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Cleanup Efficiency and Biological Effects of a Fuel Oil Spill in Cold Weather: The 1977 Bouchard No. 65 Oil Spill in Buzzards Bay, MA

Interagency Energy/Environment R&D Program Report

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CLEANUP EFFICIENCY AND BIOLOGICAL EFFECTS OF A FUEL OIL SPILL IN COLD WEATHER

The 1977 Bouchard No. 65 Oil Spill in Buzzards Bay, Massachusetts

by

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EPA Contract No. 68-03-2160

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study consists of a review and evaluation of cleanup operations following a No. 2 fuel oil spill in the ice-infested waters of Buzzards Bay, Massachusetts, and an assessment of the biological damage caused by this spill. The information gained as a result of this experience will be valuable to oil spill onscene coordinators when planning and responding to future spills under similar environmental conditions. Personnel responsible for future damage assessment surveys should also find the report useful. For further information, please contact the Oil and Hazardous Materials Branch of the Resources Extraction and Handling Division.

David G. Stephan
Director
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ABSTRACT

This study was initiated following the 1977 Bouchard No. 65 fuel oil spill in Buzzards Bay, Massachusetts. Its major objectives were to evaluate the techniques used to clean up and/or mitigate damage from this spill and make recommendations of feasible alternative methods that may be used in future spills in similar environmental conditions; to inventory and evaluate the benthic and sediment sampling effort; and to assess the environmental damage caused by the spill.

Because of the unusual ice and weather conditions at Buzzards Bay during and after the spill, much of the cleanup effort relied on methods and equipment rarely used before. Modifications of existing techniques are necessary if future spills in similar conditions are to be treated more successfully. Unlike previous No. 2 spills in the bay, acute biological effects were not observed. Long-term acute and sublethal effects may have occurred but could not be detected with presently available data. Severe biological damage was probably prevented by the entrapment of oil in both shore-fast and free-flowing ice.

This report was submitted in fulfillment of EPA Contract No. 68-03-2160 and describes work completed from June 1977 to March 1978.

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FIGURES (cont.)

FIGURES (cont.)

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TABLES (cont.)

ACKNOWLEDGMENTS

This study would not have been possible without extensive cooperation between the EPA, U.S. Coast Guard, National Oceanic and Atmospheric Administration (NOAA), and State of Massachusetts personnel. Special appreciation is extended to Leo T. McCarthy, the Project Officer, Industrial Environmental Research Laboratories, Edison, New Jersey, and Carl Eidam, the Project Manager, EPA Region I.

The work was conducted under the direction of William Van Horn, Program Manager of the Oil and Hazardous Materials Spills Program of URS Company, and Eric Schrier, the project manager. The cleanup evaluation was conducted by Michael Miller and Leon Crain; the sampling survey evaluation by Barbara Westree; and the biological damage assessment by David Maiero and Phillip Dibner. Susan Samse prepared the graphics; Michael Slack edited the manuscript; and Margaret Chatham and Donna Murzi typed and produced the final report.

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SECTION 1

INTRODUCTION

On 28 January 1977, the Bouchard No. 65 ran aground at Cleveland Ledge in Buzzards Bay, Massachusetts, eventually spilling an estimated 318,000 liters of No. 2 fuel oil. Cleanup efforts, directed by the United States Coast Guard, were initiated the following day and continued until February 22 when ice breakup and dispersion of the oil to thin sheens precluded further land- or water-based recovery. Because of the unusual weather conditions during the winter of 1977, either shore-fast or free-flowing ice contained most of the oil initially released by the spill. The dynamic nature of the ice and the nature of the oil dispersion within the ice presented cleanup personnel with recovery problems rarely encountered outside of Alaska.

An interagency program of water column, sediment, benthic, and shellfish sampling surveys was initiated immediately after the spill by the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), Massachusetts Department of Environmental Quality Engineering (DEQE), and the Massachusetts Division of Marine Fisheries. NOAA's sampling efforts were designed to trace the movement of oil in the water column, to determine the interaction of the spilled oil with surface ice present in Buzzards Bay, and, on a limited scale, to determine the long-term environmental impact of the spill. The EPA, DEQE, and Massachusetts Division of Marine Fisheries sampling efforts were designed to determine the extent of benthic sediment contamination by the spilled oil, to investigate contamination of commercial shellfish areas, and to assess the acute, short-term environmental impact of the spill. NOAA contracted with a number of firms, including the Marine Biological Laboratory at Woods Hole, Environmental Services Corporation, Science Applications, Inc., and Arctec, Inc., to assist in the overall sampling effort.

This study of the 1977 Buzzards Bay oil spill encompasses three major goals: (1) evaluate the cleanup techniques used at Buzzards Bay and recommend modifications and/or other techniques that could improve the future efficacy of cleanup under similar environmental conditions; (2) review the sampling effort and recommend how the usefulness and execution of future surveys can be improved; and (3) assess the acute short-term biological damage caused by the spill.

SECTION 2

CONCLUSIONS

When the difficulties imposed by the ice and snow conditions at Buzzards Bay and the lack of previous experience with spills in ice-infested waters are considered, the cleanup effort was commendable; roughly 89,000 liters (28%) of oil were recovered. Of the cleanup techniques used, shore-based vacuum skimming was most successful. Contaminated ice removal was least successful. Burning of oil pools was not used extensively but showed some promise. Modifications of some of the techniques used at Buzzards Bay and deployment of selected vacuum and burning equipment not used there could improve oil recovery in future spills under similar conditions. State-of-the-art regarding oil spill cleanup in cold climates is not well advanced.

The sediment and benthic sampling program was successful in providing indications of sediment contamination and acute biological effects. The absence of a single assigned individual with authority to coordinate and supervise the sampling and analytical programs of all involved agencies precluded adequate pre-planning, field quality control, standardized field procedures and interagency data exchange necessary to provide an assessment of the more subtle effects of the spill.

Acute biological effects that have been associated with previous No. 2 oil spills in Buzzards Bay were not observed during the 6 months following the 1977 Bouchard spill. The results of joint EPA/Massachusetts Marine Fisheries diving surveys and three separate analyses of available benthic data support this finding. The long-term, more subtle effects of the spill are presently being investigated by the Marine Biological Laboratory at Woods Hole under contract to NOAA.

The absence of acute adverse effects observed following this spill can probably be attributed to the presence of shore-fast and floating ice in the bay. The ice kept oil away from intertidal areas and released oil to the environment slowly and on a larger geographic scale than would be expected at other times of the year. In addition, the low metabolic rate of the marine biota during the winter months may have reduced organism uptake of hydrocarbons from the environment and mitigated the effects normally associated with a No. 2 spill.

SECTION 3

RECOMMENDATIONS

Modifications of the vacuum skimming technique to prevent the vacuum lines from freezing are recommended. In addition, expanded use of burning and the endless rope skimming techniques are recommended for future spills in similar environmental conditions. Only pooled oil should be collected; oil incorporated in ice should be allowed to go to sea. Removal of shorefast ice is not recommended. The Marco and the Lockheed skimmers should not be used under similar circumstances unless modified or used in a stationary position. Improved oil pool marking techniques and methods to enhance personnel safety are suggested as well. Adopting the above recommendations could improve cleanup efficiency at future spills; however, further research in modifying existing equipment and development of new equipment for all types of cold climates will be necessary if significant progress is to be made.

Future spill response sampling efforts can be improved by preplanning to define the criteria needed for identification of the biological effects and specifying the proposed method of data analysis. The field program should then be designed to provide data that will qualitatively and quantitatively support the analysis. Field equipment and procedures should be standardized, and procedures for quality control in the sampling program should be established. In order to implement this, a single individual should be assigned and adequate resources commited to coordinate and supervise the sampling programs of all involved agencies.

Ultraviolet fluorescense analyses can be valuable in delineating areas of oil concentration in sediments. Thus, it is recommended that in future spills when confirmation of the observed movement of oil is important to the design of the sampling effort, ultraviolet fluorescent analyses should be used for initial screening.

To eliminate the chance of discrepancies in interpretation of gas chromatogram and mass spectrometry results, only one chemical laboratory, either the EPA laboratory or one approved by the EPA, should be responsible for sample analyses. In the present case, two laboratories -- EPA and ERCO -- were involved.

Because of the problem of differentiating Bouchard oil from other petroleum sources, no further studies and/or monitoring to determine the long-term environmental effect of the spill are recommended. A benthic habitat characterization of Buzzards Bay is recommended to aid in planning sampling efforts in response to future oil spills in Buzzards Bay.

SECTION 4

BACKGROUND

An understanding of the circumstances and impact of previous spills in Buzzards Bay is useful to a damage assessment of the 1977 *Bouchard No. 65* spill at Cleveland Ledge. This section describes the most significant oil spills that have occurred in the bay since World War II, including the 1977 *Bouchard* spill, and the biological damage that resulted from each.

HISTORY OF OIL SPILLS IN BUZZARDS BAY

Buzzards Bay has been an important shipping lane for small tankers, freighters, and barge traffic since the completion of the Cape Cod Canal in 1914. New England coastal shipping regularly uses Buzzards Bay as a shortcut to move cargoes to ports north and south of Cape Cod. Ship traffic through Buzzards Bay and into Cape Cod Bay proceeds by passing through Cleveland Ledge Channel, Hog Island Channel, and Cape Cod Canal (Figure 1).

Rocky ledges and shoals on either side of Cleveland Ledge and Hog Island channels and their narrow passageways (Table 1) have resulted in numerous groundings. Compounding the physiographic hazards of Buzzards Bay are the severe weather conditions that occur frequently during the winter months and the strong tidal currents (more than 4 knots in the Cape Cod Canal).

Buzzards Bay has had a long history of shipping accidents, many of which have resulted in oil spills. The history, volume of oil spilled, and environmental damage have not been well documented except for large oil spills in recent years. The most notable of these spills was the grounding of the *Florida* in 1969. Minor spills from fishing boats, pleasure craft, and other ships have not been accurately recorded until recent years.

Late 1940's

In the late 1940's, a barge loaded with No. 2 fuel oil grounded off West Horse Neck Beach during the winter. West Horse Neck Beach is located at the western entrance to Buzzards Bay. The volume of fuel oil

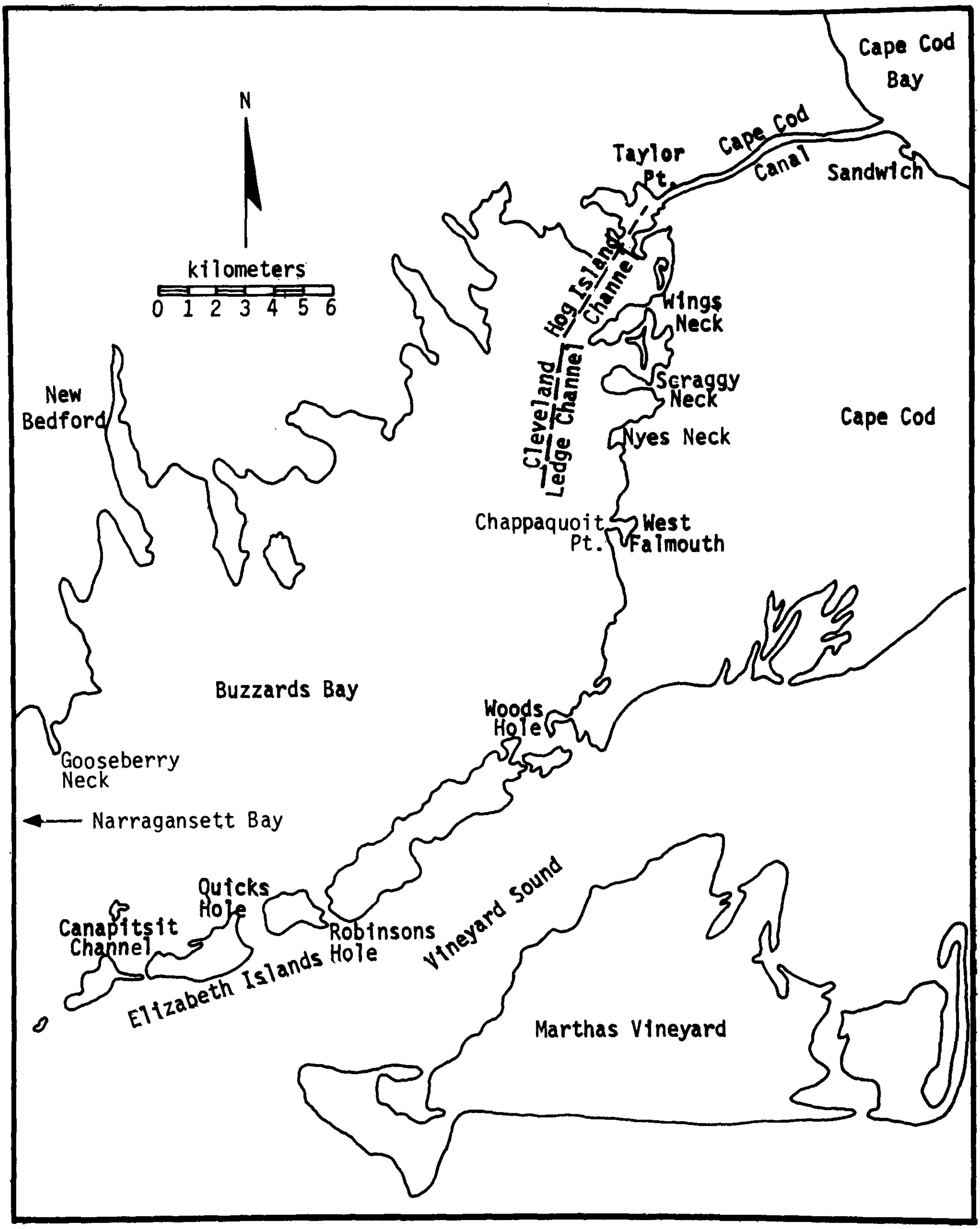


Figure 1. Buzzards Bay and vicinity.

spilled was not recorded. The effect of this spill on the shellfish beds of West Horse Neck Beach was significant. Dr. Cameron Gifford (personal communication, 1977) reported that the surf clam (Spisula sp.) received heavy mortality from the spill.

TABLE 1. PHYSICAL CHARACTERISTICS OF CHANNELS IN BUZZARDS BAY

Name	Width (meters)	Length (kilometers)	Depth at Mean Low Water (meters)
Cape Cod Canal	146	12.4	10
Hog Island Channel	153	7.4	10
Cleveland Ledge Channel	214	6.1	10

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. United States - East Coast, Buzzards Bay, Chart 13230, 28th Edition, January 1977.

Winter 1963

During the winter of 1963, a barge grounded near Cleveland Ledge, spilling an unknown quantity of No. 2 fuel oil. A moderate westerly wind and tides washed the oil ashore at Nyes Neck. Though the environmental damage was not recorded, fishermen observed sea birds feeding on dead fish. The fish mortality may or may not have been attributable to the oil spill.

September 15, 1969

On September 15, 1969, the barge Florida left Tiverton, Rhode Island, carrying approximately 2,519,000 liters of No. 2 fuel oil headed for the Northeast Petroleum Terminal at Sandwich, Massachusetts. The barge was under tow by the Narragansett Marine Salvage Company tug, New York Central No. 34.

During the evening, the radar failed while the tug and barge were proceeding up Buzzards Bay towards the Cape Cod Canal. Later, in foggy weather, the tow line and rudder broke. At approximately midnight, both the tug and barge ran hard aground on submerged rocks 180 meters to the left of Little Island, located near the mouth of West Falmouth Harbor.

Approximately 698,000 liters of No. 2 fuel oil escaped through the barge's ruptured hull. The southwest winds and tides pushed the oil towards Nyes Neck, about 3.2 kilometers to the north of the grounding. Incoming and outgoing tidal cycles resulted in the contamination of shorelines from West Falmouth to Nyes Neck.

Massive mortalities of fish, shellfish, and smaller invertebrates were observed during the week following the spill (Blumer, 1971). Within a month, the area hardest hit by the spill was described as a "biological desert." In May 1970, 8 months after the spill, oil having the same characteristic as fresh No. 2 oil from the _Florida_ barge could still be found in the sediments. By fall, 1970, the more common species (primarily worms, snails, and clams) were repopulating the site, but in low numbers (Blumer, 1971).

The fishing grounds between Chapoquoit Point and Nyes Neck, including all of the Herring River, Wild Harbor, and West Falmouth Harbor, were closed immediately after the _Florida_ spill. Heavy wind and wave action mixed the oil into the water column resulting in widespread mortality of the lobsters, clams, and scallops in this area. These grounds were reopened on October 25, 1969, after scallop meats were tested by spectrophotometer and found to be free of oil; they were closed again when scallop processors complained of an oily taste in meats taken from the Falmouth region. The next harvestable scallop crop (1970) after the spill was found to be stunted and contained as much oil in its tissues as did the adult scallops of the previous year. On June 18, 1970, Megansett Harbor was closed to shellfishing for an indefinite period bringing the total area of prohibited fishing ground to 5,000 acres offshore and 500 acres of marsh. Officials estimated that damage to the local shellfish resources one year after the accident amounted to $118,000 (Blumer, et al., 1971). In June 1972, some of the fishing beds that had been closed for approximately 2 years were once again reopened for fishing. Some areas such as Silver Beach Harbor are sill closed at the time of this writing -- 8 years later. Long-term studies of the _Florida_ spill are now documenting the persistence of the oil in the marine environment and its continued adverse effect on commercial and noncommercial organisms (Stegeman and Sabo, 1976; Krebs and Burns, 1977).

October 9, 1974

On October 9, 1974, the barge _Bouchard No. 65_, loaded with No. 2 fuel oil, struck rocks near Anchorage "C". Anchorage "C" is located to the west of Cleveland Ledge Channel midway up the channel. Three tanks were ruptured, causing an estimated loss of 17,400 liters of No. 2 fuel oil. A moderate northeast wind and tide transported and deposited the floating oil between Scraggy Neck and Wings Neck. During that week, oil was reported at Hospital Cove, Windsor Cove, and Redbrook Harbor.

The biota of southern Bassetts Island and northern portions of Scraggy Neck were the most seriously impacted by the spill. This area is known for its recreational clamming activities. A survey conducted on October 11, 1974, revealed mortality to polychaetes, small crustaceans, razor clams, and surf clams. Subsequent surveys indicated that the mortality to razor clams may have exceeded 1,000 bushels (Grice, 1974). The quahog and scallop resources in the area did receive some mortality but did not appear to affect standing crop seriously.

THE BOUCHARD NO. 65 SPILL, JANUARY 1977

Late in the afternoon on January 28, 1977 the barge Bouchard No. 65, transporting 11,900 liters of No. 2 fuel oil, ran aground approximately 0.6 kilometers due west of Cleveland East Ledge after the tug Frederick E. Bouchard left the barge to break through the dense ice floes ahead. It was discovered that the Bouchard holed four of its five port side tanks. Because it was feared that the barge would sink in deep waters, it was moved 5.6 kilometers from Cleveland East Ledge Light and grounded on sand and in shallow waters 0.3 kilometers south of Wings Neck.

At 7:30 a.m. on January 29, the barge Bouchard No. 85, under tow by the tug Crusader, was moored along side the stricken barge for fuel transfer operations. Because both barges were under ice pressure during the fuel transfer operations, the USCG cutters Towline and Bittersweet broke up the ice pack. After oil was removed from the Bouchard No. 65, the two barges were moved to the Massachusetts Maritime Academy at Taylor Point and much of the cargo offloaded.

At noon, January 30, the barges departed the Massachusetts Maritime Academy for the White Fuel Terminal at Castle Island in South Boston. They arrived there at approximately midnight, January 31. On February 2, fuel transfer from the barges was completed. The transfer tank gauging revealed that about 314,500 liters (81,000 gallons) of No. 2 fuel oil was missing and believed spilled. The spill was then reclassified from a major to a medium oil spill since it was less than 387,500 liters (100,000 gallons). The chronology of the barge movement is given in Table 2 and shown in Figure 2.

The biological effects resulting from this spill are discussed in Section 8.

TABLE 2. CHRONOLOGY OF THE MOVEMENTS OF THE BOUCHARD BARGE NO. 65

Date	Time	Event
January 28	6:18 p.m.	Coast Guard Station at Woods Hole received call from the Bouchard No. 65 that it had run aground.
	10:25 p.m.	Tug Crusader with Bouchard No. 85 was enroute to Buzzards Bay to offload cargo.
January 29	3:40 a.m.	Both barges were alongside each other at Wings Neck.
	7:30 a.m.	The two barges are securely moored alongside each other.
	9:25 a.m.	Cargo transfer from Bouchard No. 65 to No. 85 commenced.
	6:50 p.m.	The two barges are moored at the Massachusetts Maritime Academy and offload of remaining cargo commenced.
January 30	noon	Barges departed Massachusetts Maritime Academy for White Fuel Terminal, Castle Island, South Boston, Massachusetts.
January 31	10:46 p.m.	Both barges moored at the White Fuel Terminal.
February 2	6:51 p.m.	Offloading of both barges at White Fuel Terminal completed with a total product loss of 314,000 liters.

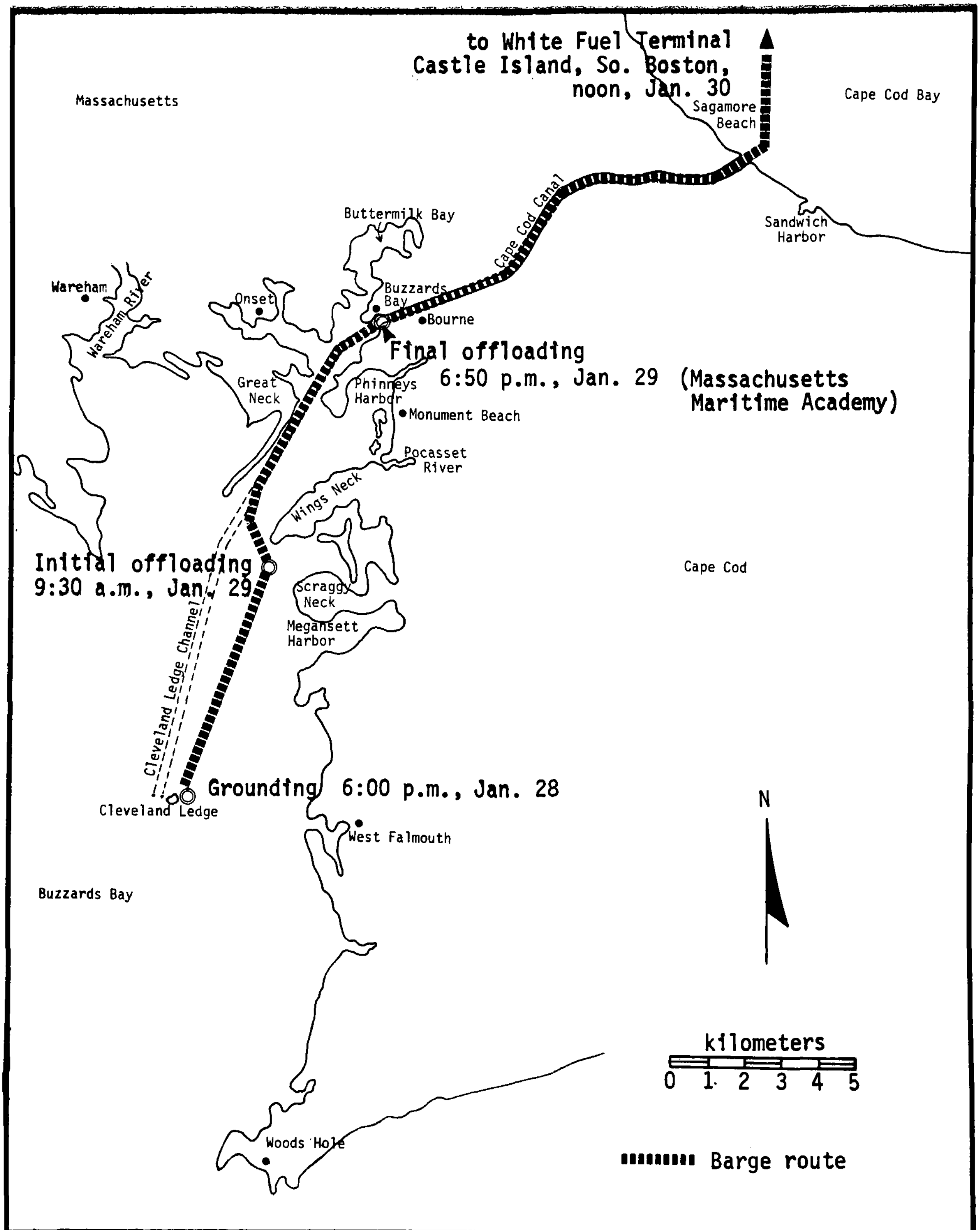


Figure 2. Barge movement.

SECTION 5

ENVIRONMENTAL SETTING

This section describes Buzzards Bay and its surroundings and the weather conditions (normal and 1977), tidal currents, and biological and socioeconomic resources of the area. This information applies to the evaluation of cleanup operations in Section 6 and provides the baseline data for the damage assessment of Section 8.

PHYSIOGRAPHY

Buzzards Bay is an elongated nonestuarine bay in southeastern Massachusetts. The terrain surrounding Buzzards Bay is predominately gently rolling hills, generally less than 30 meters above sea level. The terrain, covered by scrub wood, reforested fields, and brush land, comprises a drainage basin of approximately 980 square kilometers. Its low topography and subsequent poor drainage have created numerous swamps and bogs.

The most widely known physical features adjacent to Buzzards Bay are Cape Cod to the east, Narragansett Bay to the west, and Vineyard Sound to the south as shown in Figure 1. Buzzards Bay is separated from Vineyard Sound at the bay's south border by the Elizabeth Islands. These islands are intersected by four navigable passageways: Quicks Hole, Woods Hole, Robinsons Hole, and Canapitsit Channel. Quicks Hole and Woods Hole are the most navigable and therefore most often used. Robinsons Hole and Canapitsit Channel are narrow passages used primarily by small boats. The main shipping passage into Buzzards Bay, however, is southwest, between the Elizabeth Islands and Gooseberry Neck.

Buzzards Bay is approximately 32 kilometers long by 19 kilometers wide, covering about 620 square kilometers. At mean low water, the bay's depth ranges from about 18 meters at the mouth near Gooseberry Neck, to approximately a meter at its headlands near Cape Cod Canal. Average depth is 11 meters. Cape Cod Canal, connecting Buzzards Bay with Cape Cod Bay, is about 13 kilometers long and 10 meters deep (MLW). Two channels to the canal -- Cleveland Ledge and Hog Island -- have been dredged to a depth of 10 meters (MLW).

Buzzards Bay and the surrounding area were formed by the glacial till left by the advance and retreat of the Wisconsin icesheet more than

10,000 years ago. The glacier created most of the gravel bluffs at the bay's headlands as well as many of the bay's numerous shoals and submerged rocky formations.

The combination of glacial action and outwash deposits has created a coastline with numerous bays and coves. Many of these provide excellent sheltered anchorages for both pleasure boats and commercial ships.

Cape Cod and Elizabeth Islands act as a protective barrier against long-period ocean waves, created by storms in the Atlantic Ocean, that endanger unprotected boat anchorages. Despite this barrier, storm waves do occur in the Buzzards Bay area.

CLIMATE

Seasonal Norm

The nearby Atlantic Ocean is a major factor in determining the climate of Buzzards Bay. The Atlantic moderates temperatures: in winter precipitation usually falls as rain rather than snow; in summer, sea breezes cool otherwise hot days. In early fall, severe tropical coastal storms sometimes deliver destructive winds to the area.

The average yearly temperature in the Buzzards Bay area is 10°C (50°F), ranging from 8.3°C (47°F) in 1917 to 12.2°C (54°F) in 1949. February is usually the coldest month with a mean temperature near -1.7°C (29°F), while July is the hottest month, with a mean temperature of 21.6°C (71°F). Subzero (°C) temperatures in Buzzards Bay occur approximately 120 days per year, mostly from late November to late March. Extremely cold weather (less than -18°C) seldom occurs, averaging less than 1 day per month from December through February. The lowest temperature ever recorded in the region was -27.2°C (-17°F). During severe winters, the near-shore waters in the upper bay headlands freeze, requiring ice-breaking activity by the U.S. Coast Guard to keep the shipping lanes and channels open. The normal range of seawater temperature in Buzzards Bay is from 19.4°C (67°F) in the summer to 0.6°C (33°F) in the winter.

Snow fall in the Buzzards Bay area normally occurs from the end of November until mid-March. The average snow fall for a winter season is 91 centimeters, ranging from an average of 30 centimeters in 1937 to 178 centimeters in 1948. The months of greatest snow fall are February (averaging 25 centimeters) and January (averaging 23 centimeters). The record snow fall for any month (January 1948) is 76 centimeters.

The Winter of 1976-1977

From December 1976 to early February 1977, an arctic coldfront covered most of the eastern seaboard, causing record and near record low temperatures in most of these regions, including Buzzards Bay. A comparison between the average climate conditions and those existing before, during, and after the oil spill at Buzzards Bay are summarized in Table 3.

TABLE 3. COMPARATIVE METEOROLOGICAL DATA

Item	Historical		1977	
	January	February	January	February
Temperature °C				
Daily average	- 1.1	- 1.7	- 6.1	- 1.1
Average daily minimum	- 5.0	- 4.4	-10.6	- 4.4
Average daily maximum	1.7	4.4	- 1.7	2.8
Highest	22.2	20	8.3	10.6
Lowest	-25.0	-27.2	-18.9	-11.1
Precipitation, cm				
Snowfall	23.7	25.4	35.6	29.0
Water equivalent	8.94	8.76	9.91	7.29
Wind Speed, kph and Direction				
Mean speed	18.8	19.3	23.2	18.8
direction	NW	NNW	W	SW
Fastest speed	74	74	58	52
direction	S	SSW	WSW	SW
Number of days with heavy fog	2	2	4	4

The daily temperature for January 1977 was below average. The minimum and maximum daily temperatures were 5.6°C (10°F) and 3.3°C (6°F) below normal, respectively. February 1977 temperatures were about average. Snowfall for January and February 1977 was 12.2 and 3.6 centimeters higher than average, respectively.

Wind speeds during January 1977 were 6 kilometers per hour higher than average, but returned to normal during February. The combination of very cold temperatures and higher than normal wind speeds created a significant wind chill factor for January 1977.

The unusually cold temperatures of the winter of 1976-1977 created an ice cover over almost all of the nearshore regions in Buzzards Bay. The ice sheet even extended away from the nearshore region and covered most of Cleveland Ledge and Hog Island Channels. Not until February did this ice sheet start to melt and break up, creating ice floes that were carried by the predominant currents through Cape Cod Canal.

The day-by-day summary of the temperature and wind conditions for the Wings Neck area from 5 days preceding the spill and 6 days following termination of cleanup operations is shown in Table 4. The winds and temperatures during the initial cleanup operations (January 29 to Feburary 9) were considerably stronger and colder than normal. Temperatures averaged about -6.1°C (21°F), or 5°C (9°F) colder than normal; and wind velocities averaged 26 kilometers per hour, or 6 kilometers per hour faster than normal. The combination of these two factors imposed severe wind chill factors on the cleanup and sampling personnel and impaired operation of the mechanical equipment.

TIDES AND TIDAL CURRENTS

Ocean tides have access to Buzzards Bay through its mouth between the Elizabeth Islands and Gooseberry Neck, through the several passageways of the Elizabeth Islands, and through Cape Cod Canal.

The average tidal range in Buzzards Bay is approximately 1.2 meters. Though occurring about the same time in Vineyard Sound, the tidal range is about 0.6 meters less than in Buzzards Bay. This differential in water level creates a current in excess of 2 knots flowing through the narrow passageways of the Elizabeth Islands.

Tidal currents entering Buzzards Bay directly average from 1 to 1.3 knots; they are weaker than those passing through the Elizabeth Islands passageways because of the width of the bay mouth. A current approximately 1.6 kilometers wide parallels the northern shore of these islands, terminating near Woods Hole.

The tidal currents in the central portion of Buzzards Bay seldom exceed 0.6 knots. These currents seem not to establish a north-south directional flow pattern as one might expect, but are variable in orientation. Their flow is probably slowed by locally submerged and protruding land features and water depth.

TABLE 4. TEMPERATURE AND WIND SPEED FROM JANUARY 25 TO FEBRUARY 28, 1977*

	Temperature °C			Wind speed (knots) and direction		
	Average	Maximum	Minimum	Average	Maximum	Minimum
January:						
25	2.8	5.6	.6	7	12 NW	4 N
26	- 2.2	0	- 5.0	15	21 W	11 SW
27	- 1.7	2.8	- 3.9	19	36 WSW	11 WSW
28	- 2.8	2.8	- 7.8	13	28 SSE	2 SW
29	- 7.8	- 1.1	-12.8	23	35 NW	17 SWS
30	-10	- 6.1	-12.8	14	18 WNW	12 SW
31	-11.7	- 7.2	-12.8	17	26 WSW	13 WSW
February:						
1	- 6.7	- 1.1	-10.0	18	22 WSW	14 SW
2	- 7.8	- 3.9	-12.2	14	22 W	8 NW
3	- 5.0	- 1.1	- 7.8	11	16 SW	3 WSW
4	0	2.2	- 2.2	11	19 W	6 NW
5	0	1.1	- 2.2	8	11 NNW	4 NE
6	- 5.0	- 2.8	-10.0	18	23 WNW	13 NNW
7	- 7.8	2.8	-11.1	14	16 NW	12 SW
8	- 6.1	1.1	-11.1	10	14 NW	8 NW
9	- 4.4	0	-12.2	12	18 SW	5 SW
10	1.7	7.2	2.2	8	14 SW	3 WSW
11	0	5.0	3.9	9	18 SSW	0
12	2.2	8.9	- 1.1	6	10 SSW	1 NW
13	3.9	7.2	2.2	10	16 SW	5 SW
14	2.2	5.0	- 1.1	11	17 SW	5 W
15	1.1	2.2	1.1	8	16 NE	0
16	- 3.9	- 1.1	- 7.8	9	12 NW	4 NW
17	- 8.3	0	-11.1	15	18 NW	9 NW
18	- 5.6	- 1.1	-10.0	8	12 SSW	2 S
19	- 1.1	2.2	- 5.0	7	10 SSE	3 SSW
20	1.1	2.2	0	9	18 NNE	2 NE
21	0	2.8	- 2.8	19	22 NW	16 NE
22	- 2.8	0	- 8.9	14	18 NW	12 SW
23	2.8	4.4	0	8	12 NE	3 NNW
24	1.7	3.3	0	10	18 E	3 ENE
25	5.6	8.9	3.3	22	32 SW	10 WNW
26	5.0	8.3	1.7	11	17 WNW	6 SW
27	5.6	9.4	1.7	14	28 SSE	2 NE
28	6.1	8.9	0	14	22 SW	7 NSW

*Army Corp of Engineers Weather Station, Cape Cod Canal.

Tidal currents at the headlands of Buzzards Bay are caused by differences in time and range of tides in Buzzards and Cape Cod bays. The tide in Cape Cod Bay has a mean range of approximately 2.7 meters and occurs about 3 hours later than the 1.2 meter tide in Buzzards Bay. This difference results in a strong current through the Cape Cod Canal from Buzzards Bay. Though currents up to 5.3 knots have been recorded at midchannel of Cape Cod Canal, 4 knots is the average. Tidal currents reach their maximum strength about 1 hour after low and high water in Cape Cod Bay because of the time difference between low and high water in the bays.

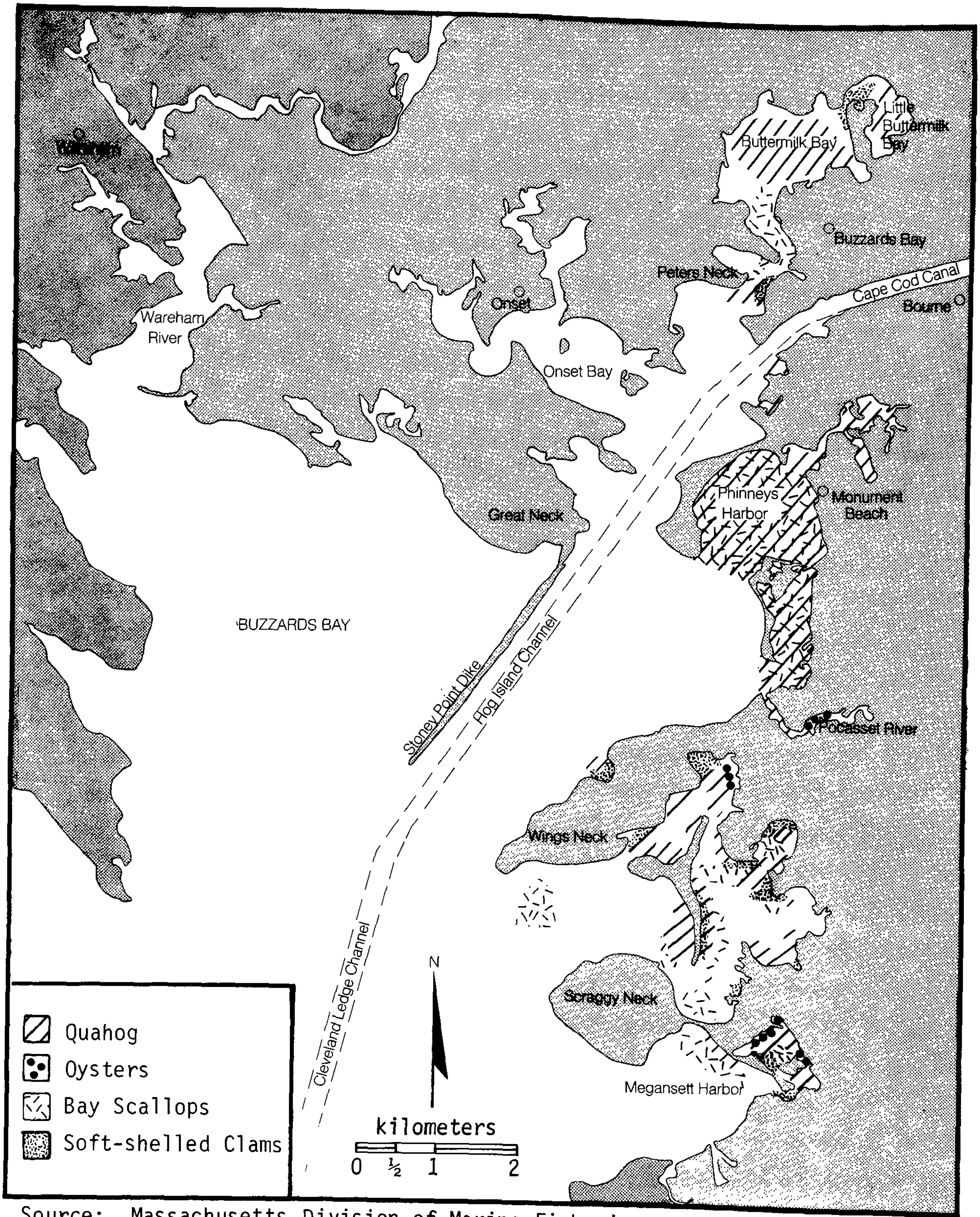
BIOLOGICAL RESOURCES

According to Sanders (1958), the benthic communities of Buzzards Bay are directly associated with sediment type. Because Buzzards Bay is protected from heavy wave action, sand and sand/silt substrates are the predominant subtidal sediments. In the vicinity of Cape Cod Canal and Elizabeth Island, strong currents have removed the finer sediments leaving open stretches of coarse sand and gravel deposits.

Sanders (1958) identified two habitat categories in the bay: (1) a group in sediments having a high silt content and dominated by the lamellibranchs and polychaetes, and (2) a group restricted to sandy sediments and characterized by amphipods. Sanders found that filter feeders made up most of the benthos in sandy sediments while deposit-feeders dominated the finer sediments. Sanders (1960) demonstrated that eight or nine species are consistently found in large numbers in the benthos of Buzzards Bay and that the bay is characterized by the dominance of a few of these species.

Finfish data for upper Buzzards Bay are scarce. Commercial and net fishing are prohibited in the bay but a significant amount of sport fishing does occur. The most common migrating fish taken by recreational fishermen are mackerel, striped bass, bluefish, scup, and sea bass. Buzzards Bay has two finfish migration periods: the spring migration out extending from mid-March to mid-July, and the fall migration which can continue into early November. Buzzards Bay also supports an active bottom fishery of which tautog, flounder, and sculpin are the most commonly taken species.

Buzzards Bay is a highly productive shellfish habitat well known for its commercial and recreational shellfish harvest. The quahog, soft-shelled clam, oyster, and scallop are the most sought after species. Lobsters are also found in Buzzards Bay. Recreational fishing of lobsters accounts for the majority of the lobster landings. Figure 3 presents the prime commercial and recreational shellfish beds in the study area. Shellfish harvested from these beds are delivered to shellfish dealers in Bourne, Wareham, or Falmouth.



Source: Massachusetts Division of Marine Fisheries.

Figure 3. Commercial and recreational shellfish beds.

The quahog (*Mercenaria mercenaria*) is a hard-shell clam that feeds by filtering minute plant life (primarily diatoms) from the water column through its digestive system. The quahog is essentially a warm water mollusk. Massachusetts marks the northern end of its range. The quahog quite naturally adapts to Buzzards Bay because its numerous inlets and bays have a medium tidal flux, warm waters, and abundant food. Of the 8,000 acres of quahog territory in Buzzards Bay, the Bourne fishing area accounts for approximately 2,500 acres and Wareham, 1,300 acres. The Falmouth area contains only small patches of good quahog territory (Massachusetts Division of Marine Fisheries).

The scallop (*Argopectin irradians*) feeds like the quahog but does not bury itself in the sediments. The scallop can move by swimming through the water column (via opening and closing its shell). Scallops have been known to migrate over short distances. Massachusetts marks the northern end of the commercial bay scallop fishery. The scallop prefers quiet waters protected from heavy winds and storms. Scallops may suffer significant mortality during severe winters (Massachusetts Division of Marine Fisheries). Buzzards Bay contains approximately 11,000 acres of scalloping territory of which the Wareham area includes 2,500 acres and the Bourne area 3,000 acres. The Falmouth fishing area in Buzzards Bay contains only small patches of scallop territory.

The soft-shelled clam (*Mya arenaria*) is found from the Carolinas to the Arctic Ocean. The clam is found on exposed tidal flats as well as below the low water mark and prefers protected areas. Because Buzzards Bay does not offer large areas of soft-shelled clam habitat, the clam industry has never reached the status of the quahog, scallop, or oyster fishery. The study area lacks the tidal flats and silt-sand habitat that the clam prefers.

