U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION I

IDENTIFICATION AND COLLECTION OF HISTORICAL DATA FOR BUZZARDS BAY, MASSACHUSETTS

TASK II - SUMMARY OF EXISTING LITERATURE

October 30, 1987

by

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FOREWORD

In 1984, Buzzards Bay was one of four estuaries in the country chosen to be part of the National Estuary Program. The Buzzards Bay Project was initiated in 1985 to protect water quality and the health of living resources in the bay by identifying resource management problems, investigating the causes of these problems, and recommending actions that will protect valuable resources from further environmental degradation. This multi-year project, jointly managed by United States Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs, utilizes the efforts of local, state, and federal agencies, the academic community and local interest groups in developing a Master Plan that will ensure an acceptable and sustainable level of environmental quality for Buzzards Bay.

The Buzzards Bay Project is focusing on three priority problems: closure of shellfish beds, contamination of fish and shellfish by toxic metals and organic compounds, and high nutrient input and the potential pollutant effects. By early 1990, the Buzzards Bay Project will develop a Comprehensive Conservation and Management Plan to address the Project's overall objectives: to develop recommendations for regional water quality management that are based on sound information, to define the regulatory and management structure necessary to implement the recommendations, and to educate and involve the public in formulating and implementing these recommendations.

The Buzzards Bay Project has funded a variety of tasks that are intended to improve our understanding of the input, fate and effects of contaminants in coastal waters. The Project will identify and evaluate historic information as well as generate new data to fill information gaps. The results of these Project tasks are published in this Technical Series on Buzzards Bay.

This report represents the technical results of an investigation funded by the Buzzards Bay Project. The results and conclusions contained herein are those of the author(s). These conclusions have been reviewed by competent outside reviewers and found to be reasonable and legitimate based on the available data. The Management Committee of the Buzzards Bay Project accepts this report as technically sound and complete. The conclusions do not necessarily represent the recommendations of the Buzzards Bay Project. Final recommendations for resource management actions will be based upon the results of this and other investigations.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

PAGE

1.0 REVIEW OF THE LITERATURE

1.1 INTRODUCTION

Since 1985, the U.S. Environmental Protection Agency (EPA) and the Commonwealth of Massachusetts have been conducting the Buzzards Bay Program initiated to provide a basinwide management approach for Buzzards Bay. One component of the approach is to characterize Buzzards Bay in areas of most critical importance. As an early step in characterization of aspects of Buzzards Bay, a study was begun with the following objectives:

Task I. Identification of historical data sets concerning water quality and nutrients, toxic substances in organisms and sediments, and lobster landings.

Task II. Review of published literature to

A. Identify temporal and spatial coverage of the literature related to water quality and nutrients, toxic substances in organisms and sediments, and lobster landings. This report incorporates literature available up the time this effort began in early 1986. Literature from 1986 and 1987 have been incorporated where readily available, but not coordinated effort has been made to cover these years.

B. Review methods used for study of polychlorinated biphenyls (PCBs), hydrocarbons, pesticides, metals, bacteria, and nutrients. This review was limited to comparison of methods and excluded examination of the use of the methods in generation of data. Such examination should be completed at the time of data characterization. Some papers did not provide methods, either because the methods were just overlooked or because the paper was a summary report.

C. Compile literature for Buzzards Bay related to lobster landings, toxic substances in organisms and sediments, and water quality and nutrients for deposition at a locale chosen by EPA and the Commonwealth of Massachusetts.

Task I has been completed; Brown and Gale (1986) reported on historical data sets available for the topics described. The present draft report covers Objectives A and B of Task II. Objective C of Task II will be completed at the time this report is finalized.

This report is organized according to three major areas: water quality and nutrients, toxic substances in organisms and sediments, and lobster landings. The discussion on water quality and nutrients covers physical and chemical characteristics, biological characteristics, and nutrients. The discussion of toxic substances in organisms and sediments covers PCBs, hydrocarbons, pesticides, and metals. Each section covering water quality and nutrients and toxic substances in organisms and sediments describes the literature, summarizes spatial and temporal coverage of the data in the literature, and identifies data gaps. Lobster landings are handled differently because they are covered in only one set of reports (i.e., those of the Commonwealth of Massachusetts) and thus could be briefly characterized here.

1.2 WATER QUALITY AND NUTRIENTS

Among the priority problems identified in the EPA Long-term Management Plan for Buzzards Bay was contamination from point and nonpoint sources that has caused the decline of water quality compromising the use of fisheries and other Bay resources. The following summary of literature on water quality and nutrients in Buzzards Bay and identification of data gaps constitutes an early and necessary step toward a complete assessment of trends in water quality in the Bay and the effects of those trends on commercial fishery resources.

Literature containing relevant water quality data in three subcategories (Physical/Chemical Characteristics, Biological Characteristics, and Nutrients) is listed in Table 1 and summarized below.

1.2.1 Physical and Chemical Characteristics

1.2.1.1 Description of Available Literature

Twenty-eight studies reporting physical and/or chemical water quality characteristics of portions of Buzzards Bay were reviewed (Table 2).

TABLE 1. WATER QUALITY AND NUTRIENTS: LITERATURE REVIEWED.

REFERENCE	SUBCATEGORY OF DATA		
	Physical/ Chemical	Biological	Nutrients
Anraku, 1964	x		
Camp Dresser & McKee Inc., 1979	x		
Camp Dresser & McKee Inc., 1983	x	x	
Collings et al., 1981	x		
Driscoll, 1972	x		
Ellis et al., 1977	x		
Fairbanks et al., 1971	x		
Fiske et al., 1968	x	x	x
FDA, 1972	x	x	
Gilbert et al., 1973	x	x	x
Hall, 1979	x	x	x
Hoff et al., 1969	x		x
Hoff, 1971		x	x
Ketchum et al., 1949	x	x	
Massachusetts DEQE, 1971	x	x	x
Massachusetts DEQE, 1975	x	x	x
Massachusetts DEQE, 1977	x	x	x
Massachusetts DEQE, 1978	x	x	x
Massachusetts DEQE, 1979	x	x	x
Massachusetts DEQE, 1980	x	x	x
Nichols et al., 1972			x

TABLE 1. WATER QUALITY AND NUTRIENTS: LITERATURE REVIEWED (Continued).

REFERENCE	SUBCATEGORY OF DATA		
	Physical/ Chemical	Biological	Nutrients
Ocean Surveys, Inc., 1978		x	
Page, 1928	x		
Pratt and Heavers, 1975	x		x
Rhoads, 1973	x		
Rhoads et al., 1975		x	x
Roman, 1978		x	x
Roman, 1980			x
Roman and Tenore, 1978		x	x
Rosenfeld et al., 1984	x		
Sanders et al., 1965	x		
Stratton et al., 1978	x		
Teal and Valiela, 1978			x
U.S. Fish Commission, 1898	x		
Valiela and Teal, 1978			x
Valiela and Teal, 1979			x
Valiela et al., 1978	x		x
Welsh et al., 1977	x		

FDA = U.S. Food and Drug Administration
DEQE = Massachusetts Dept. of Environmental Quality Engineering
Ellis et al., 1977, contains the raw data for Summerhayes et al., 1976 and 1985; therefore, only Ellis et al. is listed here.

TABLE 2. PHYSICAL AND CHEMICAL LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 3 AND 4 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Anraku, 1964
B	Camp Dresser & McKee Inc., 1979
C	Camp Dresser & McKee Inc., 1983
D	Collings et al., 1981
E	Driscoll, 1972
F	Ellis et al., 1977
G	Fairbanks et al., 1971
H	Fiske et al., 1968
I	FDA, 1972
J	Gilbert et al., 1973
K	Hall, 1979
L	Hoff et al., 1969
M	Ketchum et al., 1949
N	MA DEQE, 1971
O	MA DEQE, 1975
P	MA DEQE, 1977
Q	MA DEQE, 1980
R	MA DEQE, 1978
S	MA DEQE, 1979
T	Page, 1928
U	Pratt & Heavers, 1975
V	Rhoads, 1973
W	Rosenfeld et al., 1984
X	Sanders et al., 1965
Y	Stratton et al., 1978
Z	U.S. Fish Comm., 1898
a	Valiela et al., 1978
b	Welsh et al., 1977

FDA = U.S. Food and Drug Administration.
MA DEQE = Masssachusetts Department of Environmental Quality Engineering.

Physical and chemical parameters measured and methods used in each study are listed in Tables 3 and 4, respectively.

1.2.1.2 Summary and Data Gaps

Physical and chemical water quality parameters most often sampled in Buzzards Bay were, in order of frequency, temperature, salinity, dissolved oxygen, and pH. Parameters sampled less frequently were suspended solids, turbidity, conductivity, alkalinity, total solids, settleable solids, chemical oxygen demand, and total suspensate (Table 3).

Spatial coverage of physical and chemical water quality characteristics of Buzzards Bay is fairly good (Figures 1 and 2). The heaviest concentration of data collection is in the vicinity of New Bedford Harbor. There is also good coverage of the western side of the Woods Hole Passage. The main axis of the Bay and both the eastern and western shores are fairly well covered as well. Data on some physical and chemical characteristics of the Bay's estuaries (Westport River, Slocums River, and Pocasset River) have also been collected. Coverage of salinity and temperature in the Cape Cod Canal is relatively good; however, few other water quality data are available for that location.

Temporal coverage of the Bay's physical and chemical characteristics is quite patchy and spans the years 1895 to 1984 (Table 5). Most collection efforts for Buzzard's Bay physical and chemical water quality data have been short-term, although in 9 of the 28 studies, data were collected during all four seasons of the year. Data have rarely been collected on the same parameters and with consistent methods for longer than a two-year period. Exceptions to this trend include Fairbanks et al. (1971), who collected weekly temperature data at the eastern and western entrances to Cape Cod Canal from 1966 through 1969, and Collings et al. (1981), who reported average monthly salinities and surface and bottom water temperatures for the Cape Cod Canal and northern Buzzards Bay from 1976 through 1979. Viewed as a whole, however, the literature provides reasonably good seasonal coverage. In general, more data are available for summer than for any other season.

TABLE 3. PHYSICAL AND CHEMICAL WATER QUALITY PARAMETERS MEASURED.

METHODS	REFERENCES																										
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b
Temperature	A	B	C	D	E	F	G	H	I	J	K	L		N	O		Q	R		T	U	V	W			Z	a	b
Conductivity		B				F								N		P							W		Y			
Salinity	A		C	D	E			H	I	J	K	L	M				Q			T			W	X			a	
Dissolved oxygen		B	C		E	F		H		J	K	L		N	O		Q											
Chemical oxygen demand															O			R	S									
pH		B	C		E	F		H		J	K			N		P		R	S						Y			
Alkalinity															O	P		R	S									
Turbidity										J				N		P					U	V	W					
Settleable solids			C															R	S									
Suspended solids			C											N	O	P	Q	R	S									
Total suspensate						F																						
Total solids															O	P		R	S									

TABLE 4. METHODS USED TO MEASURE PHYSICAL AND CHEMICAL PARAMETERS.

METHODS	REFERENCES
Temperature	
Thermometer	
Mercury	A D G L W
Platinum	W
Thermistor	B F G U V W
APHA	J N O Q R
EPA	J
No information	C E H I T Z a b
Conductivity	
Electronic probe	B F W
APHA	N P
No information	Y
Salinity	
Refraction	D a
Specific gravity	D K
Titration	L T
Electrical conductivity	A D K W X
APHA	J Q
EPA	J
No information	C E G I M a
Dissolved Oxygen	
Winkler-Azide	K L
Ion selective probe	B F H
APHA	J N O Q
EPA	J
No information	C E

TABLE 4. METHODS USED TO MEASURE PHYSICAL AND CHEMICAL PARAMETERS (Continued).

METHODS	REFERENCES
pH	
Electrometrical method	B F K
APHA	J N O P R
EPA	J
No information	C E H Y
Alkalinity	
APHA	N O P R S
COD	
APHA	O R S
Turbidity	
Light transmittance	U V W
APHA	J N P
Settleable Solids	
No information	C R S
Suspended Solids	
APHA	N O P Q R S
No information	C

TABLE 4. METHODS USED TO MEASURE PHYSICAL AND CHEMICAL PARAMETERS (Continued).

METHODS	REFERENCES																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b
Total Suspensate																												
Manheim						F																						
Total Solids																												
APHA															O	P		R	S									

APHA = American Public Health Association (current edition). Standard Methods for Examination of Water and Wastewater.

EPA = U.S. Environmental Protection Agency (1971). Chemical Methods for Analysis of Water and Wastes.

Manheim = Manheim, F.T. et al. 1970. Suspended matter in surface waters of the Atlantic continental margin from Cape Cod to the Florida Keys, Science 167:371-376.

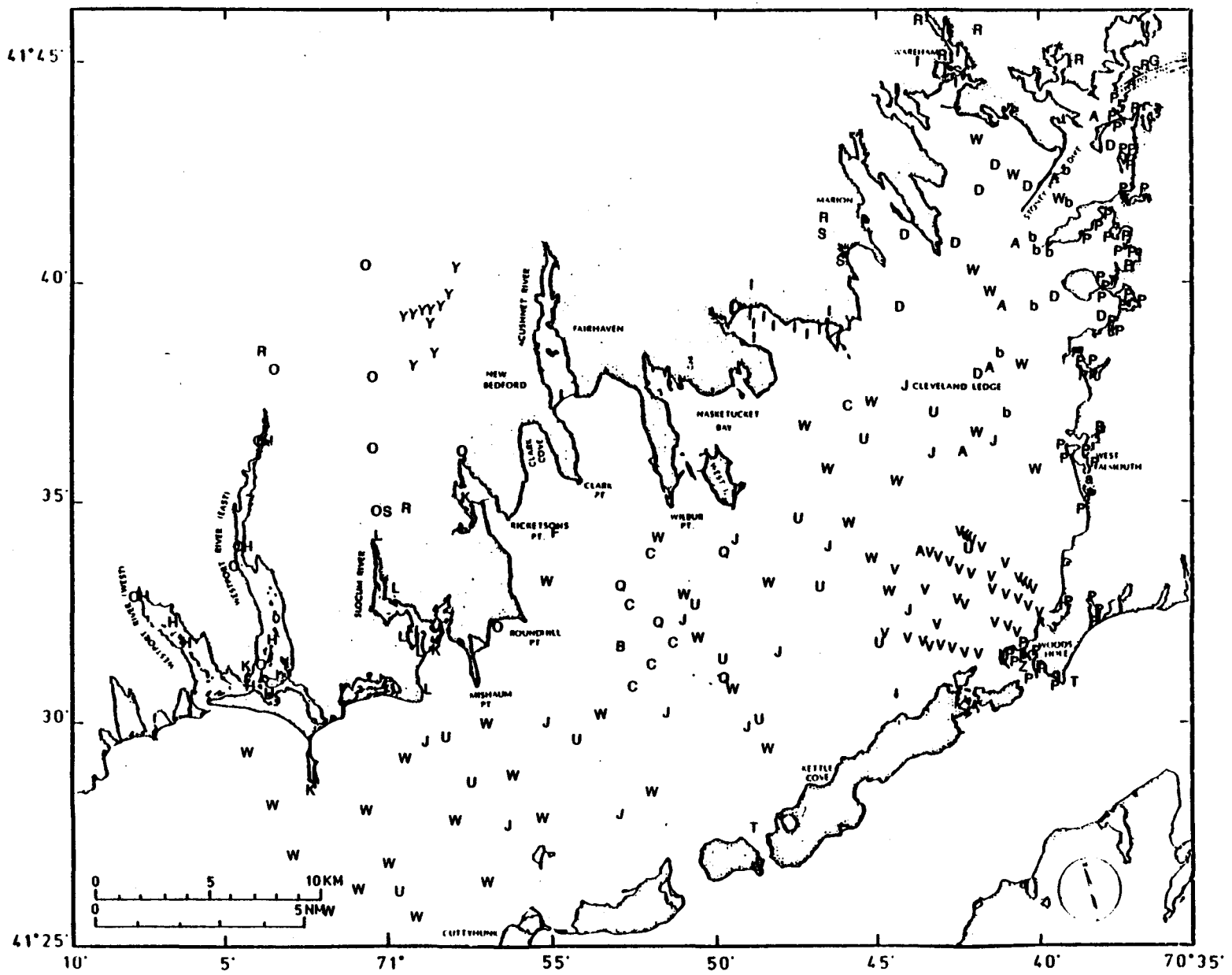

FIGURE 1. SPATIAL COVERAGE OF PHYSICAL/CHEMICAL WATER QUALITY LITERATURE REVIEWED IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 2.

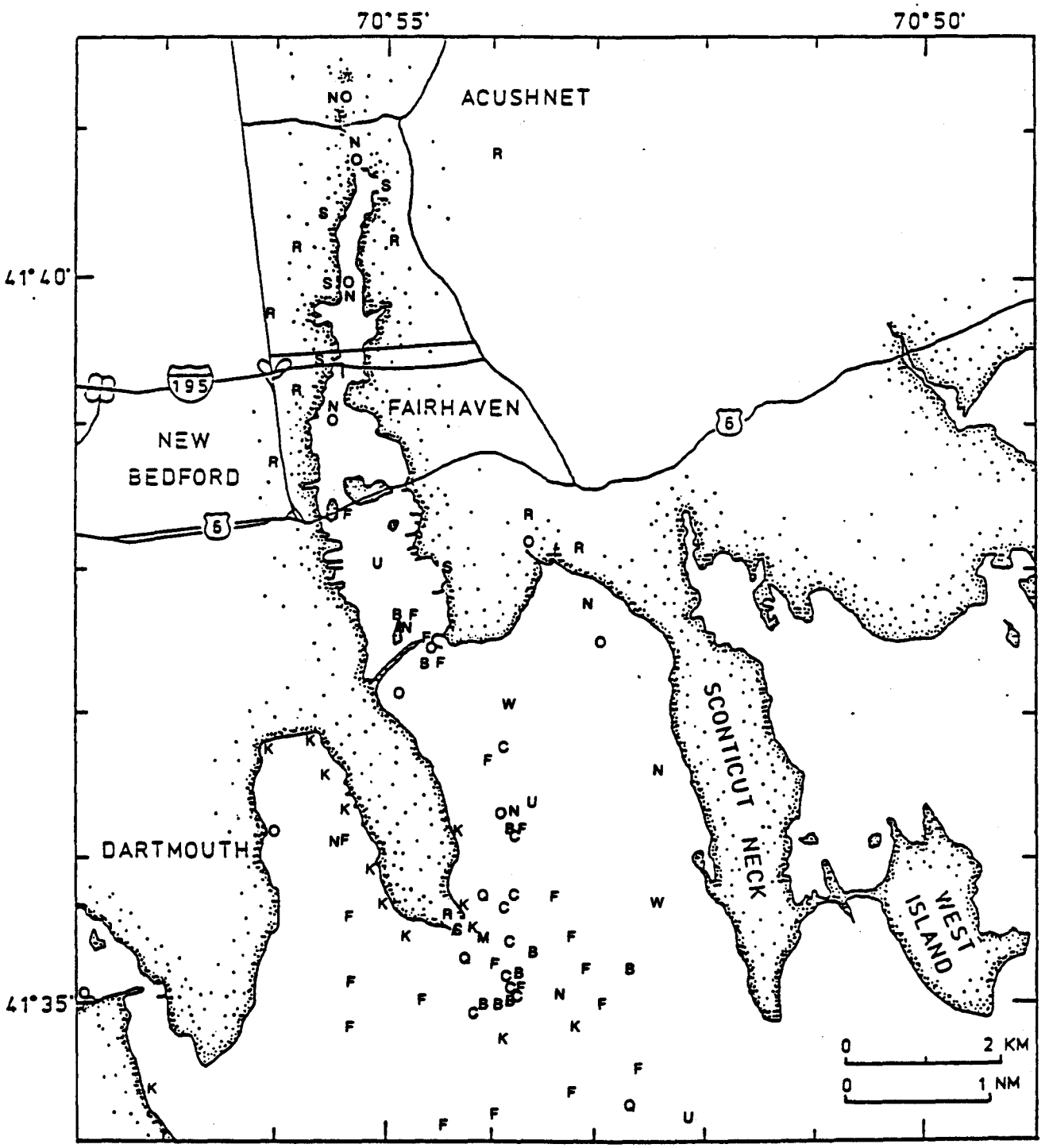

FIGURE 2. SPATIAL COVERAGE OF PHYSICAL/CHEMICAL WATER QUALITY LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 2.

TABLE 5. TEMPORAL COVERAGE OF PHYSICAL AND CHEMICAL LITERATURE.

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info.
US Fish Comm., 1898	1895-96	x			x	
Page, 1928	1928		x			
Ketchum et al., 1949	1949					x
Anraku, 1964	1959-61	x	x	x	x	
Sanders et al., 1965	1963		x			
Fiske et al., 1968	1966-67	x	x	x	x	
Fairbanks et al., 1971	1968-69	x	x	x	x	
Hoff et al., 1969	1968-69	x	x	x	x	
MA DEQE, 1971	1971		x			
Driscoll, 1972	1971-72	x	x	x	x	
FDA, 1972	1972		x			
Rhoads, 1973	1972					x
Gilbert et al., 1973	1973	x				
Pratt & Heavers, 1973	1973-74			x		

TABLE 5. TEMPORAL COVERAGE OF PHYSICAL AND CHEMICAL LITERATURE (Continued).

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info.
Hall, 1979	1974-75	x	x	x	x	
Valiela et al., 1978	1974-75	x	x	x	x	
MA DEQE, 1975	1975		x			
Ellis et al., 1977	1975-76	x	x		x	
MA DEQE, 1978	1975-77		x			
MA DEQE, 1977	1976		x			
Collings et al., 1981	1976-79	x	x	x	x	
Welsh et al., 1977	1977				x	
Stratton et al., 1978	1978		x			
MA DEQE, 1979	1978-79	x	x			
CDM, 1979	1979		x			
MA DEQE 1980	1980	x	x			
Rosenfeld et al., 1984	1982-83	x	x	x	x	
Camp Dresser and McKee, 1983	1983			x		

Temperature was measured in 23 studies (Table 3). Salinity or conductivity was measured in 20 studies (Table 3). Twelve of the studies reviewed sampled pH in Buzzards Bay waters (Table 3). Spatial coverage includes one study of the main axis (Gilbert et al., 1973), some coverage of the western shore embayments (Stratton et al., 1978; Hall, 1979), five studies of the New Bedford Harbor area (Mass. DEQE, 1971; Ellis et al., 1977; Hall, 1979; CDM, 1979, 1983), and one study of the eastern shore and Woods Hole (Mass. DEQE, 1977). In addition, pH of influent and effluent at major municipal, industrial, business, and institutional wastewater dischargers located in Dartmouth, New Bedford, Fairhaven, Acushnet, Marion, Wareham, and Bourne was measured by the Massachusetts Department of Environmental Quality Engineering (DEQE) (Mass. DEQE, 1978, 1979).

Dissolved oxygen (DO) was sampled in 11 studies covering the period 1966-1983 (Table 3). Spatial coverage is heavily concentrated in the New Bedford Harbor area (Mass. DEQE, 1971, 1980; Ellis et al., 1977; Hall, 1979; CDM, 1979, 1983). There is no coverage of the eastern shore embayments. Gilbert et al. (1973) sampled the main axis of the Bay and there is fairly good coverage of the western shore (Fiske et al., 1968; Hoff et al., 1969; Mass. DEQE, 1975; Hall, 1979). In most of the studies in which DO was measured either surface and bottom water or surface and depth intervals (to a maximum of 14 meters) were sampled. Most researchers sampled nutrients as well as DO. In three studies, chlorophyll a, nutrients, and DO were all sampled (Mass. DEQE, 1971, 1980; Gilbert et al., 1973).

Chemical oxygen demand (COD) in Buzzards Bay was sampled in three surveys conducted by DEQE (Table 3). Spatial and temporal coverage are limited to the western shore of the Bay during 1975 (Mass. DEQE, 1975) and to major wastewater dischargers (see discussion of pH above) (Mass. DEQE, 1978, 1979). Sampling was conducted during only one month of each year between July and October.

As was the case for COD, alkalinity of Buzzards Bay waters has been measured only by DEQE (Mass. DEQE, 1975, 1977, 1978, 1979). Spatial coverage of this parameter includes both the western and eastern shores of the Bay and

Woods Hole, including limited coverage of major wastewater dischargers (see discussion of pH above) (Mass. DEQE, 1978, 1979). Temporal coverage ranges from 1975 through 1979, but sampling was conducted in only one month of each year between July and October.

A variety of measures of particles in Buzzards Bay seawater were used in 12 of the studies reviewed. These measures included turbidity, settleable solids, suspended solids, total suspensate, and total solids (Table 3). Although each method provides a different measure of the particle field, they have been grouped here for purposes of discussion. Spatial coverage of particles in Buzzards Bay waters is good, covering both the main axis (Gilbert et al., 1973; Pratt and Heavers, 1975; Rosenfeld et al., 1984) and the eastern and western shores of the Bay (from Bourne to Woods Hole and from Mattapoisett to Wareham, respectively) (Mass. DEQE, 1975, 1978). Major wastewater dischargers were also sampled by DEQE (see discussion of pH above) (Mass. DEQE, 1978, 1979). Also sampled were the Acushnet River (Mass. DEQE, 1971), the Woods Hole area (Rhoads, 1973), and New Bedford Harbor (Mass. DEQE, 1971, 1980; Pratt and Heavers, 1975; Ellis et al., 1977; CDM, 1983). Temporal coverage extends from 1971 through 1983, with heaviest concentration of data collection in the spring and summer.

