The ARGO MERCHANT Oil Spill: A Scientific Assessment

MESA Special Report

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

April 1979

MESA Special Report

The ARGO MERCHANT Oil Spill A Scientific Assessment

Barbara J. Morson

Marine EcoSystems Analysis Program
Boulder, Colorado

April 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Richard Frank, Administrator

Environmental Research Laboratories
Wilmot Hess, Director

Prepared by

Marine Ecosystems Analysis Program
Boulder, Colorado

Science Applications, Inc.
2760 29th Street
Boulder, Colorado
Under Contract No.:
NOAA 03-7-022-35105

EXECUTIVE SUMMARY

On 15 December 1976 at 0600 EST, the tanker ARGO MERCHANT, carrying 7.7 million gallons of No. 6 fuel oil, ran aground on Fishing Rip, 29 nautical miles (n mi) southeast of Nantucket Island, Massachusetts. The ensuing spill became one of the largest and certainly the most studied oil spill in U.S. history.

Intensive scientific activity surrounding this event began on 15 December 1976 and ended in mid-February 1977, with a lower level of activity continuing until the present time. Most of the scientific activity conducted on-scene was related to predicting the movement and fate of the oil to aid in assessing ecological damage caused by the spill. Ten physical trajectory models were tested to determine the direction of movement of oil and risk of contacting shore. Numerous samples of the oil slick, water column, and sediments were gathered to understand the eventual fate of the oil. In addition, samples of fish, plankton, benthos, and birds were gathered to study the impact of the spill on the biota in the area. Socioeconomic studies were carried out to determine the impact of the spill on the tourist and fishing industries in the Cape Cod region and to evaluate public awareness of the incident.

At the time of this writing, most research results have been reported (Center for Ocean Management Studies, 1978). A summary of the findings are presented below:

- The oil from the ARGO MERCHANT stayed, for the most part, on the ocean surface. Some amount of the "cutter stock" entered the water column and an undetermined amount of oil reached the sediments within a 15 km^2 area around the wreck site. Analyses of water column samples collected in December revealed petroleum hydrocarbon concentrations as high as 340 parts per billion (ppb); samples from January and February indicated levels near 20 ppb. Distribution of oil found in the sediments was quite patchy, probably due to the high degree of turbulent mixing on the shoals.
- Most of the oil moved offshore following the prevailing westerly and northwesterly winds. No oil was observed within 24 km of land or north of 41°21′N latitude; an estimated 7870 km^2 of ocean were involved. Modelling efforts were successful in predicting the general direction of movement of oil, but were less than successful in describing the actual limits or boundaries of the oil slick.
- Evidence of limited direct oil contamination was found in fish, zooplankton, shellfish, and ichthyoplankton, as well as bird populations. Mortality of cod and pollock eggs and embryos were observed in some samples and some cytogenetic changes in cod and pollock eggs were found.
- A few of the collections of fish and shellfish near the spill site revealed a number of physiological changes in tissues of these organisms, and a depression in oxygen consumption rates during December and January. However, there is no *direct* cause and effect relationship which can be established between these physiological changes and the ARGO MERCHANT oil spill.
- Oiled birds were seen principally in the area of the wreck site; primary species oiled were Herring and Black-backed Gulls. Necropsies of birds washed ashore revealed that the lungs and kidneys were the major organs affected.
- There is little evidence of any acute impact on the New England fishery from the ARGO MERCHANT spill. No major loss of income was sustained among commercial fishermen during the incident and fisheries data from 1977 indicate, if anything, a slight elevation in amounts of fish landed. Other environmental variables may mask any effects on the Nantucket Shoals and Georges Bank ecosystems.
- Tourism in the Cape Cod area suffered no measurable losses due to the ARGO MERCHANT spill. Volume of trade and income earned in 1977 was as good or better than that of 1975 and 1976.
- Public perception of the spill and its impact was quite variable. Public interviews indicated that approximately 70% of the residents of Cape Cod were uninformed or poorly informed about the spill, but many blamed the ARGO MERCHANT spill for elevated fuel prices or increased fish and shellfish prices. Many were worried that the spill would threaten summer tourist business or future recreational fishing interests.
- An evaluation of Federal agency response and coordination efforts during this spill indicates the need for improvement in the mechanisms for providing scientific assistance to those involved in containment and clean-up following a major spill incident.

The assessment of environmental damage resulting from the ARGO MERCHANT oil spill has continued through two programs within the Federal Government. The Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP), an ongoing program under NMFS/NOAA that monitors productivity of fish stocks, will continue to attempt to determine whether any changes in fish stocks can be correlated with the ARGO MERCHANT spill. Energy Resources Company in Cambridge, Massachusetts, conducting physical, chemical, and biological studies in the Georges Bank region for the Bureau of Land Management's Outer Continental Shelf Program, has continued to study this area, noting any gross changes in the environment that may be due to ARGO MERCHANT oil.

It appears from what is known about the distribution and activities of the biota in the Northwest Atlantic that had the spill occurred later in the winter or early spring or during a period of onshore winds that the effects would have been more severe. It was fortunate that this spill occurred in a period of generally low biological activity in combination with a long period of offshore winds.

In summary, the results of studies to date in no way *conclusively* demonstrate the existence of any significant acute impact on the marine ecosystem from the ARGO MERCHANT oil. While effects on some species have been observed in the field and demonstrated in the laboratory, there is no way at this time to extrapolate these effects to the marine ecosystem as a whole. Indeed, results *seem* to indicate whatever the impact might have been, it was within tolerable limits for most species. Too little information is presently available to make any long-term predictions about the impact of the ARGO MERCHANT oil on the Georges Bank/Nantucket Shoals ecosystem.

ACKNOWLEDGEMENTS

I would like to acknowledge the following persons for their contributions to this report: Tim Wyant and Dick Smith, at USGS in Reston, for their time in helping me understand their trajectory model; Andy Pollack, from whose Masters thesis much of the Physical Modelling section is taken; Peter Fricke, who contributed the socioeconomic section; Ben Baxter, who contributed to the orginal manuscript; and to all the authors of papers presented at the "In the Wake of ARGO MERCHANT" Conference held at the University of Rhode Island in January 1978.

I would like to thank Jerry Galt, Carl Eidam, John Robinson, Jean Snider, and Paul Lefcourt for taking time to review and edit the manuscript and for providing valuable suggestions for improvement, and Debbie Geolfos, Sandra Novotny, and Peggy Ann Lloyd for their patience in typing and retyping and more typing. I would also like to acknowledge the Environmental Protection Agency for contributing funding for this project.

A special thanks goes to Jean Snider and John Robinson for their support through some particularly difficult times near and beyond deadlines.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AEC	Atomic Energy Commission
BLM	Bureau of Land Management
CEDDA	Center for Experimental Design and Data Analysis
DHEW	Department of Health, Education, and Welfare
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
DOT	Department of Transportation
EPA	Environmental Protection Agency
GC/MS	gas chromatography/mass spectroscopy
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program
MIT	Massachusetts Institute of Technology
NCP	National Contingency Plan
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRT	National Response Team
NWS	National Weather Service
OEP	Office of Emergency Preparedness
OSC	On-Scene Coordinator
RRT	Regional Response Team
SSC	Science Support Coordinator
SOR Team	Spilled Oil Research Team
URI	University of Rhode Island
USCG	U.S. Coast Guard
USCG R&D Center	U.S. Coast Guard Research and Development Center
USGS	U.S. Geological Survey
WHOI	Woods Hole Oceanographic Institute

1. INTRODUCTION

1.1 Purpose of Report

This report provides a final analysis and evaluation of the scientific investigations conducted by various Federal, state, and private agencies following the ARGO MERCHANT oil spill in December 1976. It documents physical, chemical, and biological investigations, as well as research into the socioeconomic effects of the spill. In addition, Federal response efforts are evaluated and recommendations offered for improving future efforts.

Research conducted during the spill incident was largely an ad hoc, or at least marginally planned, effort. At that time, no contingency plans existed for coordination of a scientific response to a major oil spill. It is hoped that through the presentation of results and evaluation of the investigations, as well as concentrated efforts towards planning, should another major spill incident occur, significant improvements will be seen in the scientific response effort.

1.2 Chronology of Events

Key events surrounding the scientific activity concerned with the spill are summarized below (Grose and Mattson, 1977). Hours are Eastern Standard Time.

15 December	The ARGO MERCHANT runs aground on Nantucket Shoals. Distress call is received by USCG at 0700. NOAA-USCG SOR Team arrives and commences scientific coordination at 2100.
16 December	All personnel are evacuated by USCG at 2300. USCG, under the Intervention Convention, assumes full responsibility and control for ARGO MERCHANT.
17 December	Coordination meeting is held at WHOI to develop scientific response.
18 December	Large amounts of oil are spilled. Heavy oil plume 12 km long moves to the northwest. USCG sights oil "pancakes" 43 km east of ship.
19 December	Approximately 1.5 million gallons are reported spilled.
20 December	WHOI vessel OCEANUS begins cruise 19.
21 December	ARGO MERCHANT splits aft of kingpost, releasing 1.5 million gallons of oil into heavy seas. OCEANUS, having gathered sediment and water samples, returns to Woods Hole due to weather.
22 December	*ARGO MERCHANT bow section splits again. USCG EVERGREEN and NOAA vessel DELAWARE II (DE 76-13) depart for scientific cruises. EPA administrator calls scientific meeting in Boston.*
23 December	U.S. Navy divers take movies of underside of slick and bottom sediments; underside of slick is mostly smooth.
24 December	*DELAWARE II completes cruise.*
25 December	Onshore wind forecast.
26 December	Three thousand drift cards are deployed in front of slick as early warning system as onshore winds continue.
27 December	EVERGREEN cruise ends. OCEANUS cruise 20 begins. First attempt to burn oil is undertaken.
28 December	ENDEAVOR cruise (ENOO2) begins.
29 December	Bow section begins moving due to currents. OCEANUS cruise 20 ends. ENDEAVOR cruise ends.
30 December	Bow section capsizes and moves 400500 m southeast of stern.
31 December	Second experiment to burn oil begins. Attempt to sink bow section with 20mm cannon fire fails. Spill now stretches 225 km in a southeasterly direction from the wreck site.
3 January	Scientific coordination meeting is held at WHOI.
4 January	Coordination meeting continues. DELAWARE II cruise (DE 77-01) begins.
9 January	Bow section is completely underwater.
10 January	DELAWARE II cruise ends.
12 January	Long-range oil mapping flight is made by NOAA and USCG personnel.
19 January	Public meeting concerning dispositon of bow section is held in Falmouth.
26 January	ENDEAVOR cruise (ENOO3) begins.
27 January	Long-range mapping flight reports no sighting of oil.
29 January	ENDEAVOR cruise is terminated due to weather.
8 February	Bow section is relocated and found empty of oil. ENDEAVOR cruise (ENOO4) begins.
11 February	Oil is found in sediments near bow section.
12 February	ENDEAVOR cruise (ENOO4) ends.

2. PHYSICAL AND CHEMICAL INVESTIGATIONS

2.1 Transport and Biochemical Transformation of the Spilled Oil

During essentially the entire period of leakage from the vessel, winds and currents transported oil from the ARGO MERCHANT southeasterly and away from shore. During the first few days following the spill, the slick movement was dominated by tidal currents in the area of Nantucket Shoals, producing a horseshoe-shaped slick near the wreck. Oil was then carried offshore as large "pancakes" and sheen to the southeast. Overflights carried out by USCG personnel tracked the oil until 8 January. On 13 and 27 January, a NOAA C-130 aircraft completed long range flights to determine as far as possible the extent of the oil. Results of the overflight program indicated overall limits of possible contamination as indicated in Figure 2.1. The trapezoid-shaped oil slick covered an estimated area of 7,870 km^2 (3,040 mi^2) and extended 250 km east of the wreck. The final extent of contamination by the ARGO MERCHANT oil is unknown.

Nine cruises between 20 December 1976 and 10 January 1977 (Figure 2.2) gathered water column samples. Analysis (using fluorescence spectroscopy) of these samples revealed that the highest petroleum hydrocarbon concentrations were found 10 feet (3.04 m) below the slick with values of up to 340 ppb. The oil found in these samples was probably the "cutter stock," which represented about 20% of the cargo. Samples taken during the ENDEAVOR cruises ENOO3 (26-29 January) and ENOO4 (8-12 February) included surface samples and water column samples at six meter depths and near the bottom. None of these samples revealed petroleum hydrocarbon levels higher than 20 ppb.

In February, May, August, and November 1977, and February 1978, large volume water samples were collected in the Nantucket Shoals/Georges Bank area, by ERCO, Cambridge, Massachusetts, under contract to BLM. At 12 stations, near-surface and bottom samples were taken, and using GC/MS techniques and glass-capillary/gas chromatography, the composition of particulate and dissolved fractions was determined (Boehm *et al.,* 1978).

