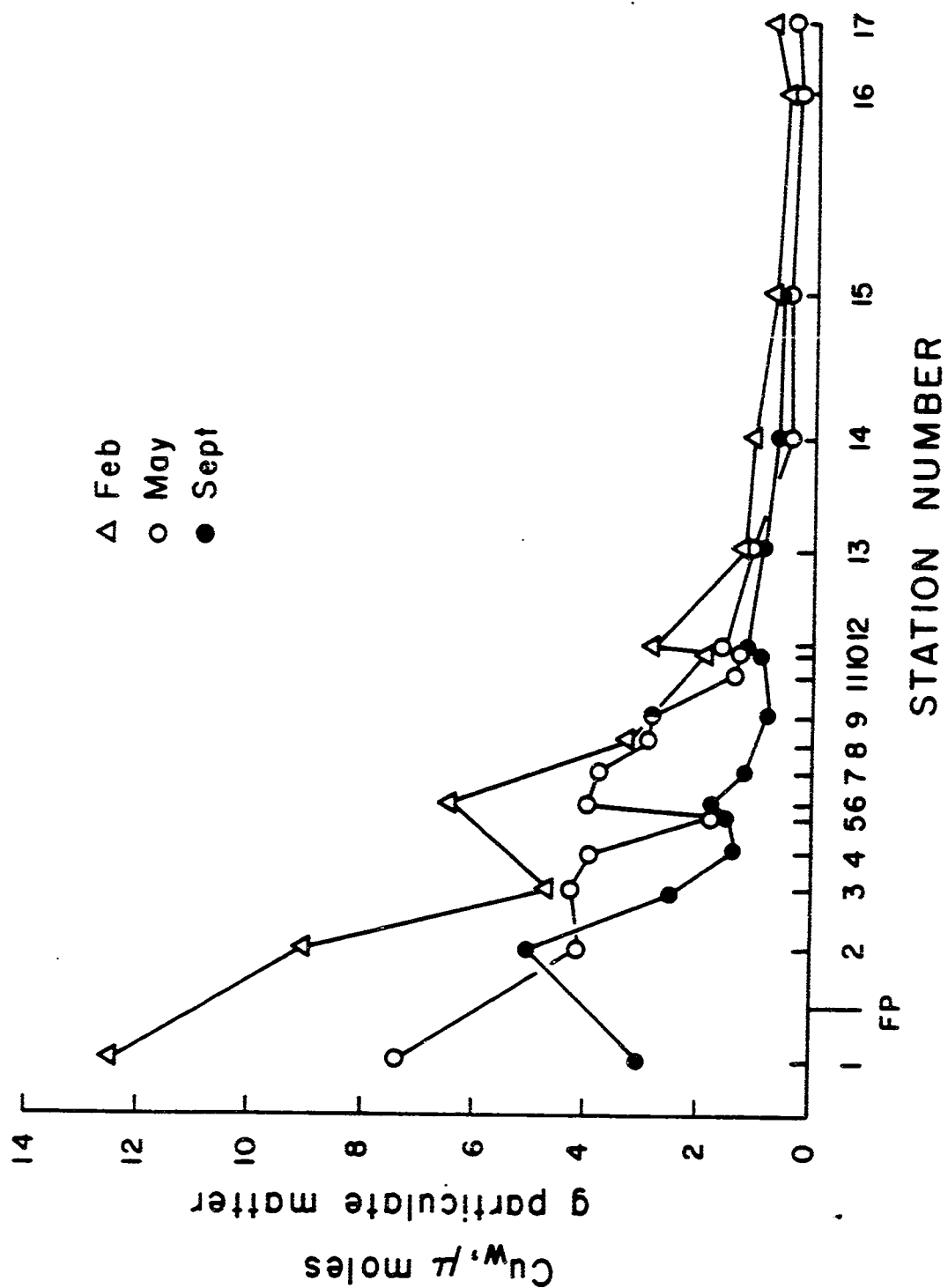


Fig. 19 Concentration of copper in particulate matter from Narragansett Bay as a function of distance from Fox Point.

Table 12. List of stations and segments (Pilson 1985) used to calculate mean and standard deviation for surface and bottom samples from the SINBADD surveys. Note that 6 in Greenwich Bay, 19 in the Sakonnet River, and 1 in the Seekonk River are not included in the averages. Station 12 at the intersection of Mount Hope Bay and the upper east passage was not included in any of the averages.

<u>Bay Region</u>	<u>Segment</u>	<u>Stations</u>
Providence River	1	2
		3
		4
Upper Bay	2	5
		10
		11
Mount Hope Bay	9	17
		18
West Passage	4,5	7
		8
		9
East Passage	6, 7, 8	13
		14
		15
		16
Rhode Island Sound	None	20
	Assigned	21
		22

Sakonnet River, and station 1 in the Seekonk River were not included in the calculation of the averages.

Average total metal (dissolved plus particulate) concentrations determined during the Fall surveys in October and November 1985, are typical of the other surveys and are used to describe the general distribution patterns within the bay (Figs. 20 to 22). Fig. 22 also includes chromium results from April (SINBADD 4). The distribution patterns can be summarized as follows:

1. For all metals surveyed, the highest metal concentrations were found in the surface waters of the Providence River. Metal concentrations in the surface waters rapidly decrease downbay.

2. The lowest metal concentrations were found in the bottom waters of Rhode Island Sound.

3. Total metal concentrations in the surface waters of Mount Hope Bay were less than those observed in the Providence River region. Total Cu, Cr, and Pb concentrations in the surface waters of Mount Hope Bay were similar to those in the upper bay. Total Ni and Cd concentrations in Mount Hope Bay were lower than found in the upper bay, but Ag was higher.

4. Total Cd, Cu, Ni, and Cr concentrations in the surface waters of the bay were always higher than in the bottom waters. Silver and Pb concentrations in the surface and bottom waters were generally similar; however Pb concentrations were slightly higher in the bottom waters. Bottom water lead concentrations in Mount Hope Bay were noticeably higher relative to the surface waters.

5. For all metals the difference between the surface and bottom water concentrations was most extreme in the Providence River. The difference between the surface and bottom water concentrations decreased in the upper bay. Differences between surface and bottom waters were relatively small in the east and west passages. These differences are consistent with those expected based on the salinity distribution in these layers, e.g., low salinity surface waters are expected to have higher concentrations of these metals and higher salinity waters at the bottom are expected to have lower metals concentrations.

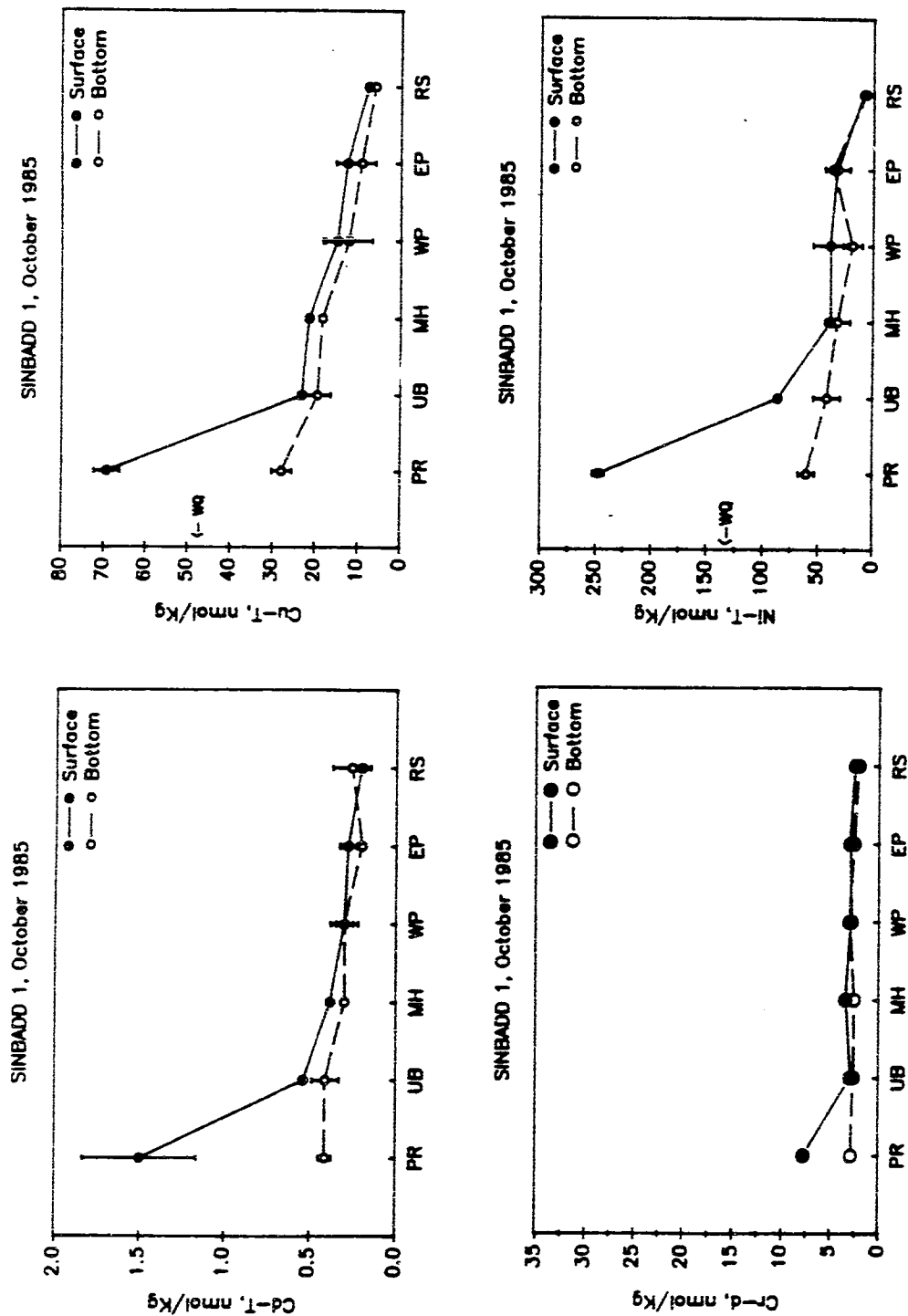
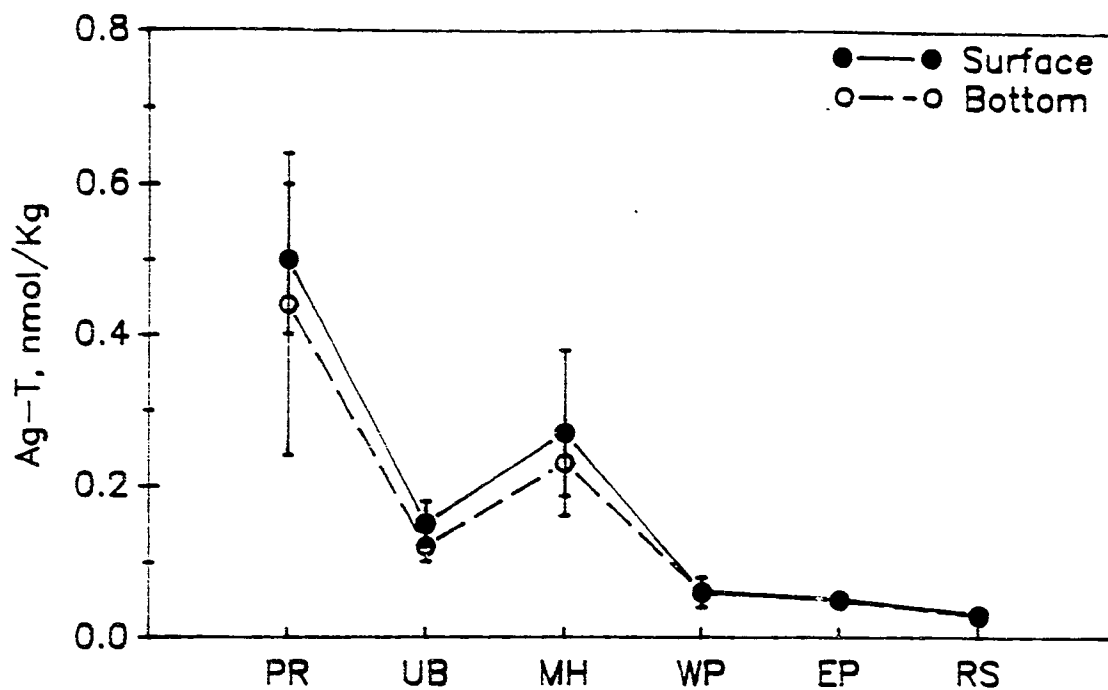


Fig. 20. Average surface and bottom total Cd, Cu, and Ni concentrations in regional sections of Narragansett Bay during October 1985. Particulate Cr data are not available for this survey, therefore dissolved Cr is presented. PR = Providence River; UB = upper bay; MH = Mount Hope Bay; WP = West Passage; EP = East Passage; RS = Rhode Island Sound. To convert metals concentrations to $\mu\text{g/l}$, multiply Cd, Cu, Cr and Ni by 0.1124, 0.0635, 0.052, and 0.0587, respectively. WQ indicates the EPA Water quality criterion for each element.

SINBADD 2, November 1985



SINBADD 2, November 1985

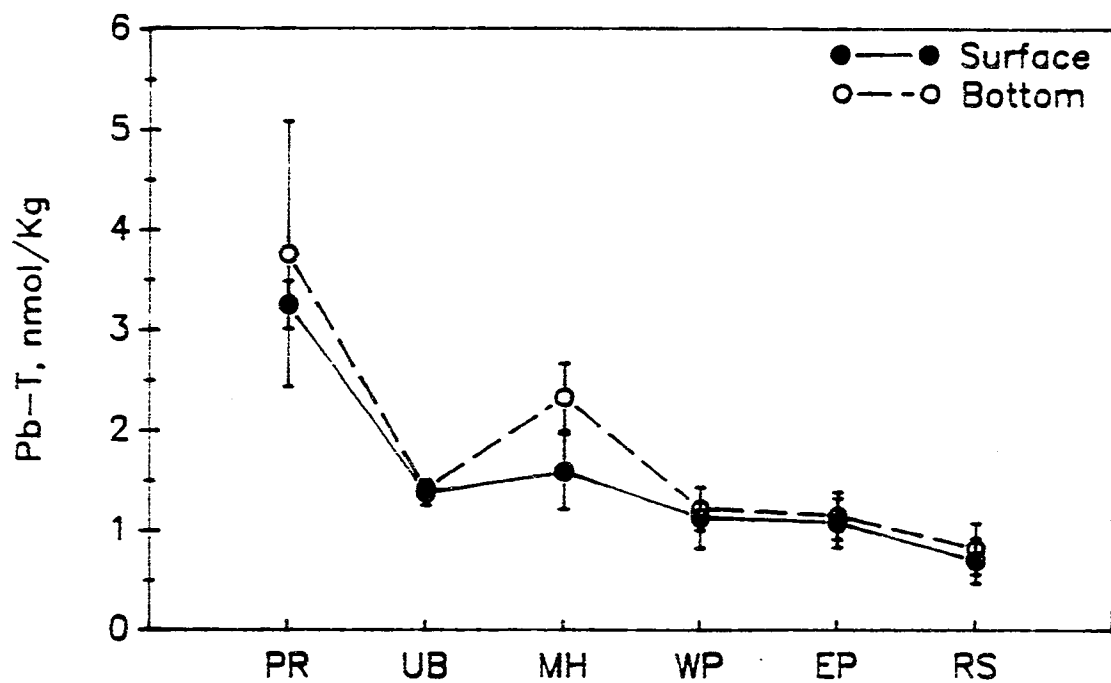
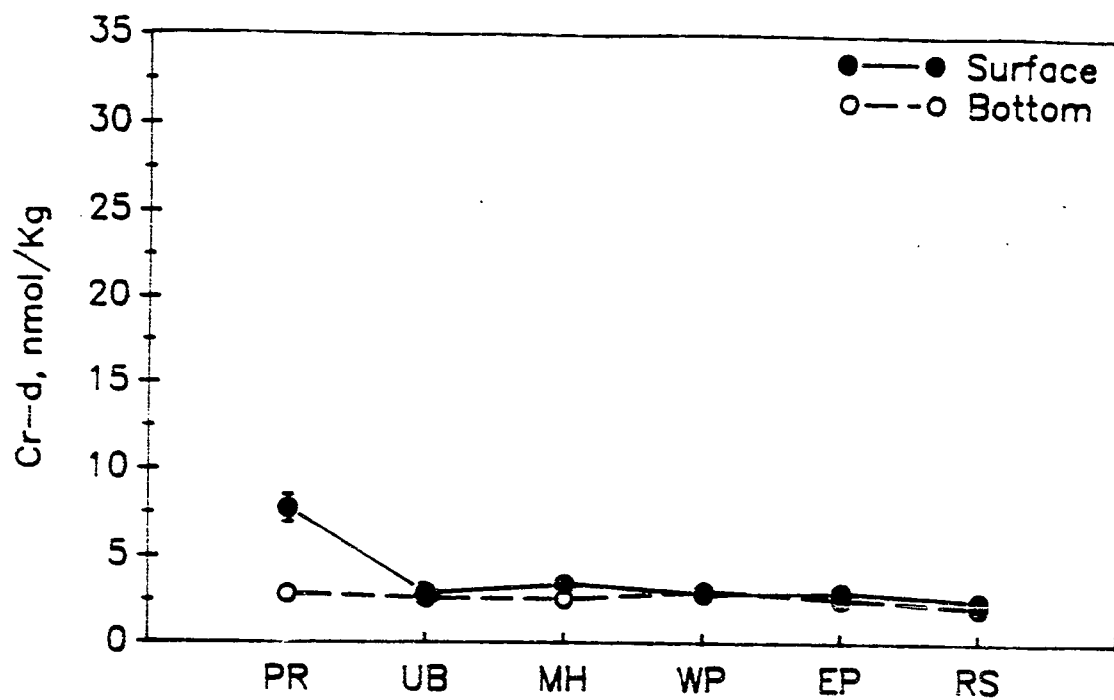


Fig. 21. Average total Ag and Pb concentrations in surface and bottom waters from regional sections of Narragansett Bay during October 1985. Section symbols are defined in Fig. 20. To convert to $\mu\text{g/l}$, multiply Ag by 0.1074 and Pb by 0.2072.



SINBADD 3, April 1986

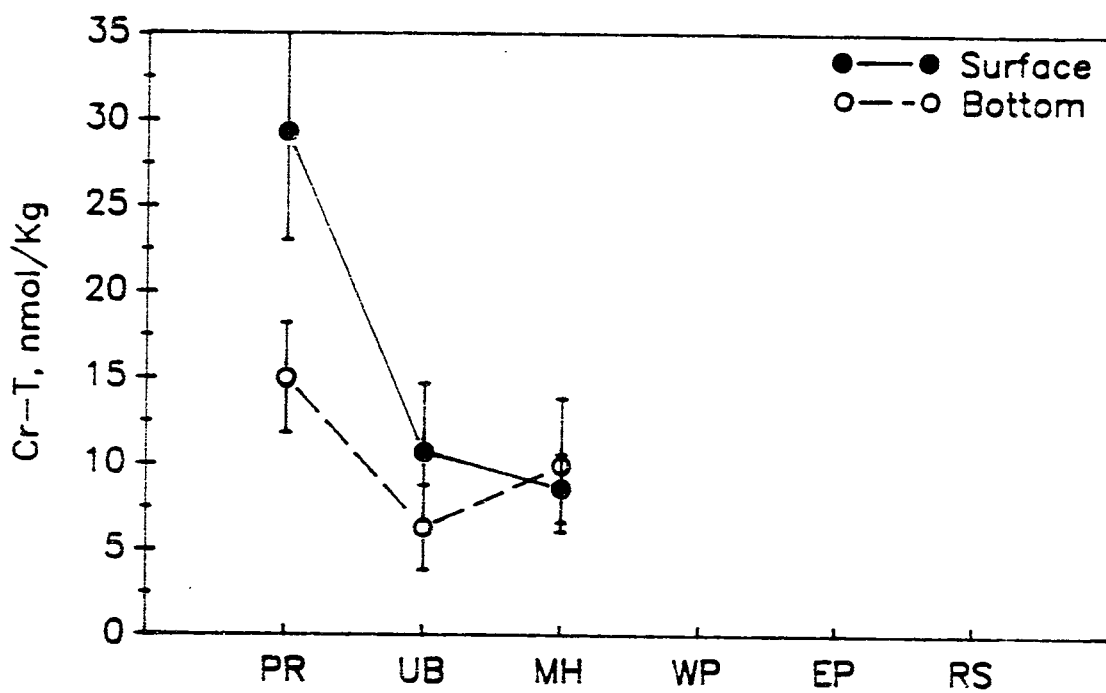


Fig. 22. Average dissolved (SINBADD 1) and total Cr distributions (SINBADD 3) in Narragansett Bay. To convert to $\mu\text{g/l}$ basis multiply by 0.052.

6. Total metal concentrations in the bottom waters of Narragansett Bay were relatively similar but displayed a consistent decrease from north to south. Differences of less than factors of 2 to 4 were seen in the bottom waters of the bay between the Providence River and Rhode Island Sound.

The variability, represented by the standard deviation of the average concentration, within each regional section was generally low except in the surface waters of the Providence River and Mount Hope Bay. The Providence River had the highest variability because of its proximity to the sources of metals, variability in input rates, and mixing with higher salinity water from the upper bay.

4. Seasonal variability

Seasonally, many factors act to alter the concentrations of metals within estuarine water. Among these are temperature, which influences chemical and biological processes, and freshwater input rates, which influences the residence time of the water, thus the rate of transport through the estuary. The SINBADD surveys were conducted during two seasons: (late fall and early spring). During these surveys, input of freshwater to the bay varied significantly prior to and during each survey (see later discussion on salinity). The temperatures of the water column over the bay also varied between each survey. Temperatures were approximately 16, 11.5, 7.0, and 15 °C during SINBADD 1, 2, 3, and 4, respectively. The temperature of the surface and bottom waters of the bay were generally constant during each survey with the exception of SINBADD 4, during which distinct surface to bottom and downbay differences in temperature were observed. Thus, the bay was surveyed during periods when major variables controlling water residence time and chemical/biological activity were substantially different, but the coldest and warmest months were not included.

Extrapolation of the discussion of seasonal variability to the summer period or conditions in which freshwater inputs are substantially different than experienced during these surveys must be made with caution and will not be attempted here. To simplify the discussion of temporal variability, the average total metal concentrations in the surface and bottom waters for each segment of each survey were plotted on the same graph (Figs. 23 to 28).

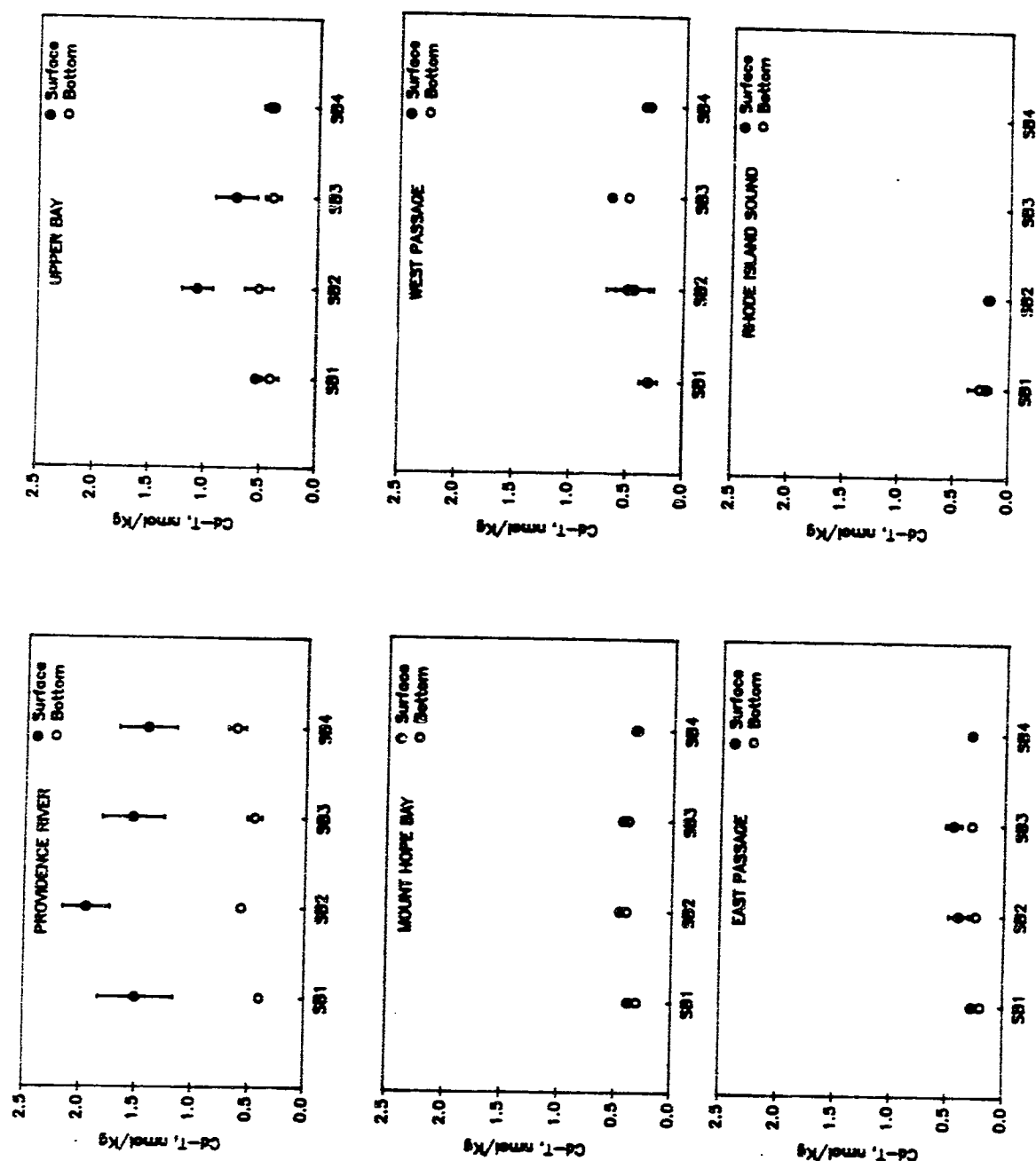


Fig. 23. Comparison of average and standard deviation of the total cadmium concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SINBADD survey. SB# represents the particular SINBADD survey. Water quality criterion in seawater is 82.7 nmol/kg.