In summary, spatial coverage of physical and chemical characteristics of Buzzards Bay in the literature is fairly good. Temporal coverage, while spanning almost 90 years, lacks continuity. No long-term studies of any physical or chemical parameters have been conducted.

1.2.2 Biological Characteristics

1.2.2.1 Description of Available Literature

Seventeen studies reporting biological water quality characteristics of parts of Buzzards Bay were reviewed (Tables 1, 6). Table 7 lists biological parameters measured in the literature examined and Table 8 lists the methods used in each study.

TABLE 6. BIOLOGICAL WATER QUALITY LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 7 AND 8 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Camp Dresser & McKee, Inc. 1983
B	Fiske et al., 1968
C	FDA, 1972
D	Gilbert et al., 1973
E	Hall, 1979
F	Hoff, 1971
G	Ketchum et al., 1949
H	MA DEQE, 1971
I	MA DEQE, 1975
J	MA DEQE, 1977
K	MA DEQE, 1980
L	MA DEQE, 1978
M	MA DEQE, 1979
N	Ocean Surveys, Inc., 1978
O	Rhoads et al., 1975
P	Roman, 1978
Q	Roman & Tenore, 1978

TABLE 7. BIOLOGICAL WATER QUALITY PARAMETERS MEASURED.

PARAMETERS	REFERENCES															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Bacteria																	
Total Coliform	A	B	C	D	E	F	G	H	I	J	K	L	M	N			
Fecal Coliform	A		C		E			H	I	J	K	L	M	N			
Total Microbes						F											
Streptococcus						F											
Salmonella					E												
Vibrio					E												
Chlor a				D				H			K				O	P	Q
BOD					E	F		H	I	J	K	L	M				

Vibrio = Vibrio parahaemolyticus
Chlor a = Chlorophyll a
BOD = Biochemical oxygen demand

TABLE 8. METHODS USED TO MEASURE BIOLOGICAL PARAMETERS.

METHODS	REFERENCES															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Bacteria																	
HFV					E												
APHA		B	C					H	I	J	K	L	M				
MPN					E									N			
MF					E	F								N			
No info	A			D			G										
Chlorophyll a																	
Fluorescence															O	P	Q
APHA				D				H	I	J	K						
BOD																	
APHA					E	F		H	I	J	K	L	M				

APHA = American Public Health Association (current edition).
Standard Methods for the Examination of Water and Wastewater
BOD = Biochemical oxygen demand
HFV = High Volume Filtration technique
MF = Membrane Filtration technique
MPN = Most Probable Number technique
Stnd FDA = Standard U.S. Food and Drug Administration procedures

1.2.2.2 Summary and Data Gaps

Biological water quality parameters most often sampled in Buzzards Bay were, in order of frequency, total and fecal coliform bacteria, biochemical oxygen demand, and chlorophyll a. Parameters sampled less frequently included total microbes, Streptococcus, Salmonella, and Vibrio parahaemolyticus (Table 7).

Spatial coverage of biological water quality characteristics of Buzzards Bay is fairly good, although not as comprehensive as the coverage of physical and chemical parameters (Figure 3 and 4). Some data exist for the main axis of the Bay, and most of the embayments and estuaries have been sampled to some extent. The heaviest concentration of data points again occurs in the New Bedford Harbor area.

Temporal coverage of Buzzards Bay's biological water quality characteristics spans the years 1949 to 1983, with the heaviest coverage occurring between 1974 and 1979 (Table 9). None of the studies were conducted for longer than two years and most sampling took place during only one or two seasons of the year. Only two studies collected data during all four seasons of the year (Hoff, 1971; Roman and Tenore, 1978). More studies were conducted during summer than any other season.

As was discussed in the Task I report for this project, comprehensive and consistently collected coliform bacteria data for Buzzards Bay are not available. A number of studies provide limited spatial and temporal coverage for small portions of the Bay. Together, these studies provide a historical database not otherwise available for coliform bacteria. Dates and locations of data collection, as well as sampling methods and frequency, vary widely among studies. A consolidation of these scattered data, as recommended in the Task I report, would significantly contribute toward an understanding of levels of coliform bacteria in Buzzards Bay.

Coliform bacteria were measured in 14 studies reported in the literature (Table 7). Spatial coverage includes the main axis of the Bay (Gilbert et al., 1973); New Bedford Harbor and Clarks Cove (Ketchum et al., 1949;. Mass.

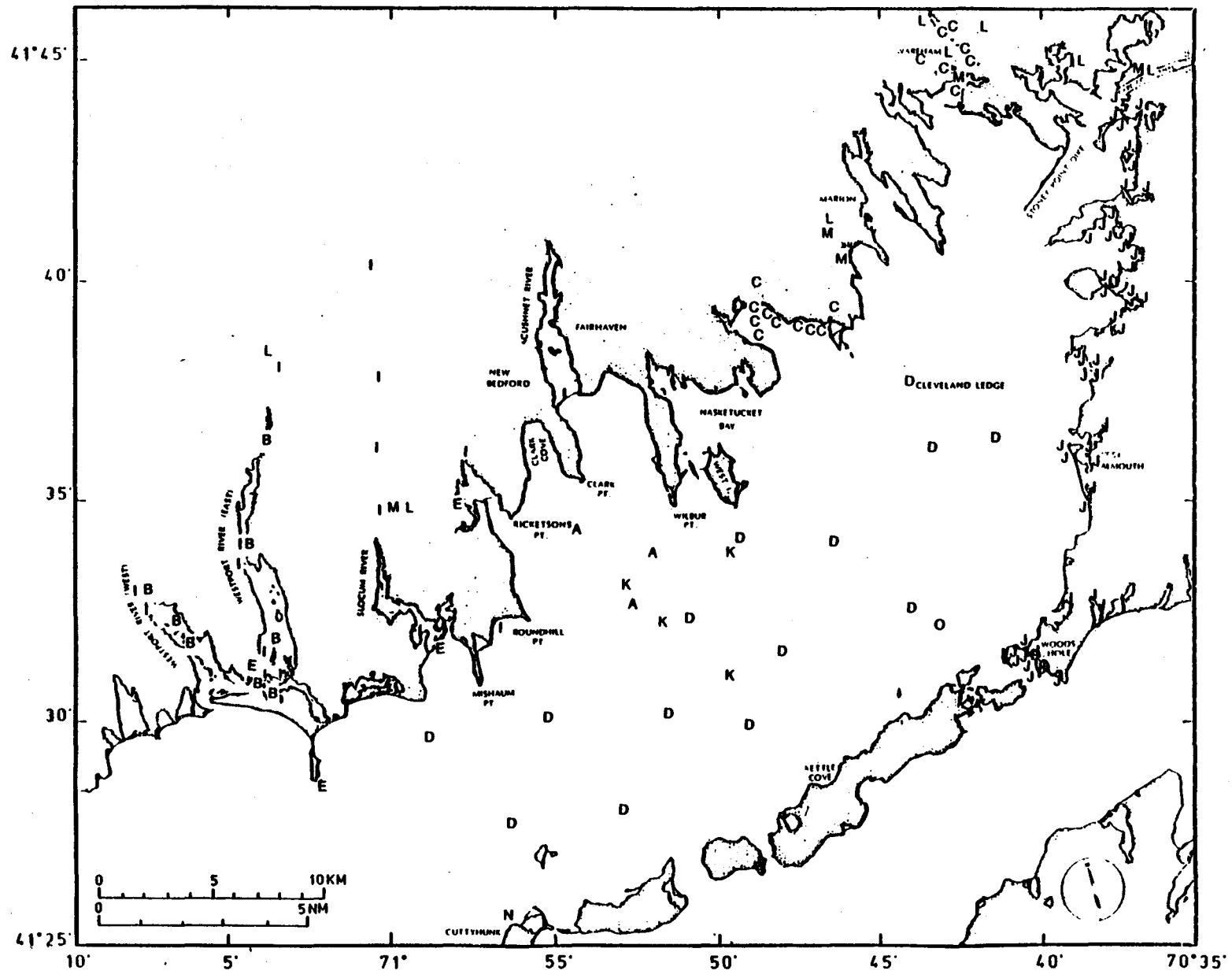

FIGURE 3. SPATIAL COVERAGE OF BIOLOGICAL WATER QUALITY LITERATURE REVIEWED IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 6. SITES FOR REFERENCE O ALSO REPRESENT REFERENCES P AND Q.

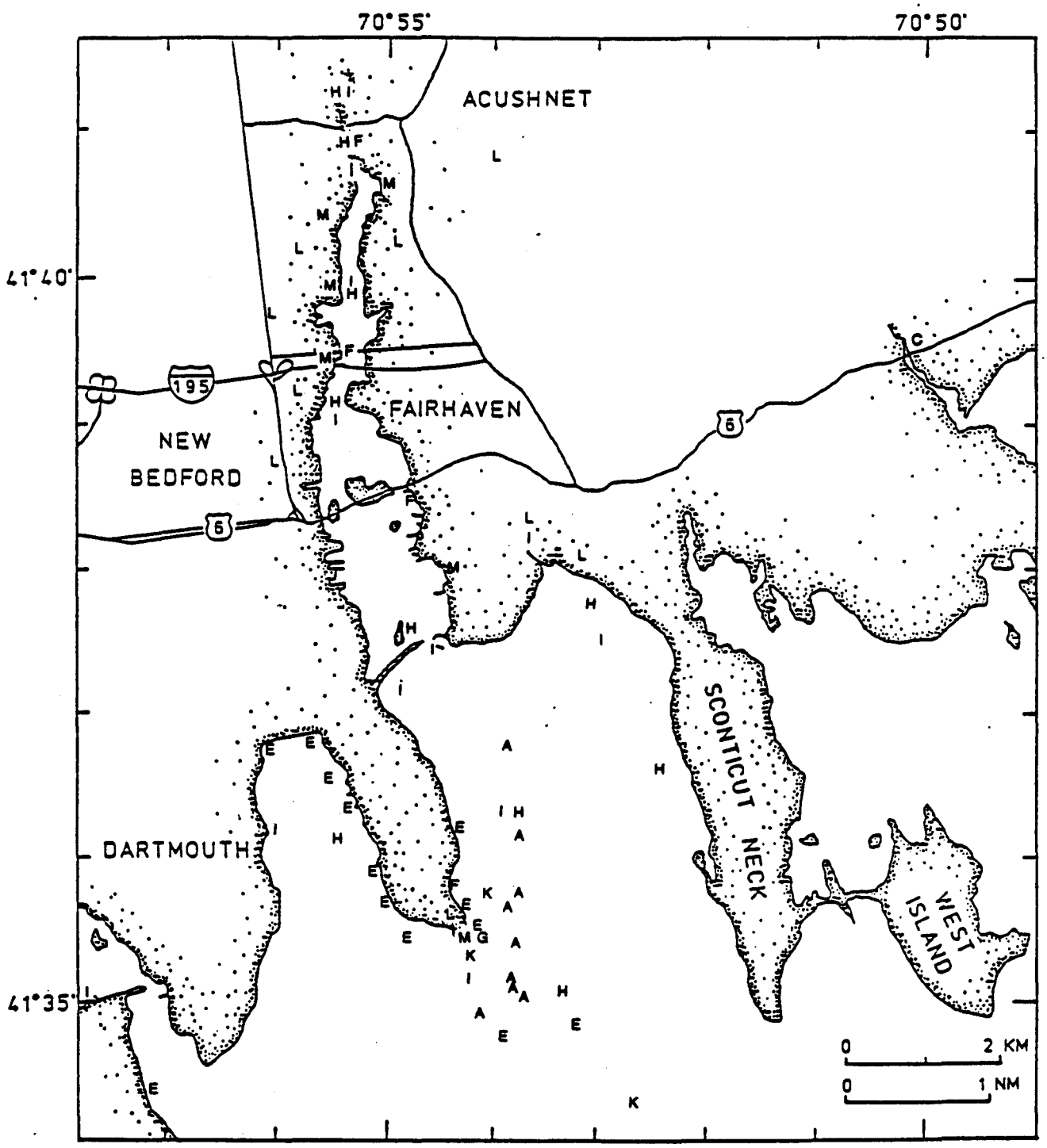

FIGURE 4. SPATIAL COVERAGE OF BIOLOGICAL WATER QUALITY LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 6.

TABLE 9. TEMPORAL COVERAGE OF BIOLOGICAL LITERATURE.

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info.
Ketchum et al., 1949	1949					X
Fiske et al., 1968	1966		X			
MA DEQE, 1971	1970	X				
FDA, 1972	1972		X			
Hall, 1979	1072		X			
Gilbert et al., 1973	1973	X				
Hoff, 1971	1970	X	X	X	X	
MA DEQE, 1975	1975		X			
Rhoads et al., 1975	1975					X
MA DEQE, 1977	1975-77			X		
Roman & Tenore, 1978	1975-77	x	x	x	x	
MA DEQE, 1977	1976		X			
Ocean Surveys, 1978	1978					X
Roman, 1978	1978					X
MA DEQE, 1979	1978-79		X	X		
MA DEQE, 1980	1980		X			
CDM, 1983	1983		X	X		

DEQE, 1971, 1980; Hall, 1979; CDM, 1983); and the Acushnet River (Hoff, 1971; Mass. DEQE, 1971). Also sampled were the Westport River (Fiske et al., 1968) and the Wareham River and Mattapoisett Harbor (FDA, 1972). In 1975, DEQE sampled coastal waters from Westport to Fairhaven and from Mattapoisett to Wareham and the watersheds of the Acushnet, Paskamanset, Westport, Mattapoisett, Weweantic, Wankinco, and Agawam Rivers (Mass. DEQE, 1975). DEQE also sampled the eastern shore embayments from Bourne to Woods Hole (Mass. DEQE, 1977) and major municipal, industrial, business, and institutional wastewater dischargers located in Dartmouth, New Bedford, Fairhaven, Acushnet, Marion, Wareham, and Bourne (Mass. DEQE, 1978, 1979). Sampling for coliform bacteria was also conducted in the vicinity of the Gosnold outfall off Cuttyhunk Island (Ocean Surveys, Inc., 1978).

Temporal coverage for coliform bacteria data reported in the literature spans the years 1970 through 1983. The majority of studies were conducted during a one-month period, most often during summer or fall.

Chlorophyll a was measured in six studies (Table 7). In five of these, nitrogen and/or phosphorus concentrations were also measured; three studies also measured dissolved oxygen (Table 7). Spatial coverage of chlorophyll a concentrations included the main axis of the Bay (Gilbert et al., 1973), New Bedford Harbor (Mass. DEQE, 1971, 1980), and one station on the western side of the Woods Hole Passage (Rhoads et al., 1975; Roman, 1978; Roman and Tenore, 1978). All of the studies included sampling of either surface and bottom water or surface and depth intervals, some with the deepest interval at the bottom.

Biochemical oxygen demand (BOD) was measured in eight surveys, six of which were conducted by DEQE (Table 7). Sampling was conducted either in surface water only or in both surface and bottom water. Temporal coverage spans the years 1970 through 1980; however, data were generally collected during only one month of each year sampled. (The months were from July through October.) Only Hall (1979) measured BOD over an entire year (July 1974 through September 1975). Spatial coverage of BOD is patchy, but includes some data collected in each of the following areas: the Acushnet River (Hoff, 1971; Mass. DEQE, 1971), New Bedford Harbor and Clarks Cove

(Mass. DEQE, 1971, 1980; Hall, 1979), along both the eastern and western shores of the Bay (from Bourne to Woods Hole and from Mattapoisett to Wareham, respectively) (Mass. DEQE, 1975, 1977), and at major wastewater dischargers on the western shore (see discussion of coliform bacteria above) (Mass. DEQE, 1979).

In summary, spatial and temporal coverage of the biological characteristics of Buzzards Bay in the literature is not as good as for physical and chemical characteristics. As noted above, sampling of coliform bacteria in the Bay is inadequate for a complete understanding of coliform bacteria levels and distribution in Buzzards Bay due to the absence of consistently collected data both spatially and temporally. Varied sampling methods and frequency contribute to the inconsistency among available coliform bacteria data. Sampling of chlorophyll *a* and BOD has been limited and lacks spatial and temporal continuity.

1.2.3 Nutrients

1.2.3.1 Description of Available Literature

Twenty-one studies reporting nutrient concentrations in portions of the Bay were reviewed (Tables 1, 10). Table 11 lists nutrient parameters described in the literature examined. Methods used in each study in which nutrient concentrations were measured are listed in Table 12.

1.2.3.2 Summary and Data Gaps

Nitrate, nitrite, and phosphate were most often studied (Table 11). Other nutrient parameters measured less frequently included total nitrogen, ammonia, ammonium, total phosphorus, particulate nitrogen, particulate organic nitrogen, dissolved organic nitrogen, inorganic phosphate, and dissolved inorganic nitrogen, in decreasing order of frequency (Table 11).

TABLE 10. NUTRIENT LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 11 AND 12 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Fiske et al., 1968
B	Gilbert et al, 1973
C	Hall, 1979
D	Hoff et al, 1969
E	Hoff, 1971
F	MA DEQE, 1971
G	MA DEQE, 1975
H	MA DEQE, 1977
I	MA DEQE, 1980
J	MA DEQE, 1978
K	MA DEQE, 1979
L	Nichols et al., 1972
M	Pratt & Heavers, 1975
N	Rhoads et al., 1975
O	Roman, 1978
P	Roman, 1980
Q	Roman & Tenore, 1978
R	Teal & Valiela, 1978
S	Valiela & Teal, 1978
T	Valiela & Teal, 1979
U	Valiela et al., 1978

TABLE 11. NUTRIENT PARAMETERS MEASURED.

PARAMETERS	REFERENCES																			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Nitrogen																					
Total N						F			I		K		M					R			
Nitrate	A	B	C	D	E		G	H	I	J	K	L				P	Q	R	S	T	U
Nitrite		B	C		E							L				P		R	S	T	U
Part. N																		R	S	T	U
PON														N	O	P					
Ammonia		B					G	H		J	K										
Ammonium																P		R	S	T	U
DIN																			S		
DON			C																S	T	
Phosphorus																					
Total P							G	H		J	K	L									
Total PO4	A	B	C			F			I								Q				U
Inorg. PO4				D	E																

DIN = Dissolved Inorganic Nitrogen
DON = Dissolved Organic Nitrogen
Inorg. PO4 = Inorganic Phosphate
N = Nitrogen
Part. N = Particulate Nitrogen
PON = Particulate Organic Nitrogen
Total P = Total Phosphorus
Total PO4 = Total Phosphate

TABLE 12. METHODS USED TO MEASURE NUTRIENT PARAMETERS.

METHODS	REFERENCES																			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Total N																					
Kjeldahl						F			I		K										
Nitrate																					
APHA	A	B				F	G	H	I	J	K										
EPA		B																			
Cd amalgam				D	E																
Strickland, 1968			C													P				T	
Strickland, 1965												L									
No information																		R	S	T	
Nitrite																					
EPA		B																			
APHA		B																			
Autoanalyzer																				T	
Strickland, 1968			C													P					U
Strickland, 1965												L									
No information		B			E														S		
Part. N																					
CHN													M								
No information																		R	S	T	
PON																					
CHN														N	O	P					
Ammonia																					
APHA		B				F	G	H		J	K										
EPA		B																			
Strickland, 1965												L									
Ammonium																					
Strickland, 1968																P					
Autoanalyzer																				T	
Solorzano																					U
No information																		R	S		
DIN																					
Strickland, 1968																	Q				
No information																			S		

TABLE 12. METHODS USED TO MEASURE NUTRIENT PARAMETERS (Continued).

METHODS	REFERENCES																			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
DON																					
Autoanalyzer																				T	
Kjeldahl-DIN																					U
Strickland, 1968			C																		
No information																			S		
Total P																					
APHA							G	H	I		K			N							
Total PO4																					
APHA	A	B				F															
EPA		B																			
Strickland, 1968			C																		U
Strickland, 1965												L									
Inorg. PO4																					
Ascorbic Acid				D	E																

Ascorbic Acid = Ascorbic Acid Single Solution method
APHA = American Public Health Association (current edition) Standard Methods for the Examination of Water and Wastewater
CHN = Carbon/Hydrogen/Nitrogen
Cd amalgam = Cadmium amalgam method
DIN = Dissolved Inorganic Nitrogen
DON = Dissolved Organic Nitrogen
EPA = U.S. Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes, U.S. EPA, Cincinnati, OH
Inorg. PO4 = Inorganic Phosphate
Kjeldahl-DIN = Total Kjeldahl Nitrogen minus Dissolved Inorganic Nitrogen
Part. N = Particulate Nitrogen
Solorzano = Solorzano, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr. 14:799-801.
Strickland, 1968 = Strickland, J.D.H. and T.R. Parsons. 1968. A Practical Handbook of Seawater Analysis. Bull. Fish. Res. Bd. Can. 167.
Strickland, 1965 = Strickland, J.D.H. and T.R. Parsons. 1965. A Manual of Seawater Analysis. Bull. Fish Res. Bd. Can. 125.
Total P = Total Phosphorus
Total PO4 = Total Phosphate

Spatial coverage of nutrient concentrations in the Bay is similar to coverage for biological parameters (Figures 5 and 6). Some data are available for the main axis of the Bay (Gilbert et al., 1973; Pratt and Heavers, 1975) and most of the embayments and estuaries have been studied at some time. The heaviest concentration of points occurs in the New Bedford Harbor area (Mass. DEQE, 1971, 1980; Pratt and Heavers, 1975; Hall, 1979). Figures 5 and 6 also illustrate coverage for nitrogen compounds because at least one form of nitrogen was measured in each of the 21 studies reporting nutrient data. Phosphorus compounds were sampled in 14 of the 21 studies, providing spatial coverage similar to that for nitrogen alone and for nutrients in general.

Nutrient concentrations in Buzzards Bay have been measured sporadically between 1966 and 1980, with the heaviest periods of data collection occurring from 1973 to 1978 (Table 13). Seasonal coverage of nutrients has been most intensive in summer, with less sampling in spring and fall and very little in winter. Samples were collected during all four seasons in six of the studies reviewed (Hoff et al., 1969; Roman and Tenore, 1978; Teal and Valiela, 1978; Valiela and Teal, 1978, 1979; Hall, 1979).

To summarize, a wide variety of nutrient parameters have been sampled in Buzzards Bay, with little consistency in compounds sampled or in spatial coverage. No long-term study of nutrients in the Bay has been conducted.

1.3 TOXIC SUBSTANCES IN ORGANISMS AND SEDIMENTS

Four major categories of toxic substances are covered in this section: polychlorinated biphenyls (PCBs), hydrocarbons, pesticides, and metals. Table 14 presents the literature assessed for the section.

1.3.1 Polychlorinated Biphenyls

Polychlorinated biphenyls are a class of compounds produced by chlorination of the biphenyl molecule. PCBs were manufactured and marketed

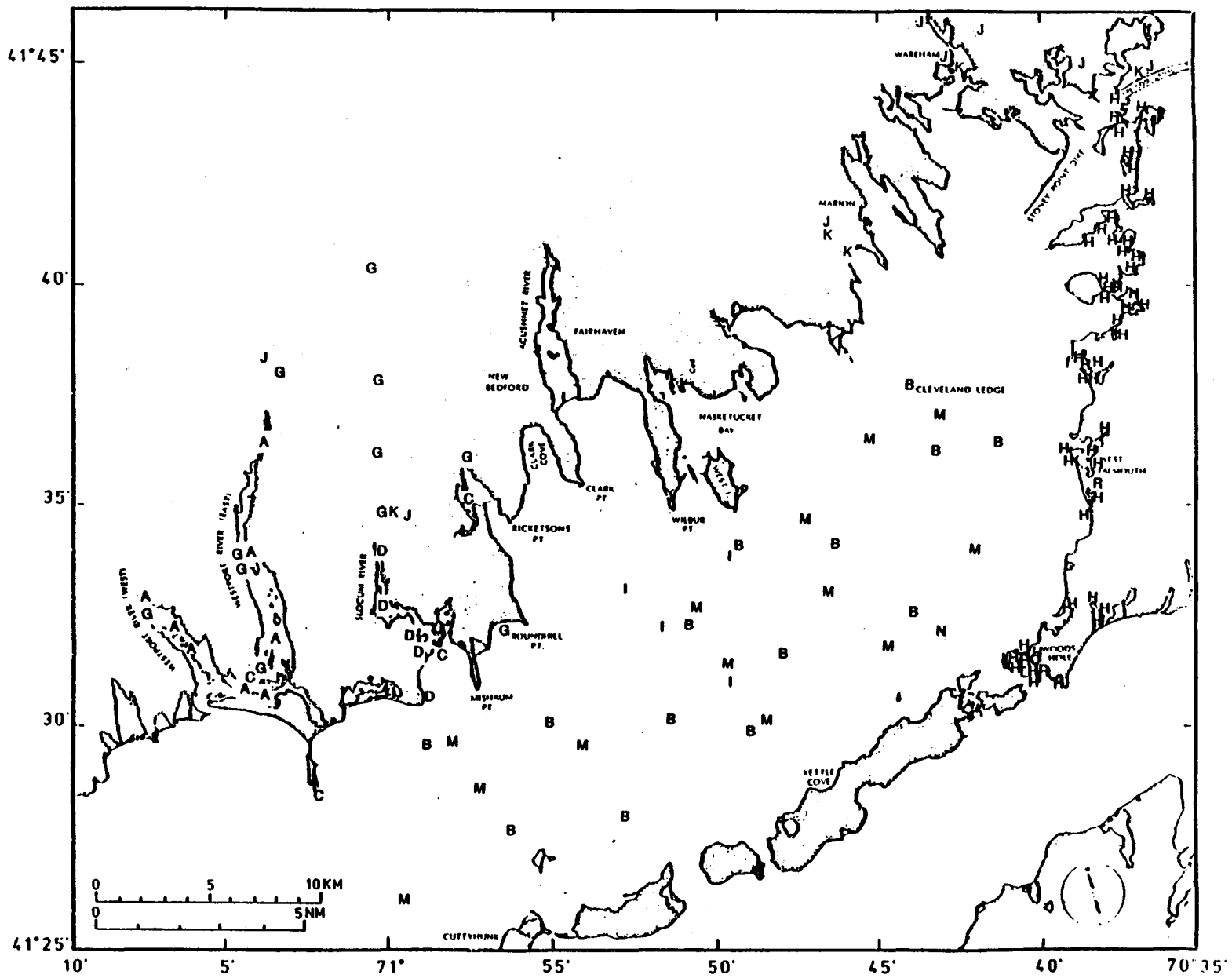

FIGURE 5. SPATIAL COVERAGE OF NUTRIENT LITERATURE REVIEWED IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 10. SITES FOR REFERENCE N ALSO REPRESENT REFERENCES O, P, Q, R, S, T, AND U.

