1981

Trace Metal Pollution in Narragansett Bay: A Case Study of the Rhode Island Quahog Fishery

Scott W. Horsley
University of Rhode island

TRACE METAL POLLUTION IN NARRAGANSETT BAY
A CASE STUDY OF THE RHODE ISLAND QUAHOG FISHERY

BY

SCOTT W. HORSLEY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

IN

MARINE AFFAIRS

UNIVERSITY OF RHODE ISLAND

1981

MASTER OF ARTS THESIS

OF

SCOTT WILLIAM HORSLEY

Approved:

Thesis Committee

Major Professor ______________________

____

____

____

Dean of the Graduate School

UNIVERSITY OF RHODE ISLAND

1981

ABSTRACT

Well over a ton of metals such as cadmium, chromium, copper, lead, mercury, nickel, and zinc (dissolved in industrial effluents and sewage treatment plant discharges) enters Narragansett Bay on a daily basis. The Bay also supports a tremendous hard shell clam fishery with annual landings exceeding six million dollars. Levels of copper in upper Narragansett Bay water suggest that productivity of clam populations in areas currently open to commercial shellfishing may be impaired and that considerable economic losses result.

Tissue levels of cadmium, copper, chromium, lead and zinc in clams are monitored by the Rhode Island Department of Health and do not appear to pose any significant health hazards at present. Levels of lead, however, often approach the recommended limit of 2 mg/kg and in a couple of instances have actually exceeded this limit in areas currently closed to shellfishing because of bacterial contamination. Although the only official regulatory limit for metals in shellfish is one promulgated for mercury, this metal is not currently monitored. Hence, the health hazard of mercury in Narragansett Bay shellfish is unknown at present.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This paper was written with two objectives in mind: to provide information relevant to the protection of the quahog fishery and the protection of human health. Both are threatened as hundreds of millions of gallons of industrial effluents and sewage treatment plant discharges enter Narragansett Bay daily. The implications of trace metal pollution with respect to the quahog fishery have received little attention to date. The purpose of this paper is to assemble scientific, legal, and socio-economic information in a fashion which will direct future research and management attempts in an effective manner.

INTRODUCTION

The hard shell clam (Mercenaria sp.) industry is economically one of the most important shellfisheries in the waters of Rhode Island. The exvessel value of landings during 1979 exceeded six million dollars.[1]

The fishery took root during the colonial period on Long Island Sound and southern New England waters. There is evidence that American Indians utilized quahogs for food and trade and introduced them to colonists. During the 1800's and early 1900's Narragansett Bay shellfishermen concentrated on the oyster with a peak harvest about 1910. By 1930, however, overfishing had taken its toll on the oyster populations and the quahog emerged as the leading shellfish resource in Narragansett Bay. The earliest commercial catch records available indicate that considerable quantities were harvested during the depression of the 1930's. A decade later, immediately following the war, meat shortages helped to increase the marketability of quahogs.

Today, quahogs are sold under three distinct names which correspond to the relative size of the individuals. The largest (over two and one-half inches in length) and cheapest clams are marketed as "chowders" which, as the name implies, are frequently used in the preparation of clam chowder, or are minced, diced, or ground for clam fritters, stuffed clams, and minced clams. "Cherrystones" are the medium-sized (two to two-and-a-half inches) and medium priced clams which are eaten raw on the half shell, steamed, or

---

[1]United States Department of Commerce, National Marine Fisheries Service, Statistics Branch.

prepared as baked clams. "Littlenecks" are the smallest (one and one-half to two inches) and most expensive of the legal-sized quahogs and are eaten raw on the half shell and as steamers. Quahogs smaller than one and one-half inches are illegal to harvest and are referred to as "buttons".

The largest problems facing the industry are water pollution and over exploitation. Hard shell clam resources are located in shallow near-shore areas where pollution sources are numerous. Pollutants from industrial, domestic, agricultural and oil spill sources commonly plague the shellfish beds. Because hard shell clams are often consumed raw or lightly steamed, bacterial contamination has received great attention. An indicator organism, coliform bacteria, has been extensively used as a contamination index and highly polluted shellfishing areas have been closed to harvesting. Large amounts of quahogs are being lost to the fishery in these restricted areas. This has long been the case in upper Narragansett Bay with respect to raw sewage which is released into the water causing excessive coliform levels and resulting in the closure of large shellfishing beds.

Another group of pollutants which has received less attention yet may pose serious implications to the industry is that of trace metals. Trace metals such as cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn) among others have been shown to be concentrated by hard shell clams as well as other shellfish to levels which may impair the productivity of the productivity of the clam populations, and/or pose health hazards to consumers. An increasing awareness, however, of the toxicity and bio-accumulation characteristics associated with certain metals has drawn the attention of resource planners and public health officials. The Rhode Island Departments of Environmental Management and Health are currently monitoring metal concentrations in hard shell clams and are comparing these results with "alert levels" recommended by the Federal Food and Drug Administration. The hard shell clam industry fears the possible establishment of metal regulatory standards and the subsequent closure of additional fishing grounds.

Comprehensive assessment of the problem is clearly needed before any such regulatory actions are undertaken. Two issues prevail as central to the theme of this analysis. They are: 1) the toxicity of trace metals upon hard shell clam populations and 2) the public health hazards associated with the consumption of contaminated clams. The methodology used to conduct this assessment follows.

METHODOLOGY

The approach taken in this paper is targeted at the decision-making body. An attempt has been made to present the information in a clear, concise, and comprehensive manner so that it is easily digested and directly applicable.

The implications of trace metal pollution do not end with the biological effects on the hard shell clam. Rather, other systems such as man's legal institutions, his economy, and possibly even his social network may also be significantly affected. All may play important decision-making roles as the pollution problem is confronted. Hence, an interdisciplinary approach has been taken to provide the "big picture". Three distinct disciplines which are relevant to the problem are discussed: 1) scientific considerations, 2) legal considerations, and 3) socio-economic considerations (see Figure 1).

In this order, these three parts represent a logical sequence through which rational decisions can be made. The scientific section defines the problem by identifying the initial impacts of trace metal pollution (i.e., the physiological impacts on the shellfish and the public health impacts) and aids in the determination of alternative solutions by describing the mechanisms through which trace metals move through the ecosystem (i.e., depuration, bio-accumulation, sediment fluxes, etc.). This information has been assembled as a result of an extensive literature search and numerous discussions with researchers currently involved in trace metal studies.

Once these characteristics are identified solutions to the problem (regulatory standards, for example) can be formulated. In the legal section of the paper the feasibility of these proposed solutions is

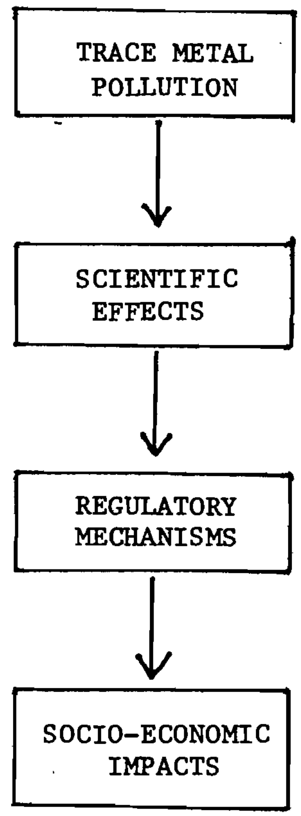


Figure 1 Schematic Illustration of Methodology

described by considering the existing institutional arrangements through which they most effectively fit. A review of relevant legal documents as well as discussions with State and Federal officials has provided the foundation for the information presented in this section.

Prior to implementation of such measures the impacts of the proposed solutions must be determined. The socio-economics section provides a sense of the value of the quahogging industry and describes the benefits and costs of the proposed solutions to the trace metal pollution problem. A questionnaire - survey was conducted to provide a profile of the labor force and to estimate fishing effort in various geographical areas.

The final section of the paper describes the conclusions of the work and offers recommendations towards the more efficient use of the marine resource.

SCIENTIFIC CONSIDERATIONS

Biology of the Hard Shell Clam

The hard shell clam Mercenaria mercenaria acquired its name due to the relative hardness of its shell with respect to other clams such as Mya arenaria, the soft shell clam. The hard shell clam also has a shorter neck than the soft shell clam, thus it is sometimes referred to as the "little neck".

The hard shell clam spawns from mid-June to mid-August producing about two million 1/235-inch (100 micron) eggs. The swimming stage is achieved in approximately 12-24 hours.[1] The early swimming larva, called the trochophore, has rudimentary internal organs but does not feed, nutrition being provided by the yolk. At this time the larva is a vigorous swimmer and migrates towards the surface of the water where it is distributed widely by wind-driven and tidal surface currents.

The digestive system of the larva becomes functional approximately 24-48 hours after fertilization.[2] The swimming behavior then becomes more moderate and the larvae are distributed more uniformly throughout the water column. The larvae feed on various forms of phytoplankton (such as Chlorella and Nitzschia) during this phase of their life cycle. Sub-optimal concentrations of phytoplankton affects survival by prolonging larval life and thus exposing the population to a greater period of predation and to the additional possibilities of transportation to both favorable and unfavorable locations. Conversely,

---

[1] Harry J. Turner and Carl J. George, "Some Aspects of the Behavior of the Quahog, Venus mercenaria, During the Early Stages", Eighth Report, Investigation of the Shellfisheries of Massachusetts, p.7.

[2] Ibid., p.8.

excessive growth of phytoplankton can be toxic to the larvae.[1] During this free swimming larval stage the quahog is vulnerable to circumstances and can do little to protect itself. The survival strategy is based on high fecundity where tremendous numbers of larvae are produced to offset the large number of deaths which occur as a result of this vulnerability.

Within ten to twelve days, at a size of 1/125 of an inch (200 microns) metamorphosis occurs with the development of the foot and gills. When the swimming organ has degenerated the larva settles to the bottom to spend the remainder of its life with the sediments. This process is referred to as "setting". It is not known if the larva selectively determines preferential sediment types during setting but it has been shown that populations develop better in certain types.[2] Once on the bottom, the juvenile quahog attaches itself to sand grains, seaweed, or other bottom substrates by means of a thread or "byssus". They remain attached until they reach a size of approximately 1/2 inch when they burrow into the sediments. The ability to move and dig decreases with increasing age; those larger than two inches seldom bury themselves.

Adult quahogs occupy the sub-tidal area in bays and inlets where salinities range from twenty to thirty parts per thousand. Sexual maturity is reached in two to four years at a size of approximately two inches. Feeding is accomplished by siphoning the overlying water column. Fine particles are delivered to the mouth by ciliary currents while coarse particles are rejected by sorting areas. Fine particles are then partly digested in the stomach and are further broken down intracellularly in the digestive gland.

---

[1] Harry J. Turner and Carl J. George, "Some Aspects of the Behavior of the Quahog, Venus Mercenaria, During the Early Stages", Eigth Report, Investigation of Shellfisheries of Massachusetts, 1972, p. 9.

[2] D.M. Pratt, "Abundance and Growth of Venus Mercenaria and Callocardia morrhuana in Relation to the Character of Bottom Sediments", Journal of Marine Research, 12:73.

Background Information

Because much of the following discussion is somewhat technical in content and because the desired audience includes individuals without extensive scientific vocabularies some background information is in order.

Based on physical properties, the elements are divided into three classes. Those elements which show a luster when polished, are malleable, ductile, and good conductors of heat and electricity are classed as metals. Those elements which do not possess these properties are nonmetals. Intermediates are referred to as metalloids.

Several metals have been shown to be commercially and industrially useful to man. Because of this we have mined and processed vast quantities of these elements. Frequently, these metals find their way into wastewaters and streams and eventually into our coastal waters. When sufficient quantities are reached they present ecological and/or health problems. These metals (and their respective chemical symbols) which have been suggested to cause such hazards include cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), and nickel (Ni).

Several different units are commonly used to describe the concentrations of metals in water, sediments, or tissue. The units used in this paper will remain as constant as possible for comparative purposes. Concentrations in water are expressed in ug (micrograms or one millionth of a gram) of metal per liter (slightly larger than a quart) of seawater. Because a liter of water weighs approximately one thousand grams and, as mentioned above, there are one million micrograms in one gram, one microgram per liter (ug/l) equals one part per billion (ppb). Hence, ug/l can be used interchangeably with ppb.

Tissue and sediment samples cannot be expressed in liters because they are not liquids. Rather, they are simply expressed by weight in kilograms (kg) which equals one thousand grams. Hence, metal concentrations in tissue and sediment is expressed in milligrams of metal per kilogram of tissue or sediment (mg/kg) which is also equivalent to parts per million (ppm).

In summary then Table 1 illustrates the standardized units which are common throughout much of the literature and will be adhered to throughout the remainder of this paper.

TABLE 1

UNITS FOR EXPRESSING METAL CONCENTRATIONS IN WATER, SEDIMENT, AND TISSUE

Sample	By Weight and/or Volume	By Proportion
Water	ug/l (micrograms per liter)	ppb (parts per billion)
Sediment	mg/kg (milligrams per kilogram)	ppm (parts per million)
Tissue	mg/kg (milligrams per kilogram)	ppm (parts per million)

Metals exist in two forms in water: particulate and dissolved. Particulate refers to solid particles (such as oxidized precipitates or algae which has taken up metals) while the dissolved fraction refers to materials in solution (consisting of both inorganic ions and organic complexes).

Sources of Trace Metals

Metals occur naturally in seawater but only in trace quantities, hence the term "trace metals" is often used to describe the constituents under study. Table 2 includes typical background levels which might be expected in unpolluted coastal waters.

Anthropogenic impacts are caused by both point sources and non-point sources. Point sources include sewage treatment plant effluents and industrial wastewater. These pollutants can be traced to a single source and thereby be quantified. Non-point sources, on the other hand, refer to more widespread events such as stormwater runoff. These pollutants originate from numerous sources and are therefore difficult to trace.

Typical concentrations of metals in both types of pollutants are shown in Table 2. The figures for both sewage treatment plant and industrial effluents are actual monitoring results generated by the Rhode Island Department of Environmental Management. The stormwater runoff figures represent typical concentrations of metals which might be expected in runoff from various land uses.

Much of this data reveals the fact that concentrations of metals in all of these various wastewaters commonly exceed background levels by a factor of one hundred or more. It should also be noted that metal concentrations greatly differ between the various discharges shown in Table 2. Copper concentrations, for example, range from 10 ug/l to 1,320 ug/l.

In order to determine the individual contribution of each of the point sources, metal concentrations were multiplied by daily discharge

TABLE 2

COMPARISON OF NATURAL BACKGROUND LEVELS AND ANTHROPOGENIC WASTEWATER LEVELS OF TRACE METALS IN NARRAGANSETT BAY (EXPRESSED IN ug/1)

	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Natural Background Levels	.10	.25	2	.07	.03	3	3
Sewage Treatment Plants							
Bristol	1	50	60	-	-	40	90
Bucklin	2	90	350	-	-	390	260
Cranston	2	20	40	-	-	190	80
East Greenwich	85	100	390	-	-	40	660
East Providence	2	20	570	50	1	490	250
Newport	20	40	150	10	5	20	370
Providence	4	150	980	-	-	890	1550
South Kingstown	1	10	370	180	-	140	230
Warren	4	20	220	30	5	250	900
Warwick	-	60	300	10	1	80	240
West Warwick	1	40	40	10	1	40	60
Woonsocket	70	120	80	100	3	30	270
Industrial Plants							
American Hoechst	-	-	620	-	-	140	120
Amperex	-	130	60	-	1	-	40
Bostich	100	60	10	-	-	-	530
Brown & Sharpe	-	50	20	-	-	50	-
Ciba Geigy	-	-	10	-	-	--	870
Corning	-	30	-	30	-	-	-
United Wire	-	50	1320	30	-	50	650
Woonsocket	-	10	-	-	-	-	-
Stormwater Runoff							
High Density Residential	1.8	120	56	870	3.8	17	210
Low Density Residential	1.5	96	46	720	3.8	14	180
Commercial	1.4	72	43	1100	2.1	15	170
Industrial	2.6	180	70	760	1.5	24	210

SOURCES: Stephan Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979, p146 and Rhode Island Department of Environmental Management files, and Rhode Island Statewide Planning Program, 208 Water Quality Management Plan for Rhode Island, Draft Plan and Environmental Impact Statement, March 1979, p. 267.

volumes (expressed in millions of gallons per day or MGD) and the results are shown in figures 2-10. From these illustrations it is clear that the heaviest discharges of metals in Narragansett Bay occur in the upper Providence River and the Pawtuxet River. Other significant sources include Bristol, Warren, Greenwich Bay, and Newport. It is also evident that sewage treatment plant effluents are much more significant contributors than industrial discharges.

It should be recognized that due to the variability inherent in discharge rates and analytical accuracy limits the actual contribution of each of these sources may vary from the data presented in the figures. For this reason this data has been tabulated in the Appendix to express the ranges to be expected within 95% confidence limits.

Environmental Levels of Trace Metals

The fate of trace metals once introduced into the Narragansett Bay ecosystem is metal-specific. It seems as though certain metals, such as iron, chromium, and mercury appear to be rapidly removed from the water column and deposited in the sediments, while others, like cadmium, remain in the water column for longer periods of time.[1]

---

[1] Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979, p. 125.

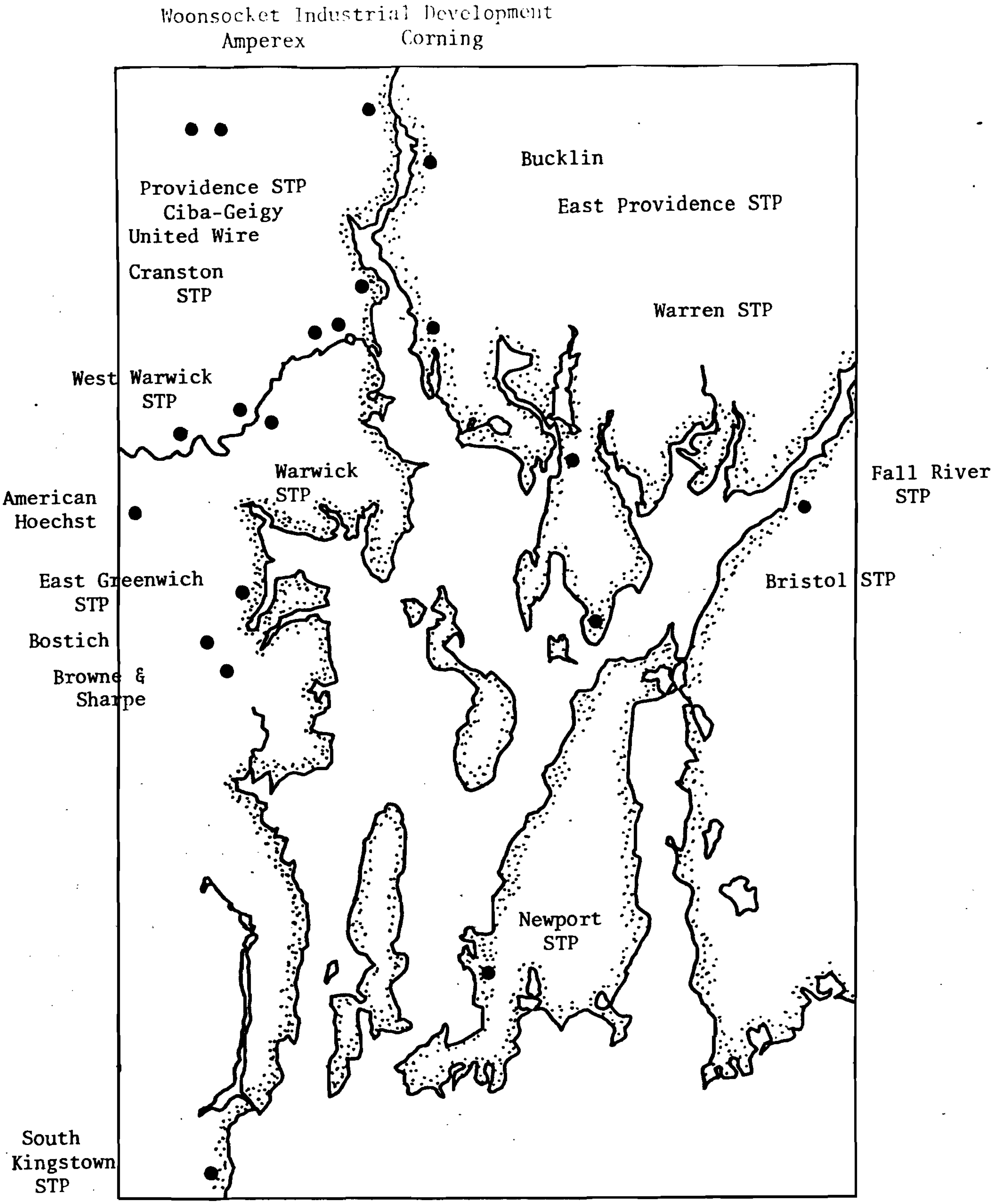


Figure 2 Key to Locations of Major Industrial and Sewage Treatment Plant (STP) Discharges on Narragansett Bay (Figures 4-10)