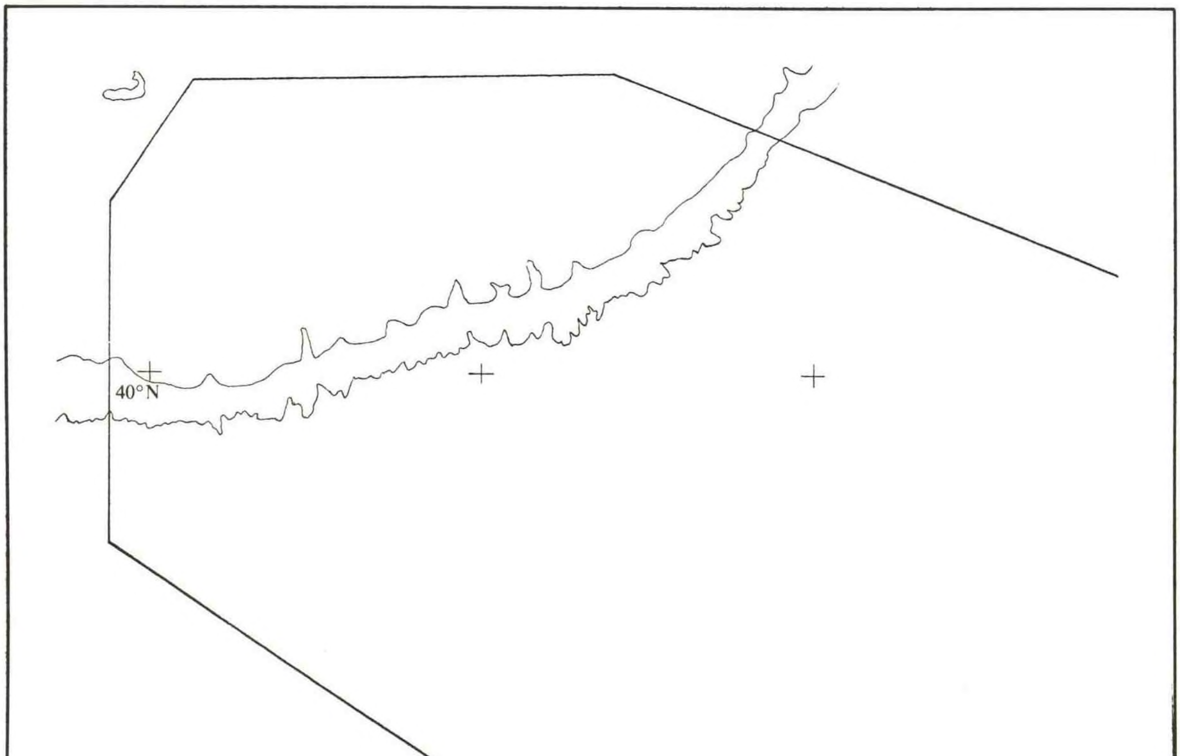

Figure 2.1. Estimated oil slick boundaries for entire period ARGO MERCHANT spill was tracked.

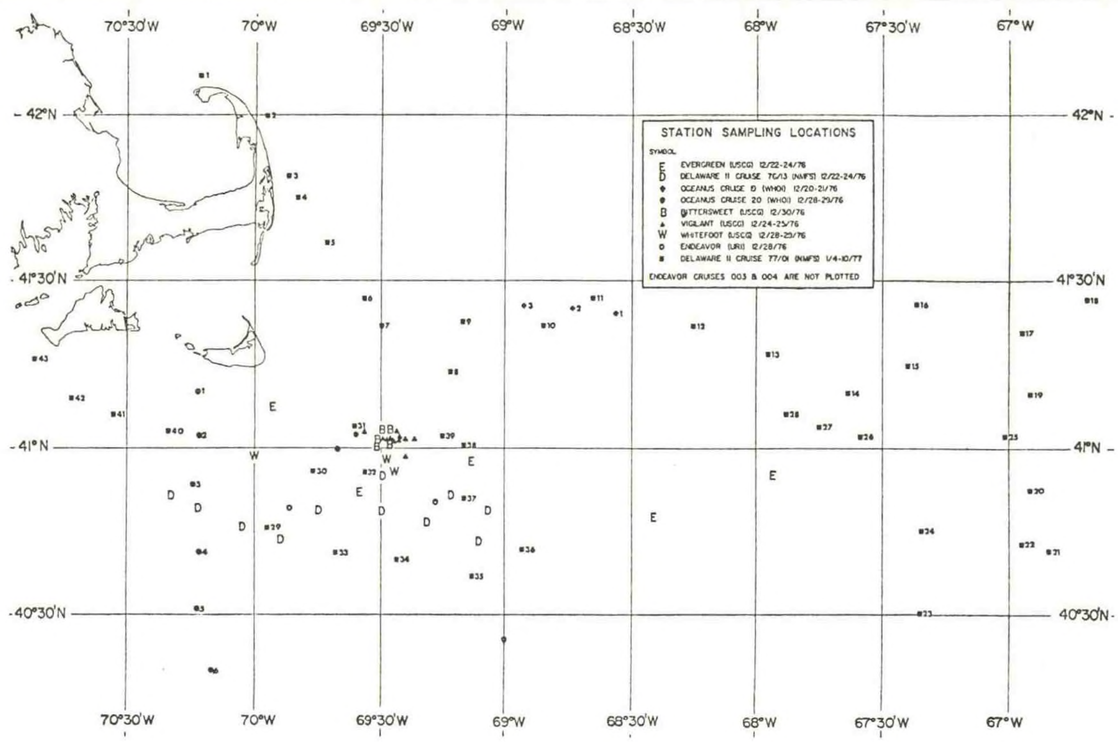

Figure 2.2. Water sampling locations.

In winter 1977, concentrations throughout the area ranged from 10-100 ppb total dissolved hydrocarbons ($\overline{x}$ = 44 ppb). In spring 1977, these concentrations ranged from 1-50 ppb ($\overline{x}$ = 11 ppb) and for the rest of the year levelled off to 1-20 ppb. Winter of 1978 showed markedly lower levels of total dissolved hydrocarbons (0.2-2.3 ppb, $\overline{x}$ = 0.42 ppb) than the winter of 1977.

In addition, water samples were gathered to determine whether oil had become entrained as droplets in the water column (Cornillon, 1978). In the 311 *l* of water analyzed, only nine oil droplets were found. These results are inconclusive, because samples were collected some seven weeks after the spill in an area where there was no visible oil. Turbulent mixing would have accounted for rapid dispersal of any oil droplets which had become entrained. However, reports from observations made by divers swimming beneath the slick (23 December) indicated that the lower side of the slick was smooth, with no visible oil droplets mixing into the water column.

Sediment samples were collected in December 1977, and in January, February, and July 1978, during a number of cruises. Samples collected on ENDEAVOR cruises were screened for the presence of oil using thin-layer chromatography and ultraviolet fluorescence techniques. Selected samples were then sent to the NOAA National Analytical Facility in Seattle for GC/MS analysis to determine whether the petroleum hydrocarbons in the samples were actually ARGO MERCHANT oil.

During the initial sampling (December-February), oil found at Stations G-43 (between the bow and stern of the vessel) and D-36 (11 km to the southwest) (Figure 2.3) showed a resemblance to ARGO MERCHANT oil based on GC/MS analysis. The sample from Station G-43 contained 10-100 ppm oil per cm^3 of wet sediment. All other samples contained less than 1.0 ppm oil. Data from Bumpus (1973) and the limited data from a URI bottom drifter study following the spill (Collins *et al.*, 1978) showed that bottom currents in this area do move toward the southwest. Most of the oil found in these samples was in the form of minute tar particles mixed in with the sand grains. Box core samples in this region were contaminated to a depth of 8-13 cm, but depth of contamination was not uniform. Because sampling was restricted to these depths, it was not possible to determine how much deeper oil contamination may have extended into the sediments.

Stations that had been found to contain high levels of petroleum hydrocarbons were reoccupied in July 1977. Only the sediments near the bow site were contaminated (0.6 ppm), and these levels were significantly lower than those found at that site in February.

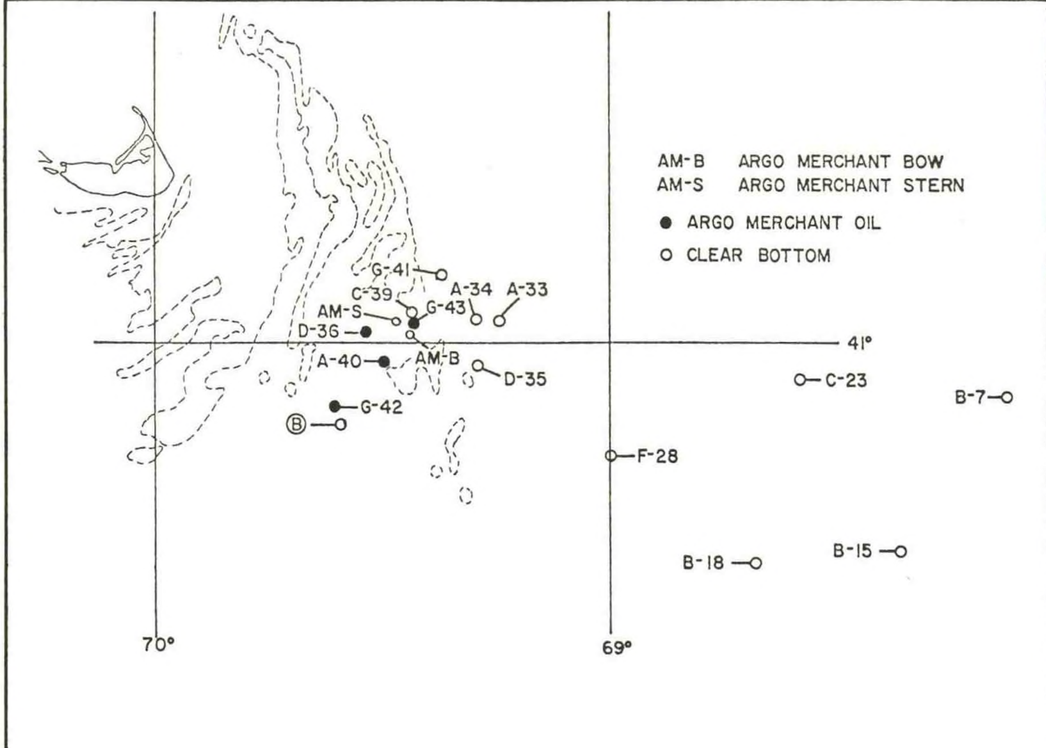

Figure 2.3. Locations and results of sediment sampling.

Overall, there was a great deal of areal patchiness, both horizontally and vertically, found in the oil contaminated sediments. This was attributed to the large amount of water and sediment movement at and around the wreck site. The lower levels of hydrocarbons found in the area in July may have been caused by chemical, physical, and biological degradation and/or from movement of sediments out of the area or vertical shifting of sediments. Oil may have been originally carried to the sediments by the movement of the ship's bow section along the bottom or mechanical mixing of oil, water, and sediments.

No studies of biochemical transformation were carried out on any oil samples gathered during the spill, nor were there enough fresh oil samples collected from the tanker to perform artificial weathering studies. Too little information was obtained with respect to oil transport through the water column and into the sediments to do anything other than speculate on the mechanisms involved in its deposition. It is hoped that, in the future, more care will be taken in securing an adequate number of samples for these types of analyses.

2.2 The Modelling Effort

In all, ten trajectory models were run during the ARGO MERCHANT spill. Only two models were run in a forecast mode in real time (by the USCG Oceanographic Unit and the USCG R&D Center). There were five risk assessment models run, and an additional probabilistic forecast made using Bumpus' (1973) drift bottle data. Many of these models were also eventually run in a hindcast mode for verification. In addition, one model was run solely in the hindcast mode (Tingle and Dieterle, 1977).

Table 2.1 contains a summary of these models. As can be seen, they have many features in common. All deal exclusively with two-dimensional advection; none includes slick dissipation, even as a sink term (*i.e.*, reducing the volume of the surface slick by paying no attention to where the oil goes after it leaves the slick).

Unresolved wind, wave, and current effects were generally represented by applying time series winds with a drift factor, leading to a statistical scatter in the trajectory end points. The various models differed in their source of wind data (climatological, real time, *etc.*) as well as in the selection of drift factor coefficients. None of the models explicitly considers wave-induced motion. Perhaps the only new feature in any of the models was the USCG Oceanographic Unit's modification of the wind effect factor to 1.2%, measured on-scene, in addition to the surface current.