The oyster (*Crassostrea virginica*) and the lobster (*Homarus americanus*) have been overfished in Buzzards Bay waters. These shellfish species, however, are in high demand in an area capable of high shellfish production. (Arnie Carr, personal communication, March 1978).

There are two methods to determine the productivity of a shellfish fishery. The first -- harvestable crop -- is an estimate of the legal-size shellfish existing in a fishing area. Table 5 presents the harvestable crop for West Falmouth Harbor, Wild River Harbor, Megansett-Squeteaque Harbor, and Red Brook Harbor for the harvest years 1969, 1972, and 1974. These estimates are made from diving and grab surveys by the Massachusetts Division of Marine Fisheries. The second method -- annual shellfish harvest -- is an accounting of bushels of shellfish delivered to a landing area. Tables 6, 7, and 8 present harvest data from 1968 to the present at Bourne, Wareham, and Falmouth. The annual shellfish harvest method incorporates a number of variables other than shellfish availability, including the size of fishing fleet, market parameters and closure

TABLE 5. LEGAL-SIZE SHELLFISH HARVESTABLE IN THE STUDY AREA IN 1969, 1972, and 1974 (in bushels)

Area	Quahog			Soft-shell Clam			Bay Scallop		
	1969	1972	1974	1969	1972	1974	1969	1972	1974
West Falmouth Harbor		39	3,197[1]		0[3]	0	7,186	830	0
Wild Harbor River	8	0	2.5	829	95	651[2]		0	0
Megansett-Suueteague Harbors		664	756		0[3]	0[3]		<300	< 1
Red Brook Harbor		3,886	3,219		>56	>46		9,760	18
Total	8	4,589	7,174.5	829	>151	>697	7,186	<10,890	19

[1] Over 2,135 bushels of quahogs transplanted into harbor.
[2] Survey completed in May 1975.
[3] Clams scattered: in West Falmouth Harbor and Megansett-Squeteague Harbors, <6 bushels in 1972 and 1 bushel in 1974.

Source: Massachusetts Division of Marine Fisheries Survey, 1977 (unpublished).

TABLE 6. ANNUAL SHELLFISH HARVEST
BOURNE (in bushels)

Year	Catch	Quahog	Soft clam	Oyster	Scallop
1977	Recreational				
	Commercial		Unknown		
Total					
1976	Recreational	1,379	50	400	300
	Commercial	2,016			2,044
Total		3,395	50	400	2,344
1975	Recreational	1,364		400	952
	Commercial	4,800			1,396
Total		6,164	0	400	2,348
1974	Recreational	1,500	500	300	355
	Commercial	7,488			3,000
Total		8,988	500	300	3,355
1973	Recreational				
	Commercial		Unknown		
Total					
1972	Recreational	824	1,242	413	12,000
	Commercial	3,280			28,000
Total		4,104	1,242	413	40,000
1971	Recreational				
	Commercial		Unknown		
Total					
1970	Recreational				
	Commercial		Unknown		
Total					
1969	Recreational	1,840	3,667	466	7,411
	Commercial	2,528			1,947
Total		2,368	3,667	466	9,358
1968	Recreational				
	Commercial		Unknown		
Total					

Source: Massachusetts Division of Marine Fisheries Survey, 1977. (unpublished).

TABLE 7. ANNUAL SHELLFISH HARVEST
WAREHAM (in bushels)

Year	Catch	Quahog	Soft clam	Oyster	Scallop	Razor clam	Mussel
1977	Recreational						
	Commercial			Unknown			
Total							
1976	Recreational						
	Commercial			Unknown			
Total							
1975	Recreational	10,000	6,000	200		50	100
	Commercial	1,300					
Total		11,300	6,000	200		50	100
1974	Recreational	10,000	5,000	100		50	100
	Commercial	1,000					
Total		11,000	5,000	100		50	100
1973	Recreational	10,000	3,000	100	800	50	50
	Commercial	800					
Total		10,800	3,000	100	800	50	50
1972	Recreational						
	Commercial			Unknown			
Total							
1971	Recreational	10,000	3,000	100	10,000		
	Commercial	325			18,600		
Total		10,325	3,000	100	28,600		
1970	Recreational						
	Commercial			Unknown			
Total							
1969	Recreational	15,000	4,000	50	2,000		
	Commercial	400			10,600		
Total		15,400	4,000	50	12,600		
1968	Recreational	15,000	4,000	50	25		
	Commercial	1,000			300		
Total		16,000	4,000	50	325		

Source: Massachusetts Division of Marine Fisheries Survey, 1977 (unpublished).

TABLE 8. ANNUAL SHELLFISH HARVEST
FALMOUTH (in bushels)

Year	Catch	Quahog	Soft clam	Oyster	Scallop
1977	Recreational				
	Commercial		Unknown to date		
Total					
1976	Recreational	4,523	600		1,171
	Commercial	7,000	300	———	900
Total		11,523	900		2,071
1975	Recreational				
	Commercial		Unreported		
Total					
1974	Recreational	3,820	1,233		1,000
	Commercial	4,500	320	———	900
Total		8,320	1,553		1,900
1973	Recreational	2,604	1,639		507
	Commercial	3,720	600		615
Total		6,324	2,239		1,122
1972	Recreational				
	Commercial		Unreported		
Total					
1971	Recreational	2,000	1,000		1,000
	Commercial	4,455	375		1,188
Total		6,455	1,375		2,188
1970	Recreational				
	Commercial		Unknown		
Total					
1969	Recreational				
	Commercial		Unknown		
Total					
1968	Recreational				
	Commercial		Unknown		
Total					

Source: Massachusetts Division of Marine Fisheries Survey, 1977 (unpublished).

of shellfish beds due to pollution. Shellfish harvests have been on the decline since 1968. Overfishing has been one of the major reasons for the decline.

SOCIOECONOMIC RESOURCES

For the purposes of a socioeconomic inventory, the study area is defined as the coastal waters and communities within Townships of Wareham, Bourne, and Falmouth (Figure 4). This area at the northeast end of Buzzards Bay, was the center of all the oil spill and cleanup activities. All of the shellfish bed closures that resulted from the spill fall within the jurisdictions of these three towns.

Historically, the study area's economic base has been heavily dependent on fishing; however, it is currently based primarily on the recreation and tourist trades. This region of Buzzards Bay, especially around Wings Neck, is still a marginally productive area for marketable fish and shellfish; however, its potential as a commercial fishery has been overshadowed by its newer recreation and tourist trades. There is also some small industry and one military base (Otis Air Force Base, Bourne) within the study area.

Excluding decreases in onbase military personnel during the 1960-1970 decade, the study area has experienced a small net in-migration. Although bordering the rapidly developing tourist and recreation areas in and around Cape Cod, the area will remain one of slow growth for the next 10 to 20 years according to the New England River Basins Planning Commission (1975, a, b, c). The area presently shows significant variation in seasonal population, employment, and income from tourist and recreational industries; it is anticipated that these industries will play an increasingly important role in the area's economy. The shellfish beds of the area have significant additional potential for intensive aquaculture uses although no extensive operations currently exist.

Selected socioeconomic characteristics of the study area are presented in Table 9.

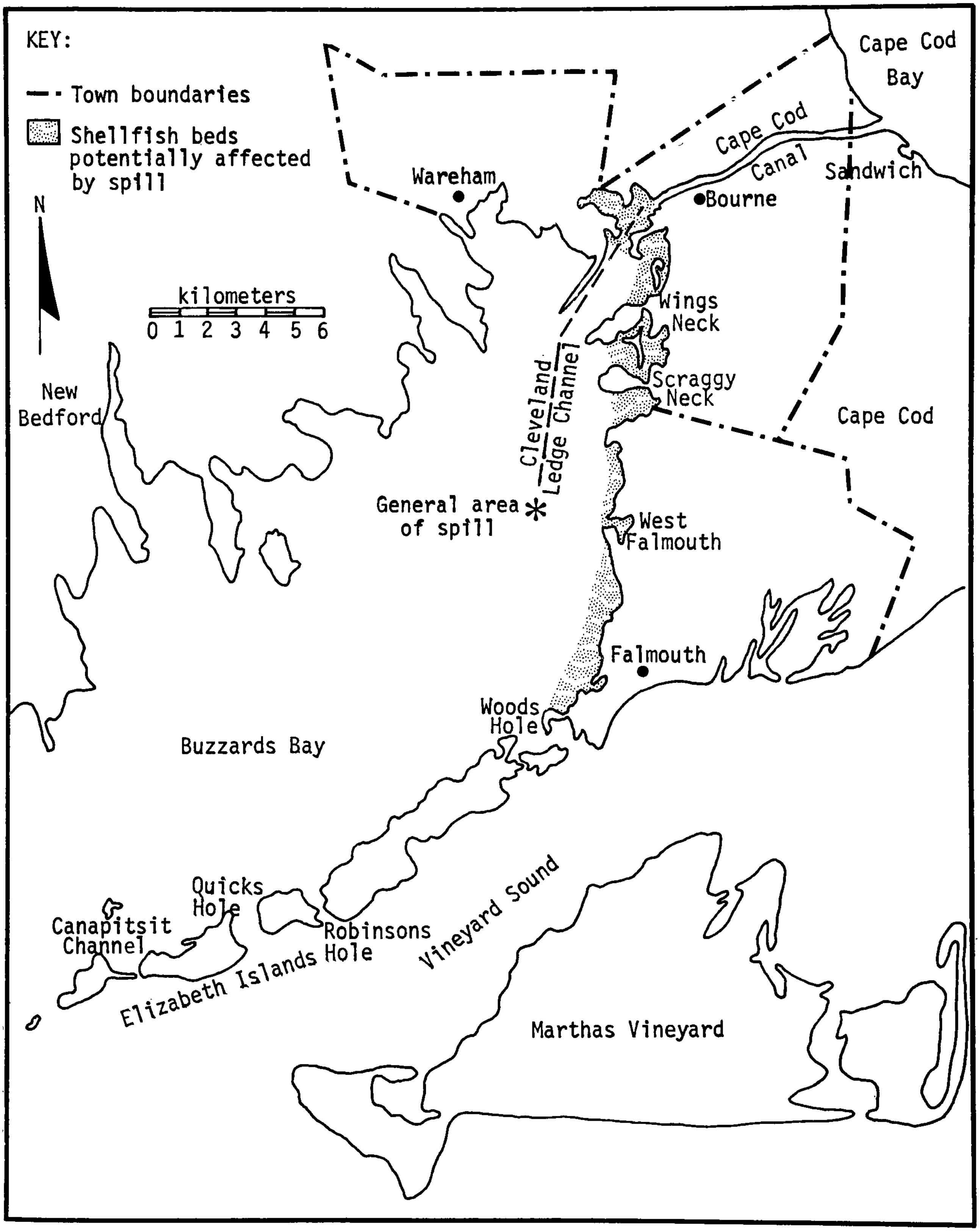


Figure 4. Socioeconomic study area.

TABLE 9. SELECTED SOCIOECONOMIC CHARACTERISTICS OF THE TOWNS OF WAREHAM, BOURNE, AND FALMOUTH, 1970-1976

	Population[1] (1970)	Work Force[2] (1974)	Annual Payroll (1,000 $)[2] (1974)	Median Family Income[1] (1970)	Annual Shellfish Harvest (bushels)[3]		Recreational Fleet[4] (1972)	Retail Trade Industry[5]	
					Recreational (1976)	Commercial (1976)		Number of Employees (1972)	Sales (1,000 $) (1972)
Study Area	34,034	9,843	$66,709	--	24,773	13,560	--	3,104	$126,994
Wareham	11,492	2,198	14,936	$8,998	16,350[6]	1,300[6]	--	684	27,946
Bourne	6,600[7]	1,973	11;416	7,264	2,129	4,060	1,150	775	31,065
Falmouth	15,942	5,672	40,357	8,324	6,294	8,200	2,185	1,645	67,983

Sources: [1]U.S. Bureau of Census, Census of Population (1970).
[2]Divsion of Employment Security, New Bedford and Hyannis Regional Branches (1974).
[3]Annual Shellfish Harvest Inventory for Wareham, Bourne, and Falmouth (1968-1977).
[4]*Air photo count of the U.S. Corps of Engineers*, 1972, as reported in New England River Basins Commission (1975).
[5]U.S. Bureau of Census, Census of Business (1972).
[6]1976 Estimates of Shellfish harvest are unavailable, these figures show 1975 harvest.
[7]Approximation starts with census count of 12,636 and excludes approximately 6,000 to account for onbase personnel at Otis Air Force Base.

SECTION 6

CLEANUP

This section describes the cleanup techniques used at Buzzards Bay and evaluates their effectiveness. Recommended modification of each technique, suggestions for alternative cleanup methods, and measures to improve personnel safety are also presented. The primary aim of this evaluation is to give future cleanup personnel faced with similar conditions the benefit of the Buzzards Bay experience. It is hoped that with this information, future cleanup efforts will be more efficient and effective.

On the morning of January 29, Cannon Engineering Corporation of West Yarmouth was hired by the U.S. Coast Guard as the lead cleanup contractor when the Bouchard Transportation Company would not accept the cleanup responsibility. Later that day Coastal Services, Incorporated of Braintree, Massachusetts and Jet Line Services, Incorporated of Stoughton, Massachusetts were hired as subcontractors to assist in the cleanup operation.

A contingent of the USCG Atlantic Strike Team, consisting of an officer and five enlisted men, arrived on the scene at noon on January 29. Early the next morning, the Pacific Coast Strike Team arrived with a Lockheed coldwater skimmer. This team consisted of an officer and three enlisted men.

On January 30, a meeting was held with the cleanup contractors, the U.S. Environmental Protection Agency, the strike teams, U.S. Coast Guard officials, the Massachusetts Division of Water Pollution Control, and the Bourne Shellfish Warden to establish cleanup priorities and responsibilities.

On the same day, the cleanup was initiated at Wings Neck Point. Figure 5 shows where and when the major cleanup operations occurred. Table 10 lists the cleanup techniques discussed in this section and the dates that these techniques were employed.

PROBLEMS POSED BY THE SPILL

The oil spill at Buzzards Bay posed unique cleanup problems. The combination of unusual weather conditions and limited experience in

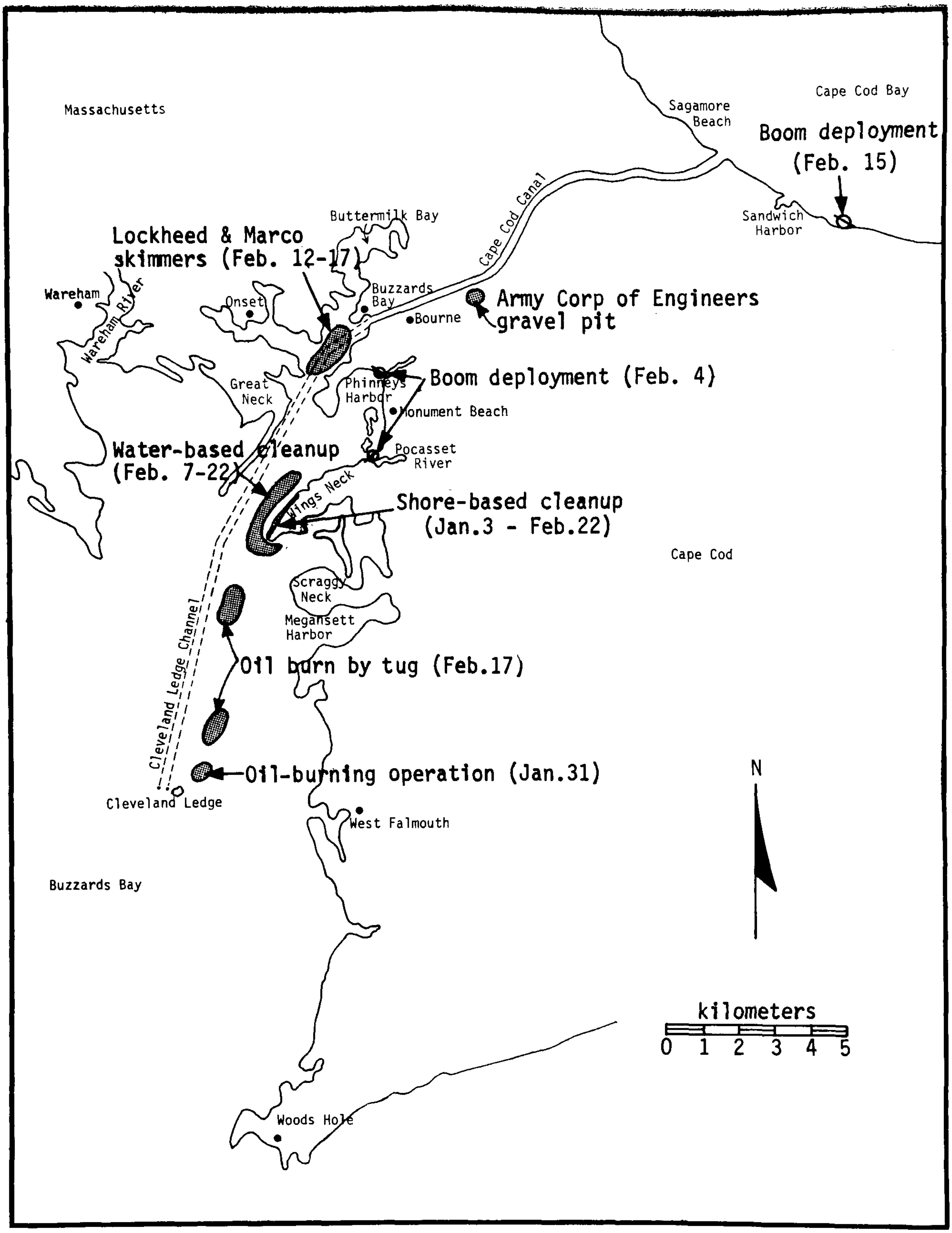


Figure 5. Sites of major cleanup activities.

TABLE 10. CHRONOLOGY OF CLEANUP ACTIVITIES

	Techniques								Weather Notes
	Vacuum Skimming		Burning	Lockheed Clean-Sweep Skimmer	Marco Recovery System	Ice Removal	Booms	Endless Rope Skimmer	
	Shore	Water							
Jan. 30	↑								Windy
31	|		↕			↑			Windy
Feb. 1	|					|		↑	Windy
2	|					↓		|	--
3	|	↑						|	--
4	|	|					↕	↓	--
5	↓	↓							--
6									--
7									--
8	↑	↑							--
9	|	|				↑			--
10	|	|				|			Warming trend
11	|	↓		↑	↑	|			
12	↓	Decreased Activity		|	|	↓			--
13	Decreased Activity	Decreased Activity		↓	↓				--
14	Decreased Activity	Decreased Activity							--
15	Decreased Activity	Decreased Activity					↕		--
16	Decreased Activity	Decreased Activity							--
17	Decreased Activity	Decreased Activity							--
18	Decreased Activity	Decreased Activity	↕						--
19	Decreased Activity	Decreased Activity							--
20	Decreased Activity	Decreased Activity							--
21	Decreased Activity	Decreased Activity							--
22	Decreased Activity ↓	Decreased Activity ↓							--

dealing with oil spills in ice-infested waters resulted in a cleanup effort that required the implementation of techniques more commonly used in spills in temperate climates.

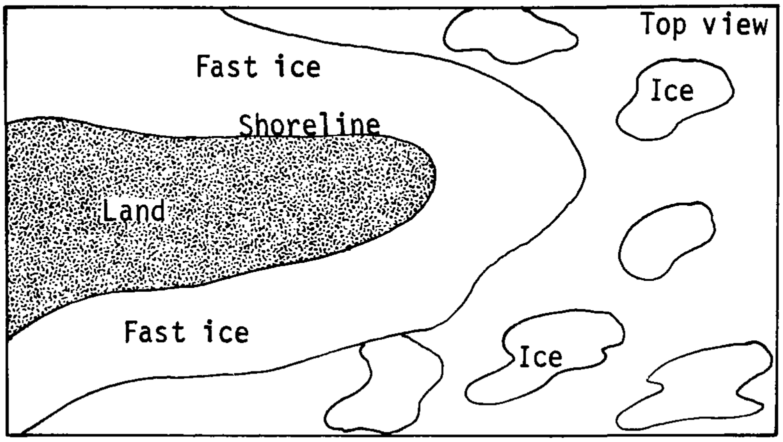
Due to the extremely cold winter on the eastern seaboard, Buzzards Bay was almost completely frozen. The shorelines were ice-fast (Figure 6) and the bay was characterized by numerous pressure ridges, leads, tidal cracks, and hummocks (Figures 7-10). Larger pieces of ice debris and floes (Figure 11) had rafted over each other, creating additional irregularities on the ice surface (Figure 12). As the oil floated to the water surface, it became lodged in these ice fissures. Penetration of oil through the ice itself, however, was negligible primarily because the residence time of the oil under the ice was short and the ice was a relatively impermeable hybrid of fresh and salt water. A report (in preparation) by the National Oceanic and Atmospheric Administration, discusses the technical aspects of ice formation and oil in ice interactions.

Most of the visible oil was contained in the leads and pools adjacent to the rafted ice. The largest volumes of oil were identified by dark yellow stains near Cleveland Ledge and about 270 meters offshore at Wings Neck Point. There was also a trail of oil from Cleveland Ledge to Wings Neck.

Virtually no movement of the oil trapped in the leads and rafted pools occurred after the second day following the spill. Strong winds had a tendency to blow some oil from the larger pools over the top of the ice making some areas of contamination appear larger than they actually were. The yellow-stained ice was easily detected from the air and aided the cleanup crews in identifying the sites of major contamination. Snowfall on February 5 and 6 covered most of the oil, however, forcing cleanup crews to suspend work until the oil could be relocated (Figure 13).

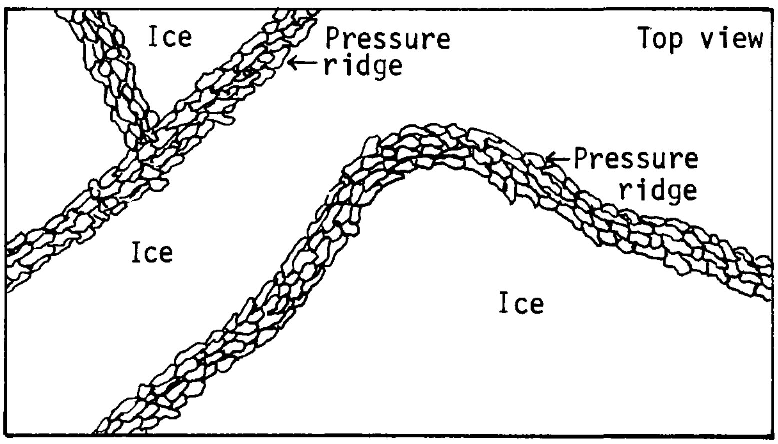
Because the heavy concentrations of oil were far from shore and the ice surface was so irregular, much of the oil was difficult to reach. In addition, the severely cold weather during the first week of the cleanup caused the equipment to freeze. When the weather did improve and temperatures moderated, the ice began to move and the oil dissipated into thin sheens that were difficult to collect. Large floating ice floes made equipment maneuverability difficult and rendered booming measures useless.

The lack of significant cleanup experience in cold climates also hindered the cleanup operations. Within the past decade, the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the United States Coast Guard (USCG) have conducted studies to determine the behavior of oil in ice-infested



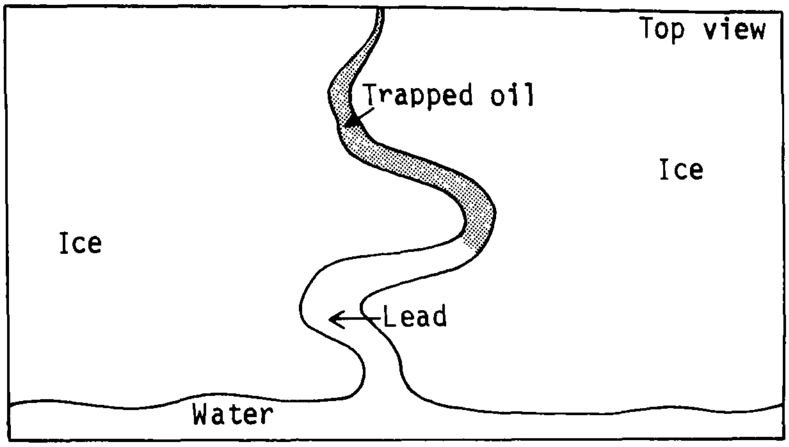
Definition: Fast ice is sea ice of any orgin that remains fixed (attached with little horizontal motion) along a coast or to some other fixed object.

Figure 6. Fast ice.



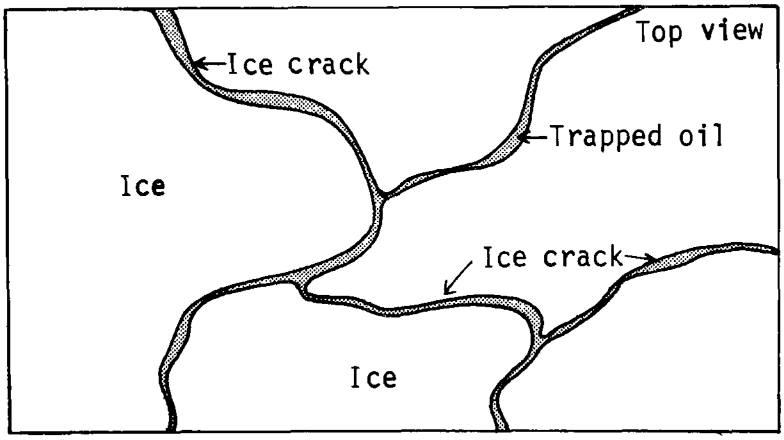
Definition: The term pressure ridge is a general expression for any elongated, ridge-like accumulation of broken ice caused by ice deformation.

Figure 7. Pressure ridge.



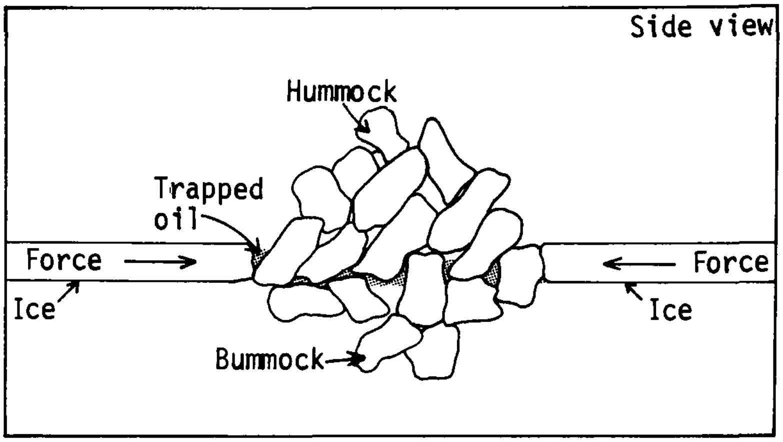
Definition: A lead is any fracture or passage through sea ice that is generally less than 1.5 meters.

Figure 8. Ice leads.



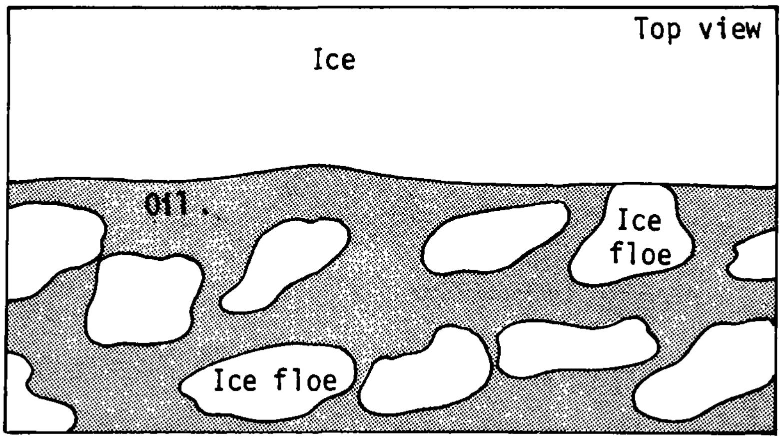
Definition: An ice crack is any fracture in the ice that has not yet parted.

Figure 9 . Ice crack.



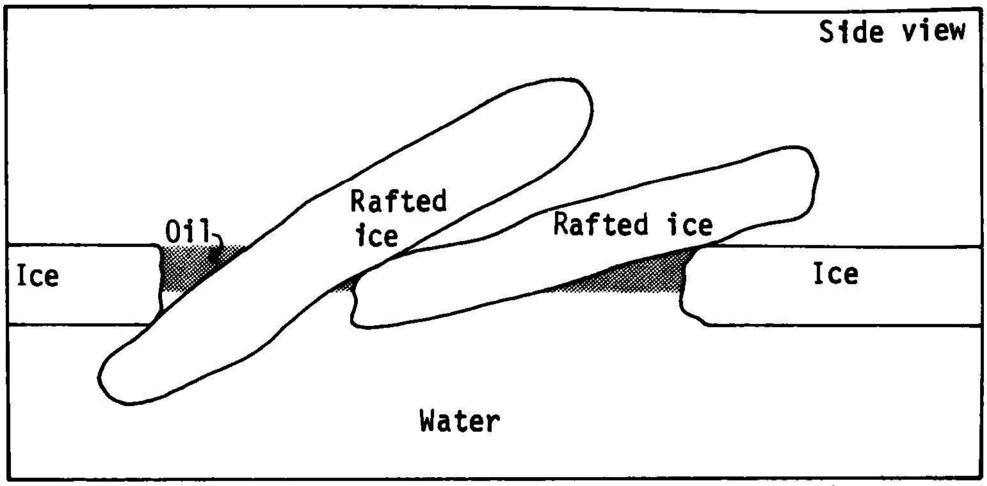
Definition: A hummock is broken ice that has been forced upward by pressure. It may be composed of fresh or weathered ice. The submerged volume of ice under the hummock, forced downward by pressure, is called a bummock.

Figure 10. Hummock.



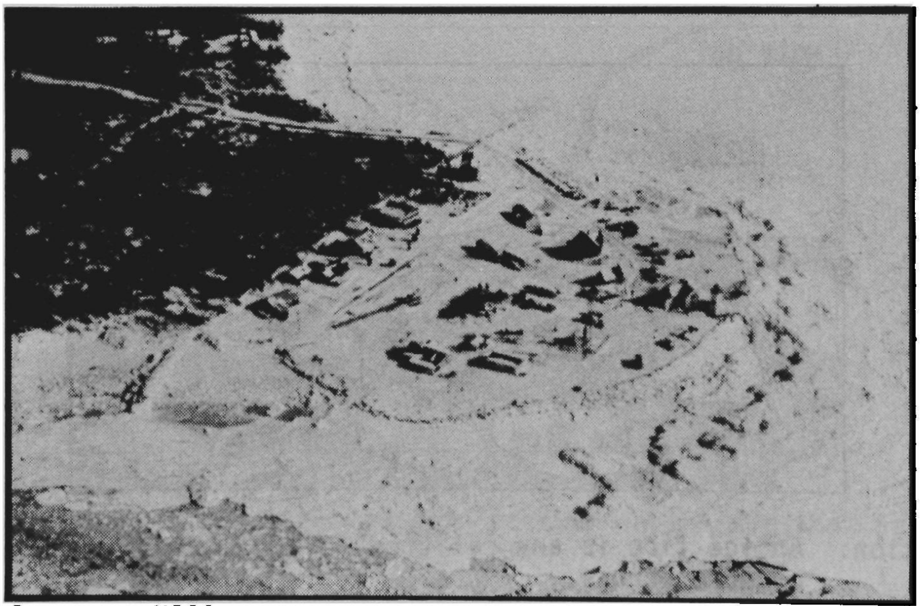
Definition: An ice floe is any relatively flat piece of ice 20 meters or more across.

Figure 11. Ice floe.



Definition: Rafting is the Process whereby one piece of ice overrides another; most obvious in new and young ice.

Figure 12. Rafted ice.



Source: NOAA.

Figure 13. Wings Neck Point after the snowfall on February 5-6.

waters, but only recently have efforts dealt with methods or systems needed to remove oil. Numerous cold-climate/ice spills have occurred in the United States and other parts of the world, but few of them have involved No. 2 fuel oil or the type of ice conditions encountered at Buzzards Bay. The Coast Guard has sponsored some research in Alaska on the use of oil spill recovery devices and has expanded that with studies on selected pieces of equipment such as the Marco and Lockheed skimmers. Most reports issued by the EPA and the USCG involving oil cleanup methods in cold climates, however, have dealt with experimentation and mock exercises only.

DESCRIPTION AND EFFECTIVENESS OF THE CLEANUP TECHNIQUES

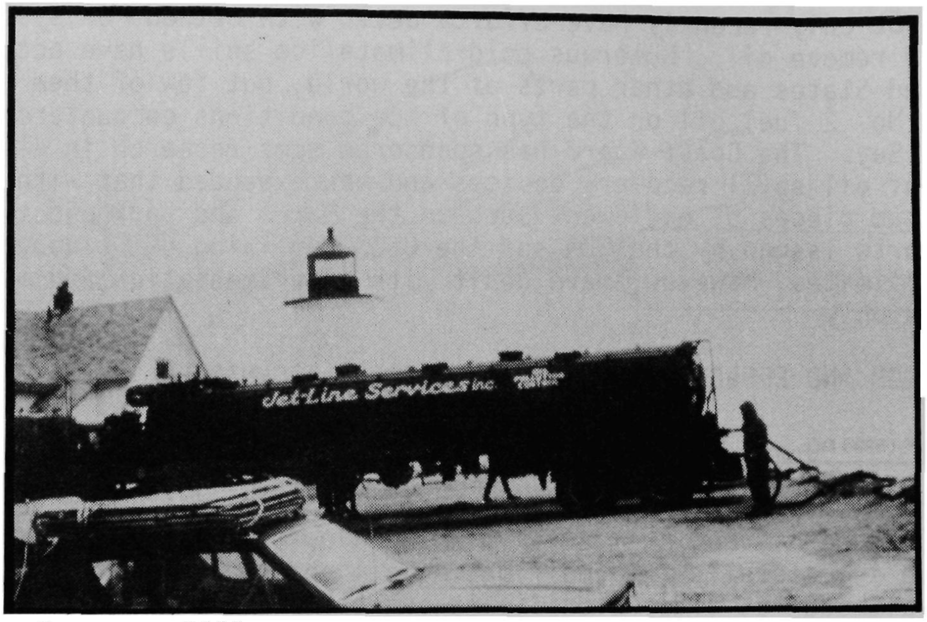
Vacuum Skimming

Vacuum skimming at Buzzards Bay was conducted with large vacuum trucks (Figure 14) and smaller skid-mounted units (Figure 15). The technique successfully removed floating oil and small pieces of ice debris, although at times significant quantities of water were also collected. The major components of the vacuum system were a diesel-driven pump, holding tank, and suction hose. The capacity of the vacuum truck tanks was 22,700 liters and the average pumping rate was 190 to 280 liters per minute. The skid-mounted vacuum units had 1,900- and 3,800-liter capacities and also pumped at an average rate of 190 to 280 liters per minute.

The vacuum recovery operations at Buzzards Bay were conducted throughout most of the cleanup and were undertaken in two phases that depended upon the ice conditions and location of the oil. The first phase, which occurred in the early part of the cleanup, was the deployment of the vacuum units from the shore, primarily at Wings Neck Point and Braille Residence Beach. This phase was undertaken when the ice was not moving, primarily during the first week to 10 days after the spill. The second phase was the deployment of skid-mounted vacuum units from tugs and barges.

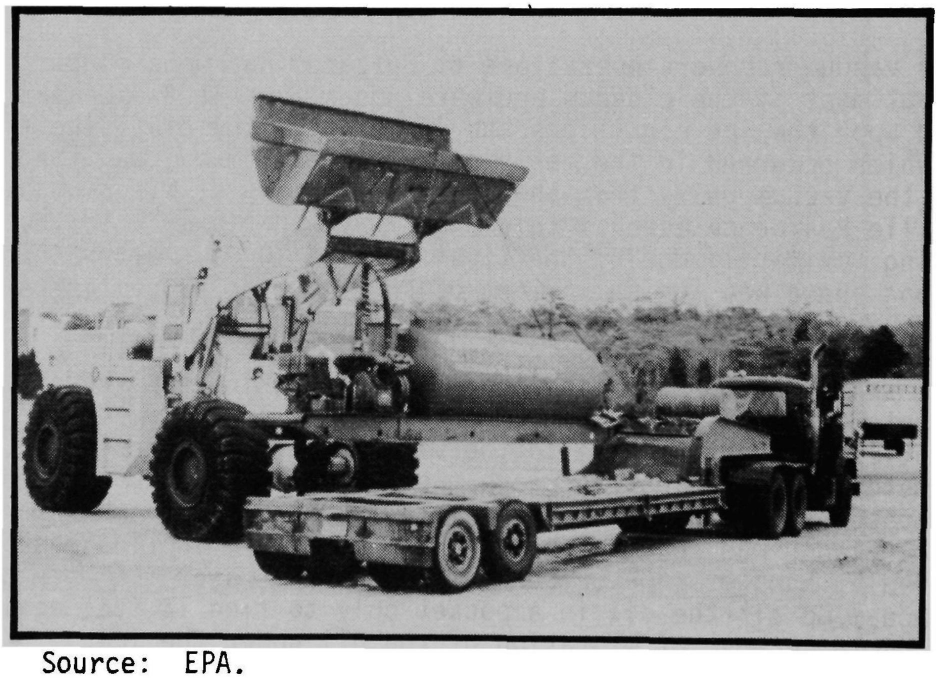
The shore-based operations consisted of backing the vacuum truck or skid-mounted units as close to the shoreline as possible, hooking up 5- or 8-centimeter-diameter hose to the vacuum unit, and connecting successive 8 meter hose sections to reach the trapped oil pockets (Figure 16). In some cases these pockets were more than 200 meters from the shore. A duck-bill flange was coupled to the open end of the suction hose and maneuvered by hand or rope (Figure 17). In some cases the work crews would vacuum up all the oil in a pocket only to find it full again after a tidal cycle because of migration of the oil under the ice.

The water-based vacuum-skimming operation was similar to the shore-based one. Skid-mounted units were used almost exclusively on the tugs



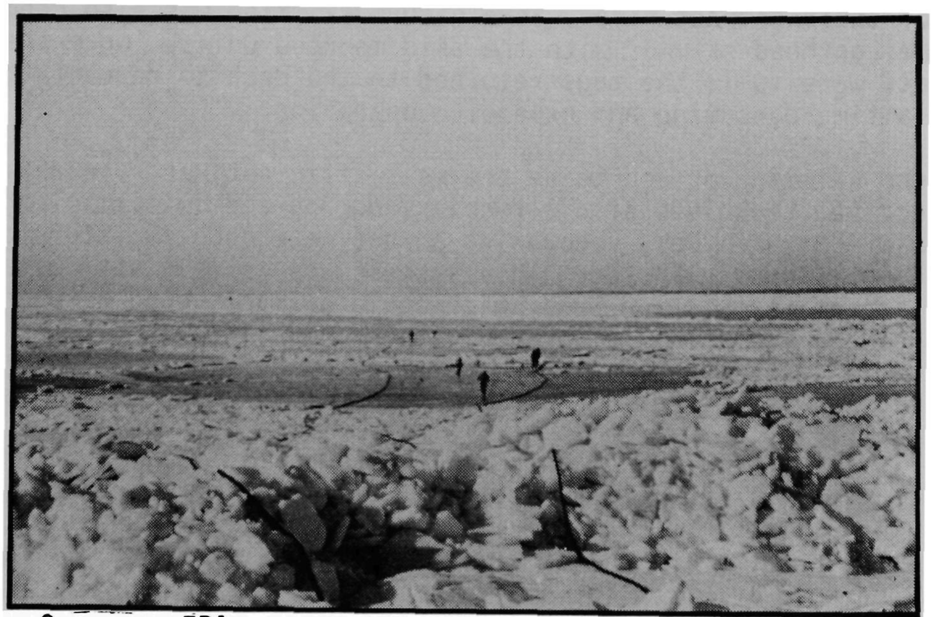
Source: NOAA.

Figure 14. Vacuum truck working at Wings Neck Point.



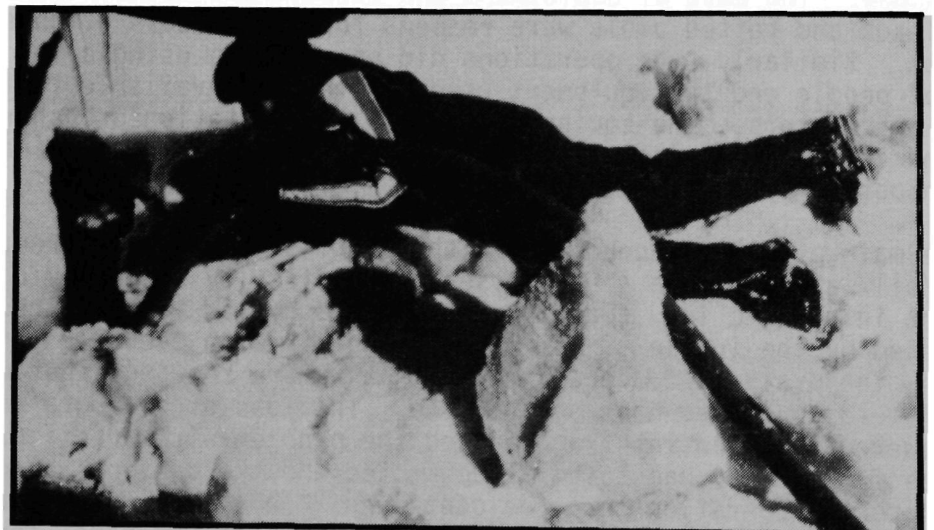
Source: EPA.

Figure 15. Skid-mounted vacuum unit being loaded on truck by a front-end loader.



Source: EPA.

Figure 16. Deployment of vacuum hoses off Wings Neck Point.



Source: NOAA.

Figure 17. Vacuum hose being used to remove oil from a tidal crack

because of their compact size. Some vacuum skimming was also conducted aboard the Lockheed skimmer with the skid-mounted units. Once the skid-mounts were full, the tugs returned to the dock to deposit their cargo -- a time-consuming and expensive operation.