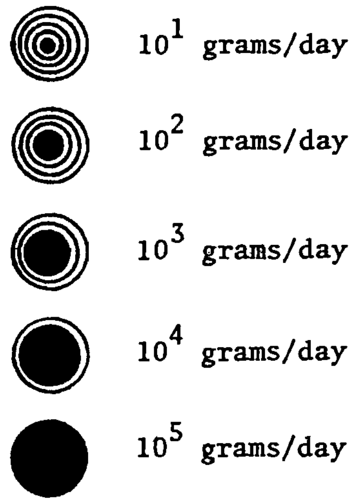


Figure 3 Key to Discharge Levels of Major Industrial and Sewage Treatment Plants on Narragansett Bay (figures 4-10)

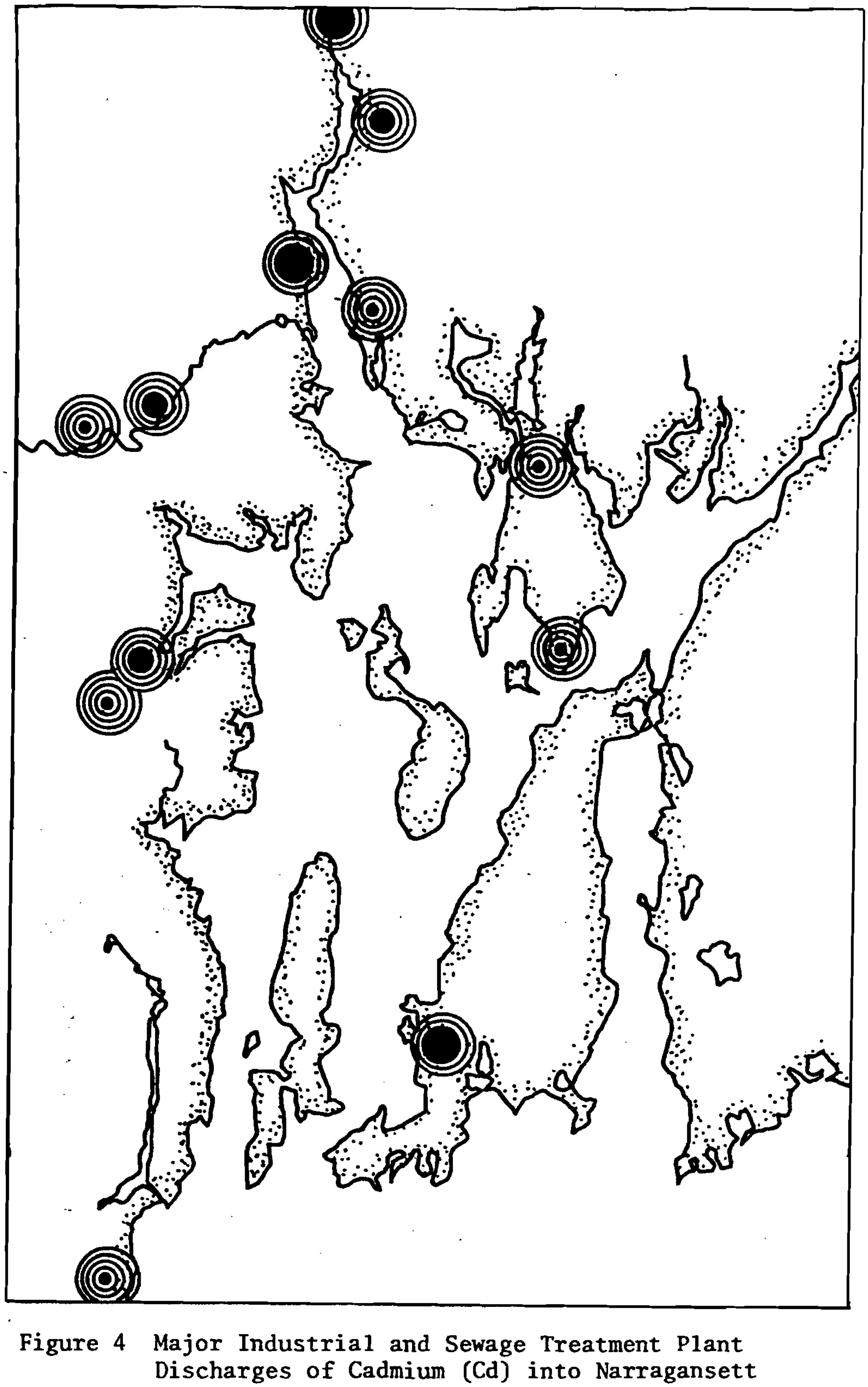


Figure 4 Major Industrial and Sewage Treatment Plant Discharges of Cadmium (Cd) into Narragansett Bay 1977.

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

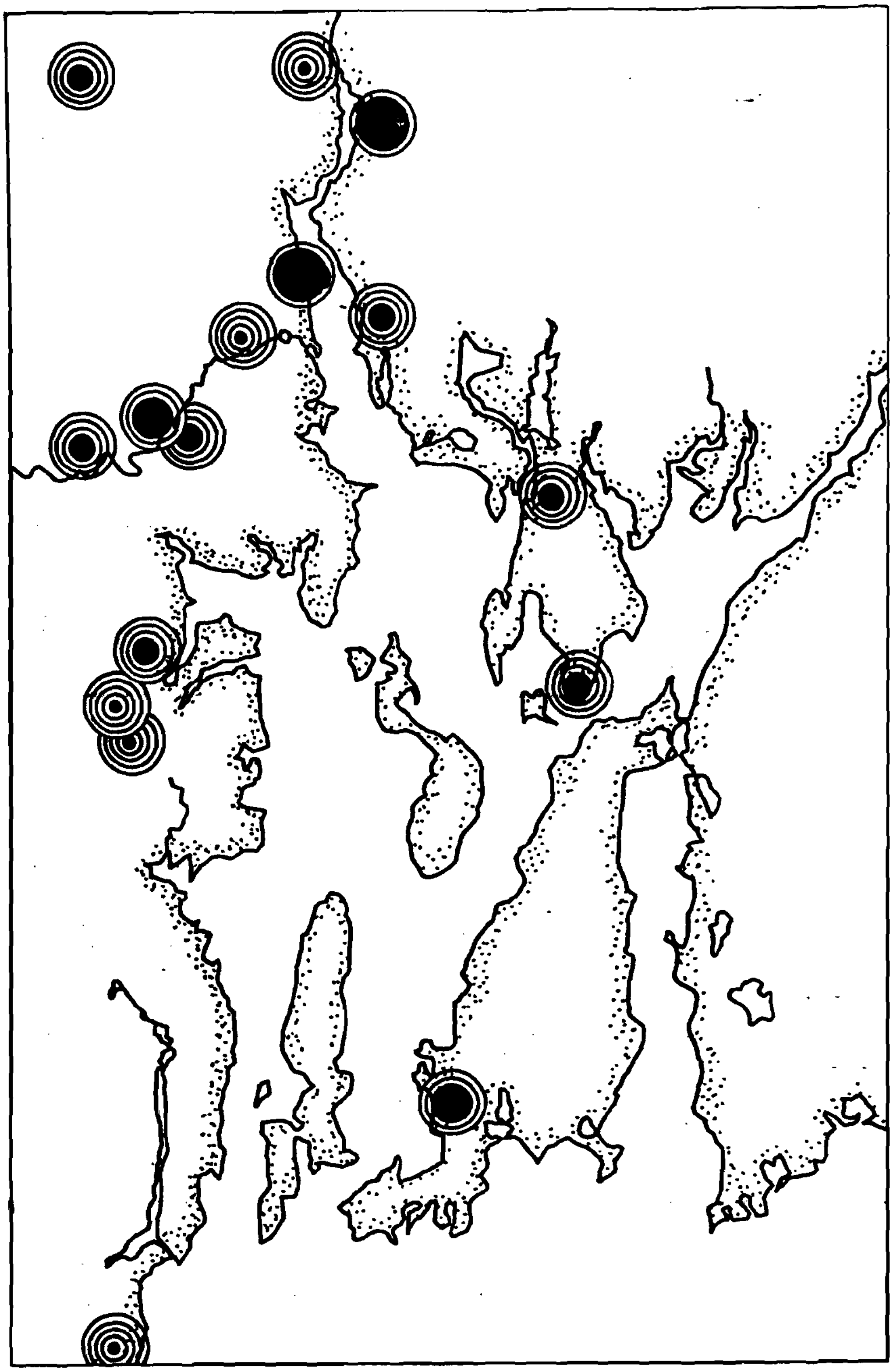


Figure 5 Major Industrial and Sewage Treatment Plant Discharges of Chromium (Cr) into Narragansett Bay 1977.

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

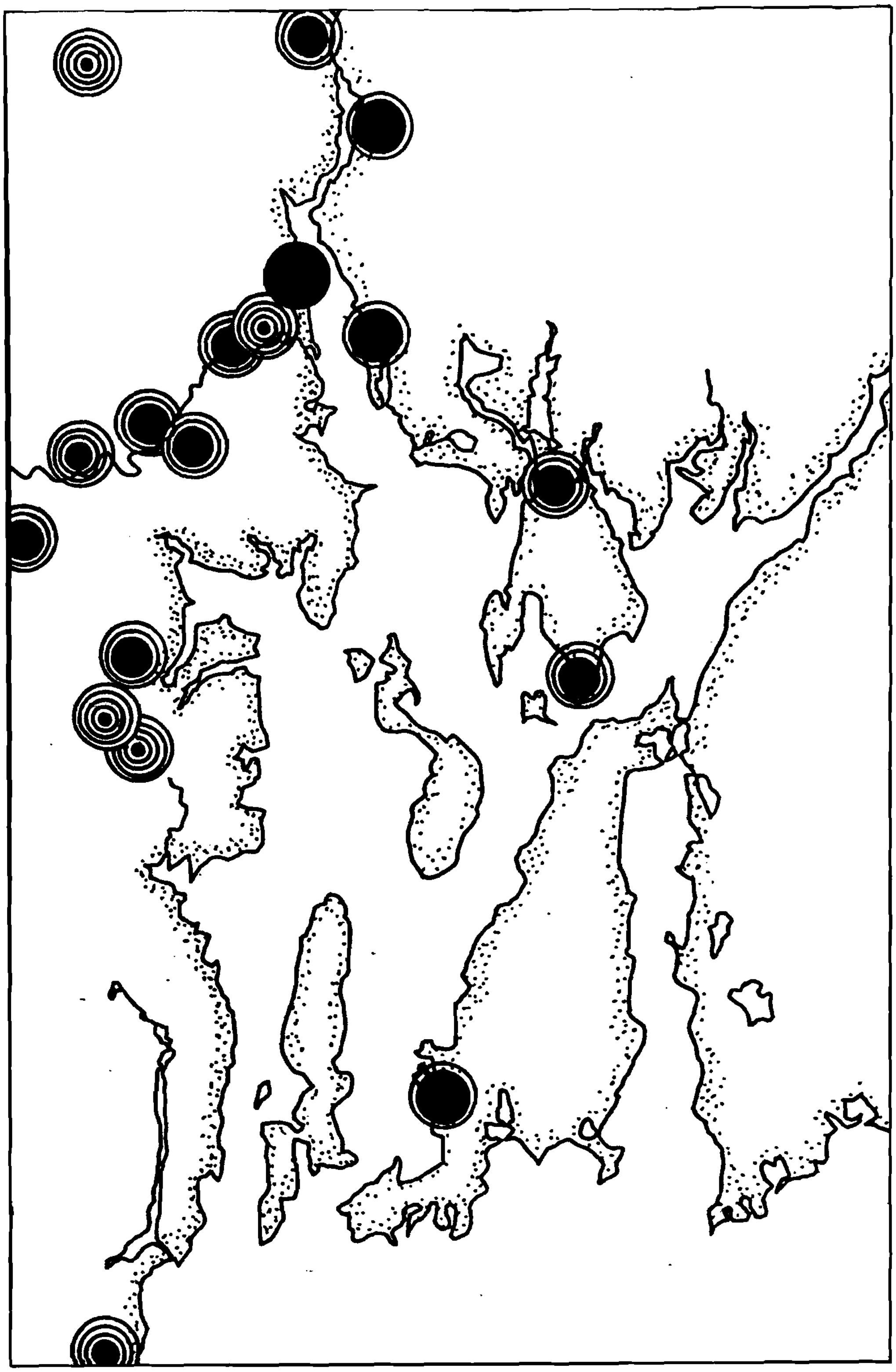


Figure 6 Major Industrial and Sewage Treatment Plant Discharges of Copper (Cu) into Narragansett Bay 1977.

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

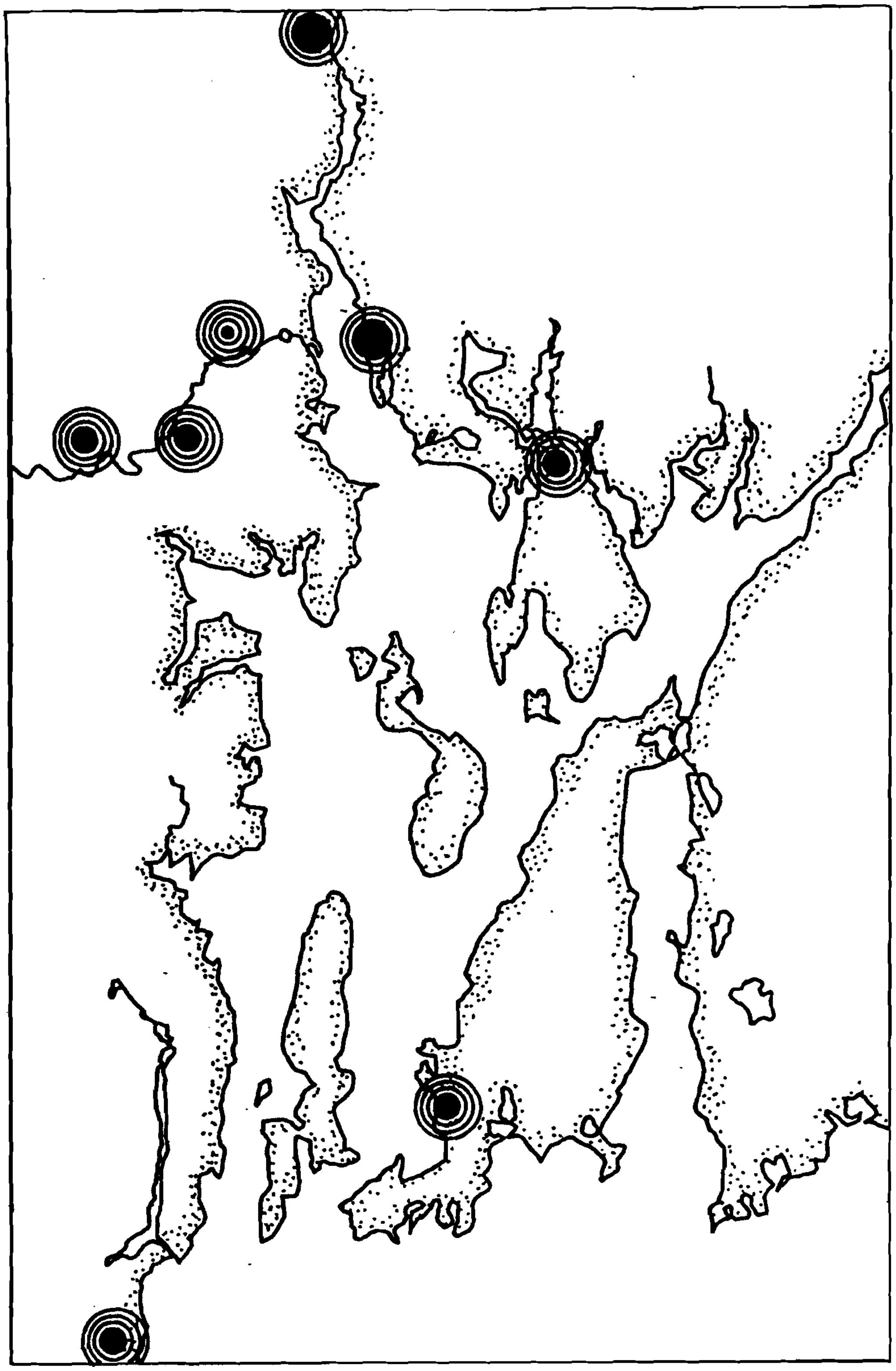


Figure 7 Major Industrial and Sewage Treatment Plant Discharges of Lead (Pb) into Narragansett Bay 1977

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

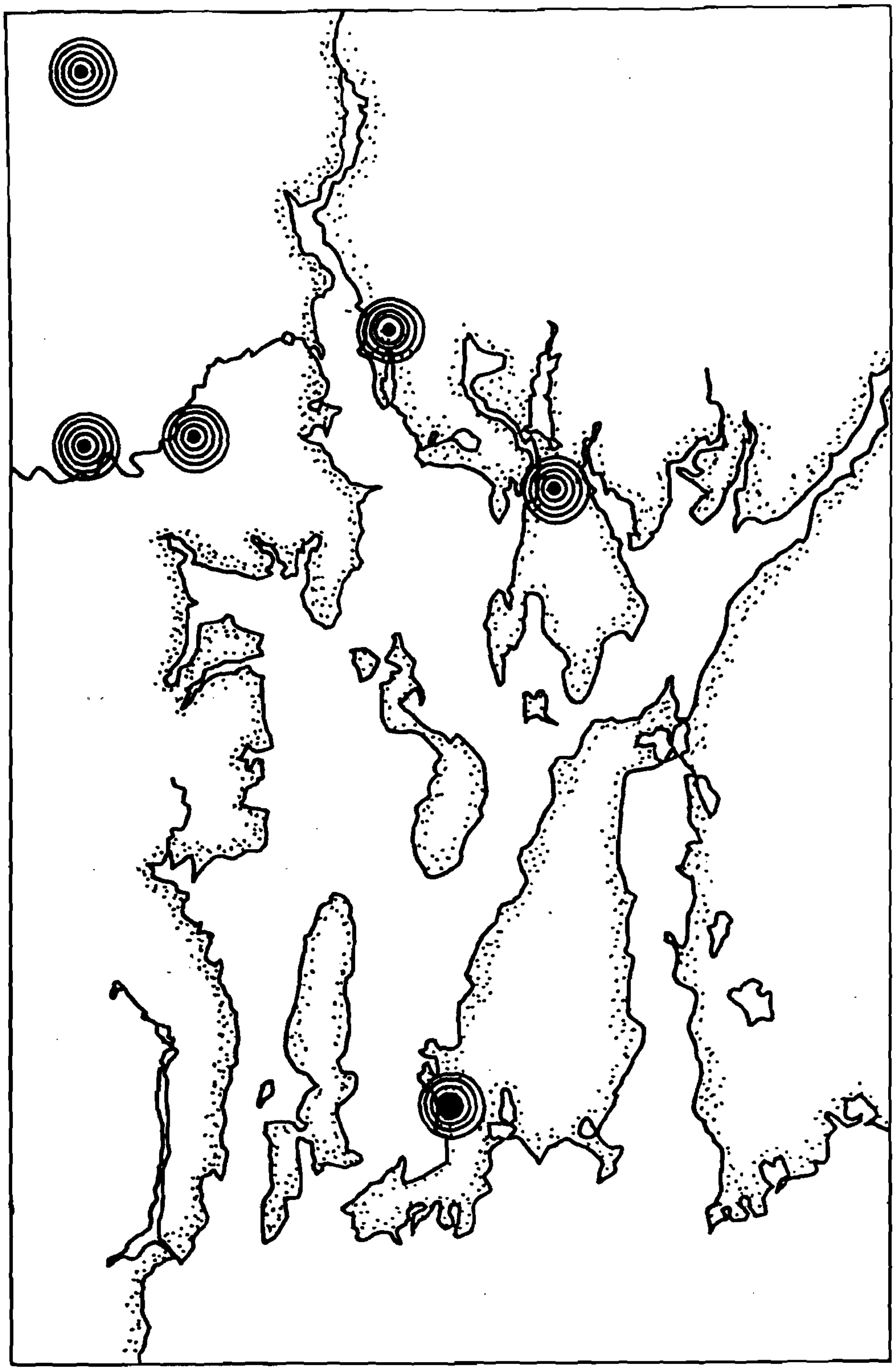


Figure 8 Major Industrial and Sewage Treatment Plant Discharges of Mercury (Hg) into Narragansett Bay 1977