Table 2.1. Summary of models used during ARGO MERCHANT spill response (after Grose and Mattson. 1977)

Model	Type	Time Step	Initial Position of Oil	Advection: Winds: Source	Advection: Winds: Effect	Advection: Winds: Tides	Advection: Source of Currents: Measured	Advection: Source of Currents: Calculated	Probability Generation
USCG Oceanographic Unit	Fore-cast	3 hours	Recent slick maps; ARGO MERCHANT	On-scene observations; NWS and Navy forecasts	1.2% of wind speed at 0° relative	Haight (1942)	Residual current backfit or estimated	Ekman-wind induc-surface current (Jelesnianski, 1970)	
USCG R&D Center	Fore-cast	1 hour	Observations: previous predictions, ARGO MERCHANT	On-scene observations; new 6-hourly forecasts	3.5% of wind speed at 0° relative	Tide Table			
USGS	Risk	3 hours	ARGO MERCHANT	5-year monthly historical records from Georges Bank and Nantucket Shoals Towers; on-scene observations	3.5% of wind speed at 0° relative		Mean monthly from Bumpus (1973)		Multiple trajectories using lag-one Markov matrices
URI	Risk	3 hours	ARGO MERCHANT	10-year monthly wind rose (U.S. Naval Weather Service Command, 1970)	3.5% of wind speed at 0° relative	Navigation charts (only some runs)			Multiple trajectories using Monte Carlo method
CED-DA	Risk	3 hours	ARGO MERCHANT	15-year record from Nantucket Lightship	3.5% of wind speed at 15° to right of wind		None and uniform current from WHOI Station D (0.25 kts at 270°		Multiple trajectories using historical record directly
USCG Oceanographic Unit	Risk		Ellipse around ARGO MERCHANT corresponding to tidal excursion	U.S. Navy summary of synoptic meteorological observations for Quonset Point area					Probability of oil going in any direction (any distance) equated to % of time wind blows that way
URI Bottom Trajectory	Risk	1 day	Various pts in vicinity of ARGO MERCHANT				Mean monthly from Bumpus (1973)		Multiple trajectories using same current but different starting points
USGS Long Range	Risk	1 day	Position of NOAA Satellite-trackable bouy	Monthly wind roses from U.S. Navy Marine Climatic Atlas for North Atlantic (Reserve, 1974)	3.5% of wind speed at 20° to right of wind		Mean currents from Marine Climatic Atlas (Reserve, 1974)		Multiple trajectories using Monte Carlo Method
Oceanographic Unit-Long Range	Risk	1 month	65°N, 40°W (slick leading edge on Jan. 1)	Mean monthly currents from U.S. Navy Marine Climatic Atlas	1.2% of wind speed at 0° relative		Mean monthly currents from Oceanographical Atlas of North Atlantic Ocean (Navy)		
Brookhaven National Laboratory	Hind-cast	1 hour	ARGO MERCHANT	Nantucket Lightship	3% of wind speed at 0° relative			Depth averaged finite difference model	

2.2.1 On-Line Forecast Models

The accuracy of the USCG Oceanographic Unit's on-line forecasts can be judged from Figure 2.4. This figure compares the forecast slick with the observed slick for 22 and 23 December, the days immediately following the tanker breakup. The forecasts can at best be called erratic. On some days (*e.g.,* 22 December), the model came fairly close to predicting the observed oil configuration; on other days it was quite inaccurate. The model was generally poor for prediction of the exact shape of the slick and the location of patches. It was somewhat better in predicting the more general slick limits, although in this too it was erratic (*e.g.*, the 23 December limits were 48 km too long). At other times, oil was found outside the limits; this occurred to some degree on all days the model was run.

It is instructive to review the possible sources of error in the forecasting. One error that cannot be adequately judged at present is the error in the model formulation itself, in other words, how much the forecast would be off even if it had accurate input (*e.g.*, wind and current) data.

Other errors arise from the overall on-line modelling and mapping system by which winds, currents, and slick positions were supplied and used. The forecasts were made for 12 or 24 hours ahead, starting from essentially new slick positions each time a new map was received. The modeller would hindcast from the previous day's map using observed winds and then forecast ahead one day using forecast winds. One possible explanation for the disagreement between the forecast and observed slick is that the maps of the observed slick were in error due to the huge area encompassed by the oil after the first few days. Because an observer could not simultaneously view all boundaries of the slick, a distortion would be found in its mapped shape. Thus, the forecasting model would have had an automatic error input. There would be no way to prevent this error other than by hourly or daily high-altitude photography such as was done by NASA on 19 December.

Another error lies in the treatment of the residual current, which could not be adequately measured at the time of the spill. Many of the models included a residual (*i.e.*, long-term tidally averaged) current, but there was general disagreement as to what this current should be. The CEDDA model used a current of 0.25 knots to the *west*, the USCG Oceanographic Unit 0.25 knots to the *northeast*. The USGS model used data from Bumpus (1973), indicating a 0.8 knot flow to the *northwest*, and Grose and Mattson (1977) report a current of 0.6 knots to the *southeast*.

The major source of error was in the wind forecasts. Grose and Mattson (1977) present some data on wind forecast errors. Roughly, winds forecast 6 hours in advance were in error by an average of about 6 knots in speed and 35° in direction. In 24-hour forecasts, they were off by 7 knots and 40°. About 10% of the forecast winds were off by more than 90°, and 10% by more than 15 knots. It is clear that wind errors account for some of the significant errors in the oil forecast. The 21 December forecast was invalidated by an unexpected change in wind direction. Barring improvements in wind forecasting, the best way to circumvent this problem would be to update the forecasts as often as possible, substituting the most up-to-date forecast and observed winds.

In summary, the on-line forecasting model was only useful in giving a general idea of the limits of spread of the oil and the general direction in which it was headed. If the oil were headed toward shore, this model may not have been sufficient to assist the OSC in placement of clean-up equipment and personnel.

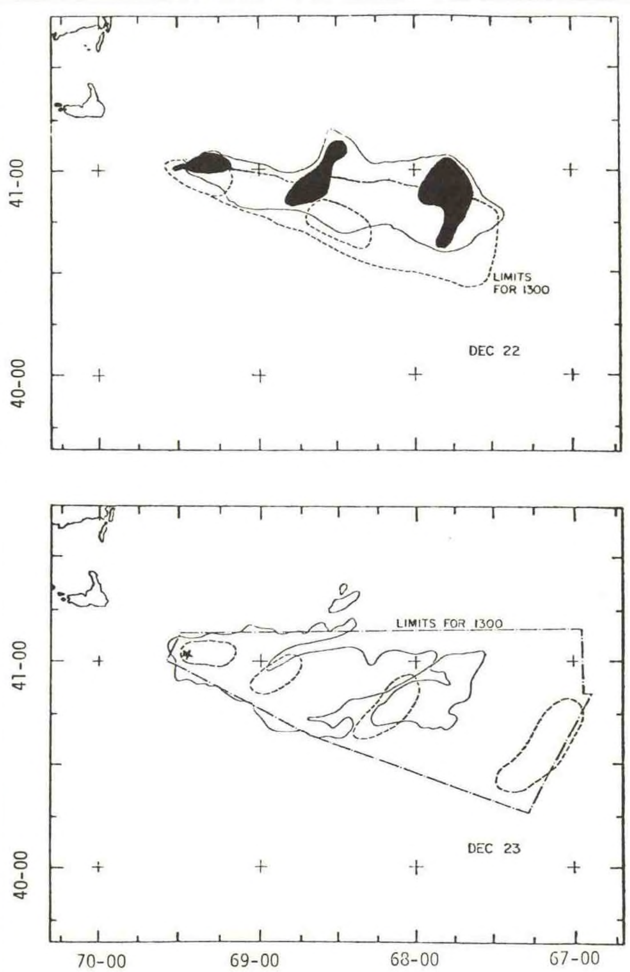

Figure 2.4. Comparison of USCG Oceanographic Unit's on-line forecast with observed slick (———). Dashed line (---) shows actual model forecast; the dot-dashed line (- · - · -) shows the slick limits which were to containg all surface oil (From Pollack, 1977).

2.2.2 Risk Assessment Models

Unlike the forecast models, risk assessment models are designed to look at long-term averages of spill movement based on regional climatology. The risk model therefore cannot be judged by the accuracy of its predictions compared with the actual path taken by the ARGO MERCHANT oil. While all the models predicted a high probability of the subsequently observed southeasterly oil drift, this in no way "confirms" the models, just as a landfall of oil would not have disproved them. Some assessment is possible, however, of the stochastic components of the models used.

There are several aspects of the stochastic component that are important. First, the data base used for the model should be as site-specific and time-specific as possible. A model based on historical winds for the entire east coast is clearly less desirable than one based on Nantucket Lightship winds, and monthly data are preferable to seasonal data, providing there are enough to be statistically meaningful. Data gathered over a long period of years are also desirable. Finally, if possible, the data should be specific for other particular conditions of the spill. For instance, the winter of 1976 was widely heralded as anomalous for its extreme cold, extreme snowfalls in the east, and drought in the west, signalling some departure from normal climatic conditions. Had such anomalies occurred at other times in the past, it may have been desirable to use data from only those winters, rather than from all winters, again subject to the *caveat* that a sufficient data base is available.

A second consideration is the manner in which the data are used to generate probability distributions. The first step in this process is to develop a time series or history for the winds. This may be done by using actual hourly observations or by using statistically derived series from historical observations. A review of these methods may be found in Stolzenbach *et al.*(1977); generally desirable features for time series include longer memory and small time steps, again providing a sufficient data base is available. The third consideration in the stochastic component involves the methods used in estimating the actual probabilities of various risks. The probability of landfall may be sensitive to the length of time each trajectory is followed. Estimated landfall probability may also be increased by modelling continuous rather than instantaneous spills (Wyant *et al.*, 1977).

The summary of the models in Table 2.1 shows that no *one* model is superior in all respects. The chief shortcoming of the USCG Oceanographic Unit model is its neglect of the persistence of the wind. It is assumed that oil released during an onshore wind will come ashore. The result of this is that probabilities of oil impacting the shore may be grossly overestimated during the seasons of the year when the prevailing winds are offshore. In the URI Monte Carlo surface current model, winds are randomly sampled so that the probability of obtaining a given wind direction and speed will be equal to the probability that such a wind would be observed in the appropriate month over the last ten-year period. This procedure is repeated every two hours; thus, this method of running the model includes no memory and is unresponsive to longer term wind conditions. The one-step memory employed in the USGS model enables the use of observed winds for the initial wind, thereby updating its probability assessments. This capability may be important in a situation where the oil was headed onshore, because the ability to update would increase the usefulness of the model in predicting the geographical area of impact. The CEDDA model uses historical wind records from Nantucket Lightship and thus had site-specific time series for the wind, rather than Georges Bank and Nantucket Shoals data such as USGS used; however, it uses a current (0.25 knots at 270°), which is not seasonally responsive.

Conceptually, all the models considered the oil as Lagrangian particles advected by the currents and with a differential oil/water velocity related to the wind. Differences arose in the sources of wind data (stochastic models, climatological wind series, or real-time winds) and for the advecting current field and wind factors. The advective current fields were externally specified and were either a general mean current, a predicted tide, or a correction term based on error estimates in the last model up-date. The wind drift factor was intended to represent the net effect of Ekman currents, Stokes drift, and momentum transfer by waves. In general, the models reflect wind-dominated transport of oil, and real-time winds coincided fairly well with climatologically derived wind. Thus, the models behaved similarly, and it is difficult to evaluate the relative accuracy of each model (Grose and Mattson, 1977).

Several of the risk assessment models considered *seasonal* changes in oil trajectories for the ARGO MERCHANT site. In general, spring and summer were the seasons when the shore was considered to be most vulnerable, but probabilities varied widely (Figure 2.5). Had the oil been headed toward shore, or had any oil been left in the ship, there may have been great differences in decisions made by the Federal OSC and the scientific community, depending on which model they used to evaluate the situation.

Again, it is difficult to assess whether any one of the assessment models was more accurate than any other. For winter, all the models predicted a general southeasterly drift, and most of them (the CEDDA model with no current is an exception) predict higher probabilities of shore impact in spring and summer than other seasons. A discussion of relative risks to resources in various seasons based on the USGS model is contained in Section 3.5.

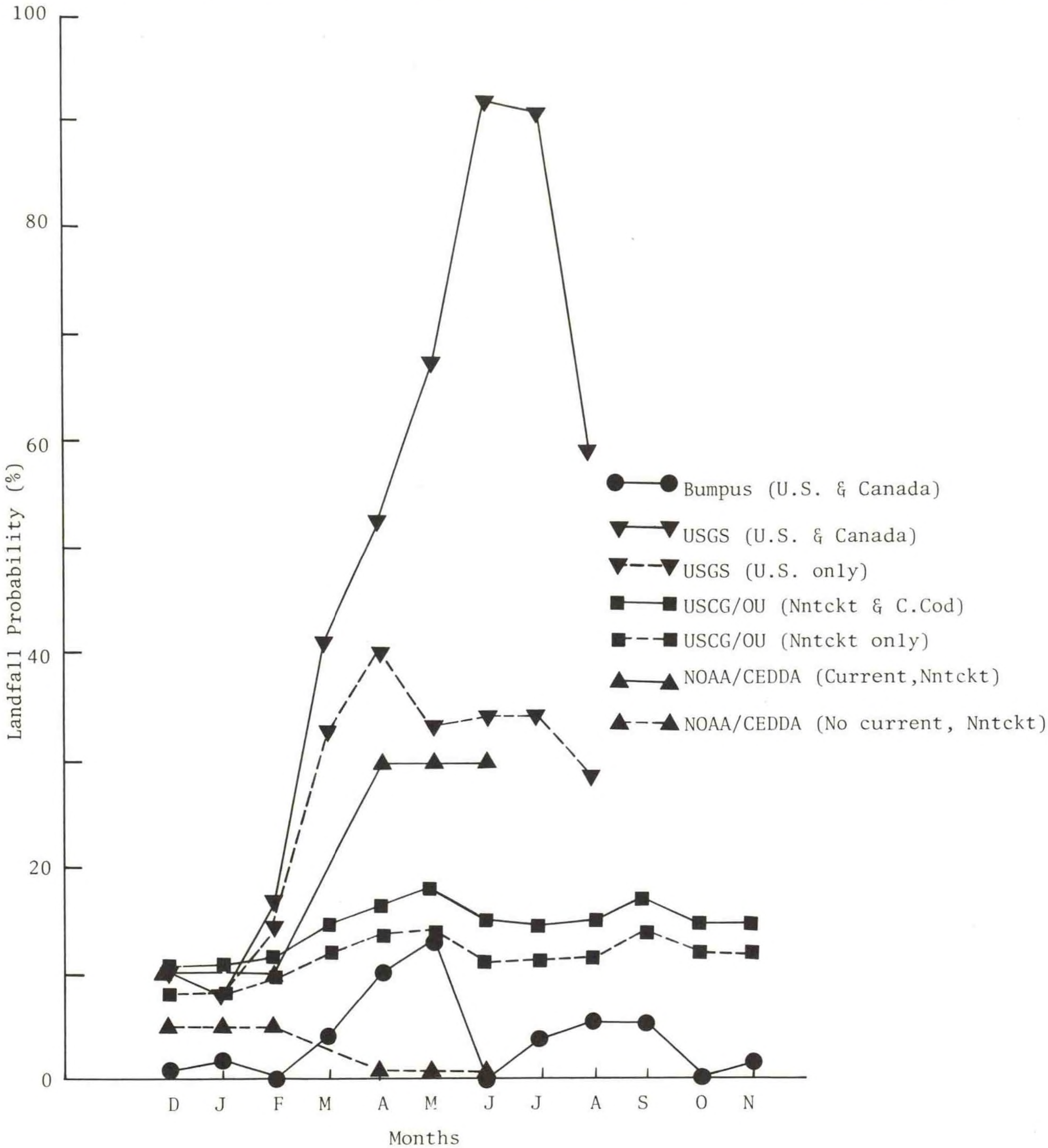

Figure 2.5. Monthly landfall probabilities calculated by various trajectory models.

