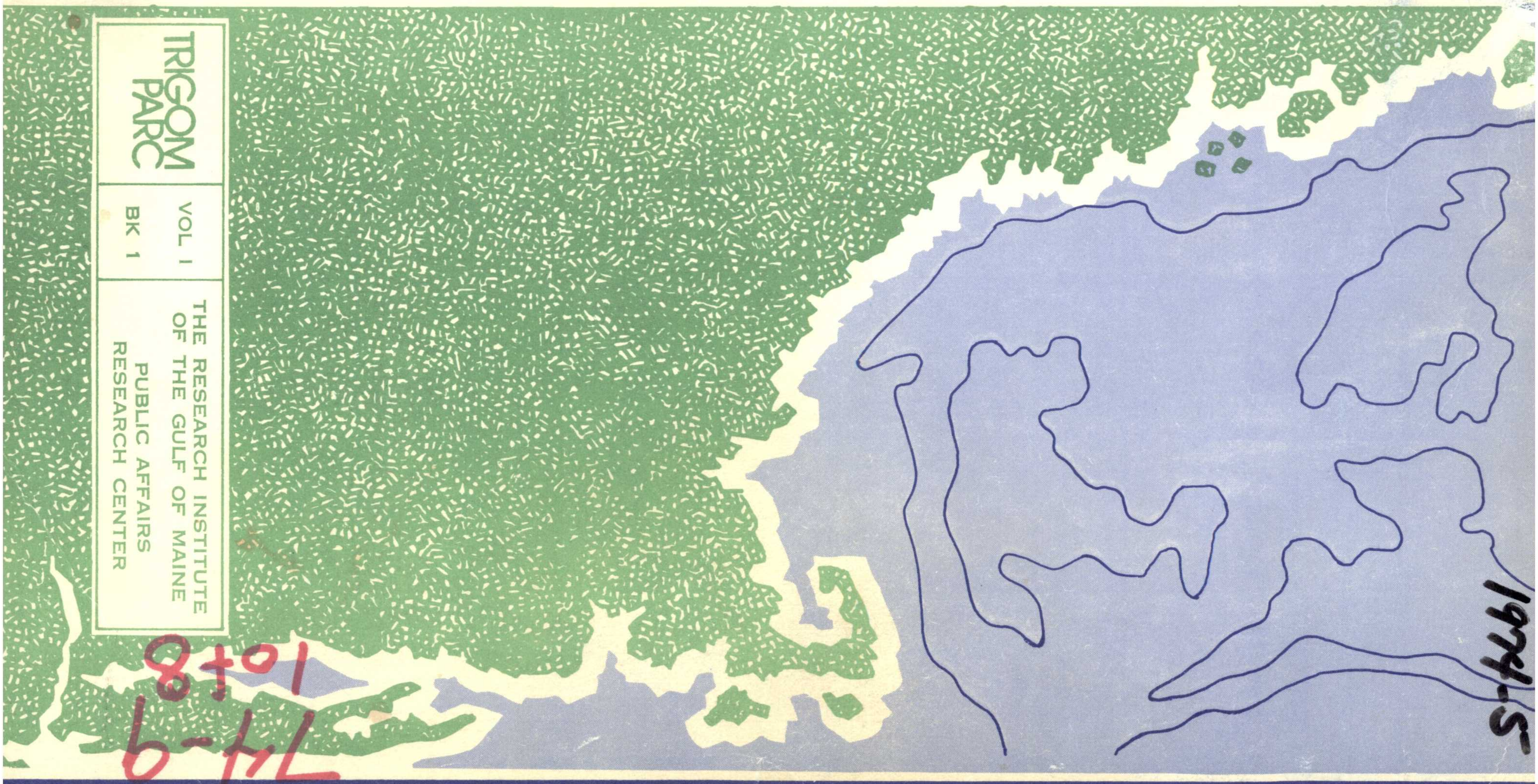
A Socio-Economic and Environmental Inventory of the North Atlantic Region

Sandy Hook to Bay of Fundy



TRIGOM
PARC

VOL I
BK 1

THE RESEARCH INSTITUTE
OF THE GULF OF MAINE

PUBLIC AFFAIRS
RESEARCH CENTER

1974-5

74-9
1 of 8

TRIGOM

The Research Institute of the Gulf of Maine (TRIGOM) is a consortium of academic institutions and research agencies dedicated to the advancement of marine science and oceanography through cooperative efforts.

TRIGOM provides a variety of services to the marine science community through publications, meetings, and seminars on subjects of common interest. In addition, the Institute seeks to undertake its own projects which will help the state and region better plan for multiple uses of the coast and to manage its natural resources.

ACADEMIC MEMBERSHIP

Bates College

Bowdoin College

Colby College

Cornell University

Maine Maritime Academy

Nasson College

Saint Francis College

Southern Maine Vocational Technical Institute

University of Maine at Farmington

University of Maine at Orono

University of Maine at Portland-Gorham

PARC

The Public Affairs Research Center was established at Bowdoin College in 1966 to act as focal point for conducting studies of economic conditions, community government, regional development, and public administration. These activities are financed through research contracts with government and business organizations, as well as through the assistance of foundation grants and contributions from business firms and individuals.

A Socio-Economic and Environmental Inventory of the North Atlantic Region

including the Outer Continental Shelf and adjacent
waters from Sandy Hook, New Jersey, to Bay of Fundy

VOLUME I

Book 1

Submitted to Bureau of Land Management, Marine Minerals Division
as partial fulfillment of Contract 08550-CT3-8

November 1974

The Research Institute of the Gulf of Maine
Box 2320
South Portland, Maine

Information in this document is unrestricted in use and may be copied in part or total, provided reference is made to TRIGOM-PARC as authors and BLM as the supporting agency.

ABSTRACT

A ten month study by The Research Institute of the Gulf of Maine (TRIGOM) was conducted to gather and inventory the existing environmental socio-economic data of the coastal zone and adjacent outer continental shelf (OCS) from Sandy Hook, New Jersey, to Bay of Fundy. These data were based on the requirements for impact assessments prior to leasing offshore areas for oil, gas, and mineral exploration and production. The marine boundaries were Hudson Canyon, the 200 meter contour, and the Canadian international line; shoreward, the limit of salt intrusion was the boundary while some 38 counties were inventoried for socio-economic data. Over 300 persons were contacted or interviewed, 3800 documents reviewed for data by about 40 scientists and consultants. The following list shows the major topics inventoried and presented in the report:

Environmental
    Geological Oceanography and Hydrology
    Physical Oceanography
    Chemical Oceanography
    Meteorological Oceanography

Systems Ecology by Habitat
    Phytoplankton, Zooplankton, Benthic Invertebrates, Macrophytes, Fishes, Birds, Mammals

Unique and Endangered Environments
    Rare, Endangered, and Threatened Species

Environmental Quality

Socio-Economic
    Demography
    Petroleum
    Recreation
    Transportation
    Fisheries
    Land and Water Use

Biological data of plants and animals and their environmental relationships have been organized according to a functional habitat-system approach rather than by taxonomic categories alone. Ten habitats are presented with about 150 representative key species. Life history profiles for key species are included along with checklists of reported species in each habitat. A series of maps of the areal extent of the habitats was prepared. Water and air quality print-outs for all coastal towns and counties are included. The report in 3 volumes is about 4900 pages in length with over 700 illustrations and 300 tables.

PREFACE TO FINAL REPORT

The material and data contained in this report have been furnished to the Bureau of Land Management under the terms of Contract 08550-CT3-8. TRIGOM, as contractor, takes full responsibility for any errors or misstatements which may still exist. This inventory was put together from a large number of sources in a ten month period. In an effort of this size, operating on a very tight time schedule, there are likely to be a number of typographical and inadvertent errors. We ask the forebearance of our colleagues and our sponsor in accepting this edition as a working document which we hope will be used, corrected, and updated in the future. Any suggestions for changes and additions will be welcomed by TRIGOM.

At the time of submission of this report Appendix D, the bibliography, is still in preparation and will be included early in 1975 in a separate Book as the last part of Volume Three. This part will also include a detailed index to all chapters.

The Staff and Editors at TRIGOM thank the many authors and contributors to this study.

Edward H. Shenton, Program Manager
Portland, Maine
November 1974

TABLE OF CONTENTS

Volume One: Environmental Inventory

Book One: Chapters One, Two and Three

Page

Chapter 1.0 Introduction

Chapter 2.0 Regional Overview

Chapter 2.0 (Continued)

Chapter 3.0 Offshore Region
3.1 Geology of Offshore Provinces

Chapter 3.0 (Continued)

Chapter 3.0 (Continued)

3.5 Biological Oceanography

Volume One: Environmental Inventory

Book Two: Chapters Four and Five

Chapter 4.0 Major Sounds and Embayments
4.1 Geology of Major Sounds and Embayments

Chapter 4.0 (Continued)

4.2 Physical Oceanography

4.3 Chemical Oceanography of Coastal Waters

4.4 Meteorology and Climate

Chapter 4.0 (Continued)

Page

Chapter 5.0 Exposed Shorelines

Chapter 5.0 (Continued)

Volume One: Environmental Inventory

Book Three: Chapters Six through Twelve

Chapter 6.0 Maritime Strand (Marine-Terrestrial Transition Zone)

Chapter 7.0 Upland Environments

Chapter 7.0 (Continued)

Chapter 8.0 (Continued)

Chapter 9.0 Zooplankton

Chapter 9.0 (Continued)

Page

Euphausiacea

Chaetognatha

Coelenterata

Cladocera

Ctenophora

Pteropoda

Chapter 10.0 Benthic Invertebrates

Chapter 10.0 (Continued)

Chapter 11.0 Macrophytes

Chapter 11.0 (Continued)

Chapter 12.0 Fishes

Chapter 12.0 (Continued)

Volume One: Environmental Inventory

Book Four: Chapters Thirteen through Sixteen

Chapter 13.0 Birds of the North Atlantic Seaboard

Chapter 13.0 (Continued)

Chapter 14.0 Marine Mammals

Chapter 14.0 (Continued)

Chapter 15.0 Unique, Significant, and Endangered Environments

Chapter 16.0 Rare, Endangered, and Threatened Species

Chapter 16.0 (Continued)

Volume One: Environmental Inventory

Book Five: Chapter Seventeen

Chapter 17.0 Environmental Quality
17.1 Water Quality

17.2 Air Quality

Chapter 17.0 (Continued)

Page

17.3 Solid Waste Disposal

17.4 Ocean Disposal and Dumping

Volume Two: Socio-Economic Inventory

Chapters Eighteen through Twenty-Seven

Chapter 18.0 Introduction

Chapter 19.0 Population and Income Characteristics

Chapter 19.0 (Continued)

Chapter 20.0 (Continued)

Chapter 21.0 Petroleum and Petrochemicals

Chapter 22.0 Outdoor Recreational Activity

Chapter 22.0 (Continued)

Page

Appendix

Chapter 23.0 Transportation

Chapter 23.0 (Continued)

Chapter 24.0 Other Marine-Related Activities

Chapter 25.0 Fisheries

Chapter 25.0 (Continued)

Chapter 26.0 Land Use

Chapter 26.0 (Continued)

Chapter 26.0 (Continued)

Chapter 27.0 Environmental Data Gaps and Research Needs

Chapter 27.0 (Continued)

Volume Three: Appendices

Book One: Appendices A, B and C

Appendix A Additional Data Sources - Environmental

Appendix C (Continued)

Appendix C (Continued)

Volume Three: Appendices

Book Two: Appendices E and F

Appendix E Areal Extent of Marine Habitats

Appendix F Contract Work Statement

Volume Three: Appendices

Book Three: Appendix D (Bibliography forthcoming)

Chapter

1 Introduction

Page

1.0 INTRODUCTION

This report presents the final results of a ten-month study entitled a SOCIO-ECONOMIC AND ENVIRONMENTAL STUDY OF THE NORTH ATLANTIC COAST AND CONTINENTAL SHELF FROM BAY OF FUNDY TO SANDY HOOK, NEW JERSEY. The Study was conducted jointly by the staff of TRIGOM (The Research Institute of the Gulf of Maine) and PARC (Public Affairs Research Center, Bowdoin College) for the United States Department of Interior, Bureau of Land Management (BLM), Marine Minerals Division, under contract 08550-CT3-8 during the period June 29, 1973 to July 29, 1974.

1.1 BACKGROUND

As a nation looking for possible solutions to our need for additional energy sources, attention has been focused on the potential of the Outer Continental Shelves (OCS) off New England and the mid-Atlantic regions. The OCS of the United States has proven to be a prolific supplier of oil and gas in the Gulf of Mexico and offshore California. Development of the OCS must be preceded by analyses of potential impacts upon the related environments, according to the National Environmental Policy Act (NEPA) of 1969. To perform such analyses, the existing environmental data together with the various existing economic factors of the areas must be described.

The primary purpose of this study has been to gather available data describing the existing environment of the coastal zone and adjacent continental shelf of the North Atlantic area (both natural and socio-economic) and present these data in comprehensive descriptions.

1.2 SCOPE OF WORK

1.2.1 AUTHORIZATION

The scope of the study was initially defined in a Request for Proposal (RFP BLM 73-2) April 2, 1973, and was amended by the proposal of TRIGOM dated May 30, 1973.

1.2.2 GEOGRAPHICAL AREA COVERED

The regional coverage from Sandy Hook, New Jersey, to Bay of Fundy was established with boundaries shown on Figure 1-1. The marine boundaries were loosely defined as the Hudson Canyon on the South, the 200 meter contour along the continental shelf, and an undetermined international boundary between the United States and Canada. The shoreward extent was generally agreed to be the coastal zone or extent of salt water intrusion for marine environmental data, and the coastal counties for socio-economic data. These counties are listed in Table 1-1.

In the process of conducting the study, these arbitrary boundaries were in some cases varied.

1.2.3 TOPICAL COVERAGE

A detailed outline of the topics to be reviewed and mentioned as agreed in the contract is presented in Appendix F. Table 1-2 contains an abbreviated list of subject areas reviewed in the report.

1.3 OBJECTIVES

1.3.1 PRIMARY OBJECTIVES

The primary objectives of this socio-economic and environmental inventory of the North Atlantic region were:

- To develop a comprehensive inventory of marine environmental data for the coastal zone and adjacent waters of the outer continental shelf

- To conduct a study of the socio-economic factors operating in the region from Bay of Fundy (Eastport, Maine) to Sandy Hook, New Jersey

- To combine these previous steps into a comprehensive compilation for use in preparing impact assessments of the development of offshore energy resources.

- To define the gaps and deficiencies that exist in the present information baseline as preliminary to conducting new research and field surveys.