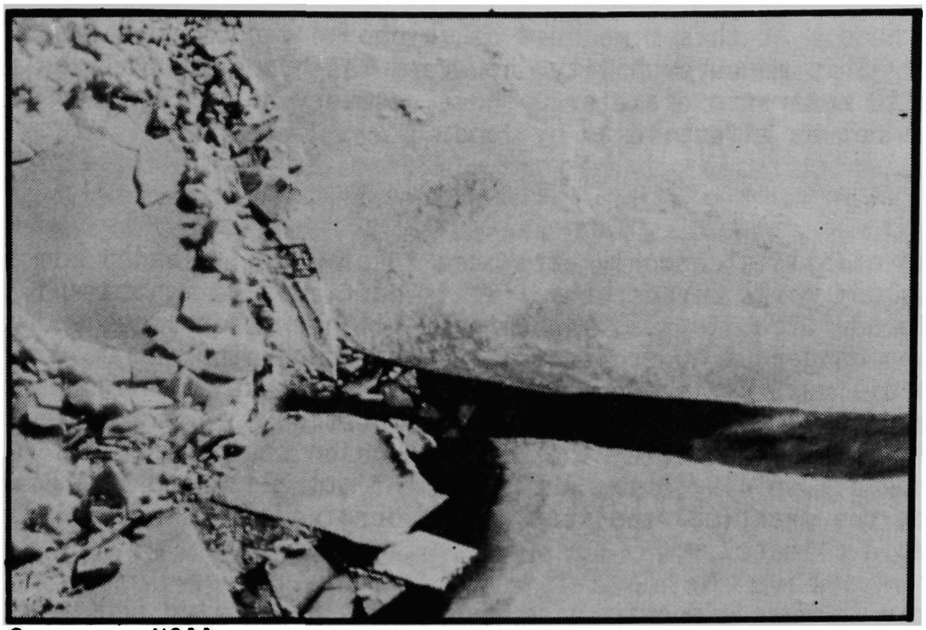
Vacuum skimming proved to be the most efficient, and probably most cost-effective, technique of oil recovery during the initial cleanup operation at Buzzards Bay, recovering an estimated 66,170 liters of the total 86,160 liters collected. This success was largely attributable to the mobility of the suction hose which could be maneuvered between the openings of the ice. The leads and rafted ice pools proved to be the best recovery locations (Figure 18). In some cases, a thousand or more gallons of oil was collected from individual pools when the ice was fairly static.

During initial operations, up to 60 percent of the liquid recovered was oil. This figure dropped off to less than 20 percent after about the fifth day because the oil that was accessible was in thinner layers and less amenable to vacuuming. Recovered oil was transported to a recovery center at Bridgewater. Trucks and other containers were not left overnight in the subzero weather because the contents would have frozen.

There were several advantages to using vacuum recovery units at Buzzards Bay. The ease of deployment and maneuverability of the hoses in the leads and rafted pools were reasons for the success of this technique. Similarly, the operations did not require using a large number of people and the equipment used was readily available to the cleanup contractors. The equipment could also be stationed onshore while the actual oil collection occurred offshore, thereby eliminating the transport of equipment on and off the ice.

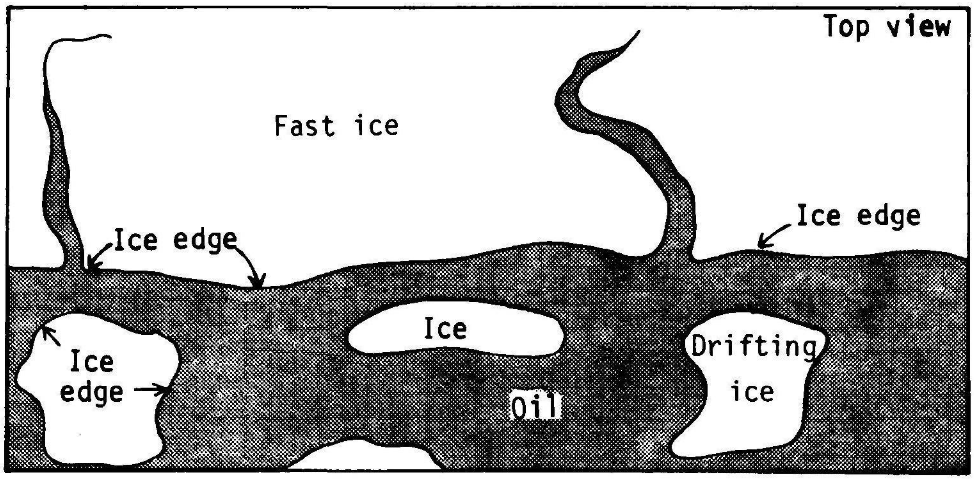
The main problems encountered with vacuum skimming were freezing of the ice/oil/water mixture in the hoses and difficulty in deploying the equipment in dynamic ice. Freezing was caused by low temperatures and facilitated by the intake of ice, water, and air with the oil. In addition, the pressure ridge and riprap near shore required that more than a 3-meter pressure head be overcome. The loss of pressure head, which lowered the flow rate, aggravated the problem with freezing. Once the hoses froze, they had to be disconnected and the contents allowed to melt before the operation could be continued. This proved to be a time-consuming process. According to the cleanup contractors, the hose would freeze after 10 to 20 minutes of operation.

Another problem was encountered under dynamic ice conditions. As the ice moved, many of the larger oil pockets present during the early part of the spill were dissipated over a larger area and released at the ice edge (Figure 19), reducing the oil thickness and encounter rate at



Source: NOAA.

Figure 18. Oil trapped in a lead and rafted ice.



Definition: An ice edge is the demarcation at any given time between the open sea and sea ice of any kind, whether fast or drifting.

Figure 19. Ice edge.

the skimmer head. At this time, use of shipborne vacuum units was intensified. Ship maneuverability, however, was hampered by large ice floes up to 10 meters in diameter. Thus, recovery of oil by ship worked well but was not as effective as by land.

Burning

Burning of oil is commonly attempted in oil spill cleanup operations but seldom works because the fire is difficult to ignite and sustain. In addition, most spills deposit oil near shorelines and a fire could be dangerous to property. Even where burning can be done safely, the oil must be concentrated in pools at least one-half-centimenter deep to initiate and sustain combustion. Some experimental studies have been conducted by the Coast Guard on the potential for burning crude oil spills in the Arctic, but little literature is available on the practical applications of burning oil (especially No. 2) in cold climates.

In order to burn effectively, the oil must be ignited and kept at or above its flash point temperature. For heavier oils (such as Bunker C and weathered crudes, this temperature may be very high and impractical in a cold-climate spill. Wicking agents have been experimented with and used with mixed success in cold-climate spills to sustain burning. The agents allow the oil to rise above the heat sink of the water and ice via capillary action.

Two attempts to burn isolated pools of the spilled oil were made during the active cleanup period. The first, on January 31, was conducted by the U.S. Coast Guard using a Tulco, Inc. wicking agent. The burn was attempted on a series of pools containing an estimated 19,000 to 23,000 liters of oil located just north of Cleveland Ledge where the barge had grounded.

The wicking agent used -- TULLANOX 500 -- is a very fine, super hydrophobic, fumed silica powder that behaves like smoke when it is released into the air. The agent floats on the oil and draws up small quantities of oil through surface diffusion and capillary action. The agent isolates this top layer from the cold oil and water (or ice) below. It provides thermal insulation and contact with air to keep the oil at its flash point for continuous burning until most of the oil is gone. The agent itself does not burn.

The deployment methodology consisted of dropping 10 boxes, each containing 5 kilograms of wicking agent, from a hovering helicopter into the pools below. Incendiary devices, jet fuel, and lube oil were placed in each box in order to initiate combustion. The incendiary devices were thermite grenades with 3-minute time fuses installed by the U.S. Army Explosive Ordinance Disposal Team from Fort Devens.

The boxes were dropped on the upwind edge of the oil pools. All of the boxes ignited and the resultant fires burned with varying degrees of success. The 20- to 25-knot winds drove the flames from pool to pool, which were theoretically covered with the wicking agent. The fire burned with intense heat for about 90 minutes and created large, black clouds of smoke. The smoke hung near the ice/water surface for 0.4 to 0.8 kilometers before rising. In areas where the wind-driven flames encountered surface pools of oil, fires were sustained. However, in other areas the fires subsided after 10 to 20 minutes due to an apparent lack of fuel. Heat loss may also have contributed to combustion being less than complete. Black streaks of residue, which were a composite of the grenade and oil in the boxes and the Bouchard oil, remained. If the burn had been complete, the ash content remaining should have been less than 1 percent. This is based on standard burning tests as reported by the American Society for Testing Materials. Estimates of ash residues after the burns at Buzzards Bay were not made.

Unfortunately, the quantity of oil present before and after burning was not estimated, so the quantification of the exercise is unreliable. Based on the apparent size of some of the oil pools that were burned and the intensity and heat of fire, it was estimated by EPA observers and the Coast Guard that approximately 7,600 liters of oil may have been consumed.

Another series of burns was conducted on February 17 on pools of oil east of Cleveland Ledge Channel between Cleveland Ledge and Scraggy Neck. Crew members of the tug Waukegan used oiled rags to ignite the surface pools. The rags were knotted into balls 15 to 20 centimeters in diameter, soaked with diesel oil and ignited. The ignited rags were then thrown into the oil which initiated combustion. In some of the larger pools, the flames extended 9 to 12 meters into the air and the oil burned for 40 to 50 minutes. Observers on the tug noted a black residue after the burn, similar to that resulting from the previous exercise. The residue was ash-like and no attempt was made to remove it. Only a slight oil sheen was observed on the water after completion. The quantity of oil burned in this operation was estimated at 7,600 liters by the tug crew and Coast Guard observers.

Other oil pools were considered for burning but were not burned because the black smoke would have been a nuisance to nearby residents and the possibility of the fire jumping ashore to beachfront property was too great. Thus, the total quantity of oil burned at Buzzards Bay was estimated at 15,000 liters.

The advantage of burning is that it works quickly in removing floating oil and can be used in areas where the oil is difficult to collect by other means. Within a few hours, a large quantity of oil can be burned. Burning is also inexpensive in comparison to other cleanup techniques, especially if oiled rags can be used to initiate combustion. Wicking agents, which are more expensive to use than rags, can aid burning if the oil is confined to a pool.

In general, the drawbacks to burning include the potential hazards to structures and people on land if the exercise is conducted too close to shore. Burning also generates large clouds of black smoke with attendant air pollution problems. Finally, in many cases it may be difficult or impossible to attain and maintain a burn because the ice and cold water acts as a heat sink.

At Buzzards Bay, there was a specific problem with the wicking agent used. Because TULLANOX 500 is so light, it does not settle well on the oil and therefore the means of deployment becomes critical. The incendiary devices employed at Buzzards Bay and the strong wind may have caused much of the agent to become airborne. Thus, the wicking agent may have been so diffusely applied on the oil that burning may have been sustained primarily by the oil itself. Based upon the later burn, which was initiated with oiled rags, it appears likely that the fire could have been sustained with little or no wicking agent present.

Lockheed Clean-Sweep Skimmer

The Lockheed Clean-Sweep operates on the principle that oil will adhere to a wet aluminum surface (Figure 20). A series of closely spaced aluminum discs are mounted on a rotating drum. The discs are separated by vanes to create an artificial current which draws the oil toward the unit. As the drum is rotated in oil, the oil will form a layer on the surface of the disc and remain there through the downward path of the drum. During the upward motion of the drum, water will drain off the disc, leaving the oil. The oil is then wiped off the disc and allowed to flow by gravity into a trough where a screw conveyor transports the oil to a sump.

The Coast Guard made four attempts to use the Lockheed Clean-Sweep during the spill, beginning February 12. Due to the draft of the tug towing the unit, the skimmer was confined to working within Hog Island Channel. When the unit was equipped with outboard motors for propulsion, it was more maneuverable, but large ice floes prevented it from reaching major sources of oil.

The Lockheed Clean-Sweep was mounted between two pontoon-like floats with one float serving as a compartment for the hydraulic motor and fluid that drive the device, and the other serving as a 1,900-liter storage tank for the recovered oil and water. The unit was towed by tug and was not properly rigged. This arrangement caused the nose of the unit to dip and the aft section to rise. The towing configuration also considerably reduced the maneuverability of the device. Most of the ice encountered was in large pieces -- over 3 meters in diameter. These ice pieces would wedge in the 2-meter opening and divert the oil away from the recovery drum, preventing effective oil encounter with the skimmer. The ice also bent the vanes and discs on the drum, further reducing the oil/skimmer encounter rate. The device was not operated according to the proper correlation between drum speed and tow speed because the tug could not tow it at a constant speed. Once the device was equipped with outboard motors, it became more maneuverable and, therefore, more effective. The Coast Guard estimated that 2,300 to 2,600 liters of oil may have been collected by the Lockheed.

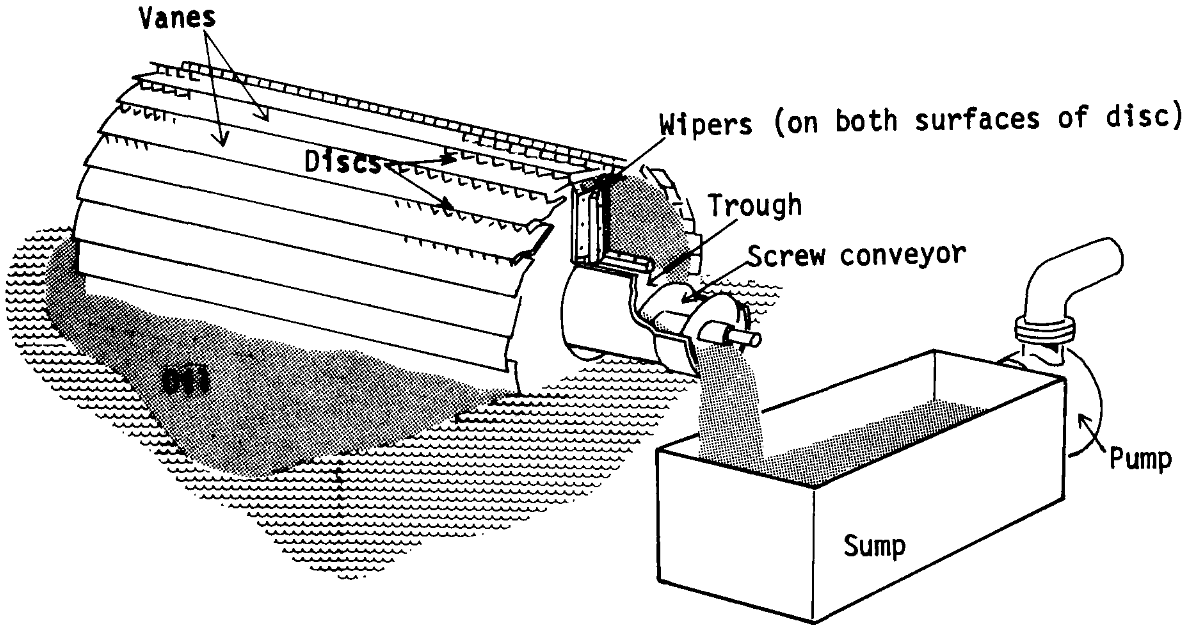


Figure 20. Layout of the Lockheed clean-sweep oil recovery system.

The Lockheed's principle of operation offers some promise. If modified, the device could be an efficient oil collector where small pieces of ice debris are present. In its present configuration, however, it does not work effectively in ice-infested waters. Another disadvantage of the unit is that it does not efficiently collect No. 2 oil less than one-third to one-half of a centimeter thick. Where the Lockheed was operated in Buzzards Bay, the oil rarely exceeded this thickness.

Marco Recovery System

The Marco Recovery System operates on the principle of submerging an endless oleophilic belt in oily water and selectively recovering oil (Figure 21). The belt is a porous, synthetic foam material that allows water to flow through it while trapping the oil within it. The oil-contaminated foam material is then lifted from the surface of the water by a continuously operating conveyor system. The conveyor system transports the contaminated foam material to a pneumatically-tensioned squeeze roller system where the oil is squeezed out of the foam and into a sump. An impeller located below the surface of the water counteracts the belt headwave and improves encounter rate with the oil by effectively allowing more oil to contact the belt.

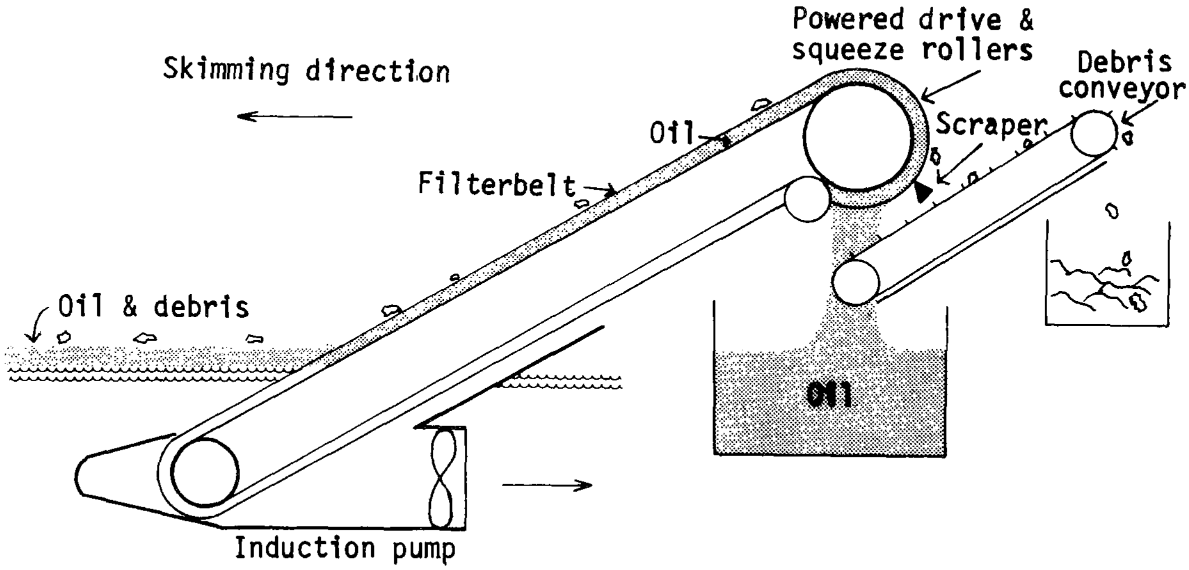
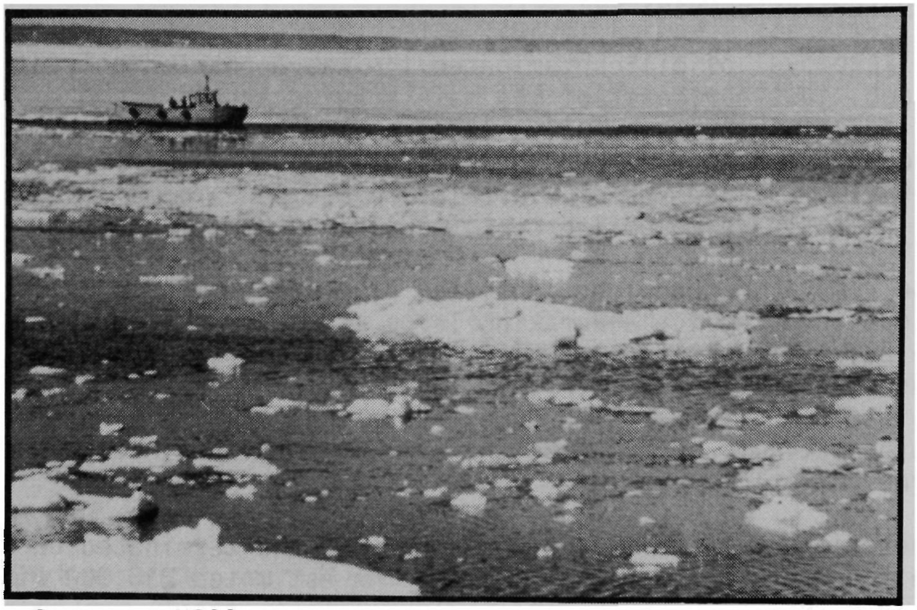


Figure 21. Layout of the Marco oil recovery system.

The Marco Recovery System used at Buzzards Bay was a self-propelled boat-mounted unit (Class V) (Figure 22). This device, as used, was ineffective in recovering oil during this spill, collecting approximately 380 to 760 liters of oil. The main factors that prevented effective oil recovery were the lack of heavy oil concentrations encountered in open water, large pieces of ice clogging the front of the belt, and limited maneuverability of the device in the ice floes.



Source: NOAA.

Figure 22. Marco Class V collecting oil off Wings Neck Point.

Source: NOAA.

Figure 23. Oil contaminated ice removal off Wings Neck.

Contaminated Ice Removal

Bulk removal of oil-contaminated ice was conducted only at Wings Neck Beach, just northeast of the main staging area. Based upon ice samples taken, the most heavily contaminated ice along the edges of pools contained 3 to 5 percent oil by volume (Deslauriers, et al., 1977; Ruby, et al., 1977). The oil in this ice had penetrated 25 to 60 millimeters. Lightly yellowed ice contained only 0.05 percent oil by volume.

The removal methodology consisted of a crane swinging a steel I-beam out onto the ice and raking large, loose pieces on shore (Figure 23). At each tidal cycle, more oiled ice was removed. Front-end loaders were used to pile the ice up on the beach and load the pieces into dump trucks. The dump trucks took the ice to a temporary separation facility approved by the Army Corps of Engineers in the Town of Bourne.

Operations were initiated on January 30 and terminated on February 2 because the operation was inefficient. An estimated 236,000 kilograms of ice were removed; approximately 2,000 liters of oil were recovered.

On February 10, the ice removal procedure was initiated again at Wings Neck Beach, apparently in response to public pressure. This time, approximately 340,000 kilograms of ice were removed with about 3,400 liters of oil recovered. Therefore, the total amount of oil recovered by this operation was approximately 5,400 liters from 576,000 kilograms (575,000 liters) of ice -- a recovery efficiency of approximately 1 percent.

Based on these figures and the time and money expended, the effort proved to be extremely inefficient. In addition, the transport and handling of the ice was poorly conducted. The ice that was piled on the beach for removal to the separation facility began to melt and the oil, most of which was on the surface of the ice, dripped onto the beach. The trucks that transported the ice to the separation facility were not lined. A sorbent boom placed at the tailgate did not prevent oil from leaking onto the ground while in transit to the separation facility.

Additionally, the removal of shorefast ice, which was protecting the shoreline, lead to increased contamination. Oil incorporated in the ice was left on the beach as the ice melted and mixed with the beach sediment by the tracks of the front-end loader.

Heavy traffic during the ice-removal procedure caused minor damage to private property on Wings Neck which required new topsoil and resodding. The access road to the staging area also had to be repaved.

A separation and temporary ice-disposal site was located in a gravel pit adjacent to Sandwich Road in the Town of Bourne. The Army Corps of Engineers sent a letter on February 9, 1977 to the U.S. Coast Guard authorizing use of the disposal site. The letter specified a number of conditions that were followed by the cleanup contractors:

1. The storage area for the contaminated ice will be covered with a vinyl-sealed lining and protected from rupture with a 0.3 meter thickness of sand.

2. Ice and, once the ice melts, the oil and water shall be contained by a dike around the storage area, with offsite disposal of this oil and water on a daily basis.

3. Maintenance of the road shall be provided during project work and left in satisfactory condition upon completion of the work.

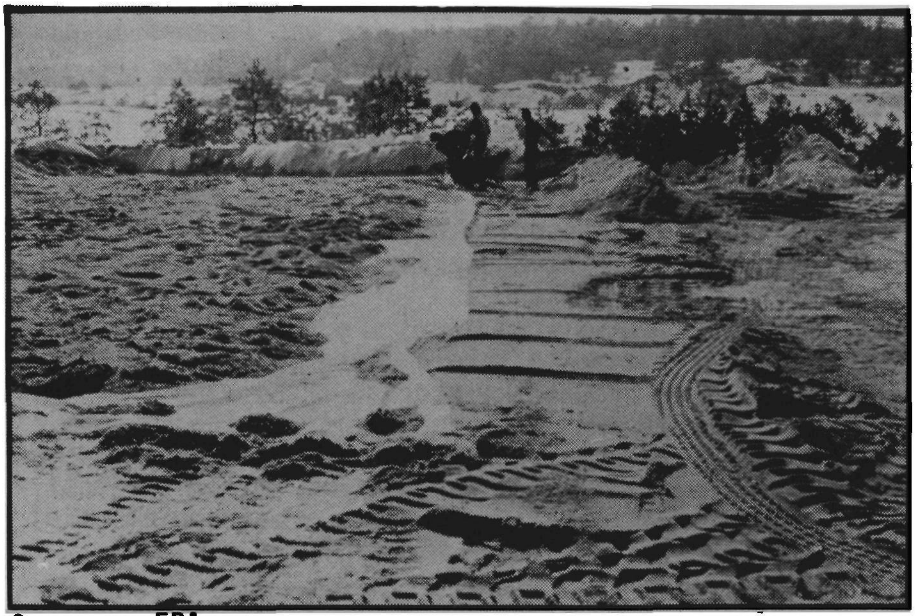
4. All environmental precautions are to be taken to prevent any spillage of contaminated ice in haul operations and of oil and water during processing and removal from the site. In the event of any spillage, the cause and cleanup of the contaminated materials should be immediately ascertained and corrected.

5. Upon completion of the work, all processing equipment and materials including the sand in the dike and diked area shall be removed from the site, leaving the site in its original condition.

The contaminated ice was placed in a diked area with a vinyl lining which was protected from rupture with a 0.3-meter layer of packed sand (Figure 24). Once the ice melted, the oil and water were separated, with the oil being taken to the central collection area in Bridgewater.

The separation process consisted of simply dumping the contaminated ice into the disposal site and allowing it to melt. Vacuum trucks then pumped out the oil, which was floating on top of the water, on a daily basis.

The separation site was dismantled following final separation of all the oil and water. All oiled debris, including sand, gravel and vinyl materials, was taken to the final landfill site in Cranston, Rhode Island.



Source: EPA.

Figure 24. Construction of oil/water separation site.

Booms

Booming of large areas to protect them from contamination was not extensively undertaken during the Buzzards Bay spill. Skirt booms (46 and 91 centimeters in depth) were deployed only at Pocasset and Back Rivers. These two areas were boomed on February 4 to protect shellfish beds. The deployment procedure involved tugs breaking the ice and towing the booms to the site. The booms froze into place and established a protective barrier. When ice movement occurred, however, the booms were destroyed by the strong forces placed on them by the moving ice. Fortunately, no significant quantity of oil reached this portion of Buzzards Bay.

On February 15, a sorbent boom was placed at the mouth of Scorton Creek in Cape Cod Bay when oil threatened the shellfish beds. The boom quickly failed, however, when ice floes were encountered. No significant quantity of oil was reported in the Scorton Creek area.

The main factors influencing the decision to limit booming were the excellent barrier properties of the ice itself and the general feeling that such attempts would be largely unsuccessful, as in fact they proved to be.

Endless Rope Skimmer

An endless rope skimmer operates on the principle that a rope containing an oleophilic material will collect oil when pulled across an oily surface. Oil is recovered by wringing the rope out and collecting the oil in a sump. Approximately 95 percent of the oil adhering to the rope is removed during the wringing process (Figure 25).

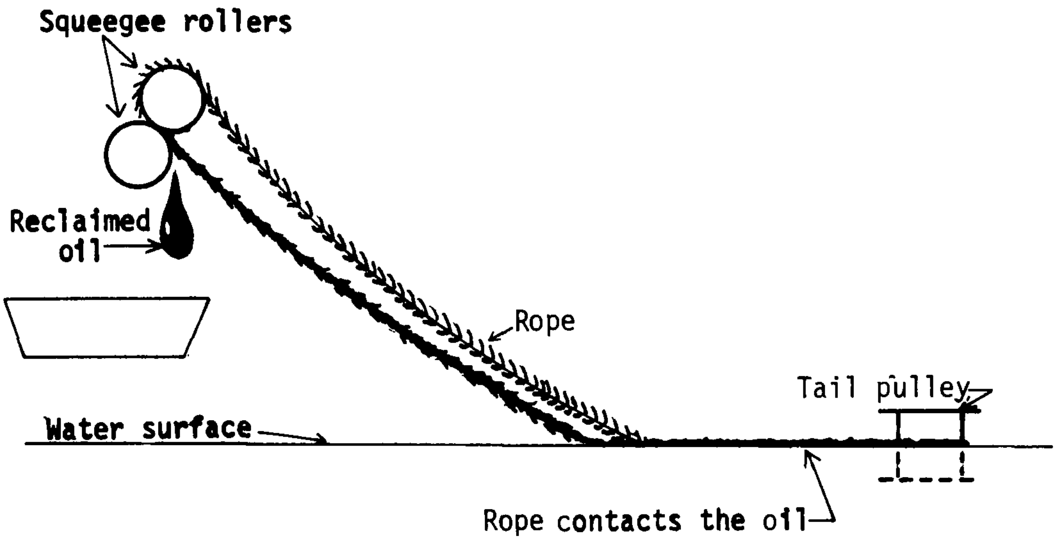


Figure 25. Layout of the endless rope skimmer.

The rope skimmer used at Buzzards Bay was small (Mark I), weighing about 90 kilograms. It was deployed on the ice by mounting it in a small jon boat. The boat offered a secure platform which would not sink if ice movement occurred. The rope was then placed in the narrow irregular pools of oil that collected in the rafted ice and tidal cracks. The tail pulley was maneuvered to maintain the configuration desired by the cleanup crews.

The rope skimmer was not extensively used during the Buzzards Bay spill because the vacuum techniques were working well and were easier to undertake. According to the cleanup contractors and the Coast Guard, however, the device was effective in removing the oil from the ice and water. Its major advantage is that it works well with irregular ice configurations. The cleanup contractors estimated that 400 to 800 liters of oil were recovered by the skimmer.

No major problems were encountered in the short period of time the skimmer was used. Potential problems of operating this device in ice conditions include the rope snagging and breaking, and insufficient power in the motor to drag the rope through ice.

Sorbents

Sorbent pads were used sparingly in the Buzzards Bay spill. Small oil pockets were cleaned in this manner, but the vacuum process proved more efficient. No estimates were made of the amount of oil collected by sorbents, but it was insignificant compared to the total quantity recovered.

Drilling Holes

In the early phase of the spill, oil appeared to be moving in large pools beneath the ice surface. Attempts to collect this oil included drilling holes in the ice (Figure 26) and inserting vacuum hoses. For the most part, this operation was conducted off Wings Neck Point and near those locations where the open pools were being vacuumed. In many instances, the cleanup crews were deceived by oil patches on top of the ice or frozen into the ice and found little or no oil upon drilling.

Source: EPA

Figure 26. Drilling holes through the ice off Wings Neck.

The most advantageous place to drill was near open pools in the rafted ice (Figure 12). In some cases the oil, being buoyant, spurted out of the hole. Problems were encountered with the holes freezing and having to be redrilled the following day. The tidal currents moved the oil back and forth, and a hole that was seemingly pumped dry would have oil in it again after a tidal cycle. Two to three days after the spill, most of the oil became trapped in leads, in rafted pools, or tidal cracks and shifted only slightly with the tides.

Overall, oil recovery through drilled holes was not efficient, primarily because the oil was difficult to locate, and in many instances, because there was just a small quantity of oil to be collected. The major problem with vacuuming through the holes was freezing of the vacuum lines. The operator could not always tell how much oil was beneath the ice so the hose frequently was sucking water.

Summary

Table 11 summarizes all the cleanup techniques used at Buzzards Bay. Vacuum skimming proved to be the most effective method. Burning also appeared to work well although quantification of the exercise was unreliable. The use of skimmers (i.e., the Lockheed and Marco) was severely limited by the ice conditions as were skirt booms.

MODIFICATIONS AND RECOMMENDATIONS FOR CLEANUP TECHNIQUES

Vacuum Skimming

The major problem encountered in employing the vacuum technique was freezing of the intake hoses which occurred on the average of every 10 to 20 minutes. Preventing the lines from freezing probably could not have been eliminated considering the low temperatures during the spill. However, the frequency of the freezeup could have been reduced by implementing some of the following techniques.

1. Take as much care as possible to collect only No. 2 fuel oil. Use of small weir skimmers in the deeper pools where no ice was present might have improved recovery efficiency.

2. Maintain the lowest possible elevation difference between the head and the pump. This will allow maximum use of the vacuum to draw liquid rather than to overcome a pressure head. Use of larger booster pumps would also aid in overcoming pressure head.

3. Place a debris screen over the mouth of the skimmer head to prevent ice from entering the hose.

TABLE 11. SUMMARY OF CLEANUP OPERATIONS AT BUZZARDS BAY

Method	Oil recovered (liters)[1]	Ice and weather conditions	Location of cleanup	Effectiveness
Vacuum skimming				
Shore-based	52,300	Varied from cold, clear, windy days with little ice movement to warmer weather and moving ice floes. Snow and blowing snow for 3-4 days.	Wings Neck Point and Brailles Beach.	Most successful during early stages of cleanup. Efforts were hindered by snowfall obscuring oil pockets and hoses freezing. Most of the oil recovered was collected by this method.
Water-based	12,800	Moving ice floes; temperature above freezing. Snow and blowing snow for 3-4 days.	West of Wings Neck and east of Hog Island Channel.	Marginally successful. The oil pools that were reachable by boat were small and others were inaccesible.
Burning	15,500[2]	First burn occurred on a cold, windy day and little ice movement; second burn occurred on an above-freezing day with moderate winds and moving ice.	First burn: near grounding at Cleveland Ledge; second burns between Cleveland Ledge and Scraggy Neck.	Moderately successful. Actual quantities of oil burned are difficult to ascertain. The commercial wicking agent used was poorly deployed and proved of little value. Use of oil-soaked rags appeared to work well in setting some oil pools afire.
Lockheed clean sweep	2,300-2,700	Moving ice; temperatures above freezing. Moderate winds.	Hog Island Channel area near Long Neck.	Unsuccessful. Ice floes blocked oil from contacting drum, manueverability was poor, and oil thickness was insufficient for efficient operation.
Marco recovery system	400-800	Moving ice; temperatures above freezing. Moderate winds.	Hog Island Channel area near Long Neck.	Unsuccessful. Ice floes blocked oil from contacting belt, maneuverability was poor, and oil thickness was insufficient for efficient operation.

TABLE 11. SUMMARY OF CLEANUP OPERATIONS AT BUZZARDS BAY (cont.)

Method	Oil recovered (liters)	Ice and weather conditions	Location of cleanup	Effectiveness
Ice removal	5,500	Shorefast ice at ice removal site. Weather varied from cold and very windy to above freezing temperatures and light winds.	North of main staging area near Brailles Beach.	Unsuccessful. Approximately 1 percent by volume of oil to water was recovered. Oil was deposited on the beach as the ice melted. Trucks transporting the ice to the separation site were not lined.
Booming	N.A.[3]	Skirt booms were deployed by boats breaking the ice and towing the booms to the site. Sorbent boom placed in ice-infested waters.	Skirt booms placed at mouths of Pocasset and Back Rivers. Sorbent boom placed at mouth of Scorton Creek.	Unsuccessful. The sorbent boom was torn by ice and, therefore, did not impede the flow of oil. The skirt booms never encountered oil and consequently their effectiveness cannot be measured.
Endless rope skimmer	400-800	Mop used in leads and tidal cracks.	West of Wings Neck near staging area and vacuum operations.	Marginally successful. Worked rather well in the small leads and tidal cracks. Not extensively used.
Drilling holes	Included in vacuum-skimming figures.	Varied from very windy and cold to above freezing temperature and light winds.	West of Wings Neck near vacuum operations.	Marginally successful. Most holes that were drilled revealed little, if any, oil beneath them. Problems were encountered with the hoses freezing if too much water was vacuumed. Also, the holes refroze overnight.
Sorbents	Negligible	Used on small pools of ice.	West of Wings Neck near staging area and vacuum operations.	Sorbents were used sparingly as vacuum operations proved much more efficient.

[1]Approximate total based upon Coast Guard estimates.
[2]This figure is approximate due to the inability to make accurate estimates.
[3]Not applicable.

4. Place an insulating mat (e.g., a sorbent roll) under the vacuum hoses. NOTE: this would be beneficial only when the air temperature is above freezing.

A substitute hose could be laid parallel to the one in use. If one line is clogged, the parallel line could be hooked up to the vacuum pump saving downtime; meanwhile the frozen section could be thawed out.

Another modification that would help concentrate the oil and alleviate freezing problems is shown in Figure 27. Oil is pumped into a 200-liter drum or similar container that serves as a gravity separator. As the drums are filled, their contents -- essentially oil -- can be pumped ashore or the drums can be removed by helicopter.

Burning

Two different burning techniques were used at Buzzards Bay but the success of each is inconclusive. Only rough estimates were made concerning the initial volume of oil prior to burning. No followup was done for either technique to measure the degree to which the oil burned.

Based upon studies conducted in the Arctic, burning may be an efficient cleanup technique for some oils. Burning generally must be attempted immediately after a spill before the oil has weathered, and when the oil is concentrated in pools of sufficient thickness. Controlled burning tests have shown that 80 to 90 percent of some crude oils can be consumed, leaving a tar-like residue (McMinn, 1972; Glaeser and Vance, 1971). In these tests, no combustion-aiding agent other than oil-soaked rags were necessary to initiate and sustain combustion. However, if the oil mixes with snow and becomes a slush, combustion inplace will be impossible. Wicking agents appeared to have no advantage over the use of oil-soaked rags in the Arctic studies or at Buzzards Bay for burning confined pools of oil in cold climate conditions.

A recent study (ARCTEC Canada, Ltd., 1977) concluded that atmospheric flares dropped from aircraft may be the best method of igniting an oil pool on water. Napalm, although dangerous to use, works best when oil is on top of the ice. Consequently, a crucial aspect to burning is finding an effective ignition device and deploying it safely.

An adverse effect of burning is the air pollution created. Large quantities of black smoke were generated by each burn at Buzzards Bay, but lasted a relatively short time. The situation dictated that burning be done far from shore to prevent the smoke from affecting nearby residents and to prevent any potential for the fire jumping to land.

In the event of another spill of No. 2 fuel oil in the New England area under similar environmental conditions, burning may be a viable

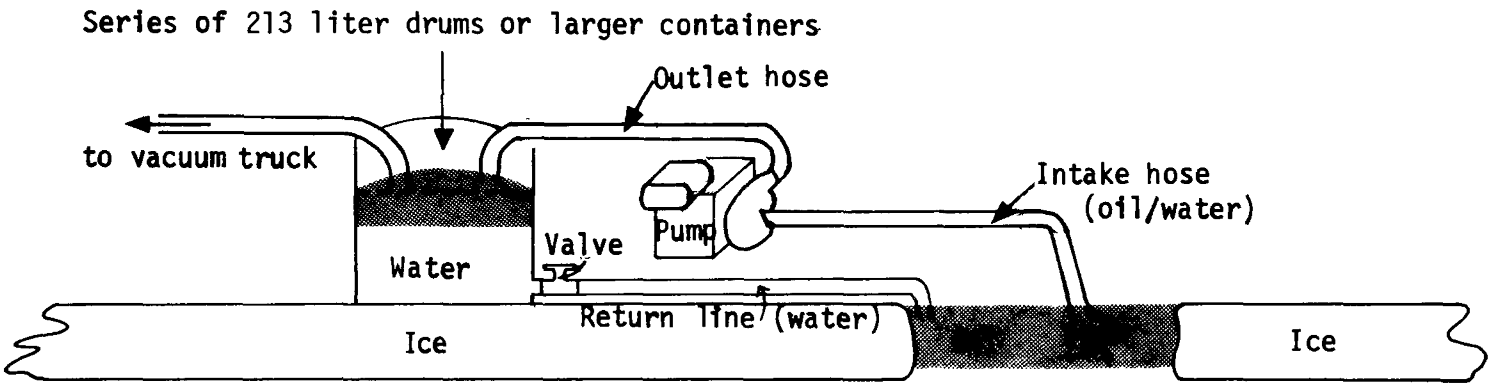


Figure 27. Oil concentration system.

option. The burning should be initiated early, before the oil has had a chance to evaporate significantly and dissipate. After burning, the pools should be surveyed for traces of residue and unburned oil. Use of commercial wicking agents is not recommended.

<u>Lockheed Clean-Sweep</u>

The Lockheed Clean-Sweep was designed to operate in open water and in thick layers of oil. Several modifications to improve its performance have been suggested in studies conducted for the Coast Guard (Deslauriers, 1976). In particular, the drum should be redesigned to withstand battering by ice, and maneuverability should be enhanced. An ice deflector (actually a unit to break up, deflect, or remove ice in the skimmer or from the skimmer's path) could be added to the Lockheed to improve oil contact with the drum. In addition, the operator must be cognizant of the proper correlation between drum speed and speed of forward advance for maximum oil recovery efficiency. With such changes and additional testing, the Lockheed Clean-Sweep may have limited use in ice-infested waters.

The Lockheed did not encounter sufficient thicknesses of floating oil to make it efficient in recovering oil in the spill under study. The amount of oil in the water must be of sufficient thickness (1/3 to 2/3 centimeter) and quantity to make implementation of the unit practical under similar environmental conditions.

The Lockheed could be deployed in a stationary position along a lead or an ice slot and oil herded toward the collection mechanism. The floating oil, however, must be relatively free of ice debris for the unit to perform effectively.

<u>Marco Recovery System</u>

The Marco Recovery System was not designed for use in ice-infested water. However, attempt to improve the Marco's cold-climate and ice-handling performance are being made. A study conducted for the USCG (Deslauriers, 1976) showed that if the Marco were equipped with an ice deflector, its performance in collecting oil from ice-infested waters would improve considerably. In addition, the operator of the device must be well-versed in the correlation between belt speed and proper speed of advance for optimum recovery.

In its present configuration, the Marco Recovery System will not work well in ice-infested waters. However, even if it were modified, it would still have been ineffective at Buzzards Bay because oil of sufficient thickness for efficient removal did not occur in those areas where the unit was operated.

Similar to that described for the Lockheed, a small Marco unit could be deployed in a stationary position for oil collection along the edge of a lead or ice slot.

Contaminated Ice Removal

Removal of contaminated ice is a time-consuming and labor-intensive task. Minor modifications of the efforts conducted at Buzzards Bay could have made this method more efficient, but it still would have been of minimal value. Better protective measures on the beach, such as a shallow pit lined with a plastic sheet to temporarily hold the contaminated ice, would have helped prevent some of the beach contamination. Lining the dump trucks transporting the ice to the disposal site would also have facilitated recovery and decreased spillage of oil in transport.

Contaminated ice removal is not recommended for spills under similar conditions. In unusual circumstances, where the ice (or snow slush) is heavily contaminated and adjacent to sensitive biological areas, removal of the ice and snow may be necessary to prevent damage when the ice melts. In that event, the ice should be removed so that minimal physical and biological damage will occur at the removal site.

It must be recognized that leaving contaminated ice in situ will result in oil going to sea and dispersing when the ice melts. Such oil is difficult, if not impossible, to recover. The possibility exists that the released oil could accumulate in bays or other combined areas and affect the biological communities. In the present case, the biological evidence to date suggests that no adverse effects occurred. Thus, the most cost effective approach to cleaning up oil incorporated in the ice (versus pooled and floating oil) is leaving it there.