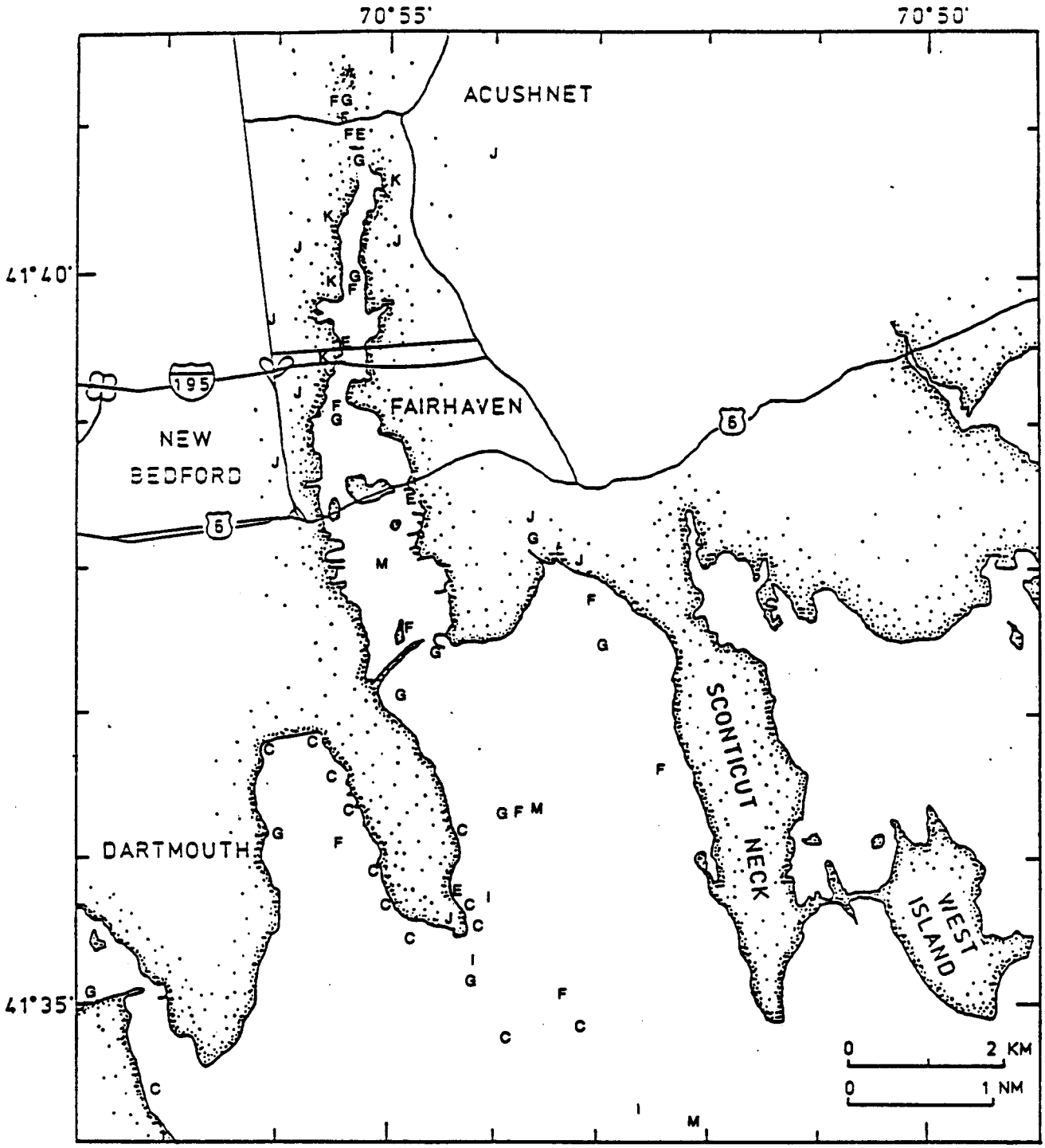

FIGURE 6. SPATIAL COVERAGE OF NUTRIENT LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 10.

TABLE 13. TEMPORAL COVERAGE OF NUTRIENT LITERATURE.

REFERENCES	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info
Fiske et al., 1968	1966		x			
Hoff et al., 1969	1966-68	x	x	x	x	
Hoff, 1971	1970	x				
MA DEQE, 1971	1971		x			
Nichols et al., 1972	1972			x	x	
Pratt & Heavers, 1975	1973			x		
Rhoads et al., 1975	1973		x			
Gilbert et al., 1973	1973	x				
Hall, 1979	1974-75	x	x	x	x	
Valiela et al., 1978	1974-75		x			
MA DEQE, 1975	1975		x			
MA DEQE, 1978	1975-77		x			
Roman & Tenore, 1978	1975-77	x	x	x	x	
MA DEQE, 1977	1976		x			
Teal & Valiela, 1978	1977	x	x	x	x	
Valiela & Teal, 1978	1977	x	x	x	x	
Valiela & Teal, 1979	1978	x	x	x	x	
Roman, 1978	1978					x
MA DEQE, 1979	1978-79		x	x		
MA DEQE, 1980	1980		x			
Roman, 1980	1980					x

TABLE 14. TOXIC SUBSTANCES: LITERATURE REVIEWED.

REFERENCES	HYDRO-CARBONS	PCBs	METALS	PESTICIDES
Aubrey, 1979			x	
Banus et al., 1974			x	
Banus et al., 1975			x	
Baxter et al., 1978	x			
Blumer et al., 1977	x			
Blumer et al., 1971	x			
Blumer & Sass, 1972a	x			
Blumer & Sass, 1972b	x			
Blumer & Sass, 1972c	x			
Blumer et al., 1970a,b,c	x			
Blumer & Youngblood, 1975	x			
Boehm, 1983a		x		
Boehm, 1983b		x		
Boehm, 1983c		x		
Breteler et al., 1981a,b			x	
Brown & Lynch, 1978	x			
Brownawell & Farrington, 1985		x		
Brownawell & Farrington, 1986		x		
Burns, 1975	x			
Burns, 1976	x			
Burns & Teal, 1979	x			
Burns & Teal, 1971	x			
Camp Dresser & McKee Inc., 1979		x	x	x
Camp Dresser & McKee Inc., 1983		x	x	x
Carey & Harvey, 1978		x		
Clark, 1972			x	
Cole, 1978	x			

TABLE 14. TOXIC SUBSTANCES: LITERATURE REVIEWED (Continued).

REFERENCES	HYDRO-CARBONS	PCBs	METALS	PESTICIDES
Deubert et al., 1981		x		
Deubert et al., 1980		x		
Ecosystems Center, 1980	x			
E G & G, 1981		x		
Ellis et al., 1977			x	
ERCO, 1983		x		
Farrington, 1979	x			
Farrington et al., 1982a,b	x			
Farrington et al., 1977	x			
Farrington et al., 1983		x		
Genest, 1979			x	
Genest & Hatch, 1981			x	
Giblin, 1982			x	
Giblin et al., 1980			x	
Giblin et al., 1983a,b			x	
Giblin et al., 1986			x	
Gidley Laboratories, 1980		x	x	
Giger & Blumer, 1974	x			
Gilbert et al., 1973 (USACOE)		x	x	
Grassle & Grassle, 1974	x			
Hall et al., 1983		x		
Hampson & Moul, 1977	x			
Hampson & Moul, 1978	x			
Hampson & Sanders, 1969	x			
Hatch et al., 1981		x		
Hites et al., 1977	x			
Kelley, 1978			x	
Kolek & Ceurvels, 1981		x		

TABLE 14. TOXIC SUBSTANCES: LITERATURE REVIEWED (Continued).

REFERENCES	HYDRO-CARBONS	PCBs	METALS	PESTICIDES
Krebs et al., 1974		x		x
Krebs & Valiela, 1977				x
Krebs and Burns, 1977	x			
Krebs and Burns, 1978	x			
Malcolm Pirnie, 1982		x	x	
Massachusetts DEQE, 1971			x	
Massachusetts DEQE, 1975			x	
Massachusetts DEQE, 1980		x	x	
Metcalf & Eddy, Inc., 1982		x		
Metcalf & Eddy, Inc., 1983		x	x	
Michael et al., 1975	x			
Moore, 1963			x	
Myatt et al., 1983		x		
New Bedford Sewer Study, 1982		x		
Nisbit & Reynolds, 1984		x		x
NOAA, 1981 & 1983		x	x	
Pruell, 1977			x	
Reimillard, 1980		x		
Ruby et al., 1977	x			
Sanders, 1978	x			
Sanders et al., 1972	x			
Sanders et al., 1980	x			
Sanders et al., 1981			x	
Schrier, 1978	x			
Smith & Cole, 1970				x
Spitzer & Poole, 1980				x

TABLE 14. TOXIC SUBSTANCES: LITERATURE REVIEWED (Continued).

REFERENCES	HYDRO-CARBONS	PCBs	METALS	PESTICIDES
Stegeman et al. (In press)		x		
Steimle et al., 1986		x	x	
Stoffers et al., 1977			x	
Stratton et al., 1978		x		
Summerhayes et al., 1977			x	
Summerhayes et al., 1985			x	
Teal et al., 1978	x			
Teal & Howarth, 1984	x			
Teal et al., 1982			x	
Tomczyk, 1981		x		
Tripp et al., 1981	x			
USACOE Vol II & III, 1980		x	x	x
USACOE, 1982			x	
Valiela et al., 1975			x	
Versar, Inc., 1981a		x		
Versar, Inc., 1981b		x		
Weaver, 1982		x		
Weaver, 1984		x		
Welsh et al., 1977	x			
Weston, Roy F., 1983		x		
Youngblood & Blumer, 1975	x			

in the United States between 1929 and 1977 by the Monsanto Corporation (St. Louis, Missouri), under the trade name Aroclor (Weaver, 1984). Over 100 varieties of PCBs have been produced since 1929 and over 200 PCB isomers exist (Tomczyk, 1981). Aroclors are mixtures of PCB isomers and are characterized by the 4-digit number that follows the Aroclor name. The first two digits identify the compound as a biphenyl and the second two digits represent the approximate percentage of chlorine by weight in the PCB blend (Aroclor 1016 is an exception to this rule)(Weaver, 1982). Because each Aroclor is a PCB blend (i.e., not a pure substance), it will behave differently depending on its specific composition of chlorinated biphenyl groups. The physical and chemical properties of the various isomers depend on both the total chlorine content and the intramolecular positions of chlorine substitutions (Metcalf and Eddy, 1983).

In New Bedford, Massachusetts, Aerovox Industries and Cornell-Dubilier Electric Corporation used PCBs in the production of capacitors. These companies discharged wastewaters containing PCB compounds into New Bedford Harbor; Aerovox from 1947 to 1976 and Cornell-Dubilier from 1942 to 1976. In 1976, the U.S. Environmental Protection Agency (EPA) conducted an areawide survey of New England and found high levels of PCBs in various New Bedford Harbor locations (Metcalf and Eddy, 1983). Since 1976, when the PCB problem was first identified, research efforts have been extensive in New Bedford Harbor and nearby Buzzards Bay.

1.3.1.1 Description of Available Literature

Thirty-nine studies reporting PCB pollution in the sediments and organisms of Buzzards Bay were reviewed (Tables 14, 15). Eleven blends of PCB (Aroclors) were reported in the literature. Many studies, however, reported data as the total amount of PCBs rather than specifying values for each PCB blend (Table 16). Isomers were not reported in any of the studies. Methods for examination of PCBs are identified in Table 17. In many cases, the methods were not reported or the reports represented summaries of previous work. In some cases, methods are not directly comparable due to the differences in the techniques used. Methods used to analyze PCBs in the

TABLE 15. PCB LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 16, 17, AND 18 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Boehm, 1983a
B	Boehm, 1983b
C	Boehm, 1983c
D	Brownawell & Farrington, 1985
E	Brownawell & Farrington, 1986
F	Carey & Harvey, 1978
G	Deubert et al., 1981
H	Deubert et al., 1980
I	E G & G, 1981
J	ERCO, 1983
K	Farrington et al., 1982
L	Farrington et al., 1983
M	Gidley Laboratories, 1980
N	Gilbert et al., 1973
O	Hall et al., 1983
P	Hatch et al., 1981
Q	Kolek & Ceurvels, 1981
R	Malcolm Pirnie, 1982
S	Metcalf & Eddy, Inc., 1983
T	Metcalf & Eddy, Inc., 1983
U	Myatt et al., 1983
V	New Bedford Sewer Study, 1982
W	Nisbit & Reynolds, 1984
X	NOAA, 1981 & 1983
Y	Reimillard, 1980
Z	Stegeman et al. (In press)
a	Steimle et al., 1986
b	Stratton et al., 1978
c	Tomczyk, 1981
d	USACOE Vol II & III, 1980
e	Versar Inc., 1981a
f	Versar Inc., 1981b
g	Weaver, 1982
h	Weaver, 1984
i	Weston, Roy F., 1983
j	Camp Dresser & McKee Inc., 1979
k	Camp Dresser & McKee Inc., 1983
l	Krebs et al., 1974
m	MA DEQE, 1980

TABLE 16. PCBS EXAMINED IN SEDIMENTS AND ORGANISMS.

	REFERENCES																																						
PCB BLENDS	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**	**Y**	**Z**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**
Aroclor																																							
1016																		R		T			W													j	k		
1221		B	C																	T																j	k		
1232																				T																j	k		
1242		B	C				G	H			K				O	P				T	U					Z					e	f				j	k		
1248		B	C	D	E			H						N	O			R		T		V														j	k		
1254		B	C	D	E	F	G	H			K				O	P		R		T	U	V	W		Y	Z		b				f				j	k		
1260															O					T	U		W													j	k		
1262																				T																			
1016/1242															O					T								b											
1242/1254				D	E							L								T	U	V																	
1248/1254																				T																			
Total PCBs	**A**	**B**					**G**	**H**	**I**	**J**			**M**				**Q**		**S**	**T**				**X**	**Y**		**a**		**c**	**d**			**g**	**h**	**i**			**l**	**m**

TABLE 17. METHODS USED TO EXAMINE PCBS.

METHOD	REFERENCE																																										
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k	l	m				
TISSUES																																											
Summary/review									I										S										c				g	h	i		k						
No methods									I								Q		S	T						Z		b	c				g	h	i	j	k						
Reference not applicable	A			D	E	F				J		L	M	N	O			R			U	V		X						e	f								m				
Sample Preparation			C*				G*																		Y*																		
Pre-extraction		B						H*								P*																							1*				
Oven-dry																							W																				
Freeze-dry											K																																
Extraction procedure																																										
Soxhlet											K[1]												W[8]																				
Ambient shaker											K[6]												W[2]																				
Digestion											K[3,4,5]																	a[7]																
Homogenization											K[2]					P[2]									Y[2]																	1[2]			
Clean-up procedure																																												
Adsorption chromatography		B						H			K												W		Y																1			
Silica																																												
Florisil								H			K												W																		1			
Silica/alumina		B									K					P									Y			a															
Alumina		B																					W																				
Sulfur removal																																												
Copper																																												
Sample Analysis																																												
Gravimetric		B																							Y																1			
Gas-Liquid chromatography		B	C				G	H			K					P	Q						W		Y			a												1			
Packed column							G	H			K					P							W																				
Fused silica																												a															
Electron capture detector		B	C				G	H			K					P							W		Y			a												1			
Gas chromatography/mass spectrometry											K												W					a															

Extraction Solvents: 1 = benzene, 2 = hexane, 3 = KOH/ethanol, 4 = acetic acid/perchloric acid, 5 = NaOH, 6 = ether, 7 = KOH, 8 = diethyl ether:hexane, 9 = methylene chloride, 10 = hexane:acetone, 11 = methanol, * = Not reported.

TABLE 17. METHODS USED TO EXAMINE PCBS (Continued).

METHODS	REFERENCE																																										
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k	l	m				
SEDIMENTS																																											
Summary/review												L	M						S											d			g	h	i				m				
No methods												L	M	N					S	T				X				b	c		e	f	g	h	i	j	k		m				
Reference not applicable		B				F	G	H	I		K					P	Q					V	W		Y	Z	a										k						
Sample Preparation			C*																											d*													
Pre-extraction	A*									J*					O*			R*			U*																			l*				
Extraction procedure																																								l[11]				
Soxhlet				D[10]	E[10]										O[10]																													
Ambient	A									J[9]					O[10]			R[10]			U[10]																							
Clean-up procedure																																												
Adsorption chromatography	A			D	E					J					O			R			U																			l				
Silica	A			D	E					J																																		
Florisil	A									J					O			R			U																			l				
Thin layer																																												
Sulfur removal	A*			D						J*					O*				S*		U*																			l*				
Copper				D	E																																						
Sample Analysis																														d*													
Gravimetric	A									J					O						U																							
Gas liquid chromatography	A		C		E					J					O			R																							l				
Packed column																		R																											
Fused silica				D	E																																						
Electron capture detector	A*			D	E					J*					O*			R																							l				
Gas chromatography/mass spectrometry					E																																							

Acushnet estuary are also listed in Metcalf and Eddy (1983). Twenty-nine species were investigated for PCB contamination (Table 18). Fish and bivalve tissues were studied most frequently. Kolek and Ceurvels (1981) summarized PCB data collected by the Massachusetts Division of Marine Fisheries (DMF) on finfish (e.g., flounder, bass, eel), shellfish (e.g., oysters, quahogs, crabs), and crustaceans from New Bedford Harbor area waters.

1.3.1.2 Summary and Data Gaps

Prior to 1980, much of the PCB sampling and analyses were done only for Aroclor 1254 (Boehm, 1983b). In the literature reviewed, Aroclors 1254, 1242, and 1248 were most commonly studied. Aroclors that were difficult to distinguish were reported together; for example, Aroclor 1016/1242. The literature contains several of these studies. The Northeast Monitoring Program of the National Oceanic and Atmospheric Administration (NOAA) generated substantial data for PCBs in sediments (NOAA 1981, 1983; Boehm 1983a,b; ERCO, 1983; Steimle et al., 1986). Other studies investigated PCB contamination in animals inhabiting the Harbor (Kolek and Ceurvels, 1981; Nisbit and Reynolds, 1984; Krebs et al., 1974). Two studies report compliance inspections of Cornell-Dubilier Electronics and Aerovox Industries (Versar, 1981a, b). Farrington et al. (1983) and Brownawell and Farrington (1986) investigated the dynamics of PCB release from sediments to the water column. Biological effects of PCBs on marine organisms have been studied (Table 18). For example, Stegeman et al. (in press) has been studying PCB distribution in scup (Stenotomus chrysops), a species of marine fish, and Reimillard (1980) studied PCB kinetics in oysters (Crassostrea virginica). Physiological processes of Mercenaria mercenaria relating to PCB depuration studies have also been investigated. Boehm (1983b) studied body burdens in Arctica islandica. Nisbit and Reynolds (1984) looked at PCB residues in terns and fish. Smith and Cole (1970) studied PCBs in winter flounder.

Spatial coverage of the PCB data outside of the New Bedford area is minimal (Figure 7). Most of the data for PCBs in Buzzards Bay are from the sediments of inner and outer New Bedford Harbor (Figure 8). Malcolm Pirnie

TABLE 18. SPECIES EXAMINED IN PCB LITERATURE.

SPECIES	REFERENCES
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z a b c d e f g h i j k l m
Ammodytes americanus (sand lance)	W
Anguilla rostrata (american eel)	Q
Arctica islandica (ocean quahog)	B a
Callinectes sapidus (blue crab)	Q
Centropristis striata (black sea bass)	Q
Clupea harrengus (sea herring)	W Y
Crassostrea virginica (oyster)	P Q T
Homarus americanus (lobster)	C I Q
Larus argentatus (herring gull)	
Menidia menidia (atlantic silverside)	W
Mercenaria mercenaria (common quahog)	G H P Q T
Merluccius bilinearis (silver hake)	Q
Morone saxatilus (striped bass)	Q
Mya arenaria (soft shelled clam)	Q
Mytilus edulis (blue mussel)	K T W

TABLE 18. SPECIES EXAMINED IN PCB LITERATURE (Continued).

SPECIES	REFERENCES
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z a b c d e f g h i j k l m
Paralichthys dentatus (summer flounder)	Q
Paralichthys oblongus (four-spot flounder)	Q
Pitar morrhuana (clam)	C
Pomatomus saltatrix (bluefish)	Q
Preprilus tricanthus (butterfish)	Q
Pseudopleuronectes americanus (winter flounder)	Q T
Scopthalmus aquosus (windowpane flounder)	Q
Stenotomus chrysops (scup)	Q Z
Sterna hirudo (common tern)	W
Tautoga onitis (tautog)	Q
Tautogolabrus adspersus (cunner)	Q
Uca pugnax (fiddler crab)	l
Urophysis chuss (red hake)	Q
Miscellaneous finfish	T
Miscellaneous shellfish	T
Marine bacteria (nearshore)	F
Sediment	A D E J L M N O b d e f j k
Summary	R S T U X c g h i

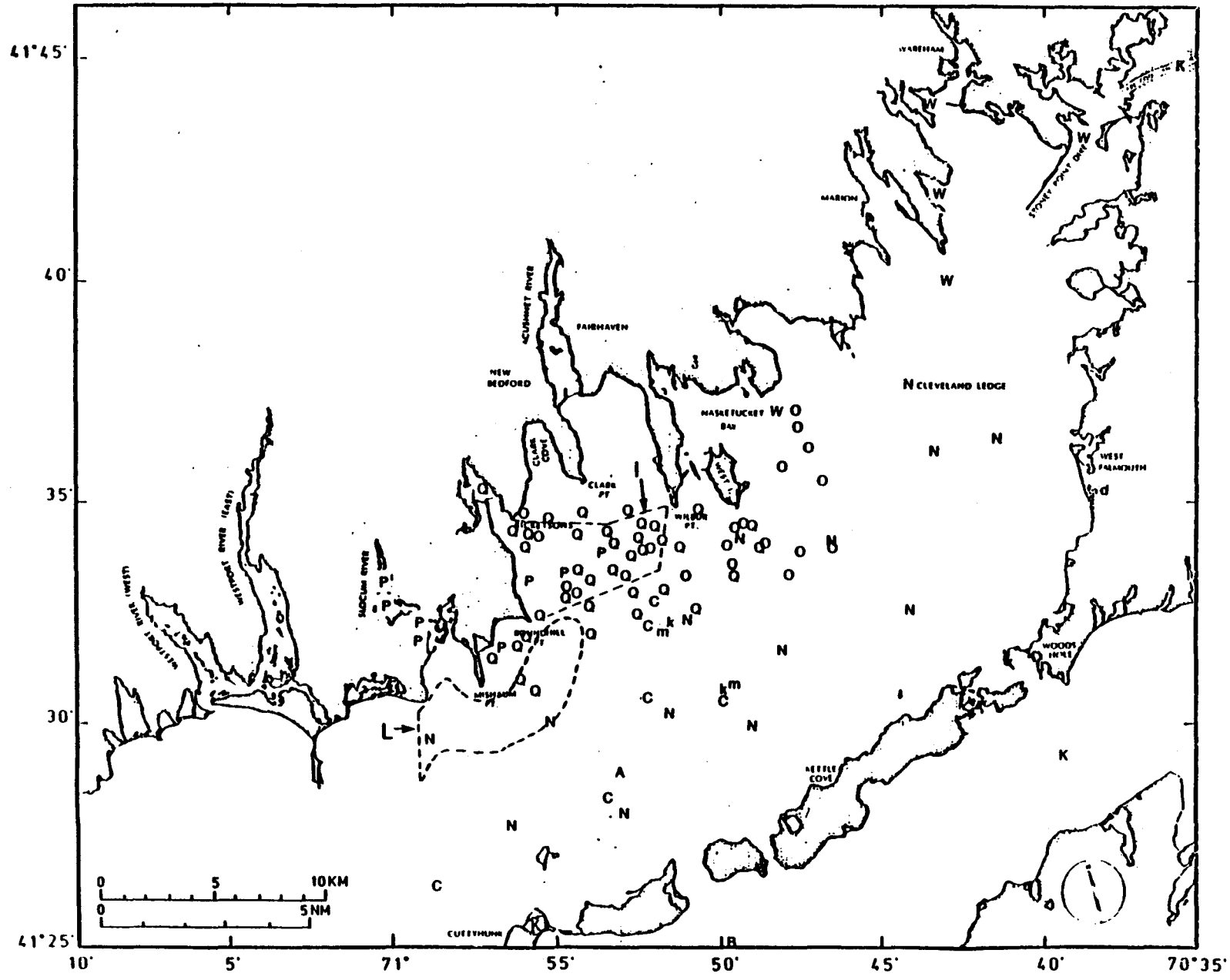

FIGURE 7. SPATIAL COVERAGE OF PCB LITERATURE REVIEWED IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 15. SITE FOR REFERENCE A ALSO REPRESENTS REFERENCES J AND X; THAT FOR REFERENCE d ALSO REPRESENTS REFERENCE 1.