3. BIOLOGICAL STUDIES

After the spill, intensive biological studies took place from late December 1976 to July 1977, with data from regular monthly NMFS cruises (MARMAP) being used after July. Due to the adverse weather conditions during the winter, sampling was neither of the desired quality or quantity. It should be understood that results of these studies should not be used to demonstrate conclusively the existence of and/or magnitude of impact to the marine ecosystem from this spill. The results do seem to indicate, however, that whatever impact there might have been, it was within tolerable limits for most species. In other words, no catastrophic die-off of any species was noted. We do not have enough information to make any predictions concerning the persistence of this oil in the sediments surrounding the wreck, or the amount of oil entering the biological components of the ecosystem; nor can we understand, at this time, the possible implications of oil entering the food web.

3.1 Fish

A total of 66 specimens of seven species of adult fish collected on DELAWARE II cruises (DE 76-13 and DE 77-01) were sent to the NOAA, National Analytical Facility, Seattle, Washington, for gas chromatographic analysis. Two samples of cod (*Gadus morhua*) stomachs (DE 77-01, stations 38 and 29) contained oil resembling ARGO MERCHANT oil. In addition, oil in a windowpane flounder (*Scophthalmus aquosus*) stomach from DE 76-13, station 4, contained oil similar to that of the ARGO MERCHANT (MacLeod *et al.*, 1978). Note that both stations 4 and 29 (DE 77-01) were in areas never crossed by the slick; in fact, station 4 was northwest of the wreck near Nauset Light, Cape Cod, Massachusetts.

Four other fish collected and analyzed showed evidence of oil contamination that did not match ARGO MERCHANT oil, indicating other sources for petroleum hydrocarbon contamination. Overall, 5% or less of the specimens examined contained oil similar to the ARGO MERCHANT. Due to location of these contaminated individuals (*e.g.*, Nauset, Massachusetts, 80 km northwest of the wreck site), it is difficult to make any conclusive statement concerning the impact of ARGO MERCHANT oil on individual adult fish.

Commercial catch statistics from Sherman and Busch (1978) indicate that catches of cod, sea scallops (*Placopecten magellanicus*), and winter flounder (*Pseudopleuronectes americanus*) in the area of the spill did not decrease during January-June 1977 from the previous two years (1975 and 1976). Indeed, catches of scallops and cod appear to be higher. These catch data are based on a 3600 mi^2 area bounded by 40° and 41° N latitude and 70° and 69° W longitude (*i.e.*, southeast of the wreck). While not corrected for fishing effort, these data are useful for a general indication of trends (see Table 3.1).

Bottom trawl surveys are conducted by the NMFS/Northeast Fisheries Center semi-annually to monitor changes in abundance of fish stocks. No dramatic changes in stocks of sea scallops, cod, or yellowtail flounder (*Limanda ferruginea*) were seen in 1975 through 1977, although yellowtail flounder did decrease (Sherman and Busch, 1978). These three species are widely distributed over the survey area, probably enhancing the chances for survival from any potential pollutant impact.

The six species of fish collected during the spill included sand launce (*Ammodytes americanus*), cod (*Gadus morhua*), pollock (*Pollachius virens*), rockling (*Enchelyopus* spp.), hake (*Urophysis* spp.), and herring (*Clupea harengus*). Only sand launce were collected in any abundance. Numbers of sand launce collected in bongo tows decreased sharply within the spill zone and increased near the periphery of the slick. Neuston tows also showed a decrease in sand launce near the spill zone (Figure 3.1). It is unknown whether these decreases are due to the impact of the oil on larvae viability or simply the "patchiness" characteristic of larval distributions. Analysis of the 1977 NMFS data indicates that there has been little change in sand launce populations in New England waters over the last four years (Sherman and Busch, 1978).

Collections of fish eggs on DELAWARE II cruise 76-13 in December 1976 contained only cod and pollock. In general, pollock eggs were found nearer the wreck site, while cod eggs were concentrated on the periphery of the spill area (see Figure 3.1). At station 9, the chorion of most of the pollock eggs was coated with oil (94% of 43 eggs) and some cod eggs were fouled (60% of 55 eggs). Assays of mortality and moribundity (embryos that had ceased mitotic division) are shown in Table 3.2 (Longwell, 1977). Pollock mortality was lower at station 8, inside the slick, than at station 9. Station 9 may have been in an area of sheen fed by the slick, potentially more toxic to eggs than the heavy oil slick at station 8. Overall, fewer cod eggs were fouled than pollock eggs. Because many of the cod eggs were at earlier developmental stages than pollock eggs, it was expected that mortality would be higher in the cod eggs. It is unknown why this did not occur (Longwell, 1978).

The lack of an adequate baseline for known natural mortality of fish eggs, in combination with the extremely small sample sizes, makes it impossible to adequately assess the impact of ARGO MERCHANT oil on fish eggs. Drastic mortalities could have resulted if eggs were concentrated in the spill zone and if the toxic lighter ends of the oil mixed into the water column in large concentrations.

Alewives (*Pomolobus pseudoharengus*), yellowtail flounder, winter flounder, herring, and haddock were collected for biochemical analysis. Serum sodium and osmolality were depressed in yellowtail flounder from oil impacted areas; winter flounder sodium was elevated (osmolality was not measured) (Table 3.3). Alewives and herring from impacted and clean areas showed no differences in sodium, potassium, or osmolality (Table 3.3). Haddock from oil-impacted areas showed depressed sodium, potassium, and serum osmolality (Table 3.3) (Thurberg *et al.*, 1978). Sample sizes were too small to permit good statistical analysis so that, while possibly indicating some stress on these animals, too little is known about these physiological parameters to make any general statements concerning severity of impact.

Table 3.1. Abundant fish species in the Nantucket Shoals - Georges Bank area* (from Sherman & Busch, 1978).

	SPILL ZONE (Metric Tons)			TOTAL AREA (Metric Tons)		
	Apr-Dec 1975	Jan-Dec 1976	Jan-Jun 1977	Jan-Dec 1975	Jan-Dec 1976	Jan-Jun 1977
Cod	5,260	5,742	3,394	15,227	14,213	10,911
Yellowtail flounder	1,203	1,333	327	16,986	14,515	4,918
Winter flounder	1,932	1,547	727	5,955	4,601	3,050
Sea scallops	2,086	5,753	8,011	7,556	14,725	14,375
Pollock	333	641	634	2,979	3,843	2,278
Haddock	369	416	329	3,986	2,894	3,006
Silver hake	282	175	10	6,584	6,407	806
Redfish	209	119	53	3,113	2,143	1,906
Summer flounder	175	314	26	1,943	3,418	1,264

*These species represent 94-99% of the total catch in each of the three years.

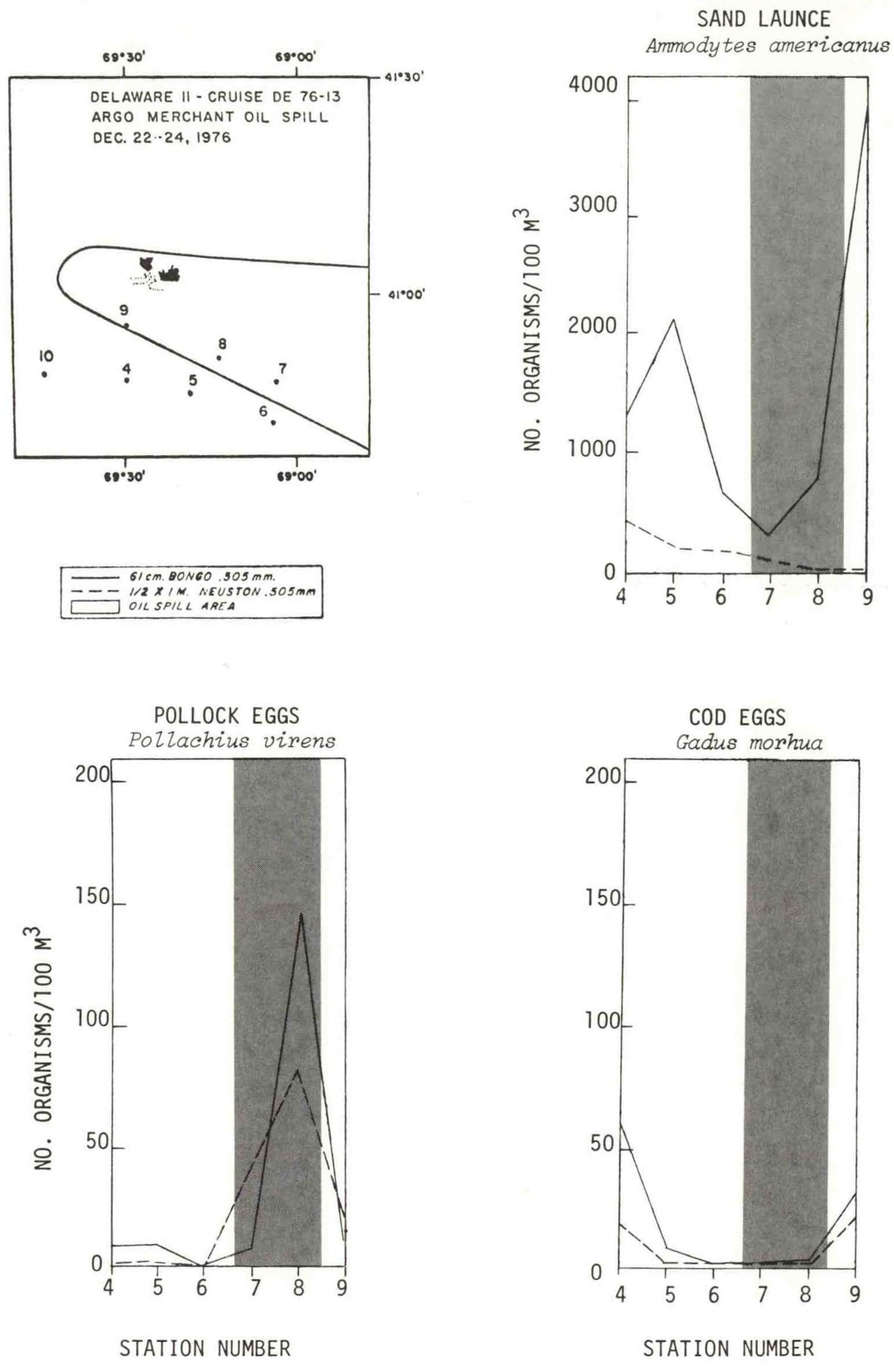

Figure 3.1. Numbers of fish larvae and eggs per 100 m³ collected on DELAWARE II cruise DE 76-13 (from Grose and Mattson, 1977).

Table 3.2. Cytological-cytogenetic assays of mortality and moribundity of cod and pollock eggs from the vicinity of the oil spill (from Longwell, 1977).

DELAWARE II Cruise DE 76-13 Station Numbers	Total No. Eggs	No. Eggs Viable	No. Eggs Dead or Moribund	No. Eggs with Malformed Embryos
Station 4				
Cod	14	13	1	0
Pollock	- -	- -	-	-
Station 5				
Cod	6	3	3	0
Pollock	11	0	11	0
Station 6				
Cod	3	3	0	0
Pollock	3	0	3	0
Station 8				
Cod	1	1	0	0
Pollock	105	86	19	19
Station 9				
Cod	55	43	12	0
Pollock	43	1	42	4
Laboratory spawning cod	75	72	3	0

Table 3.3. Serum measurements on fish species collected following the ARGO MERCHANT spill. (December 1976). Osmolality values are in m0sm/kg; others are in meg/*l* (from Thurberg *et al.*, 1978).