Once the cleanup is finished, any contaminated beach areas must be restored. This would include removal of the contaminated material and relandscaping. Because this was not done on Wings Neck, walking surveys, conducted as late as October 1977, indicated that oil was still present in the coarse sediments where the ice had been piled and allowed to melt.

Booms

At the present time, most commercially available booms have insufficient tensile strength to withstand broken and moving ice. A boom can be destroyed by ice riding over or under it, or it can break or shred under the great forces of the ice. Many materials used in manufacturing booms become brittle or inflexible in cold temperatures. If the boom becomes too inflexible or rigid, it may break or crack, thereby releasing the oil it was supposed to contain or divert. Booms may also experience a reduction in buoyancy due to icing of the top portion containing the floatation mechanism.

Some commercially available heavy-duty skirt booms do offer promise for successful application in cold-climate spills in which light, broken ice is present. However, no presently available commercial oil containment boom is suitable for general application in cold weather spills where moderate to large broken ice floes are present and moving with the currents.

Where ice conditions are static, heavy-duty booms could be deployed by cutting a section out of the ice and allowing the boom to freeze in place. This configuration will contain or divert oil but, like booms deployed in open water, will fail if the currents exceed specified design limits. The boom is less likely to incur physical damage in static ice, but still should be considered expendable. A cheaper and equally effective procedure for diverting oil moving under static ice is to freeze plywood (or other equally strong and expendable material of a biodegradable nature) into the ice. If the ice moves before the plywood can be recovered, the material is expendable. In any case, a boom in static ice can be used to divert oil either to a location where the oil can be collected through holes or to open areas where it can be collected.

A possible modification of booming with skirt booms alone would be the use of a porous ice containment boom in conjunction with a conventional skirt boom. The backup ice boom would allow most of the oil and small pieces of ice to pass through its openings (or under the boom) while diverting large pieces of ice away from the collection or containment area. Such a scheme is shown in Figure 28. Available literature does not indicate that such a system has ever been used. It does appear, however, that there is potential for such a system where booming is necessary to protect sensitive biological areas.

Under conditions similar to those in the Buzzards Bay spill, conventional booms should not be used to contain oil. Heavy-duty booms can be used as deflection booms to divert the oil to a collection device if the ice conditions are light. During most of the Buzzards Bay spill, the shore-fast ice acted as an effective containment mechanism to prevent oil from moving towards the shore.

Endless Rope Skimmer

Although the endless rope skimmer was not extensively used during the Buzzards Bay spill, it has potential as an oil-recovery technique in cold-climate oil spills. The flexibility of the rope to adapt to surface irregularities and its ability to operate in ice-infested waters

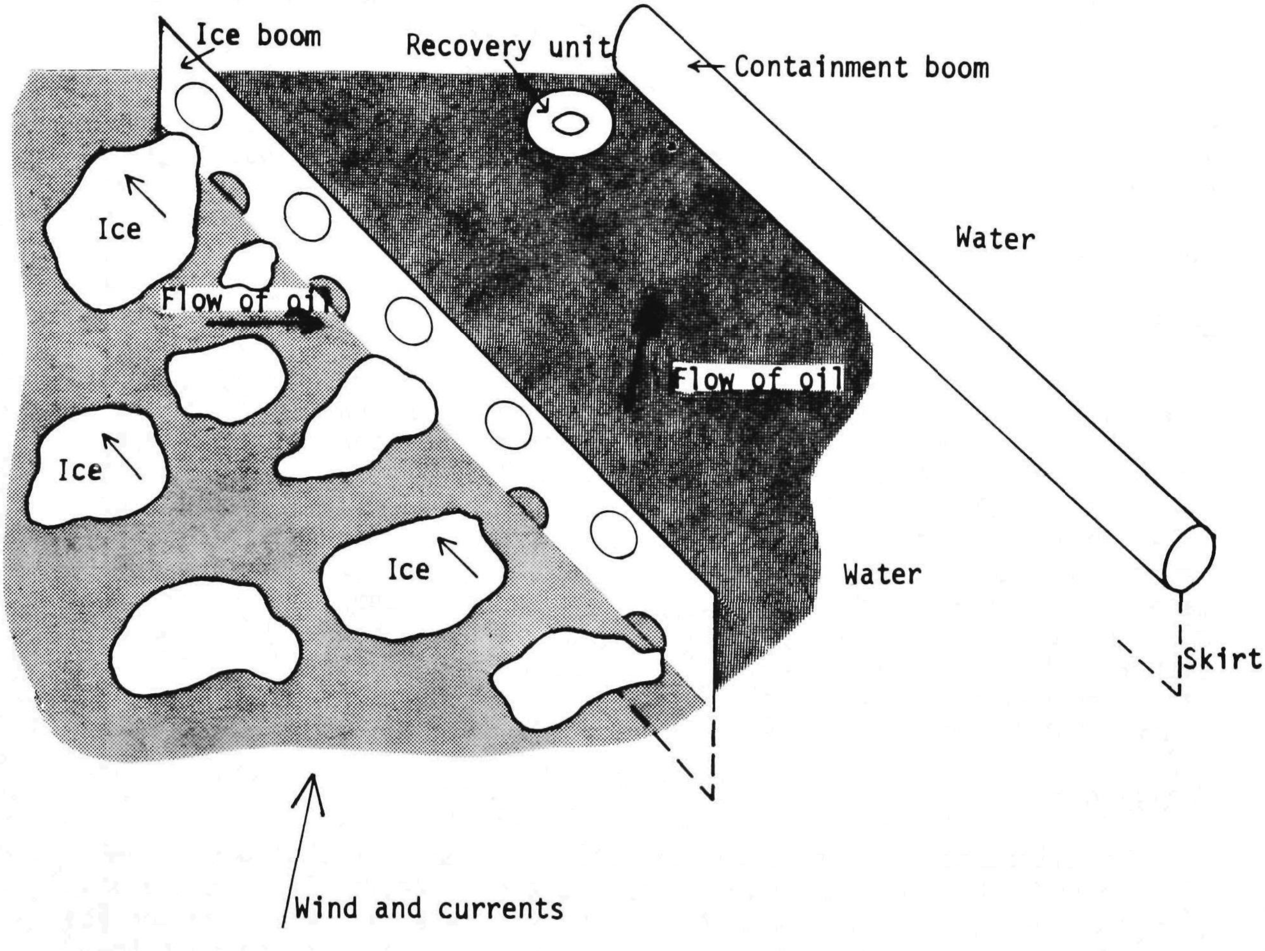


Figure 28. Ice and containment boom deployment to recover oil.

are advantages of the unit over other oil-recovery techniques. The endless rope skimmer can be deployed in small, narrow areas such as leads or tidal cracks (Figure 29A) or in open water (Figure 29B). The technique could be deployed beneath the ice by cutting holes in the ice and inserting the rope through the holes (Figure 29C); it can also be operated in broken ice fields without damage to the rope (Figure 29D). The device can be dragged across an ice sheet to recover the oil on top of the ice if the volume warrants recovery and the oil is fluid rather than frozen (Figure 29E). Therefore, the endless rope skimmer is capable of operating successfully in both static and dynamic ice conditions.

Endless rope skimmers come in several sizes. Many of the smaller models can be transported to a spill site by helicopter or small boat. If deployed on ice, the unit should be mounted in a small boat or on pontoons to prevent its sinking if the ice collapses or moves. Larger units can be deployed from ship or shore depending upon the location of the oil and available means of transporting the unit to the site.

Sorbents

Sorbents were not used extensively at Buzzards Bay and, based on studies in arctic climates, appear to have only limited use in spills on ice. This is especially true under the dynamic ice conditions such as those at Buzzards Bay. The sorbent material, whether it is natural (such as straw) or synthetic (such as polyurethane, polymeric fiber or polypropylene) must be physically removed from the oil pools; this process of application and removal can be costly in terms of time and materials. Though sorbents should not be depended upon as a major cleanup tool in conditions similar to those encountered at Buzzards Bay, either sorbent pads or rolls should be available for collection of easily accessible pools and for placement under hoses, vacuum pumps, and other items subject to leaking.

Drilling Holes

Drilling small holes to collect oil with vacuum techniques is not recommended. However, during the early phase of the spill when the oil is still moving under the ice, 1- to 2-meter slots can be cut in the ice with chainsaws or by blasting. These slots should be located such that they would intercept the flow of oil. Vacuum techniques or a stationary skimmer (e.g., endless rope skimmer) would be used to collect the oil. A board could be used to herd the oil toward the skimmer to improve encounter rate.

The slot must be wide enough to prevent refreezing. The suggested 1 to 2 meters width should be sufficient for most applications. Length

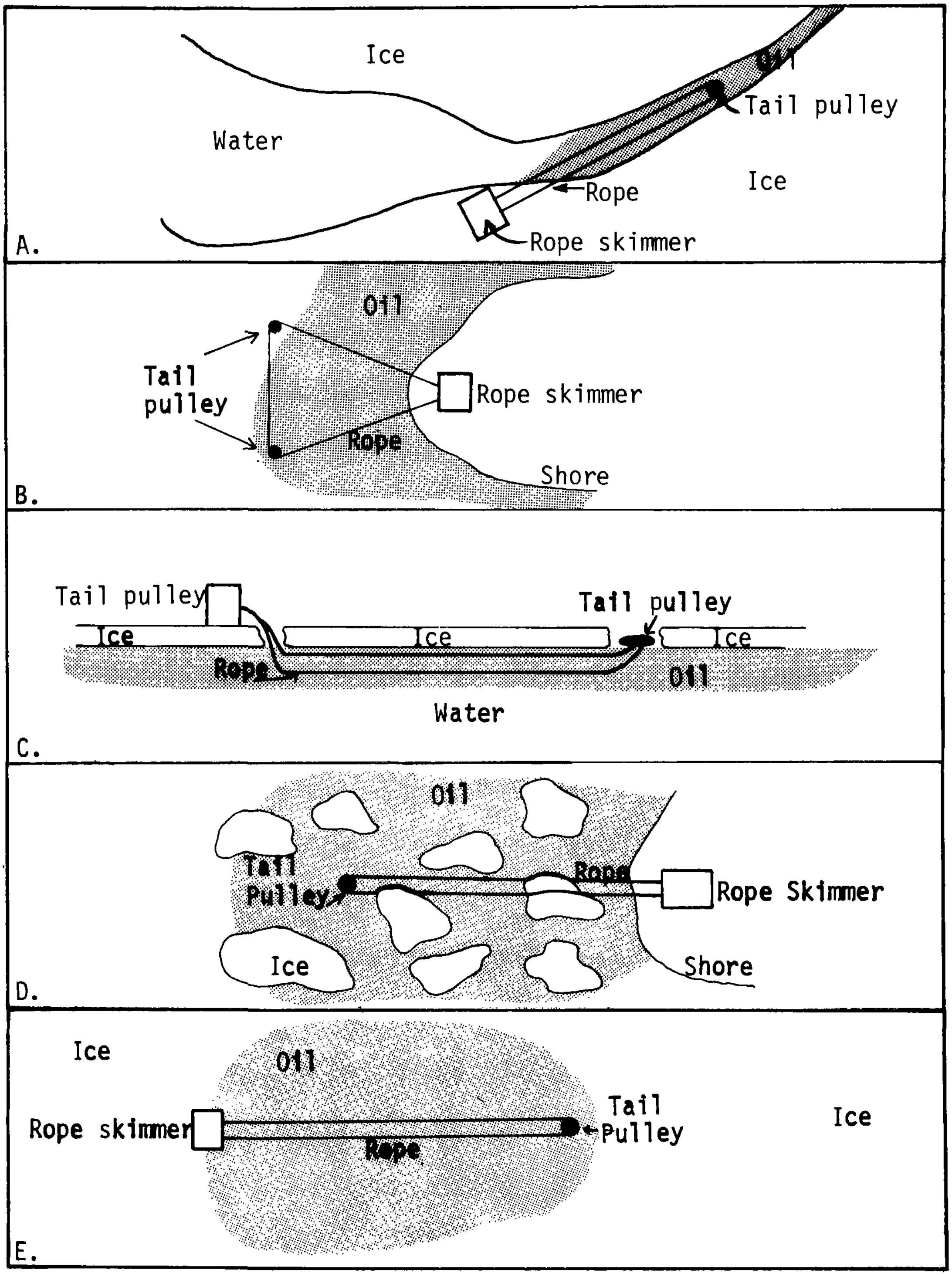


Figure 29. Possible deployment of rope skimmer in ice-infested waters.

would be dependent on the amount of oil believed to be moving under the ice. A schematic of the ice slot and skimmer arrangement is shown in Figure 30.

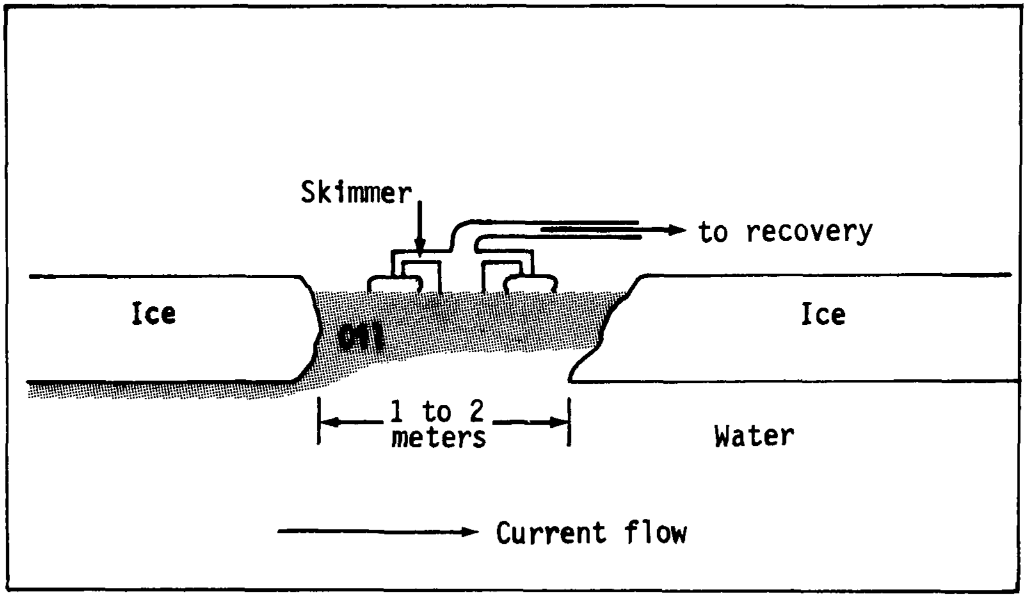


Figure 30. Ice slot for oil collection.

Miscellaneous Recommendations

Recovery of oil within the first week of the spill would have been improved if the locations of the larger oil deposits initially identified had been marked. A snowfall on February 5 obscured the oil locations and delayed the cleanup operation during a critical phase. The cleanup had to be temporarily postponed until the snow melted sufficiently and the oil was located. Possible methods of marking the larger oil pool locations include staking with colored metal posts, or throwing small buoys or floats in the pools with attached flags and counterweights. The master map prepared and updated daily by the Coast Guard and cleanup contractors is helpful in generally locating the oil, but is not specific enough to locate oil on the ice because of ice movement.

The use of helicopter for transportation of materials and equipment to different staging areas and cleanup activities has been an effective procedure at other oil spills. In addition to a helicopter standing by for safety precautions and limited surveillance, another helicopter can be used for transporting mobile cleanup equipment to cleanup sites, removing oiled debris, and shuttling any other equipment and gear to the work crews as needed.

RECOMMENDATIONS FOR ALTERNATIVE METHODS

A wide variety of devices and chemicals are used in oil spill cleanup operations today; few of these, however, have been tested or used in cold climates. Chemical agents such as dispersants, gels, surfactants, and sinking agents are not commonly used even in temperate spills in the United States. Their use in cold weather spills and in ice cannot be evaluated because little or no information is available concerning their behavior in such conditions (McMinn, 1972). If such agents were used in shallow water in ice conditions, there may be greater biological impacts than caused by the oil alone. Therefore, mechanical cleanup devices appear most viable for cold-climate cleanup.

Unfortunately, little research on mechanical cleanup equipment under cold-climate conditions has been undertaken. With oil production and transport increasing in cold climates (such as Alaska) and the new potential for oil spills in such regions, research efforts have recently increased.

Most mechanical devices used to recover oil are generally classified as skimmers and are grouped according to their method of oil recovery. The major problem with most skimmers in ice-infested waters is that ice impairs the encounter rate between the collection mechanism and the oil. As described previously, an ice deflector could be added to some skimmers. Little research, however, has been conducted on such devices; they would not be practical on many systems.

Another vacuum technique effectively used in other cold-climate spills (e.g., Hudson River spill, 1977) is the Myers-Sherman Vactor. This device has a flow rate of 11,800 cubic meters of air per minute and can pick up pieces of ice weighing up to 2 kilograms. The device uses a hose 20 to 30 centimeters in diameter and 61 meters long. The large flow rate and large hose diameter help prevent small pieces of ice debris, usually collected with the oil, from clogging the hose. It can be operated either from shore or placed on a work barge. Its disadvantages are the poor maneuverability of the large hose and the inability of the unit to reach oil pools in shorefast ice if barge-mounted.

An alternative to centralized collection and disposal for the oil is an onsite, high-volume, open-flame flaring device. This would eliminate most problems, such as hose freezing, associated with pumping oil/ice/water mixtures over long distances to shore. This device would have to be air-deployable and capable of burning diluted volumes of oil. The U.S. Coast Guard has recently published a Request for Proposal for a project that would determine the oil disposal capability of such a device. A drawback to this type of disposal, however, is that the oil is not reclaimed for reuse and air pollutants are generated. The pollution generated, however, would be far less than that from open burning on the water surface.

In summary, the state-of-the-art regarding cold climate oil spill cleanup equipment is in its infancy. Further research and development to modify existing equipment and to develop new equipment is necessary to improve upon recovery efficiency and response to oil spills of all types in cold climates.

PERSONNEL SAFETY

Cleanup and sampling operations during and after the spill posed extreme hazards to the people involved, such as cold-weather exposure and falls into the frigid waters. For the most part, everyone was adequately safeguarded. However, some additional recommendations can be made to insure that, in the event of another spill under similar conditions, the potential hazards can be further minimized.

Initially, there was not enough cold-weather survival gear available for the crews. This caused some minor delays in deploying personnel during the search for the necessary clothing.

A number of different safety precautions were taken by the field crews. Some had safety lines tied in series, so that if one person fell, someone would be nearby to pull him out almost immediately. Jon boats were stationed onshore and on the ice in the event they were needed. Some personnel also dragged jon boats along with them as they worked. During most of the cleanup, but especially when the ice began to break up, men were stationed at various distances from shore to monitor ice movement and watch for anyone in trouble. An Army helicopter was stationed nearby in the event that personnel rescue was required. However, this helicopter was used primarily to shuttle people who were observing the spill and would not have been immediately available most of the time.

A helicopter for emergency response should be standing by when cleanup and sampling crews are on the ice. Such a helicopter could be used for some local surveillance work, but only when absolutely necessary. At all times radio communications between shore-based personnel and personnel on the ice is necessary for quick response to any emergency.

Fortunately, no one was seriously injured in the course of cleanup. Some workers did fall into the water, but were able to escape. In order to be more fully prepared for another spill under similar conditions, arctic survival gear should be readily available. This equipment should be either purchased and stockpiled in advance, or a list which delineates how the gear can be obtained within a matter of hours of a spill should be supplied to the contractors, cleanup parties, and other personnel involved with the spills.

It is paramount that all people on the ice have safety lines attached to them and life vests on. Working in pairs with jon boats nearby and deploying surveillance personnel at various distances from shore are also recommended. If crews work shortly after a snowfall, open water areas may be obscured; therefore, utmost care must be exercised if work is continued during these times. In addition to safety lines and life vests and boats, probes should be used so the crews can "feel" their way along the ice.

Wind chill was also an important factor in the Buzzards Bay spill A warming house or other type of readily accessible shelter should be equipped with catalytic heaters and hand warmers for periodic use by crews. Exposure times to the cold should be limited, the time being dictated by the degree of wind chill. Under the worst-case conditions at Buzzards Bay, this exposure period should have been no more than one-half hour. A paramedic or doctor should be on hand to assist injured crew members.

SECTION 7

SAMPLING AND FIELD WORK

An interagency program of water column, sediment, benthic, and shellfish sampling surveys was initiated immediately after the spill by the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), Massachusetts Department of Environmental Quality Engineering (DEQE), and the Massachusetts Division of Marine Fisheries. NOAA's sampling efforts were designed to trace the movement of oil in the water columns, determine the interaction of the spilled oil with surface ice present in Buzzards Bay, and, on a limited scale, determine the long-term environmental impact of the spill. The EPA, DEQE, and the Massachusetts Division of Marine Fisheries sampling efforts were designed to determine the extent of benthic sediment contamination by the spilled oil, investigate contamination of commercial shellfish areas, and assess the acute, short-term environmental impact of the spill. NOAA contracted with a number of firms, including the Marine Biological Laboratory (MBL) at Woods Hole, Environmental Services Corporation, Science Applications, Inc., and Arctec, Inc., to assist in the overall sampling effort.

This section presents a review of the procedures and techniques employed by EPA staff for sampling benthic organisms, sediments, and shellfish. The information given under DESCRIPTION, is drawn entirely from EPA Region I records and interviews with Region I staff members. The EVALUATION and RECOMMENDATION discussions are the professional opinion of the authors.

DESCRIPTION

The EPA field studies were initiated after the <u>Bouchard</u> spill on 28 January 1977. These EPA studies had three purposes:

1. to interface with studies being conducted by other agencies and parties,

2. to provide indications of the presence of No. 2 oil in sediments as determined by visible oil, sheen, or odor of oil, and hydrocarbon analysis,

3. to assess short-term biological damage as determined by the presence of dead organisms.

An additional but lower priority goal was to assess gross changes in the composition of benthic biological communities due to mortality.

Several meetings were held between the EPA and other interested agencies and parties during the month following the spill. Reports of oil concentrations and movement were considered and a multi-agency sampling program was established. Each agency's program was integrated with the others and all programs were to be nonredundant and complementary.

Benthos

The EPA and Massachusetts Division of Marine Fisheries staff collected benthic samples at 20 stations chosen to represent both various biological resources and suspected sites of oil contamination. The sampling locations are shown on Figures 31 and 32. Sites 1, 2, and 4 were chosen because of their high-resource value (shellfish) and their position in the anticipated path of slick movement. Stations 13 and 180 were the sites of the intentional grounding of the barge and the initial grounding, respectively. The remaining stations were chosen based on aerial and surface observations of the movement of oil/ice within the bay.

During consultation with other agencies to coordinate the various sampling efforts, the Northwest Gutter at Ucatena Island was selected as a control site for all agencies' sampling program. Northwest Gutter was selected because it was probably uncontaminated by the Bouchard spill, was minimally influenced by any municipal or industrial wastes or past spills, and offered the opportunity for transect sampling of the entire range of sediment types encountered in the study. Further, MBL had earlier collected biological and chemical data from the area that could be used, with MBL's consent, as a baseline for the site.

The scheduled sampling was infrequent throughout February and March (Table 12) because of continual movement of the oil and the difficulties encountered in trying to collect samples from beneath ice. By late April, the sampling schedule became relatively constant at all stations since the ice had greatly diminished and the route of oil movement had been delineated. It was then possible to identify stations that best exemplified various habitats and resources that were contaminated. Several new stations were established that were sampled monthly for the remainder of the study. Station 47, selected as the control site in the first few days after the spill, was not sampled by the EPA until June because of weather conditions and boat availability. This was not considered critical, however, since at that time it was assumed that data collected by MBL at this station would be available.

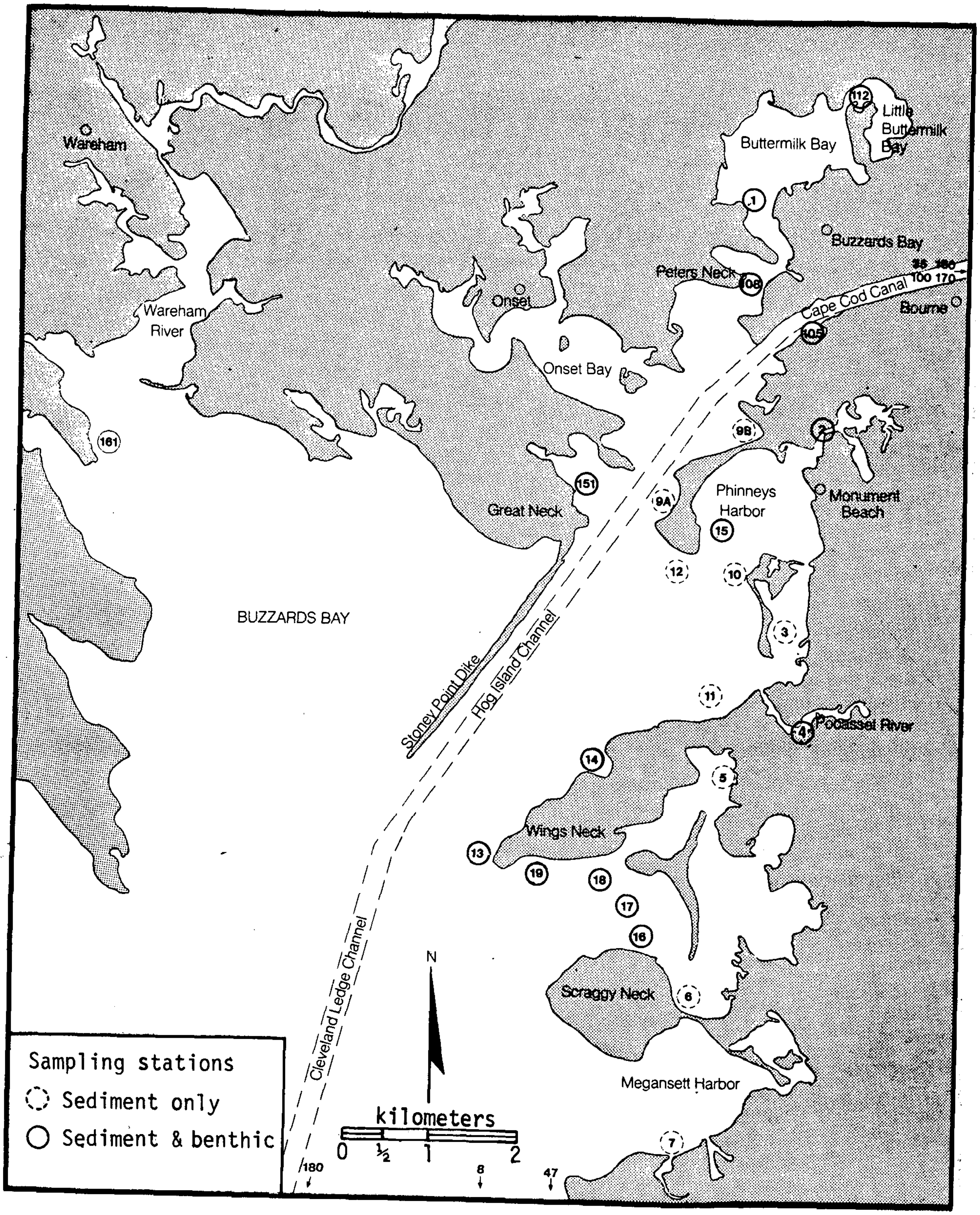


Figure 31. Location of EPA sampling stations.

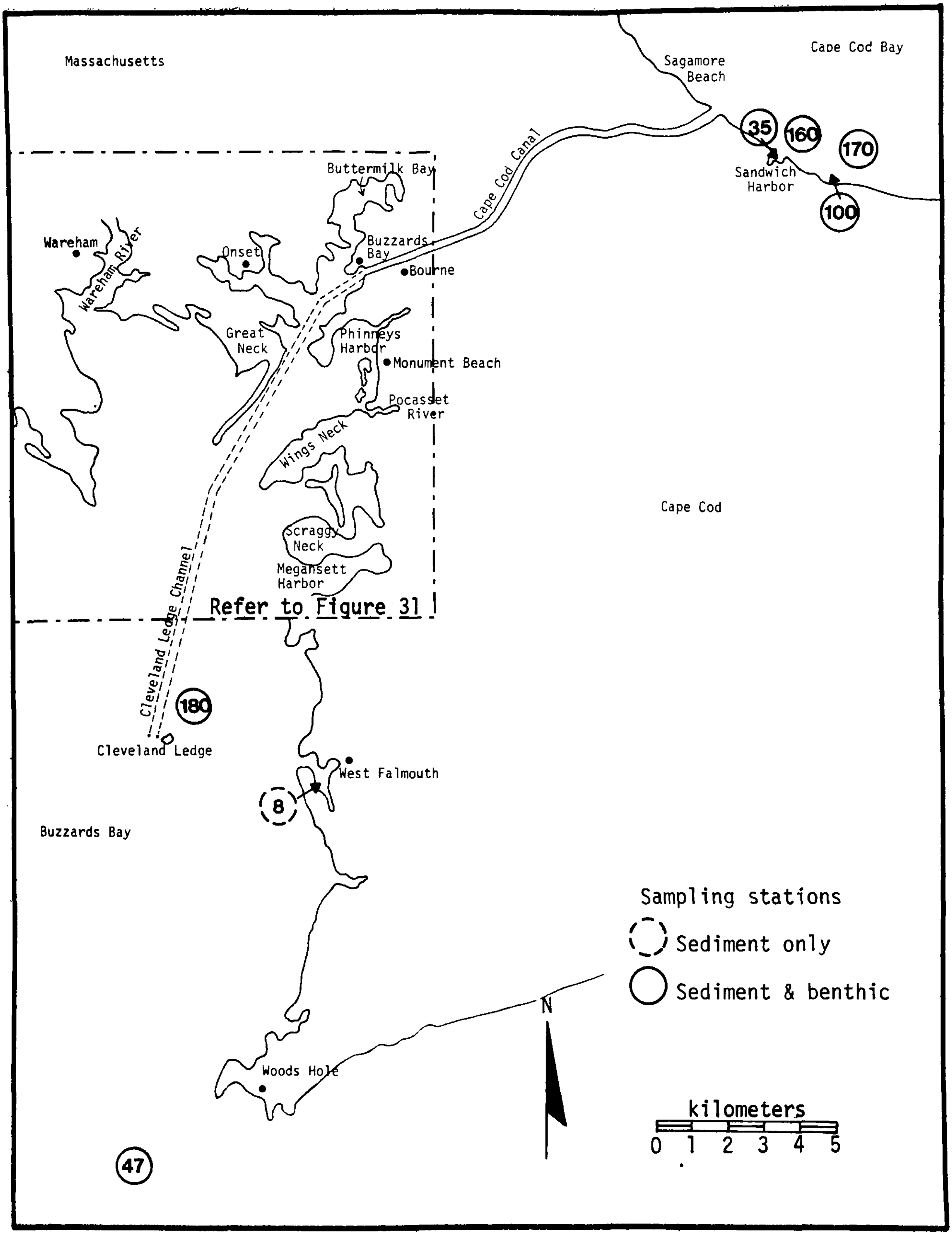


Figure 32. Location of EPA sampling stations.

TABLE 12. BENTHIC SAMPLING PROGRAM

Station number	Sampling date: Jan. 28 - Feb. 4 2/77	March 8 - 10 3/77	April 20 - 21 4/77	May 23 - 24 5/77	June 20 - 21 6/77
1		a	c	c	d
2			a	c	a
4			a	c	a
13			c	c	d
14	a[1]		a	c	d
15	a	a	c	c	d
16	a	a	c	c	d
17	a				
18	a[2]				
19	a				
35			a	c	a
47					d
100			a	c	a
105		b	a	c	a
108			a	c	a
112		b	a	c	a
151		a	c	c	d
160			c	c	d
161			c	a	d
170					d
180					d

[1]Type of sampler:
- a: Petersen
- b: Van Veen
- c: Petite Ponar
- d: Ponar

[2]No notation given for this station date. Use of Peterson grab is inferred.

Samples were collected at all stations using grab samplers. Stations 2, 4, 35, 105, 108, and 112 were reached by walking out from shore to the station location; other stations were sampled from a small boat.

Station locations were determined by unaided visual sighting using onshore landmarks. A Field Data Card was prepared at each station showing data on conditions at each station.

Four different types of samplers were used. The characteristics of each sampler are shown in Table 13. The sampler used at each location in each sampling period is shown in Table 12. Samplers were chosen based on availability.

TABLE 13. CHARACTERISTICS OF SAMPLERS USED

Type of sampler	Dimensions	Area sampled
a. Petersen	10.25 x 10.5 in. 26 x 26.7 cm	107.6 $in.^2$ 693.4 cm^2
b. Van Veen	NA	400 cm^2
c. Petite Ponar	6 x 6.5 in. 15.2 x 16.5 cm.	39 $in.^2$ 250.8 $cm.^2$
d. Ponar	8.5 x 9.5 in. 21.6 x 24.1 cm.	80.8 $in.^2$ 520.6 $cm.^2$

NA = Not available.

The number of samples taken at each station throughout the sampling period is shown in Table 14. Initially, three replicate samples were taken during the February survey. Thereafter, single samples were obtained due to resource constraints. The boat was not anchored during sampling so there probably was some drift between replicate samples. When drift was observed the boat was repositioned at the original sample site. Whenever possible, samples were rejected unless a full grab was obtained. In certain areas, hard bottom characteristics resulted in less than a full sample. The grab sampler was thoroughly rinsed in sea water between sample stations.

Grab samples were immediately sieved through a No. 30 mesh screen and placed in plastic bags or mason jars. When replicates were taken, each was handled separately. A minimum of 5-percent formalin was added to each sample to preserve the sample.

The chain of custody procedure included the following steps. A sample tag was affixed to each sample taken in the field. These tags contained information on the source of the sample, sampling crew, date, time, station number, and type of analysis to be performed on each. During the February and March sampling periods, organisms were rough-sorted in the EPA lab prior to delivery to the taxonomy lab. A laboratory number and card were assigned to each site. Replicate samples from a site were usually assigned the same laboratory number. Letters of transmittal were signed by both EPA and the receiving party when the samples were delivered to the laboratory. Marine Research, Inc., did taxonomic classification to genus and, when possible, to species.

TABLE 14. NUMBER OF BENTHIC SAMPLES AT EACH STATION

Station number	Sampling date				
	2/77	3/77	4/77	5/77	6/77
1		1	1	1	1
2			1	1	1
4			1	1	1
13			1	1	1
14	3		1	1	1
15	3	1	1	1	1
16	3	1	1	1	1
17	3				
18	1				
19	2				
35			1	1	1
47					2
100			1	1	1
105		1	1	1	1
108			1	1	1
112		1	1	1	1
151		1	1	1	1
160			1	1	1
161			1	1	1
170					1
180					2

Sediment

Samples for hydrocarbon analysis of sediments were collected at a number of sites, selected on the basis of the existing or forecast movement of the oil. Immediately after the spill, a number of sites were sampled that were later abandoned. The number of sampling stations was necessarily reduced when the budget for sampling program was established. The stations selected for further sampling were those thought to have the highest probability of contamination or resource value. The schedule of sediment sampling is given in Table 15.

TABLE 15. SEDIMENT SAMPLING SCHEDULE

Station number	Sampling date 2/77	3/77	4/77	5/77	6/77
1	X	X	X	X	X[1]
2	X	X	X	X	X
3	X				
4	X	X	X	X	X
5	X				
6	X				
7	X				
8	X				
9	X				
10	X				
11	X				
12	X				
13	X	X	X	X	X
14	X	X	X	X	X
15	X	X	X	X	X
16	X	X	X	X	X
17	X				
18	X				
19	X				
35	X	X	X	X	X
47		X[2]			X
100		X	X	X	X
105	X	X	X	X	X
108	X	X	X	X	X
112		X	X	X	X
151		X	X	X	X
160			X	X	X
161			X	X	X
170					X
180					X

[1]Two samples taken.
[2]Sample taken by Marine Biological Laboratory, March 22.

Sediment sampling stations that were not coincident with benthic sampling locations were located by unaided sightings on prominent onshore landmarks, minimizing the chance of displacement of subsequent sampling grabs.

Sediment samples were taken with the grab samplers previously described for the benthos. The sampler was thoroughly rinsed in sea water between stations. Most samples were collected by taking a subsample from the portion of the sample not in contact with the walls of the sampler. On some occasions, the entire sample was collected if less than a full grab was taken.

The samples were collected in glass quart jars that had been cleaned in the EPA laboratory. The jars were washed in 10 percent solution of "Chem-Solv" for 10 minutes, rinsed in tap water, then heated to 500°C for 4 to 6 hours. The jar lids were lined with either teflon or aluminum foil. The closed jars were immediately placed in an ice chest containing wet ice.

When the samples were returned to the laboratory they were placed in a locked freezer at about -14°C. The samples were transferred to the Energy Resources Company (ERCO) laboratory in an ice chest with wet ice. They remained in a freezer at ERCO until analyzed.

The chain of custody procedure for sediment samples was identical to that described earlier for benthos. Only samples for April, May, and June were delivered to ERCO for analysis. The EPA chemistry lab in Lexington, Massachusetts, analyzed all sediments samples taken prior to April. Hydrocarbon analyses included preparation, gas chromatography, and gas chromatography-mass spectrometry.

Shellfish

The Massachusetts Division of Marine Fisheries and Department of Environmental Quality Engineering were delegated responsibility, under the multiagency sampling program, for collecting shellfish and determining hydrocarbon contamination. In June it was learned that the state's shellfish data would not be available to other investigators. At this time, EPA staff initiated shellfish sampling to complement the benthic and sediment samples.

Molluscs were sampled in July at stations 1, 13, 15, 16, 35, 47, 112, and 151. Each of these stations is in shallow water and the sites were reached by wading. Sites were located by unaided visual sighting on onshore landmarks. The samples were obtained by digging until 15 or more approximately equal-size animals were obtained. Only one species was collected at each site; species collected were *Mercenaria mercenaria*, *Mya arenaria*, and *Mytilus edulis*. Lobsters (*Homarus americanus*) were collected in July at Station 13 for analysis of hydrocarbon concentration in hepatopancreas and muscle tissue.

Organisms were kept on wet ice until delivered to the laboratory; there they were frozen until analysis. Chain of custody procedure for shellfish samples was the same as that described earlier for benthos.

EVALUATION

Obviously, an oil spill is a difficult event around which to plan a study. No one can foresee an oil spill occurrence, the area to be contaminated, or what type of oil will be spilled. Thus, it is difficult to assure that appropriate sampling equipment and the necessary manpower and analytical capability will be available, and that access to remote locations is possible under inclement weather conditions. Although there was a minimum of planning at the outset of the EPA sampling program, this could not be avoided under the circumstances. However, after the initial emergency response, rapid turnaround of oil trajectory information and hydrocarbon analysis would have been extremely useful in planning subsequent studies and necessary sampling. Unfortunately, this rapid turnaround was not available to EPA staff after the Buzzards Bay spill.

The EPA sampling program successfully dealt with problems posed by severely adverse weather conditions and the difficulty of tracing oil dispersion. The three major purposes of the study -- coordination with studies by other agencies, indications of the presence of spilled oil, and assessment of acute, short-term effects -- were accomplished. The subordinate goal -- assessment of gross biological changes in the benthos was inconclusive owing to a lack of systematic planning and failure to assure quality control through specification and adherence to the same standard procedures throughout the sampling effort.

Benthos

An important constraint on the design of the sampling effort was that rarely did the oil ground on the shoreline. If oil had grounded in visible concentrations, it would have been relatively easy to identify sites of known contamination and assign sampling locations. Instead, sites of suspected contamination had to be inferred from the presence of oil on or in ice and from sheens.

In the initial sampling period following the spill, the investigators located sampling stations where the oil was believed to be concentrated. This was based on aerial observations of oil on the ice. Under the weather and ice conditions during this period, January 28 to mid-February, no other basis of site selection was feasible. The coverage of the areas believed to be contaminated was good.

As the movement of the oil continued, the ice breakup revealed new concentrations and sheens and new stations were established at locations where new evidence of oil was observed. Again, based on the available information, the coverage of potentially contaminated sites was good.

Except for sampling at the control site, the frequency of sampling was good. The number of replicates, however, was inadequate to provide reliable data for an assessment of changes in the composition of the benthos. For example, the taxonomic data for Station 13 show that 72 species were collected when 3 replicates were provided; but an average of 27 species was collected when only one sample was provided. This strongly suggests that one sample was inadequate to represent the patchiness and spatial dispersion of the benthic community of that location.

The methods employed in sample collection for the primary purposes of the study were generally appropriate. However, incomplete notation of observations at each sample site on the Field Data Cards was a shortcoming.

The methods employed in sample collection and handling for longer-term biological damage assessment were inadequate in the following respects:

1. Use of four different grab samplers.

2. Failure to assure standardization of methods in each sampling period.

3. Incomplete notation on Field Data Cards of number of replicates, sample volume, substrate type, type of sampler use.

Five percent formalin is presently an accepted strength for preservation of fresh biological material; given the long shelf life of the samples, however, 5 percent may have been insufficient in this case. The taxonomy laboratory reported that: "Some of the samples preserved poorly. Some mollusc shells were dissolved; some polychaetes were often so bad as to be unidentifiable to family."

Replicates for the February sampling of stations 16, 17, and 19 were improperly numbered on sample lists transmitted to the laboratory. As a result, all replicates for each station were combined by the laboratory and analyzed as single samples.

<u>Sediment</u>

The location of sediment sampling stations and frequency of sampling was good. The number of samples taken was inadequate for determining the variability of the samples. Some samples may have included material that was in contact with the sides of the grab and could have been contaminated. All other aspects of the sampling (i.e., preservation, labeling and handling) were good.

Shellfish

Given the previously discussed difficulty of determining the actual sites of oil contamination, the location of shellfish sample sites was good. The frequency of sampling was inadequate, but EPA did not originally intend to sample shellfish and initiated this part of the program only when it was learned that shellfish data would not be available because of the Massachusetts Attorney General's gag order. All aspects of handling the shellfish samples were good.

RECOMMENDATIONS

Benthos

Future spill response sampling efforts can be improved by careful planning. Although the search for "indications" of environmental effect of the spill was successful, the criteria for indications should have been stated, and observations that both met and failed to meet these criteria should have been reported.

The major weakness of the longer-term study was poor definition of the criteria for identifying impact. Without such definition, the data could not provide answers to the questions that were ultimately asked.