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

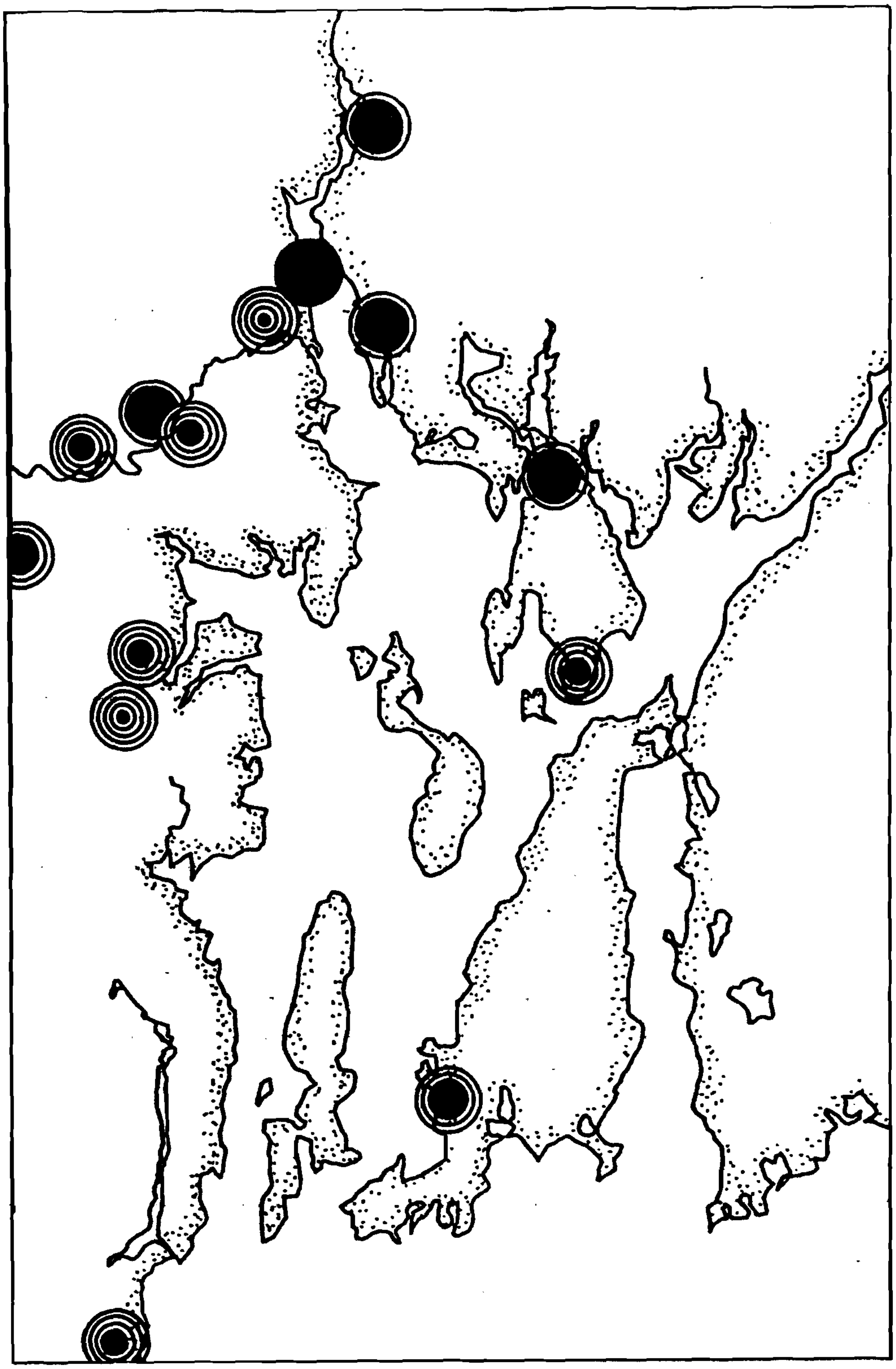


Figure 9 Major Industrial and Sewage Treatment Plant Discharges of Nickel (Ni) into Narragansett Bay 1977

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

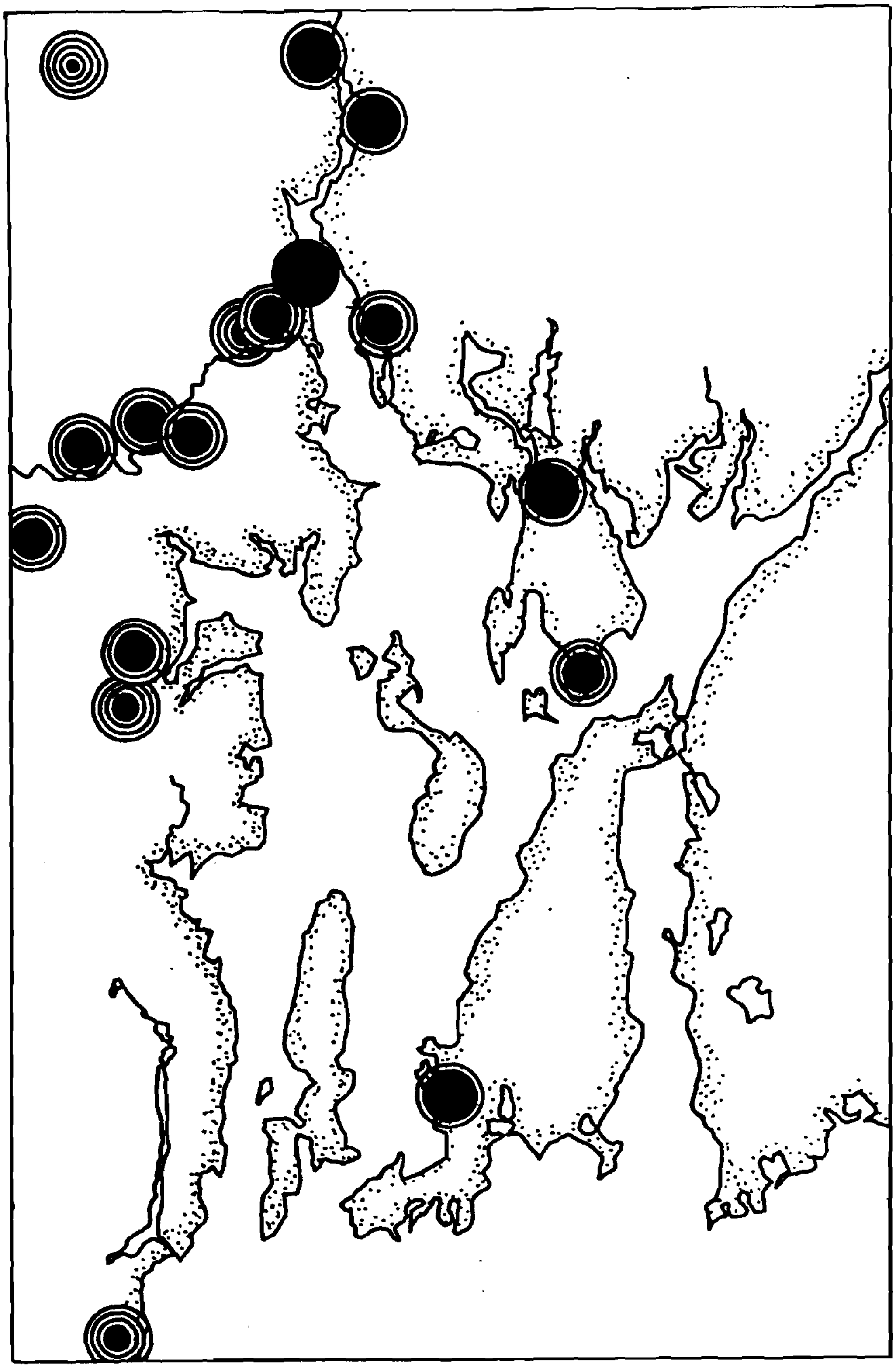


Figure 10 Major Industrial and Sewage Treatment Plant Discharges of Zinc (Zn) into Narragansett Bay 1977

NOTE: See Figure 2 for Key to Discharge Locations
See Figure 3 for Key to Discharge Levels

This differentiation in the settling rates is related to the solubility of the metal in seawater (i.e. the degree to which it dissolves). The ratio between dissolved and particulate metals were measured by Davey and Soper (1975) in seawater collected adjacent to the EPA marine laboratory.[1] The results are shown below in Table 3.

TABLE 3

TRACE METALS IN NARRAGANSETT BAY SEAWATER ADJACENT TO THE NATIONAL MARINE WATER QUALITY LABORATORY (19 MARCH 1974).

Trace Metals	Particulate (ug/l)	Dissolved (ug/l)	°/₀ Dissolved
Cd	not detected	0.1 ± 0.0	100
Cr	0.7 ± 0.3	0.1 ± 0.1	7.8
Cu	0.6 ± 0.1	1.2 ± 0.2	67
Fe	136.2 ± 100.9	0.7 ± 0.2	0.5
Mn	4.8 ± 0.7	5.9 ± 0.3	55
Ni	0.3 ± 0.3	2.2 ± 0.1	87
Pb	0.5 ± 0.2	0.4 ± 0.2	42
Zn	1.3 ± 0.3	3.1 ± 0.4	70

SOURCE: Earl W. Davey and Albert E. Soper, "Apparatus for the In Situ Concentration of Trace Metals from Seawater", Limnology and Oceanography, Vol. 20, No. 6, November 1975, pp. 1019-1023.

Chromium and iron exist almost entirely in the particulate form (and tend to be rapidly transported to the sediments) while cadmium and nickel appear dissolved (and tend to remain in the water column). Copper, manganese, lead, and zinc are intermediate in their particulate - dissolved ratio.

A concentration gradient from upper Bay sediments to lower Bay sediments is evident in at least six metals (see Figures 11-16). The

[1] Earl W. Davey and Albert Soper, "Apparatus for the In Situ Concentration of Trace Metals from Seawater", Limnology and Oceanography, Vol. 20, No. 6, November 1975, pp. 1019-1023.