Test	Yellowtail flounder serum				
	Clean (N:7)		Oil (N:17)		P
Osmolality	473	*SE:34	425	SE:11	P<.05
Sodium	208	12	193	4	P<.05
Potassium	7.26	1.10	7.07	0.73	NS
Calcium	6.30	0.38	5.97	0.30	NS
	Winter flounder serum				
	Clean (N:5)		Oil (N:5)		P
Sodium	193	SE: 7	205	SE: 2	NS
Potassium	7.08	0.41	3.97	0.13	P<.001
Calcium	5.74	0.40	5	0.38	NS
	Haddock serum				
	Clean (N:6)		Oil (N:14)		P
Osmolality	453	SE:31 E:	385	SE: 5	P<.05
Sodium	200	15	179	3	P<.05
Potassium	8.31	1.20	7.36	0.38	P<.05
Calcium	3.92	0.92	3.83	0.50	NS
	Herring serum				
	Clean (N:9)		Oil (N:7)		P
Osmolality	530		555		NS
Sodium	245		241		NS
Potassium	7.44		9.45		NS
Calcium	6.51		6.66		NS
	Alewife serum				
	Clean (N:6)		Oil (N:9)		P
Osmolality	527		497		NS
Sodium	230		228		NS
Potassium	9.24		7.97		NS

*SE = Standard error

3.2 Benthos

Numerous benthos were collected near the wreck site. It was felt that these animals would be the most likely affected if ARGO MERCHANT oil had reached the sediments in that area. In February, one dead crab, *Cancer borealis*, was found with oil in its gut, along with one moribund hermit crab, *Pagurus longicarpus*, with oil near the buccal cavity. One of 250 starfish examined had oil in the buccal cavity (Brown and Cooper, 1978). Several individuals of polychaete *Orphryotrocha* spp. had ingested oil. Several individuals of interstitial harpacticoid copepods and some burrowing amphipods (*Psammanyx nobilis*) had oil evident on the appendages (Pratt, 1978). None of this fouling was found during a repeat sampling in July 1977. Mollusc species collected in January and February included *Modiolus modiolus* and *Placopecten magellanicus*. Where spots of oil were found in contact with the mantle in *Modiolus*, lesions of one to several mm in diameter had formed. Brown and Cooper (1978) surmised that these lesions, which were calcareous in nature, were an attempt by the mollusc to wall off the oil, much like an oyster producing a pearl. Collection of this same species in July revealed only one specimen with calcium nodule formation on the mantle and adductor muscle. No oil was visible in any specimens.

Biochemical analysis of *Placopecten* showed that gill tissue oxygen consumption rates of animals in the spill area in January was 594μl O_2/**hr**/**g** (n=7). In adjacent clean areas, this rate was 675μl O_2/**hr**/**g** (n=5). In February, control sites and impacted sites were similar with animals having a mean rate of 652μl O_2/**hr**/**g** (n=8). Depressed oxygen consumption rates in the January animals *may* give an indication of stress, although sample sizes were too small to permit statistical analysis. Other investigators have reported oil-related respiratory changes in bivalve molluscs due to oil exposure (*e.g.*, Alvolizi and Nuwayhid, 1974 and Gilfillan, 1975). Samples collected in February with normal oxygen consumption rates may indicate recovery from exposure to oil or that the February specimens had never been exposed to any oil.

Serum sodium and calcium levels were elevated in *Placopecten* in January, while osmolality and potassium remained unchanged. In addition, malate dehydrogenase (MDH) activity in the adductor muscle was depressed in animals from oiled areas. Lactate oxidation was also lower, but pyruvate reduction, catalyzed by the same enzyme (D-lactate dehydrogenase) was unchanged (Thurberg *et al.*, 1978). Malic enzyme activity was also depressed. According to Thurberg *et al.* (1978), the lowered activities of MDH and malic enzyme (ME) may be due to several factors: (1) the animal's inability to maintain a normal metablolism (MDH repression), (2) a slowed feeding rate (low ME), or (3) a weakening of the ability to shift to anaerobiosis for defense against toxicants (low MDH and lactate oxidation). However, the small sample sizes make it unrealistic to form any firm conclusions concerning these data. Future measurements must be made to confirm these data and to establish physiological baselines for the species.

3.3 Plankton

Centropages typicus, an important food for both larval and adult fish, was found to be the dominant copepod in the area in December zooplankton collections. A small degree of contamination (Table 3.4) was seen in this species and the other abundant copepods in the area. Oil appeared mainly in the alimentary tracts or in the mandibular region of these planktonic species. Extraction and analysis of samples of *Centropages typicus* showed that the oil present on the animals was similar to ARGO MERCHANT oil (Sherman and Busch, 1978). While the possibility that some of these plankton could have become contaminated in the net rather than in the water column cannot be overlooked, Polak *et al.* (1978) investigated this problem and found no correlation between zooplankton contamination and net contamination.

The impact of the oil on zooplankton in the spill area is unclear. While zooplankton may ingest and store oil for a period of time (Lee, 1975 and Morris, 1974), it is not clear what the effects will be to the plankton themselves or to other elements of the food web. However, it seems unlikely that any drastic change in the Nantucket Shoals zooplankton populations will be found as a result of this spill. Little or no contamination in any of the zooplankton and no drastic changes in population numbers were found in cruises throughout 1977 (Polak *et al.*, 1978). Too little is known about baseline populations and environmental parameters affecting mortality in these populations for scientists to make any definitive statements concerning impact.

Collections of phytoplankton were made 10-24 April 1977 to determine if any changes had occurred in normal phytoplankton populations on Nantucket Shoals. Qualitative seasonal changes in distribution of species were similar to those of past studies. However, species abundance and diversity in the area of the wreck site had decreased and a massive bloom of *Gleocapsa* spp., a blue-green alga, was seen to a depth of about 50 m (Sherman, 1977). This alga may be an indication of organic pollution, possibly ARGO MERCHANT oil, although this cannot be demonstrated conclusively.

Table 3.4. Occurence of oil contamination on dominant copepod species (from Sherman, 1977).

				Type of Contamination*			
Species	No. Collected (per 100m^3)	No. Examined	No. Contaminated	E	M	I	Other
Station 4							
Centropages typicus	5,812	55	1	-	-	1	-
Centropages hamatus	1,162	10	2	-	-	2	-
Pseudo-Paracalanus	38,148	163	8	5	-	5	-
Station 5							
Calanus finmarchicus	348	20	11	2	3	6	-
Centropages typicus	4,070	100	61	1	1	59	-
Pseudo-Paracalanus	4,279	100	25	-	18	7	-
Station 6							
Calanus finmarchicus	184	41	1	-	1	-	-
Centropages typicus	847	100	16	-	2	14	-
Pseudo-Paracalanus	94	21	0	-	-	-	-
Station 7							
Calanus finmarchicus	997	100	14	2	7	0	5
Centropages typicus	374	104	30	0	1	29	-
Pseudo-Paracalanus	317	105	35	2	11	10	-
Station 8							
Calanus finmarchicus	839	76	12	-	10	2	-
Pseudo-Paracalanus	23,134	50	5	-	4	-	1
Metridia lucens	766	32	3	-	1	2	-
Station 9							
Centropages typicus	9,507	45	17	2	9	6	-
Centropages hamatus	2,560	8	3	1	2	-	-
Pseudo-Paracalanus	190,144	60	3	1	1	1	-

*Types of contamination: E = external; M = mandibular; I = ingested.

3.4 Marine Birds and Mammals

Birds were observed near the ARGO MERCHANT wreck site from 15-24 December, and over the entire northwest Atlantic every month since then as part of an ongoing baseline study. About 92% of the birds sighted in the area of the wreck were Great Black-backed Gulls, Herring Gulls, and Black-legged Kittiwakes. Approximately 41% of the Herring Gulls and 59% of the Black-backed Gulls seen were visibly oiled. One hundred eighty-one birds of 16 species washed ashore on Nantucket (173) or Martha's Vineyard (eight) from 20 December 1976 to 24 January 1977. Principal species involved were alcids (49%), gulls (27%), and loons (19%) (Powers and Rumage, 1978).

Necropsies carried out on 15 specimens of beached birds showed that, in general, all birds were underweight, waterfowl exposed to oil (Hartung and Hunt, 1966). with little body fat and no food in the digestive tract. The pathology findings are summarized in Table 3.5 (Powers and Rumage, 1978) and are similar to those found in Lung hemorrhages were found in seven birds and lipid pneumonia in two. Blockage of the Bowman's capsule (in the kidney) by cellular debris and precipitation of urates in the kidney tubules resulting in blockage of urine flow was also seen (Powers and Rumage, 1978). As a result, birds were unable to filter waste products from the blood, causing uremic poisoning. Entrance of oil into the lungs could have occurred during preening, through glottal

Table 3.5. Summary of pathology findings on 15 beached birds, Nantucket, Massachusetts (from Powers and Rumage, 1978).

Species	Sample Size	Hemmor-rhagic Lungs	Pneu-monia	Kidney Blockage	Kidney/Lung Congestion	Parasites (Chronic)
	Number of Specimens With:					
Common Loon	5	2	1	2	0	0
Great Black-backed Gull	2	2	0	0	0	0
Herring Gull	3	2	0	0	1	0
Common Murre	4	1	0	1	1	1
Thick-billed Murre	1	0	1	0	0	0

leakage or inhalation. Kidney pathology could be due to oil-induced changes or dehydration due to lack of feeding and loss of insulation.

While no quantitative statement of number of birds killed by oil can be made, it can be assumed that many more birds went offshore than came onshore, due to prevailing offshore winds and currents. Data seem to indicate, however, that the ARGO MERCHANT oil had minimal effects on coastal and pelagic bird populations (Powers and Rumage, 1978).

Overall, it appears that no drastic changes occurred in biological populations following the ARGO MERCHANT spill. It will be difficult, over the next few years, to separate oil impacts from impacts caused by other naturally occurring and/or catastrophic events in the region. Much of the problem in establishing impact lies in the lack of a sufficient number of samples, the lack of ability to truly distinguish between clean or control areas and contaminated areas, and a lack of seasonal baseline information concerning the physiology of species and population biology.

3.5 Seasonal Spill Scenarios

Several of the risk assessment models used during the ARGO MERCHANT spill considered seasonal changes in oil trajectories for the ARGO MERCHANT site. For the purposes of this report, the USGS model was chosen to demonstrate seasonal changes in direction of oil movement, because it includes the means to assess risks to certain biological and recreational resources in the North Atlantic. This model was originally developed as part of an oil spill risk analysis for the proposed Outer Continental Shelf Lease Area No. 42 in the North Atlantic. The model was designed to analyze oil slick movements between 38° and 45° N latitude and 65° longitude and the Atlantic coast. Oil slick transport is described as the vector sum of 3.5% of the wind velocity and the average residual surface currents. Wind data were derived from simulated winds based on historical data and on-site observations during the spill. Monthly surface current velocities, provided by BLM, were based in part on drift bottle studies by Bumpus (1973). Slick movement was simulated as a series of straight-line displacements over three-hour periods.

Trajectory simulations using the USGS model for the ARGO MERCHANT wreck site were run for each month of the year. The results consisted of up to 32,000 trajectories for each month, from which 300 were randomly selected for statistical analysis.

Based on the resources considered vulnerable in the USGS model (Table 3.6), one would expect that in December and January, pelagic and coastal birds, cod and haddock spawning areas, and shellfish habitats would be in danger (Figures 3.2 a-e). The results presented in Section 3.1 and 3.4 show that pelagic birds and cod spawning areas were affected in some manner. Had the spill come ashore, coastal birds and shellfish areas could have been potentially impacted. To this extent, the model was successful in predicting what resources would be affected. However, the model does not consider many of the other resources that were affected, such as zooplankton, phytoplankton, pollock, and winter and summer flounder; nor does it consider differences in probability of impact between fish eggs, larvae, and adults or the degree of impact. For the ARGO MERCHANT spill, it appears that these developmental stages were impacted differently, and that the risks to each of these forms were dissimilar. The USGS model could not take into account any subsurface transport of oil, and thus was unable to deal with this complication. Based on what we know about this particular No. 6 oil, it was probably mostly "cutter stock" (20% of the volume) that entered the water column. Water soluble fractions of this lighter oil are, in general, more toxic to marine biota than are heavier oils, such as Bunker C (or No. 6) (Malins, 1977). However, no conclusive evidence exists as to which oil caused the impact observed from this incident.

Table 3.6. Months during which coastal and nearshore resources in the North Atlantic are vulnerable to impact from oil (Wyant, 1977).

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Coastal bird wintering areas				x	x	x	x	x	x	x	x	x
Coastal bird breeding areas	x	x	x	x	x	x	x	x	x	x	x	x
Pelagic bird nesting areas				x	x	x	x	x	x	x	x	x
Pelagic bird wintering areas	x	x	x	x	x							
Cod and haddock spawning areas		x	x	x	x	x	x					
Silver and red hake spawning areas						x	x	x	x	x		
Sea herring spawning area										x	x	x
Shellfish areas	x	x	x	x	x	x	x	x	x	x	x	x
Harbor seal whelping areas						x	x	x	x	x		
Salt marshes	x	x	x	x	x	x	x	x	x	x	x	x

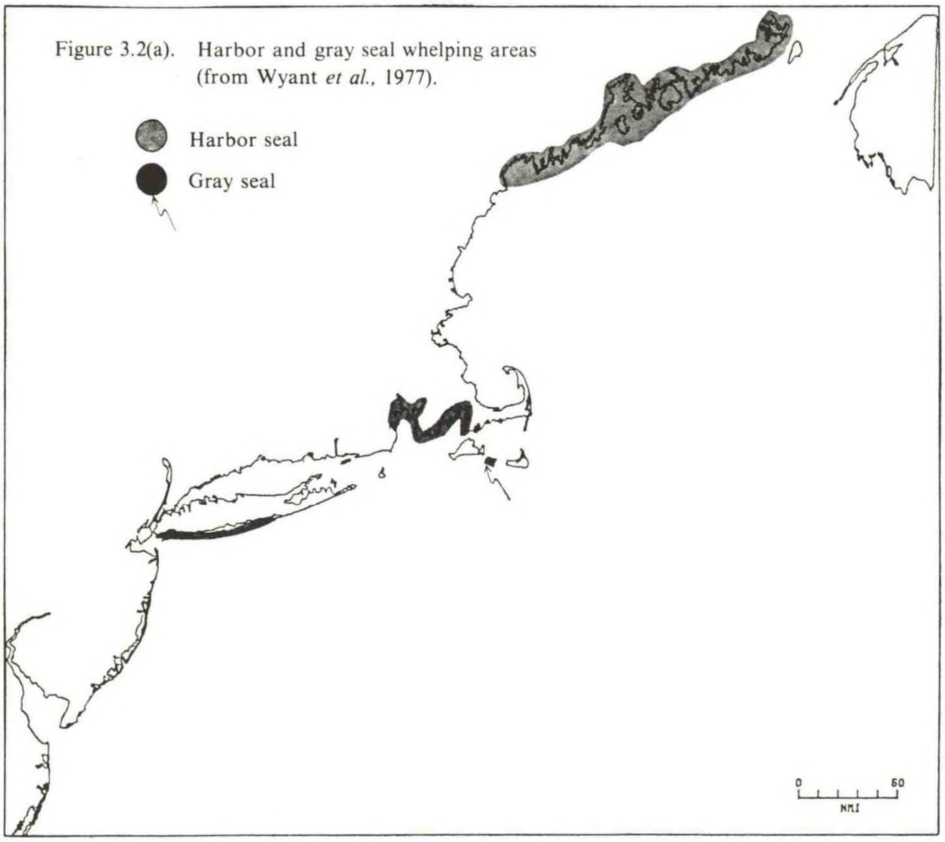

Figure 3.2(a). Harbor and gray seal whelping areas (from Wyant *et al.*, 1977).