The planning described below obviously requires time and field effort. The sponsoring agency must commit the resources (i.e., time, facilities, and financial support) necessary to carry out such planning. Unless this procedure is implemented, the investigator has no assurance that the sampling program will provide data that support rational interpretation. During the Bouchard spill sampling program, an opportunity for this program design was available between the March and April samplings.

Optimally, any study of the effects of a pollutant should be conducted as a standard scientific investigation. The following steps should be followed in designing and conducting such an investigation.

A. The problem being investigated should be clearly stated as a null hypothesis, specifying what is to be measured, the sample size, and desired level of significance of the analysis.

B. Observations, sample types, and method of analysis should then be chosen which will confirm or deny the null hypothesis. Only after completing these steps should collection of samples (i.e., data) begin. Data gathering should provide only the correct type and quality of data needed to perform the selected method of analysis. If this procedure is followed, the data analysis will confirm or deny the null hypothesis. Again, commitment of agency resources is required.

Buzzards Bay is not a homogeneous environment; therefore, prior to initiating data collection, the investigators should consider the problems of sampling in a variety of habitats. Readily available information such as navigation charts, location of water quality influences such as storm water and waste outfalls, and technical literature should be obtained. Where data are already available, they should be reviewed for their adequacy and applicability to the proposed study. Major habitat categories should be defined. With such a baseline, both control and study sites can then be selected in the habitats of interest.

Communities of benthic organisms typically exhibit nonuniform distribution, i.e., clumping and patchiness which has an important effect on sample size. To overcome this problem, the minimum sample size needed to provide statistically reliable data should always be determined empirically by first determining the number of species in several replicate samples. The cumulative mean number of species is then plotted against the area sampled and the optimum sample size is obtained from the point where the curve flattens (i.e., where variation dwindles). It is also essential to use the same sampler for all data collection, since the performance characteristics of samplers are variable.

In this sampling program only one replicate was taken in most cases at each station. At minor additional cost, investigators could have taken the optimum number of replicates at each station. Later, the number of analyses permitted by the budget could be determined so that unpromising sites could be eliminated. At this later date, when oil dispersion is plotted, and suspected sites of contamination are identified, selection of stations to be analyzed can be based on whatever is of interest to the agency (e.g., commercial resources) and suspected degree of contamination. This recommendation provides information on fewer sites, but provides much more reliable data for each site.

A major deficiency of the overall sampling program was lack of standardization of field procedures. This deficiency could have been corrected by assigning a single individual to direct all field sampling and laboratory procedures. In addition, all procedures should have been written up after each sampling effort and any deviations from standard procedures noted.

Specific procedural recommendations are:

1. Use electronic range finder or sextant to locate offshore sampling stations.

2. Use only one type of sampler.

3. Use checklist to assure that all required obervations are made.

4. Use checklist to assure that all necessary samples and replicates are collected and properly labeled at each sampling location.

5. Although 5 percent strength buffered formalin is an acceptable EPA standard for preservation, use of 10 percent buffered formalin for field preservation and transfer of samples from formalin to 70 percent alcohol in the laboratory is being used increasingly for marine samples.

6. Use checklist to assure that all samples and replicates are delivered to laboratory and that all are properly labeled.

Sediment

The program for sediment sampling should be planned in the same manner as described for benthos. Recognizing that oil contamination of sediments can also be patchy, the optimum number of samples needed to characterize the site should be empirically determined. After determining the optimum number of samples, the replicates may be composited to reduce the number of analyses.

Ultraviolet fluorescence analyses can be valuable in delineating areas of oil concentration in the sediments. It provides a quick and inexpensive screening mechanism and is an exceptionally good technique for matching fresh oils from the same source. Evidence obtained through fluorescent analysis, however, must be confirmed with gas chromatography and gas chromatography-mass spectrometry techniques. Thus, it is recommended that in future spills where confirmation of the observed movement of oil is important to the design of the sampling effort, ultraviolet fluorescent analyses should be used initially if applicable.

To eliminate the chance of discrepancies in interpretation of gas chromatogram and mass spectrometry results, only one chemical laboratory, either the EPA laboratory or one approved by the EPA, should be responsible for sample analyses. In the present case two laboratories -- EPA and ERCO -- were involved.

Shellfish

The goal of the shellfish study was to detect "indications" of oil contamination. The criteria for "indications" should be reported (e.g., smell, taste, mortality); without criteria, indications can not be definitively confirmed.

SECTION 8

DAMAGE ASSESSMENT

BIOLOGICAL RESOURCES

The *Bouchard No. 65* spill did not result in the type of visible and acute biological effects that were observed after the 1969 *Florida* spill and the 1974 *Bouchard* spill. Consequently, this impact assessment attempts to detect and describe the more subtle effects associated with the spill (e.g., changes in benthic community structure). The success of determining such effects depends on the availability of information about (1) the ultimate fate of the oil in the aquatic environment, (2) the "natural" composition of the aquatic community before the spill, (3) the composition of the community after the spill, and (4) potential influences other than the oil that might account for any changes. Rarely are all four of the information needs described above satisfied simultaneously; as a result, biological damage assessments are rarely successful in implicating recently spilled oil. The present study is no exception.

The biological damage resulting from the *Bouchard* spill is determined using the information above as follows:

A. Determine whether the data reveals differences between 2) and 3).

B. Show a positive correlation between 1) and 3), given that a difference between 2) and 3) has been established.

C. Eliminate 4) as the major reason for the correlation between 1) and 3).

Availability of Information

The Buzzards Bay impact assessment is primarily based on EPA benthic data, EPA sediment data, and Massachusetts Division of Marine Fisheries visual observations. Hydrocarbon analysis of the Marine Biological Laboratory (MBL) sediment samples was used to supplement EPA sediment data with the aim of determining suspected *Bouchard No. 65* oil movement into the benthic environment. Information regarding suspected accumulation and incorporation of the oil into shellfish tissues was obtained from chemical analyses of shellfish samples taken by the EPA, MBL, and State of Massachusetts Department of Environmental Quality Engineering (DEQE). Oil concentrations in the water column (DEQE, Environmental Devices Corporation), and in the ice (NOAA) measured shortly after the spill were not applicable to the damage assessment because corresponding biological samples did not exist.

Hydrocarbon analyses for both the EPA (April-June) and all MBL sediment samples were performed by Energy Resources Company (ERCO) of Cambridge, Massachusetts. Sediment extraction for petroleum hydrocarbons, gas chromatography, and mass spectrometry confirmations were performed in accordance with EPA specifications (Appendix A). EPA sediment samples taken prior to April were analyzed by the EPA laboratory, Lexington, Massachusetts.

Biological baseline data from the Buzzards Bay region prior to the 1977 spill is limited; it is virtually nonexistent for the area north of Wings Neck where the Bouchard oil contamination was suspected. Limitations with the EPA benthic survey in this area after the spill have been described previously (Section 7).

While general information on the currents, sediment transport, and water temperatures of Buzzards Bay exist, localized data that would reliably characterize the physical processes at the sampling stations are lacking. Similarly, how these physical factors interact to affect benthic communities is not known. Undeniably, these natural processes can mask subtle changes in the benthos that might occur as a result of an oil spill.

Chemical Analysis: Results

Sediment

Unexpected changes observed in the biological resources of an area are meaningless to a damage assessment unless they can be tied to the presence of the contaminating oil. As described in Section 7, sediment samples were taken in an attempt to determine the movement of the oil and measure its incorporation into the benthic sediment. The results of the hydrocarbon analyses performed by the EPA and ERCO suggest that (1) Buzzards Bay is subjected to a high level of chronic oil contamination, (2) the sediment stations that do show contamination by No. 2 fuel oil are generally to the north of Wings Neck, and (3) the No. 2 fuel oil found in the sediment cannot be identified as oil from the 1977 Bouchard No. 65 spill.

If Buzzards Bay were uncontaminated, the sediments would contain only biogenic hydrocarbons (hydrocarbons naturally produced by plants and animals). The sediment samples analyzed by ERCO, however, generally contained an unresolved complex mixture of hydrocarbons that cannot be generated by biogenic sources. Since there are no known natural seeps in the Northeast that could contribute petroleum hydrocarbons to the sediment, low level chronic discharges and past spill events are implicated as the primary hydrocarbon sources. Total hydrocarbon concentrations in the sediment ranged from a low of 1.7 micrograms per gram-dry weight to a high of 213.2 micrograms per gram-dry weight. These values are within the range previously found by ERCO and others for Buzzards Bay.

Because the source of hydrocarbon contamination and not the total amounts of hydrocarbons are of primary importance in assessing the damage caused by the 1977 Bouchard spill, ERCO developed five classes to qualitatively describe the oil found in the sediments (Appendix C). These classes are:

Class A -- Clean Sediment
Class B -- Moderate Amount of Chronic Pollution
Class C -- Chronic Pollution
Class D -- Chronic Pollution and No. 2 Fuel Oil
Class E -- Recent No. 2 Fuel Oil Predominating

The April, May, and June sediment results are presented in Appendix D and displayed in Figures 33 through 35. Results indicate that more sediment stations were chronically contaminated than were contaminated with No. 2 fuel oil. Not surprisingly, numerous sources of chronic pollution exist in the Buzzards Bay area including accidental discharge from tankers and barges, dischargers, and oil associated with sewage effluents, storm sewer and road runoff, industrial effluents, and urban air fallout.

In general, those stations with some fresh and/or weathered (Class "D" and "E") No. 2 fuel oil are to the north of Wings Neck. The movement of Bouchard No. 2 oil to the north generally corresponds to the observed movement of the tidal currents in the bay. A similar No. 2 oil pattern was found by ERCO in their analysis of the NOAA sediment samples (February-June). Because of the heavy shipping traffic through Cape Cod Canal, other No. 2 oil spills in the area, and the alteration of the Bouchard oil by weathering and mixing, ERCO could not identify the No. 2 oil in the sediments as Bouchard No. 65 oil. For the purposes of the impact assessment, however, the assumption was made that stations with "D" and "E" classifications could contain Bouchard No. 65 oil.

In an effort to make the February and March chemical data provided by the EPA lab comparable to the April-June samples analyzed by ERCO, the EPA laboratory reviewed the hydrocarbon data and developed sediment classifications (Appendix E) based on criteria similar to that used by ERCO. Because of potential discrepancies in interpretation, the EPA-interpreted data were used in the benthic analysis only to establish the potential presence of No. 2 oil ("D" or "E") at the February and March sampling stations.

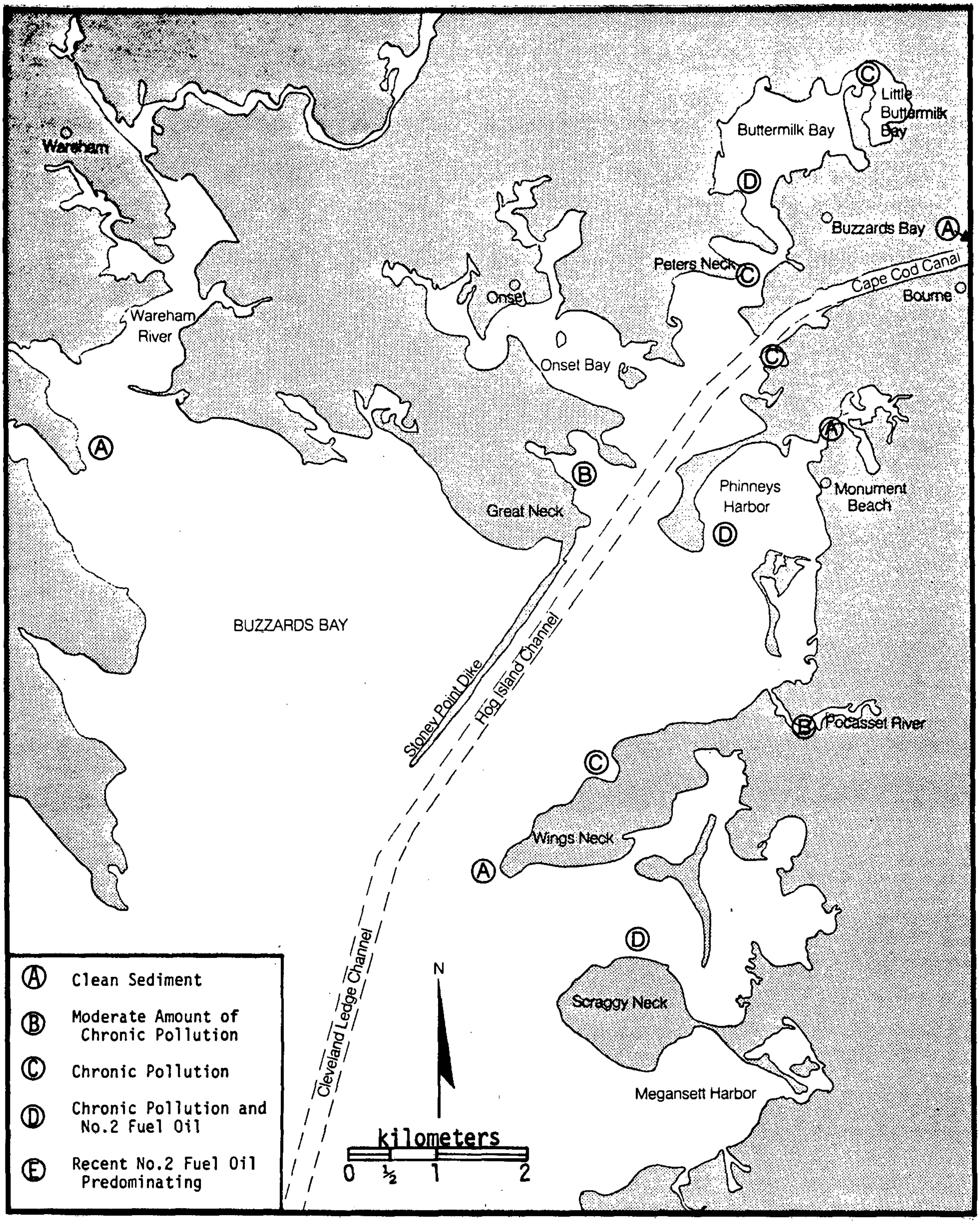


Figure 33. Classification of April sediment samples based on their oil content.

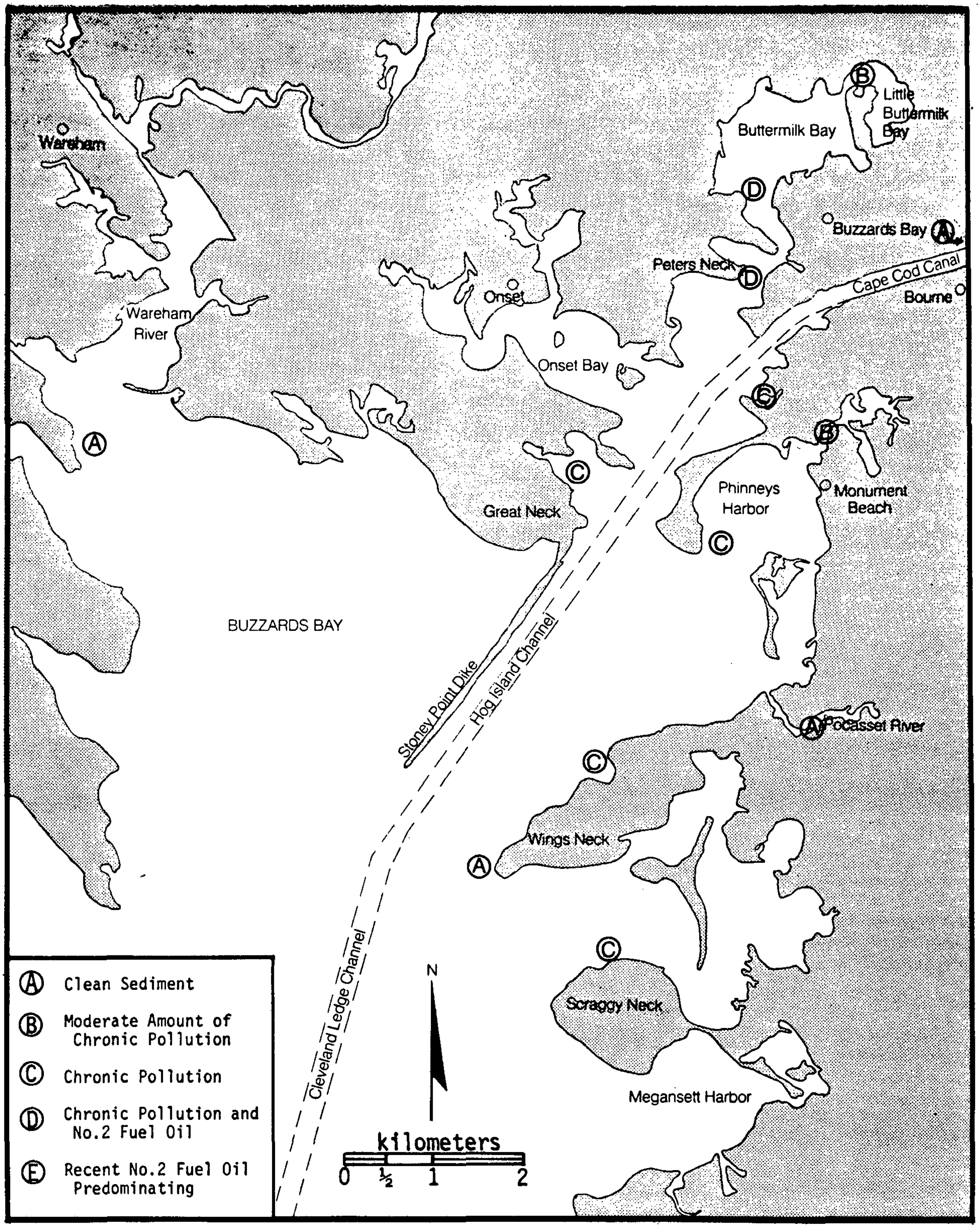


Figure 34. Classification of May sediment samples based on their oil content.

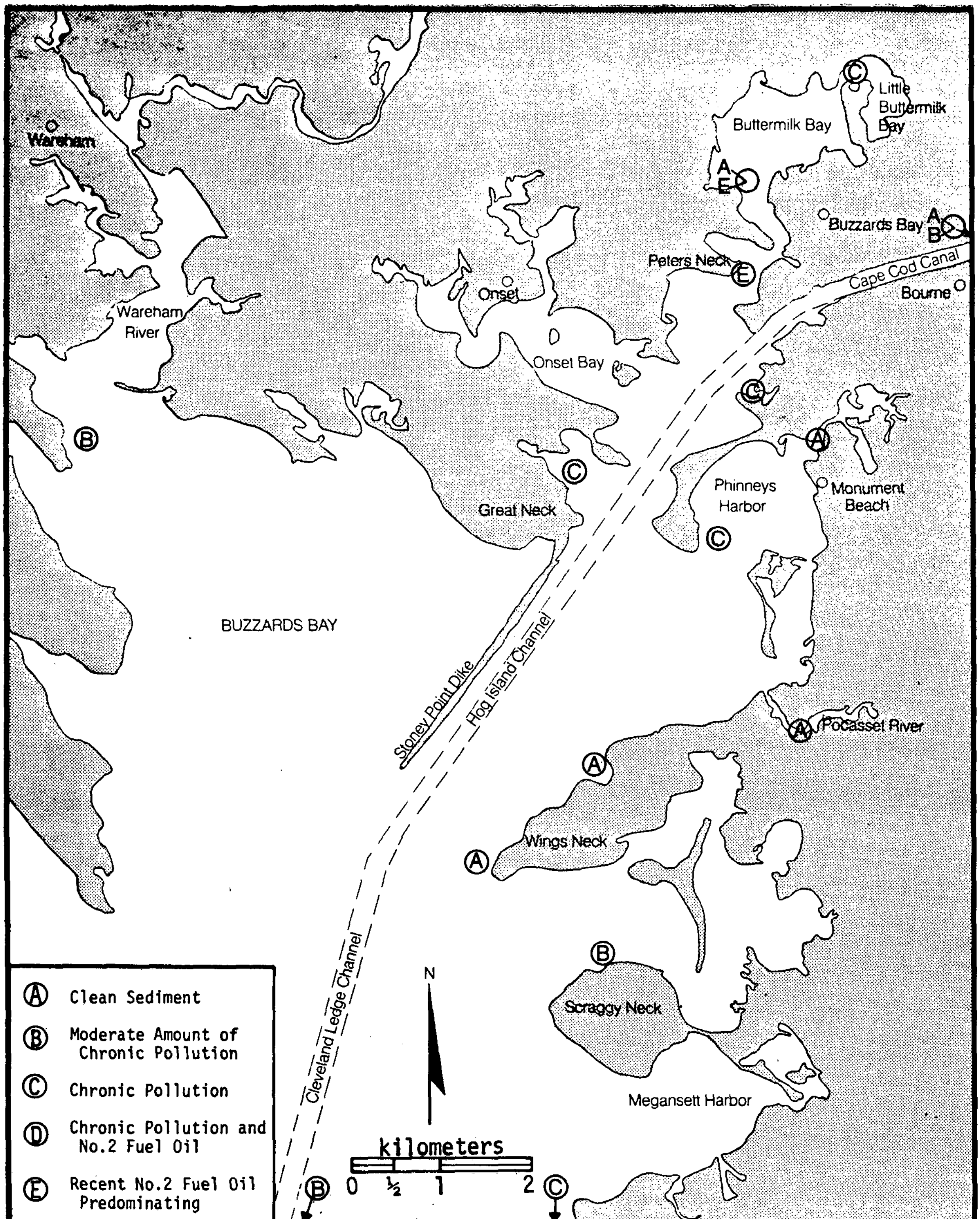


Figure 35. Classification of June sediment samples based on their oil content.

Shellfish

Bivalve and lobster samples were taken by the EPA and Massachusetts Division of Marine Fisheries on July 14-15 in an effort to find evidence of fuel oil contamination in the tissues of these organisms (Appendix F). The chemical analysis of the bivalves indicates that these organisms generally suffered from both No. 2 fuel oil and chronic pollution. The hydrocarbon distribution found in the bivalves, however, cannot be tied to a single spill event.

Figure 36 contrasts the classification of the oil found in eight July bivalve samples with the corresponding June sediment classes. Six of the eight bivalves analyzed that showed traces of fuel oil contamination (Class D) were found in sediments with undetectable levels of fuel oil (Class C or less). The absence of any correlation between oil found in the sediments and oil found in the shellfish is in keeping with the bivalves' ability to concentrate a chronic input of pollutants from the water column. Because selective uptake, depuration, and degradation alters the chemical fingerprints of the oil in the environment, oil found in the bivalves cannot be matched to the source of contamination. The presence of "D" and "E" classifications in the MBL samples taken outside the area of postulated Bouchard oil concentration (i.e., Sandwich Creek, West Falmouth Harbor, and Northwest Gutter) supports the conclusion that no single spill can be implicated as the source of contamination in the bivalves samples. In addition, bivalve oil analyses conducted by the Massachusetts Department of Environmental Quality Engineering for the 5 months following the spill, show a large range in the types (primarily No. 2 and 6), amounts, and weathering of hydrocarbons found in the shellfish.

No No. 2 fuel oil was found in the lobster samples taken off Wings Neck. The mobility of the lobsters and the lack of information on the metabolism of oil in the hepatopancreas and muscle tissues, however, prevent any conclusions from being drawn about the effect of the Bouchard spill or any other oil inputs on the lobster population in the area.

Benthic Community Analysis

This biological impact assessment attempts to identify any observed anomalies in the benthic community and match these anomalies with the presence and absence of No. 2 fuel oil. Attempts to identify unexpected changes in the benthic community were made using results from the EPA/State of Massachusetts diving survey and three separate analyses of the available benthic data. The three separate analyses of data were: (1) species characterization of the benthic communities, (2) relative abundance of opportunistic species, and (3) quantitative classification of the sampling stations based on species composition. In general,

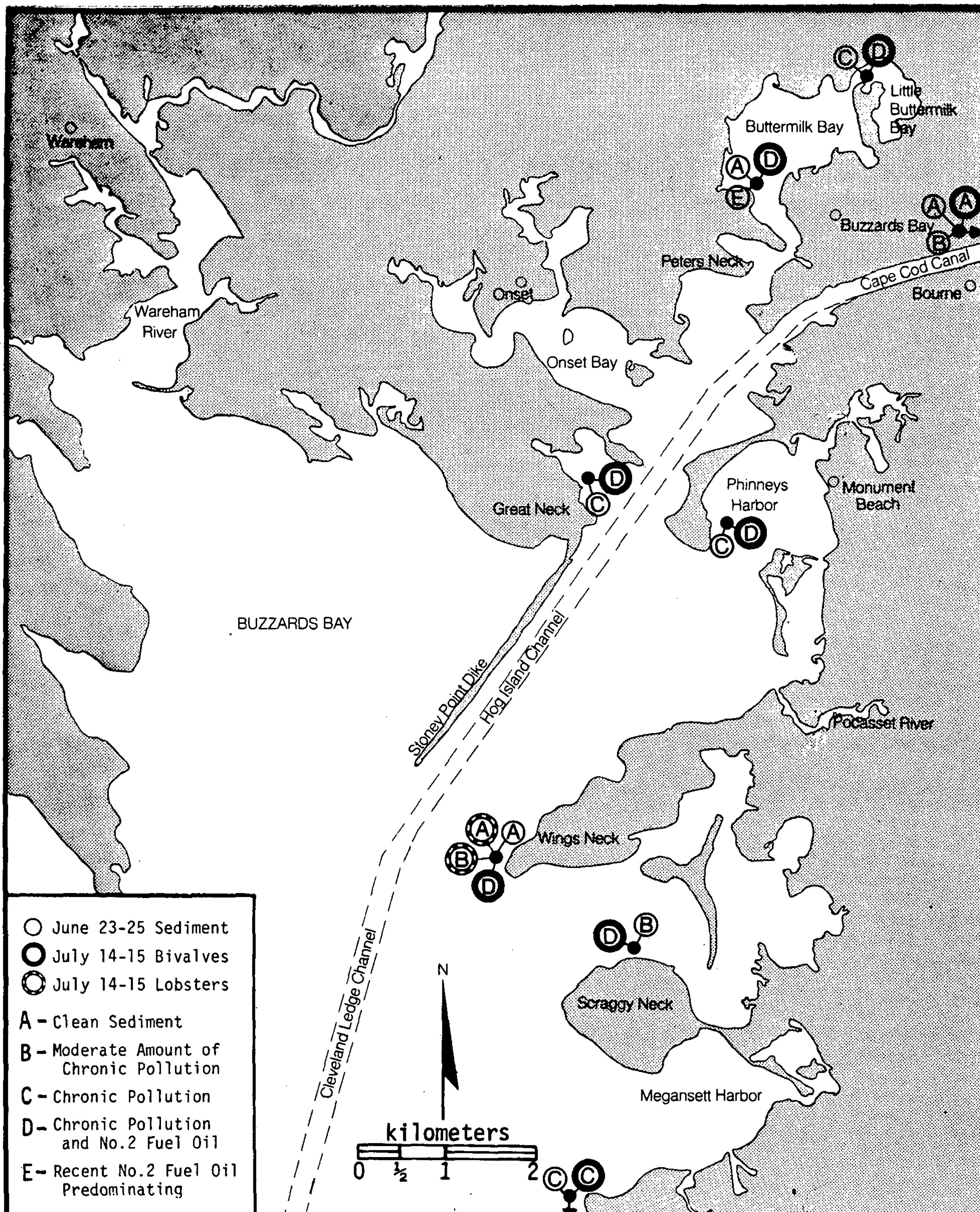


Figure 36. Comparison of oil content in the July shellfish samples with oil content in the June sediment samples.

these analyses contrasted observed and expected phenomena and qualitatively assessed whether any observed differences were a result of the Bouchard spill. Density and diversity indices were calculated but were not considered applicable to the damage assessment because of limitations in the benthic data. The results and discussion of the density and diversity calculations are presented in Appendix G.

Diving Survey - Approach

A diving survey is a qualitative tool for assessing damage to marine biota from an oil spill. Diving surveys are especially valuable when the biological effects are not acute. Divers can detect sublethal physiological effects by observing such phenomena as locomotor impairment, abnormal burrow construction, incomplete molting, and slow escape response to danger stimuli (no response to a quick hand movement or shadow). Other indicators that may be missed by a shipboard sampling survey but picked up by divers include the reduced presence of highly motile species (crabs and shrimp), accumulation of dead and decomposing organisms, and decreased seed stock.

Four diving surveys of the spill area were staged on April 1, April 13, April 21, and June 21, 1977. The first dive involved a Massachusetts Division of Marine Fisheries diving team and a team of divers from the Marine Biological Laboratory of Woods Hole. The other three dives involved Massachusetts Marine Fishery and EPA personnel.

The approach taken in using information from these diving surveys was:

1. Graphically present the diving surveys on a base map.

2. Describe the state of health of the observed organisms.

3. Look for discrete zones of biological damage.

Diving Survey - Results

The approximate locations of the 15 diving observation areas are presented in Figure 37. The first diving survey included the entrance to Buzzards Bay (1A), Widows Cove (1B), Phinneys Harbor (1C and 1D), and Little Bay (1E and 1F). Most of the locally common benthic inhabitants were found to be numerous and active. These included hermit crabs, limpets, and mud snails. Adult and seed bay scallops were found at all locations except Widows Cove and appeared to be normal and healthy. A commercial oyster bed located in Little Bay displayed no unusual mortality. Large numbers of moribund green crabs (*Carcinus* sp.) and horseshoe crabs, were found in Phinneys Harbor and Little Bay in April. It is

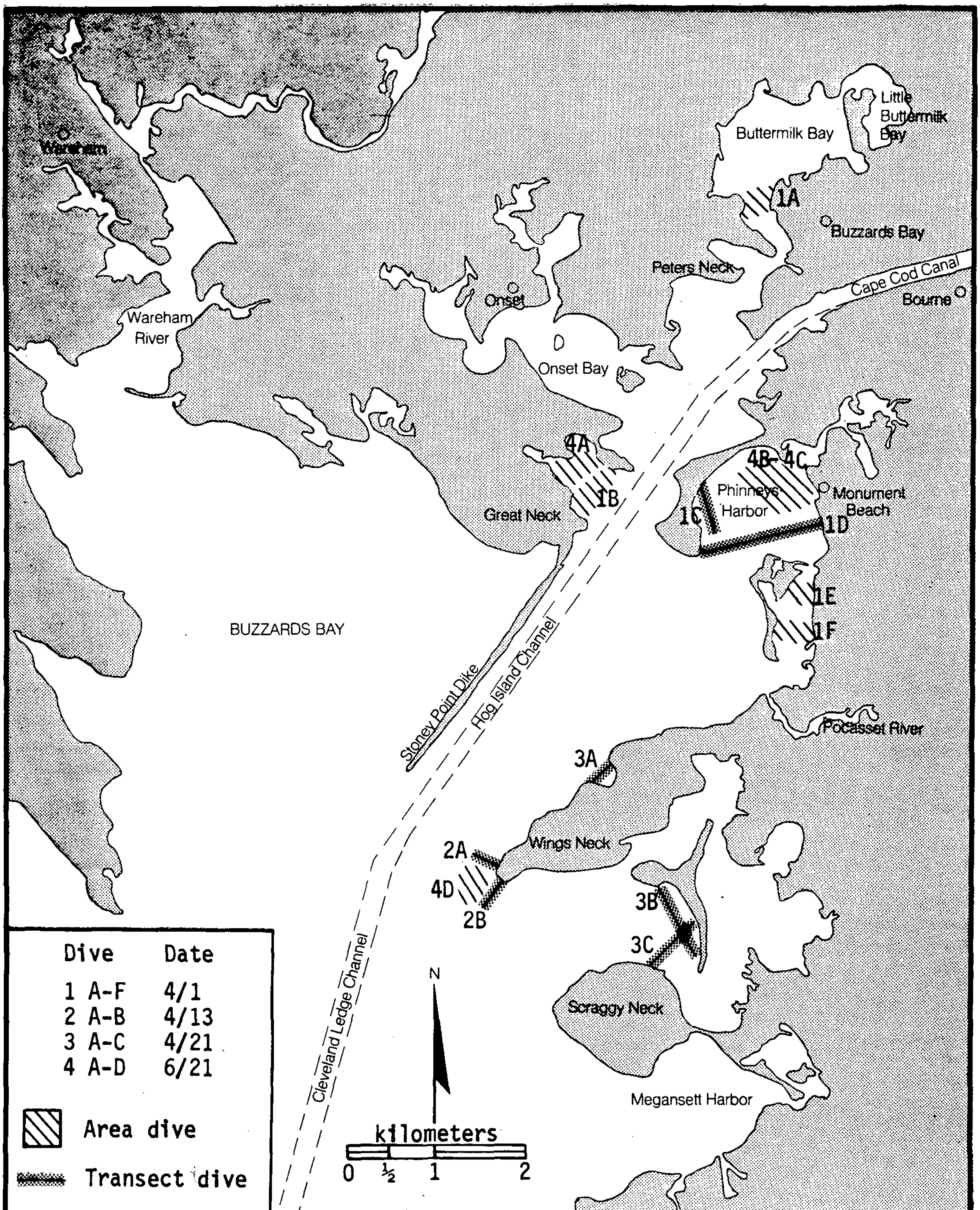


Figure 37. Locations of diving surveys.

unlikely that the mortality of these species was associated with the introduction of oil during or immediately following the spill. Evidence of acute impact from initial contamination (i.e., moribund crabs) in February would have been washed away, decomposed, or consumed by scavengers. Subsequent low-level releases of the oil as the ice melted could have resulted in acute, localized, and species-specific effects. However, a natural phenomenon (e.g., disease) or other pollution sources could also have caused the horseshoe and green crab mortalities.

The second diving survey consisted of two 100-yard-long transects (2A and 2B) commencing from the tip of Wings Neck. The divers encountered rocky and sandy areas and observed channel whelks, starfish, hermit crabs, tube worms, and a sulfur sponge. All animals were alive and behaving normally. The marine flora -- Codium and Irish moss -- appeared healthy.

The third survey consisted of shore-parallel transects at Wings Cove (3A) and Bassetts Island (3B) and a transect from Scraggy Neck to Bassetts Island (3C). No oil was observed in the water column or sediments during the dives. Similarly, no signs of mortality or behavioral abnormalities were observed in benthic populations of mud snails, hermit crabs, starfish, quahogs, scallops, and several species of worms.

The fourth survey included Widows Cove (4A), Phinneys Harbor (4B and 4C), and Wings Neck (4D). All organisms encountered were alive and behaving normally. Commercial species were represented by seed scallops in Widows Cove and lobsters in Phinneys Harbor and off the tip of Wings Neck. Other organisms observed were young and adult flounders, starfish, tube worms, limpets, and horseshoe crabs.

Overall, the diving survey suggests that the benthic organisms of Buzzards Bay were viable and behaving normally during the 5 months after the spill. The mortalities observed for the common green and horseshoe crabs may have been associated with oil from the Bouchard No. 65 barge but cannot be attributed to this spill. None of the dive teams observed any oil remaining in the substrate or water column.

Benthic Characterization - Approach

A grab sampling survey is a standard technique used to characterize a benthic environment. Such surveys are frequently initiated to detect changes in the benthos and to correlate these changes with the presence or absence of specific pollutants. Although some benthic organisms are mobile, the assumption is made that benthic sampling will characterize an entire benthic community. Consequently, the effects of known or suspected pollutants entering a benthic system can, with the proper sampling techniques, be detected either spatially (geographical comparison of benthos) or temporally (comparison of the benthos over a period of time). Benthic sampling surveys can document both the acute (immediate, severe impacts) and chronic (long-term, sublethal impacts) effects of pollution.

The approach proposed for analyzing this data was:

1. Enumerate and identify the contents of the sample to the lowest taxon possible.

2. Determine dominant species and benthic community composition for each station.

3. Observe changes in community composition over time that are different from normal, expected seasonal community changes. These changes may be caused by the effect of an extrinsic factor (e.g., pollution) upon the community.

4. If possible, identify the extrinsic factor (i.e., oil from the *Bouchard No. 65* spill).

Benthic Characterization - Results

The EPA benthic data generally supports Sanders' observation (Section 5) that few of the species account for most of the individuals present. In the spring months, however, a more even distribution of species occurred, i.e., reduction in dominance by a few species. This seasonal trend is normal for the Buzzards Bay region (personal communication, MBL). Total numbers of species present per station is presented in Table 16 and total number of individuals per station presented in Table 17.

In general, the February and March samples showed a strong dominance in the benthos by ostracods, copepods, and the snails *Nassarius triuittatus* and *Ilianassa obsoleta*. A few species of polychaetes known to be normally prevalent in the area were also present but in low numbers.

The April samples displayed a decrease in dominance by a few species. This trend persisted to the June sample. The winter faunal assemblage yielded to a spring assemblage composed more evenly of polychaetes, oligochaetes, bivalves and amphipods. Those species found with the greatest frequency were the polychaetes, *Mediomastus ambiseta*, *Exogone dispar* and *Polydori ligni* and the clam, *Gemma gemma*.

The Buzzards Bay benthos is composed primarily of filter and deposit feeders. There is a high probability, therefore, that oil being absorbed onto particulate matter in the water column or onto bottom sediments will, at one time or another, pass through the digestive system of the bottom feeders. Thus, the assumption can be made that oil from the

Bouchard No. 65 oil spill was, in undeterminable quantities, made available to the benthos.

TABLE 16. TOTAL NUMBER OF SPECIES[1]

Station number	Sampling dates 2/4	3/9	4/21	5/24	6/20
1		25	23	13	22
2			12	25	22
4			10	23	19
13			37	24	20
14	26		19	39	24
15	13	11	14	12	11
16	NA[2]	32	38	36	31
17	NA[2]				
18	37				
19	NA[2]				
35			2	20	NA[2]
47					24
100			1	2	4
105		9	5	17	25
108			11	24	18
112		14	16	19	12
151		22	13	20	33
160			13	10	20
161			32	32	22
170					11
180					NA[2]

[1]Nematodes from the February and Marsh sampling periods were removed by the EPA Laboratory prior to receipt of the samples by MRI. For consistency, only those species and individuals counted by MRI are included herein.
[2]Not Available. Replicate grabs combined as a single sample.

TABLE 17. TOTAL NUMBER OF INDIVIDUALS[1]

Station number	Sampling dates 2/4	3/9	4/21	5/24	6/20
1		501	383	59	590
2			257	780	399
4			246	325	592
13			276	118	97
14	144		182	370	278
15	332	134	68	106	78
16	1,334	443	785	314	266
17	146				
18	77				
19	68				
35			128	232	26
47					762
100			30	3	52
105		122	10	139	434
108			53	284	353
112		131	1,385	566	573
151		231	27	56	580
160			187	65	1,135
161			560	421	87
170					120
180					125
Total # individuals	2,101	1,562	4,578	3,836	6,558
Average # individuals per station	350	260	305	256	364

[1]Nematodes from the February and March sampling period were removed by the EPA Laboratory prior to receipt of the samples by MRI. For consistency, only those species and individuals counted by MRI are included herein.

In summary, no dramatic shifts from the expected species composition of the Buzzards Bay benthos are evident from the sampling survey data. Such shifts would be expected if the Bouchard No. 65 oil had adversely impacted the marine organisms in the bay. It should be noted, however, that the limitations in the benthic data (Section 7) prevents such an analysis from detecting all but the most dramatic biological responses to the spill.

Opportunistic Species - Approach

An opportunistic species is one that has the ability to exploit an environment through short-term selection. Natural or human caused environmental stress can cause a dieoff in existing populations leaving certain niches open. In the case of chronic impacts, the pollutant can serve to suppress the normal activities and processes of the various populations within a community (i.e., sexual maturation or viability of eggs or larvae). Opportunistic species are able to respond to stressed conditions more rapidly and effectively than are other, less tolerant benthic species. They have this capability because they become established quickly; reproduce rapidly; consume the resources before other, competing species can exploit them; have a relatively high rate of reproduction and a high recruitment rate; and disperse easily. Opportunistic species are always present in the environment but do not dominate the benthos of an area once recovery to a normal ecosystem has begun. This is due to the poor competitive ability of opportunistic species primarily attributable to their use of large amounts of energy for reproduction. Thus, the appearance of large numbers of opportunistic species in an area previously characterized by low numbers of these species is an indication of one or more stress factors.

Two of the stress factors that could have led to an increase in opportunistic species in Buzzards Bay are the Bouchard No. 65 spill and the unusually severe winter. By looking at the relative percent of opportunism over time, unexpected increases in opportunism can be detected and matched with natural and unnatural phenomena that may influence the presence of opportunistic species. To insure that any trends observed for opportunistic species truly reflect fluctuations in the entire benthic community, diversity indices have been incorporated into the analysis.

The specific approach to the opportunistic species analysis follows:

1. Identify and select the benthic species which are opportunistic.

2. Determine the increase or decrease of both number of individuals of each opportunistic species and total number of opportunistic species as a percentage of the total number of individuals and total number of species for each station during each sampling period.

3. Compare these plots with variations in Margalef's diversity index to determine the relationship of the overall community response to fluctuations in the opportunistic species populations.

4. Speculate if the noticeable changes in species composition and relative occurrence of opportunistic species are due to the presence of fresh No. 2 oil, chronic pollution, or natural causes.

Opportunistic Species - Results

Five polychaete species considered to be opportunistic were selected from the EPA benthic taxonomy list and confirmed by a recent study by Grassle and Grassle, 1974. These species are Capitella capitata, Polydora ligni, Syllides verrilli, Streblospio benedicti, and Mediomastus ambiseta. Because of a lack of physical and chemical data for the study area during the sampling period, treatment of these species as stress indicators is not possible; therefore, these species were grouped as a single unit that could then be compared with the fluctuations in the overall benthic community on a month-to-month basis. This comparison is expressed in Table 18 as the relative percentage of opportunistic species per sample.

The percentage of opportunism in these samples tends either to increase or remain stable from February to the June sample period. A comparison of these trends with diversity index values (Table G-2, Appendix G) indicates that increases in the percentage of opportunistic species over time does not depress diversity. Depression of diversity values followed by or simultaneous with an increase in the relative percentage of opportunistic species would be expected in the cases of severe stress from pollutants; therefore, the increase in opportunistic species at some stations (this phenomena appears to be random) indicates that a selection process is occurring which favors an increase in the numbers of opportunistic species but not to the exclusion of those species normally expected to occur in the sampled area. Because of the relative stability of diversity indices during the study period, any rise in opportunistic species is, in all probability, caused by chronic sources of pollution (population has stabilized) or seasonal variation. Thus, it appears from the existing data that Bouchard No. 65 oil is not the cause of a rise in opportunism.

Classification of Communities - Approach

Benthic characterization and opportunistic species analysis extract meaning from the raw data by isolating certain numerical features and ignoring others. For example, diversity indices incorporate both the number of species and abundance of organisms, but ignore the relative abundance of a given species in different samples. Opportunistic species analysis is obviously restricted to the relevant organisms.