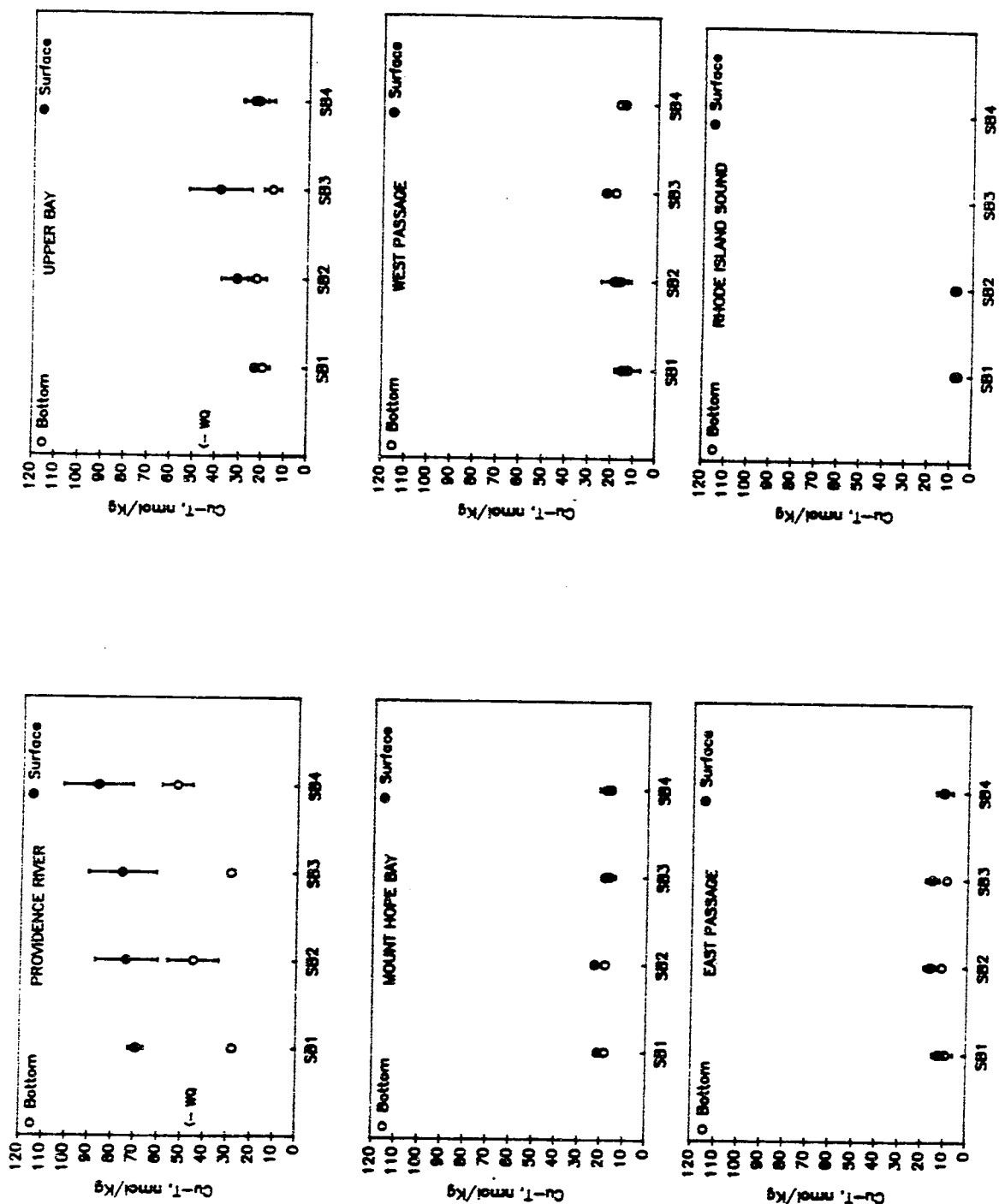


Fig. 24. Comparison of average and standard deviation of the total copper concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SINBADD surveys. SB# represents the particular SINBADD survey. Water quality criterion in seawater is 45.6 nmol/kg.

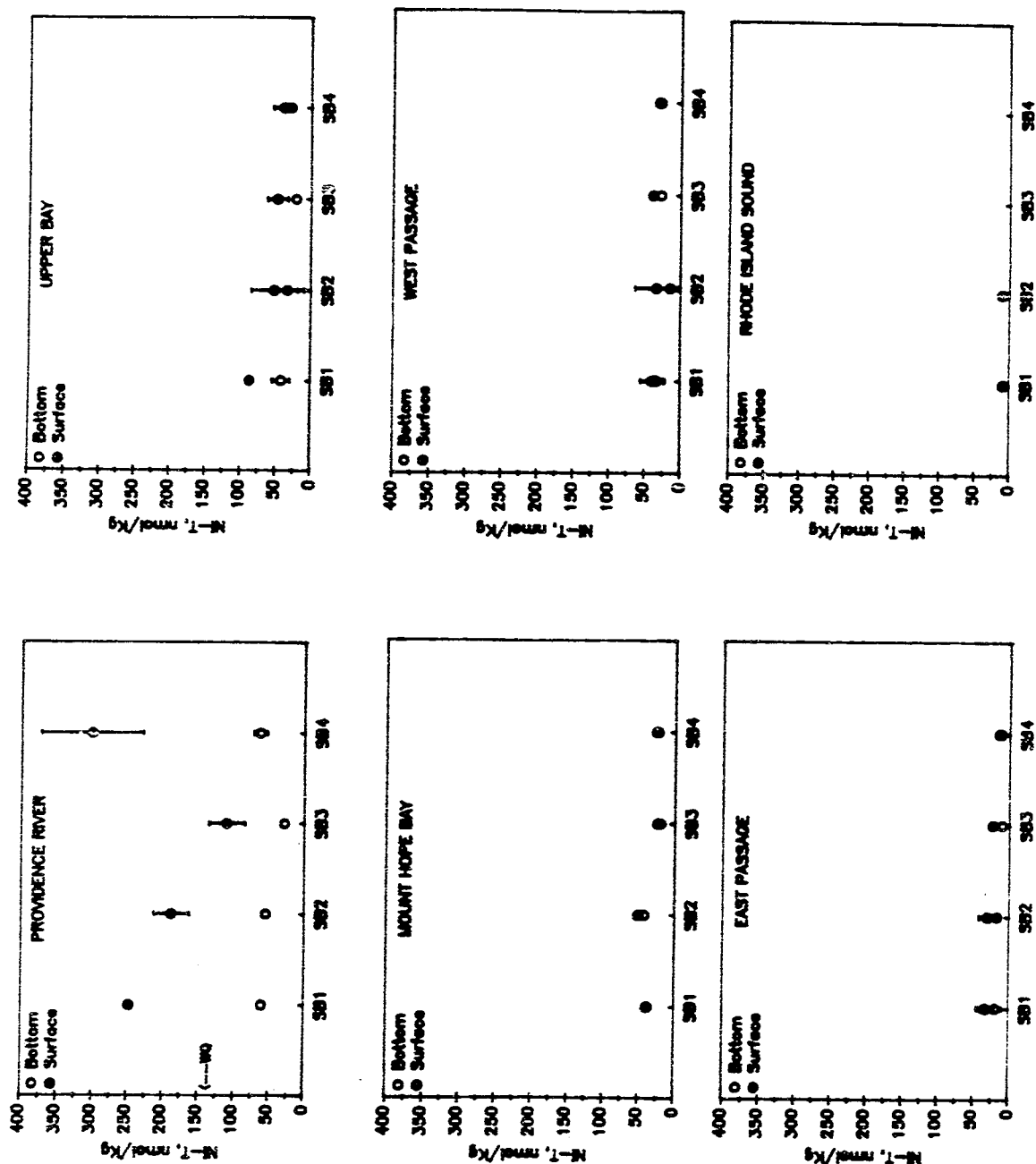


Fig. 25. Comparison of average and standard deviation of the total nickel concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SINBADD surveys. SB# represents the particular SINBADD survey. Water quality criterion in seawater is 134.6 nmol/kg.

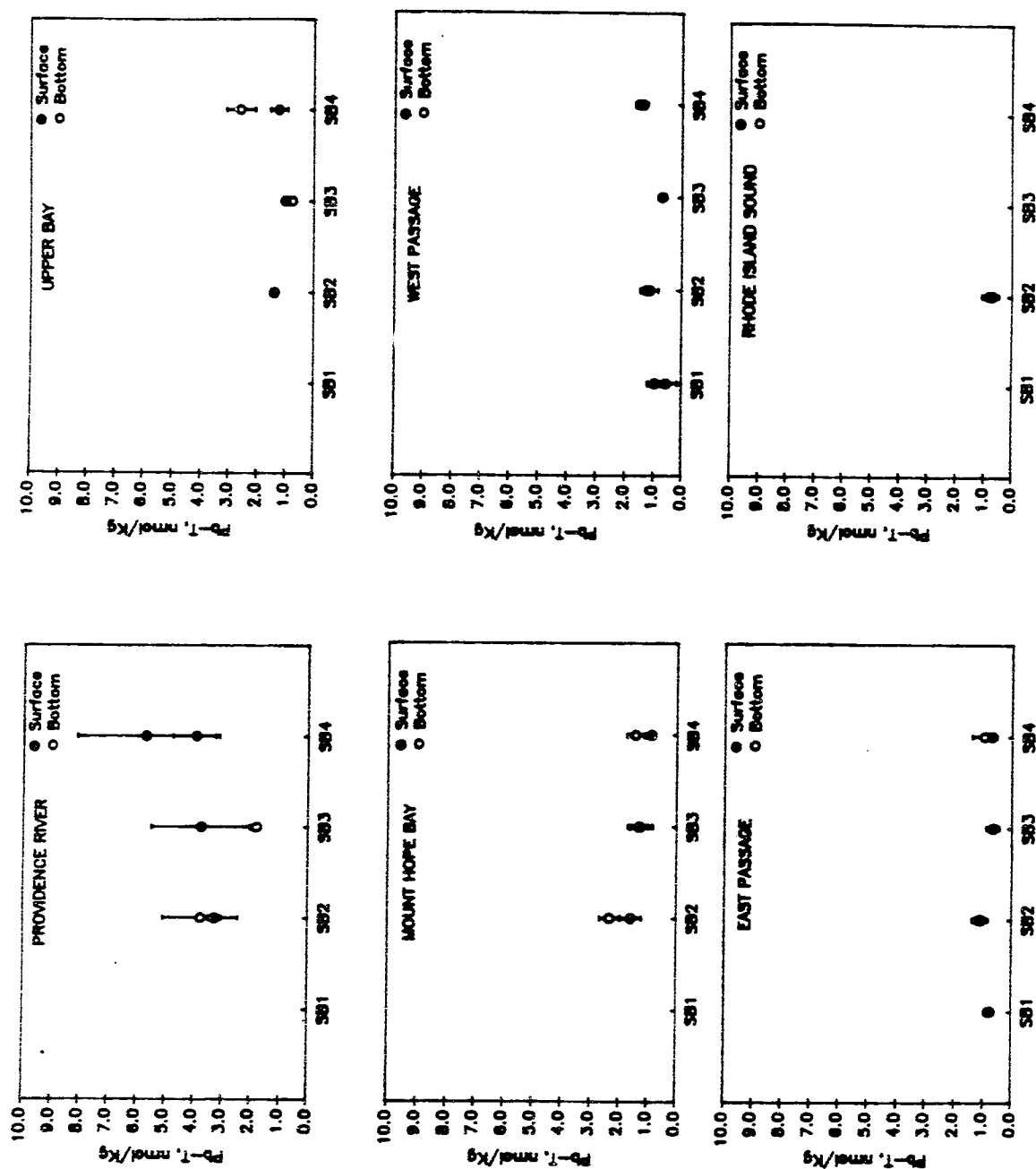


Fig. 26. Comparison of average and standard deviation of the total lead concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SINBADD surveys. SB# represents the particular SINBADD survey. Water quality criterion is 27 nmol/kg.

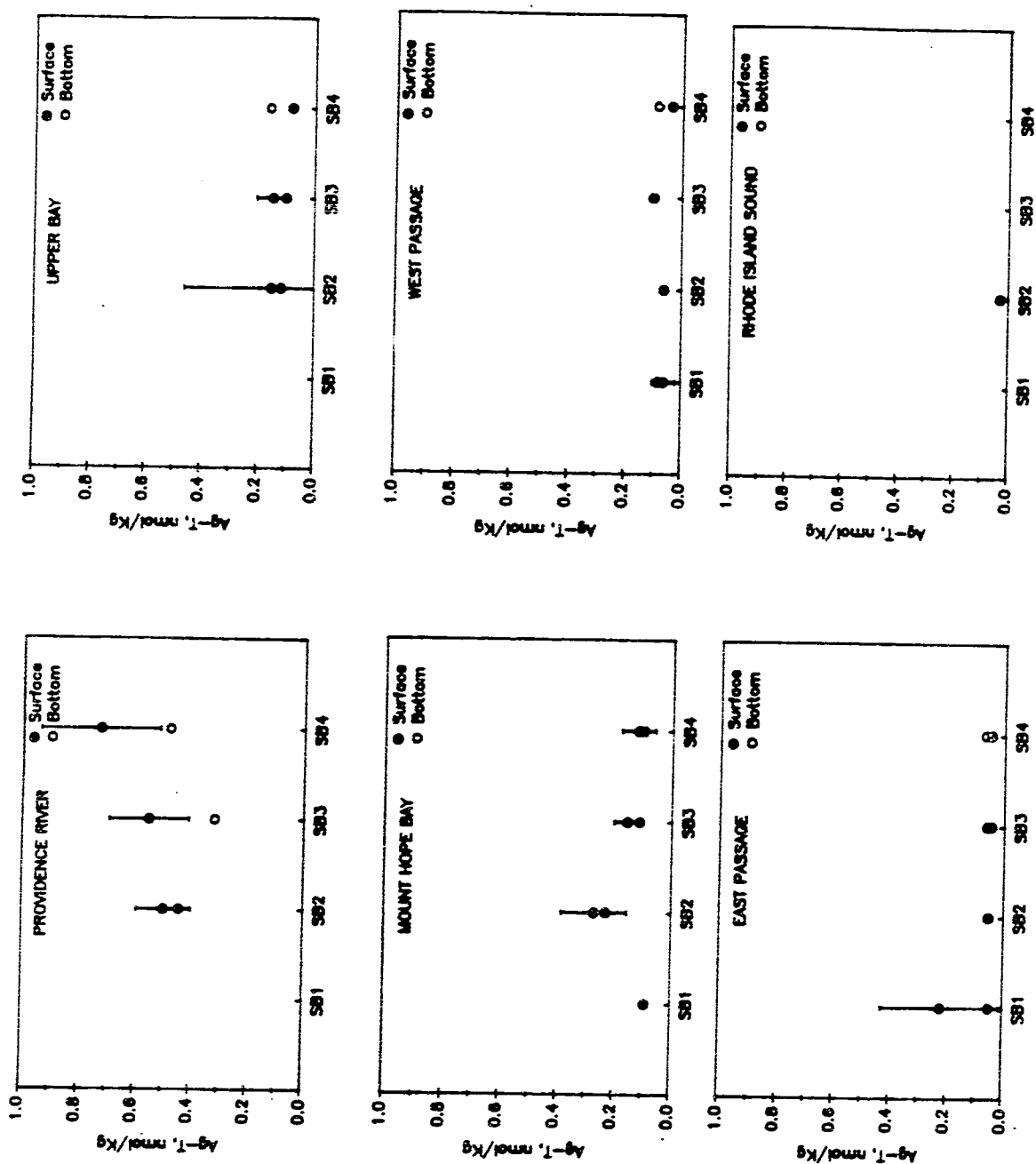


Fig. 27. Comparison of average and standard deviation of the total silver concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SIBADD surveys. SB# represents the particular SIBADD survey. Water quality criterion is 21.4 nmol/kg.

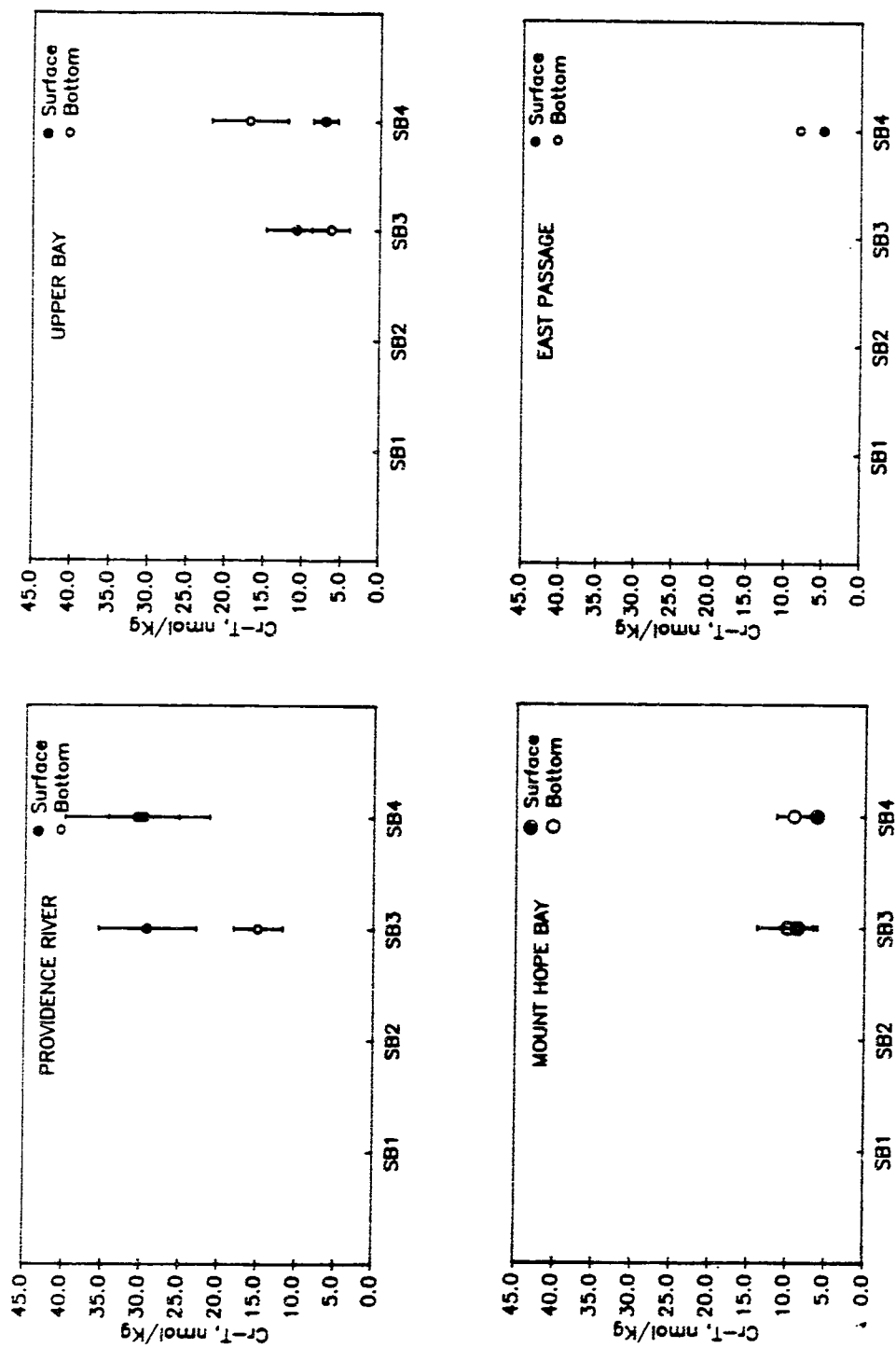


Fig. 28 Comparison of average and standard deviation of the total chromium concentrations determined for the surface and bottom waters of each geographical region of Narragansett Bay during the SINBADD surveys. SB# represents the particular SINBADD survey. Water quality criterion is 960 nmol/kg as chromium VI.

Surface waters

Variability in metal concentrations was relatively small between each survey in the lower portions of the bay. Thus, seasonal differences between fall (SINBADD 1 and 2) and spring (SINBADD 3 and 4) are small in these regions. The average concentrations of cadmium and copper within the east and west passages and Rhode Island Sound did not vary by more than a factor of 1.5 between the surveys. Slightly higher concentrations were present in November and April. For nickel and lead, the variability in these regions was even less and showed no systematic trends.

Further to the north, closer to the major sources of metals, differences between surveys were more pronounced. Within Mount Hope Bay, silver concentrations were distinctly higher during the November survey. Lead also appeared to be higher in this region during this period, especially in the bottom waters. Runoff in the four-week period preceding this survey was higher than during any of the surveys, and thus may have an important influence on the average concentration of silver and lead in this region. These data further suggest that a significant source for these metals is present in this area or upstream in the Taunton River.

The largest differences in the average concentration of each metal between the surveys were found in the Providence River and upper bay regions. However, the variability observed within these regions was not consistent for the metals studied. For instance, the average total copper concentration was relatively constant in the surface waters of the Providence river between each survey. In contrast, nickel concentrations in this region systematically declined by a factor of 2.5 between October and April, then sharply increased in May. The other metals behaved in a way similar to copper. Note also that the metal concentrations within the Providence River were much less variable, as determined from the standard deviation of the mean for the area, during the October 1985 survey. This may be related to the low volume of freshwater runoff experienced in the bay during the late summer and early fall of this year.

Within the upper bay, seasonal differences in the average concentrations ranged between a factor of 2 and 3 for cadmium, copper, and nickel. The other metals had comparatively constant concentrations between the four surveys. As in the Providence River, the seasonal pattern within the upper bay is not consistent for each metal. For instance, the highest cadmium concentrations were observed during the

November survey, whereas copper concentrations were higher during the April 1986 survey, and nickel was highest in October of 1986.

Bottom waters

Two observations can be made regarding the seasonal distributions of metals in the bottom waters of the Providence River and upper bay. First, the average concentrations between surveys are more consistent (smaller range) than found for the surface waters. This consistency is most evident for those metals that do not strongly associate with particles (Cd and Ni). The more particle-reactive metals (Pb, Cu, and Ag) were more variable. Second, the seasonal pattern was not always similar to that of the surface waters. For instance, Cd in the bottom waters of the upper bay in November did not show the relatively large increase observed in the surface waters. Likewise, the high surface copper concentrations observed in the April survey were not seen in the bottom waters. In the lower segments of the bay the seasonal distribution pattern for each metal in the bottom waters generally mirrored that observed in the surface waters.

Summary

The effect of variations in the input of freshwater can be observed in the trace metal data. However, the effect of these variations was not dramatic. Periods of high input result in higher and more variable metal concentrations in the waters of the bay, particularly in those regions closest to the major sources, e.g., the Providence River and upper bay. Differences in average metal concentrations within the upper reaches of the bay were generally within a factor of 3 or less between surveys. Within the lower segments of the bay these differences were generally less than a factor of 1.5. Thus, variations in the input of freshwater and associated metals affects the variability of metal concentrations in the lower segments of the bay to a lesser degree than in the upper bay. As a result, the influence of runoff on the observed seasonal variability in metal concentrations is most likely to be detectable in the areas adjacent to the major inputs. Areas distant from these sources will be seasonally less variable because geochemical, biological, and physical processes act to dilute variations in concentration and reduce the observed variability in the downbay direction.