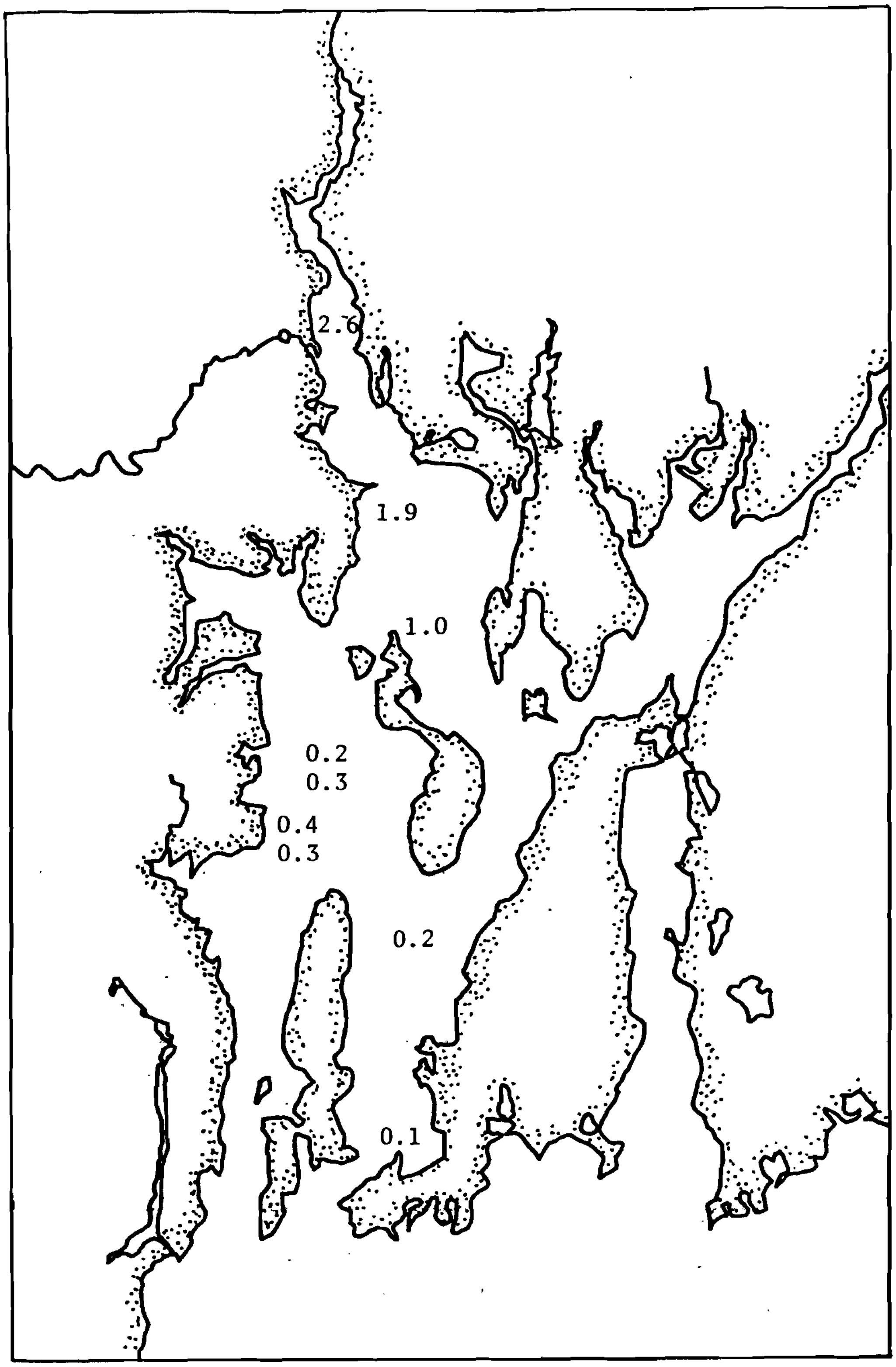


Figure 11 Cadmium in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

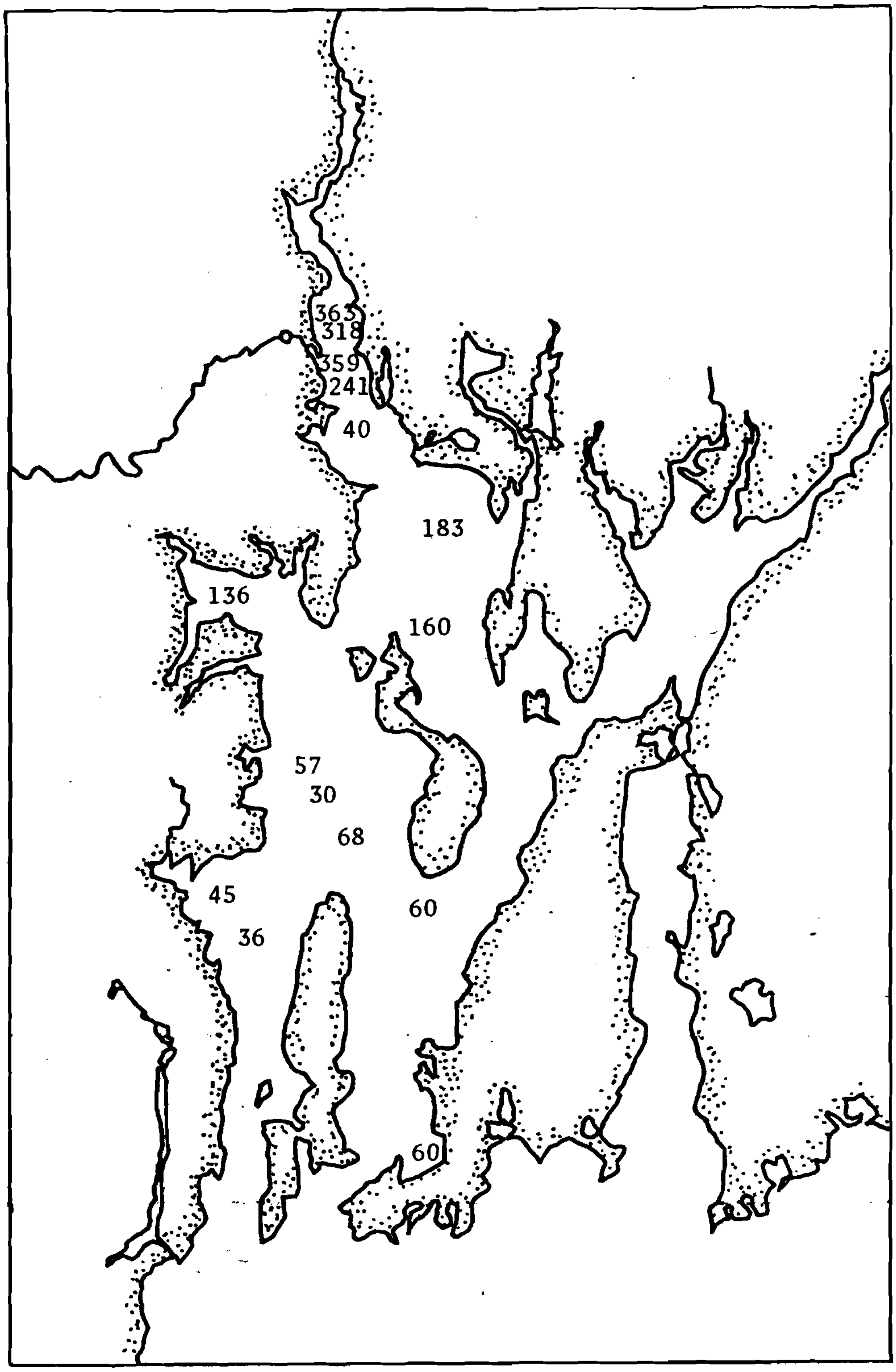


Figure 12 Chromium in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

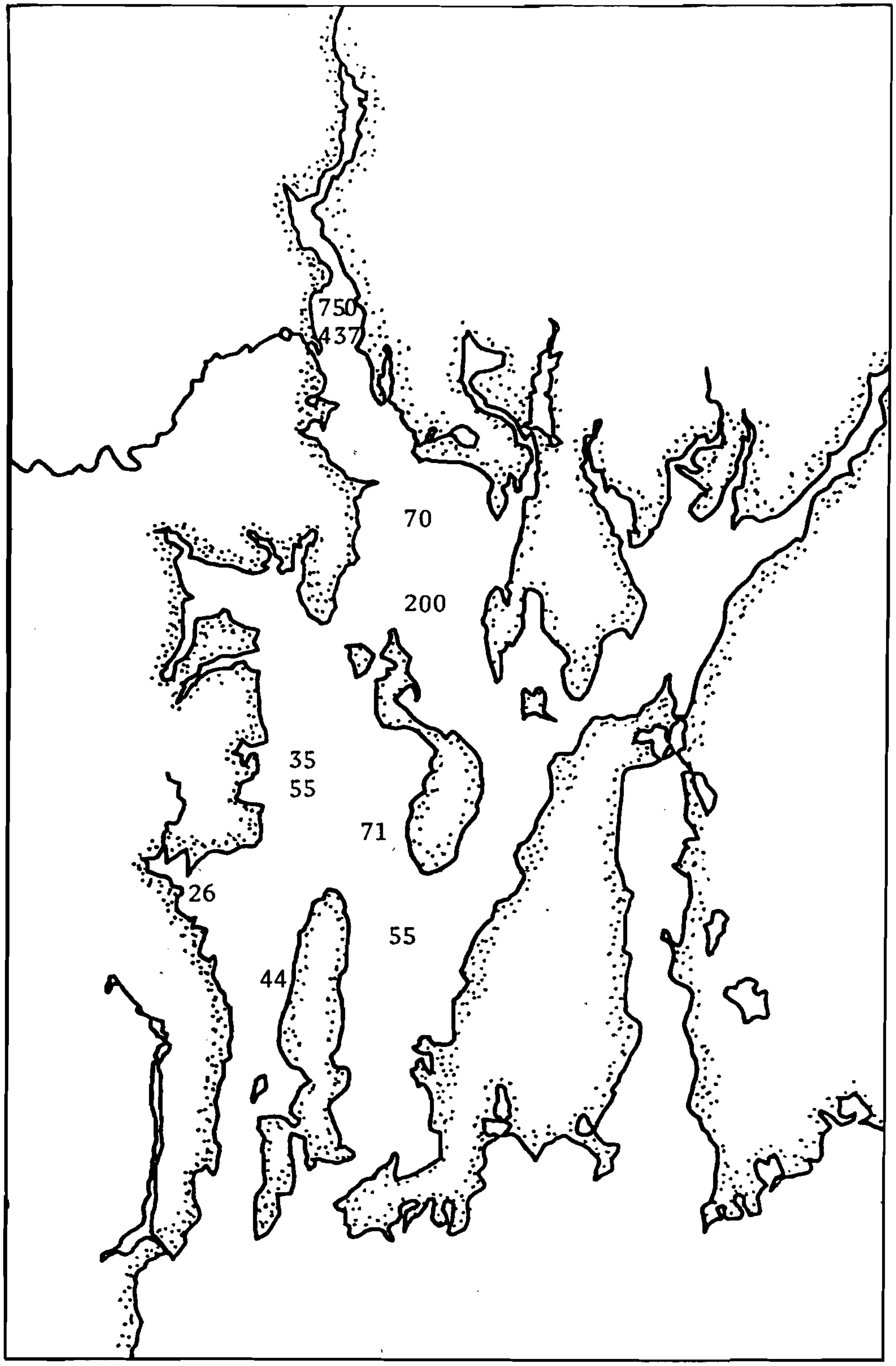


Figure 13 Copper in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

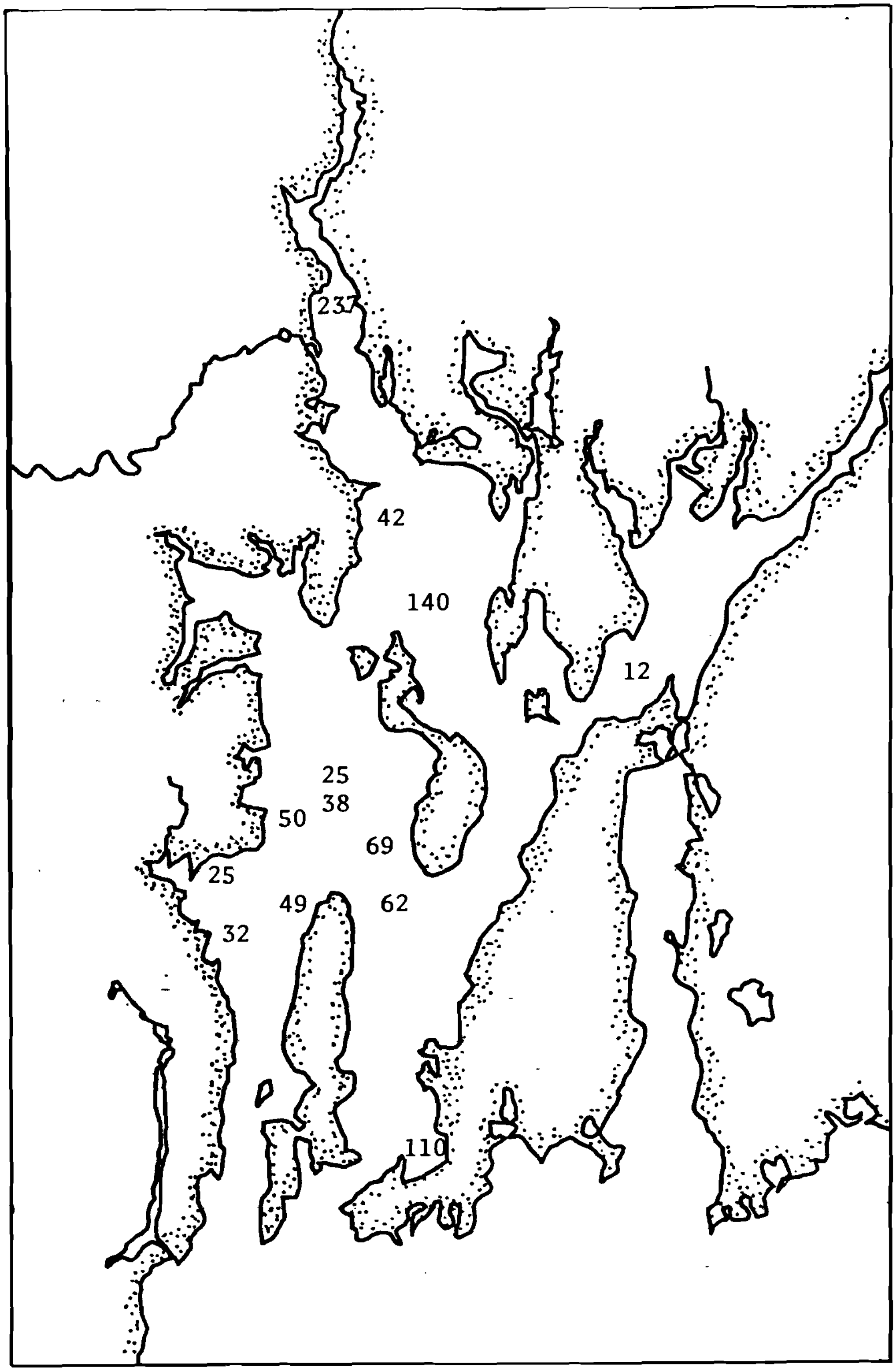


Figure 14 Lead in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

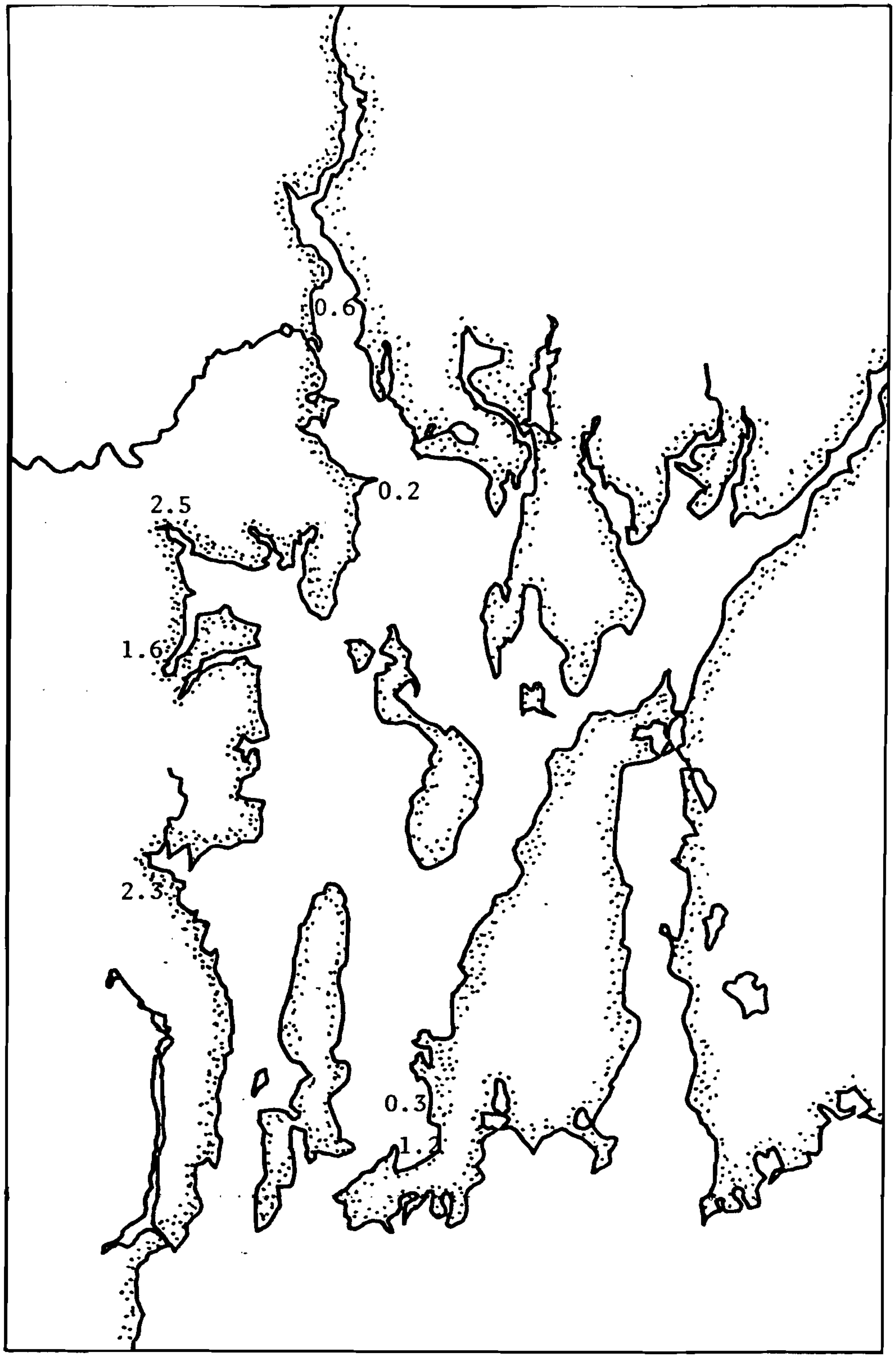


Figure 15 Mercury in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

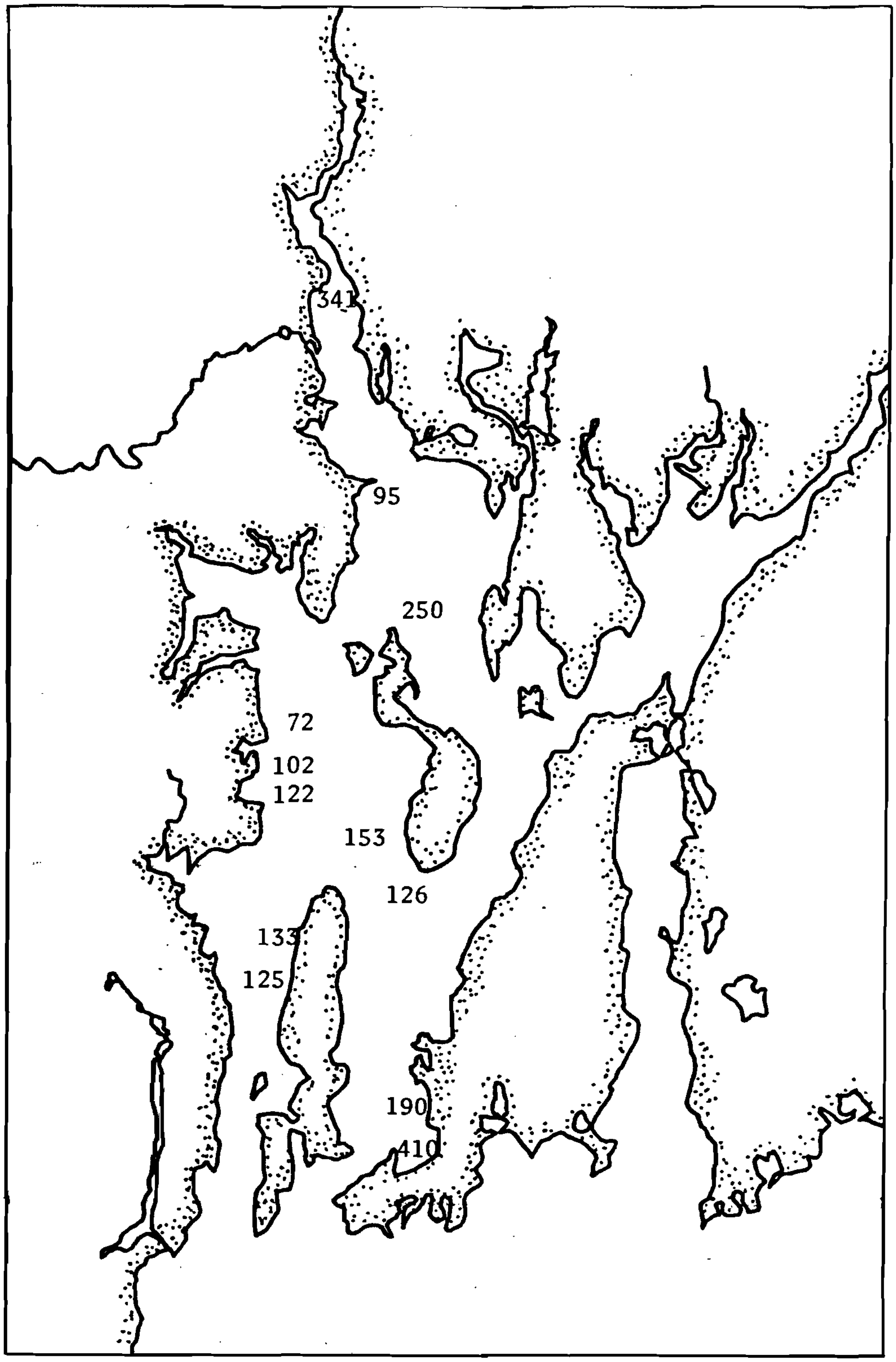


Figure 16 Zinc in Narragansett Bay Sediments (ppm dry wt.)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

highly contaminated sediments release some metals (such as chromium, iron, copper, and zinc) into the nearby interstitial and overlying waters at various flux rates for long periods of time after the pollution source is abated.[1] Other metals (such as cadmium, lead, nickel, and mercury) form more stable compounds in the sediments and tend not to be released.[2]

A limited amount of data is available with respect to trace metal concentrations in the water column. This is because the levels are so low (not necessarily as low as they should be however) that it makes analytical techniques difficult and expensive. Some data for copper, and mercury is shown in Figures 17-18. As in the sediments, upper Bay levels commonly exceed those concentrations found in the lower Bay.

---

[1] See Donald K. Phelps, Gregory Telek, and Richard L. Lapan, Jr., "Assessment of Heavy Metal Distribution Within the Food Web", Marine Pollution and Marine Waste Disposal, 1975, pp. 341-348; and Donald K. Phelps and Allen C. Myers, "Ecological Considerations in Site Assessment for Dredging and Spoiling Activities", Environmental Protection Agency, Narragansett, Rhode Island, 1977.

[2] See Michael L. Bender, Richard J. McCaffrey, J. Douglas Cullen, "The Release of Heavy Metals From Reducing Marine Sediments", Advances in Marine Environmental Research, Proceedings of a Symposium, September 1979, pp.2-25; M. Fujiki, R. Hirota, and S. Yamaguchi, "The Mechanism of Methylmercury Accumulation in Fish", Management of Bottom Sediments Containing Toxic Substances, Proceedings 2nd U.S. - Japan Experts Meeting, October 1976, Tokyo, Japan, USEPA Rpt. No. 600/3-77-083:89-95; T.A. Jackson, "The Biogeochemistry of Heavy Metals in Polluted Lakes and Streams at Flin Flon, Canada and a Proposed Method for Limiting Heavy Metal Pollution of Natural Waters", Environmental Geology, 1978, 2:173-189; and Ivan Valiela, Mario D. Banus, and John M. Teal, "Responses of Salt Marsh Bivalves to Enrichment with Metal-Containing Sewage Sludge and Retention of Lead, Zinc, and Cadmium by Marsh Sediments", Environmental Pollution, 7:1979, pp. 149-157.

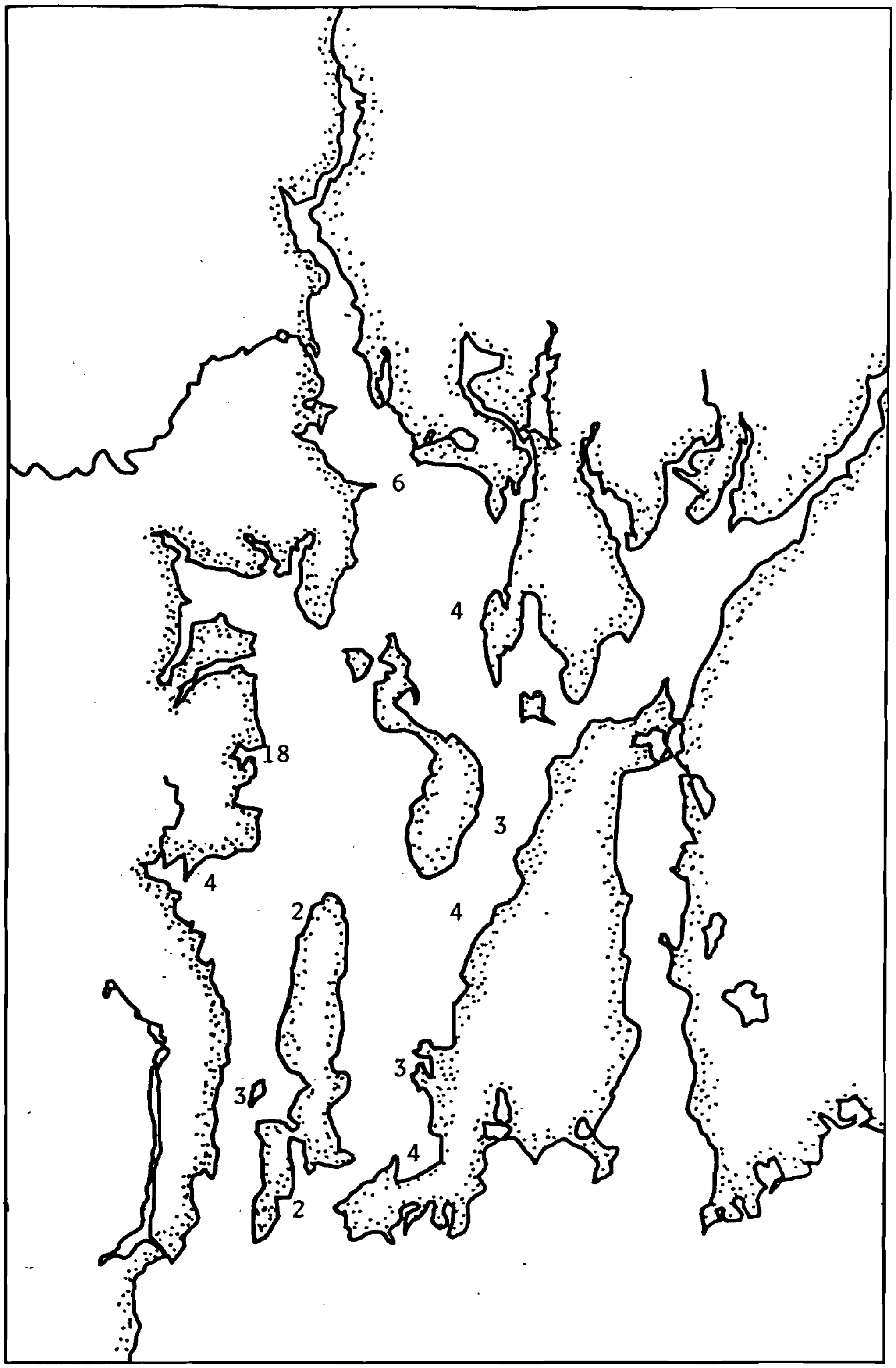


Figure 17 Copper in Narragansett Bay Water (ppb)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979