In addition to these approaches, it is desirable to reduce the data in some way which will permit a simplified comparison of the sample

TABLE 18. PERCENTAGE OF TOTAL NUMBER OF INDIVIDUALS COMPOSED OF OPPORTUNISTIC SPECIES

Station number	Sampling dates 2/77	3/77	4/77	5/77	6/77	Opportunistic trend
1		~~0~~	0.26	~~0~~	11^{Pl}	0
2			~~0~~	14^{Pl}	23^{Cc}	+
4			~~0~~	11	12^{Pl}	~~0~~
13			~~0~~	~~0~~	~~0~~	0
14	0.69		0	42Ma	61^{Pl}	+
15	76Ma	61Ma	50Ma	77Ma	74	0
16	0.19	24Ma	10Ma	25Ma	38Ma	+
17	0.46					
18	~~0~~					
19	~~0~~					
35			~~0~~	4	~~0~~	0
47					90$^{Cc/Pl}$	0
100			~~0~~	~~0~~	~~0~~	~~0~~
105		4.9	~~0~~	19	33	+
108			~~0~~	11	71^{Cc}	+
112		21	32$^{Pl/Sb}$	42^{Pl}	~~0~~	+
151		~~0~~	15	12	24	0
160			~~0~~	~~0~~	~~0~~	~~0~~
161			26Ma	12Ma	49^{Pl}	0
170					~~0~~	0
180					~~0~~	0

Ma = *Mediomastus ambiseta*.
Pl = *Polydora ligni*.
Sb = *Streblospio benedicti*.
Cc = *Capitella capitata*.
\+ = increase.
0 = no change.
\- = decrease.
~~0~~ = no opportunistic species present.

stations, but will use all of the information contained within the data. Several such techniques exist; the one used here is classification of communities, which has been discussed in some detail by Pielou (1977). The goal of this approach is to divide the sampling stations into more or less homogenous groups. This assignment into groups is made solely on the basis of the species composition of the samples; it assumes nothing about ecological processes. The groups are formed as follows:

1. An index of similarity is calculated for all possible pairs of sample stations. The index used here was Kendall's rank correlation coefficient, "tau" (Ghent, 1963). This measure compares two samples based on the proportions of individual species in each sample.

2. The two sample stations that are shown to be most similar are combined into one group.

3. The index of similarity between this new, combined group and each of the remaining sample stations is calculated.

4. The next most similar groups or individual stations are then combined.

5. The process is repeated. Sample stations are combined into groups, which are combined into clusters of groups, and so on until all the sample stations have been combined into a single group. Note that the similarity index decreases as less and less similar groups are combined. The resulting heirarchy can be examined at any level of similarity, yielding a great or a small number of groups, as the data analysis requires.

The groups of benthic sample stations are then compared with substrate and degree of oiling. If the groups of biota are characterized by different substrate types or degrees of oiling, this provides evidence that these factors have contributed to the differences between the benthic communities in those groups. For example, if all of the stations contaminated by No. 2 fuel oil are found within a single biotic group that differs markedly from the other biotic groups, it is reasonable to conclude that the oil has affected the benthos of those sampling stations. A quantitative statistical test of this relationship is theoretically possible. However, in the present case the number of sample sites is too small to perform such a test validly, even if the results were optimally distributed. Nonetheless, this qualitative analysis permits convenient visualization of the data, examination of the month to month relationships between sample sites, and the formulation of tentative conclusions about the effects of substrate and oiling upon the benthic invertebrates.

Classification of Communities - Results

The results of the classification analysis are presented in the form of dendrograms and corresponding maps in Figures 38 through 47. In the dendrograms, the ends of the branches correspond to individual sample sites. The vertical scale on the left of each dendrogram displays the values of the correlation coefficient, "tau". Horizontal lines connect the individual and grouped sample stations at the point on the tau scale that corresponds to the calculated similarity index. The higher (more positive) the value of tau, the greater the similarity between connected sample stations. For purposes of further analyses, groups formed at tau values greater than -0.25 are considered internally homogeneous.

This similarity level, i.e., tau = -0.25, has been arbitrarily selected. It reflects the desire to keep the number of groups large enough (≥ 2) to permit comparisons with substrate and oiling, but small enough (≤ 4) to keep comparisons of biological groupings simple. In an attempt to form meaningful groups, the stations were divided into groups at other levels of similarity. The results of these exercises are not shown; they did not provide any more insights than those reported here.

The presence or absence of sediment contamination by No. 2 oil was determined using the ERCO data. The assumption was made that stations receiving a "D" or "E" classification were contaminated by the Bouchard No. 65 oil spill. Three broad classes of benthic habitat were defined on the basis of particle size. In the figures and in text, these are referred to simply as "fine", "medium", or "coarse".

Inspection of the dendrograms reveals that the biologically-based groupings of the sample stations are highly variable from month to month. There are a number of possible explanations for this variability. One plausible explanation is that the benthos in each location were inadequately sampled so that what appears to be a change in the biota is actually a result of sampling error. Note that the substrate classification at several sample stations, which in part defines benthic habitat, varies with time. This, too, might result from sampling error. Sampling error, however, would not exclude the possibility that the composition of the benthic communities really did change over time. Change in the composition of the benthos might be expected to result from seasonability or from the impacts of oil contamination. Similarly, patchiness of the Buzzards Bay benthos could account for much of the variability in the sampling results.

Although the groupings of the sample stations for any one month may suggest some relationship to the presence of No. 2 fuel oil, there are no such relationships consistently evident from month to month. Some affinities that do appear to persist for several months, like that

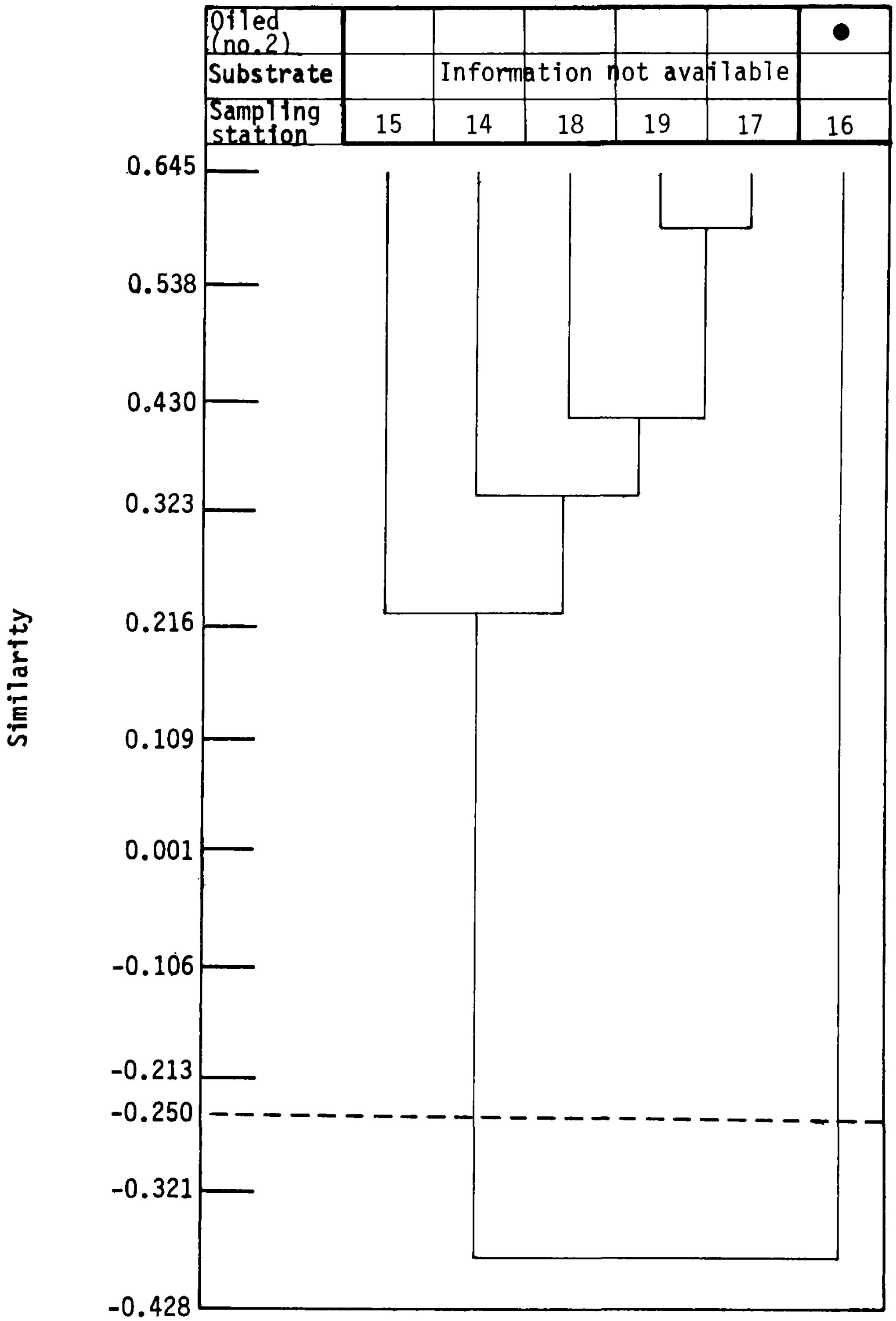


Figure 38. Similarity relationships of benthic communities: February, 1977.

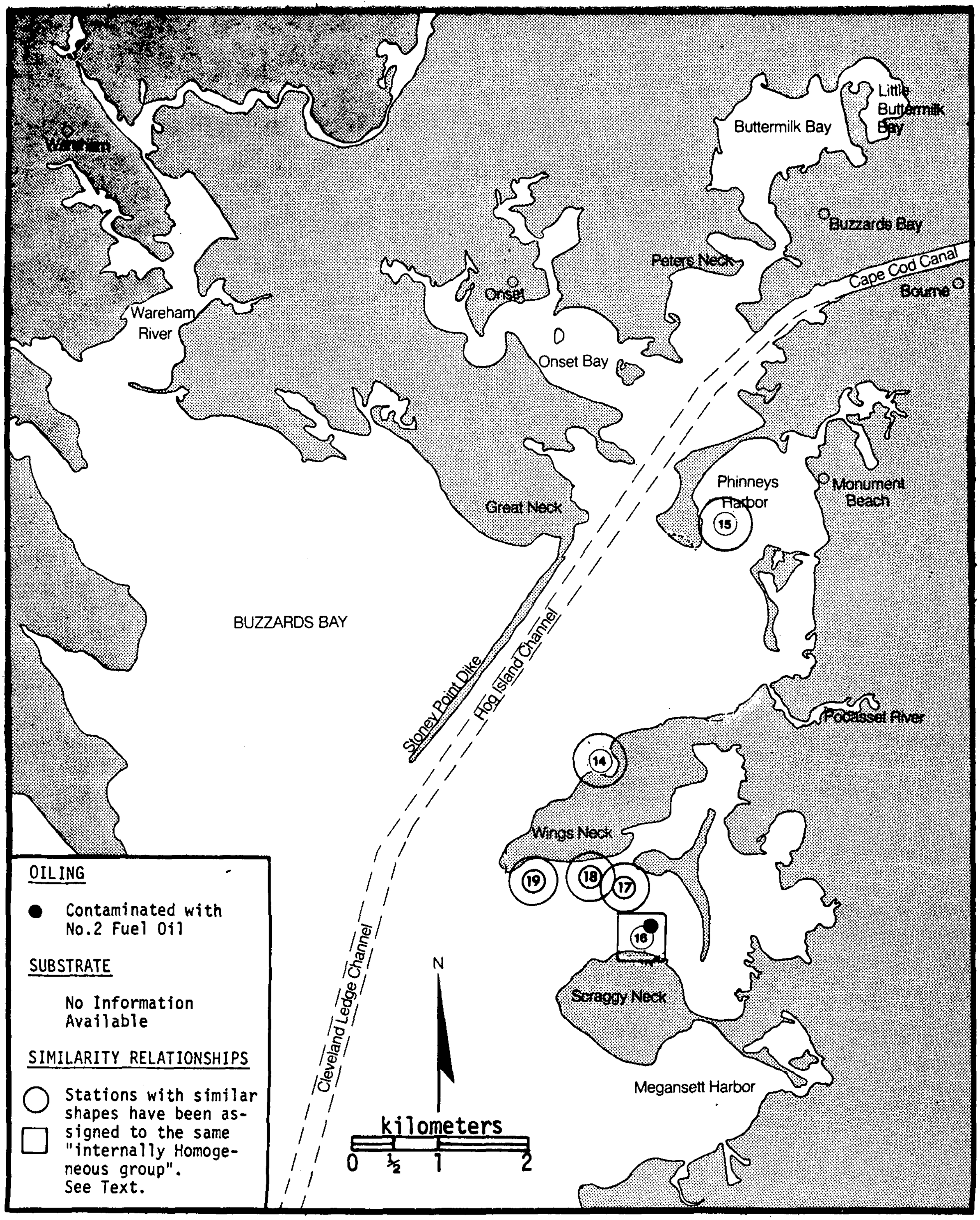


Figure 39. Similarity relationships, substrate, and oil contamination of sample stations: February, 1977.

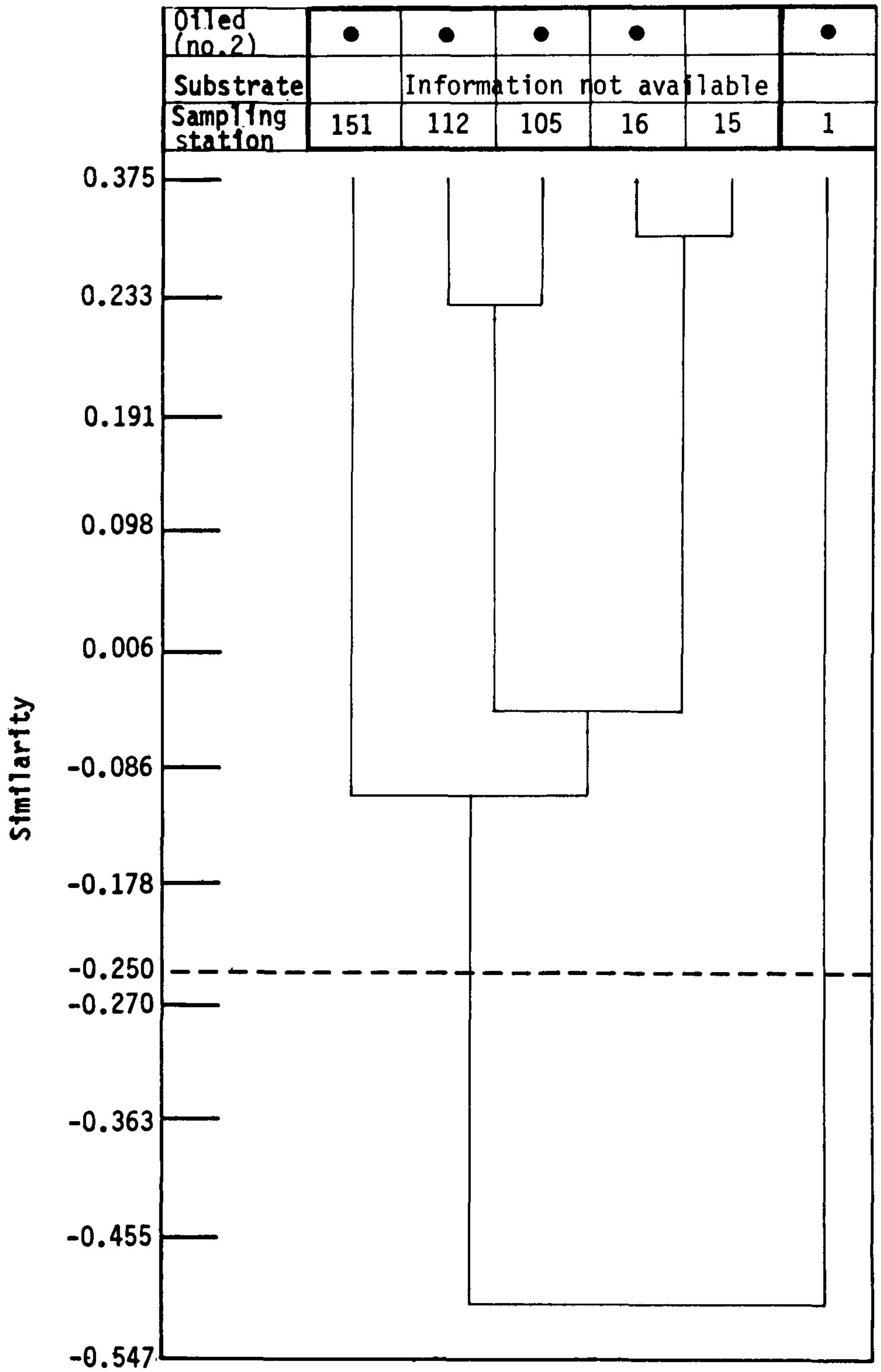


Figure 40. Similarity relationships of benthic communities: March, 1977.

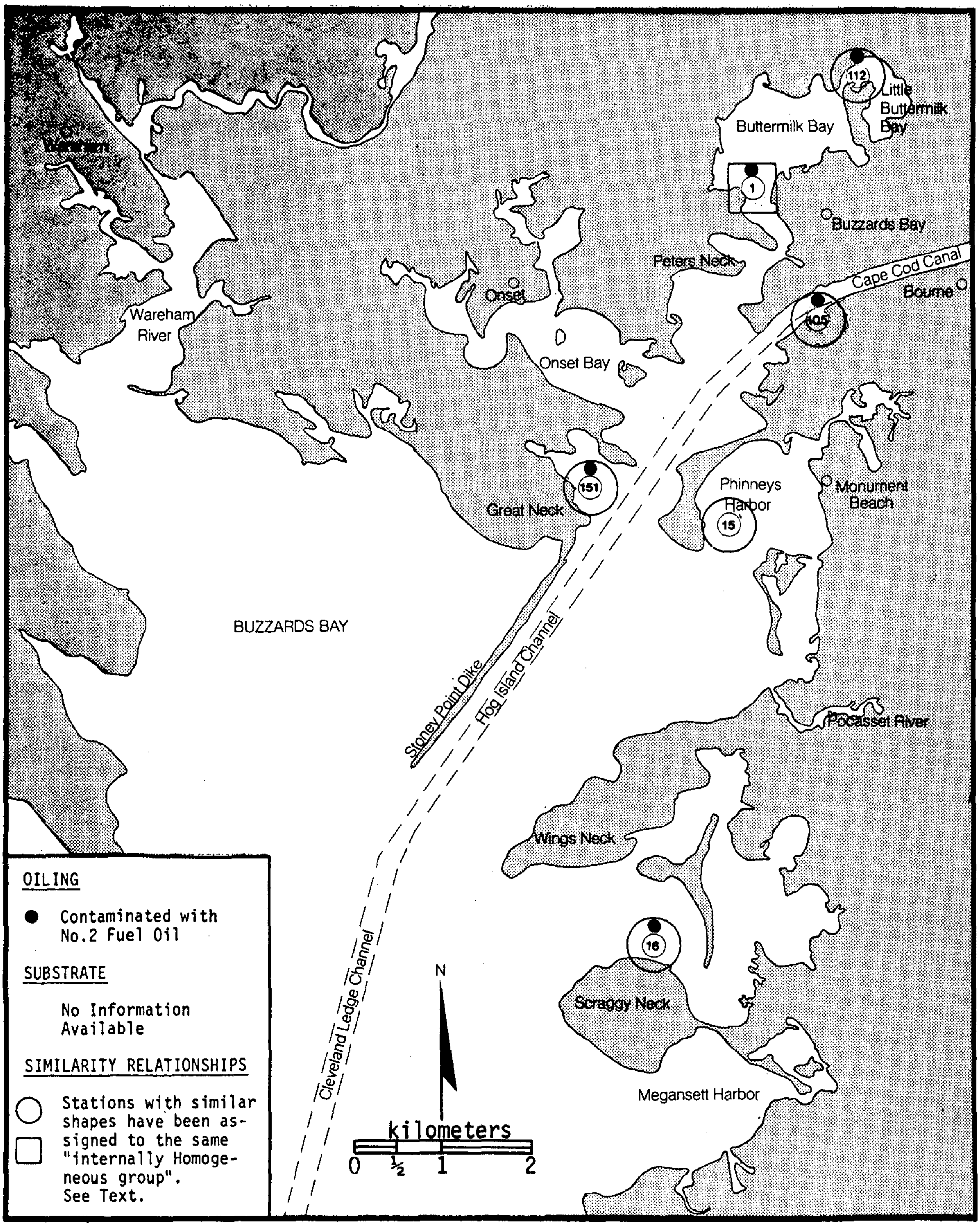


Figure 41. Similarity relationships, substrate, and oil contamination of sample stations: March, 1977.

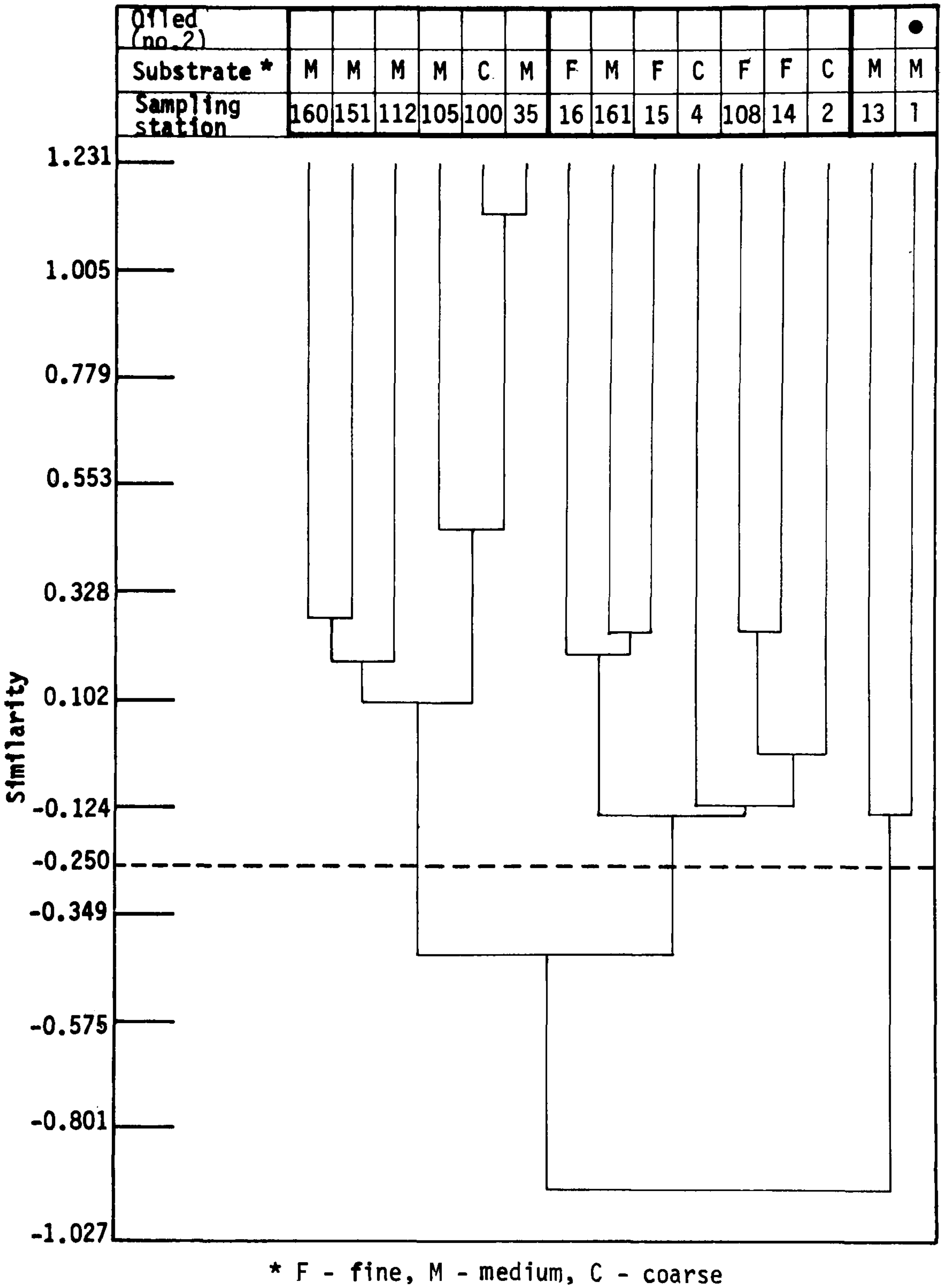


Figure 42. Similarity relationships of benthic communities: April, 1977.

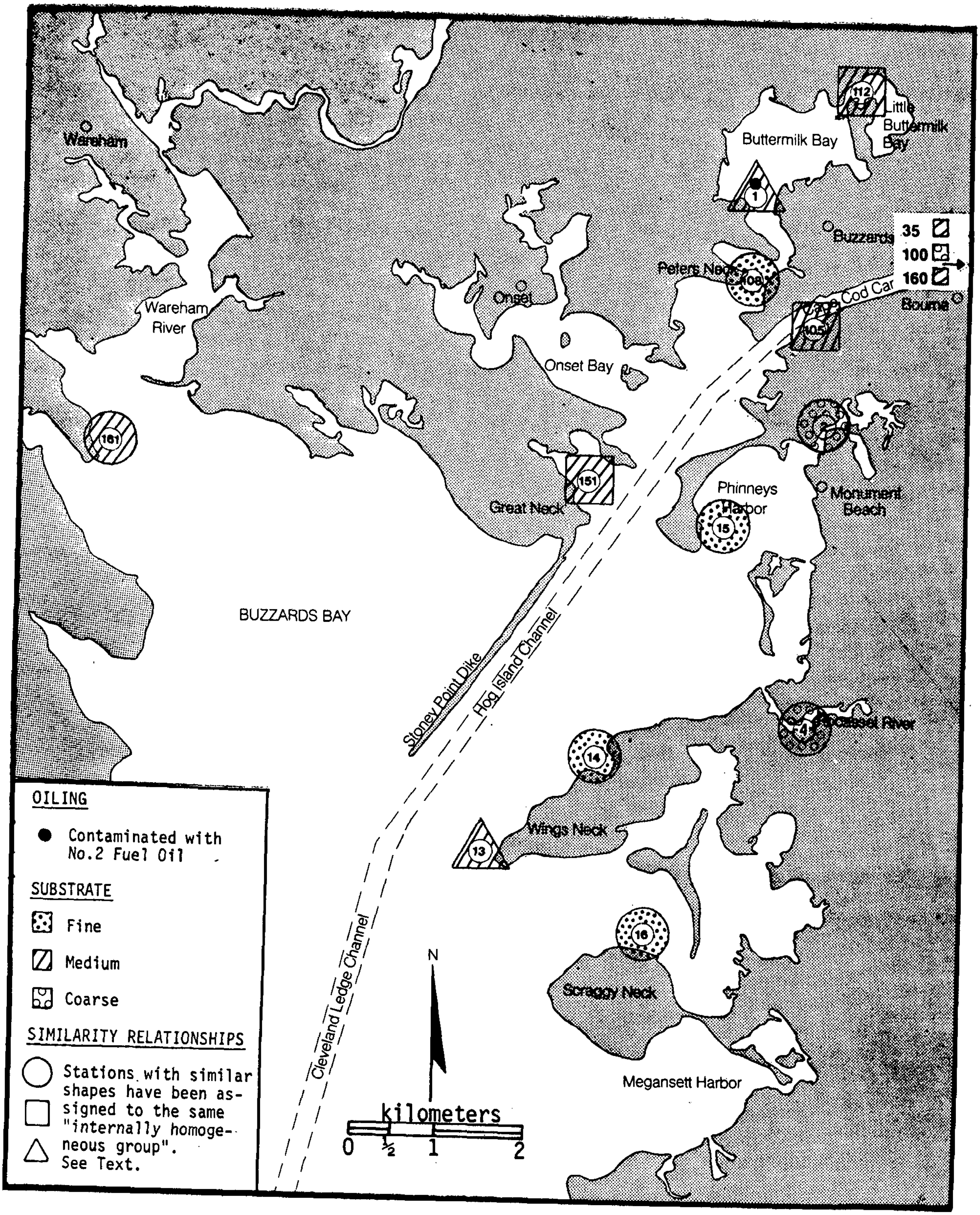
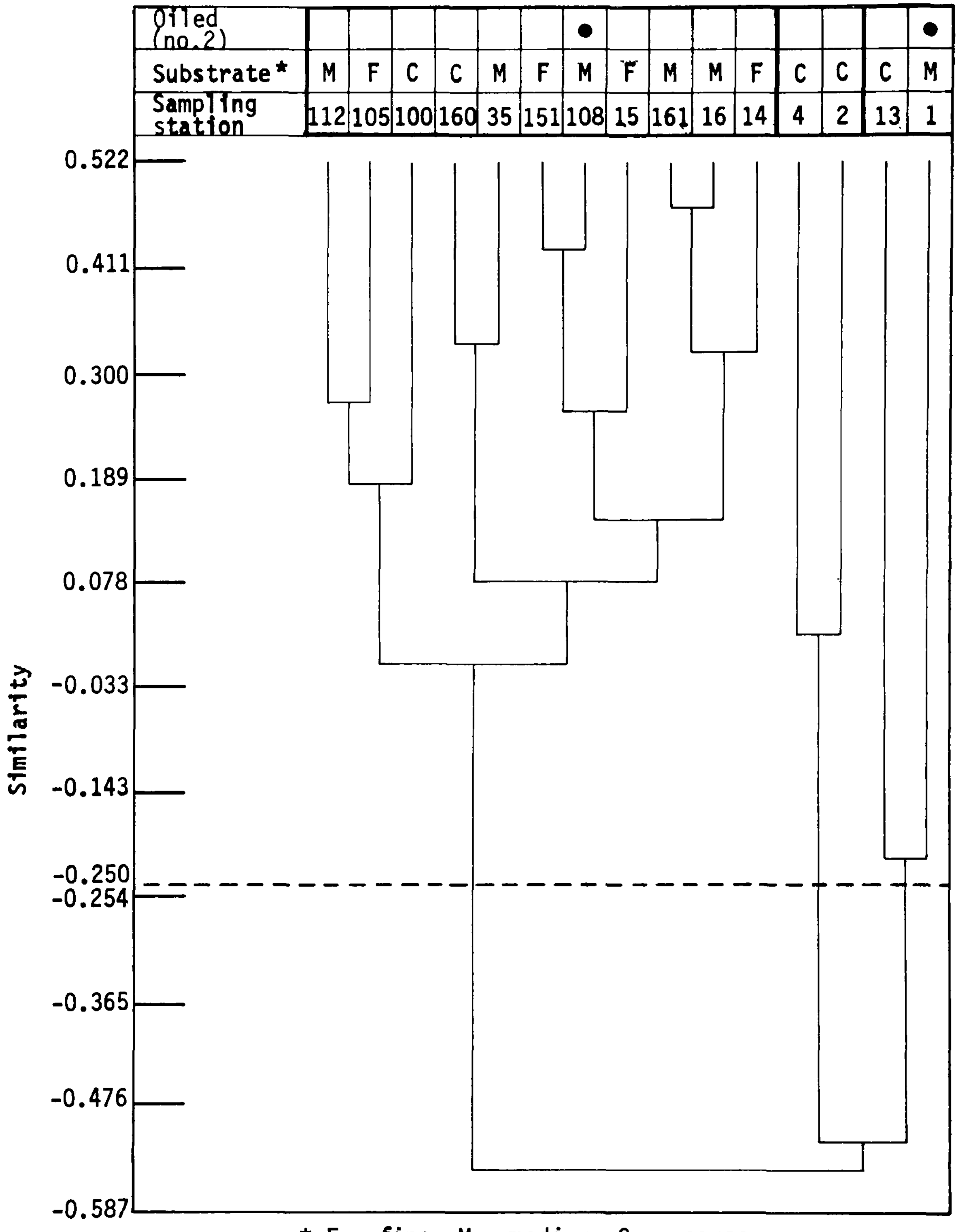


Figure 43. Similarity relationships, substrate, and oil contamination of sample stations: April, 1977.



* F - fine, M - medium, C - coarse

Figure 44. Similarity relationships of benthic communities: May, 1977.

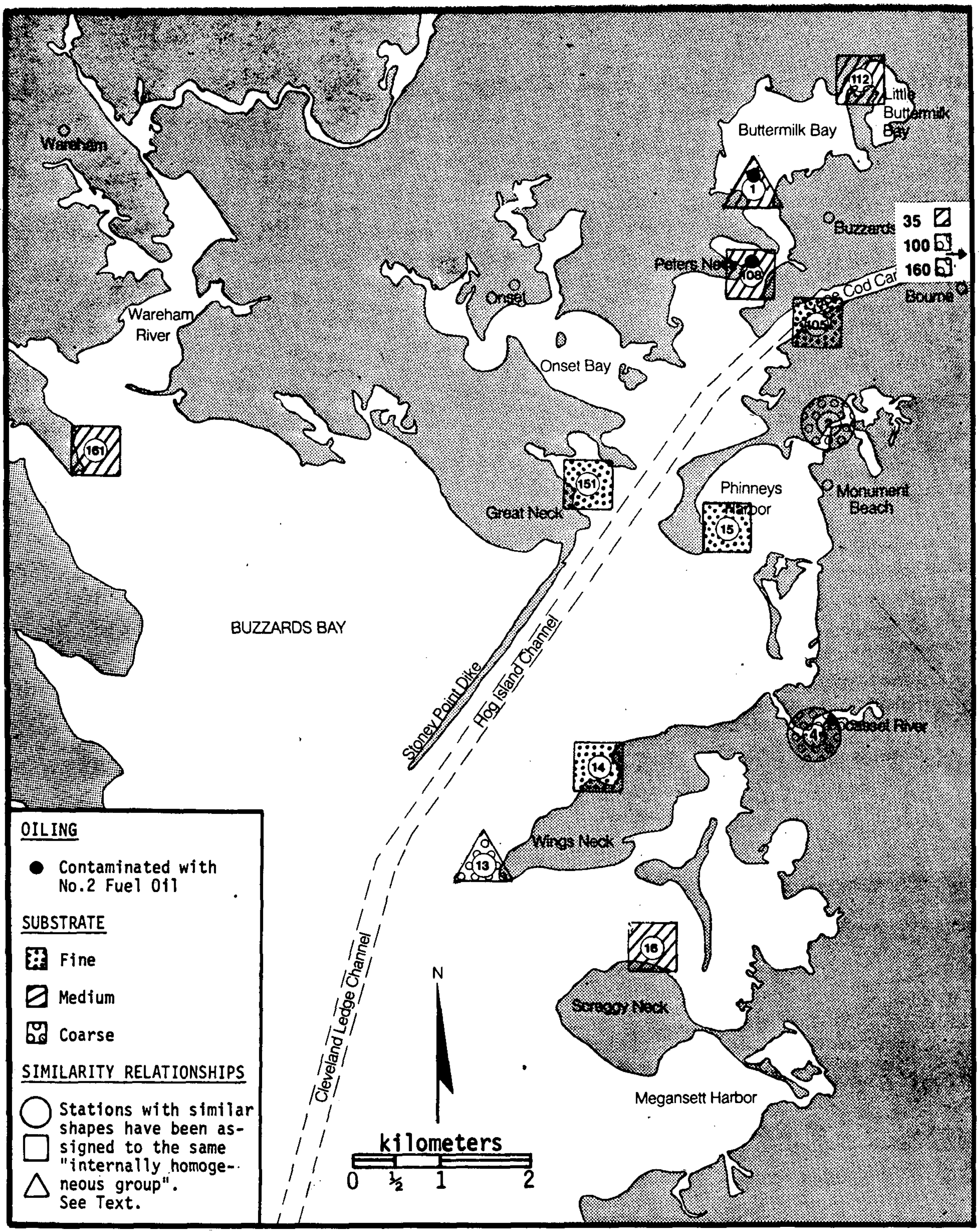
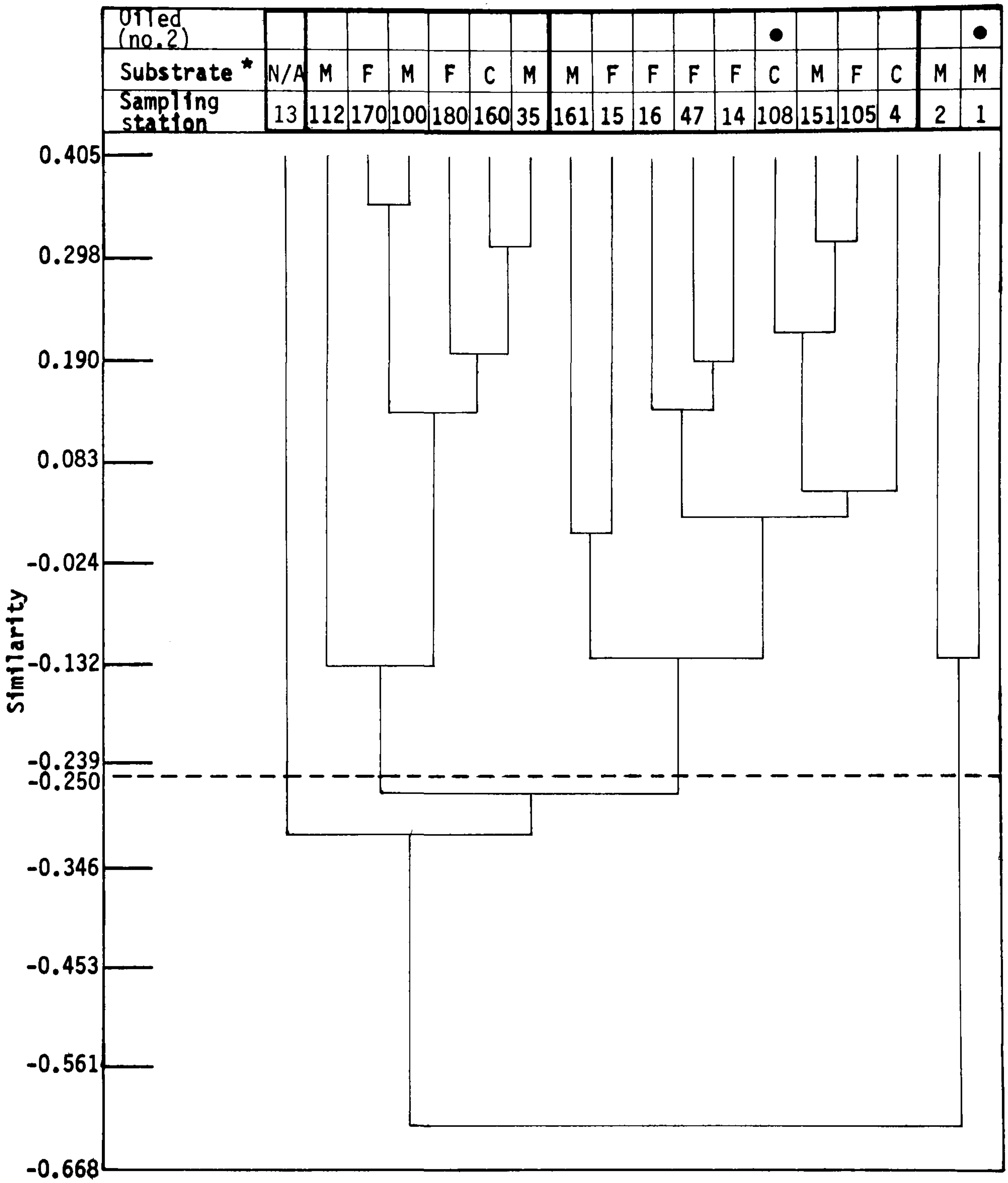


Figure 45. Similarity relationships, substrate, and oil contamination of sample stations: May, 1977.



* N/A - Not available, F - fine, M - medium, C - coarse

Figure 46. Similarity relationships of benthic communities: June, 1977.

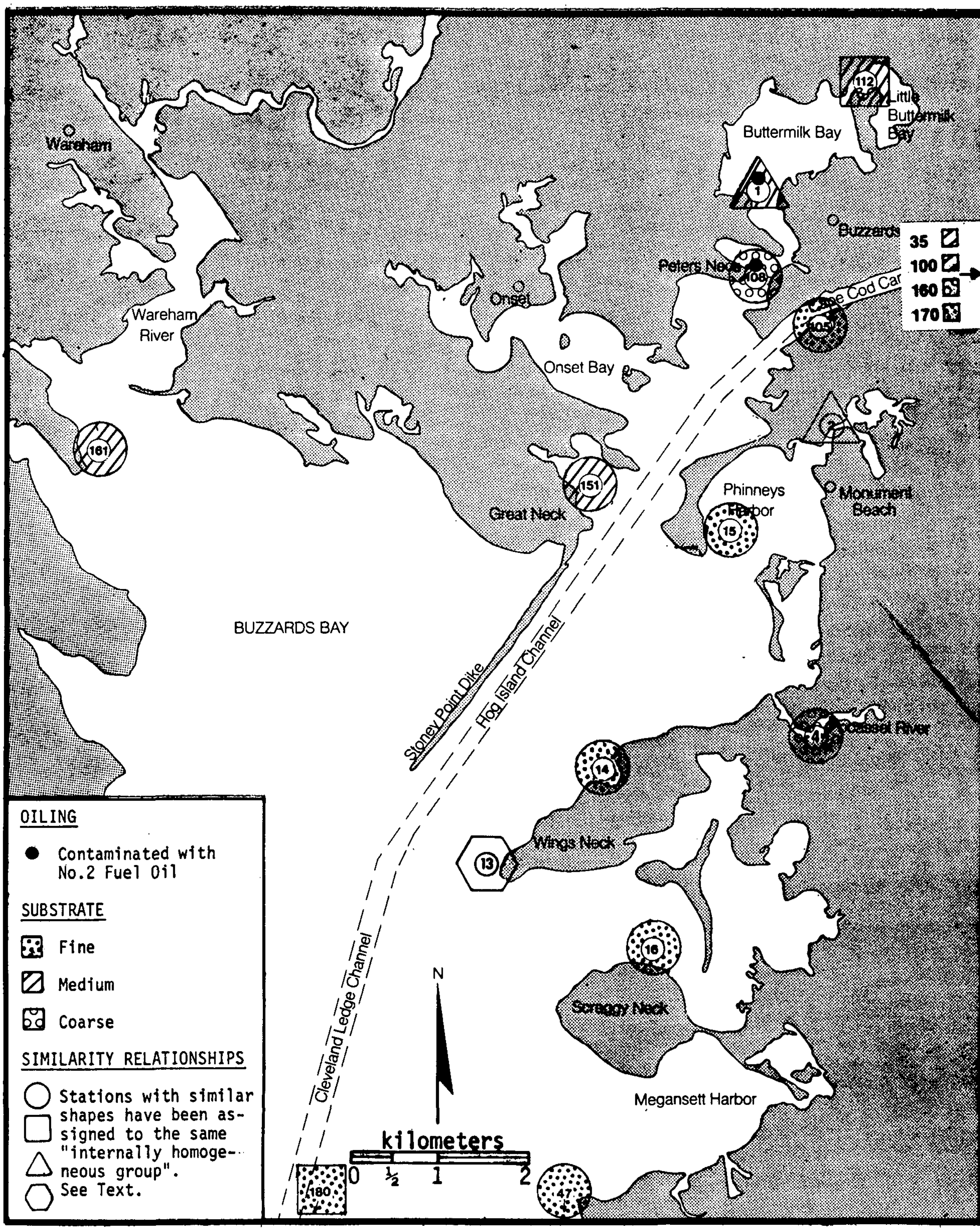


Figure 47. Similarity relationships, substrate, and oil contamination of sample stations: June, 1977.

between stations 105 and 112, or stations 15 and 16, are not related in any clear way to the presence or absence of No. 2 fuel oil. For example, stations 15 and 16 are included in the same group as station 108 in April and May. In April, both 15 and 16 showed evidence of oiling that 108 did not; in May, station 108 appeared to have been contaminated with diesel fuel, but neither 15 nor 16 did.