Several implications for the bay monitoring programs may be drawn from the analysis of metal variability within Narragansett Bay. First, more intensive time

series monitoring at fewer stations will be required to determine the magnitude of seasonal affects on water quality within the lower bay. Within the upper bay and Providence River more intense spatial and seasonal coverage is required to refine the estimates of the seasonal variability that may be expected in the bay. Second, long-term monitoring plans must address whether greater spatial or temporal resolution is required to determine trends within this system. Such assessments must be completed if monitoring of the metals concentrations in the bay is to be used either to determine the effectiveness of the regulatory process in reducing metal loading to the system or to predict the effects of changing patterns of land use in the watershed on the water quality of Narragansett Bay.

If one of the goals of bay monitoring is to anticipate the effects of continued industrial development, then a consistent monitoring program that is more intensely sampled in the highly variable regions of the bay and less intensively sampled in the less variable regions may be needed.

If the goal is to determine whether regulatory measures are effectively reducing the area of the bay exceeding EPA water quality criteria then the monitoring can be localized to the upper bay, Providence River, and possibly embayments of the main segments of the bay receiving industrial wastes. In addition, the number of metals measured may be reduced to those known either to exceed or to be very near water quality criteria. In either case, monitoring numerous stations in the lower reaches of the bay is not required.

5. Phase association

Total suspended solids

Because partitioning of metals between the dissolved and particulate phases is influenced by the concentration of particulate matter in the water column, the distribution of total suspended solids (TSS) within the bay is presented in Fig. 29. TSS concentrations within the bay were relatively low (2 to 5 mg/l) and constant in both the surface and bottom waters. Lowest TSS concentrations were observed in Rhode Island Sound surface waters. Near-bottom TSS concentrations were generally higher than surface concentrations, except in the upper bay and Mount Hope Bay during October. Within the bay, TSS concentrations were most variable in the upper bay. Significant variability in the average TSS concentration was found in the near-

SINBADD 1, October 1985

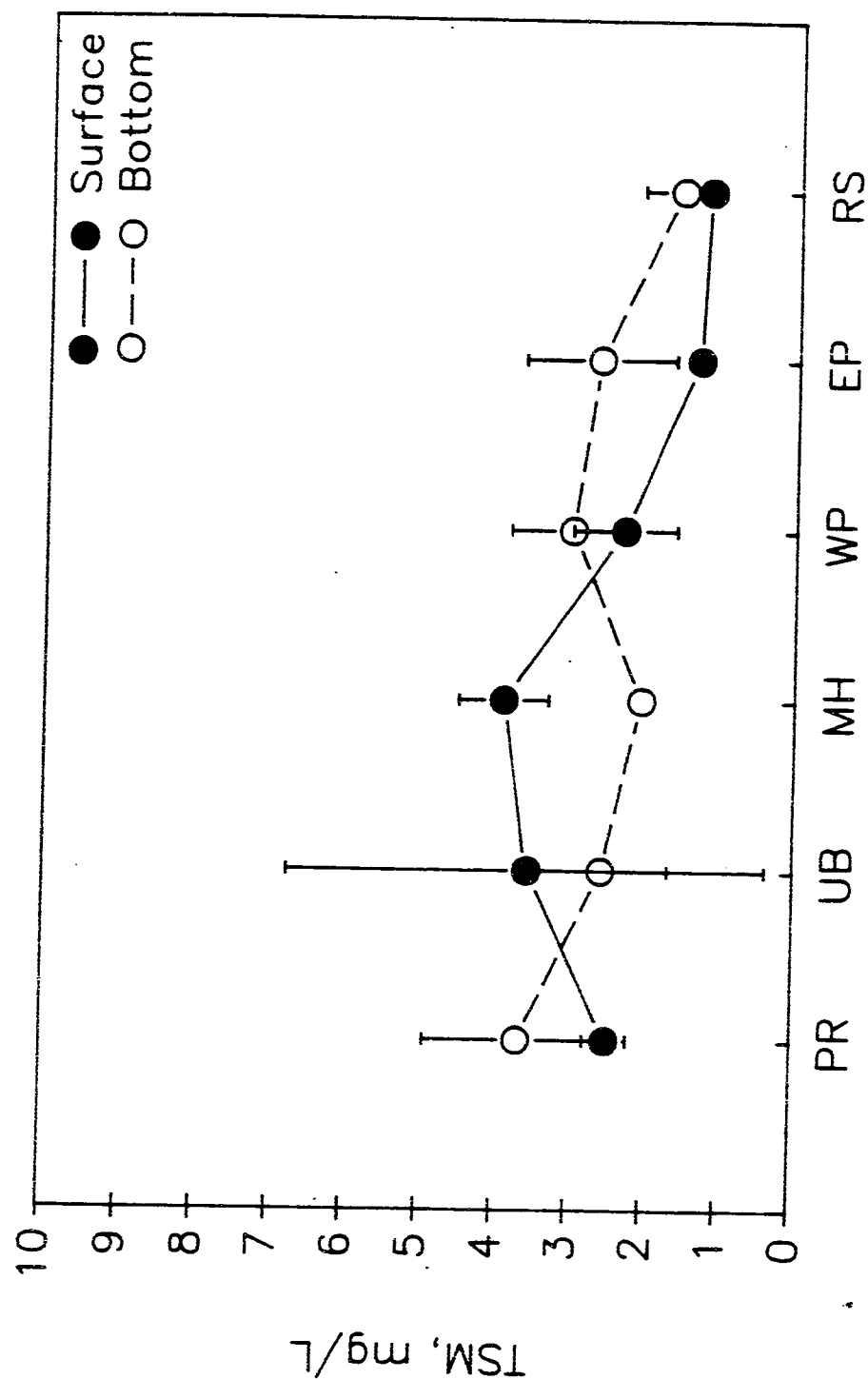


Fig. 29. Average total suspended solids in the surface and bottom waters of the major geographic regions of Narragansett Bay during October 1985.

bottom waters of the lower passages; this result is expected for depths that may be significantly influenced by sediment resuspension processes.

The general range in TSS concentrations observed in October was also found during the other surveys (Fig. 30). In general, average TSS concentrations did not vary greatly between surveys. However, high average concentrations (as high as 6 to 8 mg/l) were found in the Providence River region during November (SB2) and May (SB4), in the upper bay in May, and in the east and west passages in April (SB3). The most consistent total suspended solids concentrations were observed in the Mount Hope Bay region. The range in total suspended solids within the bay is similar to that found in the 1980 surveys.

Continuous profiles of turbidity can be found in the reports of the last three cruises (Hunt *et al.* 1987b, c, d). These profiles can be used to extrapolate the measured TSS data to the entire water column. Examination of these profiles reveals the very turbid water of the Providence River is frequently restricted to the region above the pycnocline or near the bottom. Furthermore, a region of relatively clear water can often be found between the surface and bottom layers of the bay.

Phase partitioning

Partitioning of metals between dissolved and particulate phases in the surface waters of Narragansett Bay is different for each metal (Fig. 31). More than 95 percent of the nickel and cadmium was found in the dissolved phase, whereas 60 to 80 percent of the lead was in the particulate phase. Copper was primarily dissolved (80 to 90 percent), and chromium and silver were 50 to 60 percent in the dissolved phase. These percentages are consistent with those observed for the surface waters during the 1980 surveys.

The percentage of each metal present in the dissolved phase was generally lowest in the Providence River, increased in the downbay direction, and then, for copper, lead and nickel, slightly decreased again in Rhode Island Sound.

Partitioning of metals between dissolved and particulate phases in the bottom waters reflected the same relative ranking as found in the surface waters. However, with the exception of cadmium, the particulate phase in the bottom waters contributed

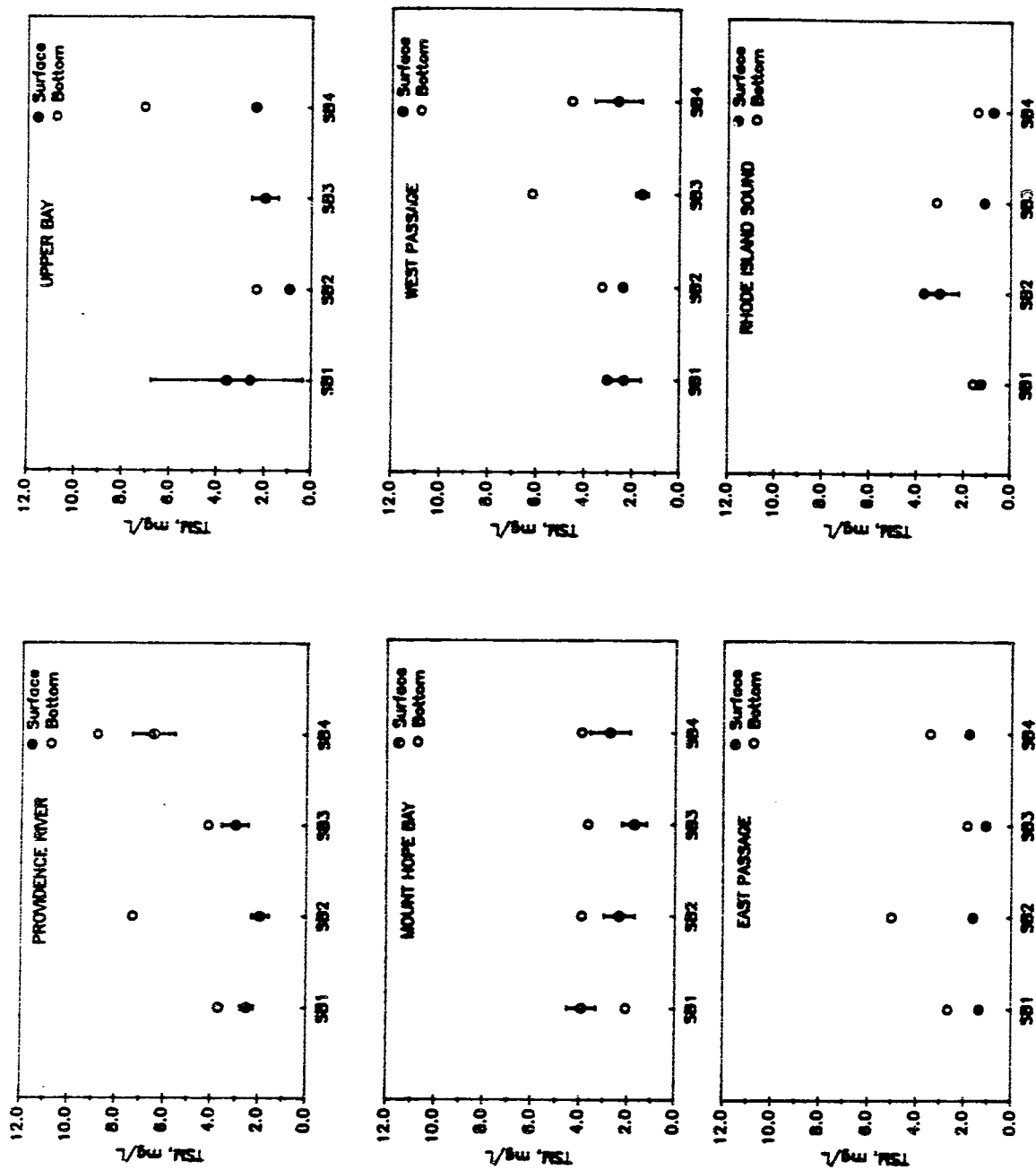


Fig. 30. Comparison of the average total suspended solids concentrations in the surface and bottom waters of the major geographic regions of Narragansett Bay during the four SINBADD surveys.

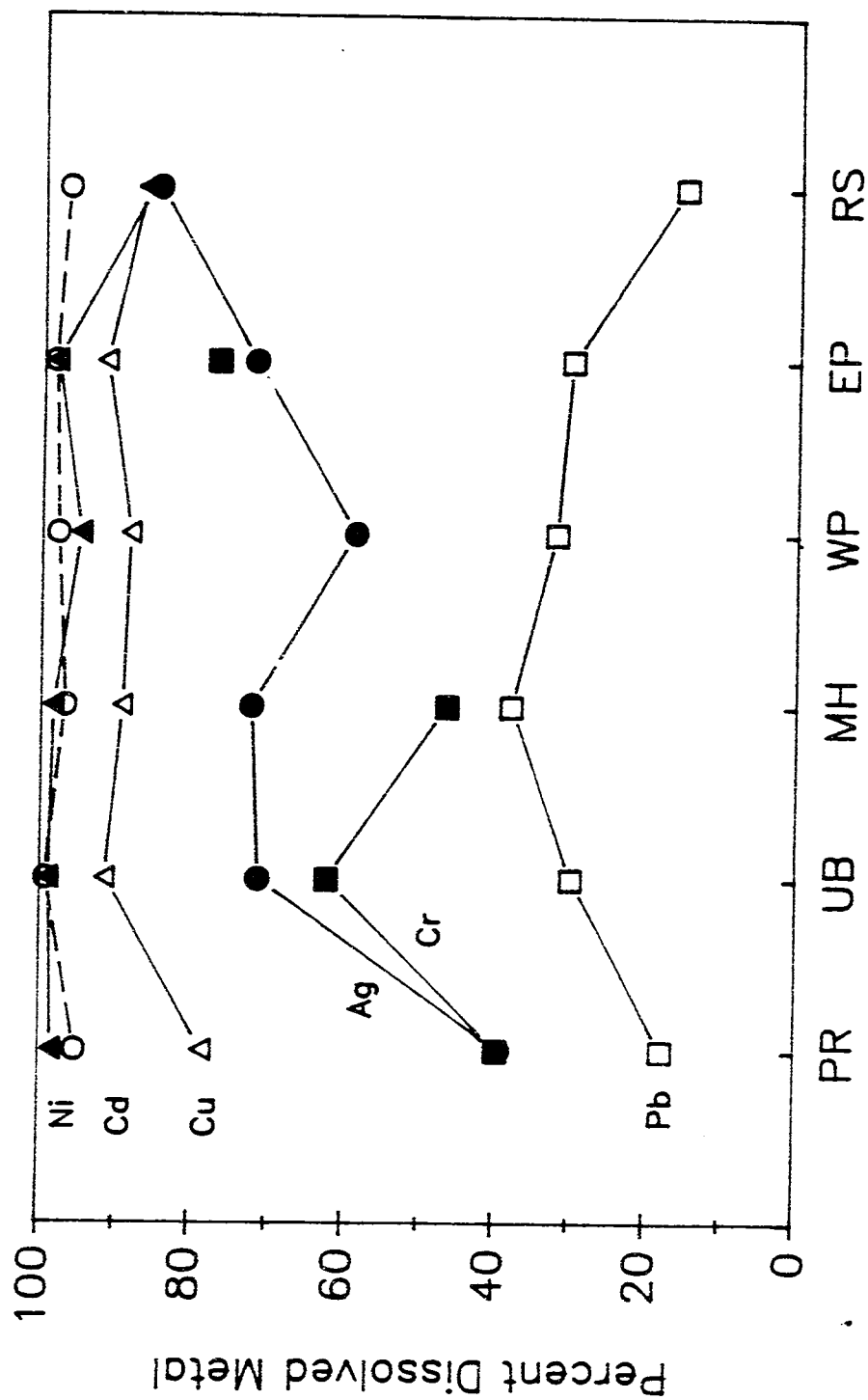


Fig. 31. Comparison of the percentage of the total metal in the dissolved phase in surface waters of Narragansett Bay by geographic region during SINBADD 2, November 1985. Chromium results are for SINBADD 3, April 1986.

between 10 and 20 percent more to the total metal concentration than found in the surface waters (Fig. 32). This contribution is consistent with the higher total suspended matter found in the bottom waters.

6. Metal Concentrations In Water Column Particulate Matter

The concentration of metals in the particulate matter for each sample from Narragansett Bay was calculated ($\mu\text{g/g}$ TSS) and the average for each bay segment determined. The results show that particulate matter from the surface waters of the Providence River had the highest concentration of Ag, Cd, Cu, Cr, Ni, and Pb (Fig. 33) per unit TSS. Concentrations of all metals in the particulate matter in the surface waters decreased rapidly in the upper bay and became relatively constant in the west and east passages. Lowest concentrations were found in the Rhode Island Sound stations. Metal concentrations in the particulate matter from Mount Hope Bay fell between that of the upper bay and west passage. Chromium in Mount Hope Bay and lead in the east passage were present in higher concentrations in the surface waters than expected based on the other metals:

Particulate matter from the bottom water of each segment had lower concentrations than found in the surface water of each respective segment. Relative to the concentration of metal in particulate matter from the surface waters, particulate metal concentrations in the bottom waters of the Providence River region are low. This is somewhat surprising considering the sediments of this region have very high metal concentrations. The particulate results suggest those organisms living at the sediment-water interface throughout the bay will experience relative constant concentrations (within a factor of 2 to 3) of metal in the particulate matter ingested from the overlying water column. However, those organisms living in the surface waters and feeding on particulate matter from in the Providence River region will ingest particulate matter with much higher metal concentrations than those organisms living in other regions of the bay.

7. Metal Behavior Versus Salinity

The relationship between salinity and metal concentration is useful for determining whether a metal behaves conservatively i.e., is not removed from the water column during transport through an estuary. This type of assessment is most effective if a single point source dominates the input. Unfortunately Narragansett Bay

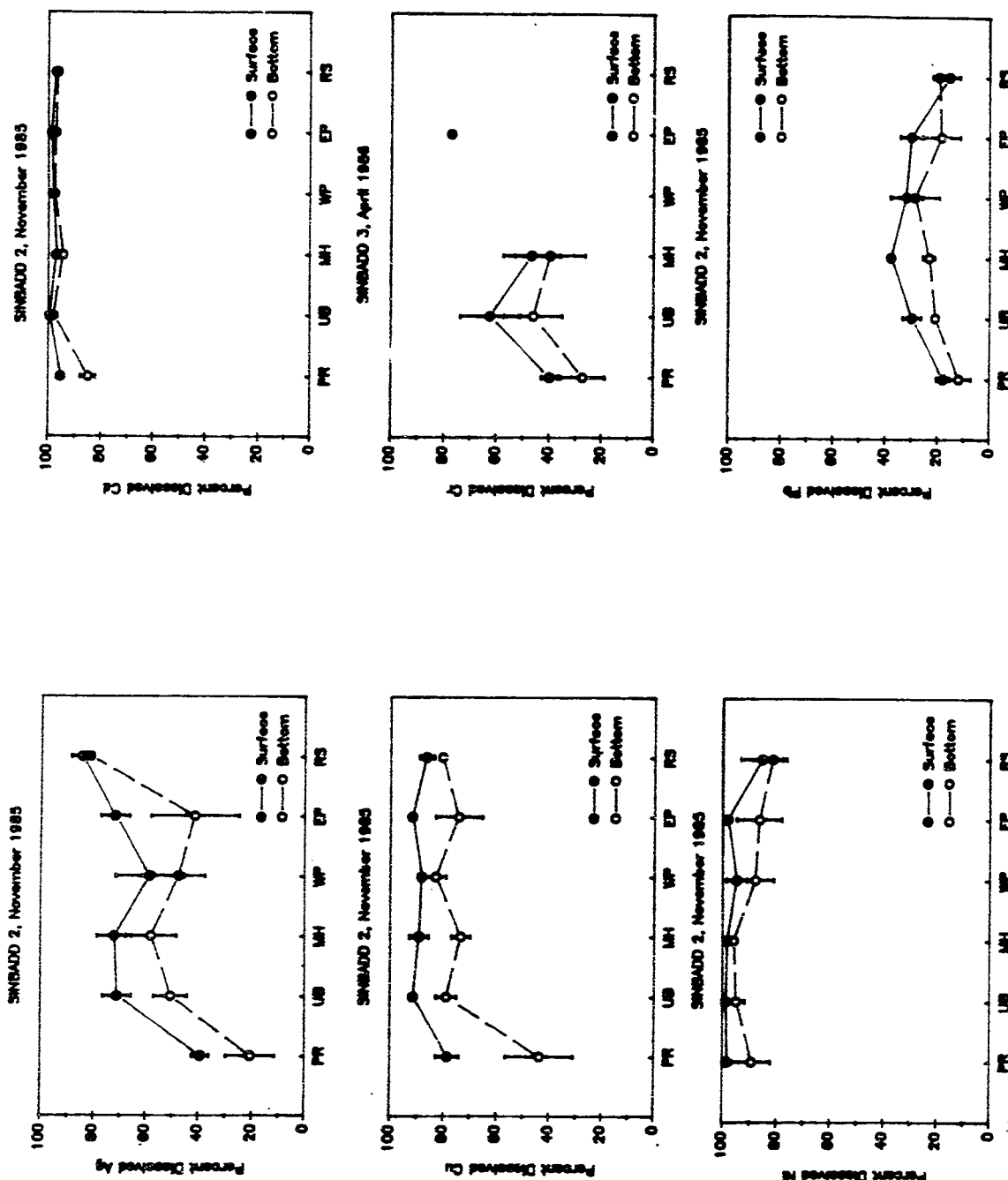


Fig. 32. Comparison of the percentage of the total metal concentration present in the dissolved phase in surface and bottom waters of Narragansett Bay during SINBADD 2, November 1985. Chromium results are for SINBADD 3, April 1986.

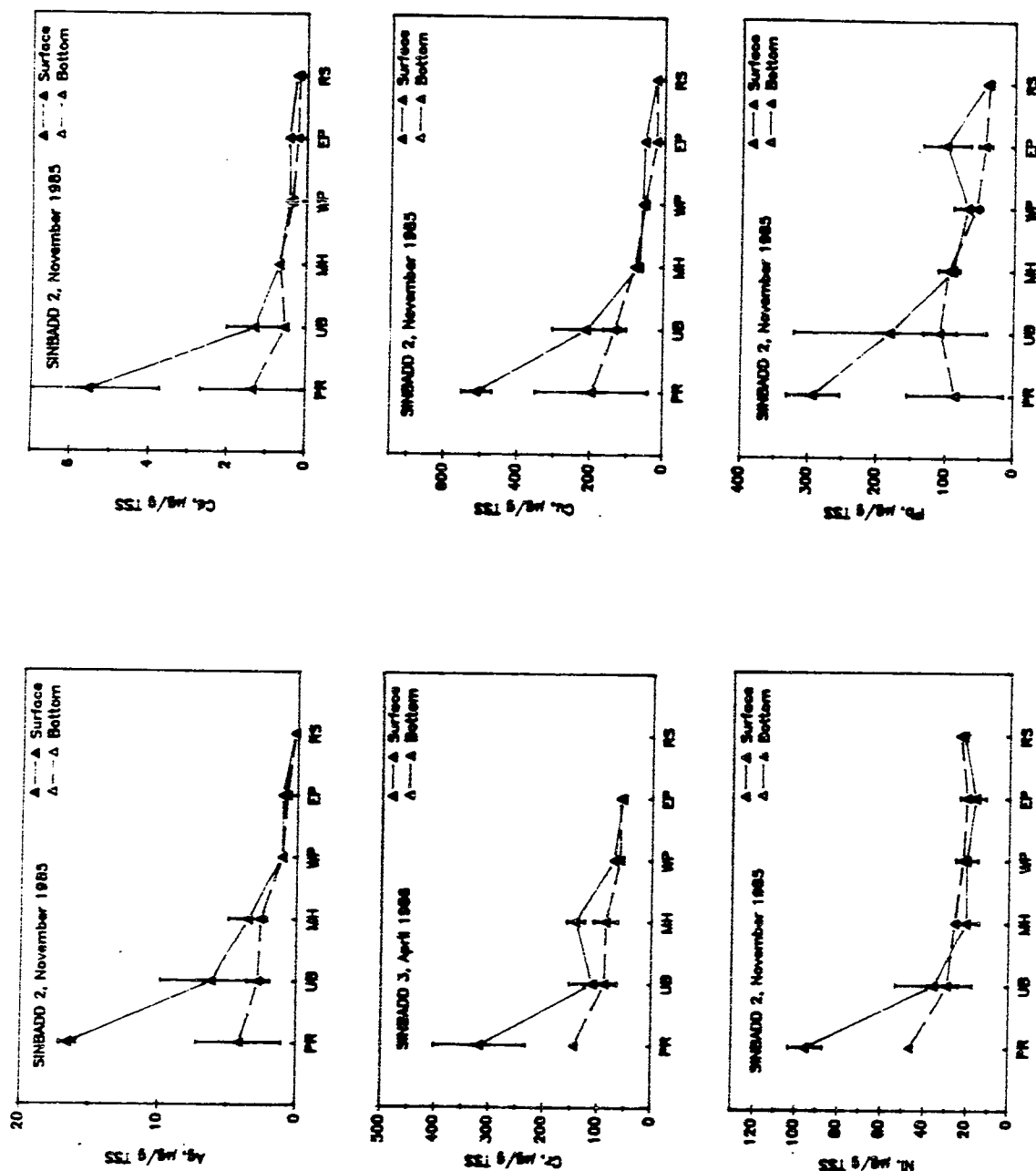


Fig. 33. Comparison of the metal concentrations in particulate matter isolated from the surface and bottom waters of Narragansett Bay during SINBADD 2 and SINBADD 3 (chromium only) as a function of region.

receives input from multiple sources. Thus, an accurate assignment of the concentration of metal used for the freshwater end-member (0 salinity) depends on the ability to construct an accurate flow-weighted average concentration. For the following discussion, such flow weighed input concentrations were calculated for each metal in all sources entering the Providence River region for each of the surveys. For each point source, the measured total metal concentration was multiplied by the total measured flow to obtain the total metal entering the bay from the source. The total metal input from each point source was summed, then divided by the sum of all flows. The resulting concentration was used as the concentration in the freshwater entering Narragansett Bay. Initially it is assumed all metals enter at one location at the head of the estuary.