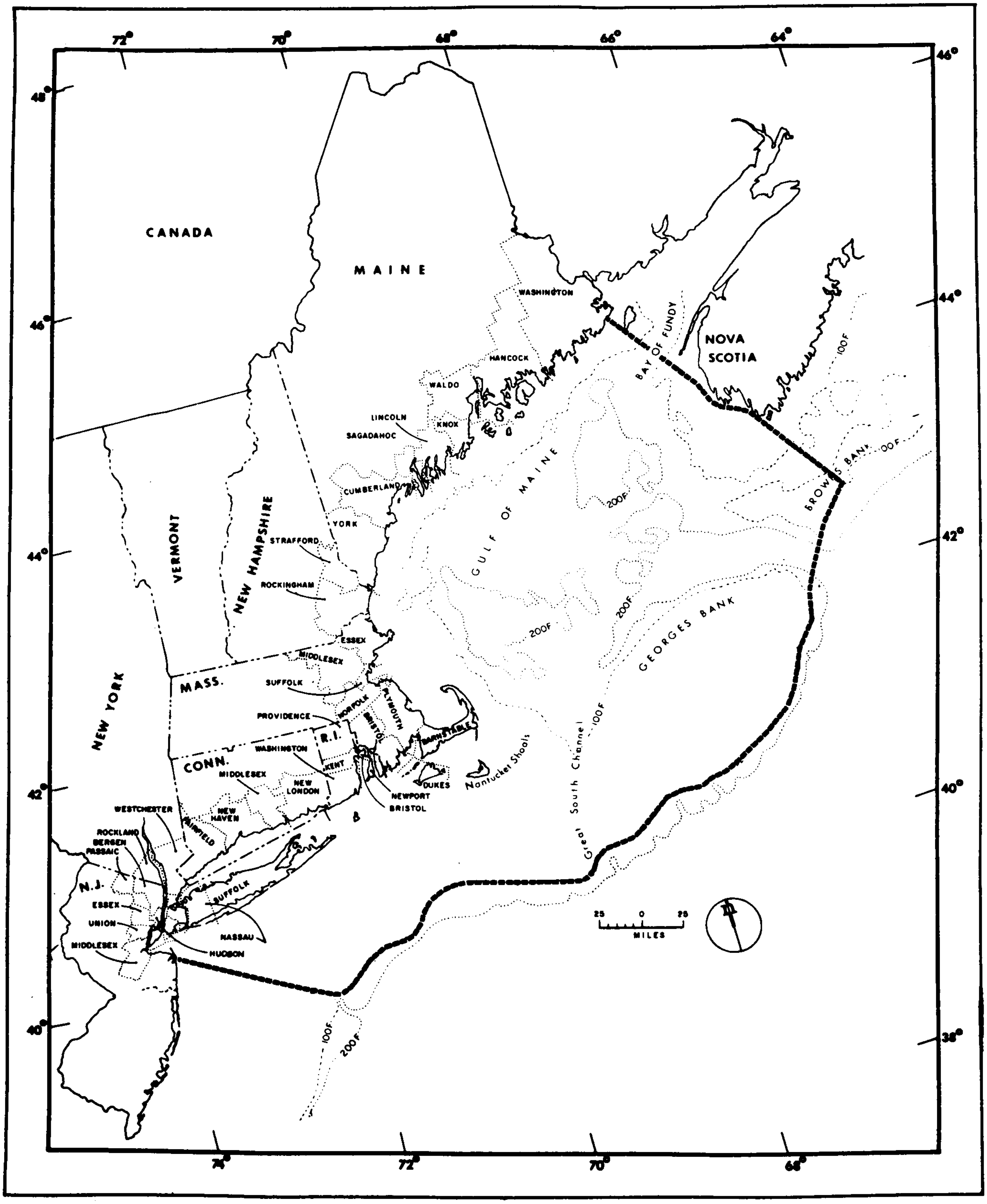
1.3.2 SECONDARY OBJECTIVES

A secondary set of objectives which altered the scope of work and made major demands on the project was added just prior to contract negotiation. This addition was requested to meet the requirements of the Council on Environmental Quality (CEQ), which included:

- Provision of general biological habitat descriptions for the two biographical regions including key species for each one

- Mapping the areal extent of these habitats

- Provision of a specific list of life history data for all key species



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 1-1

The Study Region

Table 1-1 BLM North Atlantic Inventory: List of coastal counties

Maine:

- Washington
- Hancock
- Waldo
- Knox
- Lincoln
- Sagadahoc
- Cumberland
- York

New Hampshire:

- Strafford
- Rockingham

Massachusetts:

- Essex
- Middlesex
- Suffolk
- Norfolk
- Plymouth
- Barnstable
- Nantucket
- Dukes
- Bristol

Rhode Island:

- Newport
- Bristol
- Providence
- Kent
- Washington

Connecticut:

- New London
- Middlesex
- New Haven
- Fairfield

New York:

- Suffolk
- Nassau
- Westchester
- Rockland
- New York City (5 counties)

New Jersey:

- Bergen
- Passaic
- Hudson
- Essex
- Union
- Middlesex

Table 1-2 General Topics Inventoried

- Environmental Inventory
  - Meteorological Oceanography
  - Physical Oceanography
  - Geological Oceanography
  - Chemical Oceanography
  - Biological Oceanography
    - Systems Ecology
      - Plankton-based pelagic
      - Benthos
      - Mussel-Oyster Reefs
      - Worm Clam Flats
      - Salt Ponds
      - Salt Marshes
      - Sandy Shores
      - Rocky Shores
      - Shoreland Strand
      - Terrestrial
    - Phytoplankton
    - Zooplankton
    - Benthic Invertebrates
    - Macrophytes
    - Fishes
    - Birds
    - Mammals
  - Unique and Endangered Environments
  - Rare, Endangered and Threatened Species
  - Environmental Quality

- Socio-Economic Inventory
  - Demography
  - General Economy
  - Petroleum and Petrochemicals
  - Recreation
  - Transportation
  - Fisheries
  - Other Marine Activities
  - Land and Water Use
    - Urban
    - Rural
    - Archaeological and Historic Sites
  - Land Use Plans
  - Land and Water Use Controls

1.4 METHODS AND APPROACH

This section will describe the methods and approaches used in the compilation of the environmental inventory. A similar discussion of the socio-economic inventory follows in Chapter 18. A set of tasks was initially developed, organized around four major areas as shown on Figure 1-2. It should be noted that, to a large extent, the tasks were conducted concurrently.

TASK 1: DATA COLLECTION (INITIAL)

- Organize the program approach - conduct a local workshop
- Review the literature and **data source**
- Conduct a pilot study of Maine
- Develop the overall study requirements

Approach

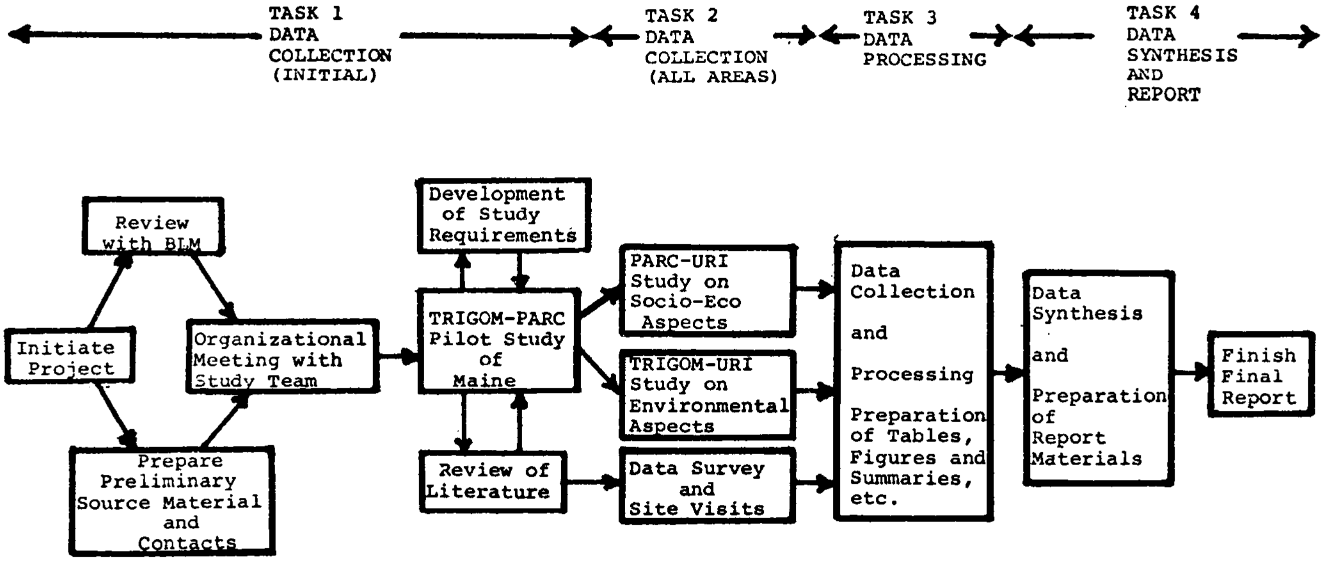
The intent of the task was to develop the proper techniques and requirements for the rest of the program by conducting a pilot study of the state of Maine where we could test a variety of approaches quickly and inexpensively and incorporate these into the larger survey of the entire region.

Method

The pilot study, however, was diverted by the pressing needs of the CEQ contractor, the Massachusetts Institute of Technology (MIT). An extremely short period of time was available in which to supply specific biological and areal descriptions. As a result, a separate set of interim tasks was established to provide MIT scientists with detailed biological habitat information. These data were presented in two sets of working papers (TRIGOM 1973a and 1973b). Results of this task largely influenced the subsequent organization and conduct of the remainder of the study as will be described in Regional Overview of Biology, Chapter 2.4.

TASK 2: DATA COLLECTION (ALL AREAS)

- Telephone Survey
- Follow-up mailing
- Visits to selected laboratories



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 1-2

Task Descriptions (TRIGOM, 1973a)

Approach

A large number of contacts were made in each state at agency, institutional, and federal levels as well as in Washington to identify ways to access data banks, on-going research programs, and bibliographic sources.

Methods

Telephone/Letter Survey: During the course of the study approximately 230 contacts were made through a telephone survey to obtain environmental data and information about related programs. A separate effort of requesting reports or data sources by mail was also conducted, as well as a routine mail follow-up to initial telephone contacts. A study abstract was included in any written request or follow up to briefly summarize the BLM program needs. The reverse side contained a map. An example is shown in Figure 1-3.

Field Visits: In cases when information was too extensive or in an uncompiled form TRIGOM sent data specialists to visit and obtain what was needed. About 95 visits were made between July, 1973, and April, 1974, by staff and consultants. A complete list of visits, agency/facility name, and persons contacted can be found in Appendix B.

Literature and Research Services: Use was made of the Smithsonian Science Information Exchange (SSIE) listing service of ongoing research projects. Two searches for all states in the study area produced about 250 notices (Appendix C-2 presents all relevant research notices arranged by state). As a follow-up, cards were sent to each principal investigator listed, requesting information and recent publications. Approximately 15 percent of the requests produced replies with papers. However, we note that replies continue to arrive some five to six months after the initial request.

Also used was the National Technical Information Service (NTIS). A listing of all relevant annotated bibliographies received for all topics in the study is presented in Appendix D. A total of 305 were reported. Although NTIS has over 300,000 listed citations in their system since 1964, the rather meager number of 305 appears to be only a minor portion of the total publications in the open literature and is probably not representative.

Similar requests for bibliographic citations or inventory data were made at this time to National Oceanographic Data Center (NODC), Environmental Protection Agency (Headquarters and Region I), NOAA, National Marine Fisheries Services; and NOAA's MESA, New York Bight Program, and the U.S. Army Corps of Engineers. A more complete description of the results and an evaluation of these efforts in relation to this study

TRIGOM
The Research Institute of the Gulf of Main

96 Falmouth S
Portland, Maine 04
Tel. (207) 773-2

Figure 1-3

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY
of the
OUTER CONTINENTAL SHELF AND ADJACENT WATERS

A Study by

The Research Institute of the Gulf of Maine

ABSTRACT

Background

The nation recently has focused its attention on the potential sources of clean energy suspected to lie beneath its continental shelves. With the possibility of inadequate supplies of energy, we now are beginning to investigate sources off the New England coast. Prior to leasing and developing any of these offshore areas we must have sufficient environmental, social, and economic data to aid in the decision process. TRIGOM has been awarded a contract by the Bureau of Land Management of the Department of Interior to undertake a one-year study to collect and assemble all relevant data for the North Atlantic outer continental shelf from the Bay of Fundy to Sandy Hook, New Jersey.

Objectives

The study objectives are to develop a comprehensive inventory of marine environmental data and related socio-economic factors for the coastal zone and outer shelf areas. The inventory will be designed to aid in gathering data to assess the impact of the development of energy resources and define areas where no relevant data exist.

The following list is a summary of the topic areas in which data, published and unpublished reports, and ongoing research are sought:

PHYSICAL ENVIRONMENT: Estuaries, tides, waves, hydrography, currents, temperatures

CHEMICAL OCEANOGRAPHY: Oxygen, nutrients, heavy metals, organic pollutants

GEOLOGY: Regional, bathymetry, structure, sediments

METEOROLOGY: Atmospheric circulation, climatic elements, air-sea interaction

SYSTEM ECOLOGY: Phytoplankton, zooplankton, benthos, fisheries, marine mammals, birds, coastal vegetation

UNIQUE AND ENDANGERED ENVIRONMENTS

INDUSTRIAL AND COMMERCIAL ACTIVITY: Resource, manufacturing, service industries

PETROLEUM INDUSTRY

DEMOGRAPHY: Population, income and employment, education and job skills

LAND AND WATER USES

POLLUTION SOURCES

TRANSPORTATION SYSTEMS

The TRIGOM study team is a three-part group composed of TRIGOM staff, the Bowdoin College Public Affairs Research Center, and the University of Rhode Island. For further information, contact: TRIGOM, Dr. Donald B. Horton or Ned Shenton (207) 773-2981 extension 306; Bowdoin (PARC), Mr. Carl Veazie (207) 725-8731 extension 591; University of Rhode Island, Dr. Saul Saila (401) 729-6239.

is given in Appendix A.

TASK 3: DATA REDUCTION

- Assemble initial bibliographies
- Collate data from field visits
- Assign chapter and topic authors
- Develop and organize report outline

Approach

During this task, we attempted to bring together the first results of the literature collection, the visits to facilities, and other inputs received. Specific topic areas such as marine geology, chemical oceanography, etc., were assigned to chapter authors. A full list of the topical areas and authors assigned is given in the acknowledgement section, and the subject is discussed further under 1.5 Organization of the Report. In general, our basic approach was to organize the study by natural habitats as defined by Odum et al. (1969) and others, rather than following the conventional topical approach.

A second aspect of this task was a redefinition of the report outline. This was necessary as a result of the decision to adopt the habitat versus topical approach, and also as the specific requirements for impact analysis were defined. (See Methods below).

Methods

Assigning Chapter Authors: A number of scientists who had recently contributed to the writing of the Coastal and Offshore Inventory of Cape Cod to Cape Hatteras (URI, 1973 and 1974) were retained to either be reviewers or contribute a portion covering the southern extent of the study area. Other professionals within the study region were contracted for specific chapter treatments.

Coordination of Authors: A considerable effort was required to coordinate the efforts of authors whose sections were closely related. TRIGOM staff assumed this responsibility, but were hindered to some extent by the large number of authors situated at some distance from one another throughout the study region. A good interchange of data did result in some cases, an example being among the estuarine dynamics. physical oceanography, and meteorology authors. There was also a similar exchange of data between the PARC - URI economics group and the marine environmental scientists.