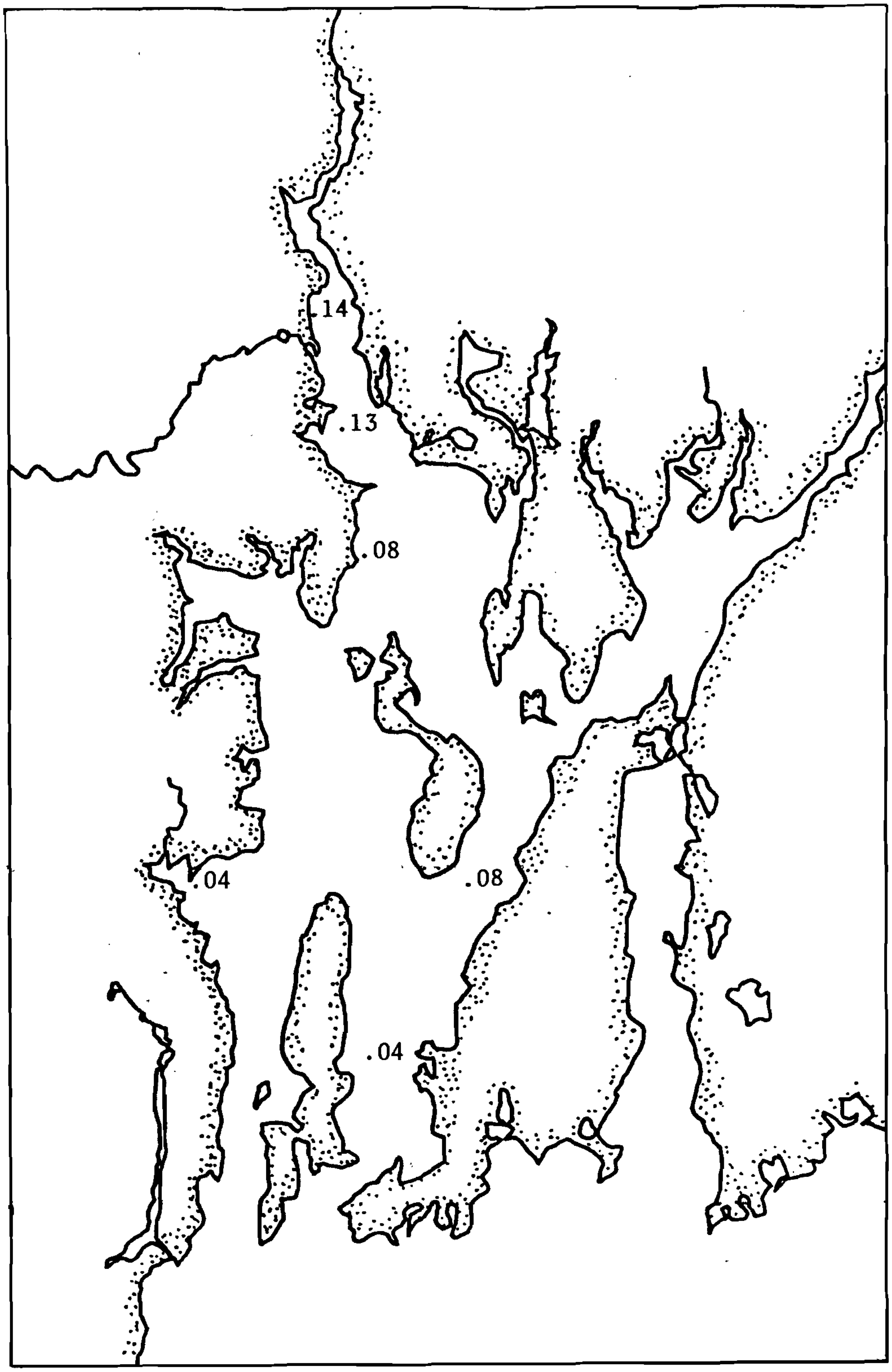


Figure 18 Mercury in Narragansett Bay Water (ppb)

SOURCE: Stephen Olsen and Virginia Lee, A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay, Coastal Resources Center, University of Rhode Island, May 1979.

Toxicological Impacts

Researchers have studied the toxicity of trace metals on the hard shell clam by exposing individuals to a variety of seawaters with different metal concentrations and observing mortality rates. Three such studies are discussed below and are summarized in Table 4.

Calabrese and Nelson (1974) studied the lethal effects of several metals on hard shell clam embryos.[1] Individuals were exposed to various concentrations of these metals for a period of forty-eight hours and mortality rates were noted. Mercury was found to be toxic at relatively low levels while significantly higher concentrations of zinc, nickel, and lead were needed to produce similar results.

In a second study Calabrese et al. (1976) experimented with Mercenaria larvae.[2] Individuals were exposed to different levels of metals for an eight to ten day period. Mercury and copper were determined to be toxic at significantly lower concentrations than either zinc or nickel. These results correlate well with those of the earlier study conducted on embryos. In comparison it can be concluded that larvae are somewhat more resistant to toxic metals in that higher concentrations over a longer exposure period were used to produce similar mortality rates.

A third study conducted by Schuster and Pringle (1967) demon-

---

[1] Anthony Calabrese and David Nelson, "Inhibition of Embryonic Development of the Hard Clam, Mercenaria mercenaria, by Heavy Metals", Bulletin of Environmental Contamination and Toxicology, Vol. 11, No.1, 1974, pp. 92-97.

[2] Anthony Calabrese, J.R. MacInnes, David A. Nelson, and J.E. Miller, "Survival and Growth of Bivalve Larvae Under Heavy Metal Stress", Marine Biology, 1976.

strated the effects of certain metals on adult clams.[1] Individuals were held for an exposure period of twenty weeks. Only cadmium and copper were tested at sufficient concentrations to achieve LC_{50} levels. Virtually no mortalities were observed at the levels of zinc and chromium studied.

TABLE 4
TOXICITY OF TRACE METALS ON THE HARD SHELL CLAM
(LC_{50} VALUES SHOWN IN ug/1)

	Calabrese & Nelson (1974) 48-hour exposure	Calabrese et al. (1976) 8-10 day exposure	Schuster & Pringle (1967) 20 wk exposure
Mercury	4.8	15	--
Copper	-	16	25
Cadmium	-	-	200
Chromium	-	-	>100
Zinc	166	195	>200
Nickel	310	5700	-
Lead	780	-	-

NOTE: An LC_{50} concentration is that concentration at which fifty percent of the test individuals are killed during the specified exposure period.

[1]Carl N. Schuster and Benjamin H. Pringle, "Effects of Trace Metals on Estuarine Mollusks", United States Department of Health, Education and Welfare, Public Health Service, 1967.

In order to determine which metals are most likely to present toxicological hazards to quahogs in the Narragansett Bay ecosystem these LC_{50} values were compared to expected background levels. Table 5 displays this data below. The lowest determined LC_{50} values were used in this illustration. Safety factors were calculated as the multiplicative difference between unpolluted background levels and LC_{50} levels. These factors therefore represent the number of times which the background level must be increased to reach a concentration lethal to fifty percent of the individuals. The lower the safety factor the more potentially hazardous is the situation. The results of this analysis indicate that copper is clearly the most likely hazard in this respect.

TABLE 5
COMPARISON OF LC_{50} LEVELS AND BACKGROUND LEVELS
OF TRACE METALS (EXPRESSED IN ug/l)

	Cd	Cr	Cu	Pb	Hg	Ni	Zn
LC_{50} Level	200	100	16	780	4.8	310	166
Backgrond Level	.10	.25	2	.07	.03	3	3
Safety Factor	2000	400	8	11143	160	103	55

Unfortunately, no copper data was reported in the Calabrese and Nelson study of embryos. Hence, this "safety factor" for copper has been based on toxicological data on larva. As is evident in Table 4, however, embryos are generally more sensitive to lower concentrations of metals over a shorter period of time than are larva or adults. Assuming a similar effect with copper one can predict that the LC_{50} value for embryos is likely to be in the vicinity of 5-10 ug/l. Data shown in figure 17 demonstrate that such levels exist in Narragansett Bay suggesting the occurence of toxicological impacts.

Before such impacts can be predicted, however, a few other factors need to be considered. The first factor is that dissolved copper occurs in both inorganic and organic forms. The levels reported for Narragansett Bay in figure 17 represent both forms whereas the toxicological data includes only the inorganic portion. Because only the inorganic portion is considered toxic[1] a direct comparison between these two sets of data could be misleading. Inorganic copper accounts for about forty to eighty percent of the total dissolved copper.[2] Hence a more accurate comparison could be made by multiplying Narragansett Bay values by these percentages to determine the amount of "toxic" copper which is present.

A second factor in determining toxicological impacts is the ecological effects of trace metal pollution. The same elevated copper levels which are toxic to the quahog embryos are also likely to be toxic to the quahog's predators. This will tend to decrease the overall impacts by allowing a greater prey survival rate.

A third factor is that toxicological impacts will occur below the LC_{50} level. This level is not a threshold concentration where

---

[1]Personal communication with Dr. Candace Oviatt, Marine Ecosystems Research Laboratory, University of Rhode Island, March 4, 1981.

[2]Personal communication with Dr. Carlton Hunt, Marine Ecosystems Research Laboratory, University of Rhode Island, April 5, 1981.

impacts begin but rather simply a point along a continuum of a range of toxicological effects where fifty percent mortality occurs. Concentrations below the LC_{50} will also cause mortalities.

Several scientists have studied the sub-lethal effects of various metals on the behavior of marine organisms.[1] Motor functions such as swimming , performance, locomotion, and equilibrium, as well as physiological responses, especially respiratory patterns have been shown to be related to metal concentrations in the environment. Unfortunately no studies are reported for the sub-lethal effects of trace metals on Mercenaria. However, metals of proven high toxicity at comparatively low concentrations to marine biota include copper, chromium, and to a lesser extent, zinc and nickel.[2]

Bio-Accumulation Characteristics

Numerous studies of metal concentration in the hard shell clam are reported by Eisler.[3] Bio-accumulation characteristics have been demonstrated in hard shell clams for cadmium, chromium, mercury, nickel, lead, and zinc, among others. Pringle et al. (1968) compared metal concentrations in hard shell clams with levels found in the surrounding environment and enrichment factors (the ratio of metals in clam tissue

---

[1] Ronald Eisler, "Behavioral Responses of Marine Poikilotherms to Pollutants", Phil. Trans. Royal Society of London, B. 286, 1979, pp. 507-521.

[2] Ronald Eisler, "Toxic Cations and Marine Biota: Analysis of Research Effort During the Three Year Period 1974-1976", Marine Pollution: Functional Responses, 1979, pp. 111-149.

[3] Ronald Eisler, Annotated Bibliography on Biological Effects of Metals in Aquatic Environments, U.S. Environmental Protection Agency, A Series of Four Volumes, 1973-1979.

compared to metals in the water column) were calculated.[1] These results are shown below in Table 6.

TABLE 6
TRACE METAL ENRICHMENT FACTORS FOR HARD SHELL CLAMS

Cd	Cr	Cu	Pb	Hg	Ni
750	23400	900	2900	5800	2000

SOURCE: Benjamin H. Pringle, Dale E. Hissong, Edward L. Katz, and Stefan T. Malawka, "Trace Metal Accumulation by Estuarine Mollusks", Journal of Sanitary Engineering Division, June 1968, pp. 455-475.

It has been reasonably well established by Schulz-Baldes (1973)[2] and by Pringle et al. (1968) that smaller individuals concentrate metals to a greater degree than do larger clams. Because the smaller "little-necks" are of greater economic importance than the larger clams this point is worth introducing into regulatory and monitoring activities.

There is evidence that once these metals are accumulated with the tissue they cannot be removed via a depuration process.[3] Phelps and Myers (1977) held contaminated quahogs for thirty days at ambient temperature in a flow-through seawater laboratory system, analysing for metals at

[1]Benjamin H. Pringle, Dale E. Hissong, Edward L. Katz, and Stefan T. Malawka, "Trace Metal Accumulation by Estuarine Mollusks", Journal of Sanitary Engineering Division, June 1968, pp. 455-474.

[2]M. Schulz-Baldes, "Trace Element Content and Body Size in Mollusks", Marine Biology, Volume 2, 1973, pp. 98-102.

[3]Depuration refers to the cleansing process whereby contaminated shellfish are transplanted to a clean environment prior to harvesting. This has been shown to be effective for reducing bacterial burdens in shellfish.

the beginning and end of the process.[1] No significant differences were found for cadmium, copper, nickel, lead, or zinc.

Tissue Levels in Narragansett Bay

Currently, quahog samples are collected at twelve stations in Narragansett Bay (shown in Figure 19) on a monthly basis by the Rhode Island Department of Environmental Management. These samples are then delivered to the Rhode Island Department of Health laboratory where they are analysed for chromium, copper, lead, and zinc (see Appendix for results). Cadmium determinations were run on only a few occassions.

Additional data has been provided by the U.S. Environmental Protection Agency (Phelps and Myers 1977) who analysed quahogs from two locations in the Bay (see Figure 19 - stations A and B). These results (shown in Table 7) demonstrate that upper Bay quahogs contain significantly higher levels of chromium and copper and slightly higher levels of cadmium, lead, nickel, and zinc than quahogs from the lower Bay.

Public Health Impacts

Elevated levels of trace metals found in the tissue of quahogs raises the question of health effects upon consumption. Cadmium, lead, and mercury are known to have such deleterious effects.[2]

Acute cadmium poisoning has been reported to have resulted from

---

[1]Donald K. Phelps and Allen C. Myers, "Ecological Considerations in Site Assessment for Dredging and Spoiling Activities", Environmental Protection Agency, Narragansett, Rhode Island, 1977.

[2]Ronald Eisler, "Toxic Cations and Marine Biota: Analysis of Research Effort During the Three Year Period 1974-1976", Marine Pollution: Functional Responses, 1979, pp. 111-149.

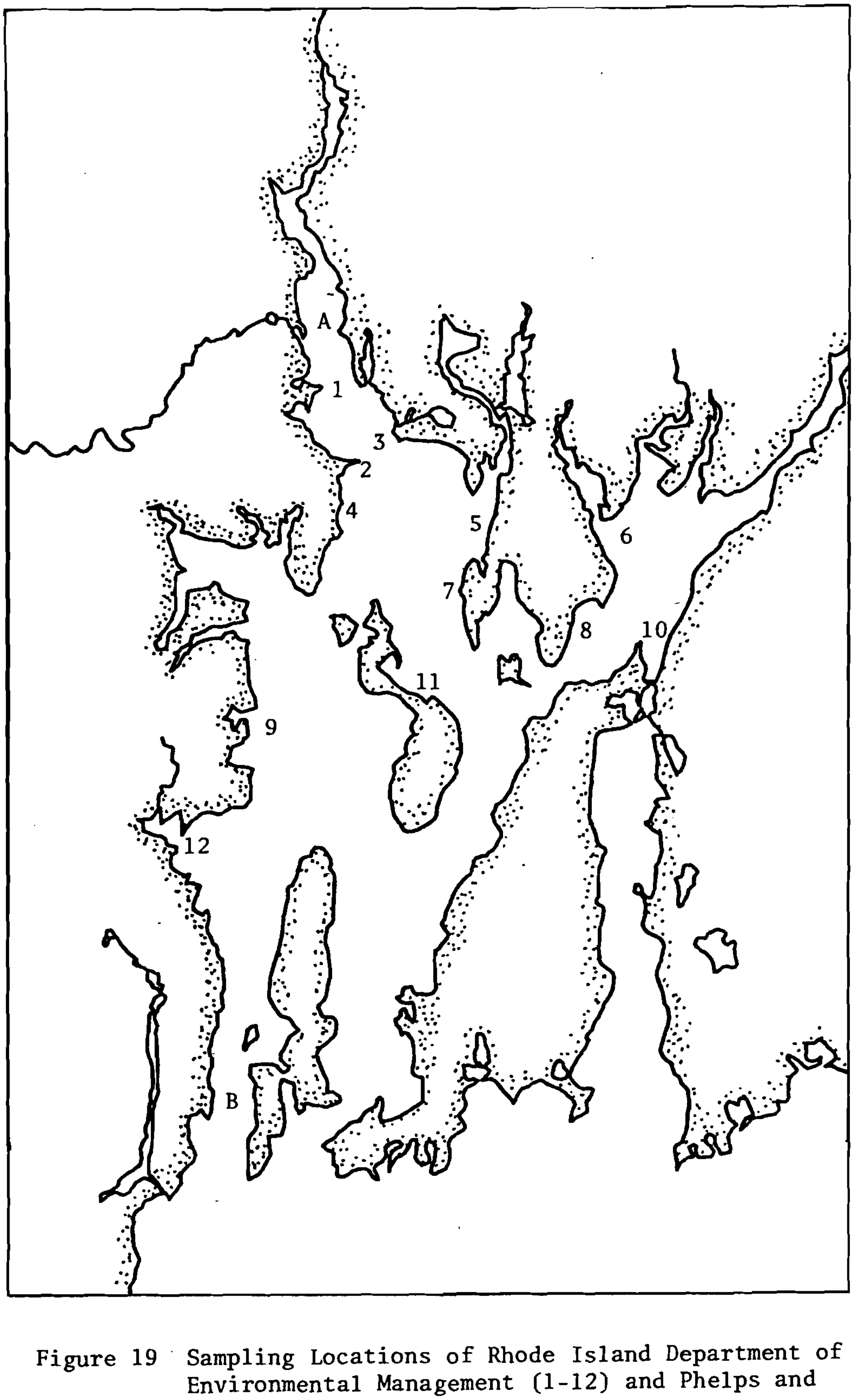


Figure 19 Sampling Locations of Rhode Island Department of Environmental Management (1-12) and Phelps and Myers (A-B)

TABLE 7

TRACE METAL CONCENTRATIONS FOUND IN THE HARD SHELL CLAM FROM CONTAMINATED SEDIMENTS (UPPER NARRAGANSETT BAY) AND UNCONTAMINATED SEDIMENTS (LOWER NARRAGANSETT BAY) - EXPRESSED IN mg/kg WET WEIGHT BASIS

Station	Cd	Cr	Cu	Pb	Ni	Zn
A (contaminated)	.20	3.2	14	1.4	4.4	42
B (uncontaminated)	.14	.9	4	1.1	3.4	40

SOURCE: Donald K. Phelps and Allen C. Myers, "Ecological Considerations in Site Assessment for Dredging and Spoiling Activities", Environmental Protection Agency, Narragansett, Rhode Island, 1977.

NOTE: These results have been converted from a dry weight basis to a wet weight basis using a conversion factor of five.

foods with concentrations as low as 15 mg/kg.[1] It is likely that chronic effects may be realized by those who consume quahogs more frequently at much lower concentrations. Tissue levels reported by both the State and EPA (shown in

Lead poisoning has received considerable attention as a dangerous pollutant. Cantarrow and Trumper (1944),[2] in their classical monograph on lead poisoning, give the lower limits of safety in man as 0.2 mg of lead per day. Assuming that an average serving of quahogs is approximately 100 grams (a little less than one quarter of a pound), this would indicate that quahogs containing more than 2 mg/kg of lead could represent a human health hazard. Tissue concentrations in excess of this level have been reported by the State Health Department on three occassions.

The toxic effects of mercury on man were dramatically illustrated during the early 1950's when some fifty persons out of more than one hundred affected in Japan died of the strange "Minimata disease". The deaths were shown to be caused by the consumption of mercury-contaminated fish and shellfish from Minimata Bay, which had received large amounts of methylmercury from the waste effluents of a plastics factory.[3] A maximum concentration of 1 mg/kg is currently considered safe for human consumption of fish in shellfish. Unfortunately, mercury levels in Narragansett Bay have not been monitored by either the State or the EPA, hence, the severity of this potential health hazard is unknown at present.

---

[1] S. Frant and I. Kleeman, "Cadmium Food Poisoning", Journal of American Medical Association, 117:86, 1941.

[2] A. Cantarrow and M. Trumper, Lead Poisoning, Williams & Wilkins, 1974

[3] L.T. Kurland et al., "Minimata Disease: The Outbreak of a Neurologic Disorder in Minimata, Japan, and its Relationship to the Ingestion of Seafood Contaminated by Mercuric Compounds", World Neurol. 1:320, 1960.

Summary

In the previous sections several technical characteristics of the trace metal pollution problem in upper Narragansett Bay have been identified. This information (summarized in Table 8) provides the framework through which solutions to the problem may be formulated. A "yes" response indicates that the metal displays the specified characteristic while a "no" response indicates the opposite. A blank response indicates that not enough information is available to determine the characteristic of that metal.