If a metal behaves conservatively (i.e., only mixing causes the concentration to vary) all concentrations within the estuary will fall on a straight line connecting the concentration in the freshwater source and the concentration in the seawater end-member. This is called the theoretical mixing line (TML). If a metal does not behave conservatively and is removed from the water column, the data points will fall below the TML. If internal sources are present in the system, the points will lie above the TML. The relationship between salinity and metal may also deviate from the TML if there is a third source that is sufficient to alter the results from mixing between the freshwater and seawater end-members. This factor is especially important for Narragansett Bay where several major point sources are located downbay from the entry point of a major river at the head of the estuary and comparable freshwater flow is introduced at the head of the east passage from Mount Hope Bay.

Classically, the TML has been generally applied to the dissolved phase only (Boyle *et al.* 1977), rather than to concentrations of total metal. In this case, any deviation from conservative behavior is interpreted as removal of metal from the water column. However, if there are phase changes within a system, involving transformations between dissolved and particulate phases but not deposition to the sediments, it is necessary to plot the concentration of total metal to evaluate the question of conservative behaviour. This has been found for iron (Mayer 1982; Wilke and Dayal 1982), one of the most likely elements to show apparent nonconservative behavior (removal) when only the dissolved phase is studied. Because the first goal of our interpretation was to examine the question of metal removal within

Narragansett Bay, evaluation of metal behavior against salinity was made using total metal concentrations.

For the mixing plots presented here (Fig. 34 and 35), the freshwater end-member is the flow-weighted average concentration in the point sources to the bay, including rivers and sewage treatment plants. The seawater end-member was chosen as the highest salinity sample from Rhode Island Sound. This sample was always the bottom sample from station 22, south of the Sakonnet River mouth. The results for SINBADD 2 are presented and are representative of the other surveys (Fig. 34).

For silver the source data were insufficient to determine a flow-weighted input concentration on this survey. However, it is evident that the majority of the silver concentrations fall along a single relationship with salinity. The several points lying above this general relationship are located in Mount Hope Bay, which, as previously discussed, appears to have a high silver concentration relative to the rest of the upper bay region. This type of data demonstrates the difficulty of using these plots to estimate removal of metals in a system in which variability introduced by multiple spatially separated sources complicates interpretation.

The concentrations of cadmium, copper, and lead within the bay generally fall below the TML for these metals, with cadmium showing the least variability. From this it may be inferred that these metals are removed from the water column of Narragansett Bay. However, the percentage of the metals that are removed is difficult to calculate due to the observed variability and the introduction of metals from multiple sources.

The lack of data in the low salinity range (0-15) presents an additional difficulty in developing relationships between salinity and metal concentrations in Narragansett Bay. For instance, during SINBADD 2 only one station had salinities below 20. This data gap makes the interpretation of the behavior of metals in the low salinity region more difficult and less definitive. Narragansett Bay is not an especially favorable place to study the processes that operate in the low-salinity end of the mixing regime. The only areas that contain significant volumes of low salinity water are the estuary of the Taunton River, and the Seekonk River, neither of which has ever been thoroughly sampled.

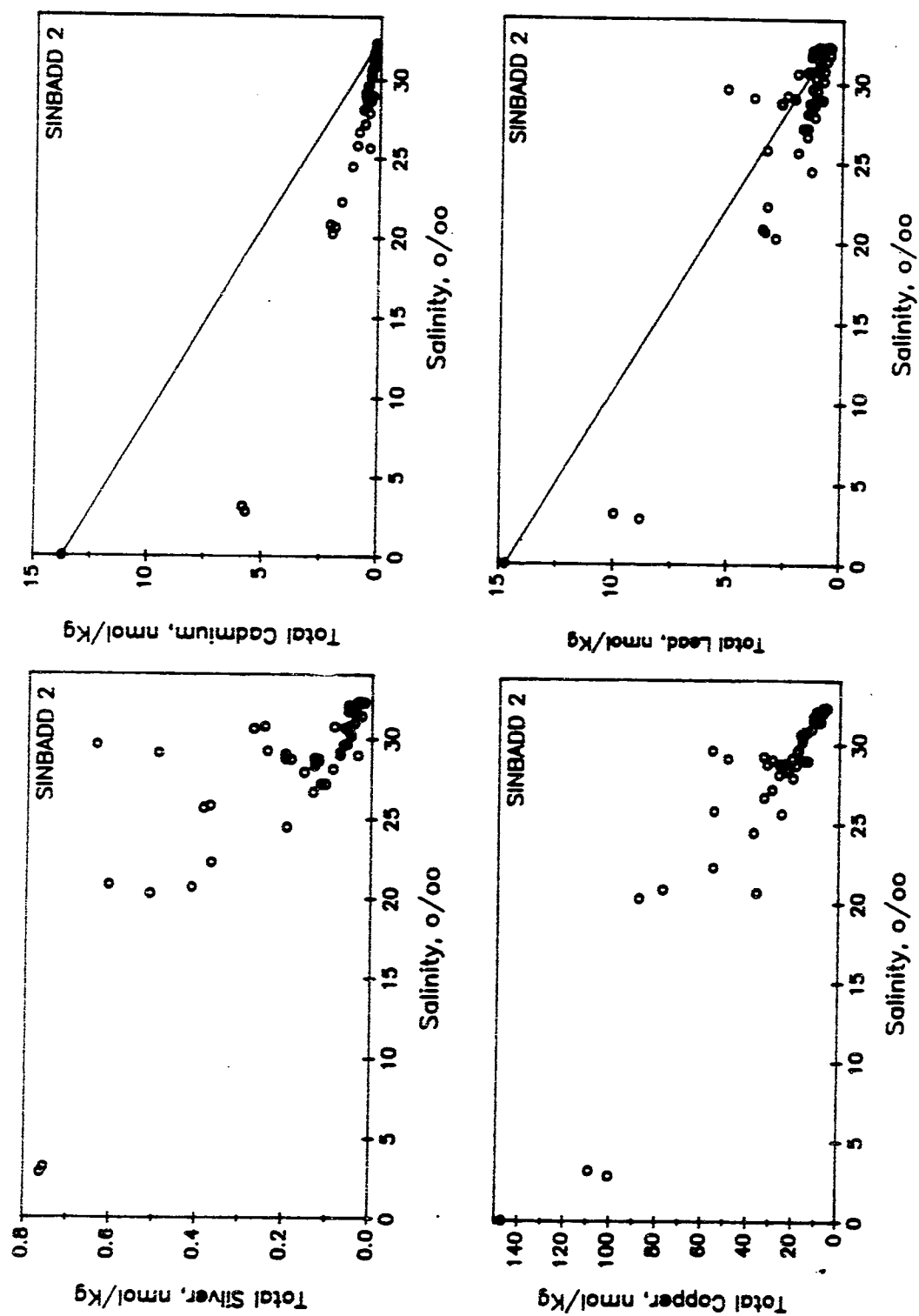


Fig. 34. Salinity versus total metal relationships observed during SINBADD 2, November 1985.

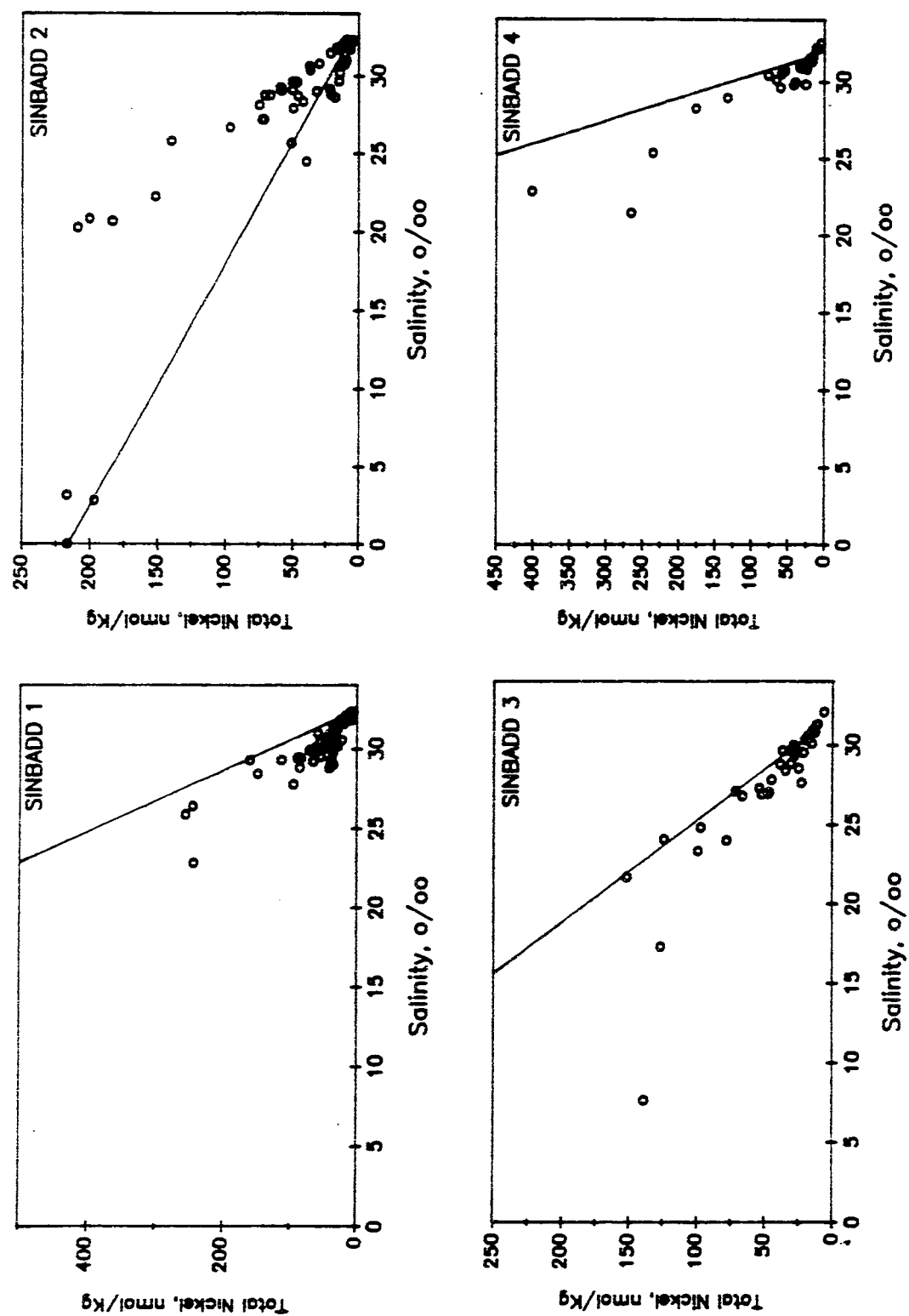


Fig. 35. Comparison of the relationship between total nickel and salinity during the four SINBADD surveys, 1985-1986. For comparison, a nickel concentration of $1 \mu\text{g/L}$ equals 17 nmol/kg .

Examination of the nickel data from all four surveys (Fig. 35) emphasizes the difficulty of using salinity versus metal relationships when more than one source introduces metal to an estuary. The calculated flow-weighted concentration of nickel in the freshwater end-member is very large (~ 1000 nmol/kg), except for SINBADD 2 where it is only 220 nmol/kg. Comparison of the actual data to the TML suggests removal of nickel from the water column for all surveys except SINBADD 2 because the nickel concentrations in the samples with low salinity all fall below the TML.

For SINBADD 2, the mixing line connecting the flow-weighted average input and Rhode Island Sound end-members is closely aligned with a small series of points that lie below the majority of the data. Close examination of the data base reveals that several of the points lying on the TML are from Mount Hope Bay, but that the majority are from the west passage. Thus, the deviations from the TML for these points are difficult to explain and indicate a complex mixing regime during this period of relatively high freshwater input.

If the salinity plot shown in Fig. 35 is regraphed with the major inputs separated into two flow-weighted discharges (Blackstone River plus Blackstone Valley and Fields Point plus East Providence), and samples from stations above Fox Point (Sta. 2) are considered as a separate segment of the bay, the effects of these two major combined sources on the mixing plot for nickel become clear (Fig. 36). The flow-weighted input concentrations for these two end-members differ by at least a factor of 3 (204 nmol/kg Blackstone versus 668 nmol/kg in the Providence River). In Fig. 36, it is evident that the nickel behavior in Narragansett Bay must be described using a mixing model with three end-members. It appears that one segment is operating between the Blackstone River and the region of the Providence River near Fields Point. The other segment appears to consist of the region from the Providence River near Fields Point discharge to Rhode Island Sound. Note further that the input of freshwater at this time below Fields Point is evident in the lower salinity found at station 3. The scatter in the relationship noted previously in the west and east passages may reflect influences from other sources in this region. However, the relationships shown in Fig. 35 suggest that nickel within Narragansett Bay is conserved relative to salinity. Close examination of the data from SINBADD 1 and 3 (Fig. 35) also suggests that a three-member mixing curve may be more appropriate for describing the relationship between nickel and salinity during these surveys.

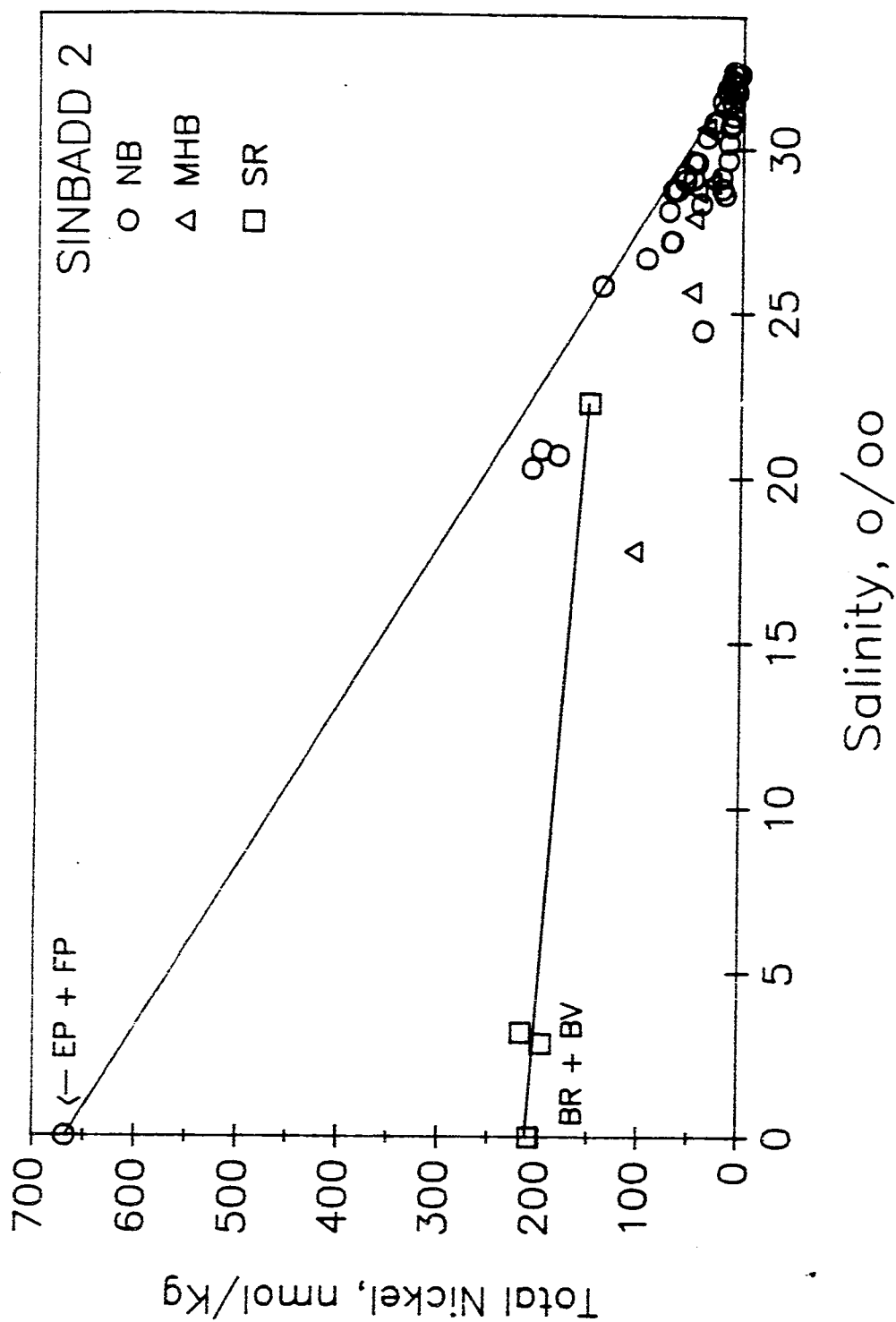


Fig. 36. Detailed analysis of effects of multiple end-member inputs to the relationship between nickel and salinity during SINBADD 2, November 1985. MHB = Mount Hope Bay, SR = Seekonk River, NB = the rest of Narragansett Bay, BR = Blackstone River, BV = Blackstone Valley POTW, FP = Fields Point Treatment Plant and EP = East Providence Treatment Plant.

The use of salinity versus metal or any other parameter within Narragansett Bay to determine removal from the water column must be carefully examined and all possibilities that may affect the relationships considered. This is particularly important for materials that are more concentrated in the treatment plants than in the rivers. Because of the complexities associated with interpreting effects of multiple source inputs and other factors causing variability within the bay, mass balance estimates may be more appropriate than salinity plots for estimating transport and deposition of metals within Narragansett Bay. As a final note, models for transport of metals in Narragansett Bay must be able to handle multiple inputs of different strengths and at different locations.

8. *Water Quality*

Concentrations of each metal from throughout the bay were compared with Environmental Protection Agency chronic Water Quality Criteria for seawater (Figs. 24 to 28). For the metals examined, only copper and nickel exceeded these water quality criteria, and these only at specific locations within the bay. Both elements were consistently higher than the criteria in the surface waters of the Providence River (Figs. 24 and 25). Nickel concentrations approached the criterion during the April survey but exceeded the criterion by at least a factor of 2 during the other surveys. In the surface waters of the Providence River, the copper criterion was exceeded by a factor of 2 on average and up to a factor of 3 at some stations. Parts of the upper bay region exceeded the copper criterion only during the April survey.

The bottom waters of this region exceeded the water quality criterion for copper only during the November and May surveys. Nickel in the bottom waters did not exceed the water quality criterion during any of the surveys.

9. *Metal Inputs*

Total inputs of metal to the bay were estimated based on the measured flow and the total metal concentration determined for each of the point sources during the monitoring surveys. Metal concentrations in several of the sewage treatment plants were reported as not detectable, particularly for SINBADD 2, 3, and 4 (Appendix Table A-10). The non-detectable results were treated as zero input even though there are metals entering the bay through these sources.

Clearly evident in the summary data (Table 13) is the effect of the non-detectable concentrations on the magnitude of the source strength estimates. For example, lead is known to be in the effluent of the treatment plants. However, because of the relatively high detection limits of the analytical method, it appears that all of the lead entering the bay is introduced through the rivers during two of the surveys. Input estimates for Ag, Cd, and Cr are similarly affected. Silver inputs differed by 350-fold between SINBADD 1 and 4. It is likely that these differences result largely from problems with the detection of the metals in the sources.

Even though significant data gaps do not allow the development of a complete picture, it is apparent that the Providence River area continues to serve as the major region for metal entry into Narragansett Bay during these non-CSO-impacted periods. These inputs are from a variety of sources including the rivers and sewage treatment plants discharging into the region. River inputs dominate the point sources to the Providence River for Cd and probably Pb. The data also suggest that a significant amount of Cd (30 percent) enters the bay from locations outside of the Providence River area. The dominant source for Ni appears to be the treatment plants but high flow may increase the relative percentage entering through the rivers (SINBADD 2). Sewage treatment plants dominate the input of Cu at all times.

10. *Preliminary Mass Balance*

Mass balance estimates were made by comparing the input to the total inventory of metal in the bay for each survey. The inventory for each metal was developed by Brooks Martin of the Narragansett Bay Project Office, using the following information and assumptions. First, the total volume of water in the bay was calculated using hypsographic information (Chinman and Nixon 1985). For this calculation, a smoothed relationship between volume and latitude was developed based on the volume histogram of Chinman. Each segment was then divided into horizontal elements and vertical layers surrounding the location of each bay station. The horizontal extent of each element was defined as the midpoint between each station. The water depth was also divided into layers, each extending to the midpoint between each succeeding depth. This procedure defined a series of volumes which could be related to the chemical concentrations measured for each depth.

The concentration of metal in each phase (dissolved and particulate) was multiplied by the volume represented by each sample. The inventory in each volume

Table 13. Summary of metal loading to Narragansett Bay from all sources sampled during the 1985-1986 bay-wide monitoring cruises. Units are in kilograms of metal/day. N.D indicates not detected in the samples.

Metal	Cruise	Total Bay Input	Providence River Total	Rivers in PR Region	%From Rivers
Ag	SB1	32.9	32.9	0.0	0
	SB2	N.D	N.D	N.D	--
	SB3	N.D	N.D	N.D	--
	SB4	0.09	0.09	0.02	22
Cd	SB1	12.3	8.4	2.4	29
	SB2	11.8	9.0	8.2	91
	SB3	5.6	2.7	2.7	100
	SB4	2.0	1.4	1.4	100
Cu	SB1	154	152	16.8	11
	SB2	147	127	52.5	41
	SB3	106	94	18.6	20
	SB4	108	81	16.8	21
Cr	SB1	11.1	11.1	3.1	28
	SB2	37.8	35.1	11.8	34
	SB3	29.4	17.2	5.4	31
	SB4	41.7	31.2	3.0	10
Ni	SB1	202	185	28	15
	SB2	98	74	50	74
	SB3	105	94	24	25
	SB4	268	260	41	16
Pb	SB1	125	80	4.1	5
	SB2	31	25	18	70
	SB3	12	7.7	7.7	100
	SB4	19	12	12	100

was then summed to give the total inventory for each metal in the bay (Table 14). If either dissolved or particulate data were missing for a depth interval, the layer was expanded vertically to account for the missing depth for that phase and no adjustments were applied to account for the missing data. This procedure probably causes small underestimates of the inventory for those metals present primarily in the dissolved phases (Cd and Ni). However, for those elements with significant partitioning between the dissolved and particulate phase (Ag, Cu, Cr, and Pb) omission of a correction factor will substantially lower the estimated inventory. This problem is probably most important in the lower bay, where large water volumes significantly influence the inventory estimates even though concentrations are relative small compared with the upper bay. Missing dissolved lead and silver data over much of the bay for SINBADD 1 result in a significant underestimate of the inventory for these metals during this survey.

The estimated total amounts of metal in the bay varied by no more than a factor of 2 between surveys. Nickel was the most abundant metal in the water column of the bay, and copper was a close second. Of the metals surveyed, silver was present in the smallest total quantities.

The inventory (Table 14) and total input estimates (Table 13) were used to estimate the residence times for the metals in the water column. The total amount of each metal during each survey was divided by the calculated daily input to the Narragansett Bay system, including Mount Hope Bay and the Sakonnett River, to obtain the residence time (Table 15). Cadmium, which is thought to be inefficiently removed in the Bay (Nixon *et al.* 1986), has surprisingly short residence times during 2 surveys (SINBADD 1 and 2) and a long residence time during SINBADD 4. The estimates for silver do not accurately reflect the residence time for this element due to the poorly quantified input estimates. Likewise, the residence time estimates for chromium during SINBADD 1 and 2 are low because of the missing particulate data.

The residence times were relatively consistent among the surveys for each of the remaining metals. Exceptions are nickel during SINBADD 2 when inputs were relatively low and the inventory was high, and lead, silver and cadmium for which data are missing during SINBADD 1. Estimates for lead may also suffer because the bay may receive significant inputs from non-point sources (Santschi *et al.* 1984). Overall, the residence time estimates scatter around an estimate of the average residence time of the water in the bay (27 days: Pilson 1985). For copper, the residence time

Table 14. Summary of the total inventory of metals in the water column of Narragansett Bay during the SINBADD cruises, 1985-1986. Units are metric tons, estimated for the whole Bay; 'd', 'p', and 't' indicate dissolved, particulate and total metal.