Data Retrieval: TRIGOM staff continued to acquire data and supply information to the chapter authors not easily obtained or available in the published literature. Data retrieved from facility visits were reviewed and where necessary, second or third trips made. Reports were received and accumulated, a bibliography was constructed, arranged by topic area, and periodically distributed to chapter authors.

Refinement of Information Needs: To make sure that our topics selected on the proposal and subsequent negotiations were complete and adequate for the anticipated activities both offshore and onshore, we reviewed several current Environment Impact Statements. Among these were several documents by BLM (1973) for the Gulf of Mexico, and the U.S. Army Corps of Engineers (1973), also in the Gulf of Mexico. From this review, a matrix was developed (Table 1-3) which enabled us to see additional environmental topics that should be emphasized including some of the socio-economic factors. As a result, an adjustment was made to the initial topics to be inventoried, for example, by adding hydrology and water resources data and solid waste considerations.

Review of Chapters: Finally, the submitted environmental sections prepared by consultants were reviewed for general accuracy, comprehensiveness, and over-all scientific quality. In many cases, these reviews were made by outside independent consultants.

TASK 4: SYNTHESIS OF DATA AND FINAL REPORT

- Distribute report outline
- Conduct program review
- Prepare final report

Approach

The intent was to develop an outline of topics early in the program and continue to update, improve, and add to it along the way. Toward the completion of the project, we had planned to conduct a one-day review of the program using an advisory board. This review committee would act as a steering body for the final report.

Methods

The outline of all topics to be inventoried was issued in the fourth month and reviewed and revised monthly so as to include topics and information discovered or decided to be of importance to the study. Although it became impossible to conduct a review (advisory board) on the entire study, a one-day review was held of the socio-economic report in April.

Table 1-3: Data Needs Matrix

ACTIVITY	DIRECT EFFECTS	PARAMETER IMPLIED
1. Dredging and Spoil Disposal 1/	a. habitat loss	a. habitat inventory (% loss over time, history of endangered environments-i.e., wetlands) productivity index of habitats
	b. destruction and loss of resident biota	b. inventory of biota by habitat and notation of those species endangered or threatened
	c. interference with ground water quality and quantity	c. water table contours and quality, identification of major aquifers
	d. salinity intrusion	d. estuarine salinity profiles, gw contours
	e. turbidity	e. delineation of bottom sediments; current levels of turbidity and current sources of sedimentation, current O_2 profiles
	f. alteration of natural current and wave patterns	f. definition of present current and wave patterns
	g. contamination of dredged area and disposal site with toxic elements in sediments	g. inventory of sediments - source, origin, age; sedimentological parameters (texture, heavy minerals, toxins)
2. Construction of Pipelines 1/	a. disruption of bottom habitat - open ocean	a. same as (a) and (b) above
	b. turbidity - open ocean	b. temporary effect; dependent on type of sediments and current sediment levels
	c. disruption of drainage systems in wetlands	c. watershed drainage systems
	d. destruction of marsh vegetation	d. inventory of unique or endangered vegetation
	e. loss of habitat	e. inventory of habitats and ecosystems
	f. erosion	f. topographic contours, soil maps

3. Supertanker Operations 1/	a. increased turbulence, scouring and wave generation causing erosion and sediment transport, and increased turbidity	a. channel depths, composition of sediments, existing turbidity levels, existing O_2 levels
	b. increased navigation hazard	b. level of use by small crafts; incidence of accidents in past
	c. spillage of oil causing 1. damage to beaches, recreation impacts, mollusc damage, destruction of bird nesting habitat	c. 1. Beach inventory -level of recreational use -extent of clam and mussel flats -definition of wildlife habitats and species nesting in intertidal zone
	2. damage to estuaries and their ecosystems	2. estuary inventory - description of ecosystems and key species including shellfish and finfish larvae
	3. damage to marsh vegetation and soil erosion	3. wetlands inventory - type of plants and soil (relative tolerance to oil pollution)
	4. destruction of species - decreased species diversity (toxic effects to organisms)	4. species diversity indexes - areas already stressed, areas of high quality, areas marginally stressed, tolerances of key species, trophic diagrams
	5. disruption of feeding or breeding or other behaviors of birds and mammals and other key species	5. life histories of key species
	6. sublethal damages to organisms	6. life histories of key species (life span, productivity, incidence of disease, etc.)
	d. oil spillage - nature of damages variable according to physiography, hydrography, weather conditions	d. physiography hydrography weather conditions

1/Note: Activity and Direct Effects information taken from the Corps of Engineers Report on Gulf Coast Deep Water Port Facilities - Vol. IV, Appendix F. 1973

4. Platform Construction 2/	a. turbidity	a. bottom geology
	b. bottom habitat loss	b. habitat inventory, species inventory
	c. new habitat loss	c. predictive analyses
	d. visual disruption	c. delineation of recreation areas and distance within line of sight
	e. navigation hazard	e. level of shipping and commercial fishing traffic, and routes
5. Drilling Operations 2/	a. turbidity from offshore disposal of drilling muds	a. habitat and species inventory
	b. loss of bottom habitat from disposal of drilling cuttings	b. habitat and species inventory
	c. change in salinity in area around drill rig from disposal of formation waters (brines)	c. life histories of species in pelagic and offshore bottom habitat - tolerances to changes in salinity
	d. burden on onshore waste treatment or disposal systems in areas adjacent (or on offshore disposal areas if available) from solid wastes; and oil or acid contaminated waters	d. availability of waste disposal sites - onshore and offshore
6. Construction of Onshore Storage Facilities 3/	a. loss of available land (possibly wetlands)	a. land use inventory (especially wetlands)
	b. when wetlands filled or drained, lowering of water table, release of organic nutrients to surrounding waters, loss of natural buffer to wave and wind erosion, possible contamination of groundwater; loss of fish and wildlife habitat	b. delineation of aquifer systems; definition of existing stresses or water quality; list of species in salt marsh habitat - especially those endangered or threatened
7. Construction of Refineries and Petrochemical Complexes 3/	a. increased air and water pollution loads	a. existing air and water quality conditions - needs of refineries and petrochemical complexes
	b. loss of lands	b. same as for storage facilities

7. Cont.	c. demands on water supply	c. water supply capabilities
	d. demands on electric power	d. power generation sites and capacities
8. Construction and Operation of Drill Rigs, Storage Facilities and Refinery Complexes 3/	a. demands on labor force - both temporary and permanent	a. labor force statistics
	b. increased income and tax base, overtime	b. total earnings/co
	INDIRECT OR INDUCED EFFECTS	
	a. demands on housing - increased rents; increased use of marginal units	a. cost of living index for the area; housing starts/yr
	b. demands on municipal services - schools, hospitals, garbage collection, sewage treatment, transportation, power, etc.	b. excess capacity of existing services - or excess demand

NOTES: 2/ Activities and Direct Effects taken from BLM Draft Environmental statement, Proposed 1973 OCS Sale No. 32, p. 21

3/ Activities and Direct Effects taken from both Corps and BLM reports, and additional sources

Review of the environmental inventory was conducted on a chapter-by-chapter basis, as described above. Thirty authors were involved in the writing of that volume.

1.5 ORGANIZATION OF THE REPORT

This report has been organized to provide inventory type data by topic area and by regional habitat area as well. The guiding philosophy of the study organization and the subsequent report has been to emphasize systems ecology in the environmental chapters. This approach is discussed in greater detail in the Regional Overview, Chapter 2.4, Biology.

In a simplified way, we have attempted to organize the report by major habitats such as Offshore Region, Major Sounds and Embayments, Exposed Shorelines, and so on, rather than by the more traditional scientific discipline (i.e., physical oceanography, geology, biology, etc.). This integrated approach we believe is important in understanding the functions and dynamics operative with a distinct region, and is based on extensive work in Systems Ecology by Odum (1969) and others. We have, however, added descriptive sections on the major plant and animal groups.

Therefore, we have first tried to view the total setting of the study area in the Regional Overview. These sections give a broad background of geology, meteorology, hydrology, biology, and chemical oceanography prior to considering each separate habitat and following that, each taxonomic group of organisms (e.g., phytoplankton, etc.)

The basic arrangement of the final report is into three volumes. These are the (1) Environmental Inventory and Assessment, (2) Socio-Economic Factors, and (3) Appendices. Within Volume One, there are several books. The Table of Contents of the report shows the major breakdown of chapters and topics. In summary this is:

Volume One — Environmental Inventory
Book one
Chapter 1. Introduction
2. Regional Overview

Environmental Systems
3. Offshore Region
4. Major Sounds and Embayments
5. Exposed Shoreline
6. Shoreland Strand
7. Upland Environments

Book two — Plant-Animal Profiles
8. Phytoplankton
9. Zooplankton

10. Benthic Invertebrates
11. Macrophytes
12. Fishes
13. Birds
14. Mammals

Other Environmental Aspects
15. Unique, Significant and Endangered Environments
16. Rare, Threatened, and Endangered Species
17. Environmental Quality

Volume Two — Socio-Economic Inventory

Chapter 18. Introduction
19. Demography
20. Economic Overview
21. Petroleum
22. Recreational Activity
23. Transportation
24. Other Marine Activities
25. Fisheries
26. Land and Water Use
27. Summary and Recommendation

Volume Three — Appendices to Volume One
A. Additional Data Sources
B. Contacts
C. Ongoing Research
D. Bibliography
E. Areal Extent of Habitat
F. Contract

1.6 LIMITATIONS

In a study such as the present one, which has at once an enormous scope and an all too limited time allowance for preparation, it is only understandable that there may be a number of distinct limitations placed both on the contract group and on the resulting product.

Briefly, we will try to list the areas in the study where problems in the approach, the results, or the lack of definition make the report less than might be desired. This is not meant to be an excuse for performance or a criticism of anyone's shortcomings; it is merely a statement of fact.

LIMITATION NO. 1: UNCERTAINTY OF PURPOSE

The present study was for the most part built around the RFP, and initial outline proposed by TRIGOM, a series of conversations with BLM personnel, and the specific requirements of the CEQ/MIT task. The basic intent was a broad inventory of a large list of diverse topics. There was for a considerable time some uncertainty as to the purpose of the inventory. As a result, it was difficult to define what elements of the study were most critical and which were irrelevant.

LIMITATION NO. 2: FOCUS: OVERALL REGION OR SITE SPECIFIC LOCALITY

Since there was an uncertainty here too, general direction was given that the socio-economic inventory was to be general with data aggregated at the county level, not site specific. The environmental side was directed toward comprehensive treatments rather than voluminous aggregations of detailed data, with a proviso to include occasional detailed studies where pertinent. As a result, the report is limited.

While it may aid in the preparation of site specific studies or EIS's, it is doubtful, since the effort has been to uniformly cover some 6,000 miles of coastline and all the offshore areas, that enough detail exists on which to base a site specific statement. This conclusion will be developed and supported in more detail in Chapter 27, Summary and Recommendations.

LIMITATION NO. 3: TIME CONSTRAINTS

A period of ten months was allowed to conduct the study. This is hardly adequate considering the steps involved: formulating an approach, collecting the data, assembling the pieces, and writing comprehensive sections (some possibly for the first time). It was an uncomfortably short time to attempt such an all-inclusive work. It is reasonable then to say that it is at best a first approximation, and cannot be considered complete, exhaustive, thorough, or the like. Any attempt to imply that these are <u>all</u> the pertinent data would be incorrect.

This is especially so for the life history data for the "key species." By stating "no information" we are saying that no data were readily available within the period of time allotted or at the particular library used. It is likely that somewhere data may be available.

LIMITATION NO. 4: DATA CONSTRAINTS

Certain portions of the data we have collected are the most recent and best available at this time, but very likely will be changed or improved within a year or two. Such parameters as air and water pollution data, land use information, economic factors, and so on, could change significantly and need re-examination. Each element should therefore be examined for its value in future use. In addition, a number of data bases (wetlands inventories, economic evaluations, marine resource analyses, recreational estimates) are already outdated, some being at least 10 years old. In such cases, data must be regarded as indicative only, and serve as example of the types of data necessary for future considerations.

1.7 ACKNOWLEDGEMENTS

The staff at TRIGOM gratefully acknowledges the assistance and cooperation of a large number of agencies, groups, and individuals who contributed freely to this study. A complete listing of those persons contacted and their affiliations is presented in Appendix B.

We are especially indebted to the contributing authors who gave willingly of their time and particular expertise, and without whom we could not have completed this report. The following are acknowledged and arranged by respective topic areas.

Geology		
South of Cape Cod	Dr. John Milliman	Woods Hole Oceanographic Institution
Gulf of Maine	Dr. Harold Palmer	Severna Park, Maryland
Beaches and Estuaries	Mr. Barry Timson	Maine Bureau of Geology
Physical Oceanography		
Northern Region	Dr. Joseph Graham	Maine Department of Marine Resources
Southern Region	Dr. Barbara Welsh	University of Connecticut, Marine Sciences Institute
	Ms. Janet P. Herring	University of Connecticut, Marine Sciences Institute
Chemical Oceanography	Dr. Ted Loder	University of New Hampshire
	Mr. Tom Shevenell	University of New Hampshire
Meteorology/Climatology	Dr. James Havens	University of Rhode Island
	Mr. Ed Levine	University of Rhode Island
	Dr. David Shaw	University of Rhode Island
System Ecology	Mr. Stanley Chenoweth	Boothbay Harbor, Maine
	Dr. William Gilbert	Colby College
	Dr. Mary Gilbert	Colby College
Phytoplankton	Dr. Hugh Mulligan	University of New Hampshire
	Ms. Frances DeLara	University of New Hampshire
Zooplankton	Dr. Donald B. Horton	TRIGOM
	Mr. William Johnson	University of Rhode Island
	Mr. Paul Reilly	University of Rhode Island
	Mr. Bruce Rogers	University of Rhode Island
Benthic Invertebrates	Mr. Alden Stickney	Maine Department of Marine Resources
	Dr. Peter Larsen	Maine Department of Marine Resources
	Mr. Sheldon Pratt	University of Rhode Island

Macrophytes	Dr. Alton Gustafson Dr. Barbara Heavers	Bowdoin College University of Rhode Island
Fishes	Mr. Stanley Chenoweth	Boothbay Harbor, Maine
Birds	Dr. Frank Heppner Mr. William Townsend Ms. Lisa Gould	University of Rhode Island Sorrento, Maine University of Rhode Island
Marine Mammals	Dr. Steve Katona Ms. Kate Darling Mr. David Richardson	College of the Atlantic College of the Atlantic Marine Department of Marine Resources
Population and Income	Dr. Kenneth E. McConnell	University of Rhode Island
Overview of Economic Activity Transportation	Mr. Carl E. Veazie	Public Affairs Research Center, Bowdoin College
Petroleum-Petrochemicals Other Marine Activities	Dr. Thomas Grigalunas	University of Rhode Island
Recreation	Dr. James W. McFarland	University of Rhode Island
Fisheries Economics	Dr. Gerald R. Visguillio	Connecticut College
Land Use	Mr. William MacDonald	Winthrop, Maine
Maine Rivers/ Water Research	Mr. Richard Harvey	Scarborough, Maine

Other Contributors and research assistants: Mrs. Jean Chenoweth, Mr. Herbert Perkins, Ms. Lee Perkins, Dr. Robert Knowlton, Mr. Diego Alonso, Ms. Nora Cippola, Robbin Hazard, Steve Burke, Steve Reinert.