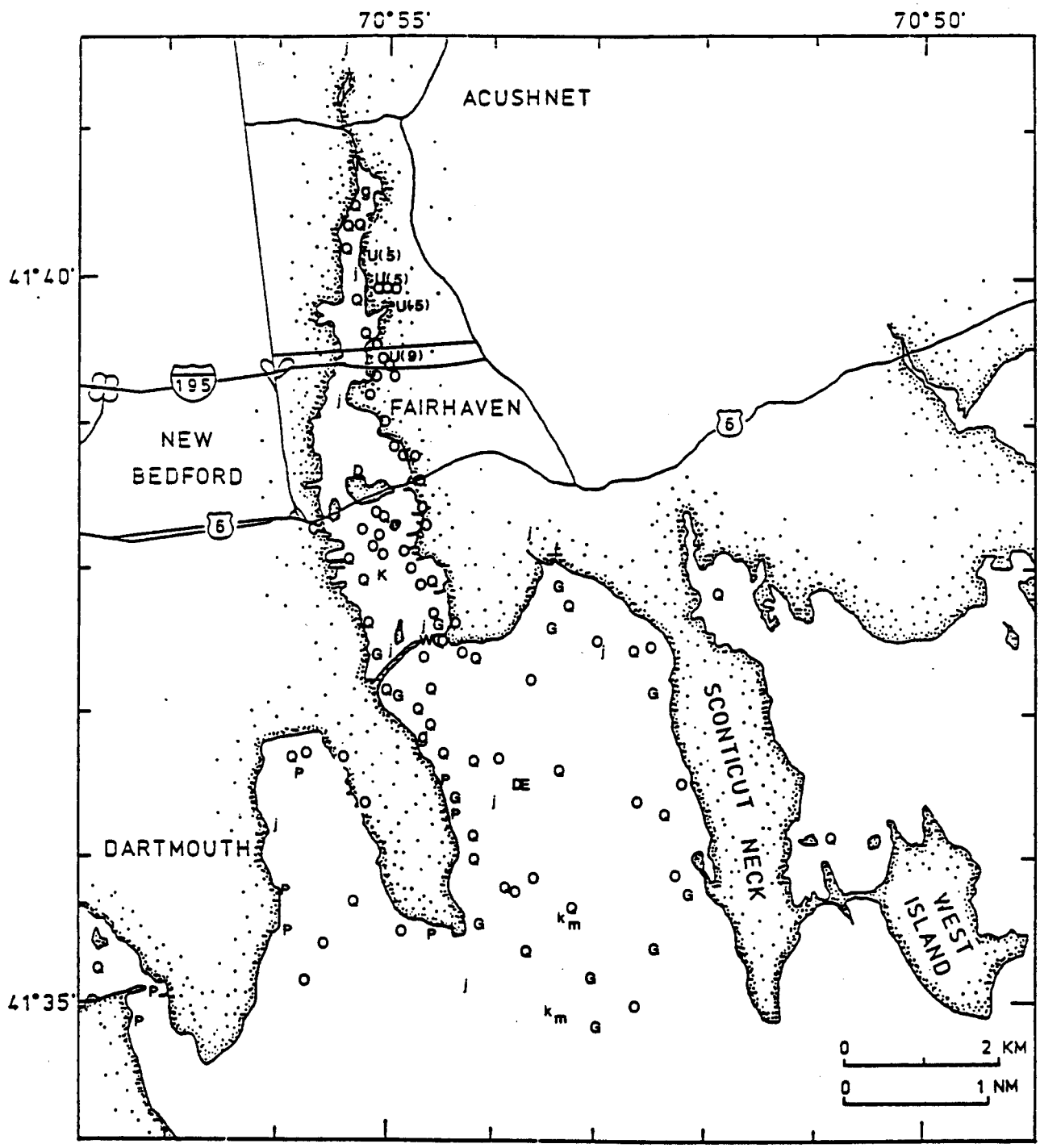

FIGURE 8. SPATIAL COVERAGE OF PCB LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 15. SITES FOR REFERENCE G ALSO REPRESENT REFERENCE H. NUMBERS IN PARENTHESES INDICATE NUMBER OF STATIONS AT OR NEAR REFERENCE U STUDY SITES.

TABLE 19. TEMPORAL COVERAGE OF PCB LITERATURE.

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				No Info.
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	
Krebs et al., 1974	1970	x	x	x		
Nisbit & Reynolds, 1984	1971-1981	x	x			
USACOE, II&III, 1980	1971-1981					x
Gilbert et al., 1973	1973	x				
Tomczyk, 1981	1973-1980					x
Farrington et al., 1982	1976-1978					x
Kolek & Ceurvels, 1981	1976-1980	x	x	x	x	
Stratton et al., 1978	1977		x			
Carey & Harvey, 1978	1978					x
Deubert et al., 1980	1978	x	x	x	x	
Hatch et al., 1981	1978	x				
Deubert et al., 1981	1978-1979	x	x	x	x	
Malcolm Pirnie, 1982	1978-1982	x	x	x		
CDM, 1979	1979					x

TABLE 19. TEMPORAL COVERAGE OF PCB LITERATURE (Continued)

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	No Info.
Gidley Labs, 1980	1979-1980	x				
EG&G, 1981	1979-1981		x	x	x	
Remillard, 1980	1980					x
MA DEQE, 1980	1980			x		
NEMP, 1981 & 1983	1980-1981					x
Versar Inc., 1981a	1981		x			
Versar Inc., 1981b	1981		x			
Boehm, 1983a	1981-1982		x	x	x	
ERCO, 1983	1981-1982		x	x	x	
Steimle et al., 1986	1981-1982		x			
Brownawell & Farrington, 1985	1981-1983			x		
Boehm, 1983b	1982					x
Boehm, 1983c	1982					x
Hall et al., 1983	1982		x			
Metcalf & Eddy, 1982	1982					x
Metcalf & Eddy, 1983	1982		x			

TABLE 19. TEMPORAL COVERAGE OF PCB LITERATURE (Continued)

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	No Info.
Weaver, 1982	1982					x
Farrington et al., 1983	1982-1983	x		x	x	
Brownawall & Farrington, 1986	1983			x		
Metcalf & Eddy, 1983	1983					x
Myatt et al., 1983	1983		x			
Weston, Roy F., 1983	1983					x
CDM, 1983	1983					x
Stegeman et al., in press	1984					x
Weaver, 1984	1984					x

(1982) and Metcalf and Eddy (1982, 1983) assembled and reviewed in detail existing data relative to the PCB contamination of the Acushnet River estuary. Tomczyk (1981) briefly summarized PCB studies conducted in the Acushnet River, New Bedford Harbor area. Myatt et al. (1983) and Hall et al. (1983) sampled bottom sediments from 66 stations for PCBs in the Acushnet River Estuary, inner and outer New Bedford Harbor, Clarks Cove, and other regions of Buzzards Bay. Stratton et al. (1978) and others have measured PCB levels at the New Bedford Municipal Landfill and surrounding rivers, such as the Paskamanset. Researchers have investigated PCB contamination in areas outside of New Bedford Harbor. Hatch et al. (1981) collected clams and oysters from New Bedford Harbor, including stations on the western shore of Buzzards Bay around the Slocums and Westport Rivers. Boehm (1983c) sampled sediments and benthic animals from several sites throughout Buzzards Bay out to Coxens Ledge. Of greatest interest in this study was examination of the possibility of PCB impact further offshore in Buzzards Bay that is related to the New Bedford problem. Gilbert et al. (1973) presents the most comprehensive sampling coverage for PCBs for the center Buzzards Bay. Very little sampling has occurred in the northern end of and near the entrance of the Buzzards Bay.

The literature on PCBs in Buzzards Bay sediments and organisms spans the years 1970 through 1984 (Table 19), with most studies being conducted after discovery of the PCB problem in 1976. Data were collected primarily during the summer and fall as a part of studies that lasted for at most one year and often less than a year. Data for a variety of finfish and shellfish were collected by the DMF from 1976 to 1980 and were summarized by Kolek and Ceurvels (1981). The Northeast Monitoring Program of NOAA (NOAA 1981, 1983) includes only one station in Buzzards Bay, but is useful for comparison of PCBs in Buzzards Bay with other coastal areas throughout time. Nisbit and Reynolds (1984) also discuss temporal trends in PCB contamination in organisms collected on the north shore of Buzzards Bay.

Total PCBs, Aroclors, and individual isomers were examined in the study of PCBs. Little work was done with individual isomers in Buzzards Bay. The reason for differences in PCBs studied relates primarily to evolution in the analytical methods used to study PCBs and in the method of choice of

individual laboratories conducting the studies. Because different mixtures of PCBs were studied using different methods (Tables 16, 17), comparisons among data are not always straightforward. Therefore, any characterization of PCBs in Buzzards Bay must be conducted by specialists capable of determining validity of data and comparability among data types.

Because PCBs may be transported out of New Bedford Harbor, the sediments and organisms of the entire Bay should continue to be monitored for PCB pollution and particular attention paid to long-term trends in the Bay. Future studies should have the following characteristics: methods standardized and well documented, station locations recorded exactly, sample collections uniform and precise, laboratory analyses performed with state-of-the-art methods and appropriate quality control and quality assurance, and records kept that are trackable over time.

Spatial coverage of PCB analyses should be increased to cover larger portions of the Harbor and Bay. Potential depositional sites outside of the Harbor should be examined. Such analyses should be conducted where methods and data are comparable. Temporal coverage of New Bedford Harbor should continue but should include parts of the Bay as well.

Field studies of the biological effects of PCBs on marine vertebrate and invertebrate populations have been limited in number as well as in spatial and temporal coverage. Recommendations for further work include better definition of seasonal effects of PCBs on marine organisms, examination of the effect of PCBs on growth and reproduction in the field, increase in number of species studied, and repetition of studies on species to add temporal information.

1.3.2 Hydrocarbons

Petroleum hydrocarbon toxicity became apparent after large oil spills (e.g., the Torrey Canyon tanker, oil well blowouts in Santa Barbara, oil well fires in the Gulf of Mexico) that had great impact on biological communities and commercially important fish and shellfish. Polynuclear aromatic

hydrocarbons (PAH) are of special interest because of their resistance to biodegradation or physical and chemical weathering (Blumer et al., 1971; Burns and Teal, 1971, 1979; Teal et al., 1978; Farrington, 1979).

Buzzards Bay has a history of oil spills. During one winter in the late 1940s, a spill of #2 fuel oil on horseneck beach on the west side of the bay (baxter et al., 1978) inundated a 3-mile strip along horseneck beach and westport. Apparently, many surf clams died as a results of the spill, and windrows of clams were washed up on the beach. No research was conducted to determine the effects of the spill; consequently, no literature was generated from this spill. In the winter of 1963, an undetermined amount of #2 fuel oil was spilled off Cleveland's Ledge, inundating Nye's Neck, Falmouth, on the east side of the Bay (Baxter et al., 1978). In this case, heavy densities of gulls were noted feeding in the oiled area, suggesting mortality of marine organisms. Neither study of the effects nor literature were produced. A major spill occurred on September 16, 1969 when the oil barge Florida came ashore off Fassetts Point, West Falmouth and spilled between 650,000 and 700,000 liters of #2 fuel oil along the shores of West and North Falmouth, Massachusetts (Hampson and Sanders, 1969; Blumer et al., 1970c). A fourth spill occurred on October 9, 1974, when the oil barge Bouchard 65 was damaged by an unknown submerged object at the west entrance of Buzzards Bay (Hampson and Moul, 1977). In an attempt to off-load the cargo, the barge was towed to an anchorage area west of Scraggy Neck. Containment of the oil was prevented by rough seas and an oil slick came ashore at Bassett's Island, Red Brook Harbor, and Winsor Cove (Hampson and Moul, 1978). A fifth spill occurred on January 28, 1977, when the Bouchard 65 again ran aground and spilled 307,000 liters of #2 fuel oil onto the ice covered Bay (Baxter et al., 1978). Swift currents carried the oil under the ice and through crack systems where it collected in rafted ice, rubble fields, and pressure ridges and was contained. The ice broke up after eight days and the oil was released and transported in the form of sheens and floes as far as Cape Cod Bay. A sixth spill occurred in 1978 in the western end of the Cape Cod Canal (Farrington et al., 1982a). This small spill resulted from the grounding of a barge carrying #2 fuel oil, spilling an estimated 6000 liters of oil. The resulting slick contacted the the shore at "Mussel Watch" stations (Farrington et al., 1982a) before tidal flushing removed traces of the oil.

Investigations on the short- and long-term effects of these spills were conducted, primarily by scientists from nearby Woods Hole Oceanographic Institution. Very little is known about other sources of hydrocarbons in Buzzards Bay and very little of the literature deals with historical characterization of hydrocarbons in the Bay.

1.3.2.1 Description of the Available Literature

Thirty-eight studies related to hydrocarbons in Buzzards Bay were reviewed (Tables 14, 20). Most of these are related to the 1969 and 1977 oil spills. Three presented data from the 1974 spill (Hampson and Moul, 1977, 1978; Farrington, 1979). The 1969 oil spill provided a unique opportunity for scientists to begin sampling immediately after the spill. This study advanced development of analytical methods for analysis of hydrocarbons, understanding of the fate of hydrocarbons in the marine coastal zone, and knowldge of the effects of hydrocarbons on marine organisms. The oil spill in January 1977 was of special interest because the winter was severe, the circumstances of the spill were comparable to Arctic conditions, and new data were generated regarding ice/oil interactions.

The fraction(s) of hydrocarbons investigated varied considerably from study to study (Table 21). Methods for examination of hydrocarbons are identified in Table 22. Many studies did not provide information on analytical techniques, either because they were summaries or reviews or because they pertained to biological effects of the hydrocarbons. The wide variety of organisms investigated (Table 23) included both plants and animals. Biological studies varied in their objectives, covering such diverse topics as population dynamics over time, benthic community response and recovery, genetics of differentially responding populations, and body burdens for hydrocarbons.

TABLE 20. HYDROCARBON LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 21, 22, AND 23 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Baxter et al., 1978
B	Blumer et al., 1977
C	Blumer et al., 1971
D	Blumer & Sass, 1972a
E	Blumer & Sass, 1972b
F	Blumer & Sass, 1972c
G	Blumer et al., 1970c
H	Blumer et al., 1970a,b
I	Blumer & Youngblood, 1975
J	Brown & Lynch, 1978
K	Burns, 1975
L	Burns, 1976
M	Krebs & Burns, 1977
N	Burns & Teal, 1979
O	Burns & Teal, 1971
P	Gilbert et al., 1973
Q	Cole, 1978
R	Ecosystems Center, 1980
S	Farrington, 1979
T	Farrington, 1982a,b
U	Farrington et al., 1977
V	Giger & Blumer, 1974
W	Grassle & Grassle, 1974
X	Hampson & Moul, 1977
Y	Hampson & Moul, 1978
Z	Hampson & Sanders, 1969
a	Hites et al., 1977
b	Krebs & Burns, 1978
c	Michael et al., 1975
d	Ruby et al., 1977
e	Sanders, 1978
f	Sanders et al., 1972
g	Sanders et al., 1980
h	Schrier, 1978
i	Teal et al., 1978
j	Tripp et al., 1981
k	Welsh et al, 1977
l	Youngblood & Blumer, 1975

TABLE 21. HYDROCARBONS EXAMINED IN ORGANISMS AND SEDIMENTS.

	REFERENCE																																						
PARAMETER	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k	l
Total hydrocarbons	A			D	E	F	G	H		J	K	L	M	N	O			R			U							b	c										
Saturated hydrocarbons	A			D	E	F	G	H			K			N	O					T	U								c										
Aromatic hydrocarbons	A				E	F		H	I		K	L		N					S	T	U	V					a	b							i	j		l
Polar hydrocarbons																				T																			
Unresolved complex mixture																			S	T	U																		
Individual hydrocarbons		B			E	F					K									T		V													i	j			
Oil and Grease																P																							
Not applicable or summary			C														Q						W	X	Y	Z				d	e	f	g	h			k		

TABLE 22. METHODS USED TO MEASURE HYDROCARBONS.

METHOD	REFERENCE																																			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k	l
TISSUES																																						
Reference not applicable		B		D	E	F			I	J						P	Q	R	S		U	V	W	X	Y		a	b	c	d	e	f	g		i	j	k	l
Summary																										Z												
Review			C																																			
Sample Preparation			NR																																			
Pre-extraction preparation	NR		NR				NR	NR			NR	NR	NR	NR	NR																			NR				
Freeze-dry																																						
Oven-dry																																						
Extraction procedure	NR		NR													NR				NR														h[7]				
Soxhlet							G	H			K	L	M	N	O																							
Solvent							G[1]	H[1]			K[1]	L[1]		N[1]	O[1]																							
Ambient shaker							G	H																														
Solvent							G[2]	H[2]																															
Clean-up procedure			NR																																			
Gel permeation chromatography																																						
Adsorption chromatography	A													N		P				T																		
Silica/silicic acid																																						
Alumina																																						
Florisil																																		h				
Silica/alumina							G	H			K	L	M			P				T																		
Thin layer chromatography																																						
Sulfur removal	NR		NR																																			
Activated copper																																						
TBA/sulfite																																						
Sample Analysis																																						
No data reported (not always noted)			C																																			
Analysis type not reported			C																																			
Gravimetric	A						G	H			K	L	M	N	O					T															h				
Fluorescence	A																																					
Fluorescence spectrophotometry	A																																					
Infrared spectrophotometer																																						
Gas-Liquid chromatography	A						G	H												T																		
Packed column							G	H																														
Flame ionization detector							G	H			K	L	M			P				T															h				
Gas chromatography/mass spectrometry	A										K			N						T														h				

NR=Not Reported, 1=methanol solvent, 2=pentane solvent, 3=redistilled petroleum ether solvent, 4=toluene solvent, 5=water:hexane solvent, 6=benzene solvent, 7=digestion in KOH methanol:water, 8=sediment digestion with methanol/toluene azeotrope and KOH, *=not conducted, **=conducted.

TABLE 22. METHODS USED TO MEASURE HYDROCARBONS (Continued).

METHOD	REFERENCE																																				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k	l
SEDIMENTS																																						
Reference not applicable												L					Q			T		W	X				b			e	f	g				k	
Summary																P			S						Y	Z				d							
Review			C	D	E											P																						
Sample Preparation				NR	NR											NR							X	Y	Z													
Pre-extraction preparation	NR	NR		NR	NR	NR	NR	NR	NR	NR	NR		NR			NR		NR			NR																
Freeze-dry																																						
Oven-dry																																						
None																																						
Extraction procedure	NR	NR		NR	NR	NR	NR	NR	NR	NR						NR																					
Soxhlet											K		M	N	O						U	V					a[1;1&6]						h[8]	i		1
Solvent (soxhlet)											K[1]		M[1]	N[1]	O[1]							V[1,6]					a							i[1,1:6]		1
Ambient shaker																		R										c									
Solvent (shaker)																		R[5]										c[3]									
Clean-up procedure				NR	NR	NR	NR	NR		NR						NR																					
Gel permeation chromatography		B							I													V															
(Picric-acid adduction)		B																																			
Adsorption chromatography	A	B				F	G	H	I		K		M	N	O																						
Silica/silicic acid																											a		c								1
Alumina									I													V															
Florisil																																						
Silica/alumina						F	G	H			K		M		O						U												h	i			
Thin layer chromatography																					U																
Sulfur removal	NR	B*		NR	NR	NR			NR	NR	K**		M**		N**	O**					NR								c**				h**	i**			
Activated copper							G	H			K		M	N	O							V							c				h	i			
TBA/sulfite																																						
Sample Analysis				NR												NR									NR	NR											
No data reported (not always noted)									I							P																					
Analysis type not reported				D												P																					
Gravimetric	A	B			E	F	G	H			K		M					R				V							c						j		
Fluorescence																																		h	i			
Fluorescence spectrophotometry	A																	R				V															1
Infrared spectrophotometer										J																												
Gas-Liquid chromatography	A					F	G	H										NR																				
Packed column						F	G	H																														
Flame ionization detection						F	G	H		J	K		M		O						U								c				h	i			
Gas chromatography/mass spectrometry	A	B			E				I					N					S		U	V					a						h	i			1

TABLE 23. SPECIES EXAMINED IN HYDROCARBON LITERATURE.

SPECIES	REFERENCE
	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z a b c d e f g h i j k l
Aequipecten irradians (bay scallop)	A G H
Anguilla rostrata (eel)	K N O
Ascophyllum nodosum (knotted wrack)	X Y
Bacteria	R
Crassostrea virginica (oyster)	A C G H
Distichlis spicata (spike grass)	X Y
Enteromorpha clathrata (green algae)	K N O X Y
Fucus vesiculosus (brown algae)	X Y
Fundulus spp. (killifish)	K N O
Geukensia demissa (mussel)	K N O
Homarus americanus lobster	h
Larus argentatus (herring gull)	K N O
Limonium carolinianum (sea lavender)	X Y
Mercenaria mercenaria (common quahog)	A G h
Mya arenaria (soft clam)	A G h
Mytilus edulis (mussel)	A C O T h

TABLE 23. SPECIES EXAMINED IN HYDROCARBON LITERATURE (Continued).

SPECIES	REFERENCE
Polysiphonia fibrillosa (red algae)	K N O
Salicornia spp. (glasswort)	K N O X Y
Spartina alterniflora (saltmarsh cord grass)	K O X Y
Spartina patens (salt-meadow grass)	N O
Sueada linearis (sea-blite)	X Y
Uca pugnax (fiddler crab)	K L M N b
Ulva lactuca (green algae)	X Y
Urosalpinx cinerea (oyster drill)	Q
Benthic invertebrates	C R W X Y Z c e f g h
Sediment	A B C D E F I J K N O P S U V a i j l
Water/ice	A J c d k
Air	J

1.3.2.2 Summary and Data Gaps

The work conducted on the 1969 oil spill is of note because it provided some of the first quantitative, objective research on the fate and effects of hydrocarbons from oil spills (Hampson and Sanders, 1969; Blumer et al., 1970a, b, c; Blumer et al., 1971; Burns and Teal, 1971, 1979; Blumer and Sass, 1972a, b; Sanders et al., 1972, 1980; Grassle and Grassle, 1974; Burns, 1975, 1976; Michael et al., 1975; Krebs and Burns, 1977, 1978; Cole, 1978; Sanders, 1978; Teal et al., 1978). The team of scientists developed a strong sampling design that combined sensitive analytical methods with detailed survey of the smaller, more susceptible components of the intertidal and benthic fauna (Blumer and Sass, 1972c). Chemical analyses of sediments demonstrated that persistence of hydrocarbons in sediments continued for longer than previously thought (Blumer and Sass, 1972b, c; Teal et al., 1978). Similarly, retention of hydrocarbons in organisms continued for long periods of time (Blumer et al., 1970b, c; Burns, 1975; Krebs and Burns, 1977, 1978). Benthic communities recovered slowly and eventually became similar to control sites (Sanders et al., 1972; Michael et al., 1975; Sanders, 1978; Sanders et al., 1980).

A major contribution of the 1977 Bouchard #65 oil spill was the development of new techniques for analyzing oil spills in conditions of heavy ice cover (Ruby et al., 1977; Welsh et al., 1977; Baxter et al., 1978; Schrier, 1978). The Ecosystems Center (1980) demonstrated that there were few impacts on the benthic community due to the 1977 oil spill. It was shown that contaminated ice can be transported long distances and contaminate new areas (Ruby et al., 1977; Baxter et al., 1978). Nearshore wave- and wind-driven surface currents were low preventing the local breakdown of oil (Ruby et al., 1977).

Other studies examined distribution of hydrocarbons with depth from sediment cores collected both in oil-impacted areas and unimpacted areas around the Bay. These studies determined that urban air hydrocarbons are the major sources of hydrocarbons to the Bay (Giger and Blumer, 1974; Blumer and Youngblood, 1975; Farrington et al., 1977; Farrington, 1979). Tripp et al. (1981) indicated that coal may be an important source of hydrocarbons to

Buzzards Bay sediments. Blumer et al. (1977) demonstrated through development of analyses of azaarenes (nitrogen-containing aromatic compounds) that prior to the use of fossil fuels the major source of hydrocarbons was pyrolysis from forest fires. Gilbert et al. (1973) collected data for the middle of the Bay; unfortunately, this information was restricted to oil and grease measurements and is not comparable to much other work conducted for the Bay.