Metal (Phase)	SINBADD 1	SINBADD 2	SINBADD 3	SINBADD 4
Ag (d)	0.013	0.016	0.013	0.011
(p)	0.009	0.011	0.012	0.013
(t)	0.022	0.027	0.025	0.024
Cd (d)	0.092	0.136	0.125	0.095
(p)	0.007	0.003	0.009	0.009
(t)	0.099	0.139	0.134	0.104
Cu (d)	2.12	2.67	2.40	2.00
(p)	0.47	0.48	0.48	0.60
(t)	2.59	3.15	2.88	2.60
Cr (d)	0.401	0.503	0.244	0.209
(p)	--	--	0.346	0.429
(t)	>0.40	>0.50	0.59	0.64
Ni (d)	5.89	5.16	3.47	3.95
(p)	0.23	0.17	0.14	0.20
(t)	6.12	5.33	3.61	4.15
Pb (d)	0.030	0.181	0.165	0.151
(p)	0.470	0.538	0.339	0.430
(t)	0.50	0.72	0.50	0.58

Table 15. Calculated residence times (days) for metals in Narragansett Bay, 1985-1986.

Survey	Ag ^a	Cd ^a	Cu	Cr	Ni	Pb
SINBADD 1	0.7 ^b	8	17	>36 ^c	30	4 ^b
SINBADD 2	.-	12	21	>13 ^c	54	24
SINBADD 3	.-	23	27	20	34	42
SINBADD 4	66	53	24	15	15	31

a. Poor information on inputs from treatment plants.

b. Missing data from bay causes low estimate of residence time.

c. Missing data from particulate phase causes low residence time estimate.

estimates are surprisingly close to the average residence time of fresh water in the Bay. This implies relatively conservative behavior for this metal in Narragansett Bay. This is unexpected and inconsistent with previously concepts of the behavior of this metal in Narragansett Bay (Santschi *et al.* 1984, Nixon *et al.* 1986).

The reasons for this apparent inconsistency are unclear, and point to the inherent difficulties of using residence time arguments when complete and appropriate information is lacking. Residence time estimates for the SINBADD surveys could be made with greater confidence if complete information on sources, inputs rates, the effects of internal biological, chemical, and geochemical processes on the water column, and variability in these factors were available. Because many factors contribute errors to these estimates, the results should not be extrapolated too far. The information most likely to improve our ability to determine the residence times of important contaminants entering Narragansett Bay, and thus improve our understanding of the response of the bay to management decisions, is improved estimates of input to the Bay.

11. A special case, Mercury

As part of the SINBADD surveys of Narragansett Bay, a series of samples was collected and sent to Professor William Fitzgerald, University of Connecticut, for analysis. The results reported here are drawn from Vandal and Fitzgerald (1988).

Twenty samples were collected during SINBADD 3, April 7-10, 1985. Four were from rivers entering the Providence River, four were from point sources entering the Providence River, nine were surface water samples from the Providence River, Upper Narragansett Bay, Mount Hope Bay and offshore, and three were deep water samples in the Providence River (Table 16). All samples were analysed for total mercury and dissolved mercury; particulate mercury was obtained by difference. All samples were collected in ultraclean Teflon bottles according to the procedures required to avoid contamination with this metal (Gill and Fitzgerald 1987). All samples were analysed after treatment with nitric acid, and 11 also after a more vigorous cold oxidation which gave considerably greater concentrations (Table 16).

Input fluxes into Narragansett Bay were estimated by multiplying the concentrations in the various streams by the averaged flow rates at the time of sampling. The measured total inputs of mercury ranged from 28.4 grams per day to

Table 16. Concentrations of mercury in waters of Narragansett Bay and sources to the bay during SINBADD 3, April 7-10, 1985. All concentrations in pM (picomoles per liter). All samples measured after digestion with dilute nitric acid. Additional values in brackets () obtained after cold oxidation with bromine monochloride suggest the presence of a putative strongly bound fraction.

Station	Depth	Salinity	Diss. Hg	Part. Hg	Total Hg	Strongly Bound Hg
Bay Stations						
1	0.2	7.7	17.0	1.5	18.5 (26)	7.5
2	0.1	21.7	7.0	5.0	12.0	
	13.0	29.7	6.0	4.5	10.5	
4	0.3	24.8	6.5	8.5	15.0 (19)	4.0
	13.3	30.4	3.5	15.5	19.0	
5	0.3	27.8	5.5	3.5	9.0 (11)	2.0
	12.7	29.7	6.5	4.5	11.0	
7	0.5	28.8	5.5	0.5	6.0	
11	0.3	28.9	3.0	3.0	6.0	
13	0.4	29.6	4.5	1.5	6.0	
17	0.3	27.7	6.0	9.5	15.5	
22	0.9	32.3	2.0	3.5	5.5	
Input Sources						
Blackstone River			12	13	25 (36)	11
Woonasquatucket River			26	3	29 (146)	117
Moshassuck River			24	-	8 (150)	142
Pawtuxet River			18	-	16 (47)	31
Blackstone Valley WTF			14	20	34 (94)	60
Fields Point WTF			68	184	252 (346)	94
East Providence WTF			24	52	76 (135)	59
Narragansett Electric			39	-	24 (42)	20

50.6 grams per day, depending on the method of analysis used (Table 17). If it is accepted that the higher numbers are closer to the true values, then 22 grams of mercury entered the bay in a strongly bound form, not released by treatment with dilute nitric acid. The three measurements by both techniques on bay samples (Table 16) showed a much smaller difference between the two techniques. Whether this is due to chemical factors in the analysis or to a lesser real difference is not known. Assuming that the difference is real, then it would appear the strongly bound mercury is not present in the water column of the bay in the same proportion it entered. It is not known whether this is due to rapid transport of this fraction to the sediments or to release into the water under the influence of the salt present in seawater.

The sampled rivers account for 2014 km² of the Narragansett Bay drainage basin, which totals about 4708 km². Thus the total fresh water input to the bay might have amounted to $3,427 \times 4708/2014 = 8,011,000$ m³ per day. If it is assumed that the mercury concentration in the non-sampled rivers was the same as in the sampled rivers, then the riverine input of mercury may have been 37 rather than 16 grams per day, or 75 gm per day if the higher analytical results are correct.

Table 17. Input fluxes of mercury into Narragansett Bay measured during SINBADD 3. Fluxes in mmol/day and grams/day. Values in brackets are derived from measurements after cold oxidation.

	Est'd. flow 1000 m ³ /day	Flux	
		mmol/day	g/day
Blackstone River	2,444	61.0	12.2 (17.6)
Woonasquatucket River	161	4.7	0.9 (4.5)
Moshassuck River	91	0.8	0.16 (3.0)
Pawtuxet River	724	11.6	2.3 (6.8)
Rivers	3,420	78.1	15.6 (31.9)
Blackstone Valley WTP	87.1	3.0	0.6 (1.7)
Fields Point WTP	230.9	58.2	11.7 (16.1)
East Providence WTP	32.2	2.5	0.5 (0.9)
Sewage Plants	350.2	63.7	12.8 (18.7)
Total inputs			28.4 (50.6)
Narra. Elect. Cooling Water	230	5.5	1.1 (1.9)

REFERENCES

- Boyle, E. A. and J. M. Edmond. 1975.
Determination of trace metals in aqueous solution by APDC chelate co-precipitation.
Pp. 44-55 in T. R. P. Gibbs, Jr. (ed), *Analytical Methods in Oceanography*.
Amer Chem Soc. Washington DC.
- Boyle, E. A., J. M. Edmond, and E. R. Sholkovitz. 1977.
The mechanism of iron removal in estuaries.
Geochem. Cosmochim. Acta **41**: 1313-1324.
- Chinman, R. A. and S. W. Nixon. 1985.
Depth-area-volume relationships in Narragansett Bay.
NOAA/Sea Grant Marine Technical Report 87,
Graduate School of Oceanography, University of Rhode Island, Narragansett, 64p.
- Frithsen, J. B., A. A. Keller and M. E. Q. Pilson. 1985.
Effects of Inorganic Nutrient Additions in Coastal Areas: A Mesocosm Experiment
Data Report. Volume 1.
MERL Series, Report No. 3. Univ. of R.I., 176 pp.
- Gill, G. A. and W. F. Fitzgerald. 1987.
Picomolar mercury measurements in seawater and other materials using stannous
chloride reduction and two-stage gold amalgamation with gas phase detection.
Mar. Chem. **20**: 227-243.
- Hunt, C. D., P. A. Sampou, S. R. Jackson, W. M. Warren, J. D. Cullen, J. Coyne and M.
E. Q. Pilson. 1987a.
Narragansett Bay Water Quality Monitoring and Source Strength Measurements.
Cruise and Data Report, SINBADD 1, Oct. 21-24, 1985.
Marine Ecosystems Research Laboratory, GSO, University of Rhode Island,
Narragansett, RI, 78 pp.
- Hunt, C. D., W. M. Warren, P. A. Sampou, S. R. Jackson, and M. E. Q. Pilson. 1987b.
Narragansett Bay Water Quality Monitoring and Source Strength Measurements.
Cruise and Data Report, SINBADD 2, Nov. 18-21, 1985.
Marine Ecosystems Research Laboratory, GSO, University of Rhode Island,
Narragansett, RI, 96 pp.
- Hunt, C. D., M. F. Fox, W. M. Warren, S. R. Jackson, and M. E. Q. Pilson. 1987c.
Narragansett Bay Water Quality Monitoring and Source Strength Measurements.
Cruise and Data Report, SINBADD 3, Apr. 7-10, 1986.
Marine Ecosystems Research Laboratory, GSO, University of Rhode Island,
Narragansett, RI, 114 pp.
- Hunt, C. D., M. F. Fox, S. R. Jackson, and M. E. Q. Pilson. 1987d.
Narragansett Bay Water Quality Monitoring and Source Strength Measurements.
Cruise and Data Report, SINBADD 4, May 19-22, 1986.
Marine Ecosystems Research Laboratory, GSO, University of Rhode Island,
Narragansett, RI, 166 pp.

- Kester, D. R., D. W. King, W. L. Miller, D. L. Cullen and C. D. Hunt. 1987.
 Compilation of trace metal concentrations in Narragansett Bay waters.
 Technical report No. 87-9. The Graduate School of Oceanography, University of
 Rhode Island, Narragansett, 33 pp.
- Kremer, J. N. and S. W. Nixon. 1978.
A Coastal Marine Ecosystem: Simulation and Analysis.
 Springer Verlag, New York, 217 pp.
- Mayer, L. M. 1982.
 Retention of riverine iron in estuaries.
Geochem. Cosmochim. Acta **46**: 1003-1009.
- Nixon, S. W., C. D. Hunt and B. L. Nowicki. 1986.
 The retention of nutrients (C,N,P), heavy metals (Mn, Cd, Pb, Cu), and petroleum
 hydrocarbons in Narragansett Bay.
 Pp 99-122 In: P. Lasserre and J. M. Martin (eds),
Biogeochemical Processes at the Land-Sea Boundary. Elsevier, Amsterdam.
- Olsen, S. and V. Lee. 1979.
 A summary and preliminary evaluation of data pertaining to the water quality of
 upper Narragansett Bay.
 Coastal Resources Center, University of Rhode Island, Kingston, 184 pp.
- Oviatt, C. A. Undated.
 Some aspects of Water Quality in and Pollution Sources to the Providence River.
 Report to Region I, Environmental Protection Agency, Sept. 1979 – Sept. 1980,
 Contract #68-04-1002, The Marine Ecosystems Research Laboratory, Graduate
 School of Oceanography, University of Rhode Island, Kingston, 236 pp.
- Pilson, M. E. Q. 1985a.
 On the residence time of water in Narragansett Bay.
Estuaries **8**: 2-14.
- Pilson, Michael E. Q. 1985b.
 Annual cycles of nutrients and chlorophyll in Narragansett Bay, Rhode Island.
J. Mar. Res. **43**: 849-873.
- Santschi, P. H., D. M. Adler, and M. Amdurer. 1983.
 The fate of particles and particle-reactive trace metals in coastal waters:
 radioisotope studies in microcosms.
 Pp. 331-349 in: C. S. Wong, E. Boyle, K. Bruland, J. D. Burton, and E. Goldberg
 (eds),
Trace Metals in Sea Water, Plenum Publishing Corp., 1983.
- Santschi, P. H., S. W. Nixon, M. E. Q. Pilson and C. D. Hunt. 1984.
 Inputs of and accumulations of sediments, trace metals, and hydrocarbons in
 Narragansett Bay.
Est. Coast. Shelf. Sci. **19**: 427-449.

U.S.G.S. 1986.

Water Resources Data for Massachussets and Rhode Island.

Water Data Reports MA-RI-86-1.

United States Geological Survey, U.S. Dept. of the Interior, Boston MA.

(Not published at time of writing; preliminary data received through Bay Project Office.)

Vandal, G. M. and W. F. Fitzgerald. 1988.

Mercury in the waters of Narragansett Bay.

Final Report to the Narragansett Bay Project, 33 pp.

Wilke, R. J. and R. Dayal. 1982.

The behavior of iron, manganese, and silicon, in the Peconic River Estuary, New York. Estuarine, Coast. and Shelf Sci. 15: 577-586.

APPENDIX

The tables in this appendix contain most of the data collected during the four SINBADD cruises and listed in the detailed cruise reports (Hunt *et al.* 1987a, b, c, d). Items in the tables are identified below:

Station No.	Keyed to Fig. 1.
Depth	Depth, meters
Temp.	Temperature, °C.
Sal, S	Salinity
Oxy.	Oxygen, $\mu\text{mol/L} = \mu\text{M}$
TSM	Total suspended matter, milligrams/L (nutrient tables) mg/kg (trace metal tables).
TN	Total fixed nitrogen, $\mu\text{mol/L}$
TDN	Total dissolved fixed nitrogen
NH ₃	Ammonia, $\mu\text{mol/L}$
NO _x	Sum of NO ₂ ⁻ + NO ₃ ⁻ , $\mu\text{mol/L}$
DON	Dissolved organic nitrogen, $\mu\text{mol/L}$
PN	Particulate nitrogen, $\mu\text{mol/L}$
TP	Total phosphorus, $\mu\text{mol/L}$
TDP	Total dissolved phosphorus, $\mu\text{mol/L}$
I PO ₄	Inorganic (molybdate-reactive) phosphorus, $\mu\text{mol/L}$
DOP	Dissolved organic phosphorus
TPP	Total particulate phosphorus
DSi	Dissolved silica
Chl	Chlorophyll <i>a</i> , $\mu\text{g/L}$
PC	Particulate carbon
Sig-t	Sigma-t, = [density of seawater (in kg/m ³) at temperature <i>in situ</i>] - 1000. Units are kg/m ³
Ag	Silver, ng/kg = 10 ⁻⁹ gram/kg. -d = dissolved, -p = particulate
Cd	Cadmium, ng/kg, -d and -p
Cu	Copper, ng/kg, -d and -p
Cr	Chromium, ng/kg, -d and -p
Ni	Nickel, ng/kg, -d and -p
Pb	Lead, ng/kg, -d and -p

Table A-1. Temperature, salinity, oxygen and nutrient concentrations observed in Narragansett Bay during SINBADD 1, Oct. 21-24, 1985.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
2	0.4	16.64	22.82	148	2.22	73	69	31.9	25.3	11.8	5.0	6.7	6.3	4.3	2.0	0.4	37.9	1.6	51.5
	2.5	16.55	27.57	na	2.34	49	46	21.8	11.9	12.3	9.4	4.6	4.6	3.3	1.3	0.0	22.6	2.4	108.5
	5.6	16.15	29.29	132	10.63	42	36	17.0	6.6	12.4	4.2	4.1	3.8	2.6	1.2	0.3	22.7	3.4	41.8
	12.5	16.11	29.91	130	1.89	35	31	16.0	3.9	11.1	6.0	4.5	4.0	2.9	1.1	0.5	20.5	1.2	57.4
3	0.5	15.25	25.87	na	2.42	69	60	32.3	15.7	12.0	9.7	5.9	5.7	3.8	1.9	0.2	30.5	5.9	82.9
	1.8	16.16	29.29	151	4.03	54	42	19.3	9.8	1.9	13.6	6.4	4.8	2.9	1.9	1.6	24.9	9.8	117.0
	6.7	15.78	27.76	151	2.61	32	28	10.8	5.6	11.6	5.8	3.6	3.5	2.0	1.5	0.1	20.6	4.9	56.6
	12.6	15.76	30.48	148	4.63	25	24	8.5	4.2	11.3	5.2	3.8	3.1	1.8	1.3	0.7	20.3	2.4	55.6
4	0.3	15.35	26.40	322	3.01	69	55	21.5	14.6	18.9	15.6	6.4	5.0	3.4	1.6	1.4	28.9	13.7	119.0
	3.3	15.25	28.44	297	3.19	42	29	5.9	8.3	14.8	11.2	4.8	3.5	1.9	1.6	1.3	21.2	10.2	90.0
	9.9	15.70	29.51	198	4.69	26	28	5.4	4.4	18.2	5.9	4.3	3.4	1.5	1.9	0.9	19.7	3.3	60.0
5	0.4	14.50	29.43	318	1.72	27	21	2.4	3.8	14.8	6.8	4.2	3.1	1.3	1.8	1.1	18.2	6.0	55.8
	1.9	14.58	na	319	1.75	28	24	2.1	3.5	18.4	7.8	3.9	3.1	1.3	1.8	0.8	17.9	7.3	55.1
	5.8	14.91	na	300	1.82	26	20	2.2	2.8	15.0	5.1	2.7	3.1	1.2	1.9	0.0	17.0	5.3	54.7
	12.8	14.94	29.77	na	2.20	29	21	2.0	2.8	16.2	7.4	3.8	3.5	1.2	2.3	0.3	17.0	6.4	60.9
6	0.5	10.70	29.21	322	3.58	32	18	0.9	0.1	17.0	11.4	3.0	2.2	0.7	1.5	0.8	23.7	11.5	105.0
	3.3	14.41	29.21	328	3.77	34	18	0.8	0.2	17.0	11.5	3.1	2.3	0.7	1.6	0.8	24.4	11.1	108.0
7	0.5	15.06	29.78	334	2.79	27	20	0.5	1.7	17.8	9.7	3.0	2.3	1.0	1.3	0.7	15.6	8.6	86.4
	2.9	15.10	29.78	356	2.58	28	19	0.5	1.6	16.9	9.5	2.9	2.3	1.1	1.2	0.6	15.9	9.1	82.3
	5.0	15.22	30.60	313	2.98	21	17	0.8	0.5	15.7	4.7	2.8	2.3	1.0	1.3	0.5	14.2	5.7	59.0
8	0.5	15.44	31.18	288	2.97	22	19	0.9	1.1	17.0	7.2	3.0	2.1	1.1	1.0	0.9	5.8	7.3	74.6
	3.3	15.40	31.36	287	2.78	22	21	0.9	1.2	18.9	6.1	2.8	2.2	1.1	1.1	0.6	9.7	6.8	67.0
	10.8	15.35	31.45	281	3.59	19	21	1.8	1.6	17.6	3.8	3.1	2.5	1.1	1.4	0.6	15.8	4.3	57.6
	18.5	15.34	31.45	280	3.97	19	18	1.8	1.6	14.6	4.2	2.8	2.2	1.1	1.1	0.6	13.9	3.7	58.7
9	0.4	15.37	31.70	289	1.30	na	na	2.8	2.7	na	3.6	na	na	1.2	na	na	8.6	2.6	41.3
	2.9	15.62	31.90	289	1.68	20	20	2.9	2.9	14.2	3.1	3.5	3.4	1.2	2.2	0.1	9.5	3.0	39.2
	7.2	15.91	32.02	269	1.18	19	20	2.4	3.6	14.0	2.8	4.3	4.0	1.2	2.8	0.3	12.8	1.9	37.4
	11.9	15.99	32.10	252	1.96	17	20	2.7	3.7	13.6	3.3	3.1	3.6	1.3	2.3	0.0	13.3	1.5	44.7

Table A-1. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
10	0.5	15.10	28.81	478	8.24	56	31	4.8	6.7	19.5	26.0	4.8	3.2	1.6	1.6	1.6	28.6	23.3	219.0
	4.5	15.64	30.99	259	1.68	27	20	2.1	4.0	13.9	4.8	3.1	2.7	1.3	1.4	0.4	18.9	3.6	45.3
11	0.3	14.50	29.39	338	0.88	27	24	2.3	5.4	16.3	5.2	4.0	3.5	1.4	2.1	0.5	17.2	5.7	45.9
	4.9	15.00	30.11	334	1.32	28	22	1.5	5.1	15.4	6.4	3.6	3.3	1.5	1.8	0.3	20.4	8.3	55.5
	8.1	15.86	31.24	241	3.85	26	25	3.7	4.3	17.0	5.4	3.1	3.2	1.5	1.7	0.0	20.5	3.8	54.2
12	0.3	15.60	30.05	338	1.79	31	25	1.2	4.9	18.9	10.9	4.8	3.6	1.5	2.1	1.2	19.2	9.6	87.1
	7.2	15.40	30.12	313	1.38	28	24	2.4	4.9	16.7	4.5	4.7	2.5	1.6	0.9	2.2	18.6	5.0	51.0
	15.0	15.81	31.21	269	3.15	22	27	3.2	4.2	19.6	3.9	4.9	3.7	1.5	2.2	1.2	16.1	2.5	46.2
13	0.5	15.25	30.70	300	1.43	25	19	1.7	2.8	14.5	5.4	3.0	2.8	1.2	1.6	0.2	13.4	5.8	51.2
	4.9	15.60	30.78	253	1.78	24	16	1.4	2.5	12.1	4.6	3.1	2.9	1.2	1.7	0.2	13.1	6.8	48.6
	15.2	15.98	31.58	231	2.40	21	na	3.4	3.6	na	2.9	3.1	na	1.4	na	na	14.3	2.6	40.1
	25.5	16.08	31.93	na	4.36	21	21	3.6	4.1	13.3	3.0	3.3	2.9	1.4	1.5	0.4	15.4	0.8	47.2
14	0.5	15.01	30.64	325	1.54	22	18	0.7	1.2	16.1	5.9	2.3	2.2	1.1	1.1	0.1	11.8	4.7	53.2
	5.1	15.47	30.95	288	1.41	27	19	1.9	3.1	14.0	3.8	2.9	2.2	1.3	0.9	0.7	16.6	3.9	45.2
	8.4	15.81	31.21	263	2.69	27	24	2.9	3.4	17.7	3.6	2.7	2.5	1.4	1.1	0.2	18.3	4.4	47.1
15	0.7	15.77	31.49	263	1.21	21	27	2.5	2.9	21.6	3.5	2.8	3.4	1.3	2.1	0.0	12.0	2.2	42.6
	6.8	15.81	31.84	272	1.84	21	21	2.5	3.1	15.4	2.6	3.5	3.3	1.2	2.1	0.2	12.7	1.6	38.3
	20.2	16.04	32.03	259	1.30	40	28	2.8	3.9	21.3	3.1	4.6	3.6	1.3	2.3	1.0	17.4	1.4	34.1
	33.6	16.10	32.06	na	1.79	18	21	2.5	4.5	14.0	2.4	4.1	3.7	1.3	2.4	0.4	17.7	1.0	40.2
16	0.5	16.03	32.07	251	1.56	17	19	2.6	3.9	12.5	2.4	3.6	3.1	1.3	1.8	0.5	13.6	1.4	34.2
	6.0	16.09	32.08	245	1.81	18	24	2.5	3.7	17.8	2.1	4.0	3.2	1.2	2.0	0.8	12.8	1.4	38.3
	17.6	16.13	32.24	258	1.24	19	na	1.8	2.5	na	1.7	3.2	na	1.0	na	na	8.2	1.8	32.7
17	0.4	17.12	28.79	303	3.34	37	30	1.9	9.6	18.5	10.0	4.9	4.6	2.0	2.6	0.3	24.9	10.9	88.7
	4.0	15.78	29.98	247	2.16	28	27	3.2	6.5	17.3	4.6	4.9	4.3	1.8	2.5	0.6	21.4	4.9	51.4
	8.8	15.76	30.22	244	2.15	26	30	3.4	5.9	20.7	3.8	4.4	4.2	1.8	2.4	0.2	19.5	3.8	50.8