Previewers of environmental chapters were: Drs. Dana Kester, Chris Martin, Michael Pilsen, Bernard McAlice and John Milliman.

We also wish to express our thanks and appreciation to the following groups and the many individuals, too numerous to list here, who were especially helpful in our search for environmental information and socio-economic data:

Federal
National Oceanographic Data Center, Washington, D.C.
National Marine Fisheries Service, Gloucester, Massachusetts
U.S. National Park Service, Washington, D.C.
U.S. Geological Survey, Boston, Massachusetts
U.S. Environmental Protection Agency, Boston & Needham, Massachusetts
Smithsonian Center for National Areas, Washington, D.C.

State
Bureau of Waterways, Maine Department of Transportation
Maine Department of Environmental Protection
Maine Department of Marine Resources, Boothbay Harbor, Maine
Maine Information Display Analysis System
Maine State Planning Office
Massachusetts Department of Natural Resources, Boston, Massachusetts
Rhode Island Department of Natural Resources
Rhode Island Division of Fish and Wildlife
Connecticut Department of Agriculture, Aquaculture Division, Milford, Conn.
Connecticut Department of Environmental Protection
New York Department of Environmental Conservation, SUNY, Stony Brook, N.Y.
New Jersey Department of Environmental Protection
Natural Resource Council of Maine, Augusta, Maine

Private and Regional
Curtis Harris Associates
American Geographical Society, New York
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
Reed & D'Andrea, South Gardiner, Maine
New England National Resources Council
New England Regional Commission
New England River Basins Commission (NERBC)

For a listing of all individuals contacted at these and other agencies, please consult the Directory of Contacts, Appendix B.

The staff of Public Affairs Research Center (PARC) and consultants wish to thank the following individuals:

Professors John Gates and Irving Spaulding reviewed and made comments on portions of the socio-economic draft. Professor Curtis Harris provided the baseline socio-economic forecasts for the North Atlantic states and coastal counties.

Research assistance was provided by a number of people, including Raymond Coombs, Peter Meyer, Robert Burford and Karen Simas. Valuable typing services were provided by Mrs. Mary Esty and Mrs. Catherine McFarland.

TRIGOM staff

Ms. Diane Brackett - Data Analyst and Archaeology

Mrs. Ruth Brown - Administrative Assistant
Ms. Barbara Caminiti - Secretary
Mr. Terry DeWan - Drawing Coordination and Production
Mrs. Nancy Goodspeed - Typist
Ms. Shirley Griffin - Habitat Mapping, Rare and Endangered Species
Ms. Betsy Holloway - Assistant
Dr. Donald B. Horton - Executive Director of TRIGOM and Zooplankton
Ms. Kathy Sage - Water Resources, Pollution Data, Endangered Environments
Mr. Edward H. Shenton - Program Manager
Ms. Judy Stanhope - Drawing Coordination

PARC Staff and Consultants

Dr. Thomas A. Grigalunas - Assistant Professor, Resource Economics, University of Rhode Island
Mr. William E. MacDonald - Planning Consultant
Dr. Kenneth E. McConnell - Assistant Professor, Resource Economics, University of Rhode Island
Dr. James W. McFarland - Assistant Professor, Resource Economics, University of Rhode Island
Mr. Carl E. Veazie - Director of PARC, Bowdoin College
Dr. Gerald R. Visguillio - Assistant Professor of Economics, Connecticut College
Ms. Johana Williams - PARC, Bowdoin College

Additional typists were:

Ms. Dee Ann Lamb - University of Rhode Island
Ms. Claudia Foret - University of New Hampshire
Ms. Elizabeth Masciadri

1.8 REFERENCES

Odum, H. T., B. J. Copeland, E. McMahan. 1974. Coastal ecological systems of the United States: a source book for estuarine planning. Conservation Foundation, Washington, D. C. 4 vol.

The Research Institute of the Gulf of Maine. 1973a. A socio-economic and environmental inventory of the outer continental shelf and adjacent waters, preliminary report, August 15, 1973, for Massachusetts Institute of Technology. Unpublished. TRIGOM, Portland, Maine. 123 pp.

____________________. 1973b. Preliminary report on general habitats from Sandy Hook, New Jersey, to Bay of Fundy, Nova Scotia. OCS Petroleum Study for Council on Environmental Quality and MIT, Part II. October 1, 1973. Unpublished. TRIGOM, Portland, Maine. 154 pp.

University of Rhode Island (URI), Marine Experiment Station, Graduate School of Oceanography. 1973. Coastal and offshore environmental inventory, Cape Hatteras to Nantucket Shoals, Marine Publications Series No. 2. URI, Kingston, Rhode Island. 681 pp.

____________________. 1974. Coastal and offshore environmental inventory, Cape Hatteras to Nantucket Shoals, Complement volume, Marine Publications Series No. 3. URI, Kingston, Rhode Island. 384 pp.

U. S. Army Corps of Engineers. 1973. Report on Gulf Coast deep water port facilities, Texas, Louisiana, Mississippi, Alabama, and Florida. Department of the Army, Lower Mississippi Valley Division, Corps of Engineers, Vicksburg, Va. 8 vol.

U. S. Bureau of Land Management. 1973. Final environmental statement for a proposed 1973 outer continental shelf oil and gas general lease sale, offshore Mississippi, Alabama, and Florida, OCS sale No. 32. Bureau of Land Management, Washington, D. C. 5 vol.

Chapter

CHAPTEF

2 Regional Overview

CHAPTER 2.0 (Continued) Page

The North Atlantic Region as depicted for the present study for the Bureau of Land Management encompasses an area stretching from Sandy Hook, New Jersey, on the south to the Canadian Border, generally referred to as the Bay of Fundy. The general bounds are shown in Figure 2-1, Study Area. The region includes the offshore areas of the Outer Continental Shelf (OCS) normally to a depth of 200 meters, although no clear distinction was made to cease coverage exactly at this depth. The southern border was the axis of the Hudson Canyon offshore, and inland included Middlesex County in New Jersey for the Socio-Economic portion of the study.

2.1 GEOLOGY OF NORTH ATLANTIC REGION

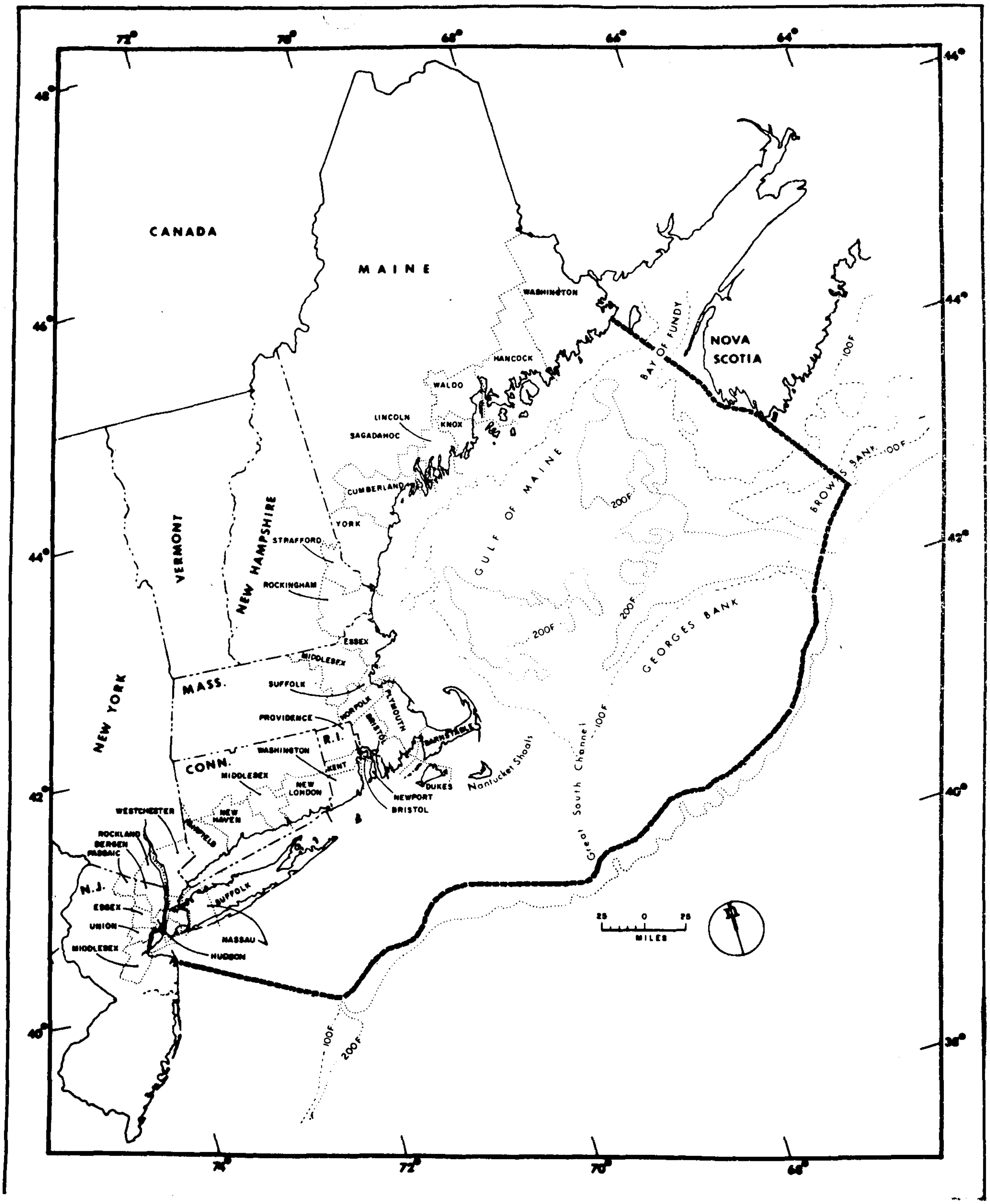
2.1.1 INTRODUCTION

The discussion presented in this chapter will include a general description and a summary of published and open file information related to the regional geology of the Gulf of Maine. The area under consideration (Figure 2-1) is bounded on the west and north by the littoral zone bordering the New England shoreline, a region accorded a separate chapter in this volume (Chapter 5.1). The Southern boundary is an arbitrary line drawn southeast from Sandy Hook, New Jersey, and terminating at the 200 meter isobath. The eastern limit was designated as coincident with this contour, and follows it along the eastern edge of Georges Bank until it encounters Northeast Channel. The boundary is projected across this depression, but turns north-northwest after reaching Browns Bank. It then continues along a curved line 3 nautical miles distant from Nova Scotia, crosses the Bay of Fundy, passes south of Grand Manan Island and intersects the Maine littoral off Eastport.

The region enclosed by the boundaries contains five major physiographic provinces. The largest, the Gulf of Maine, accounts for 35 percent of the area under consideration, and the adjacent shelf, 3 percent. Georges Bank accounts for about 25 percent, the Scotian Shelf for 7 percent and the North Atlantic Shelf for the remaining 20 percent. The geomorphic and geological aspects of each will be discussed individually in Chapter 3.1, Offshore Geology. The nearshore geology of major sounds and embayments as well as beaches is presented in Chapters 4.1 and 5.1 respectively.

2.1.2 PREVIOUS WORK

The proximity of several major centers devoted to marine research to the Gulf of Maine has resulted in an extensive bibliography which dates as early as Maury's comments regarding the Grand Banks deposits (1855). Early workers such as Shaler (1893), Upham (1894), D. W. Johnson (1924), and Goldthwait (1924) debated over the origin of the Gulf, but with



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 2-1 The Study Region

the advent of echo-sounding techniques, Shepard (1931) and later Chadwick (1948, 1949) confirmed the glacial character of the Gulf topography, and since that time others have elaborated on the glacio-fluviatile origin of the present Gulf floor. Murray (1947) and Malloy and Harbison (1966) have documented sounding surveys within the Gulf, and a detailed bathymetric chart of the region was prepared by Uchupi (1965).

Seismic profiles, both refraction and reflection, have revealed the complex nature of the subsurface in this region. Drake et al. (1954), Hoskins and Knott (1961) and Uchupi (1966b) present interpretations of structural configuration and sediment distribution, while other papers (Uchupi, 1966a, 1966c; Tagg and Uchupi, 1966) focus on local areas within the Gulf.

Geophysical investigations dealing with gravity and magnetics are best summarized by the recent work of Kane, Yellin, Bell, and Zietz (1972), who include some discussion of earlier work by Taylor, Zietz, and Dennis (1968), treating the aeromagnetic data for the eastern continental margin of the United States.

Reports of sediments and shallow structure are too numerous to cite here. Rather than present an extensive narrative of published materials, it seems appropriate to cite several publications which contain lengthy bibliographies. These materials are readily available, and include the current series of Professional Papers published by the United States Geological Survey in their series on the Atlantic Continental Shelf and Slope of the United States (Series 529). This program, begun in 1962 (see Emery, 1966, for authorization and scope) has resulted in a number of valuable and current reports. To date, publications relevant to the Gulf of Maine include:

Emery, K. O., 1966, Geological Background, 529-A
Uchupi, E., 1968, Physiography, 529-C
Stanley, D. J., 1969, Color of Marine Sediments, 529-D
Ross, D. A., 1970, Heavy Minerals of the Continental Margin from Southern Nova Scotia to Northern New Jersey, 529-G
Schlee, J., and Pratt, R. M., 1970, Gravels of the Northeastern Part, 529-H
Uchupi, E., 1970, Shallow Structure, 529-I
Trumbull, J. V. A., 1972, Sand-size Fraction of Bottom Sediments, New Jersey to Nova Scotia, 529-K.

The geological framework and petroleum potential of the region are discussed by Maher and Applin (1971), and Emery and Uchupi (1972) provide a complete synthesis of the region, plus the entire eastern continental margin, in a reference volume indispensible to marine scientists employed in studies in the western Atlantic Ocean.

The location of sediment samples collected during this program has been given by given by Hathaway (1971) along with a complete listing of the textural, petrographic, mineralogical, and chemical data obtained.

2.1.3 MAINLAND GEOLOGY OF NEW ENGLAND

The mainland portion of New England bordering the Gulf of Maine falls within the New England-Canadian Maritime physiographic province as outlined by Fenneman (1938). The region is an extension of the Appalachian mountain belt, and thus consists of a complex association of igneous and metamorphic rocks whose regional trend lies north-northeast to northeast. The region is characterized by a broad belt of stratified geosynclinal rocks between the Precambrian craton to the northwest and the Atlantic Ocean. Most of the strata are of early to middle Paleozoic age and have experienced metamorphism on a regional scale. A broad variety of igneous rocks, primarily of felsic composition, have been intruded into these units. Volcanic rocks exposed in coastal areas of Maine attest to a period of volcanism along the northwest margin of the present Gulf of Maine and within the Gulf proper.