TABLE 8
CHARACTERISTICS OF TRACE METAL POLLUTION IN UPPER NARRAGANSETT BAY

Characteristics	Cd	Cr	Cu	Pb	Hg	Ni	Zn
sources of contamination	yes	yes	yes	yes	yes	yes	yes
flux from sediments	no	yes	yes	no	no	no	yes
toxicological hazard	no	no	yes	no	no	no	-
bio-accumulation	yes	yes	yes	yes	yes	yes	yes
depuration	no	-	no	no	-	no	no
human health hazard	-	-	-	yes		-	-

Hence, the target problems identified are:

1. the toxicological hazard presented by copper (i.e. the detrimental effects upon quahog embryos and larva).

2. the human health hazards presented by lead and perhaps mercury (i.e. the health hazards associated with the consumption of contaminated quahogs).

LEGAL CONSIDERATIONS

Historical Perspective

Following the oyster-borne typhoid outbreak during the winter of 1924-1925 in the United States[1] a cooperative effort termed the National Shellfish Certification Program was undertaken by the States, the Public Health Service, and the shellfish industry.[2] At this time the following principles were agreed to:

1. shellfish represent a valuable natural food resource.
2. the cultivation, harvesting, and marketing of this food resource are valuable components in the financial bases of many coastal communities.
3. a State and Federal program is necessary to permit the safe use of this resource.
4. the transmission of disease by shellfish is preventable and and therefore not to be tolerated.

To provide the necessary control to carry out these principles the following growing area criteria were developed:

1. the area is sufficiently removed from major sources of pollution so that the shellfish would not be subjected to fecal contamination in quantities which might be dangerous to the public health.
2. the area is free from pollution by even small quantities of fresh sewage. The report emphasized that bacteriological examination does not, in itself, offer conclusive proof of the sanitary quality of an area.

---

[1] L.L. Lumsden, H.E. Hasseltine, J.P. Leak, and M.V. Veldee, "A Typhoid Fever Epidemic Caused by Oyster-Borne Infection", Public Health Reports, Supp. No. 50, 1925.

[2] United States Public Health Service, "Report on Committee on Sanitary Control of the Shellfish Industry of the United States", Supplement No. 53, Public Health Reports, November 6, 1925.

3. bacteriological examination does not ordinarily show the presence of the coli-aerogenes group of bacteria in 1 cc dilutions of growing area water.

The reliability of this three-part standard for evaluating the safety of shellfish producing areas is evidenced by the fact that no major outbreaks of typhoid fever or other enteric disease have been attributed to shellfish harvested from waters meeting the criteria since they were adopted in the United States in 1925.

More recently, in 1965, the National Shellfish Sanitation Program published guidelines for the classification of growing areas based upon coliform bacteria counts in water samples. Coliform bacteria are well established indicators of human sewage. The following classifications were established:

approved areas - these areas have demonstrated median coliform counts of less than seventy organisms per one hundred milliliters of seawater and are open to shellfishing for direct human consumption.

conditionally approved areas - these areas meet the same water quality criteria described above but only during specified times. Examples of conditional areas include areas closed during the summer because of excessive pollution caused by increased boating activity or areas closed following rains due to excessive pollution caused by runoff.

restricted areas - these areas have demonstrated median coliform counts between seventy and seven hundred organisms per one hundred milliliters of seawater. Shellfish from these areas cannot be harvested for direct human consumption but may be marketed only after a depuration process.

prohibited areas - these areas have demonstrated median coliform counts of greater than seven hundred organisms per one hundred milliliters of seawater and are closed to shellfishing.

There were no chemical water quality limits (under which trace metals would fall) recommended but rather only the following general statement was included in the description of approved areas:

"the area is not so contaminated with radionuclides or industrial wastes that consumption of the shellfish might be hazardous." [1]

Three years later, during the National Shellfish Sanitation Workshop held in February of 1968, regulatory standards for metals in shellfish were proposed.[2] These standards were based on a study by Pringle and Schuster (1967).[3] The authors assumed that the average serving of shellfish is about two hundred grams and determined maximum amounts of metals consumption which should be allowed. They then proposed maximum concentrations in shellfish as shown in Table 9. With the exception of lead and mercury these limits are considerably higher than tissue levels found in Narragansett Bay quahogs.

TABLE 9
PROPOSED MAXIMUM TRACE METAL LEVELS IN SHELLFISH (EXPRESSED IN mg/kg WET WEIGHT)

Cd	Cu	Cr	Pb	Hg	Zn
2	100	2	2	2	1500

SOURCE: B.H. Pringle and C.N. Schuster, "A Guide to Trace Metals in Shellfish", (Unpublished Paper), 1967.

The National Workshop did not accept these proposed levels because it felt that more studies were needed before action of this type was warranted. In response, a national program was initiated to collect data on the various metals from representative areas around the country. During this study it was found that metal concentrations vary geographically and between species

[1] United States Department of Health, Education, and Welfare, Public Health Service, "National Shellfish Sanitation Program Manual of Operations", 1965 Revision, p. 13.

[2] United States Department of Health, Education, and Welfare, Public Health Service, Proceedings from the 6th National Shellfish Sanitation Workshop, February, 1968.

[3] B.H. Pringle and C.N. Schuster, "A Guide to Trace Metals in Shellfish", (Unpublished Paper), 1967.

(oysters, for instance, concentrate most metals to a far greater extent than do hard shell clams). As a result, in 1971, "alert levels" were proposed specific to geographical region and animal.[1] The "alert level" concept was the use of the metal concentration in shellfish as a guide or indicator of growing area degradation resulting from industrial pollution (much the same as coliform analysis is used as an indicator of domestic pollution). Concentrations proposed for hard shell clams in the Northeast appear in Table 10. These numbers do not reflect concentrations which are harmful to humans but rather act as environmental monitors.

TABLE 10
PROPOSED ALERT LEVELS FOR HARD SHELL CLAMS IN THE NORTHEAST

Cd	Cr	Cu	Pb	Hg	Zn
0.5	1.0	10	4.0	0.2	65

SOURCE: United States Department of Health, Education, and Welfare, Public Health Service, Proceedings from the 7th National Shellfish Sanitation Workshop, October 20-22, 1971, p. 33.

These "alert levels" were proposed as guidelines to be entered into the Manual of Operations[2] but were voted out by a majority largely comprised of industry representatives.

In 1974, after considerable data had been compiled, the Food and Drug Administration (FDA) promulgated a regulatory standard known as an "action level" for mercury.[3] Under the auspices of the Federal Food, Drug, and Cosmetics Act this interim standard was set at 0.5 mg/kg. More recently this level has been raised to 1.0 mg/kg. At present this is the sole regulatory stan-

[1]These levels were calculated as the mean concentration of all samples from a region plus on standard deviation unit.

[2]U.S. Department of Health, Education, and Welfare, Public Health Service, National Shellfish Sanitation Program Manual of Operations, 1965 Revision.

[3]U.S. Department of Health, Education, and Welfare, Public Health Service, "Poisonous or Deleterious Substances in Peanuts, Evaporated Milk, Fish and Shellfish", Federal Register, December 6, 1974.

dard for trace metals in shellfish.

The Federal Food and Drug Administration's Role

This "action level" for mercury in fish and shellfish is an excellent example of how FDA might participate in the management of the trace metal pollution problem. Their authority rests in the Federal Food, Drug, and Cosmetic Act. Section 301(a) of the Act prohibits:

> "the introduction or delivery for introduction into interstate commerce of any food, drug, device, or cosmetic that is adulterated or misbranded."

The penalty of a violation (Section 303) can be as high as one thousand dollars or one-year imprisonment for a first offense and ten thousand dollars or three years of imprisonment for subsequent violations.

Section 402 (a)(1) provides that a food shall be deemed adulterated:

> "if it bears or contains any poisonous or deleterious substance which may render it injurious to health."

Section 406 permits the establishment of tolerances for added poisonous or deleterious substances in food. These tolerance levels are promulgated by the Secretary and are set at levels which he finds necessary for the protection of public health. The procedures required under Section 406 of the Act include a public hearing and substantial evidence to support the tolerance level.

When absolute toxicological evidence is not available and/or the pollutant sources are variable establishment of a tolerance level under Section 406 may not be appropriate. It may nevertheless still be appropriate to take some formal regulatory action to control a substance. In such circumstances the Commissioner will consider promulgating an action level under Sections 306 and 402(a). Section 306 of the Act has long been interpreted to permit the FDA to establish action levels in implementing the adulteration provisions of the Act.[1]

Such action levels are similar to a formal tolerance in basis and effect. In setting an action level, the Commissioner considers evidence indicating when the presence of an added poisonous or deleterious substance may render food injurious to health, which is the standard in Section 402(a)(1) of the Act. Thus, an action level is based on the same criteria as a tolerance, except that an action level is temporary until the appearance of more stable circumstances makes a formal tolerance appropriate.

The Environmental Protection Agency's Role

While FDA's activities center upon public health issues and therefore deal directly with levels of contaminants found in foods, EPA's mission is generally directed at the protection of water quality. Under the auspices of the Federal Water Pollution Control Act Ammendments of 1972[2] (FWPCA) EPA has been charged with the authority to administer the Water Quality Standards Program and the National Pollutant Discharge Elimination System (NPDES).

Section 303 of the FWPCA provides for the establishment of water quality standards. These pertain to receiving water quality as contrasted with effluent standards which apply to the quality of a waste effluent discharged to the receiving water. Water quality standards are based upon a classification of use for the body of water on which the standard is being set. Uses include public water supply, industrial water supply, fish and wildlife, aquatic life, shellfish harvest, recreation, aesthetics, navigation, and agricultural water supply. Each classification is then given water quality criteria sufficient

---

[1]United States Department of Health, Education, and Welfare, Food and Drug Administration, "Poisonous or Deleterious Substances in Food - Notice of Proposed Rule Making", Federal Register, December 6, 1974.

[2]Public Law 92-500, 33USC, 1251 et seq.

to support that use. Recommended limits are established for paramenters such as dissolved oxygen, pH, temperature, coliforms, and others.

Water quality standards are set by the States and are enforced by the States. The Administrator of EPA has authority to approve the adequacy of the state-established standards and can promulgate such standards if the state's standards are deficient. The water quality criteria for fish, wildlife and aquatic life (under which shellfish fall) are, for almost all parameters more stringent than those for any other use. The EPA recommended criterion for copper for freshwater and marine life is stated as:

> "0.1 times the 96-hour LC_{50}"[1]

In the case of Mercenaria embryos the 48-hour LC_{50} has been estimated to be 5-10 ug/l (see page 36). A 96-hour LC_{50} would be at least this low. Using the formula developed for this criterion the recommended limit for copper would be 0.5-1.0 ug/l. Because these levels are lower than natural background levels (3 ug/l) enforcement is unrealistic.

The State of Rhode Island's Role

The State of Rhode Island has legal authority in both contaminated foods and contaminated waters. The Rhode Island Food, Drugs and Cosmetic Act, administered by the Department of Health, gives the State enforcement power similar to that to the Federal Food and Drug Administration. Section 21-31-10(a) defines an adulterated food as:

> "if it bears or contains any poisonous or deleterious substance which may render it injurious to health..."

---

[1]United States Environmental Protection Agency, Quality Criteria for Water, July 1976, p. 107.

Section 21-31-13 enables the promulgation of regulatory standards as follows:

> "when such substance is so required or cannot be avoided the director of health shall promulgate regulations limiting the quantity therein or thereon to such extent as the director of health finds necessary for the protection of public health, and any quantity exceeding the limits so fixed shall be deemed to be unsafe."

Section 21-31-21(a) defines the enforcement activities of such regulations as follows:

> "the director of health or his duly authorized agent shall have free access at all reasonable hours to any factory, warehouse, or other establishment...for the purpose to secure samples or specimens of any food, drug, device, or cosmetic after paying or offering to pay for such sample. It shall be the duty of the director of health to make or cause to be made examinations of samples secured under the provisions of this section."

As mentioned earlier, the State Department of Health is monitoring trace metal levels in quahogs. However, no regulatory limits have been set under Section 21-31-13, hence no closures have resulted. As additional data confirming the health hazard of metal contaminated shellfish becomes available this Act is clearly the framework through which the State may enforce regulatory standards.

Pursuant to the Federal Water Pollution Control Act Ammendments Rhode Island is granted the authority to establish water quality standards for the protection of aquatic life (including shellfish). The Rhode Island Department of Health, Division of Water Pollution Control has set forth a series of three seawater classifications (shown in the Appendix).

Class SA seawater is the only classification suitable for shellfish harvesting for direct human consumption. Maximum limits have been set for criteria such as dissolved oxygen, pH, and coliform bacteria but a much less specific criterion for chemical constituents reads as follows:

> "none in concentrations or combinations which would be harmful to human, animal, or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, impair the palatibility of the same, or impair the waters for any other uses."

This criterion lacks specificity (numbers such as those assigned to dissolved oxygen, pH, and coliform), hence, it has been largely ignored. No monitoring for trace metals in the water column is conducted by the State and little effort is allocated to the development of specific regulatory standards to enforce this criterion. Rather, as noted earlier, the State is monitoring trace metals in quahog tissue to maintain minimal surveillance on the trace metal situation.

Summary

In the preceeding paragraphs the legislation relevant to trace metal contamination of shellfish has been discussed. The three major actors in the regulatory effort have been identified as the FDA, the EPA, and the State of Rhode Island. Copper has been identified as a toxicological problem rather than a public health problem. Hence the best means of control rests in a water quality standard rather than a tissue tolerance level. EPA has published a formula for copper levels in water which results in a water quality criterion of 0.5-1.0 ug/l. Because these levels are lower than natural background levels (3 ug/l) it is unrealistic to expect enforcement of such a regulation.

Because copper does not present a public health problem there is no reason to close areas with excessive levels. Rather shellfishing areas which exhibit toxic levels of copper should be designated as out of compliance with State seawater classifications. These areas should become high priority zones where pollutant sources should be investigated in detail and should ultimately be controlled.

Lead has been identified as a public health hazard. Unlike mercury no action level has been established. A recommended limit of 2 mg/kg has been proposed as a reasonable limit within this paper. This limit could be established by either FDA or the State of Rhode Island as the Food, Drug and Cosmetic Act which provides the necessary authority has been enacted at both the Federal and State levels. Such an action could result in the closure of areas where excessive levels of lead are found.

An "action level" has been established for mercury at 1.0 mg/kg by the Federal Food and Drug Administration. Unfortunately, no monitoring for mercury levels in shellfish from Narragansett Bay is conducted by either the State or the Federal Food and Drug Administration. Hence, there is no indication as to whether or not levels of mercury in Narragansett Bay quahogs are in compliance with this criterion.

SOCIO-ECONOMIC CONSIDERATIONS

The previous sections of this paper have described the scientific aspects of the trace metal pollution problem and have examined the existing institutional framework through which regulatory actions could take place. Before such regulations are adopted the socio-economic aspects of the problem must be considered. The following discussion provides a description of the quahog industry, a profile of the labor force, a projection of economic impacts associated with trace metal pollution, and an economic evaluation of the proposed regulatory measures.

The Rhode Island Quahog Industry

The quahog fishery is characterized by independent fishermen known as handrakers. These men harvest quahogs on a year round basis out of relatively small work skiffs. With relatively little capital investment and technology, quahogging has seen very little change over the years. Since its origin, over one hundred years ago, the primary fishing methods of tonging and bullraking have persisted. Tonging refers to the process where tongs of various lengths from two to ten feet are used to grab a portion of the sea-bottom. The silt and mud drop through the teeth (which are spaced one and one half inches apart to comply with size regulations) and the quahogs, empty shells, and stones are brought up to the boat. Bullraking is considered harder work than tonging, but the harvest is usually greater. Bullrakes consist of the rake itself, a handle, and an extension (stale) between the rake and the handle. Bullrakers work in depths up to thirty feet.

The structure of the industry begins with the delivery of quahogs to the shellfish dealers. The quahoggers (or handrakers as they are commonly called) are supplied bags free of charge by the dealers for this purpose and separate their catch into two sizes, littlenecks and large. The dealer weighs each grade and pays the handrakers cash on delivery. The quahogs are then washed, culled, and further graded. At least three grades are used as a basis of pricing (littlenecks, cherrystones, and chowders). Some of the dealers shuck clams, that is, they open them. Further processing is carried out by processors and wholesalers who process the clams into clamcakes, ground quahogs, stuffed quahogs, etc. Finally the product is sold to the retailers (grocery stores, fish markets, restaurants, etc.).

Information from the eleven largest shellfish buyers in the state, handling about ninety percent of the volume, indicated that in 1963 only twenty-six percent of their sales were to customers in Rhode Island while seventy-four percent were sold to out-of-state markets.[1] This represents an impressive import of dollars into the State's economy, clearly a reason for the State's interest in further developing the industry (i.e. improving water quality so that additional beds will be opened to fishing). Although overfishing has been cited as a problem, Sisson (1974) has indicated that closed areas, if opened, would yield an additional annual harvest worth about three million dollars.[2]

The hard shell clam is economically one of the most important species of marine life in the waters of Rhode Island. Landings peaked in 1955 at five million pounds[3] (valued at 1.9 million dollars) then steadily decreased

---

[1]Andreas Holmsen, The Rhode Island Quahog Industry - Some Economic Aspects, Agricultural Experiment Station, University of Rhode Island, 1964.

[2]Richard Sisson, "Hard Clam Resource Assessment Study in Upper Narragansett Bay and the Providence River, Rhode Island", Rhode Island Division of Fish and Wildlife, Leaflet No. 49, 1974.

[3]Landings are reported in pounds of actual meat (excluding the shell). The conversion from bushels landed to meat weight is calculated by National Marine Fisheries Service using a conversion factor of 12 pounds of meat/bushel.

to under one million pounds in 1972 (valued at 0.7 million dollars).[1] The last few years have seen an increase in the catch with landings reported in 1978 at 1.9 million pounds (valued at 4.3 million dollars) and in 1979 at 2.2 million pounds (valued at 6.3 million dollars).[2] The commercial value of the quahog varies according to its size, the most valuable size being the littleneck for which quahoggers are paid eight to ten times more that of the larger sizes.

Labor Force Characteristics

In order to understand the socio-economic effects of potential income losses due to trace metal pollution a closer look at the labor force is necessary. The number of license holders in the Rhode Island fishery has varied considerably over the last couple of decades from a high of approximately three thousand to below eight hundred. There are reasons to believe that the number of people buying a commercial handraking license is related to the State's economic cycle, that is the higher rate of unemployment the more people buy a license. In this sense the quahog fishery performs an important function in the State's economy. This would, to some extent, be modified by income expectations (i.e., catch rates and market prices). During the last several years quahog sets have been very good in Narragansett Bay and market prices of "littlenecks" have increased considerably.

The University of Rhode Island conducted a study of the Rhode Island quahog industry about fifteen years ago including an analysis of the labor force during the 1962-63 season.[3] Another survey of the labor force has been

---

[1]Rhode Island State Wide Planning Program, Rhode Island's Commercial Fisheries Industry, May 1979.

[2]United States Department of Commerce, National Marine Fisheries Service, Statistics Branch.

[3]Andreas Holmsen, The Rhode Island Quahog Industry - Some Economic Aspects, Agricultural Experiment Station, University of Rhode Island, 1964.

completed for the 1978-79 season and some of the changes which have taken place since the earlier study have become evident.

The total number of individuals holding quahog licenses (including student licenses and licenses for individuals over sixty-five years of age) more than doubled over this period. While the number increased in all age categories the average age declined considerably.

TABLE 11
AGE DISTRIBUTION OF QUAHOGGERS IN RHODE ISLAND

Age	Percent 1962-63	Percent 1978-79
Less than 20	11	17
20 - 29	17	30
30 - 39	21	17
40 - 49	18	14
50 - 59	12	9
60 - 64	4	2
65 and over	17	11

The percentage of license holders twenty-nine years of age or younger increased from 28% to 47% of the labor force.

Mail questionnaires were used in both surveys to obtain additional information about the labor force characteristics. During the earlier survey questionnaires were mailed to all commercial license holders and resulted in a 42% response rate. The more recent survey excluded holders of student licenses and holders of special licenses for people sixty five years of age or more. Otherwise the total population of handrakers were surveyed with a response rate of 28%. This lower response rate in the spring of 1980 might be due, at least in part, to the fact that it coincided with both the national census and income tax preparations. (A copy of the 1980 survey form is included in the Appendix)

Despite the fact that students and license holders sixty five years or older were not included in the 1978-79 survey, the figures suggest a significant increase in full-time handrakers. The following table shows the proportion of total income handrakers derived from quahogging in the two samples.