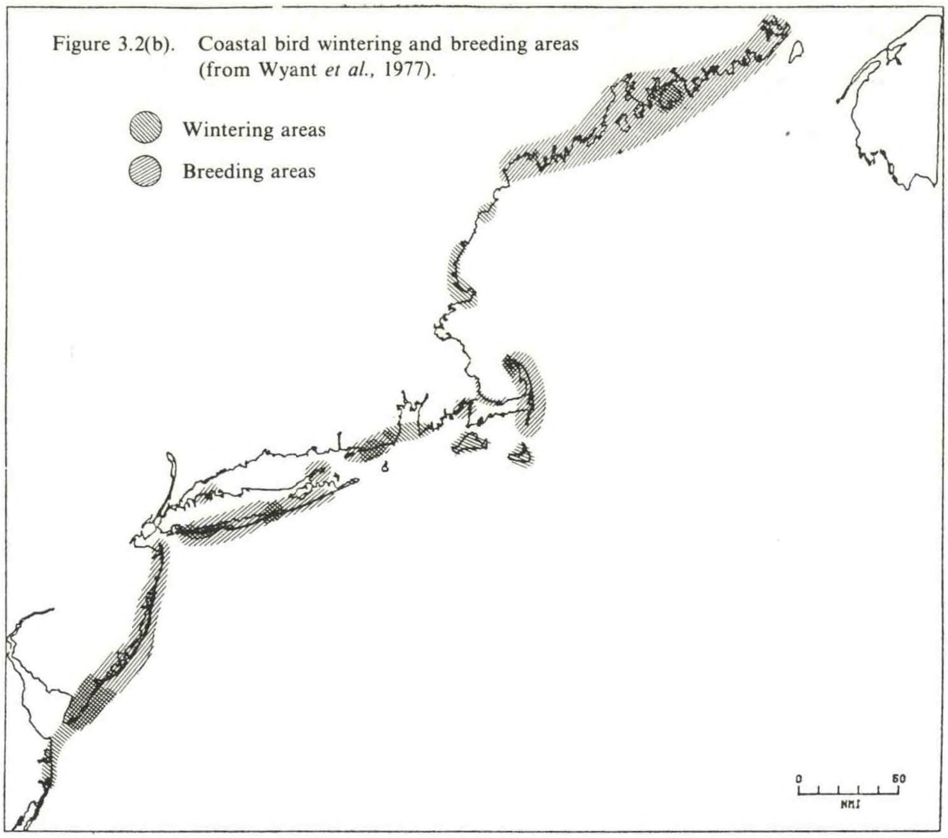

Figure 3.2(b). Coastal bird wintering and breeding areas (from Wyant *et al.*, 1977).

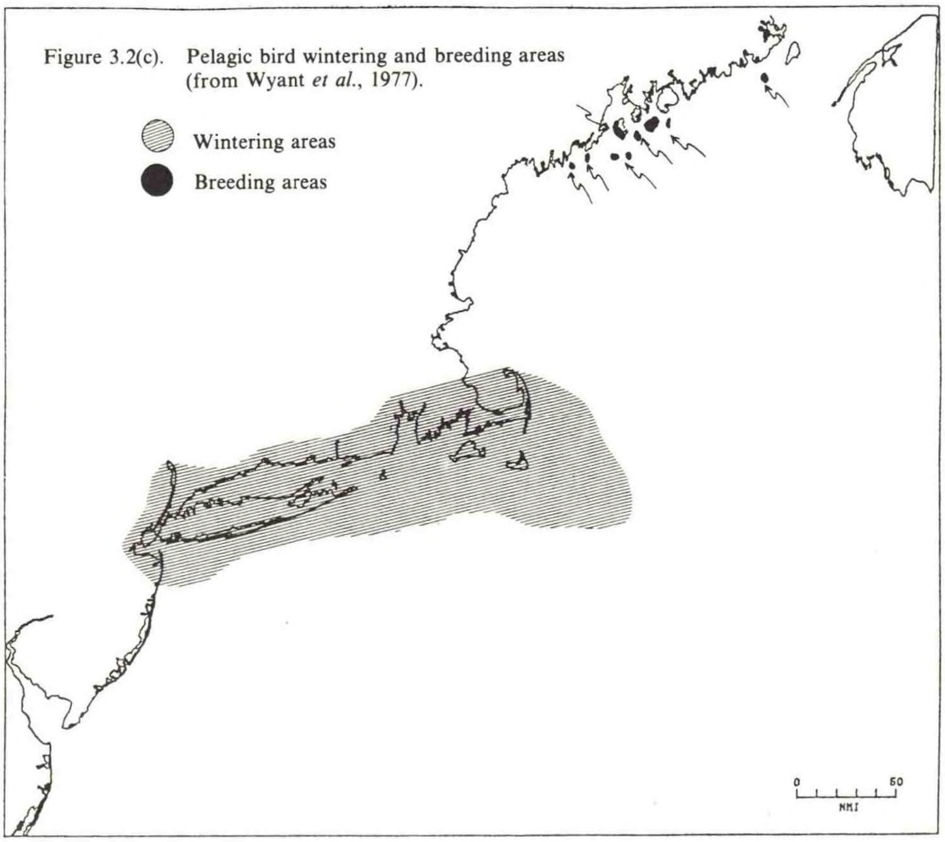

Figure 3.2(c). Pelagic bird wintering and breeding areas (from Wyant *et al.*, 1977).

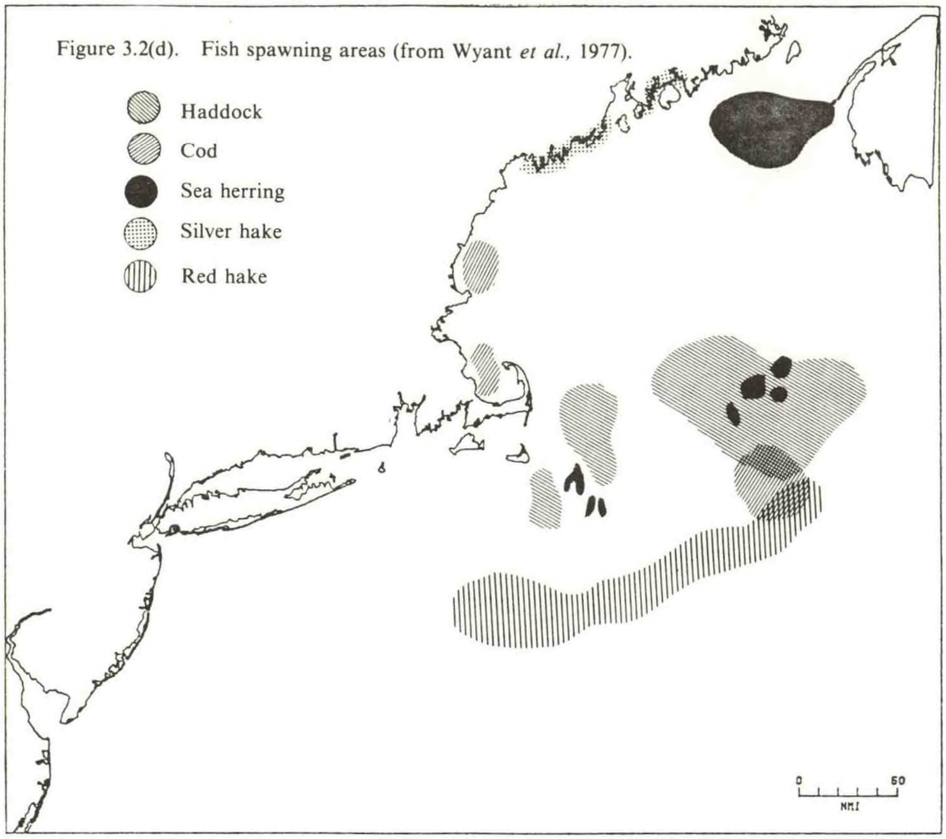

Figure 3.2(d). Fish spawning areas (from Wyant *et al.*, 1977).

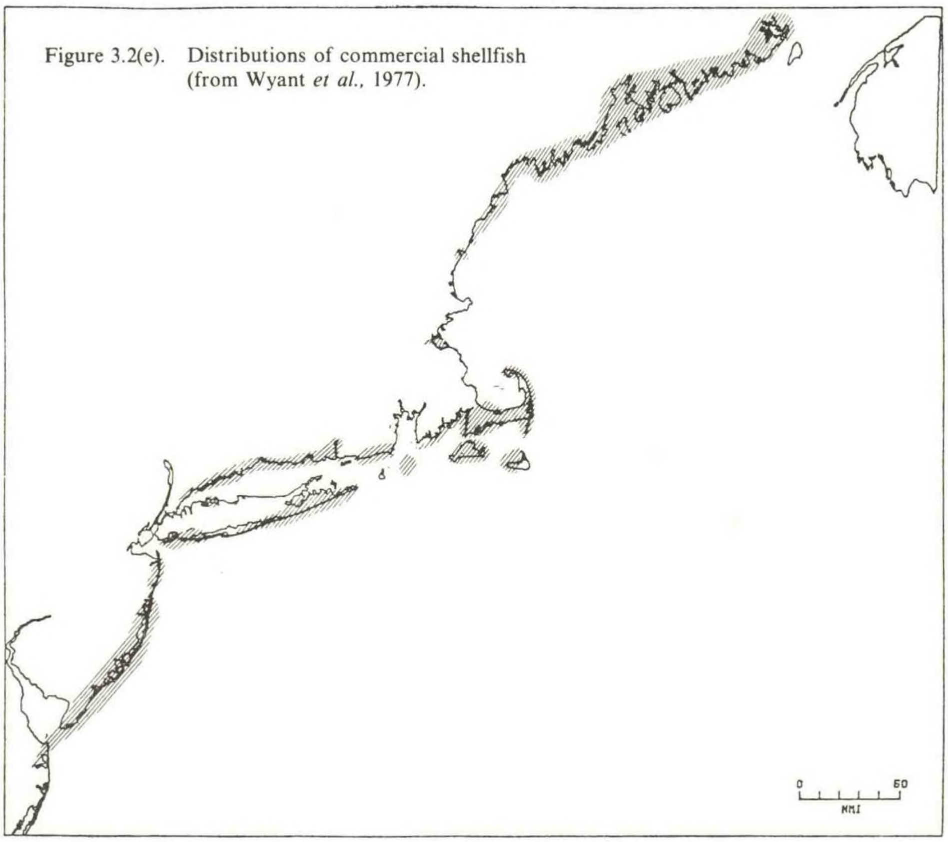

Figure 3.2(e). Distributions of commercial shellfish (from Wyant *et al.*, 1977).

The USGS model (and others) demonstrates distinct seasonal change in direction of oil transport (Section 2.2.2) and probabilities of impacts on resources. The greatest probability of spills impacting the shoreline occurs during spring and summer; during these seasons a large percentage of spills would be transported over the Georges Bank region (Table 3.7). In contrast, in autumn and winter, the majority of spills would be transported offshore to the southwest and east. Only a small percentage would be likely to come ashore. Of those coming ashore, however, time from the spill to the landfall would be relatively short because of the strength and duration of the northeasterly winds when they do occur.

Table 3.8 shows the seasonal likelihood of spills impacting biological resources of the area. For most resources, the probability of impact is very low in the winter, due to the low amount of biological activity during this season over much of the region. Exceptions include pelagic bird wintering areas and cod and haddock spawning areas. As spring begins, biological activity increases; therefore, in spring and summer, resources are more vulnerable due to their presence and activity levels. Types of impacts (Table 3.8) do not change with season to any great extent as most animals are vulnerable in the same manner throughout the year. Autumn does not represent a time of major threat to any resources except for sea herring, which is a fall spawner, and pelagic birds, which are moving into the area during that time.

Table 3.7. Seasonal likelihood of spilled oil contacting the shore and results of trajectory analysis for oil spills originating from the Nantucket Shoals (Results expressed as number hits per 100 spill) (from Wyant, 1977).