In several places, Carboniferous structural basins within the pre-Carboniferous rocks extend across the coastline and into the adjacent continental shelf. Boston Basin contains Pennsylvanian volcanic detritus, conglomerates, and shale of Pennsylvanian and Permian age to a depth of about 3 km (Eardley, 1962). It may be that the restricted deposits of Carboniferous sediments in these basins are equivalent in time and origin with those occurring farther northeast in the Bay of Fundy, New Brunswick, Nova Scotia, and Newfoundland. If so a major structural feature of continental dimensions may lie across the Gulf (Kane et al., 1972) and be associated with the proposed transcurrent (Cabot) fault postulated by Wilson (1962a,b). This rift may have been active as early as early Silurian (Gates, 1969).

On the basis of tectonic character (U.S. Geological Survey, 1962) the region may be further subdivided into four elements which trend north to northeast (Figure 2-2). The two linear belts of Precambrian and Paleozoic igneous and metamorphic rocks termed the Western and Central New England Uplands are separated by a narrow band of unmetamorphosed Devonian and Triassic rocks which, in the southern sector, occupy the Connecticut Basin. The Central New England Uplands form the coastal area of the Gulf north of Portsmouth, and rocks in this province are folded and faulted igneous and metamorphic units locally invaded by granitic intrusions (plutons) and ring dikes up to a mile in diameter.

The easternmost portion of Massachusetts and all of Rhode Island lie in the fourth province, the Southeastern Platform. The western margin of this province is characterized in part by a thrust fault which forms the boundary between it and the Central New England Uplands.

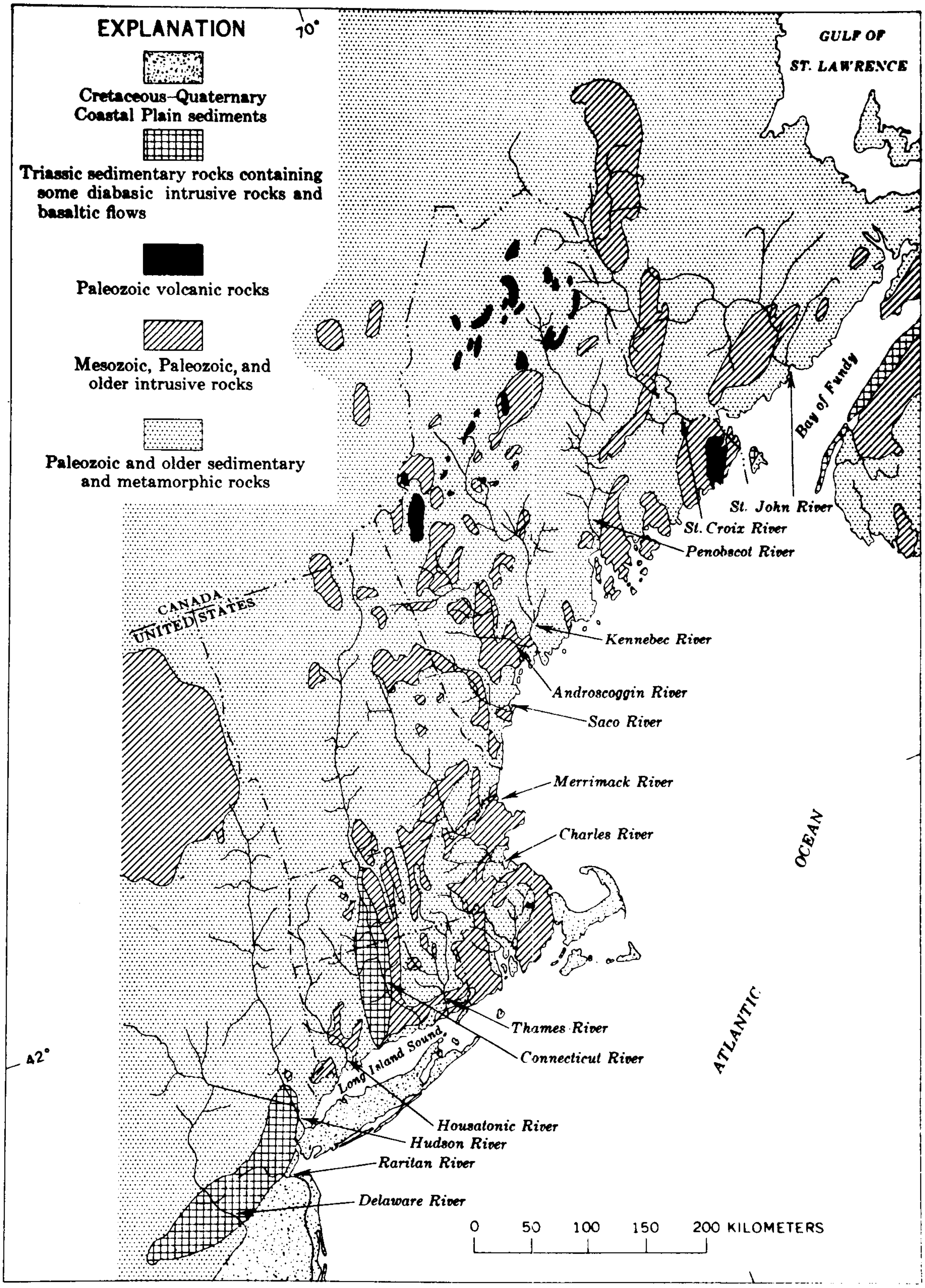


FIGURE 2-2 Generalized Geology of New England (Ross, 1970)

The region is characterized by lower topography due, in part, to the three major synclinal basins which contain softer Paleozoic sedimentary units. The largest of these filled depressions is the Narragansett Basin, a northeastward-trending syncline which occupies central Connecticut. It is nearly surrounded by a major U-shaped Precambrian outcrop (mainly granitic) which opens to the southwest. The coastal region bordering Massachusetts Bay consists primarily of the Dedham granodiorite which forms much of this exposure. The east-west trending Boston Basin, bordered by faults on three sides and the Gulf on the fourth, is smaller but contains Carboniferous sedimentary units similar to those in Narragansett Basin. The smallest depression, southwest-trending Newbury Basin, lies on the coast just north of Cape Ann, Massachusetts.

Coastal rocks of New Hampshire consist of Ordovician metavolcanics and metasediments in the northern portion and Silurian metasediments in the southern half of the state. More recent rocks, marine sediments of Cretaceous, Eocene, and Miocene age, are found in isolated coastal regions and in offshore areas (see later discussion). Cape Cod peninsula consists of glacial debris resulting from the Quaternary glacial epochs. These unconsolidated materials are also found in shoreline outcrop along portions of the coastal border of the Gulf of Maine.

A fifth tectonic element is present in the coastal areas of southeastern New York and northern New Jersey. Here, Coastal Plain strata, which are comprised mainly of post-Triassic sediments with regional dips of less than 1m/km, outcrop. East of Long Island, however, the Coastal Plain is completely submerged except for appearances on Block Island and Martha's Vineyard. These islands represent a cuesta of Cretaceous and Tertiary rocks marking the landward edge of the Coastal Plain (Johnson, 1925; Maher, 1971). As will be seen in a later section, the Coastal Plain continues over much of the northeastern continental shelf although it is locally buried by as much as 100 m of sediment. In places, erosion of upper strata has provided many of the surface sediments on Georges Bank and Nantucket Shoals.

Seismicity in New England has been considered moderate, and a zone of seismic activity (as indicated by epicenter locations) extends along the coastal zone of New England between Maine and Long Island (Woollard, 1969). Another regional alignment, termed the "Boston-Ottawa trend" by Sbar and Sykes (1973), lies at right angles to Woollard's proposed linear feature. This trend, displayed by Smith's map (1966) showing epicenters for the period 1928 through 1959, is defined by a concentration of epicenters crossing New Hampshire and northern Vermont and entering Quebec just north of Ottawa. Several epicenters of moderate to intense earthquakes lie along the extension of this alignment into the Gulf of Maine. Diment, Urban, and Revetta (1972) have extended the seaward end of the alignment still farther, and have suggested that this trend is a major crustal feature associated with the alignment of the Kelvin Seamount Chain of the Atlantic Basin. As such, it would represent activity along an "unhealed" fault zone associated with the late Paleozoic crustal fracturing accompanying the opening of the North Atlantic Basin. Evidence supporting this proposal comes from the magnetic work reported by Kane et al. (1972) in which a pronounced discontinuity (offset) in magnetic trends striking northeast across the Gulf of Maine is aligned with the Boston-Ottawa feature. This discontinuity may be related to the great imbricate thrust fault described by Bell (1967) which strikes into the Gulf north of Cape Ann. Further discussion will be found under the section on Structure for the Gulf of Maine. (Offshore, Chapter 3)

Perhaps the most tectonically active system occurs at the extreme south of the study area. The Ramapo Fault in northern New Jersey is periodically active (Page, Molnar, and Oliver, 1968) and since the early 1960's, the epicenters of a number of minor earthquakes have been located across central New Jersey and the adjoining continental shelf (J. C. Hathaway, personal communication).

Seismic activity in the form of felt earthquakes can be documented as early as the 16th century as described by Smith (1962 and 1966) but most have caused little or no damage. More than 300 years of historic records and more than 30 years of instrumentation records exist for the southern New England area (Millstone ER 1971). A compilation of locations and intensities of earthquakes is shown on Figure 2-3.

The greatest shock in the area was probably that occurring on November 18, 1755, in the vicinity of Cape Ann, Massachusetts. It has been rated at a magnitude VIII (Modified Mercalli Scale) and was felt from Chesapeake Bay in Maryland to Halifax, Nova Scotia, and reports of tremors and/or damage were received from an area of 300,000 square miles. The Cape Ann area has been the site of several shocks of damaging proportions; at least two others of similar magnitude have been cited as originating in the Gulf of Maine east of this promontory. Again, this alignment lies within the "Boston-Ottawa trend" just described. Epicenters within the Southwestern Platform are concentrated around the margins of the Newbury and Boston Basins, suggesting that these faulted boundaries are still somewhat active. The coastal portions of Maine are relatively quiescent, with a local concentration of lesser epicenters located in the vicinity of Eastport where faulting probably associated with the Fundian Fault Zone has occurred. Sweet (1973) reported no major earthquakes from Eastport, but cites minor tremors (Forbes, 1958) in 1945 with suggested small adjustments along local points. Other tectonic linaments of regional extent will be described in later sections treating their occurrence in the five offshore areas.

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 2-3

Compilation of Earthquakes (Millstone, E.R. 1971)

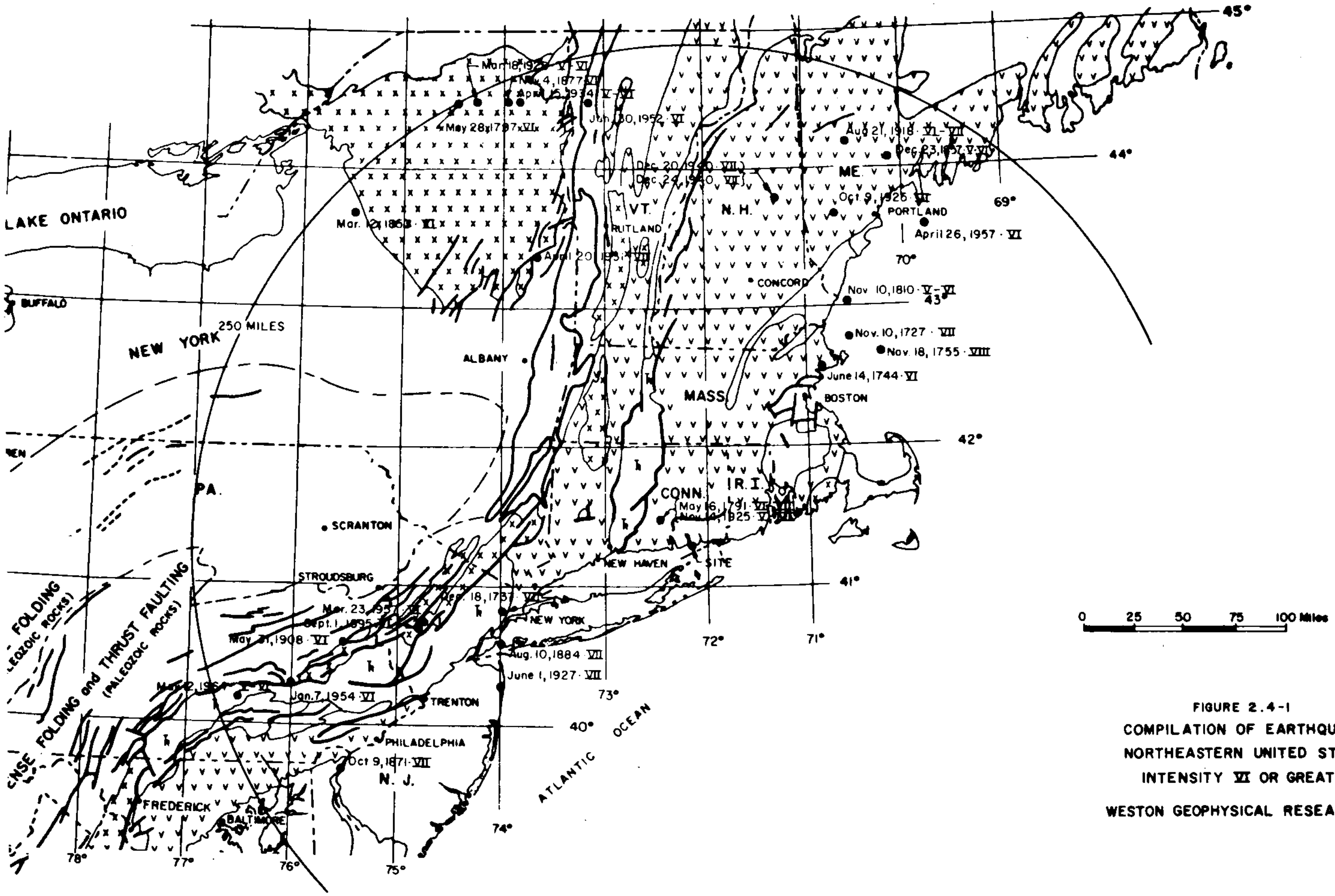


FIGURE 2.4-1
COMPILATION OF EARTHQUAKES
NORTHEASTERN UNITED STATES
INTENSITY VI OR GREATER
WESTON GEOPHYSICAL RESEARCH, INC.

2.1.4 GEOLOGIC HISTORY

PALEOZOIC AND MESOZOIC

Within the past decade, the geological sciences have witnessed a revolution in concepts related to the history of the earth. The theory of continental drift, once abandoned as a capricious exercise in paleogeography, has now developed into a unified theory of global tectonics. The history of the New England area has been re-evaluated in light of these concepts, and a brief background is presented here. Papers treating these theories will be found in Bird and Dewey (1970) and in a popular discussion by Dietz.