There is one exception. Station 1 is dissimilar to most of the other sample sites in every month that it was sampled. Moreover, the sediment chemistry consistently reveals that station 1 was contaminated by fresh No. 2 oil. However, this relationship is probably not causal. Although differences in species composition between station 1 and the other stations surfaced as early as March, total numbers of organisms at station 1 were not markedly lower. Furthermore, station 1 was not characterized by a large population of opportunistic species. If the oil had affected the benthos at station 1, a decrease in the number of organisms followed by an increase in the number of opportunistic species would have been expected. The fact that neither of these events occurred suggest that the differences in the composition of the benthic community at station 1 were already present at the time of the 1977 *Bouchard* oil spill.

The limited scope and inconsistencies of the sampling procedure, discussed in Section 7, have contributed to the difficulty of interpreting these data. The classification of data sets may proceed flawlessly, but this means nothing unless the data sets accurately represent the sampled benthic communities. Furthermore, it has been assumed here that sediments containing light oil fractions were contaminated by the *Bouchard No. 65* spill, although the oil might actually have come from other sources. A more comprehensive and uniform sampling program would have reduced or eliminated the first of these problems. The identification of the source of spilled oil, on the other hand, is a problem that would have hampered the interpretation of even the most carefully collected data.

Summary

The results from the diving survey and three types of analyses of the EPA benthic data confirm field observations following the spill that a severe, acute response to the *Bouchard* oil did not occur. The absence of the dramatic and adverse effects associated with previous No. 2 oil spills in Buzzards Bay suggests that the shore-fast ice, which kept oil away from intertidal areas, and the slow release of the oil trapped in the ice probably prevented severe impact. In addition, the low metabolic rate of the marine biota during the winter months may have reduced organism uptake of hydrocarbons from the environment and mitigated the effects normally associated with a No. 2 spill.

Although more subtle, long-term effects were similarly not picked up by the analyses, such effects may be occurring. None of the four information requirements, delineated initially in this section and needed to identify such effects, were fully met. Limitations of the benthic data and the inability to identify No. 2 oil as Bouchard oil were the most critical shortcomings. The lack of this information reduced the resolution of long-term acute and sublethal effects in the marine environment. A more comprehensive and longer-term program currently being undertaken by MBL under contract to NOAA may serve to more adequately address this problem.

SOCIOECONOMIC RESOURCES

Public and private costs from an oil spill can be categorized according to the four main sources: the spill event, cleanup activities, the response of public agencies to the spill, and the physical effects of the spilled oil.

Costs of the Spill Event

During the event, economic losses were sustained from the loss of oil, barge damage, and use of additional personnel and services required to transfer the cargo and bring in the barge. The Bouchard Barge Company, whose barge ran aground, or its insurer will bear the last two of these costs; and depending on point of sale, may bear the cost of the lost oil as well. Representatives of the barge company were unavailable for comment as of the writing of this report so that estimates of these losses had to be obtained from indirect sources.

Oil recovered from a spill can seldom be used for its originally intended use; its salvage value is as an ingredient in the manufacture of asphalt and related products. Based on 1976 average wholesale prices of fuel oil and similar products (National Petroleum News Fact Book, 1977) the net loss sustained from unrecovered oil was $0.30/gal. and the net loss from recovered oil was $0.20/gal. Accordingly, the loss from spilled oil is estimated at $22,500 ($0.30/gal. x 62,234 gal. + $0.20/gal. x 18,913 gal.).

Without confirmation by the barge company, other costs are harder to quantify. The U.S. Coast Guard tentatively estimates damages to the barge could run as high as $2.5 million. Not included are the costs of transferring cargo and bringing in the damaged barge.

Costs Resulting from Cleanup Activities

The most significant costs in this category were expenditures of the U.S. Coast Guard on cleanup operations. By the end of February, 1977, most of the cleanup activity had been completed. At that time, the Coast Guard had accrued costs amounting to $284,175. Most of these costs (95%) were paid to private contractors who carried out the cleanup operations; the remainder was accrued by the Coast Guard, the Navy, and the PAC Strike Team. Since the salaries of inservice personnel are not counted, and since there will be some additional costs after February, the total represents an underestimate of costs due to cleanup activities.

Besides being spent for cleanup activities, some of the above sum was expended in the restoration of both public and private properties in and around Wings Neck. Most damaging to beachside properties were the truck operations involved in transporting contaminated ice from spill areas to the COE dump site. After these and other operations, a few private residences and the grounds of the Wings Neck Lighthouse required minor contour restoration and reseeding. An upper limit to these costs is estimated at $5,000. The oil leaking from trucks during ice transfer operations also caused some ecological damage; however, this was not quantified nor were costs incurred.

Expenditures for the services of regional contractors, while representing direct costs to the Coast Guard, indirectly benefitted the regional economy by supporting increased trade for a few regional contractors. These contractors were located near to but outside the study area, and thus, their increased income will not be felt within the local economy.

<u>Costs Resulting from Public Agency Actions</u>

Immediately after the spill, the Massachusetts Department of Environmental Quality Engineering and Division of Marine Fisheries began monitoring shellfish beds along the coast at Bourne, Falmouth, and Wareham. Increased operating costs of these agencies due to this activity are difficult to assess since they fall within their normal operating responsibilities. However, increased work loads of present personnel marginally decreased the level of secondary, although important, public services these agencies provided while working on the spill.

The most significant public agency action has been the February 2, 1977 closure of shellfishing beds by the Massachusetts Department of Environmental Quality Engineering. These closures represent direct losses for the local commercial and recreational fishing industry. Table 19 shows estimates of these losses to date. The explicit assumptions used in these calculations are shown in Appendix H, Tables H-1 and H-2. Generally, however, these assumptions are:

A. The most important recreational and commercial crops are soft-shelled clams, quahogs, scallops, and oysters.

B. Except for scallops, all of these beds have remained closed from February through December 1977. Scallop beds were closed February through September.

C. The amount of take affected is proportional to the percentage of total acres closed for each town.

D. Historic takes for 1975 or 1976 are representative of what might have been taken without bed closures.

TABLE 19. ESTIMATES OF TOTAL VALUE OF SHELLFISH TAKE FOREGONE BY BED CLOSURES, BUZZARDS BAY STUDY AREA, FEBRUARY - DECEMBER 1977 (in dollars)

	Recreational	Commercial	Total
Bourne	$25,000	$60,520	$ 85,520
Falmouth	14,810	15,340	30,150
Wareham	35,320	3,300	38,620
Total	$75,130	$79,160	$154,290

Source: Appendix H, Table H-1.

The dollar estimates shown represent only the direct loss to commercial and recreation fishermen due to bed closure. In an area more heavily dependent upon shellfishing for its economic livelihood, the indirect or delayed effect of such bed closures could have a significant and lasting effect on the industry as fishermen went out of business and the market adjusted to other sources of supply. In this case, however, shellfishing represents a marginal industry for the area and is often merely a source of second income for persons with other fulltime jobs. Also, the commercial and recreational fleets which utilize these beds are rather small; and except for those skiffs registered only in the town of Bourne, they have available to them many alternate sites within the reaches of Buzzards Bay. Finally, the reduced take represents a relatively small decrease in the total commercial shellfish supply available to the regional market; therefore, the loss will not significantly affect prices.

As a consequence, the bed closures had a minor effect on shellfish commerce in the region and will have no lasting effect on the commercial or recreational fishing industry in the study area. Given that there is no biological damage to the seed crop, the closures may be seen as having the beneficial effect of letting the beds recover from the effects of overfishing in previous years. This is especially true for the quahog crop.

Costs Resulting from the Physical Effect of Spilled Oil

A previous study of the effects of spilled oil on marine fisheries in the Falmouth area (Grice, 1970) has estimated the average dollar cost of ecologic damage to be $122 per acre (1969 dollars). Other studies (Gosselink, et al., 1974) have given a much higher dollar value to the total life support functions of estuarine areas which could be lost through oil pollution. As described in the previous section, however, the areas in question have sustained no significant biologic effects from this event; thus, the above value estimates are not applicable in this case.

Because no significant aesthetic, biologic, or private property damages have been identified, any reduction in the study area's seasonal tourist and recreational trade resulting from the oil spill must be attributed to a perceived rather than real reduction in local amenity. Such a perceived response to "yet another oil spill in Buzzards Bay" by regional residents is too difficult to quantify. Nevertheless, depending on the area's efforts to correct any misconceptions, such a response by the regional population could have a great effect on the important seasonal recreational and tourist trade in the area.

Summary

Table 20 summarizes the monetary and nonmonetary costs that can be attributed to the spill to date. The socioeconomic effects shown here are relatively minor compared to other previous spills in and around the area. Nevertheless, the event will further any undesirable aesthetic perception which the regional population has already begun to associate with the area due to previous oil spills.

TABLE 20. MAJOR COSTS ATTRIBUTED TO THE BUZZARDS BAY OIL SPILL, FEBRUARY - DECEMBER, 1977

Cost category	Within the study area		Outside the study area	
	Monetary	Nonmonetary	Monetary	Nonmonetary
Spill event:				
Lost oil			$ 22,500	
Barge			2,500,000	
Cleanup				
USCG operation			284,200	Stimulation of regional economy
Private property	$ 5,000	Industrial use of private property		
Agency action				
Dept. of Environmental Quality Engineering				Additional public service load
Division of Marine Fisheries				
Foregone shellfish harvest	154,300	Lost recreational opportunity		
Physical effects tourist recreation trade		Loss of perceived attractiveness		Perceived loss of tourist or recreational opportunity
Total dollar value	$159,300		$2,806,700	

SECTION 9

FURTHER STUDIES AND MONITORING

ADEQUACY OF DATA COLLECTED

Review of data collected by EPA, other state and federal agencies, and other interested parties, to determine the effect of the Bouchard No. 65 spill, indicates that data were adequate to describe:

1. spread of oil;

2. acute mortality in shellfish, benthos, finfish and birds;

3. hydrocarbon contamination of sediment;

4. hydrocarbon contamination of shellfish.

Data were unresolved or inadequate for determining:

1. sublethal effects on benthos (MBL data have not been made available);

2. sublethal effects in shellfish, finfish, or birds (no studies were initiated);

3. source of hydrocarbon contamination (other potential sources of fuel oil and weathering of the Bouchard oil prevented identification).

RECOMMENDATIONS

1. It is recommended that no further studies of environmental effects of the Bouchard spill be initiated.

Several studies have been suggested for examining possible continuing, long-term effects of the spill. However, the high background levels of petroleum hydrocarbons in upper Buzzards Bay and the problem of distinguishing Bouchard oil from other petroleum sources negate the value of any future studies for describing the long-term environmental effect of this spill. While these studies would be of general interest, they would not contribute to definition of the effects of the Bouchard spill; rather, they would describe the effects of chronic contamination of Buzzards Bay. For this reason, URS does not propose that any new studies be initiated.

2. It is recommended that a program of benthic habitat characterization be initiated.

It is likely that spill incidents will occur in Buzzards Bay in the future. The problem of chronic contamination, albeit at a low level, will also continue. Nevertheless, studies to detect the effects of major spills will be desirable. The authors recommend that a program of benthic habitat characterization be initiated that will provide an inventory of habitats and a catalogue of water quality influences. This will greatly aid the planning of future studies in response to spills.

Data to be collected as part of a benthic habitat characterization program are:

A. bathymetry
B. bottom characteristics
C. surface and water column currents
D. exposure to waves and swells
E. physiography

In addition, the location of all wastewater outfalls should be established. If any of these outfalls are monitored, the nature of the monitoring program and the agency which holds the data should be recorded.

The benthic communities of the various habitats may be expected to differ from each other, and each may be expected to vary with time. It would not be cost-effective to continuously monitor the composition of each community, but it would be extremely valuable in the event of a spill to have quantitative data regarding the composition of these communities. One possible means of collecting reliable quantitative benthic community data is the establishment of a program of seasonal benthic sampling. An optimum-size sample would be collected from each habitat type, screened, and preserved. Taxonomic analysis would be performed only as needed at the outset of the characterization program to determine the optimum sample size (see Section 7). Such a program would provide preserved material which could be worked up following a spill to provide a baseline of benthic community composition.

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APPENDIX A. TAXONOMIC DATA FOR EPA BENTHIC SAMPLING

TAXONOMIC DATA FOR EPA BENTHIC SAMPLING

SPECIES / STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Phylum liemertinea	5			2	1		1			
Phylum Aschelminthes										
Cl. Nematoda*	34920	345000	2000000	1226	6800	12800	13440		2	1
Phylum Annelida										
Cl. Oligochaeta				6		3		7	24	25
Cl. Polychaeta										
Aglaophamus verrilli	1	13	7	7						
Ampharetidae	1	3			4	4			3	1
Aricidea sp.		1	3							
Aricidea neoguecica		23		51						
Aricidea suecica	10									
Brania clavata		28								
Capitella capitata	1				2	1				1
Cirratulidae				3						
Clymenella torquata	1									
Dorvilleidae		4						2		
Ephesiella minuta		1								
Eteone sp.	1	1								
Exogone dispar	187	12		3	17	26	5			
Fabricia sabella	1				1					

*Source: Marine Research Inc.
**February samples came sorted with counts of Nematodes written on tags; these are not MRI's counts.

February 4, 1977

SPECIES / STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Cl. Polychaeta (continued)										
Glycera dibranchiata	5	1	4	9	1	6				1
Glyceridae							1			
Glycinde solitaria	25					10				
Goniadella gracilis										
Goniadidae					4		16			
Harmothoe imbricata										
Hesionidae	11									
Heteromastus filiformis										
Hydroides dianthus										
Lumbrinereis sp.	28									
Lumbrinereis tenuis	5		5							
Maldanidae		1			1	3				1
Maldane sarsi										
Mediomastus ambiseta	7	1			7		2	526	251	428
Melinna cristata										
Minuspio sp.										
Minuspio cirrobranchiata										
Neanthes virens										
Nephtys sp.	1									1
Nephtys bucera										
Nephtys incisa								11	18	5
Nephtys longosetosa										
Nephtys picta		3		5						
Nereidae										
Nereis sp.	6									
Nereis arenaceodonta	13									
Nereis grayi	2									
Nereis succinea										
Notomastus latericeus										
Ophelia sp.										
Opheliidae										
Orbiniidae	7	30		3			1			
Paranaitis speciosa										
Paraonis fulgens										
Paraonis gracilis										
Paraonis lyra										
Parapionosyllis longicirrata	2									
Pectinaria gouldii	10				3	1	1	3	3	10
Pholoe minuta										
Phyllodocidae	1					1				
Phyllodoce arenae	4			1		2				

February 4, 1977

SPECIES / STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Cl. Polychaeta (continued)										
Phyllodoce maculata										
Phyllodoce mucosa										
Pista cristata										
Polycirrus eximus										
Polydora sp.										
Polydora aggregata										
Polydora ligni										
Polydora quadricuspis										
Polydora socialis										
Potamilla neglecta	1									
Praxillella sp.	1	1								
Prionospio heterobranchia										
Protodorvillea kefersteini										
Protodorvillea minuta										
Pygospio elegans										
Sabella microphthalma	6									
Sabellaria vulgaris										
Scoloplos sp.	4	2	6	3		3				
Scoloplos acutus										
Scoloplos robustus		4								
Serpulidae										
Sigalionidae										
Sphaerosyllis erinaceus	5									
Sphaerosyllis hystrix	29									
Spio filicornis										
Spionidae	1				1			6		2
Spiophanes bombyx				2	1					
Spirorbis sp.										
Streblospio benedicti										
Streptosyllis arenae	2									
Streptosyllis varians	1		9							
Syllidae		77	8					5		
Syllides setosa		1								
Terebellidae		3								
Tharyx sp.										
Travisia carnea										
Phylum Mollusca										
Cl. Gastropoda										
Aclis striata										

February 4, 1977

SPECIES / STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Cl. Gastropoda (continued)										
Anachis avara	4									
Anachis lafresnayi	1									
Anachis translirata	2									
Caecum cooperi										
Caecum pulchellum										
Cerithiopsis emersoni										
Crepidula fornicata	1									
Crepidula plana	1									
Haminoea solitaria					8	12	20	25	4	3
Ilyanassa obsoleta	259									
Littorina littorea										
Littorina saxatilis										
Lunatia heros										
Mitrella lunata	68				11	2	1			1
Nassarius trivittatus	1084	5		1	13	5	2			
Natica pusilla	7	6	1	1	3	5	3	1	1	2
Odostomia sp.		4								
Osostomia bisuturalis	33				5		1			
Pyramidella producta										
Retusa canaliculata					1		1	1		
Turbonilla elegantula	1							1		
Turbonilla interrupta	28	1			7	5	2			
Miscellaneous	33		1		1					
Cl. Bivalvia						1				
Anadara ovalis					2					
Anomia simplex										
Cerastoderma pinnulatum										
Crassinella lunulata										
Gemma gemma										
Idasola argenteus										
Lyonsia hyalina										
Macoma balthica										
Macoma tenta								5	7	
Mercenaria mercenaria										
Modiolus modiolus										
Mulinia lateralis								1		
Mya arenaria	2					1				2
Mytilus edulis										
Nucula sp.	79				9			1	1	2

February 4, 1977 SPECIES	STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Cl. Bivalvia (continued)											
Pandora gouldiana											
Petricola pholadiformis											
Solemya velum		5				1		1	2		1
Solen viridis											
Spisula solidissima		[illegible]									
Tellina agilis			1		1	10	5	8			
Thracia septentrionalis			1			2					
Yoldia limatula											
Miscellaneous		7	1				1				
Cl. Scaphopoda											
Dentalium occidentale											
Phylum Arthropoda											
Cl. Arachnida											
Acarina		1	1								
Cl. Crustacea											
Copepoda		347	158	24	6	2	[illegible]	3	1	1	1
Ostracoda		1339	20	4	22	72	33	16	10	8	7
Tanaidacea											
Leptochelia sp.											
Leptochelia rapax											
Leptochelia savignyi		3									
Leptognatha caeca											
Isopoda											
Cyathura sp.											
Cyathura polita			3								
Edotea triloba		1						1			
Erichsonella filiformis		8									
Sphaeroma quadridentatum											
Cumacea				30	1		1				
Diastylis sp.											
Diastylis polita							1				
Diastylis quadrispinosa											
Lamprops quadriplicata			1								
Oxyurostylis smithi		5	1			1		1			
Petalosarsia declivis											
Amphipoda											
Acanthohaustorius millsi											

February 4, 1977

SPECIES / STATION	16-44128	17-44142	18-44143	19-44144	14 A	14 B	14 C	15 A	15 B	15 C
Amphipoda (continued)										
Ampelisca sp.										
Ampelisca abdita	5	14	2	5	27	8	14		8	8
Bathyporeia parkeri										
Caprellidae	11									
Caprella penantis										
Corophium sp.	4									1
Cymadusa compta	9									
Dexamine thea	1									
Elasmopus levis										
Gammarus sp.										
Haustoriidae									3	
Jassa falcata										2
Lembos websteri	1									
Leptocheirus pinguis										
Listriella barnardi		3			1					
Lysianopsis alba	181				2	1	1			
Melita dentata					1					
Microdeutopus anomalus	33									
Microdeutopus gryllotalpa										
Monoculodes edwardsii										
Orchomenella minuta										
Paraphoxus spinosus										
Phoxocephalus holbolli										1
Protohaustorius deichmannae										
Trichophoxus epistomus										
Unciola sp.										
Unciola irrorata			2				1			
Decapoda										
Crangon septemspinosa				1						
Hippolyte zostericola	2									
Meterythrops robustus				1						
Pagurus sp.	2	2								
Pagurus arcuatus	4		1		6	2				
Pagurus longicarpus				3						
Pagurus pollicaris										
Pinnixa chaetopterana	31	6			5	2	2	5		
Rhithropanopeus harrisii	4									
Xanthidae	3									

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SPECIES / STATION	16-44128
Phylum Echinodermata	
Cl. Ophiuroidea	
Amphiura otteri	6
Cl. Echinoidea	
Echinarachnius parma	
Phylum Sipunculida	

March 9, 1977 SPECIES	STATION	1-25689	15-25692	16-25691	105	112	151-25690
Phylum Cnidaria							
Cl. Anthozoa							
Phylum Nemertinea						1	
Phylum Aschelminthes							
Cl. Nematoda		1500				17	
Phylum Annelida							
Cl. Archiannelida							
Protodrilus sp.							
Cl. Oligochaeta		4	28	7	101	32	
Cl. Polychaeta							
Aglaophamus verrilli							4
Ammotrypane sp.							
Amphicteis sp.							
Ampharetidae			1	12			
Arabella iricolor							
Aricidea sp.							
Aricidea neosuecica							
Aricidea jeffreysii							
Autolytus cornutus							
Brania clavata							
Brania wellfleetensis							
Capitella capitata				10	6	3	
Cirratulidae							
Cirratulus grandis							
Clymenella sp.							
Clymenella torquata				4			15
Diopatra cuprea							
Dorvilleidae							
Drilonereis longa							
Ephesiella minuta							
Eteone sp.					2		1
Eteone flava							
Eteone heteropoda							
Eteone lactea		1					
Eteone longa		4					
Eumida sanguinea							
Exogone dispar		3		11			
Exogone hebes							
Fabricia sabella							

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SPECIES / STATION	1-25689	15-25692	16-25691	105	112	151-25690
Cl. Polychaeta (continued)						
Glycera dibranchiata			1			
Glyceridae						
Glycinde solitaria			6			
Goniadella gracilis						
Goniadidae						
Harmothoe imbricata						
Hesionidae						
Heteromastus filiformis						
Hydroides dianthus						
Lumbrinereis sp.						
Lumbrinereis tenuis	21				16	
Maldanidae			14			
Maldane sarsi						
Mediomastus ambiseta		82	96			
Melinna cristata						
Minuspio sp.						
Minuspio cirrobranchiata						
Neanthes virens						
Nephtys sp.						
Nephtys bucera						
Nephtys incisa		9	2			
Nephtys longosetosa						2
Nephtys picta						
Nereidae						1
Nereis sp.				2		
Nereis arenaceodonta						
Nereis grayi						
Nereis succinea	8					1
Notomastus latericeus						
Ophelia sp.						
Opheliidae						
Orbiniidae			1		1	
Paranaitis speciosa						
Paraonis fulgens						
Paraonis gracilis						1
Paraonis lyra						
Parapionosyllis longicirrata	11					
Pectinaria gouldii		2	10			1
Pholoe minuta	1		1			
Phyllodocidae						1
Phyllodoce arenae						

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SPECIES / STATION	1-25689	15-25692	16-25691	105	112	151-25690
Cl. Polychaeta (continued)						
Phyllodoce maculata						
Phyllodoce mucosa						
Pista cristata						
Polycirrus eximus						
Polydora sp.	1					
Polydora aggregata						
Polydora ligni						
Polydora quadricuspis						
Polydora socialis						4
Potamilla neglecta						
Praxillella sp.						
Prionospio heterobranchia						
Protodorvillea kefersteini						
Protodorvillea minuta						
Pygospio elegans						
Sabella microphthalma						
Sabellaria vulgaris						
Scoloplos sp.						
Scoloplos acutus						
Scoloplos robustus						
Serpulidae						
Sigalionidae						
Sphaerosyllis erinaceus						
Sphaerosyllis hystrix						
Spio filicornis	1					
Spionidae	1	1	1	3		
Spiophanes bombyx						
Spirorbis sp.						
Streblospio benedicti					25	
Streptosyllis arenae						
Streptosyllis varians	9	1			3	
Syllidae			2			
Syllides setosa						
Terebellidae	1					
Tharyx sp.						
Travisia carnea						
Phylum Mollusca						
Cl. Gastropoda						
Aclis striata						

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SPECIES \ STATION	1-25689	15-25692	16-25691	105	112	151-25690
Cl. Gastropoda (continued)						
Anachis avara						
Anachis lafresnayi						
Anachis translirata						
Caecum cooperi						
Caecum pulchellum			1			
Cerithiopsis emersoni						
Crepidula fornicata	15					7
Cylichna gouldii						
Haminoea solitaria			23			
Ilyanassa obsoleta						
Littorina littorea						
Littorina saxatilis						
Lunatia heros						
Mitrella lunata			9			
Nassarius trivittatus			44			2
Natica pusilla		1	4			
Odostomia sp.						
Osostomia bisuturalis						
Pyramidella producta	7				10	
Retusa canaliculata			2			
Turbonilla elegantula						
Turbonilla interrupta			1			
Miscellaneous						
Cl. Bivalvia						
Anadara ovalis						
Anomia simplex						
Cerastoderma pinnulatum						
Crassinella lunulata						
Gemma gemma	192					
Idasola argenteus						
Lyonsia hyalina						
Macoma balthica						
Macoma tenta						3
Mercenaria mercenaria						
Modiolus modiolus						
Mulinia lateralis						
Mya arenaria						
Mytilus edulis				3		
Nucula sp.		3	6		20	

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SPECIES / STATION	1-25689	15-25692	16-25691	105	112	151-25690
Cl. Bivalvia (continued)						
Pandora gouldiana						
Petricola pholadiformis						
Solemya velum	1		9			2
Solèn viridis						
Spisula solidissima						
Tellina agilis	2	2	4			
Thracia septentrionalis				2		
Yoldia limatula	5					
Miscellaneous				2		
Cl. Scaphopoda						
Dentalium occidentale						
Phylum Arthropoda						
Cl. Arachnida						
Acarina						
Cl. Crustacea						
Copepoda	9		92		3	110
Ostracoda	175		40	1	5	32
Tanaidacea						
Leptochelia sp.						
Leptochelia rapax						2
Leptochelia savignyi						
Leptognatha caeca						
Isopoda						
Cyathura sp.						
Cyathura polita			3		6	
Edotea triloba	2				2	
Erichsonella filiformis						
Sphaeroma quadridentatum						
Cumacea	2				2	
Diastylis sp.						
Diastylis polita						
Diastylis quadrispinosa						
Lamprops quadriplicata						
Oxyurostylis smithi						
Petalosarsia declivis						
Amphipoda						
Acanthohaustorius millsi						

March 9, 1977 SPECIES / STATION	1-25689	15-25692	16-25691	105	112	151-25690
Amphipoda (continued)						
Ampelisca sp.						
Ampelisca abdita	9	4	19		4	9
Bathyporeia parkeri						
Caprellidae						
Caprella penantis						
Corophium sp.						
Cymadusa compta						
Dexamine thea						
Elasmopus levis						
Gammarus sp.						
Haustoriidae						
Jassa falcata						7
Lembos websteri						
Leptocheirus pinguis						
Listriella barnardi			1			
Lysianopsis alba	1					2
Melita dentata						
Microdeutopus anomalus						
Microdeutopus gryllotalpa	17					23
Monoculodes edwardsii						
Orchomenella minuta						
Paraphoxus spinosus						
Phoxocephalus hoibolli						
Protohaustorius deichmannae						
Trichophoxus epistomus						
Unciola sp.						
Unciola irrorata						
Decapoda						
Crangon septemspinosa						
Hippolyte zostericola						
Meterythrops robustus						
Pagurus sp.						
Pagurus arcuatus						
Pagurus longicarpus						1
Pagurus pollicaris			1			
Pinnixa chaetopterana						
Rhithropanopeus harrisii						
Xanthidae						

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SPECIES / STATION	16-25691
Phylum Echinodermata	
Cl. Ophiuroidea	
Amphiura otteri	
Cl. Echinoidea	
Echinarachnius parma	
Phylum Sipunculida	6

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SPECIES / STATION	1-25603	2-43586	4-43588	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Phylum Cnidaria															
Cl. Anthozoa		1													
Phylum Nemertinea	6			5		3	8					45		4	7
Phylum Aschelminthes															
Cl. Nematoda	1483	295	312	119	25	15	67	101	20	230	402	145	25	941	92
Phylum Annelida															
Cl. Archiannelida															
Protodrilus sp.				2										8	
Cl. Oligochaeta		200	1	1	2	11	16				18	368	1	109	34
Cl. Polychaeta															
Aglaophamus verrilli															
Ammotrypane sp.															
Amphicteis sp.															
Ampharetidae							1								
Arabella iricolor				1											
Aricidea sp.															
Aricidea neosuecica															2
Aricidea jeffreysii															1
Autolytus cornutus				4											
Brania clavata				12			2					8			
Brania wellfleetensis	11			3		1									
Capitella capitata	1					1	2								
Cirratulidae					16										
Cirratulus grandis					1										
Clymenella sp.															
Clymenella torquata													7		
Diopatra cuprea															
Dorvilleidae															
Drilonereis longa															
Ephesiella minuta															
Eteone sp.															1
Eteone flava													1		
Eteone heteropoda												4			
Eteone lactea															
Eteone longa															
Eumida sanguinea															
Exogone dispar							175							17	47
Exogone hebes				17											
Fabricia sabella				4								61			

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SPECIES / STATION	1-25603	2-43586	4-43588	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Cl. Polychaeta (continued)															
Glycera dibranchiata						1	4								2
Glyceridae															
Glycinde solitaria							8								33
Goniadella gracilis														1	
Goniadidae															
Harmothoe imbricata	4			18	4		20								10
Hesionidae															
Heteromastus filiformis															
Hydroides dianthus		1													
Lumbrinereis sp.				1								3			
Lumbrinereis tenuis	6														
Maldanidae						9							4		1
Maldane sarsi							7								
Mediomastus ambiseta						31	81						2		145
Melinna cristata															1
Minuspio sp.															
Minuspio cirrobranchiata															19
Neanthes virens															
Nephtys sp.															
Nophtys bucera															
Nephtys incisa															
Nephtys longosetosa													3		
Nephtys picta													1		
Nereidae			1												
Nereis sp.							1								
Nereis arenaceodonta					1										
Nereis grayi				3											
Nereis succinea											5	4			
Nereis virens	2									1					
Notomastus latericeus															17
Opheliidae				1											
Orbiniidae						1									
Paranaitis speciosa															
Paraonis fulgens															
Paraonis gracilis															
Paraonis lyra														2	
Parapionosyllis longicirrata	76													6	2
Pectinaria gouldii					1										
Pholoe minuta															
Phyllodocidae	1						3								
Phyllodoce arenae															

April 21, 1977 SPECIES / STATION	1-25603	2-43586	4-43588	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Cl. Polychaeta (continued)															
Phyllodoce maculata															
Phyllodoce mucosa															
Pista cristata				1											
Polycirrus eximus															
Polydora sp.															
Polydora aggregata															
Polydora ligni												149			1
Polydora quadricuspis															
Polydora socialis	19					1									
Potamilla neglecta															
Praxillella sp.				1											154
Prionospio heterobranchia	1						15								
Protodorvillea kefersteini															
Protodorvillea minuta															
Pygospio elegans	2														
Sabella microphthalma							1								
Sabellaria vulgaris		1													
Scoloplos sp.															
Scoloplos acutus				10								2			2
Scoloplos robustus															
Serpulidae				1											
Sigalionidae															
Sphaerosyllis erinaceus				12										1	1
Sphaerosyllis hystrix	6					1	1								17
Spio filicornis	31												2		
Spiochaetopterus oculatus							1								
Spiophanes bombyx				6			1								
Spirorbis sp.															
Streblospio benedicti						2						299	2		
Streptosyllis arenae	67			1											
Streptosyllis varians															
Syllidae															
Syllides setosa															
Terebellidae	10			47	6										18
Tharyx sp.	2			3	2							45			2
Travisia carnea															
Phylum Mollusca															
Cl. Gastropoda															
Aclis striata															

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SPECIES / STATION	1-25603	2-43586	4-43588	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Cl. Gastropoda (continued)															
Anachis avara															
Anachis lafresnayi															
Anachis translirata															
Caecum cooperi															
Caecum pulchellum	1	7		1	32		7				5				
Cerithiopsis emersoni		1													
Crepidula fornicata					14										
Cylichna gouldii															
Haminoea solitaria															
Ilyanassa obsoleta			4							2					
Littorina littorea										1					
Littorina saxatilis															
Lunatia heros															
Mitrella lunata		4		11			7								
Nassarius trivittatus		16			6		140				1				
Natica pusilla							3								
Odostomia sp.												226			
Osostomia bisuturalis			5				1								
Pyramidella producta			200												
Rotusa canaliculata															1
Turbonilla elegantula															
Turbonilla interrupta		3													
Miscellaneous															
Cl. Bivalvia															
Anadara ovalis															
Anomia simplex					1										
Cerastoderma pinnulatum				1											
Crassinella lunulata															
Gemma gemma												164			
Idasola argenteus															
Lyonsia hyalina				2											
Macoma balthica															1
Macoma tenta								25							4
Mercenaria mercenaria		3								2	1		1		
Modiolus modiolus					1										
Mulinia lateralis															
Mya arenaria			5		64						1	1			
Mytilus edulis								103	30	4				5	
Nucula sp.		14	25		19		31				3				1

SPECIES / STATION — April 21, 1977	1-25603	2-43586	4-43588	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Cl. Bivalvia (continued)															
Pandora gouldiana															
Petricola pholadiformis															
Solemya velum							1				3		1		
Solen viridis															1
Spisula solidissima															
Tellina agilis														1	
Thracia septentrionalis				2											
Yoldia limatula															
Miscellaneous	7										1			8	
Cl. Scaphopoda															
Dentalium occidentale															
Phylum Arthropoda															
Cl. Arachnida															
Acarina				1											
Cl. Crustacea															
Copepoda	99			28		1	10					3	1	20	4
Ostracoda	1			6	3	4	183				13				11
Tanaidacea															
Leptochelia sp.				1			2								
Leptochelia rapax															
Leptochelia savignyi															
Leptognatha caeca				17										5	
Isopoda															
Cyathura sp.															
Cyathura polita			1												1
Edotea triloba			1				2					3			
Erichsonella filiformis							2								
Sphaeroma quadridentatum															
Cumacea		1													9
Diastylis sp.															
Diastylis polita															
Diastylis quadrispinosa															
Lamprops quadriplicata															
Oxyurostylis smithi															
Petalosarsia declivis															
Amphipoda															
Acanthohaustorius millsi															

April 21, 1977 SPECIES / STATION	1-25603	2-43586	4-43586	13-25600	14-25601	15-25604	16-25599	35-43590	100-43589	105-43585	108-43587	112-43584	151-25604	160-25602	161-25606
Amphipoda (continued)															
Ampelisca sp.					1										
Ampelisca abdita	2					1	10								14
Bathyporeia parkeri				1											
Caprellidae				1											
Caprella penantis		6													
Corophium sp.	15			10			3								
Cymadusa compta															
Dexamine thea							7								
Elasmopus levis															
Gammarus sp.															
Haustoriidae															
Jassa falcata															
Lembos websteri				3											
Leptochelia sp.							2								
Listriella barnardi															
Lysianopsis alba							13								
Melita dentata															
Microdeutopus anomalus	13						5								
Microdeutopus gryllotalpa															
Monoculodes edwardsii															
Orchomenella minuta															
Paraphoxus spinosus							6								
Phoxocephalus hoibolli															
Protohaustorius deichmannae															
Trichophoxus epistomus															
Unciola sp.															
Unciola serrata				37											
Decapoda															
Crangon septemspinosa			3		1								1		
Hippolyte zostericola															
Meterythrops robustus															5
Pagurus sp.															
Pagurus arcuatus															
Pagurus longicarpus															
Pagurus pollicaris										2					
Pinnixa chaetopterana															
Rhithropanopeus harrisii															
Xanthidae					7		3								

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SPECIES / STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29489
Phylum Cnidaria															
Cl. Anthozoa															
Phylum Nemertinea		8	6	23	5		9	7				5		1	3
Phylum Aschelminthes															
Cl. Nematoda	468	65	16	164			47	25	2	31	403	13	2	156	32
Phylum Annelida															
Cl. Archiannelida															
Protodrilus sp.				2			1	75						16	
Cl. Oligochaeta	23	64	91	5	13	10	43	2		37	71	40	1	25	51
Cl. Polychaeta															
Aglaophamus verrilli															
Ammotrypane sp.															
Amphicteis sp.															
Ampharetidae															
Arabella iricolor															
Aricidea sp.															
Aricidea neosuecica							23								
Aricidea jeffreysii					2										
Autolytus cornutus															
Brania clavata							14				14				41
Brania wellfleetensis	2			9											
Capitella capitata		30	1		15		6	1		23					2
Cirratulidae		2													
Cirratulus grandis															
Clymenella sp.					2										
Clymenella torquata															3
Diopatra cuprea															
Dorvilleidae					1										
Drilonereis longa	4														
Ephesiella minuta															
Eteone sp.															
Eteone flava	3														
Eteone heteropoda		3	4									5			
Eteone lactea															
Eteone longa										19		3			
Eumida sanguinea															
Exogone dispar		5			11		50	10			1		2	4	117
Exogone hebes				4											
Fabricia sabella		28						1							

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SPECIES / STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29489
Cl. Polychaeta (continued)															
Glycera dibranchiata					1										
Glyceridae															
Glycinde solitaria					2										
Goniadella gracilis															6
Goniadidae															
Harmothoe imbricata					23		7						9		8
Hesionidae															
Heteromastus filiformis										2		4			
Hydroides dianthus				1											
Lumbrinereis sp.							2						1		
Lumbrinereis tenuis		4										1			
Maldanidae					1										1
Maldane sarsi															
Mediomastus ambiseta					142	81	58				1		2		47
Melinna cristata															
Minuspio sp.															
Minuspio cirrobranchiata					2										
Neanthes virens															
Nephtys sp.						3									
Nephtys bucera														2	
Nephtys incisa				2			3								
Nephtys longosetosa															
Nephtys picta								7	1		1		4		
Nereidae							2								
Nereis sp.											53		1		
Nereis arenaceodonta	16	80			2							1			
Nereis grayi															
Nereis succinea			18												
Nereis virens										8					
Notomastus latericus					4										
Opheliidae															
Orbiniidae															
Paranaitis speciosa						1									
Paraonis fulgens															
Paraonis gracilis															
Paraonis lyra														7	
Parapionosyllis longicirrata		28	7		17			1		1	30		1		11
Pectinaria gouldii					1		6								
Pholoe minuta								5							
Phyllodocidae				8			1				1				1
Phyllodoce arenae							1								

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SPECIES \ STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29439
Cl. Polychaeta (continued)															
Phyllodoce maculata					6										
Phyllodoce mucosa															
Pista cristata															
Polycirrus eximus															
Polydora sp.	2		1		1		1								
Polydora aggregata			2												
Polydora ligni		70	9							3	16	219	3		
Polydora quadricuspis											6				
Polydora socialis		89			2										
Potamilla neglecta															
Praxillella sp.					1		23								
Prionospio heterobranchia							3								2
Protodorvillea kefersteini															
Protodorvillea minuta															
Pygospio elegans		155	53							24			11		
Sabella microphthalma															
Sabellaria vulgaris															
Scoloplos sp.			1	9											
Scoloplos acutus							3					1			2
Scoloplos robustus					3										
Serpulidae															
Sigalionidae							1								
Sphaerosyllis erinaceus				14	1		1								
Sphaerosyllis hystrix					3		9				8				12
Spio filicornis		17	24					4		6					
Spionidae			1												
Spiophanes bombyx					1		2								1
Spirorbis sp.		1						1							
Streblospio benedicti		11	20			1				1		21	2		
Streptosyllis arenae				4								1			2
Streptosyllis varians		6									3		2		
Syllidae				2											
Syllides setosa			7				13				14				
Terebellidae	3	4		3	56		1				1		1		4
Tharyx sp.			1				2	5				35			4
Travisia carnea				2											
Phylum Mollusca															
Cl. Gastropoda															
Aclis striata						2									

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SPECIES / STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29489
Cl. Gastropoda (continued)															
Anachis avara															
Anachis lafresnayi															
Anachis translirata															
Caecum cooperi				2											
Caecum pulchellum				1							11				35
Cerithiopsis emersoni															
Crepidula fornicata											4				
Cylichna gouldii					4										
Haminoea solitaria															
Ilyanassa obsoleta			1												
Littorina littorea															
Littorina saxatilis								1							
Lunatia heros															
Mitrella lunata					3								9		11
Nassarius trivittatus					17	1	1						1		13
Natica pusilla	1			1	1								1		1
Odostomia sp.		55						1		1		105			
Osostomia bisuturális			2												
Pyramidella producta			67												
Retusa canaliculata						1							2		
Turbonilla elegantula															
Turbonilla interrupta				1											
Miscellaneous							4								
Nudibranchia					8										
Cl. Bivalvia															
Anadara ovalis															
Anomia simplex															
Cerastoderma pinnulatum					1										
Crassinella lunulata				6											
Gemma gemma		72	5							2	31	104			
Idasola argenteus															
Lyonsia hyalina								3							
Macoma balthica															
Macoma tenta															1
Mercenaria mercenaria											1				1
Modiolus modiolus	1			3											
Mulinia lateralis															
Mya arenaria		26	2												
Mytilus edulis								18	2	6			1		
Nucula sp.	1														20