Because the three oil spills occurred primarily along the shipping lanes in Buzzards Bay, spatial coverage of hydrocarbon data is primarily along the eastern side of the Bay (Figures 9, 10). Blumer et al. (1970a, b, c), Blumer and Sass (1972c), Giger and Blumer (1974) and Teal et al. (1978) analyzed hydrocarbons in the sediments in intertidal and subtidal stations after the 1969 oil spill. Their coverage was restricted to the area around Wild Harbor south to Sippewissett Marsh. Biological studies in the same area were conducted by Burns and Teal (1971), Sanders et al. (1972, 1980), Grassle and Grassle (1974), Burns (1975, 1976), Michael et al. (1975), Krebs and Burns (1977, 1978), Sanders (1978), and Burns and Teal (1979). The northeastern part of Buzzards Bay was studied in response to the 1977 Bouchard #65 oil spill (Ruby et al., 1977; Welsh et al., 1977; Baxter et al., 1978; Schrier, 1978; Ecosystems Center, 1980). Hampson and Moul (1977, 1978) and Farrington (1979) studied the Winsor Cove area in response to the 1974 Bouchard #65 oil spill. Farrington et al. (1982a, b) chemical analyzed of #2 fuel oil in Mytilus edulis collected from a "Mussel Watch" station in the Cape Cod Canal that was impacted by a small oil spill. The only coverage in the middle of the Bay was provided by Gilbert et al. (1973), who studied regarding potential dredge disposal sites in the Bay and analyzed sediments for a variety of factors including oil and grease.

Publications on hydrocarbons in Buzzards Bay did not appear until after the 1969 oil spill, regardless of content (Tables 20, 24). Three studies involved analysis of sediment cores with depth to determine historical records of hydrocarbons in Buzzards Bay (Blumer and Youngblood, 1975; Farrington et al., 1977; Hites et al., 1977; Farrington, 1979). The majority of papers were related to the 1969 and 1977 oil spills and spanned the period of 1969 through 1978 (Table 24).

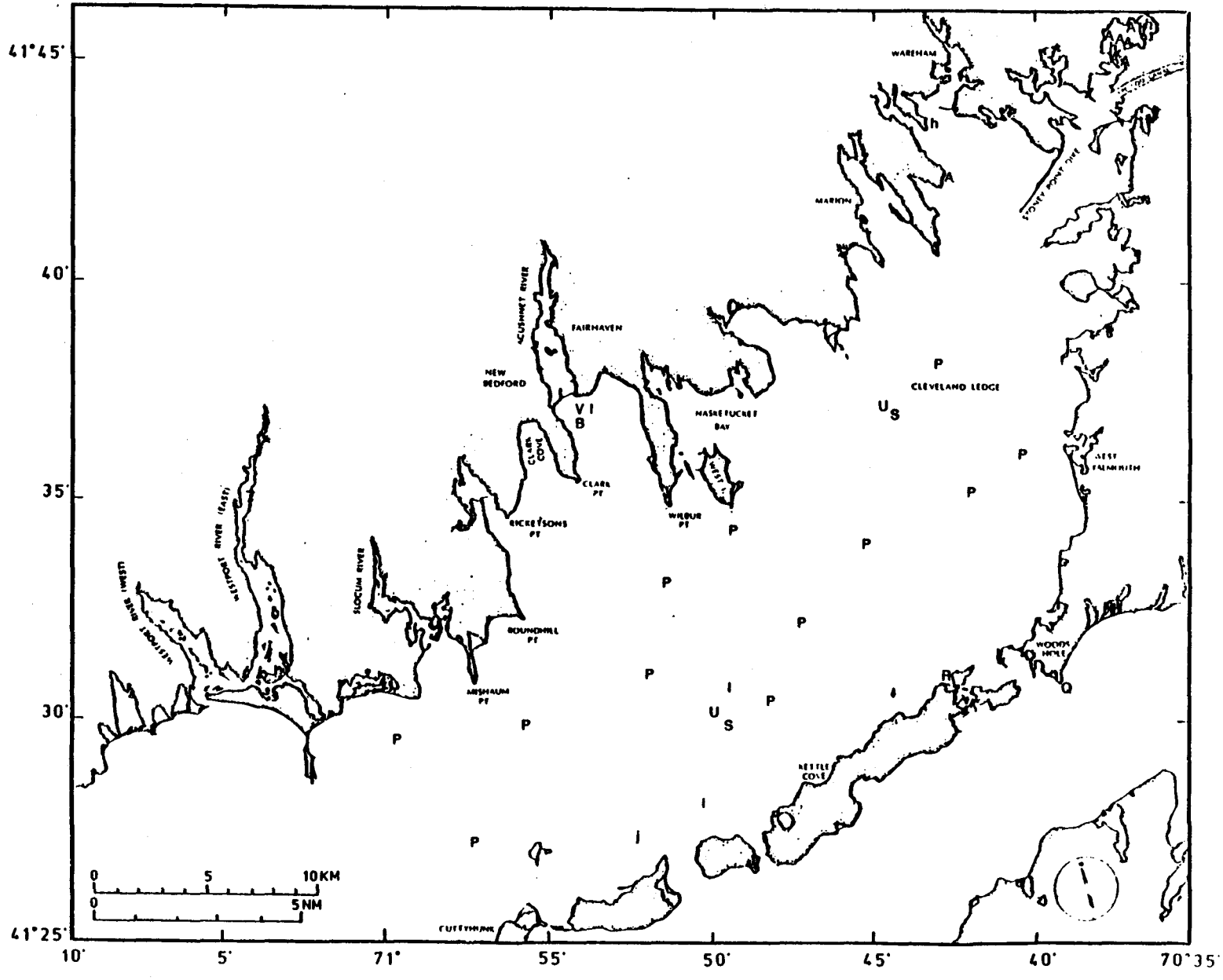

FIGURE 9. SPATIAL COVERAGE OF HYDROCARBON LITERATURE IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 20.

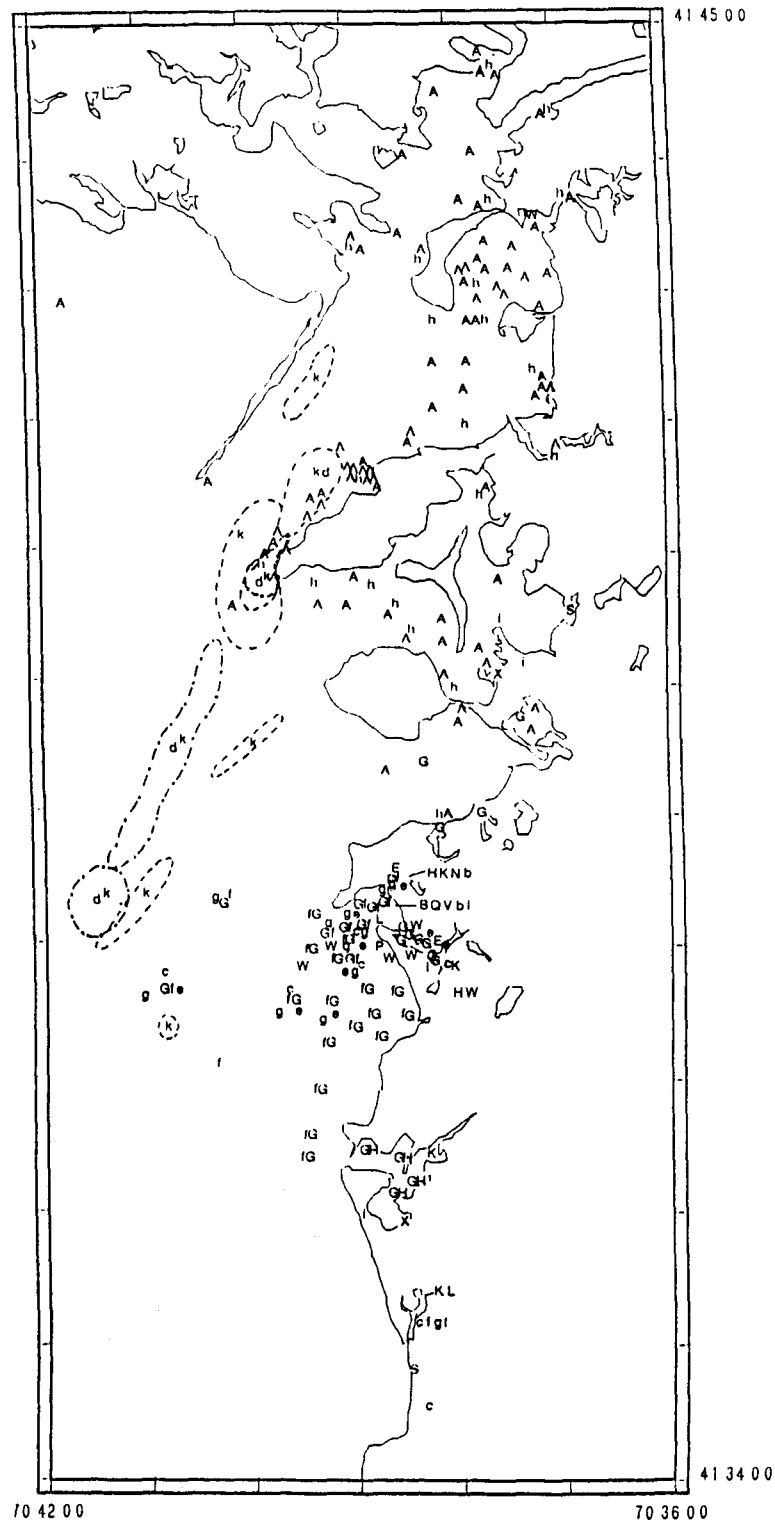

FIGURE 10. SPATIAL COVERAGE OF HYDROCARBON LITERATURE IN EASTERN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCE IN TABLE 20. LOCATIONS INDICATING REFERENCE A ALSO REPRESENT REFERENCES R AND d; THAT INDICATED REFERENCE N ALSO INDICATES REFERENCE O; THAT INDICATING REFERENCE G ALSO INDICATES REFERENCE F. DOTTED LINES ENCOMPASS AREA STUDIED FOR REFERENCE INDICATED.

TABLE 24. TEMPORAL COVERAGE OF HYDROCARBON LITERATURE.

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				No Info.
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	
Farrington, 1979	1780-1978	x		x	x	
Farrington et al., 1977	1780-1940					
Hites et al., 1977	1850-1970					
Blumer et al., 1971	1969-1970	x	x	x	x	
Blumer & Sass, 1972b	1969-1971	x	x	x	x	
Blumer & Sass, 1972c	1969-1971	x	x	x	x	
Blumer et al., 1970c	1969-1970	x		x	x	
Blumer et al., 1970a,b	1969			x		
Burns, 1975	1969-1974	x	x	x	x	
Hampson & Sanders, 1969	1969			x		
Sanders, 1978	1969-1973	x	x	x	x	
Burns & Teal, 1971	1969-1971	x	x	x	x	
Sanders et al., 1972	1969-1971	x	x	x	x	

TABLE 24. TEMPORAL COVERAGE OF HYDROCARBON LITERATURE (Continued).

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info.
Sanders et al., 1980	1969-1973	x	x	x	x	
Grassle & Grassle, 1974	1969-1972	x	x	x	x	
Krebs & Burns, 1978	1969-1978	x	x	x	x	
Burns & Teal, 1979	1970-1976	x	x	x	x	
Burns, 1976	1970-1973	x	x			
Teal et al., 1978	1970-1977	x	x	x	x	
Blumer amd Sass, 1972a	1971					x
Krebs & Burns, 1977	1972-1976	x	x	x	x	
Cole, 1978	1973-1975	x	x	x	x	
Michael et al., 1975	1973-1974	x	x	x	x	
Giger & Blumer, 1974	1973		x			
Gilbert et al., 1973	1973	x				
Youngblood & Blumer, 1975	1973-1974	x	x		x	

TABLE 24. TEMPORAL COVERAGE OF HYDROCARBON LITERATURE (Continued).

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	No Info.
Hampson & Moul, 1978	1974-1977	x	x	x	x	
Hampson & Moul, 1977	1975-1977	x	x	x	x	
Brown & Lynch, 1978	1977				x	
Ecosystems Center, 1980	1977	x	x	x		
Ruby et al., 1977	1977	x	x		x	
Schrier, 1978	1977	x	x		x	
Baxter et al., 1978	1977	x			x	
Farrington et al., 1982a,b	1977-1978	x	x	x	x	
Blumer et al., 1977	1973		x			
Welsh et al., 1977	1977				x	
Blumer & Youngblood, 1975						x
Tripp et al., 1981						x

A variety of organisms were studied during the oil spill programs (Table 23). Major emphasis was on animals, while fewer studies focused on plants. Marsh grasses and algae were studied in terms of changes in their distribution and uptake of hydrocarbons (Burns and Teal 1971, 1979; Burns, 1975; Hampson and Moul, 1977, 1978). Shellfish species received the greatest attention, primarily in terms of their uptake of oil and their survival (Blumer et al., 1970b, c; Blumer et al., 1971; Burns and Teal, 1971, 1979; Burns 1975; Baxter et al., 1978; Schrier, 1978). Burns (1975, 1976) and Krebs and Burns (1977, 1978) demonstrated the long-term effects of hydrocarbons on populations of the salt-marsh crab, Uca pugnax. Sediment oil content correlated with reduced crab density, reduced ratio of females to males, reduced juvenile settlement, heavy overwinter mortality, incorporation of oil into body tissues, and behavioral disorders (e.g., locomotor impairment and abnormal burrow construction). Few fish or crustacean species were studied (Table 23).

Given the continued input of hydrocarbons into the Buzzards Bay estuary via such sources as atmospheric inputs and sewage discharges (e.g., New Bedford Harbor), a broader look at hydrocarbons remains to be conducted. Point sources other than oil spills have not been analyzed. Areas other than the eastern shore of Buzzards Bay are notably lacking in data for hydrocarbons. Temporal coverage is restricted almost entirely to the decade following the 1969 oil spill. Sediments were used as indicators of major hydrocarbon inputs for the estuary (Giger and Blumer, 1974; Blumer and Youngblood, 1975; Hites et al., 1977; Farrington, 1979), but these studies were restricted to just a few locations. Still poorly understood is the main axis of the Bay, especially in terms of major depositional sites, resuspension of contaminated sediments, remobilization of hydrocarbons, etc. Sources of hydrocarbons to the estuaries must be identified to understand the relative importance of each of these sources. Little is known about nonpoint sources of hydrocarbons such as runoff and groundwater transport. Of particular note is the improvement of hydrocarbon analytical methods over the years. More detailed analysis of saturated and aromatic hydrocarbons should be conducted on areas other than the eastern shore of the Bay.

1.3.3 Pesticides

Pesticides have been widely used in Massachusetts for insect control, shade tree spraying, home and garden pest control, mosquito control, orchard spraying, cranberry bog pest control, and many other minor uses. Prior to about 1963, certain pesticides (e.g., DDT) were used heavily in areas such as Buzzards Bay (Nisbit and Reynolds, 1984). Although pesticide use has declined, sediments and organisms are still tested for pesticide accumulation. Organochlorine pesticides are known to accumulate in tissues and consequently are good indicators of pesticide persistence in the environment.

1.3.3.1 Description of Available Literature

Eight studies reporting pesticide levels in organisms and sediments collected from Buzzards Bay were reviewed (Tables 14, 25). In these studies, 15 pesticides, most of which are organochlorine compounds, were investigated (Table 26). Pesticide residues from sediment and tissue samples were identified and quantified using a variety of methods (Table 27). Two studies were field studies not involving laboratory analyses for pesticides. Organisms analyzed for characterization of pesticide contamination are presented in Table 28. Muscle tissue, edible tissue, and sometimes entire organisms were homogenized for evaluation of pesticide concentrations (Nisbit and Reynolds, 1984; Smith and Cole, 1970). Krebs et al. (1974) studied the effects of pesticides on the fiddler crab (Uca pugnax).

1.3.3.2 Summary and Data Gaps

DDT and its metabolites, such as DDE, were the most commonly investigated pesticides in the Buzzards Bay literature reviewed (Table 26). Aldrin and dieldrin were the second most commonly studied pesticides because they were components of a sewage-sludge derived fertilizer used in experimental treatment studies conducted in Great Sippewissett Marsh in Falmouth (Krebs et al., 1974; Krebs and Valiela, 1978). Most pesticides,

TABLE 25. PESTICIDE LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 26, 27, AND 28 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Camp Dresser & McKee Inc., 1979
B	Nisbit & Reynolds, 1984
C	Smith & Cole, 1970
D	USACOE, Vols II & III, 1980
E	Krebs & Valiela, 1977
F	Krebs et al., 1974
G	Spitzer & Poole, 1980
H	Farrington et al., 1982

TABLE 26. PESTICIDES EXAMINED IN SEDIMENTS AND ORGANISMS.

	REFERENCES							
PARAMETERS	A	B	C	D	E	F	G	H
Aldrin	A				E	F		
Chlordane	A							
DDE	A		C			F		H
DDT	A	B	C	D		F	G	
Demeton	A							
Dieldrin	A	B	C		E	F		
Endrin	A							
Guthion	A							
Heptachlor	A		C					
Heptachlor epoxide	A	B	C					
Hexachlorobenzenze	A							
Malathion	A							
Mirex	A							
Parathion	A							
TDE (DDD)		B				F		

DDE = a degradation product of DDT.
TDE (DDD) = a degradation product of DDT.

TABLE 27. METHODS USED TO MEASURE PESTICIDES IN SEDIMENTS AND ORGANISMS.

	REFERENCES							
METHODS	A	B	C	D	E	F	G	H
TISSUES								
Reference not applicable	A			D	E		G	
Sample Preparation								
Pre-extraction			C*			F*		H**
Oven-dry		B						
Freeze-dry								H
Extraction procedure			C[1]					
Soxhlet		B[2,3]				F[4]		H
Ambient shaker		B[3,5]	C					
								H
Digestion								H
Homogenization						F[5]		H
Clean-up procedure								
Adsorption chromatography		B	C			F		H
Florisil		B	C			F		H
Silica/alumina								H
Alumina		B						
Sample Analysis								
Gravimetric						F		
Gas-liquid chromatography		B	C			F		H
Packed column								H
Electron capture detector		B	C			F		H
Gas chromatography/mass spectrometry		B						H
SEDIMENTS								
No methods	A[6]							
Reference not applicable		B			E		G	H
Sample Preparation								
Pre-extraction				D*		F*		
Extraction procedure				D*				
Soxhlet						F[4]		
Homogenization						F[5]		
Clean-up procedure								
Adsorption chromatography						F		
Florisil						F		
Sample Analysis								
Gravimetric						F		
Gas-liquid chromatography				D		F		
Electron capture detector						F		

1 = acetonitrile:ether, 2 = diethyl ether:hexane, 3 + Methods modified from Reynolds and Cooper (1975), 4 = methanol:hexane, 5 = hexane, 6 = Methods according to "Sampling Analysis for Screening Industrial Effluents for Priority Pollutants," U.S. EPA, 1977 and Appendix A, approved EPA "Analytical Methods for Dredged or Fill Material, U.S. EPA, 1977, * = Not reported, ** = Several laboratories conducting pesticides analyses, with differing methods.

TABLE 28. SPECIES EXAMINED IN PESTICIDE LITERATURE.

SPECIES EXAMINED	REFERENCES							
	A	B	C	D	E	F	G	H
Ammodytes americanus (sand lance)		B						
Clupea harrengus (sea herring)		B						
Menidia menidia (atlantic silverside)		B						
Mytilus edulis (blue mussel)		B						H
Pandion haliaetus (osprey)							G	
Pseudopleuronectes americanus (winter flounder)			C					
Sterna hirudo (common tern)		B						
Uca pugnax (fiddler crab)					E	F		
Shellfish (unspecified)	A							
Sediment Only				D				

however, were reported from a single study only. Camp Dresser and McKee's investigation of New Bedford Harbor (1979) reported data for the greatest number (14 of the 15) of pesticides.

Spatial coverage of pesticide investigations conducted in Buzzards Bay is quite limited (Figures 11 and 12). Sediments and organisms collected from New Bedford Harbor were most frequently analyzed. The Federal Projects of the U.S. Army Corps of Engineers covered a few selected areas throughout the Bay, but included analyses for DDT only. Other studies (Smith and Cole, 1970; Krebs et al., 1974; Krebs and Valiela, 1978) were conducted at a single site. These studies, although limited spatially, provide useful information about existing pesticide levels for that area of the Bay and lend insight into other aspects of pesticide contamination, such as its mobilization and persistence in the environment. The main axis of the Bay is not well covered. Sampling stations were often concentrated in areas of known pollution or where produce such as cranberries and apples are grown commercially and pesticides are used regularly.

Available literature on pesticides in Buzzards Bay spans the years 1966 to 1981 (Table 29). Most work was done in the late 1960s and continued into the 1970s, coinciding with increased public awareness of pesticide pollution. Nisbit and Reynolds (1984) provide the most information on temporal trends in pesticide levels in Buzzards Bay, reporting data during the years 1971 to 1981. However, their sampling was restricted to the summer season only.

The seasonal accumulation patterns of several pesticides in winter flounder (Pseudopleuronectes americanus) found in the Weweantic River Estuary are presented by Smith and Cole (1970). However, that study was limited to a one-year duration. Krebs and Valiela (1978) and Krebs et al. (1974) provide data for pesticide transport in Great Sippewissett Marsh over three seasons of the year.

Since 1971, pesticide levels in Buzzards Bay have decreased with the decline in use of insecticides (Nisbit and Reynolds, 1984). However, pesticides are still being used around the Bay and must still be monitored. Future studies in Buzzards Bay should concentrate on areas of known pesticide

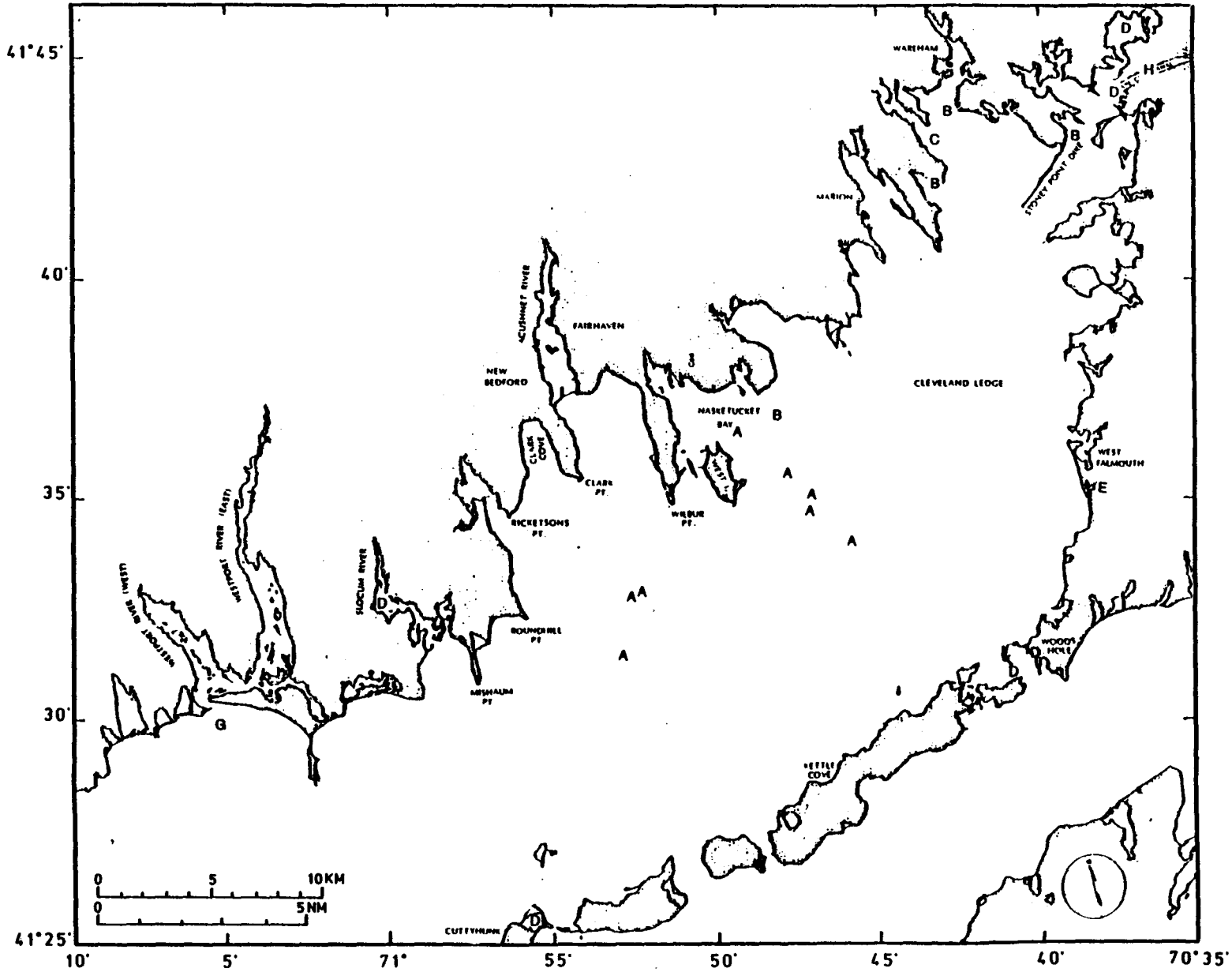

FIGURE 11. SPATIAL COVERAGE OF PESTICIDE LITERATURE REVIEWED IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 25. SITE FOR REFERENCE E ALSO REPRESENTS REFERENCE F. REFERENCE D INDICATES 33 STATIONS IN CUTTYHUNK HARBOR, 4 STATIONS IN WOODS HOLE CHANNEL, 10 STATIONS IN CAPE COD CHANNEL, 11 STATIONS IN BUTTERMILK BAY, AND 11 STATIONS IN SLOCUMS RIVER.