During much of the Precambrian, the present continents of North America and Africa were believed to be joined in a protocontinent in which no marine environments were present in the region now occupied by New England and the Gulf of Maine continental margin. In the Late Precambrian, tensional forces began to distend this landmass along a narrow zone now lying in western New England. Continued separation permitted the intrusion of marine waters, and by early Ordovician period, this "proto-Atlantic Ocean", termed the "Appalachian Atlantic" by Bird and Dewey (1970) had reached its widest extent. An oceanic trench formed along the site of the present central New England region, and by mid-Ordovician time volcanic activity had commenced along an island arc along the seaward margin of the western continental mass. Subduction of the sea floor within this trench resulted in consumption of the ocean plate, and by Silurian time numerous volcanic centers were active in what is now the coastal region of New England. Continued subduction resulted in the closure of the "Appalachian Atlantic", and by mid-Devonian time the opposing continental margins of the converging continents collided, and the ensuing deformation of the marine sediments and volcanics which now form the metasediments and metavolcanics of the New England coastal area occurred. The two major orogenic events within the region are termed the Taconic/Humbrian deformation in the western portion of New England and the Acadian deformation (mid-Devonian) of the region now lying along the coast. An earlier period of block faulting and folding in the continental margin of today occurred in Late Precambrian, but was of lesser magnitude than the two major "orogenies" of the Lower Paleozoic. It should be noted that Emery and Uchupi (1972) incorporate a different hypothesis regarding the colliding masses which produced the Acadian Orogeny. They postulate a central platform (the Avalon platform) between the African and North Atlantic continents, which was twice driven against the western landmass by the African plate; once to form the Acadian orogeny and again in Permian time, the "Alleghenian disturbance".

Following the compressional phases of Lower Paleozoic activity, the margin was subjected to tensional movements which began in the late Devonian, temporarily subsided in the late Pennsylvanian and concluded in the late Triassic. During the Paleozoic phase of this period of unrest, a major rift appears to have developed in the present Gulf of Maine region. This feature, the Cabot fault of Wilson (1962a,b), is probably of continental proportions, having been linked to the Great Glen fault in Scotland. Belt (1968) points to a narrow band of thick Carboniferous deposits which are nearly coincident with the fault zone. They occupy what has been termed the Fundian Rift Zone (see Ballard and Uchupi, 1972), a feature which may be responsible for several basins in the present Gulf of Maine.

Mesozoic activity in this region includes the major and final dislocation of the African and North American plates, an event whose inception can be attributed to the late Paleozoic dislocations along the Fundian Rift Zone. A second period of major rifting began with renewed tensional movements along the Fundian fault in late Triassic time. This activity opened many of the Carboniferous basins and promoted new rift basins along the entire length of North America. By the end of the late Triassic and early Jurassic, rocks of continental origin deposited in these basins were deformed and intruded by volcanics. To this point, much of the movement had been primarily vertical, that is, dislocations by block faulting. The ensuing motions during the remainder of the Mesozoic were transcurrent (strike-slip, or wrench fault) motions. In the Gulf of Maine, these dislocations were at right angles to the tensional trends of the great Triassic Rift basin occupying much of the Bay of Fundy and portions of the Gulf. These Jurassic dislocations include offsets of perhaps 30 km (Ballard and Uchupi, 1972) which contain intrusive rocks of early Jurassic to early Cretaceous age. All of these features (see Figure 2-4) can be attributed to the tensional regime present in this area during the separation of the African plate. Rifting probably terminated in late early Jurassic time. This final phase of rifting probably ceased with the intrusion of the large igneous body which causes the east coast magnetic anomaly, the "slope anomaly," paralleling the present coastline from Cape Fear to north of Halifax. It is offset at only one location, an east-west trend along the 40th parallel south of New York. Here the magnetic slope anomaly is offset in the right-lateral sense by nearly 200 km, suggesting that a major crustal transcurrent fault passes from the ocean basin into the continent. Watkins and Geedes (1965) have compared the regional features of the slope anomaly with those present along the Aleutian Chain and across Puerto Rico, and on the basis of similarities have proposed that the slope anomaly is a buried island arc composed of intrusive and extrusive phases of volcanism during an active phase related to the opening of the Atlantic.

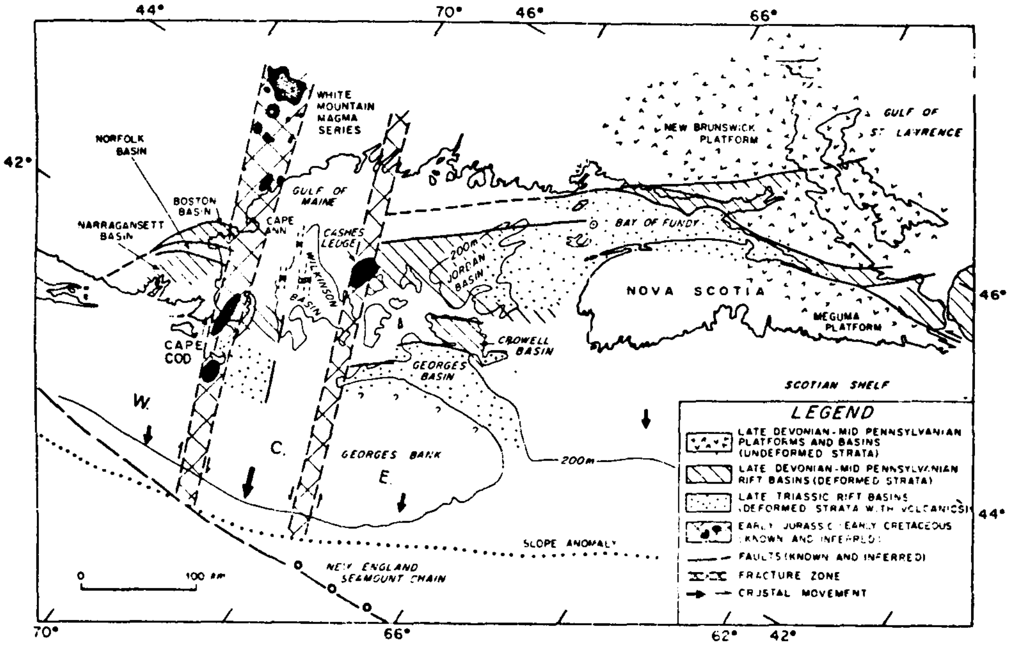


FIGURE 2-4 Tectonic Map of the Gulf of Maine Region (Ballard & Uchupi 1972)

TERTIARY

As noted in a previous section, the coastal areas of northern New Jersey, Long Island, Block Island, and Martha's Vineyard contain outcrops of Tertiary (and upper Mesozoic) Coastal Plain strata. These sedimentary strata, however, dip beneath sea level to the northeast, with the result that much of the Tertiary record for New England and the Gulf of Maine area in particular has been deduced from seismic reflection profiling over the basins and banks of the Gulf. Onshore, and in many shoal areas of the Gulf, Tertiary rocks which may have been extensive are not common. The lack of Tertiary units can be attributed to a major uplift in the late Pliocene and/or early Pleistocene as well as to the effects of multiple epochs of continental glaciation.

Tertiary sediments are found on the outcrops on the floor of Cape Cod Bay and the upper portions of Georges Bank. The Cape Cod Bay rocks are extensions of a linear belt passing beneath Cape Cod. Seismic reflections surveys reveal well-developed stratification in rocks termed "coastal plain deposits" by Oldale, Uchupi and Prada (1973). Some of these units may be late Cretaceous, similar to those recovered from Georges Bank and Martha's Vineyard. Other criteria employed in determining the Tertiary age of these units includes fossiliferous boulders of Eocene age, erosional remnants of Miocene and Eocene sediments, and silicified and carbonaceous wood of Tertiary age (see Oldale et al., 1973 for full discussion).

On Georges Bank, the deepest reflecting horizon has been tentatively identified as the pre-Triassic basement which forms the foundation for much of the Gulf of Maine (Uchupi, 1970). Smoother horizons seen in higher portions of the records are attributed to Cretaceous and Tertiary strata, within which Knott and Hoskins (1968) were able to identify buried channels which appear to plunge into the Gulf from the Bank. They are related to pre-Pleistocene drainage and possibly submarine erosion of the higher portions of the extensive Bank.

During much of the Tertiary, the Gulf of Maine was probably a shallow marine region, as suggested by glauconite deposits of Miocene age in the coastal and Gulf regions. Exceptions to this situation can be noted in the general regional uplift during the Pliocene epoch, when much of the continental margin lay exposed to subaerial agents and processes. The sea may have retreated to the present shelf edge, as clear evidence for fluviatile erosion in the area between New England and Labrador may be found in the large cuestas forming the outer banks (such as Georges Bank) and lowlands (basins) in the central part of the present Gulf of Maine. Water gaps draining these areas may be seen in the subsurface channels of Great South and Northeast Channels now partially filled with tens of meters of Quaternary sediments. Numerous buried channels of lesser dimensions are incised into features of positive relief, implying a complex of watershed areas contained within the Pliocene landscape now forming the Gulf floor. Along the present Scotian shelf, a deep irregular reflector may be related to an outer margin unconformity between unconsolidated (Tertiary and Quaternary) sediments and underlying indurated coastal plain rocks of Mesozoic age. If so, these upper strata indicate an accumulation of up to 800 meters of Cenozoic sediment in a prograding wedge originating in the western continental and inner shelf regions of New England and the Canadian Maritime Provinces.

QUATERNARY

The Quaternary, or roughly the last one million years of geologic history, includes the latter part of the Pleistocene and the Holocene, or Recent, epoch. The major events which occurred during this period were a series of glacial epochs which saw massive ice sheets cross the region now comprising the New England mainland and its adjacent continental margin. Most of the area was covered by these sheets, with only the highest peaks left ice-free. The accumulation of glacial sediments was extensive, for instance, more than 100 miles on both Long Island and Cape Cod (Emery and Uchupi, 1972).

It is impossible to distinguish glacial stages in seismic records from the offshore, and the scarcity of all but Wisconsin outcrops on shore has made the establishment of a Quaternary chronology a difficult task. A Pleistocene section on Martha's Vineyard, identified by Kaye (1964), is said to contain all stages, but most workers can only recognize two at best. Knott and Hoskins (1968) were able to distinguish five erosional surfaces atop Georges Bank, and their high resolution seismic survey revealed filled erosional channels incised into the surfaces of each reflector. Upbuilding of the Bank by successive periods of deposition related to glacial epochs is believed to account for more than 70 meters of material now present on the Bank. If so, it implies five periods in which glacial ice occupied the Gulf of Maine. The channels are thus believed to be meltwater features filled during the advance of the sea following retreat of the glacial ice. The present surface of the Bank represents sands and gravels reworked from the latest glacial debris left as terminal moraine and outwash sediments.

During the glacial epochs, the two deep channels (Great South and Northeast) served as conduits carved by the ice in its advance toward the sea. Blocked by the Pliocene cuestas of the outer margin, the ice flowed parallel to the western margins of features such as Georges Bank. Repeated ice gouging of these depressions resulted in progressive deepening of their axes, and in the case of Northeast Channel the central valley was eroded to about 360 meters, or about 120 meters below the present floor of the channel. Considering the rebound of the continental margin following the retreat of the glacial masses, the depth was probably much lower at the onset of interglacial stages. We must thus assume that a portion of these channels was cut by submarine processes.

The latest advance, termed the Wisconsin stage, occurred between 50,000 and 13,000 years B.P. (before present). The encroaching ice obliterated much of the earlier topography resulting from previous stages, and it is difficult to determine all but the latest successions of glacial deposits throughout New England. A recent analysis of large cores taken from the western Gulf of Maine (Tucholke and Hollister, 1973) have provided insight into events of the last phase of the Wisconsin stage in eastern New England.

The last advance of Wisconsin ice crossed southern New England about 20,000 yr. B.P., and by about 19,000 yr. B.P. it occupied much of the western Gulf of Maine. The ice was grounded, that is, in contact with the bottom, in even the deeper basins of the Gulf. The southern extent of the last Wisconsin ice advance can be seen by alignment of the northern shores of Nantucket, Martha's Vineyard, Black Island, and Long Island, all of which represent terminal moraines. The ice persisted near Martha's Vineyard until 15,300 yr. B.P., but by 14,250 yr. B.P. the rising sea level degrounded the glacial ice in the Gulf. By 13,000 yr. B.P. a warming trend had developed and the region became essentially ice-free. Remnants of this retreat in the form of terminal moraines now buried by Holocene marine sediments may occur where still-stands caused a concentration of detritus. Harbison (1969) describes such a region south of Pleasant Bay, Maine, where a belt of such deposits lies along the 90 meter isobath.

Pratt and Schlee (1969) have examined the locations of shoals and the seaward limit of abundant sandy gravel in order to determine the extent of Pleistocene glaciation on the continental margin off New England. From this study, it is possible to draw a line approximating the limit of Wisconsin glaciation (Figure 2-5). In the area under consideration here, this irregular boundary crosses the Great South Channel at about the 200 meter isobath, follows the northern edge of Georges Bank to its northeastern edge, swings east to cross Northeast Channel and then parallels the 200 meter isobath of the Browns Bank region. Considering the depressed sea level of the Wisconsin epoch, (at least -130 meters) Georges and Browns Banks were adjacent to a subaerial glacial front where outwash and deltas were depositing large quantities of detritus.

With the retreat of the last ice sheets the New England crust, which for thousands of years had borne the weight of the glacial masses began to rise as isostatic forces sought a new balance. This glacial rebound caused a slowing in the rate of marine transgressions as both land and water rose to a new equilibrium. Much of the coastal area stood below sea level until about 12,500 yr. B.P. when the relatively rapid rise in isostatic rebound overtook the eustatic rise in sea level. In the vicinity of Boston, the crust had been depressed some 150 meters at 15,000 yr. B.P., but following the retreat of the Wisconsin ice sheets it rebounded at a rate of 5.5 cm/year. Relative sea level remained lower than today's level until about 2,000 yr. B.P. when crustal rebound had essentially ceased.

2.1.5 REFERENCES

Ballard, R. D. and Elazar Uchupi. 1972. Carboniferous and Triassic rifting: a preliminary outline of the Gulf of Maine's tectonic history. Geol. Soc. America Bull., v. 83, p. 2285-2302.

Bell, K. G. 1967. Faults in eastern Massachusetts. (abs.) Geol. Soc. America, Abstracts, northeast section, p. 14.

Belt, E. S. 1968. Post-Acadian rifts and related facies, eastern Canada, _In_ Zen, Evan, W. S. White, J. B. Hadley, and J. B. Thompson, Jr., eds. Studies of Appalachian geology: Northern and maritime: New York, Interscience, p. 96-113.

Bird, J. M. and J. F. Dewey. 1970. Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen. Geol. Soc. America Bull., v. 81, p. 1031-1060.

Chadwick, G. H.. 1948. Peneplains in Maine (abs.): Geol. Soc. America Bull. v. 59, p. 1315.

_________. 1949. Glacial molding of the Gulf of Maine (abs.): Geol. Soc. America Bull., v. 60 p. 1967.

Diment, W. H., T. C. Urban, and R. A. Revetta. 1972. Some geophysical anomalies in the eastern United States, _In_ Robertson, E. C., ed., The nature of the solid earth, New York, McGraw-Hill, p. 544-574.

Drake, C. L., J. L. Worzel, and W. C. Bechmann. 1954. Gulf of Maine, Part 9 of Geophysical investigations in the emerged and submerged Atlantic Coastal Plain: Geol. Soc. America Bull., v. 65, no. 10, p. 957-970.