Table A-1. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
18	0.2	15.80	29.00	na	4.60	51	31	0.6	6.9	23.5	25.6	6.4	3.0	1.8	1.2	3.4	21.4	28.4	185.5
	1.4	15.37	29.26	360	2.07	36	25	0.3	7.5	17.2	9.4	5.2	3.7	1.8	1.9	1.5	20.9	16.9	75.9
	5.4	15.38	29.32	328	2.36	37	23	0.4	7.3	15.3	8.8	4.9	3.8	1.7	2.1	1.1	20.4	14.0	76.1
	8.5	15.54	30.53	281	2.07	26	26	na	na	na	4.8	4.6	3.9	na	na	0.7	na	5.8	53.4
19	0.4	15.58	30.18	313	3.14	35	26	3.3	4.9	17.8	9.6	5.0	4.2	1.8	2.4	0.8	17.2	10.1	83.6
	2.4	15.55	30.24	322	2.93	37	28	3.6	5.5	17.9	9.0	4.9	4.3	2.1	2.2	0.6	23.0	8.7	84.6
	4.7	14.75	30.54	325	2.16	26	22	2.4	3.2	16.4	5.1	5.0	3.9	1.6	2.3	1.1	22.7	2.8	58.6
	10.8	15.77	31.97	294	1.95	na	15	1.8	0.9	12.3	3.4	2.5	2.5	0.9	1.6	0.0	4.5	2.9	52.1
20	0.4	15.97	31.81	309	1.47	14	16	0.8	0.7	14.5	6.1	2.1	2.0	0.8	1.2	0.1	4.2	3.9	64.1
	1.8	15.97	31.82	294	1.50	15	14	1.0	0.7	12.3	3.2	2.3	1.7	0.9	0.8	0.6	4.7	3.8	49.4
	5.8	15.77	31.86	296	1.42	15	12	2.0	1.0	9.0	3.5	2.5	1.8	0.9	0.9	0.7	4.5	3.4	50.9
	10.8	15.77	31.97	294	1.95	na	15	1.8	0.9	12.3	3.4	2.5	2.5	0.9	1.6	0.0	4.5	2.9	52.1
21	0.5	16.32	32.13	294	1.04	17	19	1.4	2.3	15.3	5.2	2.6	2.0	1.0	1.0	0.6	8.4	2.1	58.3
	5.1	16.31	32.14	287	0.94	16	15	1.5	2.3	11.2	4.3	2.4	1.9	1.0	0.9	0.5	7.7	1.9	53.4
	14.4	16.12	32.27	283	1.03	28	12	1.4	2.2	8.4	3.0	2.2	1.7	0.9	0.8	0.5	7.0	3.3	52.7
	24.4	16.15	32.33	na	0.84	13	9	0.8	1.4	6.8	3.1	2.0	1.8	0.8	1.0	0.2	5.7	2.2	50.5
22	0.5	16.33	32.27	293	1.24	28	22	0.8	1.6	19.6	4.2	2.1	2.8	0.8	2.0	0.0	5.7	2.7	51.9
	4.4	16.15	32.19	284	1.64	13	12	1.1	1.7	9.2	2.9	2.3	1.7	0.9	0.8	0.6	5.3	3.7	47.5
	13.4	16.13	32.16	269	1.10	14	20	1.0	0.8	18.2	2.2	2.2	1.9	0.7	1.2	0.3	4.0	1.8	48.3
	22.3	16.28	32.30	na	2.00	14	15	1.8	3.4	9.8	2.4	2.5	2.1	0.5	1.6	0.4	11.7	1.0	47.5

Table A-2 Temperature, salinity, oxygen and nutrient concentrations observed in Narragansett Bay during SINBADD 2, Nov. 18-21, 1985.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM	DOC μM
1	0.1	na	2.84	na	5.52	103	96	34.0	40.0	22.0	9.8	9.6	8.0	4.2	3.8	1.6	50.6	0.65	96.1	na
	2.0	na	3.17	na	5.90	112	104	38.8	37.9	27.3	11.5	11.6	9.4	5.6	3.8	2.2	50.7	0.65	109.0	na
2	0.4	11.50	22.25	na	1.63	56	51	19.1	15.0	16.9	6.3	5.6	5.2	2.5	2.7	0.4	46.0	0.10	63.7	3.0
	2.1	12.00	25.80	247	1.74	47	45	16.6	9.8	18.6	6.3	4.8	4.6	2.1	2.5	0.2	35.4	0.30	63.0	na
	4.4	11.37	28.74	247	1.85	38	33	12.6	6.1	14.3	5.6	4.7	4.2	1.9	2.3	0.5	27.5	0.40	62.3	4.5
	10.7	11.37	29.23	228	2.62	36	33	13.0	4.8	15.2	4.4	5.4	4.1	2.0	2.1	1.3	25.9	0.35	44.3	3.3
3	0.4	11.29	20.87	272	2.49	66	63	25.8	17.6	19.6	6.5	6.0	5.5	2.7	2.8	0.5	52.2	0.50	64.3	3.4
	1.9	11.31	20.67	259	2.24	47	43	16.1	10.4	16.5	4.9	5.2	4.5	2.1	2.4	0.7	36.0	0.50	46.7	2.7
	6.6	11.39	29.08	256	10.0	34	29	9.2	5.5	14.3	6.9	4.7	4.0	1.6	2.4	0.7	25.6	0.60	72.5	na
	11.5	11.54	29.60	na	12.3	34	27	8.7	5.0	13.3	12.2	5.3	3.6	1.6	2.0	1.7	24.6	1.00	117.0	2.3
4	0.7	11.43	20.27	288	1.87	72	66	26.6	18.3	21.1	6.7	6.0	5.3	2.6	2.7	0.7	49.1	2.35	61.1	3.5
	4.7	11.26	29.04	266	2.42	32	32	na	na	na	4.8	4.6	4.1	na	na	0.5	na	0.75	49.8	2.8
	11.1	11.61	30.15	263	73.1	45	26	6.9	4.9	14.2	33.0	6.8	4.1	1.6	2.5	2.7	23.6	3.55	370.0	2.9
5	0.5	10.96	26.65	na	1.12	42	38	11.6	9.2	17.2	4.5	4.1	3.7	1.8	1.9	0.4	32.4	1.10	45.5	na
	5.1	11.08	28.05	300	1.51	35	33	8.6	7.0	17.4	3.7	3.4	3.4	1.5	1.9	0.0	29.8	1.75	35.9	na
	10.6	11.01	28.74	278	2.23	34	29	8.2	6.1	14.7	4.4	3.6	3.1	1.5	1.6	0.5	27.5	2.00	41.3	na
6	0.6	9.67	27.17	300	2.38	42	32	8.3	8.1	15.6	6.6	4.1	3.2	1.3	1.9	0.9	33.5	4.70	67.8	na
	2.9	9.51	27.17	297	2.54	47	34	8.2	7.8	18.0	6.8	4.6	3.5	1.3	2.2	1.1	32.9	4.40	63.2	na
7	0.9	10.67	28.10	na	2.53	43	31	6.7	5.6	18.7	7.4	3.9	3.4	1.4	2.0	0.5	25.6	6.35	74.1	2.5
	3.1	10.68	28.12	336	2.42	40	30	7.3	6.2	16.5	7.2	3.8	3.2	1.5	1.7	0.6	28.4	6.75	74.3	na
	5.0	10.61	29.13	316	2.55	36	26	5.0	4.7	16.3	8.0	3.6	3.3	1.3	2.0	0.3	25.7	5.90	70.3	na
8	1.0	10.87	30.17	331	2.45	29	20	2.2	2.6	15.2	11.4	3.4	4.0	1.1	2.9	0.0	21.2	7.30	94.7	1.6
	4.4	10.82	30.35	325	2.71	33	22	2.4	2.6	17.0	9.8	3.7	3.0	1.1	1.9	0.7	20.7	4.70	83.9	na
	10.1	10.93	30.54	319	2.94	28	20	2.8	2.7	14.5	4.4	4.8	3.4	1.1	2.3	1.4	19.8	2.75	46.4	na
	16.2	11.03	30.67	319	3.87	23	19	3.4	2.6	13.0	3.7	3.5	3.5	1.1	2.4	0.0	19.3	1.80	45.7	1.9

Table A-2 Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM	DOC μM
9	1.2	11.09	30.99	na	2.22	21	18	2.5	2.6	12.9	5.0	3.6	3.3	1.1	2.2	0.3	17.2	0.90	51.6	2.0
	3.2	11.43	31.24	306	2.70	27	15	2.5	2.5	10.0	3.7	3.6	4.3	1.1	3.2	0.0	15.7	1.35	41.8	na
	7.3	12.23	31.66	300	2.42	21	16	2.4	3.0	10.6	4.9	4.0	3.3	1.1	2.2	0.7	13.2	2.65	50.3	1.3
	11.8	12.28	31.71	294	3.44	na	15	2.4	2.9	9.7	4.5	na	5.3	1.1	4.2		13.2	2.30	50.6	1.1
10	0.7	11.27	24.46	313	0.58	54	47	15.7	12.6	18.7	5.6	4.3	3.8	2.0	1.8	0.5	37.4	2.45	50.2	2.5
	5.7	11.16	28.78	278	1.64	36	32	8.5	6.1	17.4	4.5	3.8	3.4	1.6	1.8	0.4	26.7	3.40	44.6	1.9
11	0.6	11.38	28.60	319	1.09	33	29	7.1	6.5	15.4	4.3	3.7	4.8	1.6	3.2	0.0	26.5	1.90	43.1	2.3
	6.2	11.67	30.08	316	1.27	29	25	5.6	4.9	14.5	4.7	3.6	3.7	1.5	2.2	0.0	21.4	2.65	43.6	1.4
	10.2	11.90	30.75	297	3.24	25	24	5.6	4.1	14.3	4.0	3.6	3.3	1.5	1.8	0.3	19.7	0.75	48.2	1.7
12	0.6	11.16	28.32	300	1.46	36	28	7.4	6.9	13.7	3.2	3.6	3.5	1.6	1.9	0.1	27.8	2.35	36.4	na
	7.5	11.27	28.87	291	1.82	37	27	6.8	6.6	13.6	4.0	4.1	3.5	1.6	1.9	0.6	26.9	3.00	44.1	na
	15.4	11.90	30.47	263	1.75	26	22	5.1	4.5	12.4	2.8	3.5	3.3	1.4	1.9	0.2	20.2	1.10	40.7	na
	21.8	11.92	30.75	na	2.28	23	20	5.1	3.9	11.0	2.1	3.2	2.9	1.4	1.5	0.3	18.3	0.65	34.0	na
13	0.7	11.26	29.66	303	1.39	28	22	4.4	4.7	12.9	3.7	3.8	3.3	1.3	2.0	0.5	22.3	1.75	40.4	na
	4.5	11.59	30.23	297	1.77	28	21	4.7	4.7	11.6	3.4	3.4	3.5	1.4	2.1	0.0	20.6	2.60	38.1	na
	12.4	12.01	31.15	266	1.94	27	22	4.7	4.7	12.6	3.1	3.5	3.5	1.4	2.1	0.0	21.6	2.95	36.4	na
	20.3	12.32	31.71	269	4.45	20	17	3.4	3.4	10.2	2.6	3.3	2.6	1.2	1.4	0.7	14.5	0.60	38.6	na
14	1.0	11.14	29.57	316	1.56	28	22	3.6	4.5	13.9	4.0	4.4	3.2	1.3	1.9	1.2	22.6	1.65	46.6	na
	5.3	11.32	29.99	288	2.04	28	21	3.6	4.0	13.4	3.6	3.2	3.1	1.3	1.8	0.1	21.2	2.20	45.9	na
	8.6	11.77	30.78	281	2.37	27	20	4.2	4.0	11.8	4.4	3.5	2.7	1.3	1.4	0.8	18.9	2.70	54.6	na
15	1.5	11.25	30.34	297	2.03	27	19	2.8	3.7	12.5	5.8	3.9	5.2	1.3	3.9	0.0	19.5	4.15	56.9	na
	7.5	11.33	30.58	309	1.63	27	19	2.7	3.5	12.8	4.4	3.7	3.4	1.2	2.2	0.3	18.8	3.35	48.1	na
	21.3	12.10	31.48	294	1.56	21	16	2.8	3.2	10.0	3.3	3.6	3.2	1.2	2.0	0.4	14.6	1.75	46.7	na
	36.7	12.45	32.07	na	9.17	25	15	2.4	2.9	9.7	5.0	3.4	3.1	1.1	2.0	0.3	11.0	1.20	59.0	na
16	1.4	11.85	31.43	306	1.56	22	18	2.7	3.3	12.0	3.7	4.3	3.1	1.2	1.9	1.2	14.2	1.75	43.2	1.3
	7.7	12.49	31.87	300	1.26	21	15	2.6	3.1	9.3	2.1	3.4	4.9	1.2	3.7	0.0	12.7	2.00	32.4	na
	19.8	12.75	32.24	297	2.10	19	16	2.0	2.9	11.1	2.0	3.9	3.7	1.1	2.6	0.2	9.9	1.15	29.4	na
	34.5	12.82	32.28	na	4.33	16	25	2.0	3.1	19.9	3.0	3.2	3.3	1.1	2.2	0.0	10.6	0.90	37.3	2.0

Table A-2 Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM	DOC μM
17	0.5	13.26	25.64	319	3.04	48	37	8.5	10.1	18.4	6.9	4.7	4.1	2.1	2.0	0.6	39.2	8.30	66.7	na
	5.9	11.95	26.46	319	2.75	46	33	7.0	8.7	17.3	6.1	4.6	3.8	2.0	1.8	0.8	36.5	9.70	53.8	na
	9.9	11.25	28.69	275	3.99	32	27	6.2	5.8	15.0	2.8	3.8	3.4	1.7	1.7	0.4	27.7	0.50	34.5	na
18	0.5	11.53	27.89	313	1.71	39	29	5.7	7.2	16.1	6.5	3.5	3.0	1.7	1.3	0.5	30.7	5.50	57.5	na
	7.5	11.37	29.24	309	1.74	28	27	6.1	5.6	15.3	2.8	2.8	2.8	1.6	1.2	0.0	25.3	0.65	33.1	na
	15.0	11.81	30.61	278	4.00	25	23	5.2	4.5	13.3	3.4	3.5	2.6	1.5	1.1	0.9	20.0	0.55	37.8	na
19	0.6	10.88	28.96	309	1.34	32	29	7.1	5.2	16.7	6.4	3.8	3.4	1.7	1.7	0.4	27.2	1.85	45.0	na
	3.8	10.81	28.99	291	1.63	33	27	7.3	5.3	14.4		4.1	3.8	1.7	2.1	0.3	28.9	1.45	36.5	na
20	0.7	11.21	31.41	303	4.24	25	28	3.1	2.4	22.5	6.1	3.3	2.8	1.1	1.7	0.5	11.6	2.85	56.0	na
	6.1	11.60	31.43	303	4.17	26	27	4.0	2.5	20.5	5.0	3.3	3.2	1.1	2.1	0.1	11.7	2.20	48.4	na
	11.0	11.65	31.95	294	4.84	17	17	3.9	2.5	10.6	5.1	3.3	2.5	1.0	1.5	0.8	8.0	1.85	51.2	na
21	0.5	12.51	31.78	291	2.51	22	18	2.1	2.9	13.0	5.9	3.2	2.7	1.1	1.6	0.5	12.4		55.5	1.3
	5.2	12.52	32.04	297	1.86	21	15	2.1	2.8	10.1	4.7	2.8	2.5	1.1	1.4	0.3	11.2	1.40	43.5	na
	14.5	12.70	32.15	288	2.06	16	16	2.0	2.8	11.2	3.4	3.0	2.6	1.1	1.5	0.4	10.2	0.85	34.0	na
	23.8	12.86	32.31	na	2.80	18	14	1.9	2.9	9.2	3.8	3.2	2.5	1.0	1.5	0.7	10.2	0.95	42.9	1.4
22	0.5	12.46	32.25	300	2.44	17	19	1.8	1.9	15.3	3.6	2.7	2.8	1.0	1.8	0.0	6.1		39.7	1.1
	5.2	12.30	32.27	294	3.25	21	18	1.7	1.9	14.4	3.8	2.6	2.3	1.0	1.3	0.3	6.2	1.90	38.9	na
	14.0	12.22	32.25	291	2.50	20	14	1.8	1.9	10.3	3.2	2.9	2.2	1.0	1.2	0.7	5.8	1.95	41.4	na
	22.7	12.22	32.27	na	3.56	19	19	1.7	1.8	15.5	4.5	2.8	2.5	1.0	1.5	0.3	5.8	1.60	45.4	1.4

Table A-3 Temperature, salinity, oxygen and nutrient concentrations observed in Narragansett Bay during SINBADD 3 April 7-10, 1986.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
1	0.2	7.63	na	303	2.80	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	2.0	17.29	na	na	4.09	72	67	28.3	1.1	37.6	11.6	7.9	4.6	2.6	2.0	3.3	30.1	7.0	94.8
2	0.1	23.34	8.40	303	2.14	53	50	17.0	0.7	31.9	10.5	2.2	3.4	1.7	1.7	na	18.2	7.8	80.4
	1.7	26.94	7.06	na	2.84	27	18	4.7	0.2	13.1	12.4	2.0	3.3	0.7	2.6	na	2.8	11.8	89.3
	13.0	29.65	5.99	257	2.48	15	11	3.5	0.0	7.5	7.2	2.3	3.6	0.9	2.7	na	1.4	3.3	61.3
3	0.3	24.00	7.60	332	2.69	33	23	7.2	0.3	15.5	14.0	2.0	2.0	0.6	1.4	na	3.8	13.7	94.1
	2.1	27.11	7.17	na	2.66	26	16	2.8	0.2	13.0	13.8	5.0	5.0	0.4	4.6	na	1.6	14.5	96.7
	12.2	29.99	6.05	277	3.97	16	9	0.4	0.0	8.6	8.6	3.2	3.2	0.4	2.8	na	1.9	2.9	61.0
4	0.3	24.82	7.70	na	3.51	54	26	6.1	0.4	19.5	17.5	4.4	4.4	0.2	4.2	na	3.5	18.8	109.1
	2.2	27.29	7.11	332	2.41	33	16	2.8	0.2	13.0	11.2	3.0	3.0	0.3	2.7	na	2.1	10.1	72.4
	13.3	30.34	6.00	294	6.16	21	10	0.4	0.0	9.6	8.3	2.1	2.1	0.4	1.7	na	2.0	3.6	58.9
5	0.3	27.81	8.00	na	1.62	28	14	0.4	0.0	13.6	9.2	2.3	2.3	0.1	2.2	na	0.4	4.7	62.5
	3.3	28.32	7.80	na	1.81	26	11	0.3	0.0	10.7	12.6	2.2	2.2	0.2	2.0	na	0.2	5.0	74.4
	12.7	29.65	6.83	298	2.51	18	9	0.5	0.0	8.5	8.8	2.2	2.2	0.4	1.8	na	1.4	3.3	60.1
6	1.0	26.91	na	281	2.08	32	15	1.3	0.1	13.6	12.9	3.3	2.0	0.2	1.8	1.3	1.9	2.7	87.2
	3.0	27.03	na	292	2.37	30	15	1.2	0.1	13.7	12.5	2.9	1.9	0.2	1.7	1.0	1.5	2.4	77.5
7	0.5	28.79	7.58	324	1.25	23	12	0.4	0.0	11.6	6.7	2.5	1.6	0.2	1.4	0.9	0.4	1.3	46.6
	4.3	28.97	7.47	301	1.46	25	12	0.3	0.0	11.7	8.7	2.7	1.9	0.2	1.7	0.8	0.4	1.3	58.6
	6.1	29.73	6.77	na	2.16	21	12	0.4	0.0	11.6	8.6	2.6	2.0	0.3	1.7	0.6	1.2	1.3	61.0
8	0.4	29.84	7.18	208	1.93	21	15	0.4	0.0	14.6	10.7	2.3	1.3	0.3	1.0	1.0	0.7	1.1	57.1
	10.1	30.48	6.66	na	3.01	17	9	0.5	0.0	8.5	6.6	2.2	1.8	0.3	1.5	0.4	0.7	1.3	45.9
	20.8	30.64	6.46	314	5.17	16	11	0.6	0.0	10.4	6.3	1.9	1.3	0.3	1.0	0.6	0.7	1.8	48.5
9	0.4	30.40	6.93	313	1.56	17	11	0.6	0.0	10.4	5.8	1.9	1.4	0.3	1.1	0.5	0.6	1.7	44.2
	6.2	31.79	5.55	na	3.36	15	11	1.0	0.0	10.0	4.1	2.2	1.5	0.4	1.1	0.7	0.4	1.5	48.3
	11.5	31.79	5.54	331	11.54	13	9	0.9	0.0	8.1	4.9	2.3	2.0	0.4	1.6	0.4	0.4	1.8	39.5

Table A-3 Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
10	0.3	26.79	8.09	376	2.84	38	19	0.7	0.2	18.1	14.0	3.1	2.1	0.1	2.0	1.0	1.3	10.4	89.1
	6.1	30.43	5.93	337	2.05	14	11	0.2	0.1	10.7	6.4	2.3	2.0	0.4	1.6	0.3	1.9	1.5	38.1
11	0.3	28.83	7.23	319	1.57	26	12	0.4	0.0	11.6	6.9	3.2	2.1	0.2	1.9	1.1	0.4	1.3	49.0
	5.5	30.23	6.06	na	1.13	13	8	0.3	0.0	7.7	5.2	2.9	2.2	0.3	1.9	0.7	1.0	1.3	42.5
	10.3	30.98	5.44	308	1.41	14	7	0.3	0.0	6.7	4.0	2.7	1.8	0.4	1.4	0.9	1.5	1.2	38.1
12	0.3	28.39	7.60	327	1.38	25	13	0.6	0.0	12.4	8.8	3.1	2.1	0.2	1.9	1.0	0.5	1.8	61.1
	11.3	29.72	6.49	331	1.60	15	9	0.3	0.0	8.7	5.1	2.6	2.0	0.3	1.7	0.6	0.8	1.5	49.0
	14.7	30.23	6.37	na	1.47	na	10	0.3	0.0	9.7	4.3	na	2.0	0.3	1.7	na	1.1	1.6	44.5
13	0.4	29.58	7.00	321	0.92	18	11	0.5	0.0	10.5	6.2	3.0	2.1	0.3	1.8	0.9	0.6	1.0	47.2
	10.2	30.14	6.34	312	0.74	17	10	0.4	0.0	9.6	4.8	3.0	2.4	0.5	1.9	0.6	0.8	1.0	36.3
	16.6	31.30	5.69	na	1.63	14	9	0.8	0.0	8.2	2.8	2.6	2.5	0.5	2.0	0.1	1.7	0.8	23.7
14	0.3	29.29	7.30	317	1.42	15	13	0.4	0.1	12.5	7.3	3.2	2.1	0.2	1.9	1.1	0.8	0.8	49.8
	8.4	31.28	5.47	305	0.80	12	10	0.9	0.1	9.0	2.8	3.1	2.5	0.5	2.0	0.6	2.2	0.7	24.9
15	0.3	30.82	6.10	322	0.92	14	10	0.5	0.0	9.5	2.9	2.7	2.3	0.3	2.0	0.4	0.5	1.0	27.0
	7.9	30.96	5.99	na	0.90	12	8	0.4	0.0	7.6	2.9	2.5	2.7	0.4	2.3	0.0	0.6	1.1	24.5
	17.7	31.62	5.76	326	1.06	12	8	0.3	0.0	7.7	2.8	2.8	2.3	0.4	1.9	0.5	0.4	1.3	25.5
	32.7	32.07	5.54	na	2.13	9	6	0.5	0.0	5.5	2.4	3.2	2.2	0.4	1.8	1.0	0.8	1.1	22.3
16	0.5	31.49	5.80	324	1.08	14	11	0.4	0.0	10.6	4.1	2.5	2.2	0.4	1.8	0.3	0.4	1.6	35.0
	13.0	32.05	5.46	na	2.11	17	9	0.3	0.0	8.7	3.0	2.1	1.8	0.4	1.4	0.3	0.4	1.3	27.8
	26.8	32.27	5.50	329	2.88	13	7	0.3	0.0	6.7	3.1	1.9	1.5	0.4	1.1	0.4	0.3	1.5	29.9
17	0.3	27.62	7.81	314	2.30	22	14	0.5	0.0	13.5	13.2	3.4	2.7	0.5	2.2	0.7	0.5	10.4	86.8
	3.1	28.05	7.58	na	2.92	21	13	0.5	0.1	12.4	10.8	3.2	2.7	0.4	2.3	0.5	0.4	9.9	70.7
	10.9	29.53	6.57	302	5.03	23	10	0.4	0.0	9.6	8.8	3.8	2.6	0.3	2.3	1.2	0.6	4.3	62.6

Table A-3 Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₄ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
18	0.2	28.52	7.40	317	1.21	18	10	0.4	0.0	9.6	7.2	3.2	2.2	0.2	2.0	1.0	0.3	1.7	50.7
	5.3	29.08	6.90	307	1.30	18	10	0.4	0.0	9.6	7.8	3.8	2.6	0.3	2.3	1.2	0.6	1.6	52.5
	13.3	30.57	5.90	na	2.44	13	8	0.4	0.0	7.6	7.2	3.1	2.6	0.4	2.2	0.5	1.3	1.4	67.1
19	0.1	30.09	7.40	295	1.40	21	15	0.5	0.0	14.5	7.4	3.6	2.7	0.4	2.3	0.9	1.2	2.6	47.8
	5.9	30.81	7.03	297	3.07	21	9	0.6	0.1	8.3	8.9	4.1	2.7	0.5	2.2	1.4	1.6	4.0	56.7
21	0.7	32.11	6.00	336	1.16	7	10	0.2	0.0	9.8	3.1	1.7	1.4	0.4	1.0	0.3	0.2	1.0	35.8
	12.8	32.26	5.50	na	1.29	8	7	0.2	0.0	6.8	3.4	1.5	1.5	0.4	1.1	0.0	0.1	1.2	33.6
	25.7	32.32	5.15	337	3.79	9	5	0.3	0.0	4.7	3.7	2.0	1.9	0.4	1.5	0.1	0.5	2.0	42.7
22	0.9	32.23	6.00	335	1.05	11	7	0.5	0.0	6.5	1.9	2.2	1.7	0.4	1.3	0.6	0.1	1.0	25.0
	11.6	32.27	5.98	na	0.83	10	7	0.3	0.0	6.7	2.2	2.3	1.5	0.3	1.2	0.8	0.3	1.0	25.3
	22.0	32.48	5.46	332	2.62	10	8	0.5	0.0	7.5	2.4	2.7	1.7	0.4	1.3	1.0	0.7	2.1	29.2