	Winter	Spring	Summer	Autumn
Hits on United States	10.6	35.3	32.3	18.3
Hits on Nova Scotia	0.7	18.3	51.0	3.0
Hits on Land (U.S. & N.S.)	11.3	53.6	53.3	21.3
Spills decayed	7.7	21.0	5.0	27.7
Spills off map to: N	0.0	0.0	3.3	0.0
E	75.3	25.0	10.7	41.3
S	5.7	1.3	0.0	9.0
Time to Land (days):				
Minimum	1.3	2.3	3.3	2.0
Maximum	29.3	57.7	54.0	45.0
Mean	10.7	25.3	24.3	18.0

Table 3.8. Seasonal likelihood and category of impact for oil spills originating from the Nantucket Shoals (impacts expressed as number spills impacting resource per 100 spills/type of impact) (from Wyant, 1977).

Resource	Winter	Spring	Summer	Autumn	Type of Impact*
Coastal Bird Wintering Areas	10.7	18.0	NA	10.0	1b,2b,3b,4b,5b
Coastal Bird Breeding Areas	2.7	6.3	9.3	2.3	1, 2b,3,4b,5b
Pelagic Bird Nesting Areas	0	0.7	3.0	0.3	1,2b,3,4b,5b
Pelagic Bird Wintering Areas	100.0	66.7	NA	43.7	1b,2b,3b,4b
Eagle and Osprey Nesting Sites	0.3	7.0	4.0	2.3	2b,3b,4b
Cod and Haddock Spawning Areas	67.3	95.3	32.0	NA	1,2,3a,4
Silver and Red Hake Spawning Areas	NA	17.7	1.3	8.3	1,2,3a,4
Sea Herring Spawning Areas	0	0.3	12.0	100.0	1,2,3a,4
Shellfish Areas	3.7	10.7	4.3	4.3	1,2,3,4,5b
Harbor Seal Whelping Areas	NA	1.3	6.3	NA	4,5
Grey Seal Whelping Areas	NA	2.3	0.3	NA	4,5
Salt Marshes	1.3	3.0	1.3	1.3	1-5

*Types of impacts: 1. Direct lethal toxicity. 2. Sublethal effects on physiology and behavior. 3. Direct coating effects. 4. Tainting and bioaccumulation. 5. Changes in habitats. An "a" after the number (e.g., 5a) indicates that only eggs and larvae are affected. A "b" after the number indicates only adults are affected. NA indicates not applicable.

From a biological point of view, this spill occurred at an advantageous time, and had a relatively innocuous cargo. Had it occurred a month or two later, the effects could potentially have been much more acute, due to the increased levels of biological activity and the greater probability of landfall.

If a different type of cargo had spilled, especially a lighter fuel oil, biota in the area could have been much more acutely affected. Water soluble fractions of lighter oils are more toxic to organisms than heavier oils; these data are well summarized in Malins (1977). Lighter oils become accommodated much more easily into the water column, and their effects occur more because of ingestion and absorption rather than coating of the organism.

4. SOCIOECONOMIC EFFECTS

4.1 Effects on the Fishing Industry

The fishing industry on Cape Cod and the Islands is a complex one, but characterized only by coastal and near-shore fishing efforts. The vessels used are relatively small and the longest trips made are about a week. The fishing effort is directed toward both shellfish and fin fish, and the fish caught are landed at the larger ports, *e.g.*, Nantucket, Edgartown, Chatham, Provincetown, and New Bedford. Since fishermen frequently land fish at ports other than their homeport, it is difficult to distinguish clearly the impact of an offshore oil spill on a particular community. The fishermen can, if a particular fishing area is closed because of oil slicks, shift their efforts elsewhere unless they are tied to the exploitation of a certain species in a specific area.

Although the press had reported the possibility of a major loss of income to fishermen due to the ARGO MERCHANT oil spill, fishermen interviewed reported that the 1977 season was as good or better than the 1976 season for both catch and earnings. Of the three cases which reported that the spill had affected earnings, all had been temporary losses and were recouped later in the season. The loss of income in each of the three cases was caused by the closure of the area around the slick by the USCG and the subsequent inability of the fishermen to haul lobster pots (Fricke and Maiolo, 1978).

Recreational fishing is also an important industry around Cape Cod and the Islands. The NMFS (DOC, 1977a) estimated in their annual review, *Fisheries of the United States: 1976,* that some 626,000 households in Massachusetts engage in recreational marine fishing each year. This is equivalent of approximately 1.3 million persons. Table 4.1 shows that many others from nearby states also fish in Massachusetts waters. Again, interviews with 100 recreational fishermen indicated that there was no drop in catch that could be attributed to the ARGO MERCHANT accident. The 1977 period was seen as good as or better than previous years by three-quarters of the recreational fishermen. Also interviewed were seven owners of bait and tackle shops, who reported that their businesses did well in 1977. Their previous best year had been 1975, and all characterized 1977 as surpassing 1975 for volume of tackle sales and rental (Fricke and Maiolo, 1978).

4.2 Effects on the Tourist Industry

Tourism, and the service industries associated with it, is a major business concern on Cape Cod and Islands (Nantucket and Martha's Vineyard). It is estimated that 75-85% of the overall economy of the region is directly attributable to travellers (seasonal houseowners, businessmen, and tourists) as they move about and stay in the Cape Cod region (Cournoyer and Kindahl, 1977). Table 4.2 shows that visitors to the region spent nearly $341 million in 1975, and over $301 million in 1976, on lodgings and services. The drop in expenditures by travellers in 1976 is attributed by businessmen and officials to bicentennial activities elsewhere in the United States that attracted both seasonal residents and tourists. This is reflected in Table 4.3, showing the number of passengers carried by the Woods Hole, Martha's Vineyard and Nantucket Steamship Authority ferries. In 1977, however, the number of passengers carried was significantly higher than in 1975 and 1976. Hoteliers and other businessmen reported in interviews that the 1977 season was as good as or better than that of 1975 in terms of both volume of trade and in income earned (Cournoyer and Kindahl, 1977).

Included in a random sample of 262 residents of Cape Cod and the Islands were 65 owners of businesses. Of these, 35 (54%) reported that their trade was seasonal, *i.e.*, was tourist oriented. As was expected, the percentage differed by community: 82% in Edgartown, 64% in Chatham, 50% in Nantucket, and 38% in Falmouth. All had felt concerned that the ARGO MERCHANT incident would adversely affect their summer season because of the weight of publicity in December 1976. However, 60% of the business owners felt that the summer of 1977 had brought the normal number of tourists to their region. Forty percent of the owners felt that a change had occurred, and of these, three-quarters said that their trade and the number of tourists had increased. Of all the proprietors, 92% felt their business in 1977 was the same as (60%) or better than (32%) previous years (Fricke and Maiolo, 1978).

Although the annual summary prepared for the Commonwealth of Massachusetts by the University of Massachusetts on travel and tourism is not yet available, it would appear from press reports of beach use and participation in other recreational activities, such as the recreational fishing contests, that 1977 had been a good year for the tourist and travel industry. Nearly all the businessmen interviewed, however, agreed that if either the oil from the ARGO MERCHANT spill had come ashore or there had been a spill in the late spring or early summer, the impact upon tourism would probably have been much greater.

Table 4.1. Estimated number of people participating in marine recreational fishing in Massachusetts by northeastern state of residence; June 1973 - June 1974 (DOC 1977a).

Connecticut	94,000
Delaware	5,000
Washington, D.C.	2,000
Maine	7,000
Maryland	16,000
Massachusetts	1,300,000
New Hampshire	36,000
New Jersey	98,000
New York	271,000
Pennsylvania	83,000
Rhode Island	61,000
Vermont	10,000
Virginia	14,000
West Virginia	3,000
TOTAL	1,998,000

Table 4.2. Expenditure by travellers to Cape Cod, Martha's vineyard, and Nantucket in thousands of dollars (Cournoyer and Kindahl, 1977).

1975	Cape Cod*	Martha's Vineyard**	Nantucket	Total for Region
Winter	$ 37,090	$ 840	$ 811	$ 38,741
Spring	77,023	3,543	3,136	83,702
Summer	147,262	10,155	6,483	163,900
Fall	50,811	1,928	1,791	54,530
1975 TOTAL	$312,186	$16,466	$12,221	$340,873
1976				
Winter	$ 29,323	$ 724	$ 918	$ 30,965
Spring	65,479	3,888	3,864	73,231
Summer	143,739	9,830	8,105	161,674
Fall	32,212	1,746	1,582	35,540
1976 TOTAL	$270,753	$16,188	$14,469	$301,410

*Barnstable County
**Dukos County

Table 4.3. Passengers carried by the Woods Hole, Martha's Vineyard and Nantucket Steamship Authority between Cape Cod and the Islands* (from Fricke and Maiolo, 1978).

	1972		1973		1974		1975		1976		1977	
	No.	%†	No.	%†	No.	%†	No.	%†	No.	%†	No.	%†
January	23,328	100	27,063	116	25,879	111	28,231	121	28,594	123	22,956	98
February	22,205	100	27,803	125	24,343	110	29,574	133	35,044	158	26,299	118
March	30,360	100	36,878	122	36,919	122	40,947	135	37,591	124	36,011	119
April	52,655	100	63,483	121	61,300	116	57,553	109	73,139	139	72,666	138
May	77,999	100	82,267	106	90,428	116	100,039	128	104,220	134	117,790	151
June	125,414	100	133,479	106	133,759	107	154,731	123	156,803	125	160,371	128
July	220,638	100	213,085	97	226,608	103	263,809	120	258,988	117	298,893	135
August	260,421	100	265,326	102	279,059	107	312,548	120	292,025	112	329,170	126
September	128,997	100	145,969	113	132,064	102	144,896	112	157,570	122	169,185	131
Totals	942,017	100	995,353	106	1,010,359	107	1,132,328	120	1,143,974	121	1,233,341	131

*Statistics supplied by the Woods Hole, Martha's Vineyard and Nantucket Steamship Authority.
†% of traffic carried in 1972.

4.3 Public Awareness of the Incident

As can be seen from the review of the fishing industries, it would appear that the effects of the ARGO MERCHANT oil spill on the economy of Cape Cod and the Islands were negligible. A random sample of 262 residents of Chatham, Edgartown, Falmouth, and Nantucket were interviewed by researchers from the WHOI during October and November 1977, to determine what, if any, knowledge they had of the spill, as well as their perceptions, if any, of the effects upon their communities and their own activities (Fricke and Maiolo, 1978).

To assess the quality of the knowledge of respondents, a scale was constructed on which the depth of information could be measured. The researchers labelled the respondents "well-informed" if they were able to identify the two major polluters and the location of the incidents that occurred in the area during the winter of 1976-77. Persons knowing of one of the two vessels and its location were labelled "informed." Persons knowing either of one of the two ships or of one of the two locations only were labelled "poorly informed." Persons not able to recall any information were labelled "uninformed." As it turned out, this scale had to be collapsed to the categories of "informed" and "poorly informed/uninformed," because only 14% of the sample could be considered well-informed, and 17% met the criteria for informed respondents. Fully 69% of the sample were badly informed or had no knowledge (or recall) of the two major spills in the area 11 months before the interviews (Table 4.4).

The respondents were asked to name the organization or agency that had the responsibility for ensuring that spilled oil was cleaned up. For coastal oil spills, such as those of the ARGO MERCHANT and BOUCHARD #65, the USCG is responsible for clean-up, and it was expected that well-informed and informed respondents would know this. The results are shown in Table 4.5, and indicate that nearly three-quarters (74%) of the informed group believed that the USCG had some or all of the responsibility for oil spill clean-up. Fifty-five percent of the poorly informed/uninformed group of respondents believed that USCG had some or all responsibility, while 23% named other agencies, and 38% did not know who was responsible.

Table 4.4. Knowledge of the **ARGO MERCHANT** and BOUCHARD #65 oil spill by community (%) (from Fricke and Maiolo, 1978).

Level of knowledge	Chatham	Edgartown	Falmouth	Nantucket	Total
Informed	29	25	45	23	31
Poorly informed/uninformed	71	75	55	77	69

Table 4.5. Comparison of informed and poorly informed respondents' knowledge regarding responsibility for oil spill clean up (%) (from Fricke and Maiolo, 1978).

Responsible Organization	Informed Group	Poorly informed/ uninformed group
U.S. Coast Guard	54	47
Coast Guard and other agencies	20	8
Other	15	23
Don't Know	11	38

The respondents were asked if they had actually seen or experienced effects of the ARGO MERCHANT oil spill, and 45% of all the sample said they had seen effects (Table 4.6). Thirty-four percent of the whole sample reported that their lives had been affected in some way, but only 5% reported that specific activities had been affected by the oil spill. Of those who reported experiencing effects (34% of the whole sample), it was found that the reported effects were 'presumed" to be effects, but at best were indirect. For example, the increased price of shellfish was attributed to the ARGO MERCHANT spill, as was the rising cost of fuel oil.

Information about the ARGO MERCHANT oil spill was obtained from television programs by 65% of the sample. In addition, 53% of the respondents reported that they obtained information from newspapers, and 42% also heard news stories about the spill on the radio. Relatives were an additional source of information for 5% of the respondents and friends for 18%. Seventy-two percent of the persons interviewed said that they "knew" of some of the effects of the ARGO MERCHANT spill, and here differences were found by community. Ninety-five percent of the residents of Falmouth who were interviewed said they "knew" of effects; in Edgartown, 82%; in Nantucket, 59%; and in Chatham, 52%. Newspapers were found to be the most frequently cited source of knowledge of effects (53%), followed by television (47%), and radio (33%) (Fricke and Maiolo, 1978).