Eardley, A. J. 1962. Structural Geology of North America. (2nd ed.), New York, Harper & Row, 743 p.

Emery, K. O. 1966. Atlantic continental shelf and slope of the United States: Geologic Background. U.S. Geol. Survey. Prof. Paper 529-A, 23 p.

Emery, K. O. and Uchupi, E. 1972. Western North Atlantic Ocean: Topography, Rocks, Structure, Water, Life and Sediments. Memoir 17, Amer. Assoc. Petroleum Geologists, Tulsa, 532 p.

Fenneman, N. M. 1938. Physiography of the eastern United States. New York, McGraw-Hill, 714 p.

Forbes, C. B. 1958. Maine Earthquakes - a summary, 1927-1957. Maine Field Naturalist. 14(2):30-36 Portland, Maine.

Gates, O. 1969. Lower Silurian-Lower Devonian volcanic rocks of New England coast and southern New Brunswick. In Kay, Marshall, ed., North Atlantic - Geology and continental drift. Amer. Assoc. Petroleum Geologists Mem. 12, p. 484-503.

Goldthwait, J. W. 1924. Physiography of Nova Scotia: Canada Geol. Survey Mem. 140, 179 p.

Harbison, R. N. 1969. Possible morainal deposits in the Gulf of Maine. Maritime Sediments, v. 5, p. 19-21.

Hathaway, J. C. 1971. Data file, continental margin program, Atlantic coast of the United States. Vol. 2, Sample collection and analytical data. Woods Hole Oceanographic Institution Tech. Rept. 71-15, 496 p. (unpubl. ms.).

Hoskins, Hartley, and S. T. Knott. 1961. Geophysical investigation of Cape Cod Bay, Massachusetts, using the continuous seismic profiler: Jour. Geology, v. 69, No. 3 p. 330-340.

Johnson, D. W. 1925. The New England-Acadian shoreline: New York, John Wiley & Sons. 608 p.

Johnson, D. W. and M. A. Stolfus. 1924. The submerged coastal plain and old land of New England: Science, new ser., v. 59, no. 1526, p. 291-293.

Kane, M. F., M. J. Yellin, K. G. Bell, and Isidore Zietz. 1972. Gravity and magnetic evidence of lithology and structure in the Gulf of Maine region: U.S. Geol. Survey Prof. Paper 726-B.

Kaye, C. A. 1964. Outline of Pleistocene geology of Martha's Vineyard, Massachusetts, U.S. Geol. Survey Prof. Paper 501-C, p. 0134-0139.

Knott, S. T. and Hoskins, Hartley. 1968. Evidence of Pleistocene events in the structure of the continental shelf off the northeastern United States: Marine Geology, v. 6 p. 5-43.

Maher, J. C. and Applin, E. R. 1971. Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf. U.S. Geol. Survey Prof. Paper 659, 98 p.

Malloy, R. J., and Harbison, R. N. 1966. Marine geology of the northeastern Gulf of Maine: U.S. Coast and Geol. Survey Tech. Bull. 28, 15 p.

Maury, M. F. 1855. The Physical Geography of the Sea (3rd Ed): New York, Harper and Bros., 287 p.

Millstone Environmental Report. 1971. Millstone Nuclear Power Station Construction Permit Stage, Millstone, Connecticut.

Murray, H. W. 1947. Topography of the Gulf of Maine, field season of 1940: Geol. Soc. America Bull. v. 58, no. 2. p. 153-196.

Oldale, R. N., Uchupi, E. and Prada, K. E. 1973. Sedimentary framework of the western Gulf of Maine and the southeastern Massachusetts offshore area. U.S. Geol. Survey Prof. ppr. 757, 10 p.

Page, R. A., P. H. Molnar and J. Oliver. 1968. Seismicity of the Ramapo Fault, New Jersey - New York. Seismol. Soc. Amer. Bull., 58:681-687.

Pratt, R. M. and Schlee, J. 1969. Glaciation on the continental margin off New England. Geol. Soc. America Bull., v. 80, p. 2335-2342.

Ross, D. A. 1970. Source and dispersion of surface sediments in the Gulf of Maine - Georges Bank area. Jour. Sed. Petrology, v. 40, 906-920.

Ross, D. A. 1970. Atlantic continental shelf and slope of the United States-Heavy minerals of the continental margin, southern Nova Scotia to northern New Jersey: U.S. Geol. Survey Prof. Paper 529-G, 40 p.

Sbar, M. L. and L. R. Sykes. 1973. Contemporary compressive stress and seismicity in eastern North America: An example of intra-plate tectonics. Geol. Soc. America Bull., v. 84, p. 1861-1882.

Schlee, J. and R. M. Pratt. 1970. Atlantic continental shelf and slope of the United States - Gravels of the northeastern part U.S. Geol. Survey Prof. ppr. 529-H, 39 p.

Shaler, N. S. 1893. The geological history of harbors: U.S. Geol. Survey Ann. Report, v. 13, pt. 2, p. 93-209.

Shepard, F. P. 1931. Glacial troughs of the continental shelves: Jour. Geology, v. 39, p. 345-360.

Smith, W. E. T. 1962. Earthquakes of eastern Canada and adjacent areas, 1534-1927: Dominion Observatory Ottawa Pubs., v. 26, p. 271-301.

__________. 1966. Earthquakes of eastern Canada and adjacent areas, 1928-1959: Dominion Observatory Ottawa Pubs., v. 32, p. 87-121.

Stanley, D. J. 1969. Atlantic continental shelf and slope of the United States - Color of Marine sediments. U.S. Geol. Survey Prof. ppr. 529-D, 15 p.

Sweet, Richard A. 1973. In Shenton, E. H. and D. B. Horton 1973. Literature Review of the Marine Environmental Data for Eastport, Maine. Prepared for Pittston Company, New York by the Research Institute of the Gulf of Maine (TRIGOM).

Tagg, A. R. and Uchupi, Elazar. 1966. Distribution and geologic structure of Triassic rocks in the Bay of Fundy and the northeastern part of the Gulf of Maine: U.S. Geol. Survey Prof. Paper 550-B, p. B95-B98.

Taylor, P. T., Isidore Zietz, and L. S. Dennis. 1968. Geologic implications of aeromagnetic data for the eastern continental margin of the United States: Geophysics, v. 33. p. 755-780.

Trumbull, J. V. A. 1972. Atlantic continental shelf and slope of the United States - Sand-size fraction of bottom sediments, New Jersey to Nova Scotia. U.S. Geol. Survey Prof. ppr. 529-K, 45p.

Tucholke, B. E. and C. D. Hollister. 1973. Late Wisconsin glaciation of the southwestern Gulf of Maine: New evidence from the marine environment. Geol. Soc. America Bull., v. 84, p. 3279-3296.

Uchupi, Elazar. 1965. Map showing relation of land and submarine topography, Nova Scotia to Florida: U.S. Geol. Survey Misc. Geol. Inv. Map I-451, 3 sheets, scale 1:1,000,000.

__________. 1966a. Topography and structure of Northeast Channel, Gulf of Maine: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 1, p. 165-167.

__________. 1966b. Structural framework of the Gulf of Maine: Jour. Geophys. Research, v. 71, no. 12, p. 3013-3028.

__________. 1966c. Topography and Structure of Cashes Ledge, Gulf of Maine: Maritime Sediments, v. 2, p. 117-120.

__________. 1968. Atlantic continental shelf and slope of the United States - Physiology: U.S. Geol. Survey Prof. Paper 529-C, 30 p.

__________. 1970. Atlantic continental shelf and slope of the United States - Shallow structure. U.S. Geol. Survey Prof. ppr., 529-I, 44 p.

Upham, Warren. 1894. The fishing banks between Cape Cod and Newfoundland: Am. Jour. Sci., 3d serv., v. 47, p. 123-129.

U.S. Geological Survey 1962. Tectonic Map of the United States (exclusive of Alaska and Hawaii). 2 sheets, prepared in conjunction with Amer. Assoc. Petroleum Geologists.

Watkins, J. S. and Geddes, W. H. 1965. Magnetic anomaly and possible orogenic significance of geologic structure of the Atlantic shelf. Jour. Geophys. Research, v. 70, p. 1357-1361.

Wilson, J. T. 1962a. Cabot fault, an Appalachian equivalent of the San Andreas and Great Glen faults and some implications for continental displacement: Nature, v. 195, p. 135-138.

__________. 1962b. Some further evidence in support of the Cabot fault, a great Paleozoic transcurrent fault zone in the Atlantic provinces and New England: Royal soc. Canada Trans., v. 61, p. 31-36.

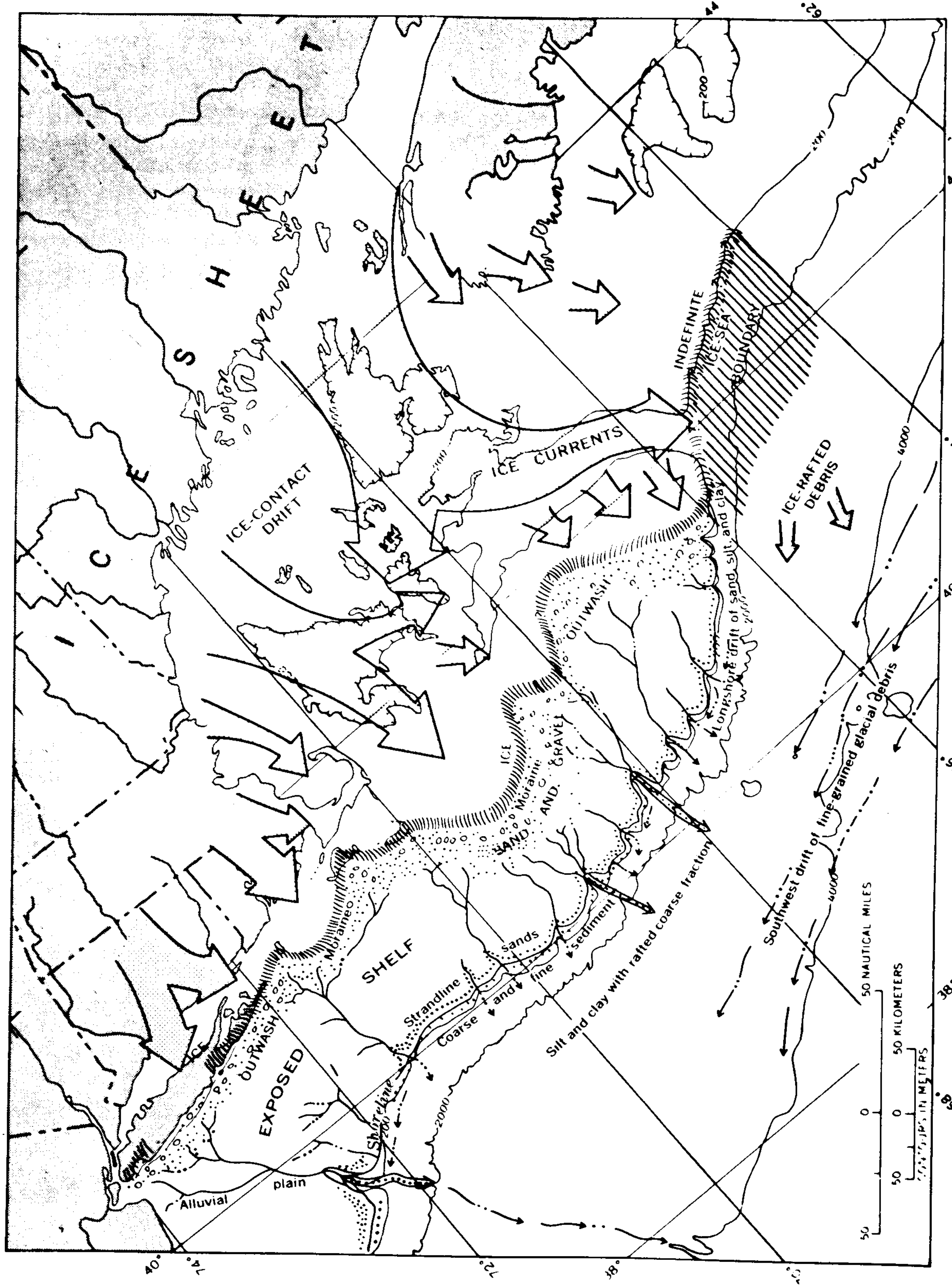
Wollard, G. P. 1969. Tectonic activity in North America as indicated by earthquakes, In J. P. Hart, ed., The earth's crust and upper mantle. Amer. Geophys. Union, Geophys. Mon. Ser. 13, p. 125-133.

2.2 CLIMATE AND METEOROLOGY OF NORTH ATLANTIC

2.2.1 CLIMATE

The North Atlantic Study Area is generally located between 40° and 45° North Latitude, and lies in the global zone of westerly winds in the mean path of tropical air masses from the Gulf of Mexico. The Appalachian Mountains to the west and the Atlantic Ocean to the east have a significant influence on the area's climate. The interaction between northward moving warm air masses from the south and eastward progressing continental air masses is conducive to the development of rapid climatic changes and major storms. Precipitation is generally plentiful throughout the area.

The overall climate of the area is humid, with four distinct seasons, and is characterized by frequent weather changes. Along the coast, the climate is moderated substantially by the effects of the ocean and large bays, in contrast to colder, inland portions.



TRIGOM PARC

FIGURE 2-5

Schematic Diagram of the Distribution and Movement of Glacial Ice (Wisconsin Stage) (Schlee and Pratt, 1970)

During the winter, onshore winds tend to maintain higher temperatures in coastal areas, because the ocean retains heat longer than the land mass. Conversely, summers are cooler along the immediate coast because of the slower rate of heat absorption by the Atlantic Ocean.

2.2.2 METEOROLOGIC DATA

There are over 100 recording stations used to make observations of the precipitation, temperature, and wind velocity along the coast and inland areas of the six states in the area. There are far fewer recording stations for offshore regions, resulting in an inadequate data base compared with the land region. Many of the data from the U.S. Navy have been obtained from ships passing coastwise as well as across the Gulf of Maine. Of course, these are far from representative, synoptic, or uniform. The following brief account of the overall region's meteorological condition is taken from the U.S. Army Corps of Engineers, North Atlantic Region Water Resources Study (1972) which affords an overview based on land observations.

TEMPERATURE

The average annual temperature in the area varies from slightly less than 40 F in northern Maine to about 50 F in southern New York Bight. An example of coastal eastern Maine shows Eastport with an annual mean temperature of 43 F, a mean high of 64.7 F and 13.2 F mean minimum temperature. On the southern end of the coastal zone, New York City has an annual 54.5 F, 74.4 F summer mean, and 33.8 F winter mean. As expected, inland areas exhibit far greater extremes. Northern winters are fairly long and severe, with an average growing season of less than 100 days in some areas. In the southern portion of the region, growing seasons average up to 200 frost-free days, and the summers are long and hot. Figure 2-6 shows isotherms of average annual temperature in the area.

PRECIPITATION

Average annual precipitation in the area is about 41 inches, distributed fairly evenly throughout the year, and ranging from slightly less than 30 inches near the northern end of Lake Champlain in New York and Vermont, to more than 70 inches in some mountainous areas in Maine and New Hampshire. Precipitation is generally about four inches greater along the coast than in nearby inland areas. Most of this difference is accounted for by the greater coastal precipitation in the fall, since most of the coast receives less precipitation in the spring and winter. There is little difference in the summer. Figure 2-7 is an isohyetal map showing average annual precipitation in the study area.