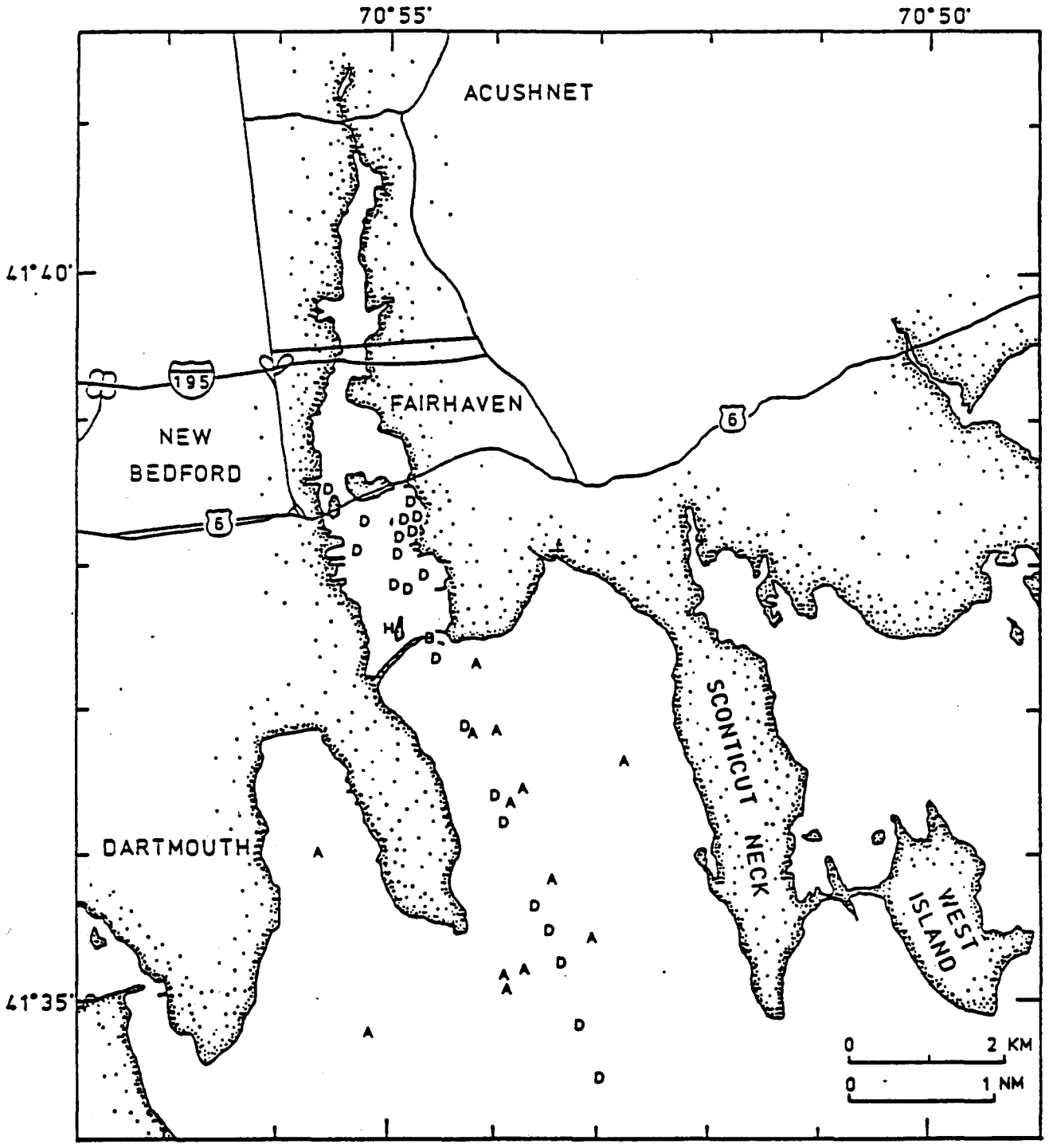

FIGURE 12. SPATIAL COVERAGE OF PESTICIDE LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 25.

TABLE 29. TEMPORAL COVERAGE OF PESTICIDE LITERATURE.

REFERENCE	Years of Data Collection	DATA COLLECTED BY SEASON: Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	No Info.
Smith and Cole, 1970	1966-1967	x	x	x	x	
USACOE, II&III, 1980	1969-1980					x
Spitzer and Poole, 1980	1969-1979					x
Krebs et al., 1974	1970	x	x	x		
Nisbit and Reynolds, 1984	1973 1971-1981		x			
Farrington et al., 1982	1976-1978					x
Krebs and Valiela, 1977	1977	x	x	x		
Camp Dresser and McKee, 1979	1979	x	x			

use. The Massachusetts Department of Environmental Quality Engineering is monitoring pesticide outflow from cranberry bogs draining into Buttermilk Bay. Sampling techniques should focus on nonpoint sources of pesticides in addition to point sources because of the diffuse mechanisms by which pesticides enter the estuary from cranberry bogs. Attention should be paid to seasonal aspects of data collection because pesticides are applied during different seasons. The time of year in which samples are collected is significant in determining the presence or absence and quantity of a particular pesticide or breakdown product. Because maximum exposure may coincide with critical life-history stages, seasonality is also important in the assessment of the effect of pesticides on organisms. Sampling locations should be chosen to best represent the model for discharge of pesticides into the estuary.

1.3.4 Metals

Marine sediments from bays and estuaries near large industrial and urban areas are typically contaminated with heavy metals such as copper, lead, zinc, chromium, and cadmium (Stoffers et al., 1977). New Bedford Harbor has been cited as "the most heavily industrially polluted of all coastal regions in the United States" (Forstner and Wittmann, 1979). Historical records show that the Harbor has been used as a discharge point for metal-rich industrial wastes for about 100 years (Summerhayes et al., 1985). Consequently, metal contamination of the sediments and organisms in New Bedford Harbor has been of major concern to researchers and the public. Investigators have also directed attention toward the spreading of metal contamination throughout Buzzards Bay by sediment transport from New Bedford Harbor.

1.3.4.1 Description of Available Literature

Thirty-five studies investigating metal concentrations in the sediments and organisms of Buzzards Bay were reviewed (Tables 14, 30). Seventeen metals were examined in these studies (Table 31). Methods for examination of metals are identified in Table 32. In many cases, the methods were not

TABLE 30. METAL LITERATURE: KEY TO REFERENCES. ABBREVIATIONS USED IN TABLES 31, 32, AND 33 TO DESIGNATE REFERENCES.

ABBREVIATION	REFERENCE
A	Aubrey, 1979
B	Banus et al., 1974
C	Banus et al., 1975
D	Breteler et al., 1981a
E	Breteler et al., 1981b
F	Camp Dresser & McKee Inc., 1979
G	Camp Dresser & McKee Inc., 1983
H	Clark, 1972
I	Ellis et al., 1977
J	Genest, 1979
K	Genest & Hatch, 1981
L	Giblin, 1982
M	Giblin et al., 1980
N	Giblin et al., 1983a
O	Giblin et al., 1986
P	Giblin et al., 1983b
Q	Gidley Laboratories, 1980
R	Kelley, 1978
S	Malcolm Pirnie, 1982
T	Metcalf & Eddy, Inc., 1983
U	Pruell, 1977
V	Sanders et al., 1981
W	Steimle et al., 1986
X	Stoffers et al., 1977
Y	Summerhayes et al., 1977
Z	Summerhayes et al., 1985
a	Teal et al., 1982
b	Gilbert et al., 1973
c	USACOE, Vols. II & III, 1980
d	Valiela et al., 1975
e	MA DEQE, 1971
f	USACOE. 1982
g	NOAA, 1983
h	NOAA, 1981
i	Moore, 1963
j	MA DEQE, 1975
k	MA DEQE, 1980

TABLE 31. METALS EXAMINED IN SEDIMENTS AND ORGANISMS.

METALS	REFERENCES																																		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k
Antimony (Sb)						F														T																
Arsenic (As)						F											Q			T								b	c		e	f					k
Beryllium (Be)						F																															
Cadmium (Cd)			C			F			I		K	L	M	N	O	P	Q	R		T	U		W	X	Y	Z	a	b	c	d	e	f	g	h			k
Cobalt (Co)																				T															i		
Chromium (Cr)						F	G		I			L	M	N	O	P	Q			T			W	X	Y	Z		b	c		e	f	g	h	i	j	k
Copper (Cu)	A					F	G		I			L	M	N	O	P	Q			T			W	X	Y	Z		b	c		e	f	g	h	i		
Iron (Fe)									I		K	L	M	N		P									Y	Z	a								i	j	
Lead (Pb)		B	C			F	G		I		K	L	M	N		P	Q			T			W	X	Y	Z	a	b	c	d	e	f	g	h	i	j	k
Manganese (Mn)									I			L	M	N		P									Y	Z									i	j	k
Mercury (Hg)				D	E	F		H	I																	Z		b	c		e			h		j	k
Nickel (Ni)						F														T			W					b	c		e	d	g	h	i	j	k
Silver (Ag)						F			I						Q								W		Y	Z							g				
Selenium (Se)																				T																	
Thallium (Tl)						F														T																	
Vanadium (Vc)																												b	c			f			i		
Zinc (Zn)			C			F	G		I		K	L	M	N		P		Q		T			W	X	Y	Z	a	b	c	d	e	f	g	h		j	k

TABLE 32. METHODS USED TO MEASURE METALS.

METHOD	REFERENCE														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
TISSUES															
Partial Metal - HNO_3		B													
Oven dried, wet ash HNO_3, then 30% H_2O_2			C												
H_2SO_4/HNO_3 with heat, $KMnO_6$, NH_2OH				D	E			H*							
Oven dried, ash at 450-500°C, HNO_3, added to ash									I						
Oven dried, cold digest in HNO_3, heat at 40° and 85°C										J	K				
Oven dried 60°C, hot HNO_3, H_2O_2												L	M		
U.S. EPA, 1977						F**									
Method(s) not discussed or literature review	A														
SEDIMENTS															
Total Metal (except mercury)														N	
Partial Metal - Aqua regia						F?	G?		I?			L	M		
Partial Metal - HNO_3		B	C	D	E			H	I?	J	K	L	M		
Weakly Bound Metal (HCl)															O
Weakly Bound Metal (acetic acid)															
Total Mercury				D	E			H							
Method(s) not discussed or literature review	A														

*Methyl mercury, benzene extraction, then NaOH, followed by HCl
**Sampling and analysis procedures for screening fish for priority pollutants
? = Procedures presented in literature not clear.

TABLE 32. METHODS USED TO MEASURE METALS (Continued).

METHOD	REFERENCE																			
	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i
TISSUES																				
Partial Metal - HNO_3																				
Oven dried, wet ash HNO_3, then 30% H_2O_2																				
H_2SO_4/HNO_3 with heat, $KMnO_6$, NH_2OH																				
Oven dried, ash at 450-500°C, HNO_3 added to ash																				
Oven dried, cold digest in HNO_3, heat at 40° and 85°C																				
Oven dried, HNO_3, H_2O_2	P							W												
Oven dried, muffled at 450-500°C			R									a			d					
Concentrated HNO_3 with heat						U														
U.S. EPA, 1977																				
Implimentation Manual for Section 103 of Public Law 92-532														c						
SEDIMENTS																				
Total Metal (except mercury)										Y	Z									
Partial Metal - Aqua regia	P									Y?	Z?	a								
Partial Metal - HNO_3												a			d					
Partial Metal - HNO_3 and H_2SO_4													b							
Weakly Bound Metal (HCl)	P																			
Weakly Bound Metal (acetic acid)																				
Total Mercury																				
EPA Chemistry Laboratory Manual																	f			
Acid digestion (USEPA Methods of Chemical Analysis of Water & Wastes)														c						
Method(s) not discussed or literature review		Q		S	T		V		X							e		g	h	i

reported due to oversight or were not included because the publication was a literature review. In other cases, the methods are not directly comparable due to different techniques used. Metcalf and Eddy, Inc. (1983) and Malcolm Pirnie (1982) reviewed studies with metals data for New Bedford Harbor, but do not include the methods used. Organisms investigated for metal contamination are listed in Table 33. Edible tissue, muscle tissue, and entire organisms were used for metal analyses. Tissues from Mercenaria mercenaria (quahog), Geukensia demissa (mussel), and Spartina alterniflora (salt marsh cordgrass) were studied most frequently.

1.3.4.2 Summary and Data Gaps

In the literature reviewed, cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) were most commonly studied and were usually included in the same studies (Banus et al., 1975; Ellis et al., 1977; Stoffers et al., 1977; Giblin et al., 1980, 1983a, b; Giblin, 1982). These metals were components of a sewage-sludge fertilizer used in experimental treatment studies that investigated metal uptake and mobilization through the sediments and salt marsh grass of Great Sippewissett Marsh in Falmouth (Banus et al., 1974, 1975; Giblin et al., 1980, 1982, 1983a, b; Breteler et al., 1981a, b). Arsenic (As), iron (Fe), mercury (Hg), nickel (Ni), and silver (Ag) were also frequently studied (Clark, 1972; Ellis et al., 1977; Genest and Hatch, 1981; Steimle et al., 1986). Other elements such as antimony (Sb), beryllium (Be), cobalt (Co), selenium (Se), thallium (Tl), and vanadium (V) were included in only two or three reports (Camp Dresser & McKee, 1979, 1983; Metcalf & Eddy, 1983). The literature contains two types of studies. The first type analyzes the distribution and concentration of a single metal in the sediments or the organisms of Buzzards Bay (Banus et al., 1974; Pruell, 1977; Breteler et al. 1981a, b). The second type of study investigates several (4 to 12) metals together. Camp Dresser & McKee (1979), for example, analyzed sediments and shellfish in New Bedford Harbor for twelve metals, and Gilbert et al. (1973) studied ten metals in Buzzards Bay sediments.

Spatial coverage of metals data for Buzzards Bay is presented in Figures 13 to 15. The greatest number of studies have been of the sediments of both

TABLE 33. SPECIES EXAMINED IN METALS LITERATURE.

SPECIES	REFERENCES
Amphiphora paludosa (diatom)	V
Anadara transversa (transverse ark)	I R
Arctica islandica (ocean quahog)	W
Busycon canaliculatum (channeled whelk)	I R
Cancer irroratus (rock crab)	I R
Chaetoceros spp. (diatom)	
Crassostrea virginica (oyster)	E d
Crepidula fornicata (slipper limpet)	I R
Fundulus heteroclitus (killifish)	L M U
Libinia emarginata (spider crab)	I R
Mercenaria mercenaria (common quahog)	E I J K R
Geukensia demissa (ribbed mussel)	C E L M P d
Neopanope texana (mud crab)	I R
Ovalipes ocellatus (lady crab)	I R
Skeletonema costatum (diatom)	V
Uca pugnax (fiddler crab)	B D L P a
Spartina alterniflora (tall and dwarf saltmarsh cord grass)	B C D E M P a
Spartina patens (saltmarsh hay)	B C D E P
Sediment	A G H N O Q S T X Y Z a b c e f g h i j k

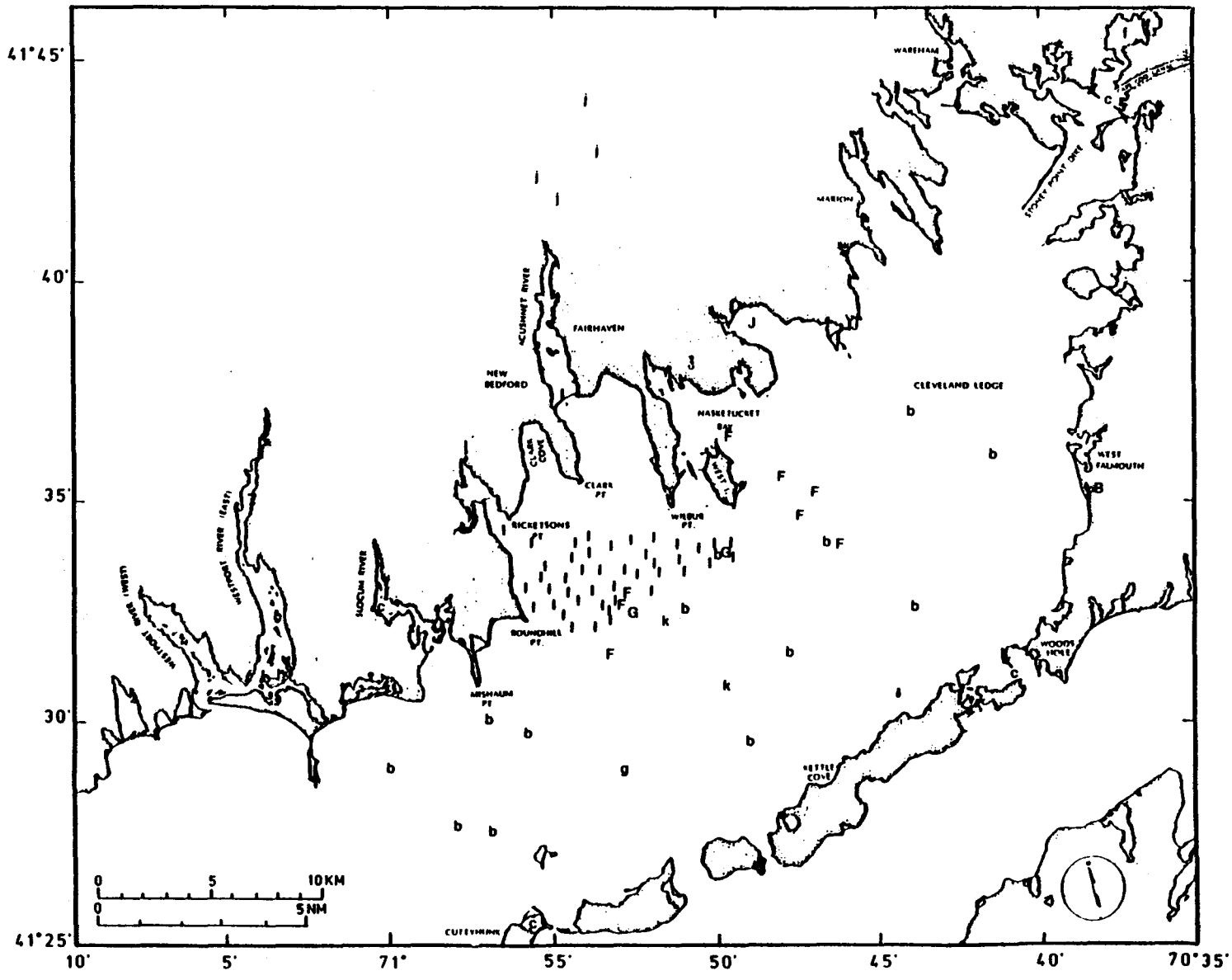

FIGURE 13. SPATIAL COVERAGE OF METALS LITERATURE IN BUZZARDS BAY. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 30. SITE FOR REFERENCE B ALSO REPRESENTS REFERENCES C,D,E,L,M,N,O,P,a, AND b; THOSE FOR REFERENCE I ALSO REPRESENT REFERENCE X,Y, AND Z; THAT FOR REFERENCE J ALSO REPRESENTS REFERENCE K; THAT FOR REFERENCE g ALSO REPRESENTS REFERENCE h. REFERENCE f CORRESPONDS TO 6 STATIONS IN BUTTERMILK BAY CHANNEL.

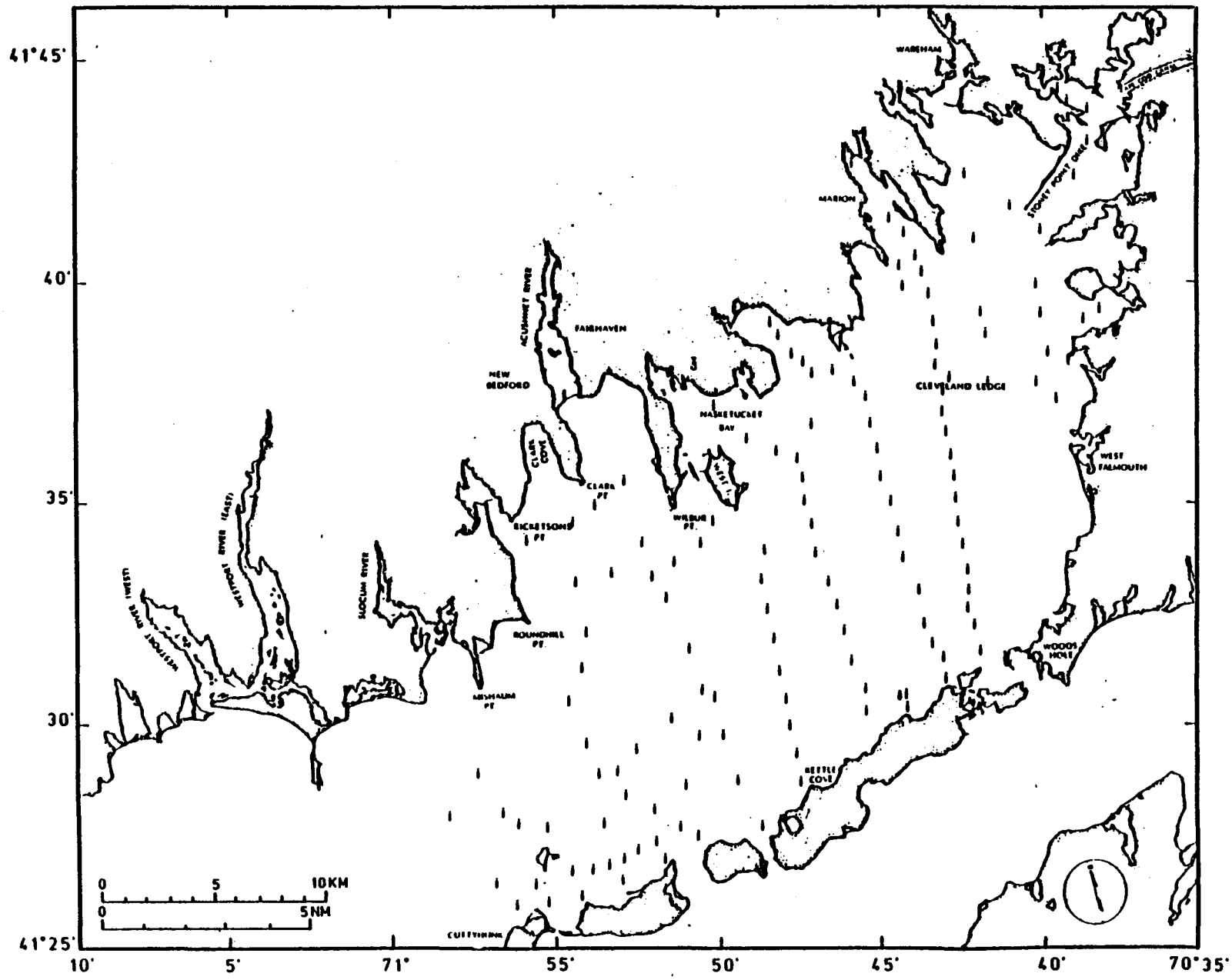

FIGURE 14. SPATIAL COVERAGE OF METALS STUDIED BY MOORE (1963 = REFERENCE 1 OF TABLE 30) IN BUZZARDS BAY.