Table A-4 Temperature, salinity, oxygen and nutrient concentrations observed in Narragansett Bay during SINBADD 4 May 19-22, 1986.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
2	0.4	16.70	21.40	247	5.61	106	79.0	22.0	27.6	29.4	18.5	8.4	4.5	3.3	1.2	3.9	3.3	34.9	153.3
	4.4	15.40	28.20	na	4.44	59	43.0	15.2	8.3	19.5	7.7	6.0	4.0	2.5	1.5	2.0	6.3	15.0	66.9
	11.8	11.20	30.40	236	3.53	59	52.0	29.7	3.8	18.5	4.9	11.0	9.0	7.7	1.3	2.0	16.5	4.9	56.1
3	0.4	18.00	22.80	318	7.83	123	73.0	18.8	21.2	33.0	24.1	8.0	4.0	2.1	1.9	4.0	4.8	67.9	183.7
	4.3	16.50	28.90	na	5.49	42	28.0	4.3	2.3	21.4	10.8	4.0	3.0	1.2	1.8	1.0	4.2	10.8	95.3
	11.3	13.20	30.50	237	8.65	36	22.0	8.6	1.3	12.1	9.8	5.0	3.0	2.0	1.0	2.0	8.3	7.8	101.5
4	0.5	18.20	25.30	312	6.34	64	39.0	5.0	6.8	27.2	19.7	5.0	3.0	0.8	2.2	2.0	2.1	25.8	149.6
	5.5	15.70	30.10	na	5.54	34	17.0	0.6	0.3	16.1	12.1	4.0	2.0	0.6	1.4	2.0	4.3	8.1	109.5
	15.3	14.00	30.70	259	14.80	32	14.0	0.9	0.1	13.0	15.1	4.0	2.0	0.7	1.3	2.0	6.4	9.1	132.5
5	0.4	15.80	30.93	296	2.53	19	15.0	0.5	0.1	14.4	7.7	3.0	3.0	0.4	2.6	0.0	2.0	4.8	65.5
	5.9	15.80	30.93	na	3.30	20	17.0	0.4	0.1	16.5	6.1	3.0	3.0	0.4	2.6	0.0	2.1	4.8	54.2
	12.7	15.70	30.95	299	5.15	20	22.0	0.4	0.1	21.5	7.7	4.0	2.0	0.4	1.6	2.0	2.1	4.7	73.2
6	0.5	18.80	29.80	314	4.71	34	20.0	0.3	0.1	19.6	15.0	4.0	3.0	0.1	2.9	1.0	10.1	14.8	122.3
	3.1	18.50	29.96	299	3.80	34	21.0	0.4	0.1	20.5	15.6	4.0	2.0	0.3	1.7	2.0	7.4	10.5	120.6
7	0.5	15.23	31.07	305	2.31	21	19.0	0.6	0.1	18.3	5.9	3.0	2.0	0.4	1.6	1.0	2.8	4.1	52.6
	5.9	14.80	31.15	298	3.88	24	10.0	1.0	0.1	8.9	6.4	3.0	2.0	0.3	1.7	1.0	2.5	4.5	60.6
8	0.6	11.80	31.52	304	3.95	18	9.0	0.4	0.1	8.5	6.7	3.0	2.0	0.5	1.5	1.0	2.0	8.5	62.5
	4.6	11.67	31.52	na	3.97	16	31.0	0.6	0.2	30.2	7.0	3.0	2.0	0.8	1.2	1.0	2.0	7.0	60.7
	9.8	11.30	31.50	293	5.20	21	14.0	0.4	0.1	13.5	6.7	3.0	2.0	0.5	1.5	1.0	3.1	11.5	59.3
9	0.7	11.79	32.00	308	1.52	17	27.0	0.3	0.1	26.6	4.0	3.0	2.0	0.4	1.6	1.0	1.4	2.9	43.6
	8.1	10.67	32.27	na	1.35	10	22.0	1.0	0.1	20.9	3.8	2.0	2.0	0.4	1.6	0.0	1.5	2.7	40.1
	10.4	10.00	32.40	298	4.73	14	7.0	0.8	0.1	6.1	5.4	2.0	2.0	0.4	1.6	0.0	1.7	3.2	51.7
10	0.4	17.72	29.60	278	2.70	35	15.0	0.8	0.2	14.0	9.9	3.0	2.0	0.5	1.5	1.0	1.5	7.8	85.0
	6.6	13.50	31.03	273	9.13	24	19.0	0.6	0.1	18.3	10.3	3.0	2.0	0.6	1.4	1.0	5.2	8.1	96.6

Table A-4 Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
11	0.5	14.24	31.09	311	2.05	18	13.0	0.4	0.1	12.5	6.9	3.0	2.0	0.4	1.6	1.0	2.3	4.6	60.0
	9.6	12.75	31.34	268	4.12	18	14.0	0.7	0.2	13.1	5.9	4.0	3.0	0.5	2.5	na	4.4	6.4	56.7
	12.3	11.61	31.52	na	7.40	20	18.0	2.2	0.6	15.2	6.5	3.0	3.0	0.8	2.2	0.0	7.9	5.2	70.0
12	0.5	15.01	30.94	313	1.75	17	na	1.0	0.1	na	8.2	3.0	na	0.5	na	na	2.6	2.3	75.2
	10.4	14.01	31.10	na	2.31	21	13.0	0.4	0.1	11.5	5.9	3.0	3.0	0.4	2.6	0.0	2.7	5.7	56.1
	15.1	12.16	31.47	324	2.51	21	19.0	0.9	0.4	17.7	6.2	3.0	3.0	0.6	2.4	0.0	4.8	5.7	60.4
13	0.6	13.61	31.45	319	2.06	15	14.0	0.4	0.1	13.5	5.0	2.0	2.0	0.3	1.7	0.0	2.0	3.1	42.8
	10.0	12.34	31.65	299	2.69	15	13.0	0.4	0.2	12.4	5.3	2.0	2.0	0.4	1.6	0.0	3.0	4.6	44.9
	28.8	10.09	32.17	na	5.18	14	12.0	1.6	0.9	9.5	4.3	2.0	2.0	0.6	1.4	0.0	6.5	2.7	51.8
14	0.5	12.59	31.55	314	1.79	15	12.0	0.4	0.1	11.5	5.2	2.0	1.0	0.4	0.6	1.0	2.6	3.6	40.9
	8.2	12.20	31.57	315	4.88	16	9.0	0.5	0.2	8.3	6.2	2.0	1.0	0.4	0.6	1.0	3.1	3.7	56.6
15	0.6	11.38	32.13	307	1.57	13	8.0	0.3	0.1	7.6	4.9	3.0	2.0	0.3	1.7	1.0	1.9	3.1	49.8
	15.3	9.97	32.44	289	1.44	9	12.0	0.5	0.2	11.3	3.4	3.0	2.0	0.5	1.5	1.0	2.1	1.8	30.6
	33.7	9.54	32.47	na	1.74	9	9.0	0.9	0.4	7.7	3.1	2.0	2.0	0.5	1.5	0.0	3.4	1.5	30.3
16	0.6	10.73	32.31	301	1.04	13	11.0	0.4	0.2	10.4	3.6	3.0	2.0	0.4	1.6	1.0	1.6	1.9	42.8
	14.0	10.11	32.43	na	1.18	14	15.0	0.4	0.1	14.5	2.3	3.0	2.0	0.4	1.6	1.0	1.9	1.9	43.8
	27.0	9.73	32.49	296	2.05	34	17.0	0.6	0.2	16.2	2.0	4.0	2.0	0.5	1.5	2.0	2.6	1.7	35.2
17	0.9	16.79	29.81	344	3.72	33	18.0	0.5	0.2	17.3	11.7	4.0	3.0	0.6	2.4	1.0	2.1	15.9	81.8
	6.1	15.24	30.05	na	3.47	29	22.0	0.6	0.4	21.0	9.3	4.0	3.0	0.7	2.3	1.0	5.8	13.6	77.1
	10.1	13.00	30.81	280	5.49	25	12.0	1.0	0.2	10.8	6.2	4.0	2.0	0.7	1.3	2.0	6.9	9.0	64.3
18	0.6	14.03	31.07	316	1.93	23	15.0	0.4	0.1	14.5	5.5	3.0	2.0	0.5	1.5	1.0	2.7	6.2	50.4
	2.9	13.84	31.09	na	2.25	21	16.0	0.5	0.2	15.3	5.5	3.0	3.0	0.5	2.5	0.0	2.9	5.8	47.7
	9.8	13.00	31.19	298	2.52	21	15.0	0.6	0.2	14.2	5.2	4.0	3.0	0.5	2.5	1.0	3.6	5.8	50.6

Table A-4. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Oxy. μM	TSM mg/L	TN μM	TDN μM	NH ₃ μM	NO _x μM	DON μM	PN μM	TP μM	TDP μM	IPO ₄ μM	DOP μM	TPP μM	DSI μM	Chl μg/L	PC μM
19	0.5	15.06	31.34	283	1.85	23	15.0	1.1	0.3	13.6	5.5	3.0	3.0	1.0	2.0	0.0	7.8	3.7	48.2
	14.3	14.63	31.64	262	7.75	24	19.0	0.9	0.1	18.0	8.4	3.0	3.0	0.9	2.1	0.0	7.1	4.2	84.1
20	0.8	14.38	32.24	299	1.14	10	13.0	0.6	0.1	12.3	2.8	2.0	2.0	0.4	1.6	0.0	0.4	0.7	29.6
21	1.2	11.27	32.30	305	0.52	9	12.0	0.3	0.1	11.6	2.7	2.0	2.0	0.4	1.6	0.0	0.7	1.2	35.6
	10.6	9.85	32.53	na	0.52	11	15.0	0.4	0.1	14.5	2.3	2.0	2.0	0.5	1.5	0.0	0.4	1.3	33.4
	28.0	8.48	32.69	302	1.69	12	9.0	1.0	0.6	7.4	2.2	3.0	2.0	0.6	1.4	1.0	5.6	1.5	33.7
22	1.0	12.53	32.51	294	0.60	7	21.0	0.3	0.1	20.6	2.2	3.0	2.0	0.4	1.6	1.0	0.2	0.4	26.6
	7.2	11.71	32.53	na	0.33	6	9.0	0.3	0.1	8.6	1.3	2.0	2.0	0.4	1.6	0.0	0.1	0.4	19.6
	26.9	8.22	32.73	302	0.99	10	7.0	0.3	0.1	6.6	2.1	3.0	2.0	0.4	1.6	1.0	2.2	3.1	24.5

Table A5. Trace metal data from SINBADD 1, October 21-24, 1985. Average of replicate analyses reported per kg of seawater. The concentration units for the metals are ng/kg, = 10^{-9} g per kilogram. The symbol 'na' means not analysed, a value of '0' means less than 0.5.

Sta.	Depth m	Temp. °C	Sal. S	Sig-t kg/m ³	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
2	0.4	16.64	22.82	16.3	2.17	na	38	211	12	3050	1473	450	14000	227	na	440
	2.5	16.50	27.57	19.9	2.29	na	35	na	9	na	1652	na	na	182	na	430
	5.6	16.10	29.29	21.3	10.41	na	104	47	111	1300	5166	270	5720	882	na	1450
	12.5	16.15	29.91	21.8	1.85	na	12	35	6	840	701	170	4070	90	na	280
3	0.5	15.25	25.87	18.9	2.37	na	32	138	5	3900	660	400	14800	140	na	480
	1.8	16.16	29.29	21.3	3.95	na	25	89	7	1730	1090	250	9230	143	na	350
	6.7	15.78	27.76	20.2	2.56	na	12	72	4	1120	590	160	5490	93	na	300
	12.6	15.76	30.48	22.3	4.53	na	24	44	8	700	1204	130	2980	230	na	540
4	0.3	15.35	26.40	19.3	2.95	na	20	136	5	3460	661	350	14180	147	na	180
	3.3	15.25	28.44	20.9	3.12	na	11	93	3	1760	653	220	8540	129	na	150
	9.9	15.70	29.51	21.6	4.59	na	16	43	4	760	1092	150	2960	219	na	280
5	0.4	14.50	29.43	21.8	1.68	na	3	56	2	1360	144	150	5150	55	na	120
	1.9	14.58	na	na	1.71	na	3	64	7	1300	140	160	4950	48	na	140
	5.8	14.91	na	na	1.78	na	5	56	3	1150	223	140	4260	72	na	160
	12.8	14.94	29.77	22.0	2.15	na	6	55	3	1160	278	150	1990	98	na	170
6	0.5	10.70	29.21	22.3	3.51	na	5	55	4	1530	224	240	3670	115	na	240
	3.3	14.41	29.21	21.6	3.69	na	5	55	4	1510	232	190	3730	109	na	240
7	0.5	15.06	29.78	21.9	2.73	na	2	43	3	1120	130	170	3490	63	na	160
	2.9	15.10	29.78	21.9	2.53	na	2	46	2	1060	114	210	3660	66	na	81
	5.0	15.22	30.60	22.5	2.92	na	5	35	2	910	250	180	2490	124	na	260
8	0.5	15.44	31.18	22.9	2.91	9	2	26	2	690	119	150	1880	70	29	150
	3.3	15.40	31.36	23.1	2.72	4	2	21	1	640	104	140	1880	67	28	130
	10.8	15.35	31.45	23.2	3.52	9	4	27	2	650	165	140	1880	127	44	180
	18.5	15.34	31.45	23.2	3.89	9	4	25	2	660	187	150	1910	147	46	200
9	0.4	15.37	31.70	23.4	1.27	2	0	27	1	690	86	130	1290	33	55	110
	2.9	15.62	31.90	23.4	1.65	3	1	22	2	480	93	120	1170	40	40	110
	7.2	15.91	32.02	23.5	1.16	3	1	20	2	460	162	130	990	95	46	110
	11.9	15.99	32.10	23.5	1.92	2	2	38	2	220	93	150	930	51	24	120

Table A5. Continued

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
10	0.5	15.10	28.81	21.2	8.07	na	5	56	5	1220	249	147	4950	78	na	170
	4.5	15.64	30.99	22.7	1.65	na	2	45	1	1180	121	118	3390	38	na	150
11	0.3	14.50	29.39	21.8	0.86	na	1	61	1	1340	72	157	4920	19	na	100
	4.9	15.00	30.11	22.2	1.29	na	2	60	1	1190	101	152	3570	25	na	95
	8.1	15.86	31.24	22.9	3.77	na	6	33	2	680	285	137	1670	123	na	220
12	0.3	15.60	30.05	22.0	1.75	na	2	43	1	990	85	147	2820	49	na	89
	7.2	15.40	30.12	22.1	1.35	na	2	40	1	970	111	127	2720	18	na	120
	15.0	15.81	31.21	22.9	3.09	na	5	31	2	720	225	108	1650	85	na	220
13	0.5	15.25	30.70	22.6	1.40	na	2	34	4	890	102	176	2270	50	na	150
	4.9	15.60	30.78	22.6	1.74	na	2	31	1	920	107	137	2080	47	na	110
	15.2	15.98	31.58	23.1	2.35	na	3	27	1	710	135	137	1060	67	na	180
	25.5	16.08	31.93	23.4	4.27	na	6	20	3	550	285	127	780	227	na	270
14	0.5	15.01	30.64	22.6	1.51	55	1	29	1	790	84	167	2680	45	32	140
	5.1	15.47	30.95	22.8	1.36	32	1	28	1	710	95	137	2270	36	30	110
	8.4	15.81	31.21	22.9	2.63	5	2	26	1	610	135	147	1880	80	28	170
15	0.7	15.77	31.49	23.1	1.19	9	1	33	1	670	109	162	1620	97	49	87
	6.8	15.81	31.84	23.4	1.80	5	1	21	2	490	101	157	1350	82	20	100
	20.2	16.04	32.03	23.5	1.27	2	1	31	1	430	86	157	920	67	26	77
	33.6	16.10	32.06	23.5	1.75	4	0	17	1	310	92	147	750	82	14	87
16	0.5	16.03	32.07	23.5	1.53	3	3	20	2	400	126	108	800	107	11	180
	6.0	16.09	32.08	23.5	1.77	3	3	19	2	400	125	108	780	113	20	170
	17.6	16.13	32.24	23.6	1.21	0	1	18	3	300	74	108	560	68	21	120
	29.7	16.18	32.33	23.7	2.00	2	2	18	2	260	98	108	480	107	21	140
17	0.4	17.10	28.79	20.7	3.27	3	7	40	2	1200	139	191	2300	108	na	150
	4.0	15.78	29.98	21.9	2.12	na	5	34	1	1000	169	137	2080	82	na	270
	8.8	15.76	30.22	22.1	2.11	na	5	33	1	1030	167	147	2070	79	na	260

Table A5. Continued

Sta.	Depth m	Temp. °C	Sal. S	Sig.-1 kg/m ³	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
18	0.2	15.80	29.00	21.2	4.51	na	6	39	3	1230	136	167	2050	60	na	260
	1.4	15.37	29.26	21.5	2.05	na	5	38	1	1220	125	157	2220	56	na	200
	5.4	15.38	29.32	21.5	2.31	na	5	40	2	1200	136	172	2140	54	na	200
	8.5	15.54	30.53	22.4	2.03	na	4	33	1	960	154	118	2100	64	na	170
19	0.4	15.58	30.18	22.1	3.06	na	3	28	2	890	114	142	1660	52	na	97
	2.4	15.55	30.24	21.2	2.87	na	3	30	2	190	144	176	1660	53	na	85
	4.7	14.75	30.54	22.6	2.12	na	2	24	2	670	130	127	1300	60	na	120
20	0.4	15.97	31.81	23.3	1.44	na	1	21	3	420	79	108	430	69	na	210
	1.8	15.97	31.82	23.3	1.47	na	6	21	10	410	245	98	430	346	na	780
	5.8	15.77	31.86	23.4	1.39	na	1	22	3	370	58	123	380	40	na	140
	10.8	15.77	31.97	23.5	1.91	na	1	42	4	390	67	98	420	86	na	220
21	0.5	16.32	32.13	23.5	1.02	na	1	19	3	440	69	118	590	31	na	73
	5.1	16.31	32.14	23.5	0.92	na	1	20	2	420	58	98	540	38	na	75
	14.4	16.12	32.27	23.6	1.01	na	1	19	5	340	65	108	490	22	na	37
	24.4	16.15	32.33	23.7	0.82	na	0	17	2	300	58	108	360	17	na	37
22	0.5	16.33	32.27	23.6	1.21	na	0	19	1	400	41	157	470	6	na	73
	4.4	16.15	32.19	23.6	1.61	na	0	19	1	360	55	147	500	14	na	41
	13.4	16.13	32.16	23.5	1.08	na	0	20	1	350	44	137	450	6	na	83
	22.3	16.28	32.30	23.6	1.96	na	1	20	1	260	64	118	260	49	na	160

NOTE: In this and in the three succeeding tables the concentrations of all metals are given in ng/kg (= parts per trillion). This was done for two reasons. It was felt desirable to express the concentrations of all metals in the same units, to avoid misreading and to make it easy to compare the concentrations of the various metals with each other. Also the use of this unit avoids the presentation of a large number of zeros after the decimal point, or the use of exponential notation which would vary between elements. It must be realized that, even at best, the precision of the metal data is not better than two or sometimes at most three significant figures. The numbers are not further rounded to avoid the accumulation of rounding errors. To convert to µg/kg (parts per billion), divide by 1000.

Table A-6. Trace metals data from SINBADD 2, November 18-21, 1985. Average of replicate analyses reported per kg of seawater. The concentration units for the metals are ng/kg, = 10^{-9} g per kilogram. The symbol 'na' means not analysed, a value of '0' means less than 0.5.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
1	0.1	na	2.84	na	na	5.41	25	58	573	63	3340	3040	na	10990	530	600	1230
	2.0	na	3.17	na	na	5.78	28	54	581	70	3700	3200	na	12200	510	700	1360
2	0.4	11.50	22.25	17.00	35.1	1.56	15	25	174	12	2640	890	613	8760	135	150	540
	2.1	12.00	25.80	19.20	33.9	1.70	15	25	104	9	2510	1000	550	8060	150	108	580
	4.4	11.37	28.74	21.78	33.9	1.64	9	12	66	4	1380	660	320	4070	63	1100	450
	10.7	11.37	29.23	22.28	41.3	2.44	8	18	55	8	1210	930	260	3300	120	83	420
3	0.4	11.29	20.87	15.53	37.2	2.44	24	42	228	13	3740	1210	760	1150	260	116	610
	1.9	11.31	20.67	15.43	37.3	2.19	17	28	209	8	1280	1030	760	10600	150	182	520
	6.6	11.39	29.08	22.27	47.9	9.29	7	46	59	9	1180	1960	280	2580	360	91	720
	11.5	11.54	29.60	22.75	70.3	12.07	7	61	529	12	1100	2470	240	2400	530	73	980
4	0.7	11.43	20.27	15.29	34.4	1.83	24	31	224	6	4750	850	902	12100	170	95	510
	4.7	11.26	29.04	22.16	43.4	2.37	9	12	74	1	1340	550	323	3280	130	91	350
	11.1	11.61	30.15	22.93	71.0	71.59	5	na	65	na	1120	na	245	2150	na	79	na
5	0.5	10.96	26.65	20.35	25.6	1.10	10	5	104	1	1920	200	456	5600	35	110	213
	5.1	11.08	28.05	21.48	20.4	1.48	8	na	75	na	1560	na	392	4200	na	66	na
	10.6	11.01	28.74	21.99	33.8	2.19	7	6	68	1	1340	330	323	3820	70	62	242
6	0.6	9.67	27.17	20.97	37.9	2.33	9	4	72	1	1650	240	343	4110	51	112	251
	2.9	9.51	27.17	20.98	38.3	2.49	7	5	76	1	1640	260	323	4200	50	75	242
7	6.9	10.67	28.10	21.54	28.3	2.47	6	4	83	1	1490	200	422	4320	44	91	230
	3.1	10.68	28.12	21.61	37.7	2.37	5	na	75	na	1220	na	402	1160	na	79	na
	5.0	10.61	29.13	22.38	34.7	2.50	5	3	74	1	1190	150	304	1230	45	97	143
8	1.0	10.87	30.17	23.10	40.8	2.40	4	1	48	1	950	100	176	820	36	70	102
	4.4	10.82	30.35	23.19	38.8	2.65	4	na	75	na	900	na	176	1500	na	75	na
	10.1	10.93	30.54	23.36	36.4	2.88	5	na	40	na	940	na	157	730	na	62	na
	16.2	11.03	30.67	23.44	37.9	3.80	3	4	41	1	850	210	157	680	90	85	228

Table A-6. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-1 kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
9	1.2	11.09	30.99	23.76	39.5	2.17	2	3	31	1	680	110	na	520	59	56	150
	3.2	11.43	31.24	23.86	42.0	2.64	2	na	32	na	690	na	na	480	na	52	na
	7.3	12.23	31.66	24.04	39.6	2.37	3	na	27	na	570	na	na	350	na	44	na
	11.8	12.28	31.71	24.04	44.2	3.37	2	3	27	1	490	120	na	310	82	37	170
10	0.7	11.27	24.46	18.65	29.0	0.57	15	7	134	1	2210	190	608	2300	33	85	197
	5.7	11.16	28.78	21.96	38.6	1.61	8	6	67	1	1270	260	353	1190	53	60	218
11	0.6	11.38	28.6	21.28	24.5	1.07	10	3	65	na	1280	120	358	1050	16	64	191
	6.2	11.67	30.08	22.82	31.9	1.24	9	na	41	na	950	na	236	560	na	56	na
	10.2	11.90	30.75	23.42	46.0	3.17	4	6	37	1	760	270	196	650	66	64	236
12	0.6	11.16	28.32	21.62	28.4	1.43	11	4	65	1	1340	130	383	2460	16	99	189
	7.5	11.27	28.87	22.07	31.2	1.79	15	na	58	na	1210	na	323	1080	na	131	na
	15.4	11.90	30.47	23.45	36.7	1.71	13	na	35	na	820	na	216	740	na	81	na
	21.8	11.92	30.75	23.49	36.2	1.49	22	5	35	1	760	200	196	600	53	87	230
13	0.7	11.26	29.66	22.64	27.6	1.36	4	2	57	0	1060	100	294	870	18	77	203
	4.5	11.59	30.23	22.95	31.8	1.73	1	na	45	na	970	na	245	1080	na	75	na
	12.4	12.01	15.58	23.62	36.6	1.90	1	na	35	na	720	na	216	1510	na	66	na
	20.3	12.32	31.71	24.06	41.4	4.36	1	5	29	1	530	230	157	830	84	62	228
14	1.0	11.14	29.57	22.62	26.7	1.52	6	1	56	0	1120	70	294	2720	15	73	160
	5.3	11.32	29.99	22.91	32.1	2.00	1	na	46	na	1030	na	275	2370	na	66	na
	8.6	11.77	30.78	23.45	38.4	2.32	4	2	36	0	810	110	196	1710	36	48	120
15	1.5	11.25	30.34	23.17	33.2	1.99	4	2	42	1	950	93	na	2120	32	91	155
	7.5	11.33	30.58	23.28	31.7	1.60	4	na	42	na	880	na	na	1900	na	48	na
	21.3	12.10	31.48	23.88	35.2	1.52	3	na	25	na	570	na	na	1140	na	19	na
	36.7	12.45	32.07	24.26	49.9	8.99	3	4	23	1	420	240	na	540	173	23	257