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SPECIES / STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29489
Cl. Bivalvia (continued)															
Pandora gouldiana															
Petricola pholadiformis															
Solemya velum															
Solen viridis															
Spisula solidissima								4						5	
Tellina agilis					1		1	84							3
Thracia septentrionalis				12						3					
Yoldia limatula															
Miscellaneous							2								
Cl. Scaphopoda															
Dentalium occidentale				2											
Phylum Arthropoda															
Cl. Arachnida															
Acarina															
Cl. Crustacea															
Copepoda					3	2	4				9			2	4
Ostracoda		1	1		2		4			1	1	5			6
Tanaidacea															
Leptochelia sp.															
Leptochelia rapax															
Leptochelia savignyi			1												
Leptognatha caeca								1							
Isopoda															
Cyathura sp.							1								
Cyathura polita												3			
Edotea triloba												3			
Erichsonella filiformis															
Sphaeroma quadridentatum		16													
Cumacea															
Diastylis sp.						2									
Diastylis polita															
Diastylis quadrispinosa															
Lamprops quadriplicata															
Oxyurostylis smithi															
Petalosarsia declivis															
Amphipoda															
Acanthohaustorius millsi														2	

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SPECIES / STATION	1-27798	2-29782	4-29781	13-29774	14-29777	15-29778	16-27800	35-29779	100-29780	105-29488	108-29490	112-29491	151-27799	160-27797	161-29489
Amphipoda (continued)															
Ampelisca sp.															
Ampelisca abdita		3		1	3	1	10					6			5
Bathyporeia parkeri				1											
Caprellidae															
Caprella penantis		2								1					
Corophium sp.	1					1					3		1		2
Cymadusa compta															
Dexamine thea															
Elasmopus levis							1								
Gammarus sp.												4			
Haustoriidae															
Jassa falcata	1														
Lembos websteri															
Leptocheirus pinguis															
Listriella barnardi															
Lysianopsis alba	1														
Melita dentata					3										
Microdeutopus anomalus															
Microdeutopus gryllotalpa										1					
Monoculodes edwardsii					1										
Orchomenella minuta															
Paraphoxus spinosus															
Phoxocephalus holbolli													1		
Protohaustorius deichmannae															
Trichophoxus epistomus															
Unciola sp.															
Unciola irrorata															
Decapoda															
Crangon septemspinosa								1			1				
Hippolyte zostericola															
Meterythrops robustus															
Pagurus sp.															
Pagurus arcuatus															
Pagurus longicarpus							1				2				
Pagurus pollicaris															
Pinnixa chaetopterana											1				
Rhithropanopeus harrisii															1
Xanthidae					5										

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SPECIES	STATION 160-27797
Phylum Echinodermata	
Cl. Ophiuroidea	
Amphiura otteri	
Cl. Echinoidea	
Echinarachnius parma	1
Phylum Sipunculida	

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SPECIES / STATION	1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Phylum Cnidaria									
Cl. Anthozoa									
Phylum Nemertinea	4	3	1	7	1		6		3
Phylum Aschelminthes									
Cl. Nematoda		116	31	36	38		26	46	134
Phylum Annelida									
Cl. Archiannelida									
Protodrilus sp.				1				1	
Cl. Oligochaeta		171	152	2	26	5	17	11	5
Cl. Polychaeta									
Aglaophamus verrilli									
Ammotrypane sp.				6					
Amphicteis sp.									
Ampharetidae							1		
Arabella iricolor		1							
Aricidea sp.									
Aricidea neosuecica				1	1				
Aricidea jeffreysii									
Autolytus cornutus									
Brania clavata							2		
Brania wellfleetensis				6					
Capitella capitata	3	77	5		6	25			495
Cirratulidae									
Cirratulus grandis									
Clymenella sp.									
Clymenella torquata					28		20		
Diopatra cuprea									
Dorvilleidae									
Drilonereis longa									
Ephesiella minuta									
Eteone sp.									2
Eteone flava	85	4							
Eteone heteropoda									2
Eteone lactea									
Eteone longa			5		1				
Eumida sanguinea									
Exogone dispar	2	5			7		28		3
Exogone hebes									
Fabricia sabella		5							

June 20, 1977 SPECIES / STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Phylum Cnidaria									
Cl. Anthozoa									
Phylum Nemertinea		2				1			6
Phylum Aschelminthes									
Cl. Nematoda	32	50	19	52	83	1392	47	5	15
Phylum Annelida									
Cl. Archiannelida									
Protodrilus sp.						81			1
Cl. Oligochaeta	4	180	3		20	799		2	14
Cl. Polychaeta									
Aglaophamus verrilli									
Ammotrypane sp.									
Amphicteis sp.									11
Ampharetidae					2				
Arabella iricolor		2		2					
Aricidea sp.		1							
Aricidea neosuecica									1
Aricidea jeffreysii									1
Autolytus cornutus									
Brania clavata							1		1
Brania wellfleetensis							14		1
Capitella capitata		4	171		7		7		
Cirratulidae									7
Cirratulus grandis									
Clymenella sp.									1
Clymenella torquata		6			4				
Diopatra cuprea									
Dorvilleidae									
Drilonereis longa									
Ephesiella minuta									
Eteone sp.		1		7		1			
Eteone flava								1	
Eteone heteropoda									
Eteone lactea									
Eteone longa		40			5				
Eumida sanguinea		1							
Exogone dispar		60	2		11	20	1		9
Exogone hebes									
Fabricia sabella									

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SPECIES / STATION	1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Cl. Polychaeta (continued)									
Glycera dibranchiata							2		1
Glyceridae									
Glycinde solitaria									
Goniadella gracilis									
Goniadidae									
Harmothoe imbricata	14	1					2		
Hesionidae									
Heteromastus filiformis									
Hydroides dianthus	2								
Lumbrinereis sp.									
Lumbrinereis tenuis	9	2							
Maldanidae									
Maldane sarsi									
Mediomastus ambiseta					27		93		1
Melinna cristata									
Minuspio sp.						1			
Minuspio cirrobranchiata									
Neanthes virens									
Nephtys sp.				1					
Nephtys bucera									
Nephtys incisa						5			
Nephtys longosetosa									
Nephtys picta									
Nereidae		38							
Nereis sp.									1
Nereis arenaceodonta	144								
Nereis grayi									
Nereis succinea		6	24						10
Notomastus latericeus									
Ophelia sp.									
Opheliidae									
Orbiniidae			2			1			
Paranaitis speciosa									
Paraonis fulgens					1				
Paraonis gracilis									
Paraonis lyra									
Parapionosyllis longicirrata	24	3	7				6	1	
Pectinaria gouldii									
Phobe minuta									
Phyllodocidae					1				1
Phyllodoce arenae	3								

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SPECIES / STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Cl. Polychaeta (continued)									
Glycera dibranchiata									1
Glyceridae									
Glycinde solitaria									
Goniadella gracilis						2			
Goniadidae	1						1		
Harmothoe extenuata									1
Harmothoe imbricata					12		3		2
Heteromastus filiformis									
Hydroides dianthus									
Lumbrinereis sp.						1			
Lumbrinereis tenuis									1
Maldanidae					188				
Maldane sarsi									
Mediomastus ambiseta					14				63
Melinna cristata									
Minuspio sp.									
Minuspio cirrobranchiata									
Neanthes virens									
Nephtys sp.									
Nephtys bucera									
Nephtys incisa						1			9
Nephtys longosetosa									
Nephtys picta									
Nereidae				1			1		1
Nereis sp.		4			10	1			
Nereis arenaceodonta			15						
Nereis grayi									
Nereis succinea									
Notomastus latericeus									1
Ophelia sp.						1			
Opheliidae									
Orbiniidae									
Paranaitis speciosa									1
Paraonis fulgens			2					49	4
Paraonis gracilis									
Paraonis lyra						44			1
Parapionosyllis longicirrata		1				57			3
Pectinaria gouldii					1				
Pholoe minuta									
Phyllodocidae									
Phyllodoce arenae		4			6				

SPECIES (June 20, 1977) / STATION	1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Cl. Polychaeta (continued)									
Phyllodoce maculata									
Phyllodoce mucosa									
Pista cristata									
Polycirrus eximus		24							
Polydora sp.									
Polydora aggregata									
Polydora ligni	60	15	49		134		7		812
Polydora quadricuspis									
Polydora socialis						3			
Potamilla neglecta									
Praxillella sp.							7		1
Prionospio heterobranchia							2		
Protodorvillea kefersteini									
Protodorvillea minuta				3					
Pygospio elegans			140						
Sabella microphthalma		1							
Sabellaria vulgaris									
Scoloplos sp.				9					
Scoloplos acutus					3		2		
Scoloplos robustus									
Serpulidae									
Sigalionidae									
Sphaerosyllis erinaceus				3			2		
Sphaerosyllis hystrix					1		24		1
Spio filicornis			28		1				
Spionidae		1					1	1	
Spiophanes bombyx							2		
Spirorbis sp.									
Streblospio benedicti			6		3	33			69
Streptosyllis arenae				4					
Streptosyllis varians							1		
Syllidae			12	5					
Syllides setosa			10				1		
Terebellidae		25					3		3
Tharyx sp.									
Travisia carnea				1					
Phylum Mollusca									
Cl. Gastropoda									
Aclis striata									

June 20, 1977 SPECIES	STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Cl. Polychaeta (continued)										
Phyllodoce maculata										
Phyllodoce mucosa										
Pista cristata										
Polycirrus eximus										
Polydora sp.										
Polydora aggregata										
Polydora ligni			12	78		126		35		
Polydora quadricuspis										
Polydora socialis										
Potamilla neglecta										
Praxillella sp.										7
Prionospio heterobranchia						1		2		
Protodorvillea kefersteini			1				1			13
Protodorvillea minuta										
Pygospio elegans			58	5		67				
Sabella microphthalma										
Sabellaria vulgaris								1		
Scoloplos sp.										
Scoloplos acutus			2	26				1		8
Scoloplos robustus										
Serpulidae										
Sigalionidae						8				
Sphaerosyllis erinaceus										
Sphaerosyllis hystrix						3				1
Spio filicornis			9	6		1				1
Spionidae										
Spiophanes bombyx						1				1
Spirorbis sp.										
Streblospio benedicti			1	1		7		1		
Streptosyllis arenae						6				
Streptosyllis varians										
Syllidae				4						
Syllides setosa										
Terebellidae										15
Tharyx sp.										26
Travisia carnea										
Phylum Mollusca										
Cl. Gastropoda										
Aclis striata										

June 20, 1977 SPECIES	STATION	1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Cl. Gastropoda (continued)										
Anachis avara										
Anachis lafresnayi										
Anachis translirata										
Caecum cooperi										
Caecum pulchellum			8							
Cerithiopsis emersoni										
Crepidula fornicata		2								
Cylichna gouldii										
Haminoea solitaria										
Ilyanassa obsoleta										
Littorina littorea										
Littorina saxatilis										
Lunatia heros										
Mitrella lunata										
Nassarius trivittatus										
Natica pusilla					1			5		
Odostomia sp.									2	2
Ososstomia bisuturalis										
Pyramidella producta				103						
Retusa canaliculata							2			
Turbonilla elegantula								1		
Turbonilla interrupta										
Miscellaneous				3		1		1		
Cl. Bivalvia										
Anadara ovalis										
Anomia simplex										
Cerastoderma pinnulatum										
Crassinella lunulata					4					
Gemma gemma				37						
Idasola argenteus										
Lyonsia hyalina										
Macoma balthica										
Macoma tenta										
Mercenaria mercenaria										
Modiolus modiolus										
Mulinia lateralis										
Mya arenaria		2	2	4						
Mytilus edulis									10	
Nucula sp.		1	3				1	4		

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SPECIES / STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Cl. Gastropoda (continued)									
Anachis avara									
Anachis lafresnayi									
Anachis translirata									
Caecum cooperi									
Caecum pulchellum									
Cerithiopsis emersoni									
Crepidula fornicata			6		9		1		
Crepidula plana					2				
Haminoea solitaria									
Ilyanassa obsoleta									
Littorina littorea									
Littorina saxatilis			1						
Lunatia heros						1			
Mitrella lunata									
Nassarius trivittatus		1					2	1	
Natica pusilla									
Odostomia sp.				383					
Osostomia bisuturalis									
Pyramidella producta									
Retusa canaliculata									
Turbonilla elegantula									
Turbonilla interrupta									12
Miscellaneous									
Cl. Bivalvia									
Anadara ovalis									
Anomia simplex									
Cerastoderma pinnulatum									
Crassinella lunulata									
Gemma gemma		3	23	142					
Idasola argenteus		1							
Lyonsia hyalina						3			
Macoma balthica									
Macoma tenta			1						
Mercenaria mercenaria					1				
Modiolus modiolus									
Mulinia lateralis									
Mya arenaria				6					
Mytilus edulis	45	33			1	1			
Nucula sp.							2		

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SPECIES / STATION	1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Cl. Bivalvia (continued)									
Pandora gouldiana				1	1				
Petricola pholadiformis									
Solemya velum									
Solen viridis									
Spisula solidissima	4					1			
Tellina agilis					1		1		
Thracia septentrionalis				5					
Yoldia limatula									
Miscellaneous					7		1		
Cl. Scaphopoda									
Dentalium occidentale				1					
Phylum Arthropoda									
Cl. Arachnida									
Acarina				2					
Cl. Crustacea									
Copepoda		1	1	34	2				
Ostracoda	20						17		2
Tanaidacea									
Leptochelia sp.									
Leptochelia rapax									
Leptochelia savignyi									
Leptognatha caeca									
Isopoda									
Cyathura sp.									
Cyathura polita							2		
Edotea triloba		3	3		1				1
Erichsonella filiformis									
Idotea phosphorea						1			
Cumacea									
Diastylis sp.									
Diastylis polita									
Diastylis quadrispinosa					1				
Lamprops quadriplicata									
Oxyurostylis smithi									
Petalosarsia declivis									
Amphipoda									
Acanthohaustorius millsi									

SPECIES (June 20, 1977) — STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Cl. Bivalvia (continued)									
Pandora gouldiana									
Petricola pholadiformis		1							1
Solemya velum									
Solen viridis									
Spisula solidissima									
Tellina agilis					12			2	
Thracia septentrionalis									
Yoldia limatula									
Miscellaneous							1		7
Cl. Scaphopoda									
Dentalium occidentale									
Phylum Arthropoda									
Cl. Arachnida									
Acarina						2			
Cl. Crustacea									
Copepoda	2			1	1	115		4	1
Ostracoda				6	3		1		
Tanaidacea									
Leptochelia sp.									
Leptochelia rapax									
Leptochelia savignyi				1					
Leptognatha caeca						2			
Isopoda									
Cyathura sp.									
Cyathura polita				4					
Edotea triloba				19					
Erichsonella filiformis									
Sphaeroma quadridentatum									
Cumacea									
Diastylis sp.									
Diastylis polita									
Diastylis quadrispinosa									
Lamprops quadriplicata									
Oxyurostylis smithi			1						
Petalosarsia declivis							1		
Amphipoda		3							
Acanthohaustorius millsi								6	

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SPECIES	STATION 1-36665	2-43577	4-43576	13-36660	14-36662	15-36663	16-36661	35-43580	47-36670
Amphipoda (continued)									
Ampelisca sp.									
Ampelisca abdita	1				22		3		63
Bathyporeia parkeri									
Caprellidae									
Caprella penantis	10								
Corophium sp.	15								10
Cymadusa compta									
Dexamine thea									
Elasmopus levis									
Gammarus sp.									
Haustoriidae									
Jassa falcata									
Lembos websteri									
Leptocheirus pinguis									
Listriella barnardi									
Lysianopsis alba	25								
Melita dentata									
Microdeutopus anomalus									
Microdeutopus gryllotalpa	159								33
Monoculodes edwardsii									
Orchomenella minuta									
Paraphoxus spinosus									
Phoxocephalus hoibolli									
Protohaustorius deichmannae									
Trichophoxus epistomus									
Unciola sp.									
Unciola irrorata									
Decapoda									
Crangon septemspinosa							2		
Hippolyte zostericola									
Meterythrops robustus									2
Pagurus sp.									
Pagurus arcuatus									
Pagurus longicarpus	1				1				
Pagurus pollicaris									
Pinnixa chaetopterana									
Rhithropanopeus harrisii									
Xanthidae									1

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SPECIES / STATION	100-43579	105-43578	108-43581	112-43583	151-36664	160-36666	161-36669	170-36667	180-36668
Amphipoda (continued)									
Ampelisca sp.							1		
Ampelisca abdita									11
Bathyporeia parkeri									
Caprellidae									
Caprella penantis									
Corophium sp.		6		1	5				2
Cymadusa compta									
Dexamine thea									
Elasmopus levis									
Gammarus sp.									
Haustoriidae									
Jassa falcata									
Lembos websteri									
Leptocheirus pinguis									1
Listriella barnardi									
Lysianopsis alba									
Melita dentata									
Microdeutopus anomalus							4		
Microdeutopus gryllotalpa			7		43	1			
Monoculodes edwardsii									
Orchomenella minuta								1	
Paraphoxus spinosus									
Phoxocephalus holbolli					1				1
Protohaustorius deichmannae								48	
Trichophoxus epistomus								1	
Unciola sp.					1				2
Unciola irrorata									
Decapoda		1							
Crangon septemspinosa							1		
Hippolyte zostericola									
Meterythrops robustus									
Pagurus sp.									
Pagurus arcuatus									
Pagurus longicarpus			1						
Pagurus pollicaris									
Pinnixa chaetopterana					1				
Rhithropanopeus harrisii									
Xanthidae									

June 20, 1977 SPECIES	STATION	170-36667	180-36668
Phylum Echinodermata			
Cl. Ophiuroidea			
Amphiura otteri			1
Cl. Echinoidea			
Echinarachnius parma		5	
Phylum Sipunculida			

APPENDIX B. HYDROCARBON EXTRACTION AND ANALYSIS*

Methods

Sediment Extraction and Analysis --

Sediment samples were well mixed by hand and a visual description noted. Approximately 20 g was removed for dry weight determinations. Approximately 100 g wet weight sediment was placed in 1 liter round-bottomed flask and digested for 4 hours with 300 ml methanol/toluene azeotrope and 30 ml 2.5 n KOH/H_2O. The solvent was decanted and filtered through glass fibre filter. The sediment was rinsed with an additional 50 ml methanol/toluene. The extract and rinse were combined in a 1-liter separatory funnel to which 100 ml dist. H_2O had been added. Toluene layer was removed. The aqueous methanol was extracted with 2 x 5 cc hexane. The combined toluene and hexane extracts were back extracted with water, dried over sodium sulfate, and concentrated by rotary evaporation. Sulfur was removed by freshly activated copper dust. Column chromatography used 7.5 g silica gel (activity grade 1) and 2.5 g alumina, 5 percent deactivated. The aliphatic fraction (F1) was collected in 18 ml hexane. The aromatic fraction (F2) eluted with 20 ml benzene.

The amounts of petroleum hydrocarbons in the aliphatic and aromatic fractions were determined gravimetrically on the Cahn balance. Each fraction was analyzed by glass capillary gas chromatography for a qualitative determination of the nature of the hydrocarbons present.

Organism Extraction and Analysis --

A given species from a single station was blended in a Waring blender. In the case of bivalves, all individuals were homogenized. A minimum of 20 g of homogenate was digested for 4 hours with 200 ml of 1:1 solution of 0.5 n KOH methanol:water. A smaller portion of homogenate was removed for dry weight determination. Upon completion of digestion, the mixture was diluted with an equal volume of saturated NaCl solution and extracted with 3 x 100 ml portions of hexane. The hexane extract was dried and concentrated for a lipid weight determination. Column chromatography was the same as for sediments.

The amounts of aliphatic and aromatic hydrocarbons in the organisms were determined by gas chromatography through the use of internal standards Weights were also determined gravimetrically but the presence of large amounts of biogenic hydrocarbons in most fractions precluded the usefulness of this data.

Gas Chromatography --

Gas chromatography was performed on the extracts with Hewlett-Packard Model 5840 gas chromatographs (gc). Each gc was equipped with a spitless mode injector and a 15 m glass capillary column (J&W Scientific).

*Source: Energy Resources Company.

Conditions: T_{inj} 250
T_{det} 300
T_{oven} 60-110 @ 10° C/min
110-260 @ 3° C/min
gas helium 2 ml/min

A computer interface system allowed data to be processed and amounts of resolved components to be calculated from the internal standard. Computer also calculated retention indices R_i, which relate the retention time of a given component to that of the n-alkane series, i.e., pristane elutes immediately after n-C_{17}; R_i pristane = 17.10. A biogenic olefin elutes midway between n-C_{25} and n-C_{26}; R_i = 25.50. Internal standards used in this study are hexaethylbenzene R_i 16.70, n-C_{20} R_i 20.00, androstane R_i 19.50, cholestane R_i 27.90 and tridecylcyclohexane R_i 19.60.

Mass Spectrometry --

Gas chromatography/mass spectrometry (GC/MS) analysis was performed on samples shown to have No. 2 fuel oil by gc analysis. A 15 m SE-30 glass capillary column (J&W Scientific) was employed. Temperature program was from 80 to 250° C at 2° C/min. A Hewlett-Packard Model 5980A was used with 5934A system which provided hard copy of the data.

Quality Control Program

Each sample extracted contained an internal standard for both saturated and aromatic fractions. The amounts of individual resolved hydrocarbons and unresolved complex mixture (UCM) in the organism samples were calculated with respect to these internal standards. The percent recovery of the F1 internal standard was determined in 4 cases by addition of an external standard prior to gas chromatography. Results are listed in Table B-1.

TABLE B-1. PERCENT RECOVERY OF THE F1 INTERNAL STANDARD

	Item	Recovery
1.	Sediment 14-29777	96%
2.	Sediment 47-36670	97%
3.	Mercenaria 1-41980	36%
4.	Mya 13-41986	56%

The poor recovery of internal standards in the case of the organisms stems from the fact that in both cases an unknown large amount of extract was lost upon repeated injections on gc before recovery experiments were performed. This was assumed to be 50 percent, but recovery indicates it was much more.

Procedural blanks are run routinely in our laboratory as part of our overall quality control effort. Blank levels were routinely 5 to 10 times lower than the lowest level samples and more often several orders of magnitude lower than most samples. This is true for the sediment and macrofaunal samples.

APPENDIX C. CRITERIA FOR CLASSIFICATION OF SEDIMENTS AND SHELLFISH

Energy Resources Company

Class A - Clean Sediment--

The biogenic hydrocarbons, n-C_{25}, n-C_{27}, n-C_{29}, and n-C_{31} derived from land plants and marsh grasses predominate in the higher molecular weight range. Lighter n-C_{15}, n-C_{17}, n-C_{19} from algae may also be found. The biogenic olefins mentioned earlier may be found. There is little or no UCM characteristic of fossil fuels. Total hydrocarbon load is less than 5 g/g dry weight.

Class B - Moderate Amount of Chronic Pollution --

Resolved petroleum hydrocarbons and UCM are found in amounts roughly equal to biogenic input.

Class C - Chronic Pollution --

Characteristics are homologous series of n-alkanes and branched alkanes from n-C_{25} to n-C_{33} and a large UCM maximum at n-C_{28} - n-C_{29}.

Class D - Chronic Pollution and Number 2 Fuel Oil --

The sediment contains hydrocarbons from Class C but also has lower boiling constituents. N-alkanes from C_{14} to C_{21} are present. The UCM has a biomodal distribution reflecting the two inputs. The lower boiling material has a maximum at n-C_{17} - n-C_{18} whereas the higher molecular weight chronic materials peak at n-C_{28}.

Class E - Recent Number 2 Fuel Oil Predominating --

A homologous series of n-alkanes and branched alkanes from n-C_{14} to n-C_{21} are present. The UCM peaks at n-C_{17}.

Environmental Protection Agency

Class A - Clean, low level background
Class C - Chronic pollution from higher molecule weight fuel oil
Class D - No. 2 fuel oil plus chronic pollution from higher molecular weight fuel oil
Class E - Recent No. 2 fuel oil and chronic pollution from higher molecular weight fuel oil.

APPENDIX D. ERCO SEDIMENT DATA AND INTERPRETATION

ERCO SEDIMENT DATA AND INTERPRETATION

Station Name	EPA Station Number	Physical Description	F1 µg/g	F2 µg/g	Total HC µg/g	Classification
Widows Cove	151(770523)27799	Fine sand, 10% mud	23.0	17.0	40.0	C_1
	151(770421)27794	Medium sand, 20% mud	9.3	10.2	19.5	B_1
	151(770620)36664	Medium sand, Anoxic lenses	15.7	17.3	33.0	C_2
Phinney's Harbor	15(770421)27795	Fine sand, Anoxic lenses	27.0	14.0	41.0	D_1
	15(770523)29778	Fine silty sand, Anoxic lenses	17.2	41.5	58.7	C_3
	15(770620)36663	Fine silty sand, Anoxic lenses	109.1	104.1	213.2	C_4
Scraggy Neck	16(770420)27789	Fine sand, Anoxic lenses	22.6	20.0	42.6	D_2
	16(770523)27800	Medium sand, Anoxic lenses	95.0	87.0	182.0	C_5
	16(770620)36661	Fine sand, Anoxic lenses	7.9	7.8	15.7	B_2
Back Bay	2(770421)43591	Coarse sand, 10% pebbles, Anoxic lenses	6.6	8.0	14.6	A_1
	2(770524)29782	Coarse sand, 10% pebbles, Anoxic lenses	7.4	24.0	31.4	B_3

Station Name	EPA Station Number	Physical Description	F1 µg/g	F2 µg/g	Total HC µg/g	Classification
Back Bay	2(770620)43577	Medium sand, pebbles, shell fragments	3.1	4.5	7.6	A_2
Scorton Creek	100(770621)43579	Medium sand	3.9	4.4	8.3	A_3
	100(770421)43595	Coarse sand	.9	1.1	2.0	A_4
	100(770521)29780	Coarse sand	1.6	2.1	3.7	A_5
Cove West of Railroad bridge, Cape Cod Canal	105(770421)43594	Medium sand, Anoxic lenses	10.6	10.0	20.6	C_6
	105(770620)43578	Fine sand, Anoxic lenses	7.0	6.7	13.7	C_7
	105(770524)29488	Fine sand, Anoxic lenses	8.1	9.2	17.3	C_8
Peter's Neck	108(770421)43596	Fine sand, Anoxic lenses	21.7	21.5	43.2	C_9
	108(770524)29490	Medium Sand, Anoxic lenses	12.8	9.9	22.7	D_3
	108(770621)43581	Coarse sand, Anoxic lenses	7.2	4.8	12.0	E_1

Station Name	EPA Station Number	Physical Description	F1 µg/g	F2 µg/g	Total HC µg/g	Classification
Sandwich Harbor	160(770523)27797	Coarse sand	2.6	0.1	2.7	A_6
	160(770421)27791	Medium sand, 5% shell	1.3	0.9	2.2	A_7
	160(770620)36666	Coarse sand, Anoxic lenses	1.4	1.1	2.5	A_8
Wings Cove	14(770420)27791	Fine sand, Anoxic lenses	16.0	16.0	32.0	C_{10}
	14(770523)29777	Fine sand	18.9	10.5	29.4	C_{11}
	14(770620)36662	Fine silty sand, anoxic	15.8	7.3	23.1	A_9
Buttermilk Bay	1(770523)27798	Medium sand, Anoxic lenses, duplicate	9.4	9.5	18.9	D_4
	1(770523)27798	Medium sand, Anoxic lenses	15.4	11.3	26.7	D_5
	1(770621)43582	Medium sand, Anoxic lenses	27.0	15.0	42.0	E_2
	1(770421)27793	Medium sand, Anoxic lenses	7.7	7.3	15.0	D_6
	1(770620)36665	Coarse sand, Anoxic lenses	1.9	0.5	2.4	A_{10}

Station Name	EPA Station Number	Physical Description	F1 µg/g	F2 µg/g	Total HC µg/g	Classification
Sandwich Creek (control)	35(770524)29779	Medium sand	3.2	4.1	7.3	A_{11}
	35(770621)43580	Medium-coarse sand	1.5	1.8	3.3	A_{12}
	35(770421)43593	Medium sand	1.7	3.0	4.7	A_{13}
Wareham River	161(770524)29489	Medium sand	2.4	2.0	4.4	A_{14}
	161(770421)27796	Medium sand, 20% organic matter	13.0	12.0	25.0	B_4
	161(770621)36669	Medium silty sand, anoxic lenses	3.7	5.4	9.1	B_5
Pocasset River	4(770524)29781	Coarse sand	1.6	1.6	3.2	A_{15}
	4(770421)43592	Coarse sand, 5% organic material	6.4	3.2	9.6	B_6
	4(770620)43576	Coarse sand, 5% shell	4.3	8.8	13.1	A_{16}
Little Buttermilk Bay	112(770621)43583	Medium-coarse sand, 20% organic	39.5	60.5	100.0	C_{12}
	112(770524)29491	Medium sand, Anoxic lenses	22.2	22.1	44.3	B_7
	112(770421)43597	Medium sand, 20% organic	116.0	63.0	179.0	C_{13}

Station Name	EPA Station Number	Physical Description	F1 µg/g	F2 µg/g	Total HC µg/g	Classification
Wings Neck	13(770523)29774	Coarse sand, Anoxic lenses	2.9	13.0	15.9	A_{16}
	13(770420)27790	Medium coarse sand	1.0	0.7	1.7	A_{17}
	13(770620)36660	Medium sand, shell fragments	1.3	1.6	2.9	A_{18}
Northwest Gutter	47(770322)4195901A	Fine sand, Anoxic	24.1	22.9	47.0	D_7
	47(770622)36670	Fine Silty sand, heavily anoxic	78.0	134.0	212.0	C_{14}
Cleveland Ledge	180(770621)36668	Fine sand, Anoxic lenses	9.0	6.0	15.0	B_8
Scorton Creek	170(770620)36667	Fine sand	1.5	3.2	4.7	B_9

Source: Energy Resources Company

APPENDIX E. EPA SEDIMENT DATA AND INTERPRETATION

EPA station number	Date	Lab code	µg/gm - dry weight	Classification
8	1/30	42651	K6*	C
7	1/30	42652	K2	C
6	1/30	42653	K2	C
5	1/30	42654	K5	C
3	1/30	42655	K5	C
4	1/30	42656	K3	A & chronic pollution
1	1/30	42657	K2	C
2	1/30	42658	K2	C
2	2/2	42659	K8	C
3	2/2	42660	K4	C
9B	2/2	42661	K1	C
10	2/2	43903	0.63	D
15	2/3	43904	K1	C
14	2/3	43906	K2	C
17	2/4	44142	K2	C
18	2/4	44143	K1	C
19	2/4	44144	K1	C
16	2/4	44128	K1.0	D
108	2/24	4197301	12.6	E
105	2/24	4197302	5.3	E
35	2/24	4197303	K0.5	A
1	2/24	4197304	12.5	E
4	2/24	4197305	K0.5	C
2	2/24	4197306	K0.5	A
2	3/9	43355	K1.0	C
4	3/9	43356	1.07	D
35	3/10	43358	K1.0	C
100	3/10	43359	K1.0	A
108	3/10	43360	5.16	E No chronic pollution
112	3/10	43361	1.55	D
151	3/9	44147	4.95	D
16	3/9	44148	1.92	Not classified
15	3/9	44150	K1.0	C

*"K" value represents "less than" for a No. 2 fuel oil. If No. 2 fuel oil were present it would be below the K value.

APPENDIX E. SEDIMENT DATE AND INTERPRETATION (cont.)

EPA station number	Date	Lab code	µg/gm - dry weight	Classification
14	3/9	44149	0.5	Not classified
105	3/8	43357	L.A.*	D
1	3/9	44146	5.1	E No chronic pollution
47	3/22	4195901ABC	3.8	D

*Lab accident.

Source: Environmental Protection Agency.

APPENDIX F. ERCO ORGANISM DATA AND INTERPRETATION

ERCO ORGANISM DATA AND INTERPRETATION

Station Name	Species	Station Number	F1 µg/g	F2 µg/g	F1 & F2 µg/g	F1 & F2 mg/100g wet weight	Classification
Little Buttermilk Bay	Mya arenaria (15 individuals)	112(770713)41979	15.8	28.8	44.6	.60	D
Scraggy Neck	Mya arenaria (15 individuals)	16(770714)41985	20.8	19.5	40.3	.53	D
Wings Neck	Mya arenaria (15 individuals)	13(770714)41986	22.8	27.7	50.5	.60	D
West Gutter (control)	M. mercenaria (15 individuals)	47(770714)41984	159.7	14.1	173.8	2.1	C
Widow's Cove	M. mercenaria (15 individuals)	151(770713)41981	14.0	0.2	14.2	.19	D
Buttermilk Bay	M mercenaria (14 individuals)	1(770713)41980	12.5	0.6	13.1	.18	D
Phinney's Harbor	M. mercenaria (15 individuals)	15(770713)41982	12.3	3.3	15.6	.20	D
Sandwich Creek	M. edulus (15 individuals)	35(770713)41983	40.7	2.3	43.0	.73	A
Wings Neck	Homarus americanus (Hepatopancreas)	13( )41963	47.5	6.0	53.5	1.4	A
Wings Neck	Homarus americanus (Muscle)	13( )41963	23.0	3.4	26.4	.50	A

Station Name	Species	Station Number	F1 µg/g	F2 µg/g	F1 & F2 µg/g	F1 & F2 mg/100g wet weight	Classification
Wings Neck	Homarus americanus (Hepatopancreas)	13( )41987	13.1	22.2	35.4	.90	B
Wings Neck	Homarus americanus (Muscle)	13( )41987	22.7	1.9	24.6	.48	B
Wings Neck	Homarus americanus (Hepatopancreas)	13( )41988	45.3	2.9	48.2	1.3	B
Wings Neck	Homarus americanus (Muscle)	13( )41988	4.4	.1	4.5	.08	B

Source: Energy Resources Company

APPENDIX G. DENSITY AND DIVERSITY

Approach

Density and diversity of organisms were calculated for the Buzzards Bay benthic samples. Density and diversity are two measurements frequently used to detect and characterize changes in benthic communities.

Density is a simple measure of the number of organisms per unit area of surface and can be translated as numbers of organisms occupying a given area of available habitat. The density of benthic organisms comprising the benthic communities of Buzzards Bay, or any aquatic environment, is expected to fluctuate above and below an equilibrium level. A goal of this study was to determine if the factors affecting observed density fluctuations were density-independent (independent of the size of the population) or density-dependent (dependent on the size of the population). Density-independent factors in Buzzards Bay include the Bouchard No. 65 oil spill, the severe winter, alterations of bottom substrate type, and other sources of pollution. Density-dependent factors are characterized by competition for food and predation.

While density is a measure of the effect of the environmental forces of Buzzards Bay upon the benthic community as a whole, species diversity is a measure of environmental forces upon the components of the benthic community, the species. The diversity (variety in numbers and kind) of species in a community can be expressed in the form of a numerical index called a species diversity index. This index is generally the ratio between the number of species and an important biotic value or measure (Odum, 1971). Examples of this biotic value are numbers of individuals, an importance value given to individual species according to the role they play in the community, biomass, or productivity. Species diversity values tend to be mid-range in physically stressed ecosystems or those subject to perturbations (e.g., poor weather, poor water circulation, and pollutants). Conversely, diversity indices in ecosystems not subject to stress tend to be either very high or very low. High values suggest the existence of a well developed food web and community stability; low values suggest the presence of a climax community.

Three diversity indices were applied to the EPA benthic data: Simpson's diversity index (D)[1]; Shannon-Weaver diversity index (H)[1]; and Margalef's diversity index (d). Each of these indices analyzes the characteristics of the community from a different viewpoint. Simpson's index is sensitive to changes in the dominant species in the community. The numerical value for Simpson's index increases with heterogeneity. The Shannon-Weaver index gives an indication of the evenness (decrease in dominance) and variety of species in the community, while the Margalef index (the easiest to calculate) is an indicator of the species richness (number of species) in the community.

It should be kept in mind that numbers generated by a species diversity equation do not, in themselves, have any meaning. These numbers only have meaning when compared on a temporal or spatial basis, or as indicators of a trend in combination with other types of measurements. In this study, the values gained from the density and diversity computations will be compared to determine if any changes occurred in the benthic community during the sampling period (February through June).

Results

Because of the aforementioned limitations of the sampling program, density and diversity values were calculated but could not be accepted without qualification. The following is an attempt to interpret calculated density and diversity values. The reader should not attempt to draw any impact determination from these results.

The density of each station is shown in Table G-1. The calculated results were achieved by dividing the total number of individuals per station by the area of the grab sampler and converted to a standard area. Because a variety of grab samplers were used, four surface area dimensions were applied.

TABLE G-1. DENSITY (NUMBER ORGANISMS/100 cm^2)

Station numbers	Sampling dates				
	2/77	3/77	4/77	5/77	6/77
1		72	153	24	113
2			37	311	58
4			35	130	85
13			110	47	19
14	21		26	148	53
15	48	19	27	42	15
16	192	64	313	125	51
17	22				
18	12				
19	10				
35			18	92	4
47					146
100			4	1	8
105		31	1	55	63
108			8	113	51
112		33	120	225	83
151		33	11	22	111
160			75	26	218
161			223	61	17
170					23
180					24

Results of the Margalef diversity index are presented in Table G-2. Results from the Margalef index are the only results presented because the Margalef index is the only index that is not significantly influenced by sample size. The Simpson and Shannon-Weaver indices are sample size dependent. These indices were calculated but are not presented herein.

TABLE G-2. MARGALEF DIVERSITY INDEX

Station numbers	Sampling date				
	2/4	3/9	4/21	5/24	6/20
1		3.9	3.7	2.9	3.3
2			2.0	3.6	3.5
4			1.6	3.8	2.8
13			6.4	4.8	4.1
14	5.0		3.4	6.4	4.1
15	2.0	2.0	3.1	2.3	2.3
16	NA*	5.1	5.5	6.1	5.4
17	NA				
18	3.0				
19	NA				
35			0.2	3.5	1.5
47					NA
100			0.0	0.9	0.7
105		1.7	1.7	3.2	3.9
108			2.5	4.1	2.9
112		2.6	2.1	2.8	1.7
151		3.8	3.6	4.7	5.0
160			2.3	2.1	2.7
161			4.9	5.1	4.7
170					2.1
180					NA

*NA = Not available

In general, the density of most stations showed no change, other than expected seasonal ones, throughout the sampling period. These seasonal changes were reflected in the shift in dominance from copepods and ostracods during the winter months to a more even faunal composition, dominated by polychaetes, amphipods, and bivalves, during the spring months. A slight increase in density is noted during the spring months.

For the most part, Margalef's diversity index also remained steady throughout the sampling period. A slight increase in the diversity index during the spring months corresponds to the increase in density values. This is also an expected phenomena because of the normal trend of the benthos toward evenness during these months. The absence of observable effects can either mean that there simply was no effect as a result of the spill or that the effects were not detected by the sampling survey.

APPENDIX H. ANNUAL AVERAGE SHELLFISH TAKE AND PERCENTAGE OF ANNUAL TAKE AFFECTED BY BED CLOSURES, BUZZARDS BAY STUDY AREA

TABLE H-1. ANNUAL AVERAGE SHELLFISH TAKE AND PERCENTAGE OF ANNUAL TAKE AFFECTED BY BED CLOSURES

	Bourne*		Falmouth*		Wareham**	
	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial
Quahog						
Average take (bushels)	1,379	2,016	4,523	7,000	10,000	1,300
% take affected, 1977	100%	100%	22%	11%	15%	15%
Soft clam						
Average take (bushels)	50	--	600	300	6,000	--
% take affected, 1977	100%	--	10%	23%	15%	--
Oyster						
Average take (bushels)	400	--	--	--	200	--
% take affected, 1977	100%	--	--	--	15%	--
Scallops						
Average take (bushels)	300	2,044	1,171	900	--	--
% take affected, 1977	100%	100%	27%	8%	--	--
Razor clam						
Average take (bushels)	--	--	--	--	50	--
% take affected, 1977	--	--	--	--	15%	--
Mussel						
Average take (bushels)	--	--	--	--	100	--
% take affected, 1977	--	--	--	--	15%	--

*1976 average take
**1975 average take

Source: Massachusetts State Department of Fish and Game

TABLE H-2. ESTIMATES OF TOTAL SHELLFISH CASH CROP FOREGONE DUE TO BED CLOSURES, FEBRUARY - DECEMBER 1977

	Quahog		Soft shell		Oyster		Scallop		Razor clam		Mussel	
	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial
Current value per bushel*	$ 10	$ 18	$ 25	$ 25	$ 18	$ 18	$ 20	$ 20	$ 45	$ 45	$ 5	$ 5
Number of seasons closed*	11/12	11/12	11/12	11/12	1	1	4/6	4/6	11/12	11/12	1	1
Number of bushels foregone per season												
Bourne	1,380	2,020	50	--	400	--	300	2,040	--	--	--	--
Falmouth	1,000	770	60	70	--	--	320	70	--	--	--	--
Wareham	1,500	200	900	--	30	--	--	--	8	--	15	--
Total	3,800	2,990	1,010	70	430	0	620	2,110	8	0	15	0
Total case crop foregone												
Bourne	12,650	33,330	1,150	--	7,200	--	4,000	27,190	--	--	--	--
Falmouth	9,170	12,820	1,380	1,600	--	--	4,270	920	--	--	--	--
Wareham	13,760	3,300	20,610	--	540	--	--	--	330	--	80	--
Total	$35,580	$49,450	$23,130	$1,600	$7,740	$ 0	$8,270	$28,110	$330	$ 0	$80	$ 0

*Source: Massachusetts State Department of Fish and Game (1977).

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-133	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CLEANUP EFFICIENCY AND BIOLOGICAL EFFECTS OF A FUEL OIL SPILL IN COLD WEATHER: The 1977 Bouchard No. 65 Oil Spill in Buzzards Bay, Massachusetts		5. REPORT DATE July 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Eric Schrier		8. PERFORMING ORGANIZATION REPORT NO. URS 7004-05-01
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		11. CONTRACT/GRANT NO. 68-03-2160
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This study was initiated following the 1977 Bouchard No. 65 fuel oil spill in Buzzards Bay, Massachusetts. Its major objectives were to evaluate the techniques used to clean up and/or mitigate damage from this spill and make recommendations of feasible alternative methods that may be used in future spills in similar environmental conditions; to inventory and evaluate EPA sampling techniques and problems; and to assess the environmental damage caused by the spill.

Because of the unusual ice and weather conditions at Buzzards Bay during and after the spill, much of the cleanup effort relied on methods and equipment rarely used before. Modifications of existing techniques are necessary if future spills in similar conditions are to be treated more successfully. Unlike previous No. 2 spills in the bay, acute biological effects were not observed. Long-term acute and sublethal effects may have occurred but could not be detected with presently available data. Severe biological damage was probably prevented by the entrapment of oil in both shore-fast and free-flowing ice.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Fuel oil	Buzzards Bay, Mass.	47A
Sea ice	Burning	47C
Gas chromatography	Vacuum skimming	48C
	Contaminated ice removal	68D
	Rope skimmers	
	Oil Spills	
	Benthic effects	
	Oil Spills - cleanup	

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