TABLE 12
PROPORTION OF TOTAL INCOME FROM QUAHOGGING

Proportion	1963 Sample Number	1963 Sample %	1979 Sample Number	1979 Sample %
No Income	49	17	31	11
Less than 20%	130	44	82	29
About 1/4	29	10	33	11
About 1/2	23	8	37	13
About 3/4	11	4	8	3
Over 90%	49	17	96	33
Total	291	100	287	100

If we classify a full-time handraker as a person deriving at least 75% of his total income from quahogging, and sample sizes were adequate, then there were 168 full-time handrakers in 1963 and 372 full-time handrakers in 1979 (an increase of more than double).

Another question in the more recent survey inquired about the amount of formal education completed by handrakers. The following table shows education levels completed by the sampled individuals.

TABLE 13
EDUCATION COMPLETED BY HANDRAKERS, 1978-79

Education	Number	Percent
Elementary School	3	1
Junior High School	29	10
High School	140	54
Some College Education	53	20
College Degree	31	12
Some Graduate Studies	10	3
Total	266	100

Alternative skills held by handrakers was the subject of another question. While most considered themselves able to find alternative income as a skilled laborer, 18% considered themselves to have no alternative skills.

TABLE 14
ALTERNATIVE SKILLS OF HANDRAKERS, 1978-79

Skill	Number	Percent
Skilled Labor	160	76
Professional	12	6
None	38	18

If, for some reason, handrakers were forced out of the quahog industry and had to seek alternative employment their estimated or expected income would in most cases decline, but some indicated that they could double their income by doing work other than handraking.

TABLE 15
EXPECTED OPPORTUNITY INCOME OF HANDRAKERS, 1978-79

Alternative Income Relative to Current Income	Number	Percent
Less than 10%	25	12
About 1/4	15	7
About 1/2	49	23
About 3/4	35	16
About the same	40	19
Somewhat more	24	11
Twice as much	27	12

The cost of handraking is rather modest compared to other commercial fishing methods, so the economic factors determining whether to enter the quahog fishery, be it on a part-time or full-time basis depends on the returns or gross income. If incomes in the industry should decline, either due to increased closing of areas, reduced catches or drop in prices, who will leave the industry depends to some extent whether it is a part-time or full-time occupation and also on what the alternative income might be.

TABLE 16
HANDRAKERS WHO WOULD LEAVE THE INDUSTRY IF INCOME DECLINED

Drop in Income	Number	Percent
10%	40	18
25%	71	31
50%	80	36
75%	18	8
90%	16	7

This data indicates that with a drop of about 25% in income approximately half of the handrakers would leave the industry. It should also be noted that several written comments on the returned questionnaires indicated that some have already been "forced" out of the industry and others are close to leaving.

Based on the sample 69 percent of Rhode Island's handrakers live on the west side of Narragansett Bay and 31 percent on the east side. As has been the case for a long period of time, the heaviest concentration of quahoggers is found in the City of Warwick, which accounts for 22% of the labor force in this industry. Other areas of high concentration are Tiverton, East Greenwich, Portsmouth and Bristol.

The final question of the survey attempted to approximate the intensity of quahogging in various areas of Narragansett Bay. The proportion of time which was indicated for each geographical area was multiplied by the proportion of that individual's total income derived from handraking to obtain an estimate of the number of man-years spent in each area. The results are shown in the following figure.

Economic Impacts of Trace Metal Pollution

Elevated levels of copper in Narragansett Bay are probably causing some mortality among quahog embryos. With the existing amount of data it is impossible to predict precisely how much damage to the fishery this is causing. It is likely, however, that a reduction in the population available for harvesting is occurring. Because of the manner in which the surviving larvae are distributed throughout the Bay by surface currents these impacts will not be limited to those locations where high copper levels are found but rather will affect population densities over larger areas. Such decreases in quahog density lead to less efficient handraking and the yield per unit effort diminishes. As this efficiency declines the total value of landings also is likely to decline.

Economic impacts do not end with these losses in the value of landings however. This is because of "secondary effects"[1] or the impact on the rest of the economy. Reduced landings, for instance, will not only affect handrakers' incomes but will also affect seafood wholesalers, retailers, and restaurants for example. To quantify such "secondary effects" an economic tool referred to as a "multiplier" is used. Such multipliers for marine industries of the Southeastern New England region have been researched and developed by a number of

[1]for a full explanation of secondary effects see Peter G. Sassone and William A. Schaeffer, Cost-Benefit Analysis - A Handbook, Academic Press, Inc., London, 1978, pp. 37-40.

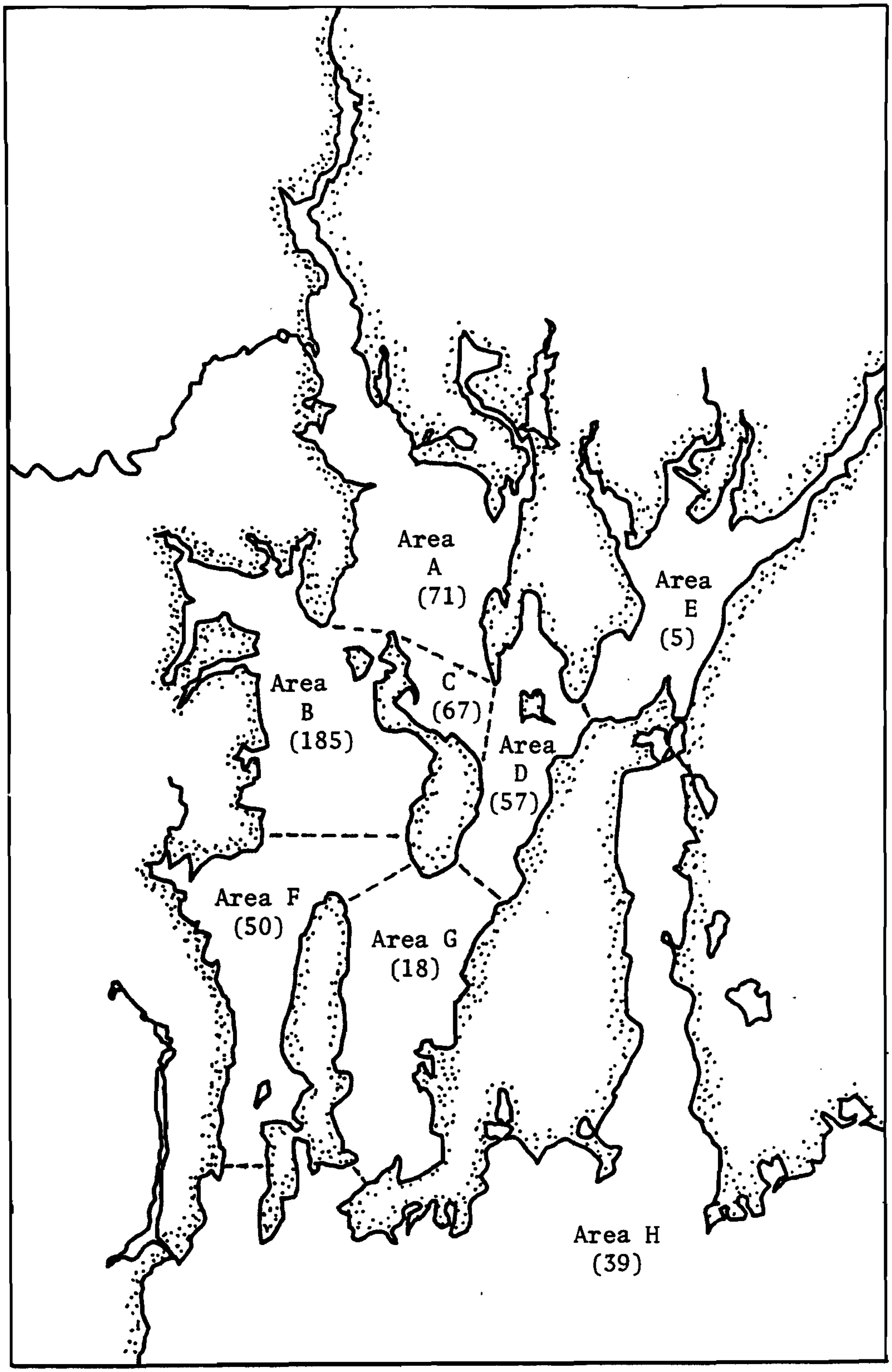


Figure 20
Intensity of Quahogging in Selected Areas of Narragansett Bay (Expressed in Man-Years)

resource economists.[1] These studies have estimated the multiplier for shellfisheries to be between 1.31 and 1.71. Actual losses in landings multiplied by these figures would represent the total economic impact on the region's economy. If one wishes to take a larger perspective to determine the economic impacts on the entire nation a multiplier of 2.5 has been developed for this purpose by the National Marine Fisheries Service.[2]

---

[1]Niels Rorholm, H.C. Lampe, Nelson Marshall, and J.F. Farrell, Economic Impacts of Marine-Oriented Activities - A Study of the Southeastern New England Region, Rhode Island Agricultural Experiment Station, University of Rhode Island, Bulletin 296, 1962. Also see: Dennis W. Callaghan and Robert Comerford, The Economic Impact of Commercial Fishing in the State of Rhode Island 1975, College of Business Administration, University of Rhode Island, Sea Grant Marine Technical Report 65, May 1978. Also see: Dennis M. King and David A. Storey, Use of Economic-Environmental Input-Output Analysis for Coastal Planning with Illustration for the Cape Cod Region, Water Resources Research Center, University of Massachusetts, Amherst, Publication #40, 1974. Also see: Thomas Grigalunas and Craig A. Ascari, "estimates of Income and Employment Multipliers for the Marine-Related Activity in the Southern New England Marine Region", forthcoming in Journal of the Northeast Agricultural Council, 1981.

[2]United States Department of Commerce, National Marine Fisheries Service, 1976.

Economic Impacts of Regulatory Measures

Mercury and lead have been identified as two metals which may pose public health threats in Narragansett Bay. An action level regulatory standard of 1 mg/kg has been established for mercury. Unfortunately, current monitoring efforts do not include mercury analyses. Hence, the extent of contamination of quahogs by mercury in Narragansett Bay is unknown and area closures based upon non-conforming mercury levels cannot be estimated.

A similar action level regulatory standard has been proposed in this paper for lead at 2 mg/kg. Areas where quahog tissue concentrations exceed this limit would be subject to closure to protect public health. The existing pool of data (shown in Figure 22) indicates that excessive concentrations were determined at locations 1, 8, and 10. It should also be noted that these excessive concentrations occurred on single occassions and all other data at these locations indicated that lead levels are within the proposed limits. Because all three areas are currently closed to shellfishing no immediate economic impacts would be felt as a result of the proposed regulatory standard for lead, if adopted.

If, however, any of these areas were to be opened in the future on the basis of acceptable coliform levels the regulatory standard would come into play. Because lead concentratiqns in quahog tissues cannot be cleansed via a depuration process those areas with excessive concentrations would remain closed. Hence, the impacts of the proposed lead standard would only be felt in the event of a significant abatement of bacterial contamination of the Bay.

CONCLUSIONS AND RECOMMENDATIONS

Narragansett Bay is a rich natural resource which supports a myriad of human activities including tourism, boating, swimming, finfishing, shellfishing, and waste-water disposal. In certain instances these activities may result in conflicts whereby the proliferation of one may preclude another. Such is the case with waste-water disposal and shellfishing.

Toxicological Impacts - Copper

Well over a ton of metals (dissolved in industrial effluents and sewage treatment plant discharges) enters Narragansett Bay on a daily basis. When in sufficient concentrations toxicological impacts are felt. Such concentrations of copper were found to exist at certain locations in Narragansett Bay. Sources of copper contamination include industrial effluents, sewage treatment plant discharges, runoff, and anti-fouling paints used on hull bottoms. Lethal effects occur among embryos during the summer months when spawning takes place. Because of the widespread distribution of the surviving larvae, impacts are felt throughout much of the Bay. Losses in landings are likely to occur as handraking efficiency diminishes. To determine the ultimate effect on the economy these losses must be expanded using relevant economic multipliers to account for secondary or respending effects. These multipliers indicate that handraking revenue is beneficial not only to the individual handrakers but also from a regional and national perspective.

Pursuant to the Federal Water Pollution Control Act Ammendments, Rhode Island has established a seawater classification for areas suitable for shellfish harvesting. The criterion for chemical constituents reads as follows:

"none in concentrations or combinations which would....make the waters unsafe for fish or shellfish or their propagation."

This criterion seems to be clearly contradicted in the case of copper and warrants further investigation. To better document the case which has been presented in this paper two research projects are recommended:

1. A toxicological study of the effects of copper concentrations in the vicinity of 5-10 ug/l upon hard shell clam embryos. This study should also include predators of the quahog embryos and larvae to determine ecological impacts.

2. A water quality study of Narragansett Bay specific to copper concentrations of water directly overlying shellfish beds. This study should be conducted in July during the spawning period.

Public Health Impacts - Lead and Mercury

Trace metals (such as cadmium, chromium, copper, lead, mercury, nickel and zinc) are accumulated by hard shell clams to levels which are thousands of times greater than what is found in the surrounding water column. Once contaminated the clams are unable to cleanse themselves when placed in pristine waters (a process known as depuration). Concentrations of cadmium, chromium, copper, and zinc found in clam tissue all appear to be well within suggested health limits. Lead levels, however, have exceeded the suggested limit of 2 mg/kg on a limited number of occassions in the Upper Bay. Because these areas are currently closed to shellfishing due to excessive bacterial contamination, no immediate health hazard is posed by clams exhibiting excessive lead concentrations.

At present there is but one regulatory standard for trace metals in shellfish. This "action level" for mercury was promulgated by the Federal Food and Drug Administration. Unfortunately, no data is available for mercury levels in hard shell clams from Narragansett Bay. Hence, the health hazards posed by mercury are unknown at present.

The existing trace metal monitoring program conducted by the State has provided a good amount of information which has been helpful in identifying the major problem areas. As a result of this research effort the following modifications to the program are recommended:

1. Include mercury analysis of quahog tissues. The additional costs can be offset by decreasing the frequency of less hazardous metals such as zinc.
2. Collect littleneck-sized quahogs for analysis because they concentrate metals to a greater extent than do the larger-sized individuals.

APPENDIX

RECEIVED
R. I. DEPARTMENT OF HEALTH

SEP 25 1980

DIV. FOOD PROTECTION & SANITATION
CENTRAL OFFICE

DIVISION OF FOOD PROTECTION AND SANITATION

INTRADIVISIONAL COMMUNICATION

23 September 19 80

TO : Manuel T. Canario, Chief
Division of Food Protection & Sanitation
DEPT: Health/Community Health Services

FROM: William Iannucci, Principal Sanitarian
Division of Food Protection & Sanitation
DEPT: Health/Community Health Services

SUBJ: Heavy Metal Sample Results for 1979 - 1980

Month: January 1979

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
1	.21	0	2.25	0	18.8
2	.14	.09	1.92	.15	
3	.68	.02	2.49	0	14.8
4	.55	.01	2.25	0	16.0
5	.68	.05	1.2	0	20.0
6	Trau	.01	1.5	0	10.2

Month: March 1979

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
6	1.13		1.37	.29	38.3
7	1.13		1.45	.18	35.1
8	.83		1.10	.04	66.0
10	.70		1.58	0	55.6
11	.81		1.94	0	34.7

Month: April 1979

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
1	1.23		1.35	.06	7.8
2	.83		1.4	.03	8.6
3	1.13		1.6	.09	10.7
4	.69		1.3	.12	6.7
5	.83		1.35	.06	11.1
12	.93		.96	.06	6.9

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
Month: May 1979					
6	.91		1.19	.12	28.0
7	.61		1.03	.12	25.5
8	2.42		3.95	.45	38.2
9	.45		1.09	.06	27.4
10	1.21		.94	.06	24.0
11	.60		1.09	.08	26.5
1	.84		1.8	.05	32.7
2	.73		1.1	.11	32.7
3	.62		1.0	.14	14.0
4	.53		1.1	.02	27.5
5	.50		1.0	.07	16.5
12	.67		0.0	.04	23.0
Month: June 1979					
6	.62		3.0	.53	17.2
7	.74		5.4	.26	22.2
8	1.4		4.4	1.05	36.1
9	.62		4.5	.29	27.3
10	1.0		6.0	.48	34.2
11	.74		9.6	.79	15.3
1	1.3		14.0	.72	29.1
2	1.5		6.4	.42	53.1
3	1.2		5.1	.21	51.0
5	1.0		6.8	.34	27.3
Month: July 1979					
6	1.47		1.78	0.43	40.0
7	.99		2.28	.36	13.2
8	1.24		2.0	0.95	19.8
9	.55		1.89	0.18	17.3
10	1.04		2.46	0.37	32.0
11	0.75		1.73	0.36	19.0
1	2.7		9.8	.22	30.1
2	1.8		10.4	.88	27.9
3	1.8		4.4	1.0	25.5
4	1.1		6.9	.66	13.7
5	1.6		3.8	.33	37.0
12	1.4		3.5	.22	31.8
Month: August 1979					
6	1.6		3.6	.16	26.2
7	1.0		5.4	.53	24.5
8	.52		5.0	.09	26.2
9	.91		4.9	.10	18.4
10	.52		4.0	.16	17.1
1	1.1		6.4	0.47	24.8
3	1.7		7.4	0.36	38.0
5	1.0		4.0	.21	22.6
2	1.4		6.8	0.37	33.9
4	1.6		4.4	.52	23.9

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
Month: October 1979					
6	1.5		4.13	.18	38.0
7	0.56		3.63	0.25	24.3
9	0.54		3.56	0.16	17.8
11	0.54		4.94	0.30	16.1
10	.75		4.23	.26	21.3
8	.56		5.75	.21	23.1
2	0.92		2.24	0.62	12.0
12	0.64		1.72	1.1	13.9
4	0.58		2.19	0.47	8.2
1	0.65		3.3	0.32	12.8
3	0.77		3.7	0.57	11.1
5	0.54		1.6	0.13	8.6
Month: November 1979					
9	0.47		3.8	0.12	23.7
6	0.57		3.4	0.30	9.8
11	.60		2.3	0.17	16.4
7	0.79		3.0	0.24	21.2
8	0.78		3.52	0.43	31.3
Month: December 1979					
12	0.59		3.4	0.18	22.0
4	1.1		4.7	0.38	22.1
3	1.3		5.0	0.29	18.4
7	0.83		5.1	0.30	15.7
1	0.94		1.3	0.38	20.5
5	0.62		3.2	0.20	15.0
Month: January 1980					
8	0.40		2.4	0.51	9.1
7	0.76		3.64	0.22	21.3
10	3.2		6.6	0.32	82.0
11	0.59		3.6	0.40	16.0
6	1.0		3.64	0.67	39.0
Month: February 1980					
1	0.73	0.10	4.2	0.18	12.3
2	0.94	0.08	4.3	0.18	13.8
3	0.49	0.11	3.8	0.29	8.4
4	0.94	0.14	4.9	0.29	8.1
5	1.2	0.15	.80	0.16	15.5
12	0.68	0.09	2.4	0.12	14.3
A (new areas)	1.0	.12	2.5	0.27	12.2
B	0.74	0.07	3.1	0.13	8.2
C	0.89	0.09	3.8	0.22	11.1
D	0.49	0.05	3.8	0.22	13.1
E	1.3	0.12	3.1	0.19	12.8