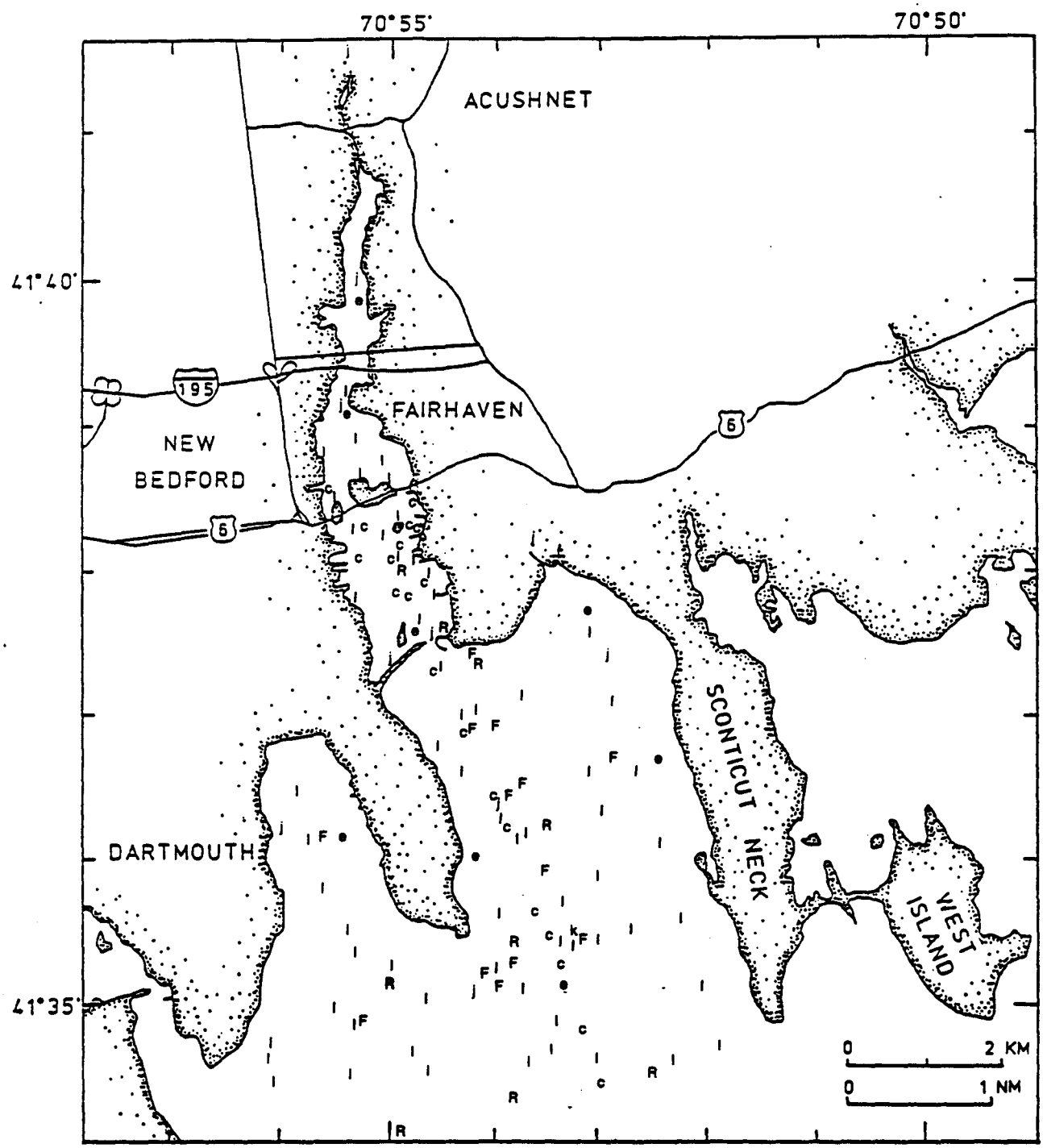

FIGURE 15. SPATIAL COVERAGE OF METALS LITERATURE REVIEWED IN NEW BEDFORD HARBOR. ABBREVIATIONS DESIGNATE REFERENCES IN TABLE 30. LOCATIONS INDICATING REFERENCE I ALSO REPRESENT REFERENCES X, Y, AND Z.

inner and outer New Bedford Harbor (Ellis et al., 1977; Summerhayes et al., 1977, 1985; Camp Dresser & McKee, 1979, 1983). The distribution, fate, and uptake of metals in salt marsh sediments and grasses in Great Sippewissett Marsh in Falmouth have also been well studied (Banus et al., 1974, 1975; Valiela et al., 1975; Giblin et al., 1980, 1983a, b; Breteler et al., 1981a, b; Teal et al., 1982). The Northeast Monitoring Program (NOAA, 1981, 1983), conducted by the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration, includes only one station in Buzzards Bay, but is useful for comparison of contamination with other coastal areas. A variety of other locations such as Angelica Point near Mattapoisett, Buttermilk Bay, and Cuttyhunk Harbor have been studied within Buzzards Bay (Figure 13); however, with the exception of Moore's study (1963) (Figure 14), which focused on the chemical composition of sediments rather than on metal contamination, a comprehensive study of metal pollution throughout the Bay has not been conducted. Individual metals have also not been covered well in the Bay.

Literature on metals in Buzzards Bay sediments and organisms spans the years 1963 through 1983 (Table 34). Most investigations including metals data were conducted in the 1970s. Studies conducted in Great Sippewissett Marsh since 1971 provide useful information regarding both temporal and seasonal trends in metal concentrations in sediments and marsh grasses from control and treatment plots. Most of the metals data were collected during the spring and summer as part of studies that lasted for, at most, one year and often considerably less than a year (Banus et al., 1974; Ellis et al., 1977; Stoffers et al., 1977; Teal et al., 1982). Genest (1979), however, showed an interaction between season and site that suggests that, in bivalves, seasonal tissue changes in metal levels are affected by monthly variation in plankton production, spawning conditions, and other varying inputs.

Summerhayes et al. (1985) suggested that New Bedford Harbor sediments, especially the fine-grained ones, are contaminated with Cu, Cr, Pb, and Zn. This study (Summerhayes et al., 1977, 1985) also inferred that the seaward movement of metal-enriched clay has led to metal contamination of the top 20 cm of sediments in the middle of Buzzards Bay. Because metals may be

TABLE 34. TEMPORAL COVERAGE OF METALS LITERATURE.

REFERENCE	YEARS OF DATA COLLECTION	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	No Info.
Moore, 1963	1953-1955					x
Banus et al., 1974	1971	x	x	x		
MA DEQE, 1971	1971		x			
Giblin, 1982	1971-1978	x	x	x		
USACOE, II&III, 1980	1971-1981					x
Banus et al., 1975	1972			x		
Clark, 1972	1972					x
Valiela et al., 1975	1972	x	x	x		
USACOE, 1982	1972	x	x	x	x	
Gilbert et al., 1973	1973	x				
Giblin et al., 1983a	1974	x	x			

TABLE 34. TEMPORAL COVERAGE OF METALS LITERATURE (Continued).

REFERENCE	Years of Data Collection	DATA COLLECTED BY SEASON				No Info.
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	
MA DEQE, 1975	1975			x		
Ellis et al., 1977	1975-1976	x	x		x	
Stoffers et al., 1977	1975-1976	x	x		x	
Summerhayes et al., 1977	1975-1976	x	x		x	
Summerhayes et al., 1985	1975-1976	x	x		x	
Giblin et al., 1980	1975-1977	x	x	x	x	
Giblin et al., 1983b	1975-1981	x	x	x	x	
Pruell, 1977	1976	x	x			
Teal et al., 1982	1976-1977	x	x	x	x	
Kelley, 1978	1977	x				
Breteler et al., 1981a	1977-1978	x	x	x		

TABLE 34. TEMPORAL COVERAGE OF METALS LITERATURE (Continued).

REFERENCE	Years of Data Collection	DATA COLLECTED BY SEASON				
		Spring (Mar-May)	Summer (June-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)	No Info.
Breteler et al., 1981b	1977-1978	x	x	x		
Aubrey, 1979	1978					x
Genest, 1979	1978-1979	x	x	x	x	
Genest & Hatch, 1981	1978-1979	x	x	x	x	
Camp Dresser and McKee, 1979	1979		x			
Sanders et al., 1981	1979		x	x		
Gidley Labs, 1980	1979-1980	x	x	x	x	
MA DEQE, 1980	1980			x		
Giblin et al., (in press)	1980	x	x	x	x	
NOAA, 1981	1981					x
Steimle et al., 1986	1981-1982		x			
Malcolm Pirnie, 1982	1982			x		
Metcalf & Eddy, 1983	1983					x
NOAA, 1983	1983					x

transported out of New Bedford Harbor, sediments and organisms of the entire Bay should continue to be monitored for metal pollution. Methods for metal analysis should be standardized and trackable. Studies of long-term trends are lacking and should be conducted to monitor any changes in metal distribution in the Bay.

1.4 LOBSTER LANDINGS

The only existing literature on lobster landings consists of the lobster fishery statistics published annually by the Massachusetts Division of Marine Fisheries (DMF) since 1967 (Mass. DMF, 1969-1984). This data set was described in detail in Brown and Gale (1986). Summary lobster fishery statistics include lobster landings for all of coastal Massachusetts. Data are reported as statewide and county totals by license type. Between 1979 and 1980, lobster license categories were changed, with a parallel change in data reporting. For this reason, it is difficult to use these data to construct a time series covering the entire period for which annual reports are available (1967-1984). Summary data available for the periods 1967-1979 and 1980-present are listed in Table 35.

As discussed in Brown and Gale (1986), the organization of the data by county presents problems in terms of spatial coverage because three of the four counties that border on Buzzards Bay also border on other water bodies. Numbers developed by summing the data for the counties that are a part of Buzzards Bay (hereafter referred as a county total) do not accurately portray landings in Buzzards Bay (Dukes County has been deleted because there are no data to indicate landings on the Elizabeth Islands).

It is possible to estimate the percentage of lobster landed in each county on Buzzards Bay using data on pounds of lobster landed by city or town added to the annual lobster statistics beginning in 1979 (see Tables 36 and 37). Based on these calculations, approximately 100 percent of Bristol County, 2 percent of Barnstable County, and 6 percent of Plymouth County landings occur in Buzzards Bay. These percentages may also be used to

TABLE 35. LOBSTER FISHERY SUMMARY DATA AVAILABLE BY COUNTY IN THE ANNUAL MASSACHUSETTS LOBSTER FISHERY STATISTICS.

PERIOD: 1967-1979	1980-PRESENT
Major topics:	
Number of fishermen	Number of fishermen
Pounds of lobster landed	Pounds of lobster landed
Number of pots fished	Number of pots fished
Value of diving gear	Value of diving gear
Number of lobsters landed	Number and value of power boats
Ex-vessel value of lobsters landed	Number and value of non-power boats
Number and value of inboard power boats	
Number and value of outboard and non-power boats	
Categories of fishermen:	
Regular (full-time commercial)	Inside 69°W, 41°N (Inshore
Potmen	Coastal)
Divers	Diver
Potmen-Divers	Potman
Casual (seasonal-commercial)	Both
Potmen	Seasonal
Divers	Potman
Potmen-Divers	Offshore
Other (noncommercial)	Trawl
Potmen	Potman
Divers	Outside 69°W, 41°N (Offshore)
Potmen-Divers	Coastal
	Potman
	Offshore
	Trawl
	Potman

TABLE 36. SAMPLE TABLE FROM 1982 MASSACHUSETTS LOBSTER FISHERY STATISTICS: DATA ON POUNDS OF LOBSTERS LANDED BY CITY OR TOWN.

CITY/TOWN	INSIDE 69°W 41°N	OUTSIDE 69°W 41°N	TOTAL POUNDS
Beverly	545,285		545,285
Boston	939,407	20,807	960,214
Bourne	65,162		65,162
Chatham	144,756		144,756
Chilmark	92,841		92,841
Cohasset	533,625		533,625
Danvers	46,642		46,642
Dartmouth	4,159		4,159
Dennis	46,863		46,863
Duxbury	30,783		30,783
Essex	42,548		42,548
Fairhaven	95,105		95,105
Falmouth	24,966		24,966
Gloucester	716,842	9,816	726,658
Gosnold	12,044		12,044
Harwich-Brewster	279,318	81,634	360,952
Hingham	201,122		201,122
Hull	160,180		160,180
Ipswich	71,735		71,735
Kingston	23,691		23,691
Lynn	30,251		30,251
Manchester	219,521		219,521
Marblehead	552,498		552,498
Marshfield	652,543		652,543
Mattapoisett	37,771		37,771
Nahant	250,859	578	251,437
Nantucket	20,334		20,334
New Bedford	65,002	61,778	126,780
Newburyport-Newbury-Salisbury	69,111		69,111
Oak Bluffs-Edgartown	6,270		6,270
Orleans	57,856		57,856
Plymouth	707,355	3,272	710,627
Provincetown	113,276	689	113,965
Quincy	40,018		40,018
Revere-Medford	33,726		33,726
Rockport	442,149		442,149
Salem	63,090		63,090
Sandwich-Barnstable	273,900	399,443	673,343
Saugus	458,290		458,290
Scituate	495,146		495,146
Swampscott	376,945		376,945
Tisbury	2,110		2,110
Truro	1,314		1,314
Wareham	11,117		11,117
Wellfleet-Eastham	18,602		18,602
Westport	196,909	601,358	798,267
Weymouth	137,770		137,770
Winthrop	168,176		168,176
Out-of-State	15,726	335,001	350,727

TABLE 37. CITIES AND TOWNS USED FOR ESTIMATE OF PERCENTAGES OF COUNTY LOBSTER LANDINGS OCCURRING IN BUZZARDS BAY.

Bristol County:	-	Dartmouth
	-	Fairhaven
	-	New Bedford
	-	Westport

Estimated percentage of Bristol County lobster landings occurring in Buzzards Bay = 100 percent

Barnstable County: - Falmouth

Estimated percentage of Barnstable County lobster landings occurring in Buzzards Bay = 2 percent

Plymouth County:	-	Bourne
	-	Marion-Mattapoisett
	-	Wareham

Estimated percentage of Plymouth County lobster landings occuring in Buzzards Bay = 6 percent

estimate number of lobsters in Buzzards Bay because numbers and pounds are directly related.

1.4.1 Data Analysis

1.4.1.1 Pounds of Lobsters Landed

In general, the number of pounds of lobster landed in Buzzards Bay has increased since 1967. Between 1967 and 1984, a total of 119 million pounds were landed in Massachusetts; of these, 47 million pounds (39.7 percent) were landed in the three counties bordering Buzzards Bay. Based on the percentage estimates discussed above, approximately 12 million pounds (9.9 percent) were landed in Buzzards Bay (Table 38).

Although the absolute number of pounds of lobsters landed for Buzzards Bay and Massachusetts is different, they follow a similar pattern. In Buzzards Bay, lobster landings decreased slightly from 1971 (about 500,000 lb/yr) to 1973 (about 450,000 lb/yr) and again from 1974 (about 550,000 lb/yr) to 1977 (about 300,000 lb/yr) and then increased steadily until 1982 (to about 1.2 million lb/yr) and leveled off until 1984 (the latest record for this study).

1.4.1.2 Numbers of Lobsters Landed

Between 1967 and 1984, 99 million lobsters were landed in Massachusetts. Of these 99 million, the three-county total comprised 39 million (39.3 percent). An estimated 10 million (9.7 percent) were landed in Buzzards Bay (Table 38). In Buzzards Bay, the number of lobsters landed between 1967 and 1979 ranged between 200,000 and 450,000.

As expected, the number of lobsters landed shows a direct relationship with the number of pounds landed. A difference in number of lobsters landed among the three groups occurred when the numbers for Massachusetts increased as those for the three counties and Buzzards Bay decreased.

TABLE 38. COMPARISON OF BUZZARDS BAY ESTIMATE, COUNTY TOTAL AND MASS. TOTAL FOR POUNDS, NUMBER, FISHERMEN AND POTS FISHED.

	Pounds		Number		Fishermen		Pots Fished	
	No.	%	No.	%	No.	%	No.	%
Buzzards Bay	11,790,642	9.9	9,601,507	9.7	---	---	---	---
County Total	47,295,802	39.7	38,809,224	39.3	32,093	45.9	1,705,662	41.2
Mass.	119,000,000	100	98,635,960	100	69,844	100	4,133,891	100

No. = the number reported in the annual reports.

% = the percent of the Mass. total.

1.4.1.3 Number of Fishermen

The classification of fishermen by license type changed over the years and a record of the total number of fishermen has not been consistently reported. In 1980, noncommercial fishermen were excluded from the annual reports because these fishermen hold a large number of the lobster licenses, but contribute little to the catch. Consequently, number of fishermen dropped beginning in 1980. This change in data reporting makes construction of a time series for this data category difficult. As a result, data for the numbers of fishermen, 1980-1984, are not included in this discussion.

Data were not available to estimate the number of fishermen or pots fished for Buzzards Bay versus the county total. However, based on trends in numbers and pounds of lobster landed in the counties and Buzzards Bay, the county total probably provides a relatively good estimate of the Buzzards Bay trend for the numbers of fishermen and the number of pots fished.

In general, the number of fishermen increased between 1967 and 1984 from approximately 1500 to almost 4000. The total number of fishermen decreased between 1973 and 1974, increased between 1974 and 1976, and decreased again between 1976 and 1978. In 1973, the number and pounds of lobster landed and the number of fishermen decreased while in 1975, the number of fishermen increased as pounds and numbers decreased. Possible explanations for this phenomenon include both effects of increased fishing pressure and an anomaly in the data due to the fact that the reporting rate dropped from 83.1 percent in 1974 to 57.8 percent in 1975.

1.4.1.4 Number of Pots Fished

The number of pots fished increased from approximately 50,000 pots in 1967 to almost 200,000 pots in 1984. The number of pots fished dropped between 1972 and 1974, as did the number of pounds landed, number of lobsters landed, and number of fishermen. Number of pots fished also increased with the number of fishermen in 1975 when number of pounds decreased. It appears

that in 1975, there were more fishermen using more pots, but landing fewer lobsters.

1.4.1.5 Reporting Rate and Number Fishing

Between 1967 and 1971 and between 1979 and 1984, the annual lobster fishery reports stated what percentage of licensed fishermen submitted catch reports to DMF. Reporting rates for 1971 to 1979 were calculated using number of fishermen reporting divided by the number of licenses issued.

From 1967 through 1971, the reporting rate was 90 percent or better. In 1972, the rate began to fall and reached a low of 57 percent in 1977. Since 1977, the reporting rate has increased, but has not exceeded the 80 percent level. An average value of 74 percent reporting for the years 1967-1984 was calculated.

Also included in the reports is the number of those reporting who fished during the year. Between 1967 and 1984, the percent fishing ranged from 55 percent to 84 percent. The trend since 1974 has been towards increased numbers of fishermen reporting. On the average, 70 percent were fishing between 1967-1984.

1.4.2 Discussion and Data Gaps

Although the annual lobster fishery statistics are of value as the only existing historical data on lobster landings in Buzzards Bay, the substantial changes in data presented between 1979 and 1980 have diminished the value of the temporal coverage of the data. Although it is possible to estimate lobster landings in Buzzards Bay, data specifically collected for the purpose of providing statistics on the lobster fishery in Buzzards Bay would be useful.

The data currently collected on lobster landings also do not adequately address the question of where the lobsters are caught. Specific data on

lobster catches within the Bay should be collected in the future. Further, the data do not provide an estimate of the size of natural lobster populations as they exist in the field.

Current and past data collection efforts have concentrated primarily on information of value in assessing economic aspects of the lobster fishery. For example, poundage has been recorded more systematically than numbers of lobsters caught, emphasizing the dollar value rather than the population dynamics of the lobster resource. Greater emphasis should be placed on monitoring the lobster resource in Buzzards Bay. Numbers, sizes, and perhaps reproductive status should be examined.

Normal fluctuations as well as the effects of pollution and overharvesting should be investigated. Researchers (e.g., Fogarty 1983; Mathiessen, 1977) have studied the distribution of larval lobsters (Homarus americanus). Other researchers (Atema et al., 1982a, b; Derby and Atema, 1981) have studied the effects of fuel oil on lobster behavior. Additional research is needed to provide information necessary for effective management of the lobster fishery in the future. The fishery statistics must be standardized and computerized before any true understanding of the fishery can be achieved.

2.0 METHODS REVIEW

At the request of EPA, this section reviewing methods was included in this report. The objective of the review is to provide preliminary information on the comparability of methods to persons using the literature discussed (Section 1.0 above) for purposes of characterizing Buzzards Bay. Resources were limited and only the methods mentioned in the literature could be covered and, even then, only in a preliminary fashion.

2.1 METHODS FOR THE DETERMINATION OF BACTERIA IN WATER

2.1.1 Description of Methods

Total and fecal coliform bacteria are the principle indicators of the degree of water contamination in water supplies. The group includes all of the aerobic and facultative anaerobic gram-negative, non-spore-forming, rod-shaped bacteria. The microorganisms ferment lactose with gas formation within 48 h at 35°C. The coliform bacteria includes the genera Escherichia, Citrobacter, Enterobacter, and Klebsiella. The fecal coliform bacteria are part of the total coliform group and are present in the gut and feces of warm-blooded animals. The major species in the fecal coliform bacteria group is Escherichia coli.

Another group of bacteria commonly measured is the fecal streptococci. The normal habitat of fecal streptococci is the intestines of humans and animals. Analysis of fecal streptococci also supplies valuable supplementary data on the bacteriological quality of water.

Several procedures have been developed for the detection and enumeration of total and fecal coliform bacteria as indicators of water quality. The membrane filtration (MF) technique involves direct plating for the observation and estimation of coliform densities. The method of multiple-tube fermentation reports results in an index of the most probable number (MPN) of coliform bacteria that would represent results from laboratory examination. The high volume filtration technique has also been implemented in the analysis for coliform bacteria. Multiple-tube dilution, membrane filter procedures, and a pour plate method are also employed for the assay of fecal streptococci.

2.1.1.1 Coliform Membrane Filtration (MF) Technique

The MF technique can be used in the detection of total and fecal coliform bacteria where differentiation of the nutrient media provides

specificity. The water sample or its dilution is passed through a membrane filter. The filter retains the bacteria and is subsequently placed on a nutrient medium that is selective for the growth of coliform bacteria while inhibiting the growth of other microorganisms. The sample is incubated at a specific temperature for a given length of time. The physical characteristics of coliform colonies that develop will vary, depending upon the medium, or broth, selected. Grown on media, total coliform colonies typically produce a golden-green metallic sheen. The fecal coliform group produce colonies that are blue to green-blue in color. Colonies are counted on the filters, which generally have 20-80 colonies per membrane. Coliform density is reported by the following equation:

$$\text{coliform colonies/100mL} = \frac{\text{coliform colonies counted}}{\text{mL sample filtered}} \times 100$$

A commercial multi-test system may be used for verification of coliform bacteria. The colony is inoculated in a multi-test identification system for Enterobacteriaceae that includes lactose fermentation and/or B-galactosidase (ONPG) and cytochrome oxidase (CO) test reactions.

2.1.1.2 Coliform Multiple-Tube Fermentation Technique (MPN)

Total Coliform Multiple-Tube Test

Presumptive Phase. A series of decimal dilutions is produced by transferring an inoculum from the diluted water samples into liquid tube media. The tubes are mixed and incubated at 35°C. After 24 h, each tube is shaken and examined for gas production. If no gas is present, the tubes are reincubated and examined at the end of 48 h. Formation of gas within 48 h constitutes a positive test.

Confirmed Phase. Inocula from the positive presumptive tubes are transferred to tubes of brilliant green lactose bile (BGLB) broth. The BGLB nutrient medium is selective for the growth of coliform organisms. Gas

production after incubation for 24 to 48 h at 35°C constitutes a confirmed test. Counts are calculated from the MPN table (APHA, Section 908D).

Completed Phase. Positive tubes from the confirmed test are submitted to additional testing to verify the identification of the isolated microorganisms. A LES Endo nutrient agar plate is streaked with inocula from each positive confirmatory tube and incubated at 35°C for 24 h. Typical coliform colonies are selected and inoculated into lauryl tryptose fermentation tubes that are incubated for 24 to 28 h. If no gas is produced, the tubes are incubated and examined at 48 h. A gram stain is performed on inocula from tubes exhibiting positive gas production. The formation of gas and microscopic examination of gram-negative, rod-shaped bacteria constitute a positive test for the completed phase, thus indicating the presence of coliform bacteria.

Fecal Coliform Multiple-Tube Test

Culture from positive tubes from the total coliform (MPN) test is inoculated into either EC medium or A-1 medium. Tubes are incubated at a specified temperature for a given time. Gas production in the confirmatory tubes within 24 h constitutes a positive test reaction, indicating coliforms of fecal origin.

2.1.1.3 Coliform Quantitative High-Volume Sampling Technique

A high-volume filtration (HVF) technique for sampling water has been developed that, when used in conjunction with the MPN procedure, allows quantification of coliforms and other microorganisms that are present at very low densities in water. A volume of water is passed through a complex filtration apparatus. The amount of time required to filter large volumes of water will vary with the turbidity of the water. Samples are inoculated in enrichment medium and incubated for 72 h at 41°C. Tubes are examined daily for a positive reaction of brick-red color. The positive tubes are then streaked for isolation onto brilliant green agar or Hektoen enteric agar

plates. The positive colonies are then counted. The expected bacterial densities are determined from a five-tube, total coliform MPN.

2.1.1.4 Fecal Streptococci

Fecal streptococci indicate the sanitary quality of water and wastewater. Fecal streptococci do not multiply in the environment; their occurrence indicates fecal contamination by warm-blooded animals. In conjunction with data on coliform bacteria, the presence of fecal streptococci provides supplementary information on the source and extent of pollution.

MF and MPN

The MF and MPN techniques are used in the enumeration and identification of fecal streptococci in waste and wastewater. The method selected depends upon the characterisitcs of the sample. Procedures for these methods are similar to those performed for fecal coliform bacteria. Media are selected to promote the growth of fecal streptococci and deterring growth of other microorganisms.

Pour Plate Method

An aliquot of the water sample or its dilution is delivered to the bottom of an empty, sterile petri dish. Liquified agar is added and the contents of the dish are mixed. Depending on the media and incubation conditions, fecal streptococci are brown-black with brown or red-pink halos. The colonies for each plate are counted and reported as fecal strep/100 mL.

2.1.2 DISCUSSION OF METHODS

Several methods can be used in the laboratory to test water for the presence of bacterial pollution indicators. The application of these techniques is constrained by the requirements of the study performed and the

sample characteristics. Water is generally examined to estimate the density of bacterial contamination, determine the source of pollution, and enforce water quality standards.