Of the sample of 262 residents of Cape Cod, Martha's Vineyard, and Nantucket that were interviewed about their knowledge and perceptions of the effects of the ARGO MERCHANT oil spill, 69% were either poorly informed or uninformed (or had no recall) of the events of the winter of 1976-77. An operating assumption of the study was that if basic information was unknown, more detailed knowledge of the extent of oil spills, environmental damage, and pollution clean-up would also be unknown. It can be fairly stated that an uninformed public is a susceptible one. Impressions, incomplete reports, and informal sources of information can appreciably affect public opinion to the extent that a large gap frequently exists between perception and reality. It seems highly desirable that knowledge of these perceptions be incorporated into any future efforts to inform the public and into any planning for the prevention of or response to oil spills.

Table 4.6. Perceived effects of the ARGO MERCHANT oil spill by community (%) (from Fricke and Maiolo, 1978).

	Chatham	Edgartown	Falmouth	Nantucket	Whole Sample
Reported effects	23	74	53	38	45
Reported affecting respondent	16	43	49	25	34
Reported specific activities affected	*	*	*	*	*

*Number of responses too small to compare by community.

5. FEDERAL AGENCY SCIENTIFIC RESPONSE

5.1 Response Preparedness

The NCP for the removal of oil and other hazardous substances was prepared under section 311 of the Federal Water Pollution Control Act, as amended (P.L. 92-500). The Plan provides a system of coordinated, integrated response by departments and agencies of the Federal government through an established NRT and ten RRT's based upon the Standard Federal Regions. The NRT is composed of representatives from five primary agencies (DOC, DOD, DOI, DOT, and EPA) and five advisory agencies (AEC, DHEW, Justice, OEP, and State). The NRT serves as the national body for planning and preparedness actions before a pollution discharge and for coordination and advice during a pollution emergency. The RRT consists of regional representatives of the primary and selected advisory agencies, as appropriate, and acts within its region as an emergency response team performing advisory functions at the regional level. Individual states lying within a region are invited to furnish liaison to the RRT for planning and preparedness activities and during a pollution emergency to participate in RRT deliberation. During any given pollution emergency, the RRT's primary function is to serve in an advisory capacity to the designated OSC.

The ARGO MERCHANT incident was the first major test of the NCP, and many elements contributing to an effective response were found to be lacking. Although extensive scientific response capabilities existed at the time to provide assistance to those involved in clean-up, containment, and damage assessment, the Federal government was not prepared to mobilize rapidly and coordinate an effective scientific response team (DOC, 1977b).

Equipment of all kinds, especially ships and aircraft, was difficult to procure. No plans had been made for diversion of vessels from regular duties, nor was any sampling equipment stockpiled or readily available for use. Lack of such planning resulted in unavoidable delays that in some instances may have reduced the amount and quality of data collected and used for damage assessment. In most cases, however, it appeared that agencies were making every effort to cooperate in providing this equipment whenever possible.

NOAA's initial response consisted of SOR Team personnel and local NMFS and NWS personnel working as essentially separate entities. SOR Team coordination of NOAA elements was essentially nonexistent, and lack of a single NOAA representative to the RRT made it difficult for the OSC to coordinate activities or ask for support. In additon, the role of the SOR Team with respect to other NOAA elements had not been internally clarified. The SOR Team was thrust into the role of providing coordination of scientific activities; this action caused some amount of internal friction in NOAA because of the lack of a clearly defined leadership role. In spite of these problems, the SOR Team and various NOAA elements eventually were able to provide a great deal of assistance to both the OSC and the scientific community.

For much of the initial period following the spill, agencies tended to act as independent entities rather than forming cooperative working units. Largely due to the OSC and the SOR Team, in particular at a 3-4 January 1977 scientific meeting in Woods Hole, Massachusetts, agencies, both public and private, met to draw up a *coordinated* research plan. This was a large effort, and while some later sampling efforts did not use the recommendations of the meeting, at least the attempt at coordination had been made. Some problems stemmed from communications difficulties generated by a general lack of knowledge of roles and responsibilities of the various individuals and agencies involved.

5.2 Regional Environmental Response Requirements

The ARGO MERCHANT incident, along with other recent spills, has clearly identified serious deficiencies in the organization of scientific efforts associated with major pollution discharges. Under the auspices of the NRT, EPA and NOAA have taken the lead in developing a plan to establish the mechanisms required to provide a rapid scientific response. The plan is a first effort to define the interagency program and expand on the previous mechanisms implemented under the NCP. The document traces the development and rationale of the program and the system being organized to respond to the problems identified during the ARGO MERCHANT incident. The program will focus on three major objectives:

1) To provide the NRT, RRT's and OSC's with scientific assistance in mitigating the environmental and socioeconomic impacts of spills of oil and other hazardous substances.
2) To provide scientific assistance in assessing the environmental damage resulting from such spills.
3) To maximize the research advantage offered by the spill situation, especially with respect to improving future response capabilities.

Towards meeting these objectives, a series of regional workshops have been undertaken to define technical issues, and to identify potential response personnel and scientific tasks to be undertaken. Based on the recommendations received during these workshops, individual regional response plans will be prepared to address the objectives of the scientific support concept. In consultation with participating agencies, priorities of scientific support tasks can be identified in order to adequately meet operational requirements. Meetings of public and private agencies have taken place in Hartford (EPA Region I), Anchorage (EPA Region X), Tampa (EPA Regions IV and VI), Philadelphia (EPA Regions II and III), and Charleston (EPA Region IV); response plans and projects are now being drafted. It is hoped that these workshops will aid in development of *coordinated* response plans which are responsive to immediate on-scene needs of the OSC and RRT and which provide priorities for research in future spill incidents.

5.3 Funding

Costs associated with the initial response to the ARGO MERCHANT oil spill were, for the most part, borne within existing resources of the various participating agencies. In the case of NOAA's SOR Team, initial support came from an on-going contract through the BLM (DOC, 1977c).

The ARGO MERCHANT incident demonstrated that within both the public and private sectors of the scientific community, there was a great deal of essential expertise and capability for damage assessment and advisory roles. However, the lack of an established funding mechanism caused ARGO MERCHANT related studies to become a major concern of many scientists when they became diverted from their on-going contract and grant research. While initially some funds were provided by the DOC and DOI for short-term assessment studies, delays in finding sources of funds and determining amounts available altered the timing of these investigations and limited the involvement of much of the scientific community.

The NOAA Project Development Plan for NOAA Response to Spills of Oil and Other Hazardous Substance has identified funding sources for scientific response operations as they apply to the three major objectives of the project. Scientific response operations undertaken in direct support to assist the OSC will be reimbursed through the NCP "Pollution Fund," if other conditions regarding the use of this fund have been met. Damage assessment activities undertaken at the request of the EPA will be reimbursed by the Pollution Fund through provision of pending liability legislation. Research activities that fall outside either of the above categories are to be funded by the agency or institution sponsoring the research.

In addition to the categories outlined above, other response activities will require separate agency funding. Such a funding requirement includes support for the following activities:

- Planning, management, and administration.
- Scientific and developmental activity undertaken in preparation for the spill incident, *e.g.*, training of response personnel, preparing computer programs, and identifying critical habitats.
- Response activity undertaken in support of the OSC oversight function in those instances in which other conditions regarding use of the Pollution Fund have not been met, *e.g.*, instances in which a pollution discharge is averted, instances in which the Federal government does not intervene in clean-up and containment operations, *etc.*
- Capital equipment necessary to support response operations.
- Salaries of Federal employees participating in this program.

It is recommended that, regardless of source, funding should be available specifically for crisis response to oil spills and should be administered through a designated lead agency. Funds must be available on short notice for real-time analysis of samples, equipment purchase, transportation expenses, and short-term contracts. In addition, funding should be made available for longer term damage assessment studies. It is only through the *prompt* release of funds that well-coordinated and meaningful responses can be made to future spills.

LITERATURE CITED

Avolizi, R.J. and M. Nuwayhid. 1974. Effects of crude oil and dispersants on bivalves. Marine Pollution Bulletin 5:149-152.

Boehm, P.D., G. Perry and D.L. Fiest. 1978. Hydrocarbon chemistry of the water column of Georges Bank and Nantucket Shoals, February-November 1977. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Brown, R.S. and K.R. Cooper. 1978. Histopathologic analyses of zooplankton and benthic organisms from the vicinity of the ARGO MERCHANT. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Bumpus, D.F. 1973. A description of the circulation of the continental shelf of the East coast of the United States. Progress in Oceanography 6:111-157.

Center for Ocean Management Studies. 1978. In the Wake of the ARGO MERCHANT, Proceedings of a Symposium Held January 11-13 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Collins, B.P., C.A. Griscom and E.J. Hoffman. 1978. Near-bottom transport in the vicinity of the ARGO MERCHANT: A seabed drifter study. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Cornillon, P. 1978. Oil droplet measurements made in the water at the ARGO MERCHANT. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Cournoyer, N.G. and J.K. Kindahl. 1977. Travel and tourism in Massachusetts, 1976. University of Massachusetts, Amherst, Massachusetts.

Fricke, P. and J. Maiolo. 1978. Public knowledge and perceptions of the effects of the ARGO MERCHANT oil spill. *In* Center for Ocean Management Studies, In the Wake of ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Gilfillan, E.S. 1975. Decrease of net carbon flux in two species of mussels caused by extracts of crude oil. Marine Biology 29:53-57.

Grose, P.L. and J.S. Mattson (eds). 1977. The ARGO MERCHANT Oil Spill—A Preliminary Scientific Report. NOAA Special Report, Washington, DC. 133 pps.

Hartung, R. and G.S. Hunt. 1966. Toxicity of some oils to waterfowl. Journal of Wildlife Management 30:564-569.

Lee, R.F. 1975. Fate of petroleum hydrocarbons in marine zooplankton. *In* Proceedings of the 1975 Conference on Prevention and Control of Oil Pollution.

Longwell, A.C. 1977. A genetic look at fish eggs and oil. Oceanus 20(4): 46-58.

Longwell, A.C. 1978. Measuring stress responses of fish eggs at the cell and chromosome levels in the laboratory and at sea—how and why. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

MacLeod, W.D., Jr., M. Uyeda, L.C. Thomas and D.W. Brown. 1978. Hydrocarbon patterns in some marine biota and sediments following the ARGO MERCHANT spill—a preliminary report. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Malins, D.C. (ed). 1977. Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Academic Press, Inc., New York. 500 pps.

Morris, R.J. 1974. Lipid composition of surface films and zooplankton from the eastern Mediterranean. Marine Pollution Bulletin 5:105-109.

Polak, R., A. Filion, S. Fortier, J. Lanier and K. Cooper. 1978 Observations on ARGO MERCHANT oil in zooplankton of Nantucket Shoals. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Pollack, A. 1977. Crisis Science: Investigations in Response to the ARGO MERCHANT Oil Spill. Masters Thesis, Department of Civil Engineering Massachusetts Institute of Technology, Cambridge, Massachusetts.

Powers, K.D. and W.T. Rumage. 1978. Effect of the ARGO MERCHANT oil spill on bird populations off the New England coast, 15 December 1976 through January 1977. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Pratt, S.D. 1978. Interactions between petroleum and benthic fauna at the ARGO MERCHANT spill site. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Sherman, K. (ed). 1977. The ARGO MERCHANT Oil Spill and Fishery Resources of Nantucket Shoals: A Preliminary Assessment of Impact. International Council for Exploration of the Sea. CM 1977/E:58. 39 pps.

Sherman, K. and D. Busch. 1978. The ARGO MERCHANT oil spill and the fisheries. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Stolzenbach, K.D., O.S. Madsen, E.E. Adams, A.M. Pollack and C.K. Cooper. 1977. A Review and Evaluation of Basic Techniques for Predicting the Behavior of Surface Oil Slicks. Technical Report #222, Ralph Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Thurberg, F., E. Gould and M.A. Dawson. 1978. Some physiological effects of the ARGO MERCHANT oil spill on several marine teleosts and bivalve molluscs. *In* Center for Ocean Management Studies, In the Wake of the ARGO MERCHANT Conference, January 1978. University of Rhode Island, Narragansett, Rhode Island. 181 pps.

Tingle, A.G. and D.A. Dieterle. 1977. A Numerical Oil Trajectory Forecast Model to Assess the Hazard to Long Island Beaches From Oil entering the New York Bight Apex, February 11-24, 1977. Report Number BNL 50649, Brookhaven National Laboratory, Long Island, New York.

U.S. Department of Commerce. 1977a. Fisheries of the U.S., 1976. NOAA/NMFS, Washington, DC.

U.S. Department of Commerce. 1977b. Program Development Plan for NOAA Response to Spills of Oil and Other Hazardous Substances. NOAA/MESA/ERL, Boulder, Colorado. Unpublished.

U.S. Department of Commerce. 1977c. The ARGO MERCHANT Oil Spill Incident: December 15, 1976 to February 15, 1977. A Report to the Administrator, NOAA Disaster Survey Report 77-1, Rockville, Maryland. 42 pps.

U.S. Department of Transportation. 1977. The ARGO MERCHANT Oil Spill On-Scene Coordinator's Report. U.S. Coast Guard, Marine Safety Office, Boston, Massachusetts. 124 pps.

Wyant, T.S. 1977. Computer-Printouts of ARGO MERCHANT Oil Spill Trajectory for Each Month of 1977. U.S. Geological Survey, Reston, Virginia. Unpublished.

Wyant, T.S., R.A. Smith and J.R. Slack. 1977. The ARGO MERCHANT Oil Spill: Trajectory Model Verification on Forecasting Studies. U.S. Geological Survey, Reston, Virginia. Unpublished.