Station Number	Lead(PPM) Pb	Cadmium(PPM) Cd	Copper(PPM) Cu	Chromium(PPM) Cr	Zinc(PPM) Zn
Month: March 1980					
6	0.11	0.12	3.0	0.26	15.1
7	0.85	0.06	3.2	0.35	11.1
8	0.86	0.07	2.5	0.29	13.0
9	0.68	0.09	2.5	0.11	10.7
11	0.65	0.07	3.2	0.16	14.2
1	1.06	0.13	3.87	0.28	25.4
2	0.79	0.13	5.10	0.51	24.6
3	0.66	-0.05	3.48	0.27	17.8
4	0.73	0.05	2.52	0.09	18.2
5	0.79	0.09	4.37	0.46	18.0
12	0.66	0.07	2.17	0.18	15.8
6	0.25	0.11	1.88	0.13	13.44
7	0.42	0.11	2.07	0.20	10.92
8	0.42	0.11	2.21	0.40	10.92
9	0.59	0.11	0.71	0.13	13.44
10	0.42	0.11	1.69	0.13	10.08
11	0.42	0.11	1.27	0.07	10.92
Month: April 1980					
1	0.94	0.35	5.5	0.28	20.16
2	1.04	0.12	5.05	0.40	27.72
3	0.94	0.17	3.94	0.28	18.48
4	0.94	0.17	3.55	0.28	15.12
5	1.04	0.17	3.77	0.28	23.52
12	0.62	0.12	2.72	0.28	21.84
Month: August 1980					
1	1.60	0.24	2.70	0.62	20.51
2	1.20	0.18	3.64	0.52	19.87
3	1.00	0.12	4.37	0.42	18.59
4	1.00	0.12	2.70	0.52	17.31
5	0.80	0.18	3.33	0.42	14.74
12	0.66	0.13	1.60	0.46	14.10
Month: September 1980					
6	1.20	0.25	2.25	0.73	27.56
7	1.20	0.12	3.50	1.04	18.59
8	0.40	0.18	2.75	0.94	16.03
9	0.60	0.12	2.75	0.94	20.51
10	0.60	0.12	2.00	0.62	16.67
11	1.20	0.18	2.75	0.62	23.72

W.I.

pab

TABLE 3-1 (continued)

STATE OF RHODE ISLAND
DEPARTMENT OF HEALTH
DIVISION OF WATER POLLUTION CONTROL

WATER QUALITY CRITERIA FOR SEA WATER *

Item	Class SA	Class SB	Class SC
	Suitable for all sea water uses including shellfish harvesting for direct human consumption (approved shellfish areas), bathing and other water contact sports.	Suitable for bathing, other recreational purposes, industrial cooling and shellfish harvesting for human consumption after depuration (restricted shellfish area); excellent fish and wild life habitat; good aesthetic value.	Suitable fish, shellfish and wild life habitat; suitable for recreational boating, and industrial cooling; good aesthetic value.
. Dissolved oxygen	Not less than 6.0 mg/l at any time	Not less than 5.0 mg/l at any time	Not less than 5 mg/l during at least 16 hours of any 24-hour period nor less than 4 mg/l at any time
2. Sludge deposits-solid refuse-floating solids-oils-grease-scum	None allowable	None allowable	None except that amount that may result from the discharge from a waste treatment facility providing appropriate treatment
3. Color and turbidity	None in such concentrations that will impair any usages specifically assigned to this Class	None in such concentrations that would impair any usages specifically assigned to this Class	None in such concentrations that would impair any usages specifically assigned to this Class
4. Coliform bacteria per 100 ml	Not to exceed a median MPN of 70 and not more than 10% of the samples shall ordinarily exceed an MPN of 230 for a 5-tube decimal dilution or 330 for a 3-tube decimal dilution	Not to exceed a median value of 700 and not more than 2300 in more than 10% of the samples	None in such concentrations that would impair any usages specifically assigned to this Class

TABLE 3-1 (continued)

tube decimal dilution
or 330 for a 3-tube
decimal dilution

TABLE 3-1 (continued)

SEA WATER (Continued)

Item	Class SA	Class SB	Class SC
Fecal coliform bacteria/100 ml	(See Note S.9)	(See Note S.9)	
Taste and odor	None allowable	None in such concentrations that would impair any usages specifically assigned to this Class and none that would cause taste and odor in edible fish or shellfish	None in such concentrations that would impair any usages specifically assigned to this Class and none that would cause taste and odor in edible fish or shellfish
pH	6.8 - 8.5	6.8 - 8.5	6.5 - 8.5
Allowable temperature increase	(See Note S.10)	(See Note S.10)	(See Note S.10)
Chemical constituents (See Note S.4)	None in concentrations or combinations which would be harmful to human, animal or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, impair the palatability of same, or impair the waters for any other uses	None in concentrations or combinations which would be harmful to human, animal or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, or impair the water for any other usage assigned to this Class	None in concentrations or combinations which would be harmful to human, animal or aquatic life or which would make the waters unsafe or unsuitable for fish or shellfish or their propagation, or impair the water for any other usage assigned to this Class
Radioactivity	(See Note S.7)	(See Note S.7)	(See Note S.7)

Dr. Andreas Holmsen
Mr. Scott W. Horsley

Department of Resource Economics
University of Rhode Island

QUAHOG INDUSTRY SURVEY

The purpose of this survey is to determine the effects of possible future shellfishing area closures upon the quahog industry. Your cooperation is needed to help preserve the fishery and is greatly appreciated. The information received through this survey will be used only for University research purposes.

---

1. What town do you live in? ____________________

---

2. Your age is:
   less than 20 ___ 20-29 ___ 30-39 ___ 40-49 ___ 50-59 ___ 60-64 ___ 65 and over ___

---

3. What is your last grade of education completed?
   elementary school (grades 1-6) ___ some college ___
   junior high school (grades 7-8) ___ college degree ___
   high school (grades 9-12) ___ graduate studies ___

---

4. Number of years that you have been quahogging:
   less than 2 ___ 5-9 ___ 20-29 ___ 40-49 ___
   2-4 ___ 10-19 ___ 30-39 ___ 50 or more ___

---

5. Proportion of your current total income from quahogging is:
   less than 10% ___ about 1/2 ___ about 90% ___
   about 1/4 ___ about 3/4 ___ 100% (full-time) ___

---

6. What drop in income from quahogging would force you out of the quahogging industry?
   about a 10% drop ___ about a 1/2 drop ___ about a 90% drop ___
   about a 1/4 drop ___ about a 3/4 drop ___

---

7. If, in the event of severe closures or poor sets, you were forced to look for alternative work what would you do (what other skills do you have)?

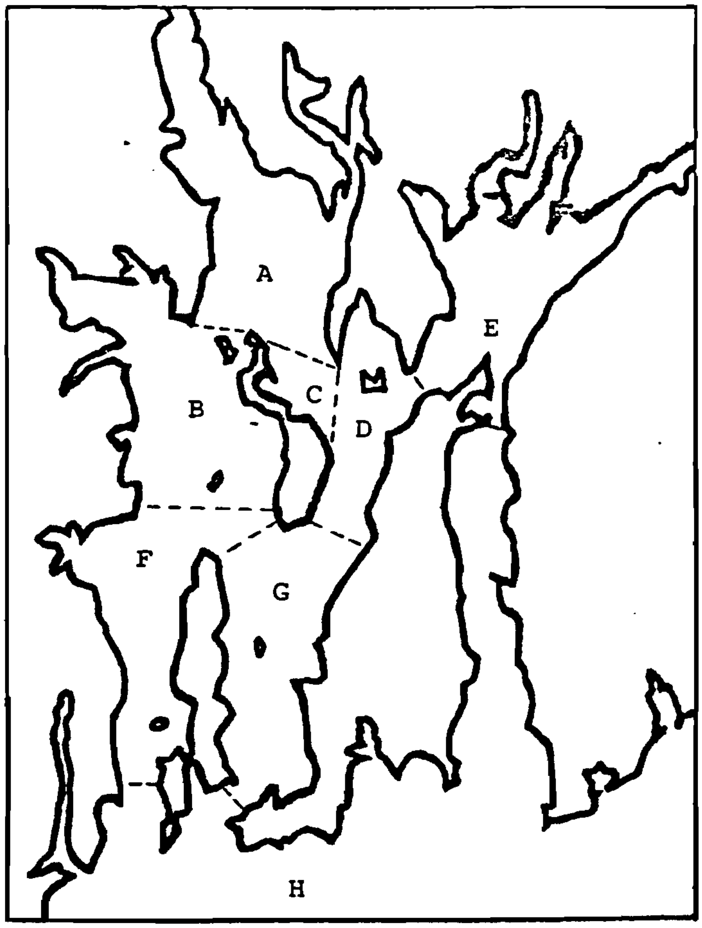
---

8. What do you expect your new income from this alternative work to be compared to your current income earned from quahogging?
   less than 10% ___ about 1/2 ___ about the same ___ twice as much ___
   about 1/4 ___ about 3/4 ___ a little more ___

---

9. Please circle those general map areas which you fish for quahogs and estimate about what portion (or percentage) of your total annual landings come from each of these areas: (please see reverse side for general map areas)

Map Areas:	A	B	C	D	E	F	G	H
Portion	___	___	___	___	___	___	___	___



NARRAGANSETT BAY

---

10. Other comments:

TRACE METAL LOADINGS OF SEWAGE TREATMENT PLANT DISCHARGES
AND INDUSTRIAL DISCHARGES IN NARRAGANSETT BAY (EXPRESSED IN GRAMS/DAY

	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Sewage Treatment Plants:							
Bristol	3-490	140-2400	200-2600			120-1800	310-3700
Cranston	6-98	56-960	130-1700			580-8600	380-3200
East Greenwich	250-390	280-480	1300-1700			120-180	2300-2700
East Providence	6-98	56-950	2000-24000	150-2300	3-48	1500-23000	870-10000
Newport	58-920	110-1900	510-6300	31-490	16-240	60-900	1300-15000
Providence	470-920	17000-35000	134000-200000			110000-200000	220000-320000
South Kingstown	3-49	30-500	1200-16000	520-8400		420-6400	800-9400
Warren	12-180	56-950	740-9200	85-1400	15-230	760-11000	3100-37000
Warwick		170-2900	980-1200	29-47	3-5	240-360	840-980
West Warwick	3-49	110-1900	130-1700	31-490	3-48	120-1800	210-2500
Industries:							
American Hoescht			2000-26000			420-6400	410-4900
Amperex		360-600	200-260		3-5		140-160
Bostich	300-460	170-290	36-44				1800-2200
Brown and Sharpe		140-240	67-83			150-230	
Ciba Geigy			36-440				3000-36000
Corning		81-140		85-140			
United Wire		140-240	4500-5600	85-140		150-230	2300-2700
Woonsocket		30-50					

recorded values reflect ranges in discharges reported by Rhode Island Department of Environmental Management and 95% confidence limits for comparable analytical values as reported in Standard Methods, 14th Edition.

BIBLIOGRAPHY

Atlantic States Marine Fisheries Commission, Marine Resources of the Atlantic Coast, (Unpublished), June 1970.

Bell, F.W. and Canterbery, D.R., "An Assessment of the Economic Benefits which will Accrue to Commercial and Recreational Fisheries, from Incremental Improvements in the Quality of Coastal Waters", submitted to the National Commission on Water Quality, July 1975.

Bockstall, G., "Comprehensive Report on the Hard Clam (Mercenaria mercenaria) Industry in Rhode Island. Unpublished manuscript, College of Marine Studies, University of Delaware, 1976.

Bryan, G.W., Hummerstone, L.G., "Heavy Metals in the Burrowing Bivalve Scrobicularia plana from Contaminated and Uncontaminated Estuaries." Marine Biological Association of the United Kingdom Journal, 58(2):401-419, 1978.

Calabrese A. and Nelson, D.A., "Inhibition of Embryonic Development of the Hard Clam, Mercenaria mercenaria, by Heavy Metals", Bulletin of Environmental Contamination and Toxicology, Volume II (1), 1974.

Curley, Lawton, Chadwick, Rebock, Hickey, Division of Marine Fisheries, Department of Natural Resources Executive Office of Environmental Affairs (MA), A Study of the Marine Resources of the Taunton River and Mount Hope Bay, August 1974.

Davey, E.W. and Phelps, D.K., "Trace Metals in the Oceans: Problem or No?", Estuarine Pollution Control: A National Assessment (report in preparation), Environmental Protection Agency, 1976.

Eisler, Ronald, "Behavioural Responses of Marine Poiklotherms to Pollutants", Phil. Trans. R. Soc. Lond. B. 286:507-521, 1979.

Eisler, R. and Weinstein, M.P., "Changes in Metal Composition of the Quahog Clam, Mercenaria mercenaria, After Exposure to Insectides.", Chesapeake Science 8:253-258, 1967.

Eisler, Ronald, "Toxic Cations and Marine Biota: Analysis of Research Effort During the Three-Year Period 1974-1976", Marine Pollution: Functional Responses, pp 111-149, 1979.

Eisler, Ronald, "Toxicity Evaluation of a Complex Metal Mixture to the Softshell Clam Mya arenia " Marine Biology, 43(3):265-276, 1977.

Environmental Protection Agency, "Modification of Secondary Treatment Requirements for Discharges into Marine Waters", Federal Register, 44 (117):34783-347832, June 15. 1979.

Feng, S.Y., "Report on Trace Metal Concentrations in Shellfish From the Thames River to the Northeast Fisheries Center", National Marine Fisheries Service, Sandy Hook. 1976.

Gross, M. Grant, Oceanography - A View of the Earth, second edition, Prentice Hall, Inc., 1972.

Guthrie, R.K., Davis, E.M., Cherry, D.S., and Murray, H.E., "Biomagnification of Heavy Metals by Organisms in a Marine Microcosm", Bulletin of Environmental Contamination and Toxicology, 21 (1-2): 53-61, January 1979.

Holmsen, Andreas, "The Rhode Island Quahog Industry - Some Economic Aspects", Agricultural Experiment Station Bulletin 384, University of Rhode Island.

Hugget, R.J., Bender, M.E., and Stone, H.D., "Utilizing Metal Concentration Relationships in the Eastern Oyster (Crassostrea virginica) to Detect Heavy Metal Pollution", VIMS Contribution Number 495, Water Research, Volume 7, pp 451-460, 1973.

Jones, G.B., and Jordan, M.B., "The Distribution of Organic Material and Trace Metals in Sediments From the River Liffey Estuary, Dublin", Estuarine and Coastal Marine Science, 8 (1): 37-47, January 1979.

Kumaraguru, A.K. and Ramamoorthi, K., "Accumulation of Copper in Certain Bivalves of Vellar Estuary, Porto Novo, S. India in Natural and Experimental Conditions", Estuarine and Coastal Marine Science, pp 467-476, October 1979.

Mann Ryther, Taylor, Corwin, Bowker (Woods Hole), Uptake and Deprivation of Trace Contaminants by Organisms Grown in a Waste Recycling - Aquaculture System, (prepared for the Sarah Scaife Foundation, Inc.), September 1978.

McHargue, V.S., "The Proportion and Significance of Copper, Iron, Manganese, and Zinc in Some Mollusks and Crustaceans", Trans. Kentucky Acad. Sci., 2: 46-52, 1927.

Mericam, P., and Astruc, M., "The Chemical State of Some Heavy Metals (Cd, Cr, Cu, Ni, Pb, Zn) in Natural Soft Waters and Seawater:1 - Soluble Inorganic Species (Review)., Techniques Et Sciences Municipales Et Revue L'Eau, 74 (1): -3-40, January 1979.

Olsen, Stephen, and Lee, Virginia, "A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Upper Narragansett Bay", Coastal Resources Center, University of Rhode Island, May 1979.

Phelps, Donald K., Telek, Gregory, and Lapan, Richard L. Jr.,"Assessment of Heavy Metal distribution Within the Food Web", reprinted from Marine Pollution and Marine Waste Disposal, by Pearson and Frangipane, Oxford and New York: Pergamon Press, 1975.

Pratt, D.M., "Abundance and Growth of Venus mercenaria and callocardia morrhuana in Relation to the Character of Bottom Sediments", Journal of Marine Research 12:73.

Pratt, D.M., and Campbell, D.M., "Environmental Factors Affecting Growth in Venus mercenaria", Limnology and Oceanography, 1 (1): 9.

Pringle, B.H., Hisseng, D.F., Katz, E.L., and Mulawka, S.T., "Trace Metal Accumulation by Estuarine Mollusks", Journal of Sanitary Engineering Division 94 SA3: 455-475. 1968.

Rhode Island Department of Environmental Management, Division of Water Resources, The State of the State's Waters - Rhode Island:A Report to Congress (PL 92-500, 305b), April 1978.

Rhode Island Department of Health, Division of Water Pollution Control, Annual Report 1976-77.

Rhode Island Statewide Planning Program, "Rhode Island's Commercial Fisheries Industry", Report Number 36B, May 1979.

Romeril, M.G., "The Occurence of Copper, Iron and Zinc in the Hard Shell Clam, Mercenaria mercenaria, and Sediments of Southampton Water",Estuarine and Coastal Marine Science, pp 423-434, October 1979.

Roosenburg, Willian H., "Greening and Copper Accumulation in the American Oyster, Crassostrea virginica, in the Vicinity of a Stream Electric Generating Station", Chesapeake Science, Volume 10, Number 347, pp 241-252, September- December 1969.

Saila, S.B., Flowers, J.B., and Canario, M.T., "Factors Affecting the Relative Abundance of Mercenaria mercenaria in the Providence River, Rhode Island", Proceedings, National Shellfisheries Association 57:89.

Save the Bay Inc., Department of Environmental Management, Upstream, April 1978.

Schmidt, R.L., "Copper in the Marine Environment - Parts I and II", Chemical Rubber Company, Cleveland, CRC Critical Reviews in Toxicology, 8 (2): 101-152, November 1978.

Schuster, C.N.Jr., and Pringle, B.H., "Effects of Trace Metals on Estuarine Mollusks", Proceedings First Mid-Atlantic Industrial Waste Conference, 13-15 November, 1967: 285-304, 1968.

Simpson, R.D., "Uptake and Loss of Zinc and Lead by Mussels (Mytilus edulis) and Relationships with Body Weight and Reproductive Cycle", Marine Pollution Bulletin, 10 (3):74-78, March 1979.

Sisson, Richard, T., "Hard Clam Resource Assessment Study in Upper Narragansett Bay and the Providence River, Rhode Island", Rhode Island Division of Fish and Wildlife, Leaflet Number 49.

Turner, Harry J., and George, Carl J., "Some Aspects of the Behavior of the Quahog, Venus mercenaria, During the Early Stages". Eighth Report, Investigations of Shellfisheries of Massachusetts, p.9.

United States Environmental Protection Agency, National Shellfish Register of Classified Estuarine Waters 1974, December 1975.

United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, A Comprehensive Review of the Commercial Clam Industries in the United States, March 1977.

United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, A Comprehensive Review of the Commercial Mussel Industries in the United States, March 1977.

United States Department of Commerce, National Oceanic and Atmospheric Administration, "State of Rhode Island Coastal Management Program and Final Environmental Impact Statement", 1978.

United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, "Water Quality and Molluscan Shellfish:An Overview of the Problems and the Nature of Appropriate Federal Laws",March 1977..

United States Department of Health, Education and Welfare, Food and Drug Administration, 1971 National Shellfish Register of Classified Estuarine Waters, 1971.

United States Department of Health, Education and Welfare, National Shellfish Sanitation Program Manual of Operations, Part 1 - Sanitation of Shellfish Growing Areas, 1965 Revision.

United States Department of Health, Education and Welfare, National Shellfish Sanitation program, Manual of Operations, 1965 Revision.

United States Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Shellfish Sanitation Branch, Proceedings 7th, 8th, 9th, 10th, National Shellfish Sanitation Workshop, October 20-22, 1971, January 16-18, 1974, June 25-26. 1975, and June 29-30, 1977.

United States Department of Health, Education and Welfare, Public Health Service, National Register of Shellfish Production Areas, 1966.

United States Water Resources Council, "Principles and Standards for Planning Water and Related Land Resources", Federal Register, September 10, 1973.

University of Missippi Law Center, "The Problem of Ocean Pollution - Legal Remedies Available", Missippi/Alabama Sea Grant Consortium, 1978.

Valiela, I., Banus, M.D., and Teal, J.M., "Response of Salt Marsh Bivalves to Enrichment with Metal-Containing Sewage Sludge and Retention of Lead, Zinc, and Cadmium by Marsh Sediments", Environmental Pollution, 7:149-157, 1974.

Von Westernhagen, H., Dethlefsen, V., Rosenthal, H., et. al., "Fate and Effects of Cadmium in an Experimental Marine Ecosystem", Helgolaender Wissenschaftliche Meeresunter-Suchungen, 31(4):471-484, December 1978.

Yeats, P.A., Brewers, J.M., and Walton, A., "Sensitivity of Coastal Waters to Anthropogenic Trace Metal Emissions", Marine Pollution Bulletin 9: 264-268, 1978.

Young, D.R., Alexander, G.V., McDermott-Ehrlich, D., "Vessel-related Contamination of Southern California Harbours by Copper and Other Metals", Marine Pollution Bulletin, 10 (2): 50-56, February 1979.