The MF technique is of value because of its precision. It offers a direct count of the microbial population of the sample, whereas the MPN method is based upon probability. MF is preferred when time is the major constraint. This particular method is portable and can easily be performed in the field. Samples can be filtered and immediately transferred to nutrient medium. This approach will reduce any additional growth from the available organics. Immediate filtration will also decrease microbial exposure to toxins present in the sample. A larger volume of sample can be examined with MF than with MPN. The portability of the method and the greater volume of sample allows for an effective representation of the environment from which the sample was extracted. Definitive results can be obtained within 22 to 26 h.

Samples containing large quantities of colloidal materials or suspended solids will impede the filtration process by clogging the filter pores. Turbid samples can be filtered by decreasing the volume. The data of several small-volume replicates can be compiled as well. A large population of non-specific microorganisms may mask the appearance of indicators on selective media. MF reliability is decreased when the sample is high in turbidity and the bacterial count is low.

Industrial wastewaters may contain metals such as copper or zinc. These can interfere with the growth of bacteria by adsorbing onto the surface of the membrane filter. Growth inhibition may occur in seawater or result from toxins such as chlorine or phenols. When sewage effluent that has been chlorinated is examined, thiosulfate may be added to samples to neutralize the toxic effects of chlorine. Recoveries of coliforms from effluents are low and variable for the MF procedure compared to the MPN method.

When verification is necessary, MF analysis requires preparation of MPN medium. When the MF technique has not been previously used, a parallel MPN test is required to determine applicability.

The MPN method of determining the bacteriological quality of water is chosen when certain considerations apply to the sample or the environment from which the sample was taken. The MPN technique for the presumptive and confirmed test requires data only on presence or absence of gas for coliforms, or growth/no growth for fecal streptococci. Because samples for the MPN method are greatly diluted, high turbidity or high algal densities generally do not affect the use of this method. The dilution of the sample may also decrease effects of a toxin. MPN may be the only method applicable to problem samples such as bottom sludges, muds, soils, and sediments.

One limitation of the MPN method is that the volume of sample examined is, in most cases, restricted to 10 mL. Background organisms or toxic constituents in 10 mL of marine water can interfere or yield false positives. Portions of 100 mL have been used, however, in the assay of shellfish water. The time required to complete the multiple-tube fermentation test, 48 to 96 h, is considerably longer than that of the MF method.

Multiple-tube fermentation data are calculated from probability tables and, therefore, have poor precision (a 23 percent bias at the 5-tube, 3-dilution level normally used). Unless a large volume of sample is examined, precision of the MPN is low. Statistical comparisons of results obtained by the MPN and MF techniques indicate that the MF is more precise. Although both provide good information on water quality, their quantitative results are not comparable. The statistical reliability of the MF technique is greater than that of the MPN procedure.

The high-volume sampling technique differs from the standard method of membrane filtration in that the sample volume is larger and the amount of lactose broth used in each tube is greater. The time required to filter the sample may limit the application of HVF. Problems associated with MF, such as the adsorption of toxic metal ions and overgrowth by background organisms, are also associated with HVF. HVF utilizes the MPN codes for reporting results. The degree of statistical error described above for the MPN method will apply to HVF as well.

The limited survival of fecal streptococci in the environment restricts the use of these microorganisms as water quality indicators. When used in conjunction with fecal coliform data, results on fecal streptococci provide specific information about the source of pollution due to the host specificity of fecal streptococci. Biochemical characterization or speciation of fecal streptococci is useful in obtaining source information.

One disadvantage of the fecal streptococci method is that one subspecies is not confined to the intestines of humans and animals. S. faecalis subspecies liquefaciens has been found in association with vegetation, insects, and some soils. When examining low density fecal contamination, the presence of this subspecies can present problems in data interpretation. When the count is less than 100 fecal strep/100 mL, S. faecalis subspecies liquefaciens usually predominates.

The sanitary conditions surrounding the source of the sample are important in interpreting bacteriological water quality data. The evaluation of water quality should be made only after a series of samples are collected over a protracted period of time.

2.2 NUTRIENTS

2.2.1 Assessment of Methods Used

Measurement of nutrient elements (nitrogen, phosphorus, silica) and associated biological parameters (dissolved oxygen, pH, chlorophyll a) in seawater has progressed from manual to automated techniques over the past 20 years. For instance, quantitative methods for measuring inorganic nutrients by colorimetric techniques have progressed from manual to automated laboratory procedures and then to in situ methods involving pumping systems and flow injection analysis. Likewise, dissolved oxygen (DO) methods have progressed from the classical Winkler titration to instrumentation capable of in situ real-time measurements using a sensor that is deployed through the water column. Each type of equipment and measuring device has advantages depending on cost, frequency of analysis, and number of samples required. As

these methods have developed, improvements in the measurements have also been achieved. A critical requirement in the improved methodologies is the comparability of data generated by the methods employed.

Nutrient elements can occur in seawater in several species and phases (dissolved or particulate). The relative proportion of these species and phases depends greatly on the biological activity in the seawater and on the season of the year. This variability and our ability to study it creates one of the more effective diagnostic tools in the marine sciences. Because of the number of species and phases involved in understanding nutrient dynamics in the coastal zone, it is critical, in evaluating data sets, that a common terminology be defined from which the strength and weaknesses of the quantitative analytical methods can be evaluated.

Foremost, seawater has a different ionic strength than freshwater. If not understood, this difference can lead to subtle differences in results. Furthermore, in the coastal zone, widely varying salinity can cause artifacts in analytical data if not compensated for by the analyst; e.g., refractive index changes between low and high salinity waters can cause systematic offsets in dissolved silica data when determined against a common standard curve using colorimetric techniques. The discussion that follows defines nutrient phases and species commonly determined in oceanic systems. The progression is from total measurements to total dissolved and particulate phases to specific species of the elements.

The commonly used methods for nutrient analysis can be found in Strickland and Parsons (1965, 1968) and in Standard Methods for Examination of Water and Wastewater (APHA, 1985 plus preceding editions).

2.2.2 Total Nitrogen and Phosphorus

Total nitrogen and phosphorus includes both the dissolved and particulate phases of these elements and does not involve separation of the sample into these phases. Total nitrogen is determined by a persulfate digestion followed by analysis for the nitrogen by colorimetric methods.

Total phosphorous is also determined following the persulfate digestion using colorimetric methods. Other digestion methods may include a nitric plus sulfuric acid digestion or perchloric acid digestion. The perchloric method is recommended for difficult to digest samples, whereas the persulfate method is the simplest technique (APHA, Standard Methods, 1985). The nitric plus sulfuric method is not acceptable for nitrogen analysis for obvious reasons.

Total phosphorus may be listed as total P or total PO_4 depending on the method and investigator. Care must be taken to determine whether the investigator is referring to the total phosphorus as described in this section or dissolved inorganic phosphate as described in the sections that follow.

2.2.3 Total Dissolved Nitrogen and Phosphorus

Total dissolved nitrogen and phosphorus are determined after passing a sample through a filter (0.4 um) to remove particulate phases from the sample. The sample methods discussed under total nitrogen and phosphorus may be used to quantify these elements. This fraction includes both the inorganic and organic forms of the nitrogen. No nitrogen or phosphorus species are measured by this technique.

2.2.4 Particulate Nitrogen and Phosphorus

2.2.4.1 Nitrogen

Particulate nitrogen can be determined by first filtering a sample through a glass fiber filter and then either combusting the captured particles in an elemental analyzer or digesting them with persulfate followed by quantification by colorimetric techniques. The pore size of the filter is important because some particles may pass through a filter if pore size is too large. Elemental analyzers have an advantage in that carbon can be determined simultaneously with nitrogen.

The difference between total nitrogen and total dissolved nitrogen can also be used as a measure of particulate nitrogen. As with any difference calculation, the result is subject to error based on the analytical precision of the method and detection of small differences between two large numbers.

2.2.4.2 Phosphorus

Particulate phosphorus can be determined by filtration followed by persulfate digestion and colorimetric methods. More routinely, the difference between total and total dissolved phosphorus is used to estimate particulate phosphorus concentrations, but this method is subject to the errors considered above.

2.2.5 Dissolved Inorganic Nutrients

2.2.5.1 Ammonia (NH_3)

This nitrogen species is also referred to as ammonium (NH_4^+) ion. Ammonia is subject to storage artifacts such as volatilization, alteration by plant and microbial activity, and contamination (cleaning products and cigarette smoke); thus analysis of fresh samples is recommended. If samples must be preserved, the techniques employed are critical to accurate determination of this nitrogen species. Ammonia can be frozen for a short period prior to analysis, but, once thawed, the ammonia in the sample must be determined.

Ammonia may be determined by colorimetric methods, titration, ion selective electrodes, or other more recent methods such as ion chromatography. These methods may be manual or automated.

2.2.5.2 Nitrate plus Nitrite ($NO_3 + NO_2$)

Nitrate plus nitrite is also known as reactive nitrate. The concentration determined depends on the fraction that reacts with the color-forming reagents. Generally the nitrate in the sample is reduced with cadmium metal to nitrite and both species are determined colorimetrically. Unless specified, it should be assumed that both nitrate and nitrite are being reported for the cadmium reduction method. Some authors may report the nitrate as determined by the cadmium amalgam method. This method measures nitrate plus nitrite. Other methods are available but have not found widespread use in the marine environment.

2.2.5.3 Nitrite (NO_2)

Nitrite can be measured independently from nitrate by eliminating the reduction step in the analytical method described above.

2.2.5.4 Nitrate (NO_3)

Reactive nitrate can be determined as the difference between the two above results.

2.2.6 Dissolved Organic Nitrogen

The difference between the total dissolved nitrogen and the sum of the dissolved inorganic species can be used as a measure of the dissolved organic nitrogen present in a sample. The Kjeldal method can provide a direct measure of organic nitrogen as long as ammonia is removed from the sample. If ammonia is not removed, the results are referred to as Kjeldal nitrogen. If ammonia is removed, the results are considered to be organic nitrogen. In either case, azides, azo, azine, hydrozone, nitrate, nitrite, nitrile nitro, nitroso, oxime, and semi-carbazone are not accounted for by the method.

(APHA, Standard Methods, 1985) Analysis of fresh samples is recommended for the Kjeldal method.

2.2.7 Dissolved Inorganic Phosphate

Inorganic phosphate is also known as orthophosphate phosphate. Phosphate may be determined by any of three colorimetric methods: vanadomolybdophosphoric acid method, stannous chloride method, or ascorbic acid method. Portable field kits are available for phosphate determination but accuracy, precision, and detection limits are not equal to those of laboratory-based equipment. In marine waters the ascorbic acid method is generally the method of choice because of its lower detection limits. Samples run directly, without acidification, give a measure of the reactive phosphate, and the difference between this and results obtained after a mild acid hydrolysis are considered to be acid hydrolyzable phosphate.

2.2.8 Dissolved Organic Phosphorus

Dissolved organic phosphorus is determined from the difference between total dissolved phosphorus and inorganic phosphate.

2.2.9 Dissolved Silicate

Dissolved silicate (SiO_2) is measured by gravimetric, colorimetric, or atomic absorption methods. Each measures a different fraction of the silica. The gravimetric and atomic absorption methods will measure total silica, whereas the colorimetric methods measure molybdate-reactive silica. The latter implies a nonreactive silicate fraction which to date has not been accurately defined. For all methods, use of plastic containers is recommended. The molybdate method is known to have a refractive index interference on the analysis, thus samples with highly variable salt content can not be measured against a single standard curve generated in deionized water. Both Strickland and Parsons (1972) and Standard Methods (APHA, 1985)

list the molybdate method for silicate and this is the method generally used by investigators in the marine field.

2.2.10 Salinity

Salinity is most commonly analyzed by instrumentation that determines the conductivity of a sample. The salinity can then be calculated using appropriate temperature and depth corrections. Salinity can also be determined by titration to measure the Cl^- ion content of the sample or hydrometry. Results from these methods are related to the salinity through well-defined equations.

Modern instrumentation can determine salinity directly using sensors deployed remotely from shipboard or left moored over long time periods. The accuracy of all of these methods can be traced to a common salinity standard, Standard Sea Water, or Copenhagen water. As with any method, the accuracy of the measurement technique should be defined in any published document.

2.2.11 Temperature

As with salinity, a variety of methods are available for measuring temperature. These range from hand-held thermometers to mechanical devices that profile the temperature as a function of depth (bathythermograph) to sophisticated remote sensing devices. Most methods should give comparable results as long as the accuracy of the device is monitored through routine quality assurance checks.

2.2.12 Dissolved Oxygen

The standard technique for determining dissolved oxygen (DO) in seawater is the Winkler or iodometric titration. Several modifications to the method may be used. The most common modification uses azide to remove interferences from high nitrite concentrations that may be present in a sample. Remote

sensing devices that allow in situ DO measurements have recently been marketed. These usually involve diffusion of oxygen across a membrane. When operated properly, for the most part these systems will generally provide accurate results. However, they are subject to drift and slow responses that must be characterized, understood, and controlled by the operator.

2.2.13 Discussion of Methods

Examination of the papers listed in Tables 10 and 12 indicate most methods employed for nutrient analysis are either from Standard Methods (APHA, 1985) or Strickland and Parsons (1972). Standard Methods includes the methods described in Strickland and Parsons, but includes additional methods. It is assumed that these methods give comparable results for the type of measurement discussed. The authors cited in Tables 10 and 12 frequently do not give clear indications as to the specific technique used in their work, thus for any reference to Standard Methods or APHA, one must assume methods comparable to Strickland and Parsons were used. Thus, results generated using these methods should be comparable. In some cases, the authors cited in these tables used different terminology in reporting data. These differences can be identified by referring to the discussion above.

2.3 POLYCHLORINATED BIPHENYLS, HYDROCARBONS, AND PESTICIDES

In the literature reviewed for this study, numerous methods were used to extract and analyze organic contaminants (i.e., PCBs, hydrocarbons, and pesticides) in sediments and organisms. Tables 17, 22, and 27 present the methods used for each of the papers reviewed for Buzzards Bay. This section provides, within the constraints of this program, a short description of the methods used, and a discussion of the methods as they compare to each other. More extensive reviews of methodologies are available (e.g., Boehm, 1981 for hydrocarbons) that provide more comprehensive comparisons among different methods.

2.3.1 Description of Methods Used

2.3.1.1 Sample Preparation

Pre-extraction. A pre-extraction procedure is often not reported in the literature and is not essential in the preparation of samples for analysis. Prior to extraction, samples may be oven-dried or freeze-dried to remove water and to facilitate homogenization and/or extraction. Volatile fractions may be lost and other low molecular weight components may evaporate during these procedures. There is also the risk of contamination of the sample during freeze-drying.

Extraction. Hydrocarbons, pesticides and PCBs are extracted from sediment and tissue samples using the following procedures:

a. Soxhlet Extraction. A sample is placed in a porous thimble and extracted repeatedly with distilled solvent in a glass extractor (soxhlet extractor).

b. Ambient Shaker. An orbital shaker is used to agitate an extraction container containing an organic sample and solvent. Extraction occurs at room temperature.

c. Digestion. Digestion is used for extraction of tissues. In this case, an acid or base is used to digest the tissue matrix, which is then extracted with solvent.

d. Homogenization. Homogenizing apparatus is used to break down the sample matrix (generally biological tissue) and extract the sample with organic solvent.

Cleanup. Various cleanup procedures are used to remove components in the extract that will interfere with analysis (matrix interferences) or to separate the different molecular weight components or components of different polarity into fractions for specific analyses.

a. Gel Permeation Chromatography (GPC). A gel is used to separate materials according to their molecular size. The larger molecules are excluded from the porous gel and are eluted first. Low molecular weight organic compounds are collected in the later fractions. GPC is most useful as a cleanup procedure for the analysis of biological tissue samples.

b. Adsorption Chromatography. Components are adsorbed to a column or a plate (thin-layer) of polar material, solvent is passed through the column, and the organic analytes are eluted in order of increasing polarity. The following types of adsorbents are listed by increasing polarity: silica/silicic acid, florisil, and alumina.

c. Sulfur Removal. Elemental sulfur is present in most marine sediments and some industrial wastes. Sulfur is soluble in the various solvents used in the above procedures and therefore follows the organic compounds through the extraction and cleanup techniques. The sulfur will be evident in the gas chromatograms and will mask the peaks of interest. Copper is used to remove the sulfur by the formation of copper sulfide on the surface of the copper.

2.3.1.2 Sample Analysis

Gravimetric Methods. Extracts are weighed to provide total extractable material or fraction weights. This method is not compound specific.

Spectroscopic methods. Several types of spectroscopic methods are used in sample analysis.

a. Fluorescence Spectrometry. This technique measures fluorescing compounds including 2- to 5-ring aromatic hydrocarbons and other unsaturated hydrocarbons. It is not suitable for saturated hydrocarbons. Fluorescence spectrometry is usually used on partially cleaned extracts as a screening process for semiquantitative analysis of aromatic hydrocarbons.

b. Infrared (IR) Spectrometry. An IR spectrometer measures the compounds that absorb light in the IR region of the visible spectrum. In

environmental samples, IR spectrometry has been used almost exclusively for the analysis of saturated hydrocarbons. However, the low selectivity of this technique generally requires stringent sample cleanup such as column chromatography.

c. Gas-Liquid Chromatography (GLC). GLC is used to analyze organic samples and to obtain either individual components or the sum of total components. Two types of columns were used for GLC in studies in Buzzards Bay. One type, the packed column, involves steel or glass columns that are packed with inert material coated with liquid phase. The second type is the fused silica (wall-coated open tubular) column. Fused silica columns have the interior walls coated with the liquid phase to allow increased resolution in comparison to packed columns.

Two types of detection were used in the Buzzards Bay studies reviewed. The first type is the flame ionization detection (FID). In this case, a hydrogen-air flame is used to ionize components producing an electrical current. As the organic compounds are ionized, the conductivity increases and this change is measured by the detector as a response. FID is generally used to analyze hydrocarbons. The second type of detection is electron capture detection (ECD). ECD uses a radioactive source to supply electrons that are captured by the electrophyllic substance passing through the column and the detector. The change in frequency of the current is measured as a response. ECD is generally used to analyze halogenated compounds such as PCBs and pesticides.

d. Gas Chromatography/Mass Spectrometry (GC/MS). A mass spectrometer is used as a detector for a gas chromatograph. It uses an electron current to ionize components and then separates the ion fragments according to mass. GC/MS provides positive identification of individual analytes by retention time and unique mass fragmentation patterns. GC/MS can be used to measure hydrocarbons, pesticides, and PCBs.

2.3.2 Discussion of Methods

Unlike water analyses, for which standard methods have been promulgated, there are no EPA-approved methods for the analysis of sediment or tissue samples for organic environmental contaminants. Researchers for years have been employing several different methods and generating, in general, equivalent data for the anlysis of sediment samples for PCBs, hydrocarbons, and pesticides. All the methods presented in this section should produce equivalent data in the hands of competent, trained analytical chemists.

For sediments, several methods are in common use. Organic contaminants are extracted from the sediment with organic solvents. The solvent extract is dried and concentrated, then processed through one of several adsorption chromatography methods to isolate contaminant fractions. Because sulfur interferes with the analysis of most organic analytes, it is selectively removed before analysis with one of several methods. Purified extracts are then analyzed by gas chromatography using flame ionization detection or mass spectrometer detection for hydrocarbons, or by gas chromatography using electron capture detection for pesticides/PCBs.

Laboratory intercomparison exercises have been conducted to compare methods for sediment analysis. Alford-Stevens et al. (1985) found that soxhlet extraction or extraction with the ambient shaker method consistently gave the highest recovery of PCB contaminants. However, all tested methods gave roughly equivalent results for the analysis of PCBs in polluted harbor sediments. EPA 301(h) protocols (Tetra Tech, 1986) recommend soxhlet extraction followed by gel permeation chromatography. However, EPA Contract Laboratory Program protocols require extraction through sonication.

Recently, researchers have been using surrogate materials to monitor extraction performance. This technique is particularly effective for PAH or PCB analysis by GC/MS where deuterated or C-13 aromatic compounds may be used to monitor performance. There are fewer surrogate materials that are appropriate when employing universal detectors such as flame ionization or electron capture detection. Requirements that the surrogate be clearly distinguished from all potential contaminants and from matrix interferences

considerably narrow the number of surrogates that may be employed. Because the use of surrogates is a recent phenomenon, none of the studies cited in this report used surrogate materials to monitor performance.

As with sediments, there are no EPA-approved methods for the preparation of tissue samples for organic contaminant analysis. Two general extraction procedures are in common use. One method employs a saponification procedure to remove the majority of lipid from the sample. Other methods use extraction procedures similar to those used for sediments and require more exhaustive cleanup procedures to remove lipid. Both methods have been shown to give equivalent results for the analysis of PAHs and PCBs in tissues. Generally, if pesticide analytes are being determined, the latter extraction procedure is used, for there are several pesticides that are labile under alkaline digestion conditions.

EPA 301(h) methods recommend the use of exhaustive soxhlet extraction followed by gel permeation chromatography for the preparation of tissue samples. NOAA National Status and Trends methods use homogenization/ extraction followed by adsorption column chromatography and gel permeation chromatography for the same analysis. In the hands of competant chemists, both methods give equivalent results. Earlier methods generally tended to use exhaustive adsorption chromatography rather than gel permeation chromatography to remove lipid from samples. These methods are also equivalent.

Surrogate methods are also now commonly used to monitor laboratory performance for each tissue sample extracted. As with sediments, this is a relatively recent phenomenon, and few of the studies in this report employed this technique.

2.4 METALS

Analytical results for metal determinations in sediment and tissue samples are highly dependent on the type of procedure used to digest the

material. The following definitions are provided to help interpret published metal results with respect to the different methods of extraction.

2.4.1 Sediments

A recent International Council for the Exploration of the Sea (ICES) study (Loring, 1986) compared several extraction techniques for determining metal concentrations in three types of marine sediment. The general procedures recommended and a nomenclature describing that procedure, are listed below. The category partial metal (HNO_3) was not defined in the ICES study but is included due to the number of studies that have used this method in various forms.

1. **Total metal (except mercury).** Includes metals bound in all sediment phases as determined by nondestructive methods such as neutron activation analysis (NAA), x-ray fluorescence (XRF) or x-ray emission analysis (XRE) or by spectrophotometric techniques following total dissolution of the sample with hydrofluoric acid (HF) plus aqua regia (HNO_3 + HCl) or HF plus perchloric acid ($HClO_4$). This may also be referred to as the bulk sediment concentration.

2. **Partial metal (aqua regia).** Metal extracted with aqua regia.

3. **Partial metal (HNO_3).** Metal extracted with concentrated or dilute nitric acid.

4. **Weakly bound metal (HCl).** Metal extracted with 1 N HCl.

5. **Weakly bound metal (acetic acid).** Metal extracted with 25 percent acetic acid. Also considered to be metals in ion exchange positions of sediment phases.

6. **Total mercury.** Mercury determined after extraction with HNO_3 and H_2SO_4.

Other partial extraction methods employed to extract metals from sediment include HNO_3 with H_2O_2, hydroxylamine hydrochloride or other reagents specific to either organometal species or sedimentary phases such as pyrite or manganese oxides. In addition, metals in ion exchange positions of organic matter, clay minerals, and other sediment phases can be extracted using Mg^{2+}. The partial extraction techniques may also be described in the literature as extracting environmentally active, acid soluble or labile metals depending upon the investigator's preference and frame of reference.

Each extraction method will give differing results. The amount of metal determined by each method depends on the composition (organic rich, reducing, oxidizing, calcareous, hydrothermal, etc.) and grain size distribution of the sediment. Metal in the clay fraction of the sediment is frequently reported. This value does not represent the total or bulk composition of the sediment because it does not account for contributions from organic and oxide phases of the sediment nor metals associated with larger sediment grains. In general, reported metal concentrations will decrease in the order of the extraction methods listed above. Results from extractions with nitric acid alone will generally fall between those from aqua regia and HCl used alone.

The differences in results due to extraction procedures require that the methods of extraction be known before sediment results can be compared. Even in the absence of direct procedures for partial metal extractions, partial metal results may be derived from total results if aluminum or iron data are available for the samples. This involves subtraction of the concentration metal of metal in the mineral (aluminosilicates) phase from the total or bulk sediment concentration. The correction factor is based on the ratio of the metal to aluminum or iron in specific aluminosilicate mineral phases known to be in the samples or using an average for the earth's crustal minerals.

Table 32 lists extraction methods used to determine metals in sediments in the Buzzards Bay region. The method is also classified relative to the procedures described above.

2.4.2 Organisms (Plant and Animal)

As with sediments, many procedures exist to digest and prepare organisms for metal analysis. Unlike sediment procedures, these are total methods designed to digest all tissue and release the metal for analysis. Depending on the procedure, certain metals may be lost or added to the sample. Thus, care must be taken to determine whether procedural loss or addition occurred. Table 32 provides a summary of the digestion methods documented in the literature of the Buzzards Bay region.

3.0 ACKNOWLEDGMENTS

This summary could not have been completed without assistence from several people. Dr. Carlton Hunt, Mr. William Steinhauer, and Ms. Suzanne Duffy provided considerable help with chemical methodology. Ms. Ellen Baptiste, Ms. Elizabeth Haase, Ms. Brenda Cavicchi, and Ms. Heidi Benz helped format the report and prepare the graphics. Ms. Ann Loftus and Ms. Barbara Greene typed the many tables.

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