Table A-6. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-I kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
16	1.4	11.85	31.43	23.87	31.4	1.53	3	1	32	0	680	69	na	1230	35	35	106
	7.7	12.49	31.87	24.26	28.7	1.23	3	na	26	na	500	na	na	700	na	25	na
	19.8	12.75	32.24	24.37	41.0	2.05	2	na	22	na	380	na	na	520	na	25	na
	34.5	12.82	32.28	24.37	43.3	4.24	2	2	22	1	360	120	na	470	106	35	182
17	0.5	13.26	25.64	19.23	42.6	2.97	27	14	48	2	1380	230	294	2920	76	153	255
	5.9	11.95	26.46	20.05	44.7	2.69	33	na	44	na	1220	na	na	2810	na	91	na
	9.9	11.25	28.69	22.02	45.0	3.91	10	10	43	2	940	280	na	2610	94	116	437
18	0.5	11.53	27.89	21.22	37.1	1.68	13	4	52	1	1210	93	275	2880	24	97	155
	7.5	11.37	29.24	22.40	31.3	1.70	22	na	49	na	940	na	255	2680	na	79	na
	15.0	11.81	30.61	23.29	42.1	3.91	20	9	41	3	760	330	216	2090	102	108	307
19	0.6	10.88	28.96	22.17	29.9	1.32	3	1	37	1	830	60	na	1870	8	87	93
	3.8	10.81	28.99	22.20	29.1	1.60	7	1	38	0	910	83	na	1860	16	81	128
20	0.7	11.21	31.41	23.97	53.7	4.15	2	1	23	1	450	95	na	580	95	23	191
	6.1	11.60	31.43	24.27	53.7	4.08	2	na	22	na	470	na	na	600	na	23	na
	11.0	11.65	31.95	24.32	55.0	4.74	3	1	20	1	380	107	na	350	113	48	197
21	0.5	12.51	31.78	24.07	37.0	2.46	4	1	25	1	530	65	na	940	48	23	91
	5.2	12.52	32.04	24.30	34.0	1.82	3	na	23	na	460	na	na	750	na	33	na
	14.5	12.70	32.15	24.37	29.0	2.02	3	na	22	na	400	na	na	630	na	35	na
	23.8	12.86	32.31	24.40	45.7	2.75	3	1	20	0	330	75	na	510	65	29	95
22	0.5	12.46	32.25	24.41	39.7	2.39	2	0	19	0	330	45	na	164	53	15	91
	5.2	12.30	32.27	24.44	39.3	2.12	2	na	22	na	290	na	na	410	na	21	na
	14.0	12.22	32.25	24.46	40.5	2.45	2	na	20	na	300	na	na	340	na	12	na
	22.7	12.22	32.27	24.47	45.3	3.48	2	0	20	1	300	68	na	320	80	23	118

Table A-7. Trace metals data from SINBADD 3, April 7-10, 1986. Average of replicate analyses reported per kg of seawater. The concentration units for the metals are ng/kg. = 10^{-9} g per kilogram. The symbol 'na' means not analysed, a value of '0' means less than 0.5.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
1	0.2	na	7.63	2.74	na	na	38	37	360	51	3480	1760	560	1460	7840	324	270	1360
	2.0	na	17.28	4.01	na	na	28	47	320	38	3080	2780	490	1470	7160	263	180	1230
2	0.1	8.40	23.34	16.86	48.4	2.10	16	32	166	24	2510	140	560	950	5570	244	137	780
	1.7	7.06	26.94	21.23	50.0	2.78	16	35	98	26	1950	1670	420	960	2460	303	135	600
	13.0	5.99	29.65	23.39	28.4	2.43	13	16	46	13	1040	770	216	350	2090	80	56	350
2A	0.2	8.00	21.68	17.20	50.6	3.71	36	52	197	24	4382	1720	745	1390	8560	350	600	820
3	0.3	7.80	23.23	18.20	53.5	2.99	15	33	119	12	2840	1320	500	730	4380	200	90	430
	2.1	7.17	27.11	21.37	49.8	2.61	13	31	108	11	2420	1160	450	740	3990	198	75	270
	12.2	6.05	29.99	23.65	28.7	3.89	9	21	44	10	980	920	206	590	1510	178	83	270
3A	0.5	7.71	24.07	18.55	67.0	3.16	25	37	161	11	4660	1120	660	840	7020	265	166	350
4	0.3	7.70	24.82	19.30	64.5	3.44	18	32	141	9	3450	950	520	736	5480	213	108	400
	2.2	7.11	27.29	21.54	47.5	2.36	10	18	82	6	2050	640	320	390	3030	124	81	250
	13.3	6.00	30.34	23.92	33.5	6.03	3	40	32	8	800	1010	167	800	1000	174	79	290
5	0.3	8.00	27.81	21.70	37.6	1.59	10	4	75	3	3050	410	340	196	2600	36	54	195
	3.3	7.80	28.32	22.02	40.4	1.77	6	na	65	na	1540	na	300	na	2420	na	29	na
	12.7	6.83	29.65	23.27	33.1	2.46	9	8	51	3	980	350	226	280	1740	69	54	122
6	1.0	na	26.91	na	na	2.04	11	6	87	3	1890	460	350	260	2990	69	261	320
	2.5	na	27.03	na	na	2.32	7	7	76	4	1620	320	330	220	2680	65	73	230
7	0.5	7.58	28.79	22.49	26.5	1.22	8	3	71	1	1300	130	na	86	2210	45	44	102
	4.3	7.47	28.97	22.68	26.7	1.43	8	na	65	na	1240	na	na	na	2010	na	37	na
	6.1	6.77	29.73	23.36	32.6	2.12	6	5	54	1	950	220	na	125	1520	62	31	110
8	0.4	7.18	29.84	23.41	24.3	1.89	3	na	53	na	930	na	na	na	1502	na	54	na
	10.1	6.66	30.48	23.94	28.3	2.95	4	na	46	na	710	na	na	na	1170	na	311	na
	20.8	6.46	30.64	24.13	31.7	5.06	4	na	42	na	680	na	na	na	1140	na	37	na

Table A-7. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
9	0.4	6.93	30.40	23.85	24.9	1.53	2	na	43	na	760	na	na	na	1230	na	23	na
	6.2	5.55	31.79	25.13	25.8	3.29	2	na	30	na	420	na	na	na	560	na	35	na
	11.5	5.54	31.79	25.13	33.0	11.30	2	na	28	na	410	na	na	na	550	na	60	na
10	0.3	8.09	26.79	20.88	57.3	2.78	9	15	103	7	1990	150	390	430	3780	113	44	180
	6.1	5.93	30.43	24.01	25.1	2.01	4	4	42	2	720	208	88	179	1010	32	44	116
11	0.3	6.58	29.36	23.31	26.2	1.69	5	3	50	2	960	143	162	110	1390	38	44	106
	5.5	6.06	30.23	23.81	23.8	1.11	4	na	40	na	750	na	157	na	990	na	41	na
	10.3	5.44	30.98	24.41	24.0	1.46	4	3	34	1	630	101	127	84	820	29	33	106
12	0.3	7.60	28.39	22.20	29.3	1.35	7	4	59	2	1270	142	250	86	1990	40	54	118
	11.3	6.49	29.72	23.39	25.6	1.57	5	na	45	na	840	na	176	na	1070	na	91	na
	14.7	6.37	30.38	23.52	25.8	1.44	4	3	40	1	750	105	167	91	1050	33	66	97
13	0.4	7.00	29.58	23.20	23.2	0.90	5	2	54	1	1030	85	na	56	1500	25	108	97
	10.2	6.34	30.14	23.80	22.3	0.72	5	na	43	na	780	na	na	na	1140	na	39	na
	16.6	5.69	31.30	23.74	27.0	1.60	4	2	36	1	640	94	na	94	640	33	60	85
14	0.3	7.30	29.29	22.90	26.5	1.39	5	2	55	1	1040	96	216	64	1600	38	27	81
	8.4	5.47	31.28	24.75	17.2	0.78	4	1	36	0	610	53	186	58	680	21	79	62
15	0.3	6.10	30.82	24.30	20.7	0.90	4	1	38	0	690	48	na	50	870	16	33	68
	7.9	5.99	30.96	24.40	20.6	0.88	3	na	35	na	610	na	na	na	730	na	37	na
	17.7	5.76	31.62	24.97	21.9	1.04	4	na	32	na	440	na	na	na	530	na	17	na
	32.7	5.54	32.07	25.34	24.3	2.22	2	1	25	0	280	69	na	101	340	42	27	79
16	0.5	5.80	31.49	24.87	22.7	1.06	2	na	32	na	510	na	na	na	700	na	35	na
	13.0	5.46	32.05	25.36	24.6	2.07	1	na	25	na	350	na	na	na	420	na	15	na
	26.8	5.50	32.27	25.51	27.6	2.82	1	na	25	na	300	na	na	na	340	na	41	na

Table A-7. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
17	0.3	7.81	27.62	21.59	43.2	2.25	8	13	45	3	1040	260	196	360	1260	69	124	209
	3.1	7.58	28.05	21.95	41.0	2.86	7	na	44	na	1000	na	226	na	1290	na	108	na
	10.9	6.57	29.53	23.22	35.3	4.93	5	12	42	3	840	400	186	530	1120	136	66	290
18	0.2	7.40	28.52	22.30	30.6	1.19	8	4	49	1	950	125	196	146	1410	35	77	128
	5.3	6.90	29.08	22.80	26.0	1.25	5	na	43	na	940	na	186	na	1290	na	73	na
	13.3	5.90	30.57	24.10	25.4	2.39	4	3	41	1	760	140	167	148	1000	51	66	108
19	0.1	7.40	30.09	23.50	29.5	1.37	4	2	33	1	650	71	na	47	880	27	54	81
	5.9	7.03	30.81	24.16	36.0	3.01	2	2	27	2	490	105	na	101	720	54	85	91
21	0.7	6.00	32.11	25.30	22.3	1.14	1	na	25	na	420	na	na	na	360	na	19	na
	12.8	5.50	32.26	25.49	20.1	1.26	1	na	23	na	300	na	na	na	350	na	21	na
	25.7	5.15	32.32	25.59	30.1	3.71	1	na	23	na	280	na	na	na	310	na	12	na
22	0.9	6.00	32.23	25.40	19.6	1.03	1	na	23	na	290	na	na	na	310	na	19	na
	11.6	5.98	32.27	25.44	19.0	0.81	1	na	23	na	290	na	na	na	310	na	17	na
	22.0	5.46	32.48	25.67	26.5	2.57	1	na	21	na	147	na	na	na	220	na	4	na

Note: Station 2A (41° 47.3' N, 71° 22.7' W) and Station 3A (41° 44.7' N, 71° 22.3' W) were two extra stations occupied during this cruise only; only near-surface samples were taken. Sta 2A was near the boil from the Field's Point sewage treatment plant effluent.

Table A-8. Trace metals data from SINBADD 4, May 19-20, 1986. Average of replicate analyses reported per kg of seawater. The concentration units for the metals are ng/kg, = 10^{-9} g per kilogram. The symbol 'na' means not analysed, value of '0' means less than 0.5.

Sia.	Depth m	Temp. °C	Sal. S	Sig-1 kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
2	0.4	16.70	21.40	15.50	77.6	5.5	18	58	156	29	3080	2500	640	1300	14800	720	410	1380
	4.4	15.40	28.20	20.70	53.6	12.9	11	32	89	24	2200	1480	360	700	9860	480	91	490
	11.8	11.20	30.40	23.20	37.4	3.5	9	32	53	30	990	1760	280	970	4170	310	87	770
3	0.4	18.00	22.80	15.90	87.9	7.7	24	83	152	22	4570	2120	610	1320	22550	990	240	930
	4.3	16.50	28.90	21.00	54.0	5.4	9	53	87	12	2080	2420	350	1090	7310	470	126	580
	11.3	13.20	30.50	22.90	66.6	8.5	5	57	51	16	1110	2630	240	1350	2970	450	102	900
4	0.5	18.20	25.30	17.90	76.9	6.2	16	35	105	15	3400	920	450	450	13290	530	157	410
	5.5	15.70	30.10	22.10	49.3	5.4	6	18	52	7	1390	1030	280	540	3580	250	102	250
	15.3	14.00	30.70	22.90	67.3	14.5	4	48	45	17	1010	2580	240	1590	2500	630	104	490
5	0.4	15.80	30.93	22.69	43.0	2.5	5	4	46	2	870	280	230	198	1800	64	93	200
	5.9	15.80	30.93	22.70	43.0	3.2	3	na	41	na	920	na	210	na	1800	na	79	na
	12.7	15.70	30.95	22.73	44.0	5.0	5	11	44	3	902	450	210	440	1800	126	91	320
6	0.5	18.80	29.80	21.14	79.0	4.6	7	5	57	4	1735	288	255	160	2320	100	73	340
	3.1	18.50	29.96	21.32	74.4	3.7	7	3	54	3	1578	241	236	161	2210	88	62	380
7	0.5	15.23	31.07	22.93	41.6	2.3	2	2	33	1	745	172	na	120	1740	38	62	220
	5.9	14.80	31.15	23.07	44.1	3.8	3	6	37	2	735	340	na	260	1530	83	81	230
8	0.6	11.80	31.52	23.95	49.3	3.9	4	na	34	na	600	na	na	na	1140	na	58	na
	4.6	11.67	31.52	23.97	50.3	3.8	3	na	34	na	680	na	na	na	1140	na	na	na
	9.8	11.30	31.50	24.00	50.5	5.1	4	na	33	na	640	na	na	na	1170	na	35	na
9	0.7	11.79	32.00	24.32	35.0	1.5	3	na	29	na	520	na	na	na	750	na	23	na
	8.1	10.67	32.27	24.74	27.2	1.3	3	na	26	na	390	na	na	na	410	na	15	na
	10.4	10.00	32.40	24.90	32.5	4.6	2	na	23	na	320	na	na	na	480	na	15	na
10	0.4	17.72	29.60	21.23	43.5	2.6	5	6	52	4	1690	290	280	150	3420	90	102	218
	6.6	13.50	31.03	23.25	54.7	8.9	4	19	39	8	880	1120	230	1010	1680	250	77	590

Table A-8. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
11	0.5	14.24	31.09	23.15	31.8	2.0	5	2	39	1	921	97	196	58	1410	29	62	102
	9.6	12.75	31.34	23.63	45.6	4.0	3	na	37	na	780	na	190	na	1170	na	85	na
	12.3	11.61	31.52	23.98	64.2	7.3	3	12	36	3	610	560	160	600	980	168	110	420
12	0.5	15.01	30.94	22.87	28.0	1.7	3	2	38	1	870	117	210	79	1800	27	64	140
	10.4	14.01	31.10	23.20	32.9	2.3	4	na	37	na	780	na	180	na	1140	na	64	na
	15.1	12.16	31.47	23.84	38.0	2.5	3	3	36	1	760	160	160	140	1050	49	60	150
13	0.6	13.61	31.45	23.55	33.7	2.0	5	1	35	0	730	82	na	88	1070	29	58	116
	10.0	12.34	31.65	23.95	34.0	2.6	6	na	35	na	650	na	na	na	940	na	48	na
	28.8	10.09	32.17	24.75	38.2	5.1	4	7	33	1	520	320	na	370	560	109	62	240
14	0.5	12.59	31.55	23.82	34.0	1.7	5	1	32	0	690	77	160	93	960	33	44	116
	8.2	12.20	31.57	23.91	43.7	4.8	5	3	31	1	670	200	160	260	910	80	44	170
15	0.6	11.38	32.13	24.50	28.7	1.5	4	0	28	na	490	38	na	42	490	16	31	79
	15.3	9.97	32.44	24.99	21.2	1.4	3	na	25	na	290	na	na	na	310	na	23	na
	33.7	9.54	32.47	25.08	20.6	1.7	3	0	23	na	290	44	na	59	280	28	15	73
16	0.6	10.73	32.31	24.76	22.3	1.9	3	na	27	na	510	na	na	na	450	na	37	na
	14.0	10.11	32.43	24.95	20.9	1.2	2	na	25	na	310	na	na	na	340	na	15	na
	27.0	9.73	32.49	25.06	22.7	2.0	2	na	27	na	310	na	na	na	340	na	68	na
17	0.9	16.79	29.81	21.61	44.8	3.6	11	7	39	2	1180	180	190	190	1440	42	81	140
	6.1	15.24	30.05	22.13	40.7	3.4	9	na	37	na	990	na	160	na	1400	na	93	na
	10.1	13.00	30.81	23.17	48.6	5.4	4	10	31	3	780	340	130	470	1300	99	68	300
18	0.6	14.03	31.07	23.17	32.0	1.9	5	2	34	1	850	98	180	86	1520	19	56	97
	2.9	13.84	31.09	23.23	32.3	2.2	4	na	36	na	860	na	180	na	1420	na	62	na
	9.8	13.00	31.19	23.47	33.1	2.5	5	4	36	1	800	170	200	160	1260	36	73	160

Table A-8. Continued.

Sta.	Depth m	Temp. °C	Sal. S	Sig.-t kg/m ³	Turb. %	TSM mg/kg	Ag-d ng/kg	Ag-p ng/kg	Cd-d ng/kg	Cd-p ng/kg	Cu-d ng/kg	Cu-p ng/kg	Cr-d ng/kg	Cr-p ng/kg	Ni-d ng/kg	Ni-p ng/kg	Pb-d ng/kg	Pb-p ng/kg
19	0.5	15.06	31.34	23.16	24.6	1.8	2	1	28	1	580	79	na	61	960	29	83	99
	14.3	14.63	31.64	23.48	61.9	7.6	2	6	23	4	420	290	na	360	790	140	124	210
20	0.8	14.38	32.24	24.01	19.1	1.1	2	na	23	na	350	na	na	na	460	na	23	na
	1.2	11.27	32.30	24.65	20.8	0.5	2	na	26	na	410	na	na	na	500	na	17	na
21	10.6	9.85	32.53	25.08	16.1	0.5	1	na	22	na	220	na	na	na	310	na	8	na
	28.0	8.48	32.69	25.42	23.8	1.7	1	na	22	na	230	na	na	na	290	na	10	na
22	1.0	12.53	32.51	24.58	15.9	0.6	1	na	23	na	260	na	na	na	310	na	140	na
	7.2	11.71	32.53	24.75	14.9	0.3	1	na	23	na	260	na	na	na	310	na	56	na
	26.9	8.22	32.73	25.48	19.7	1.1	1	na	23	na	230	na	na	na	260	na	25	na

Table A-9. Measured concentrations of trace metals in river samples collected during the SINBADD cruises. Reported as dissolved (-d) and as total (-t) concentrations in units of ng/L ($= 10^{-9}$ g/L); 'na' means not analysed, 'nd' means not detected.

River	Sal S	Ag-d ng/L	Ag-t ng/L	Cd-d ng/L	Cd-t ng/L	Cu-d ng/L	Cu-t ng/L	Cr-d ng/L	Cr-t ng/L	Ni-d ng/L	Ni-t ng/L	Pb-d ng/L	Pb-t ng/L
SINBADD-1													
Blackstone	0.04	nd	nd	1160	1450	6130	9670	1140	2280	12380	12620	980	2700
Woonasquatucket	3.30	na	na	470	420	17900	32000	na	na	86000	73000	na	na
Moshassuck	1.50	28	30	300	210	3740	5580	730	1410	9290	97600	1290	3550
Pawtuxet	0.31	nd	nd	2400	2260	11090	12500	600	840	30950	32620	840	2410
Taunton	25.90	na	na	640	660	2460	2700	na	na	4660	12970	na	na
SINBADD-2													
Blackstone	0.03	nd	nd	1280	1970	7920	10000	950	2490	8570	9760	930	3230
Woonasquatucket	0.03	nd	nd	120	120	2450	3220	2900	2420	5240	5380	890	2930
Moshassuck	0.05	nd	nd	220	1280	6390	7770	1250	1600	4390	4520	2180	3530
Pawtuxet	0.01	nd	nd	110	110	4970	7830	300	650	9090	9760	760	2580
Taunton	17.77	na	na	860	840	2510	4200	na	na	5410	6340	na	na
SINBADD-3													
Blackstone	0.02	nd	nd	890	1050	5030	6450	980	1760	7620	8570	930	2450
Woonasquatucket	0.74	nd	nd	250	310	8850	11700	5850	6400	12380	14050	1780	6040
Moshassuck	0.06	nd	nd	210	340	5550	9540	460	1030	2270	2320	1910	7450
Pawtuxet	0.04	nd	nd	1050	1290	7520	10230	300	650	14520	16430	980	2630
Taunton	0.03	nd	nd	120	180	3100	3510	520	890	1820	1810	980	2310
SINBADD-4													
Blackstone	0.05	nd	nd	580	920	6690	8490	950	1760	23300	29000	2010	10120
Woonasquatucket	0.99	23	20	150	250	5150	9440	4100	5960	10000	13100	1240	6050
Moshassuck	0.07	nd	nd	80	310	5550	11800	710	1600	3500	3600	1680	5750
Pawtuxet	0.09	48	50	590	940	8240	14700	430	1270	17600	24100	930	1920
Taunton	0.77	nd	nd	90	120	3840	4100	760	1660	2400	2800	890	683

Table A-10. Concentrations of metals measured in the effluent from municipal sewage treatment plants during the SINBADD cruises. Only total concentrations were measured. Data provided courtesy of the Narragansett Bay Commission. All concentrations in $\mu\text{g/L}$ ($=10^{-6}$ g/L).

Treatment Plant	Flow $10^3\text{m}^3/\text{d}$	Ag-t $\mu\text{g/L}$	Cd-t $\mu\text{g/L}$	Cu-t $\mu\text{g/L}$	Cr-t $\mu\text{g/L}$	Ni-t $\mu\text{g/L}$	Pb-t $\mu\text{g/L}$
SINBADD-1							
East Providence	18.2	86	16	10	<9	166	237
East Greenwich	na	151	17	49	<9	86	332
Fields Point	196.8	116	23	672	41	691	266
Fall River	87.1	114	21	<10	<9	63	344
Bristol	na	91	34	<10	<9	41	153
Blackstone Valley	na	108	15	35	<9	225	248
Newport	43.5	116	29	<10	<9	66	261
Warren	5.3	55	23	29	<9	69	230
SINBADD-2							
East Providence	28.4	<10	3	21	21	64	<18
East Greenwich	3.97	<10	2	147	24	35	183
Fields Point	204.4	<10	3	347	97	36	36
Fall River	96.5	<10	2	53	12	19	37
Bristol	11.7	<10	3	46	10	<5	<18
Blackstone Valley	75.7	<10	2	44	39	136	<18
Newport	32.2	<10	6	60	22	14	26
Warren	10.6	<10	<2	72	12	72	37
Jamestown	4.16	<7	9	<21	<9	<15	<29
Quonset Point	5.68	<7	10	41	80	123	<40
SINBADD-3							
East Providence	32.2	<7	<5	<21	<9	<15	<29
East Greenwich	3.9	<7	5	258	72	27	77
Fields Point	230.9	<7	<5	328	51	305	<29
Fall River	94.6	<7	5	<21	29	<15	<29
Bristol	7.7	<7	<5	<21	<9	<15	<29
Blackstone Valley	87.1	<7	12	<21	46	94	<29
Newport	45.4	<7	25	70	78	<15	<29
Warren	8.7	<7	<5	97	10	<15	<29
Jamestown	1.9	<7	<5	<21	<9	<15	<29
SINBADD-4							
East Providence	30.3	<7	<5	<21	22	60	<29
East Greenwich	3.9	<7	<5	179	41	58	<29
Fields Point	348.3	<7	<5	185	80	624	<29
Fall River	85.2	<7	<5	42	34	<15	<29
Bristol	4.8	15	8	45	55	<15	<29
Blackstone Valley	94.3	<7	<5	179	41	58	<29
Newport	26.5	<7	17	56	58	<15	61
Warren	6.0	<3	<3	163	16	40	<40
Jamestown	1.1	<7	<5	<21	14	<15	<29
Quonset Point	2.8	<3	<3	150	45	52	<40