Wide fluctuations in precipitation from the average occur frequently,

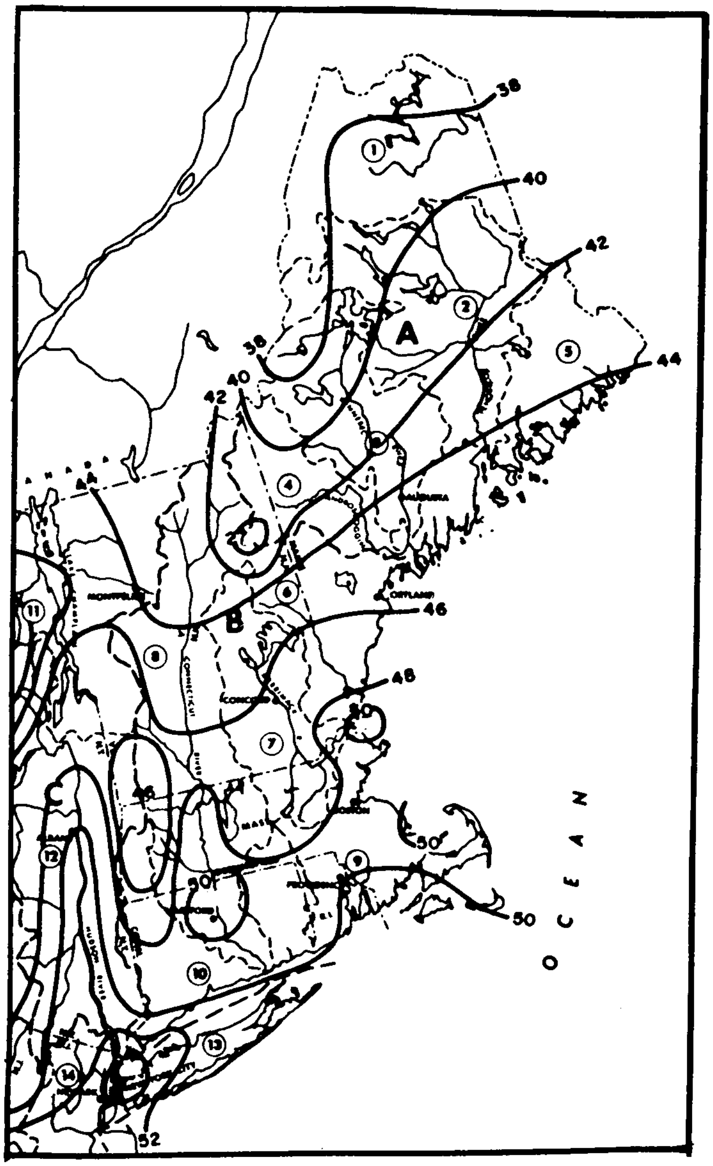


FIGURE 2-6 Average Annual Temperature (U.S. Army Corps of Engineers, 1972)

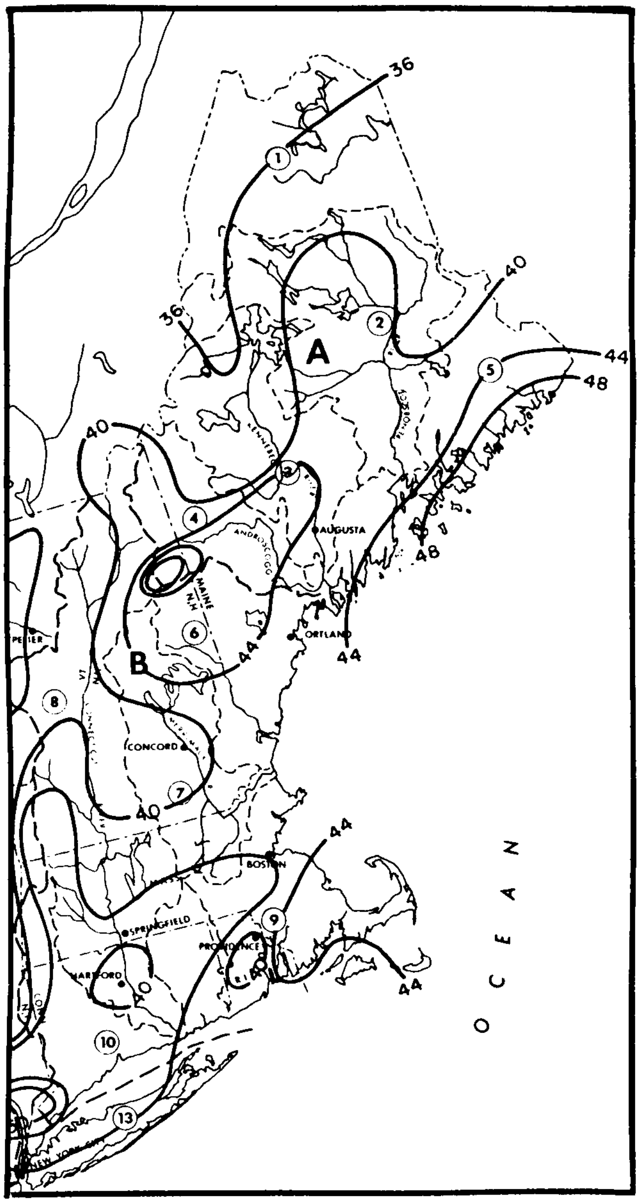


FIGURE 2-7 Average Annual Precipitation (U.S. Army Corps of Engineers, 1972)

resulting in extreme high or low streamflows in some parts. Periods of precipitation deficiency occasionally last for months or even years, as in the case of the droughts of the 1930's and the 1960's, and affect large portions.

Average annual snowfall is predominantly a function of latitude, although some high altitude areas in the south receive much more snow than more northerly coastal lowlands. Snowfall in the extreme southern coastal portion averages about five inches, while more than 100 inches falls in northern Maine and northern New York State. More detailed data for temperature and precipitation are presented in the subsequent chapters dealing with the offshore region and the major sounds and embayments along the coastal region (see sections 3.4 and 4.4).

WIND

The average wind velocity in the northern region from Maine to Cape Cod is from 8 to 10 knots. North-to-northwest winds prevail in summer through inland areas. Local topographic influences result in wind directions parallel to the valleys. Onshore coastal winds blow several miles inland in spring and tend to reduce temperatures. Coastal storms, or northeasters, produce very strong winds along the coast, and the occasional storm of tropical origin in summer or fall may result in winds of near-hurricane force (75 m.p.h.). For example, records from Eastport for over a 79-year period, indicate maximum winds of 83 m.p.h. (fastest mile) and 55 m.p.h. (five-minute velocity). Locally, thunderstorms and a rare tornado will produce high winds. Thunderstorms occur on an average of 20 days a year, mostly in the summer, with the coastal area somewhat below average, and as much as up to 30 days in some places inland. On the average, tornadoes probably occur at least once a year, predominantly in July. Many are undoubtedly not reported, however, because of the large, remote, and unsettled regions.

The southern region from Cape Cod to New York lies in the belt of prevailing westerlies, with slight seasonal drift in wind direction from the NW quadrant in the winter to winds from the SW quadrant in summer. Topography influences prevailing wind direction locally. For example, the winds in the Connecticut Valley follow the north-south orientation of the valley, blowing from due north in the winter and from due south in the summer. The average wind speed for this region ranges between 5 and 12 m.p.h. This generally is true for most other valleys including the Hudson River - Lake Champlain Valley, also in a north-south orientation. However, Long Island is unaffected this way and the westerlies are dominant. In other northern parts, the coastal winds average 10 to 12 knots at the ocean surface.

With this very general overview in mind, we have presented more detailed data for offshore areas in Section 3.4 and for the sounds and embayments in Section 4.4. The latter is a less distinct division since the available data are based on major recording sites along the coast in principal cities or in sites where data have been gathered for special purposes.

2.2.3 REFERENCES

U. S. Army Corps of Engineers, North Atlantic Division. 1972. North Atlantic Regional Water Resources Study Coordinating Comm., New York. 25 vol.

2.3 HYDROLOGY OF THE NORTH ATLANTIC REGION

2.3.1 SURFACE WATER HYDROLOGY

HYDROLOGIC DIVISIONS

In the area from Sandy Hook, New Jersey, to the Canadian border, there are 17 major coastal watersheds, as defined by the U.S. Department of Interior and U.S. Environmental Protection Agency. (See Figure 2-8). Table 2-1 defines the lengths of the major rivers and tributaries and their drainage areas.

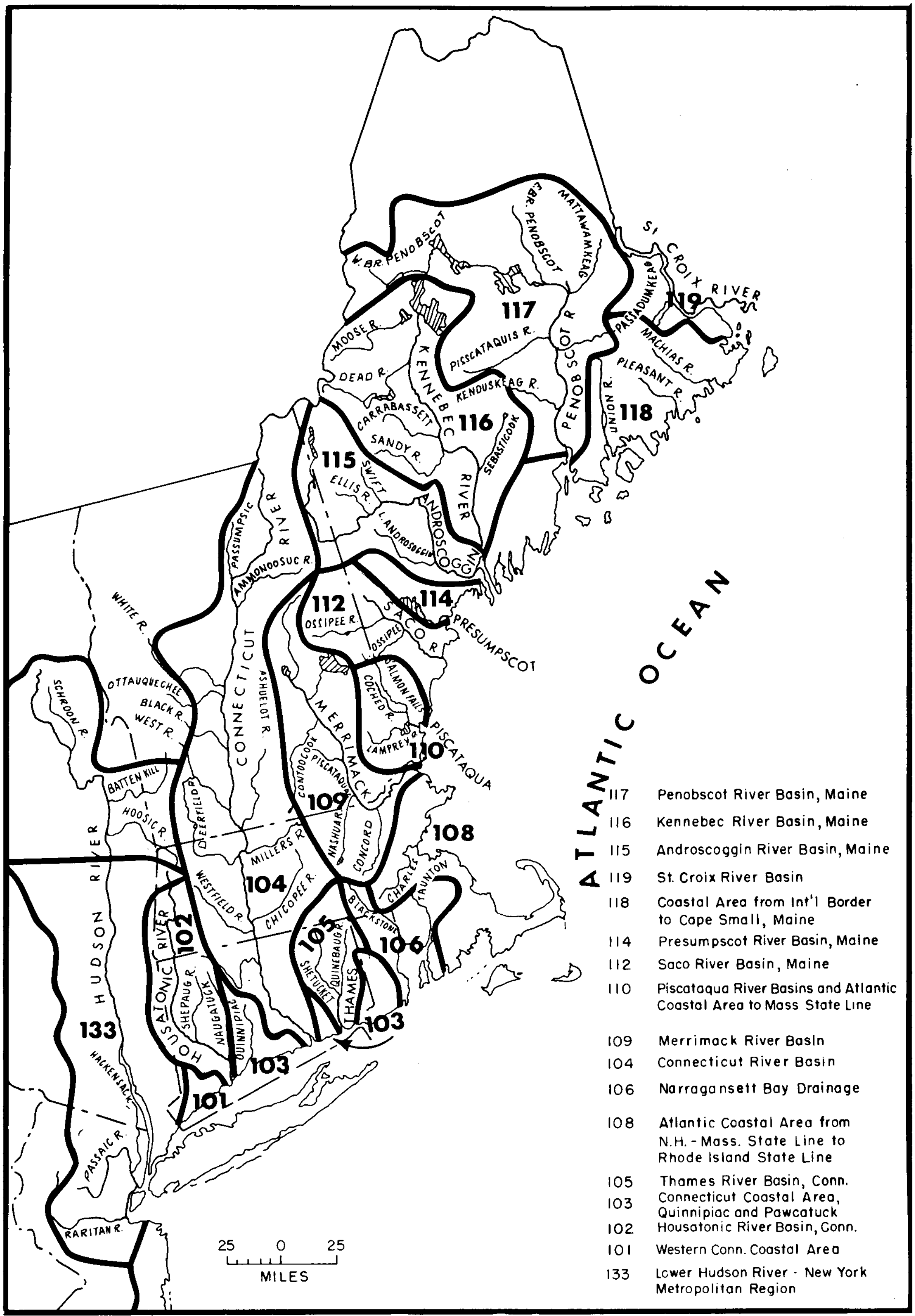
RUNOFF AND STREAMFLOW CHARACTERISTICS

Table 2-2 exhibits the average annual runoff in these drainage areas, as well as the average annual minimum monthly, and minimum 7 day streamflows of the major rivers, based on data through 1965.

Only three rivers in the study area have flows in excess of 10,000 cubic feet/second (cfs). These are the Penobscot River in north central Maine: (11,560 cfs); the Connecticut River which flows south from Canada through Vermont, New Hampshire, Massachusetts, and Connecticut (16,060 cfs); and the Hudson River in New York (12,710 cfs). This can be compared to the average annual flow of the Susquehanna River (35,000 cfs), the largest on the East Coast.

Certain areas, in contrast, have a notable scarcity of surface water flow. Northern Coastal Maine, areas 115-119 of Figure 2-8, has a combined annual surface water flow of 3,194 cfs; Southern Coastal Maine, areas 110-114, has a combined flow of approximately 4,700 cfs; Coastal Massachusetts and Rhode Island, areas 103, 106, and 108, have a combined flow of less than 2,800 cfs, with no single flow greater than 800 cfs; Long Island has very minimal streamflow; Northern New Jersey has a surface water flow of less than 2,000 cfs.

Minimum flow figures were calculated by the U.S. Army Corps of Engineers (1972), to be used as the basis for regional development potential. Minimum monthly flows represent the minimum discharges that can be expected

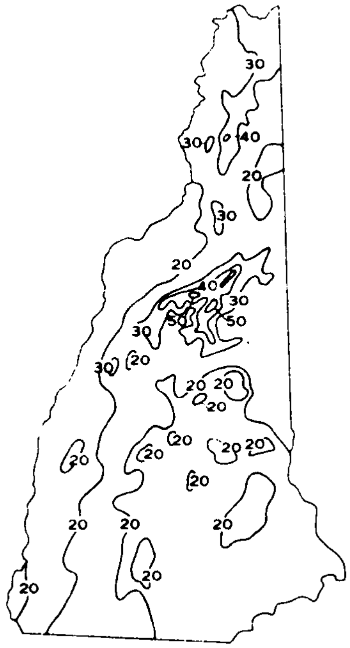


117	Penobscot River Basin, Maine
116	Kennebec River Basin, Maine
115	Androscoggin River Basin, Maine
119	St. Croix River Basin
118	Coastal Area from Int'l Border to Cape Small, Maine
114	Presumpscot River Basin, Maine
112	Saco River Basin, Maine
110	Piscataqua River Basins and Atlantic Coastal Area to Mass State Line
109	Merrimack River Basin
104	Connecticut River Basin
106	Narragansett Bay Drainage
108	Atlantic Coastal Area from N.H.-Mass. State Line to Rhode Island State Line
105	Thames River Basin, Conn.
103	Connecticut Coastal Area, Quinnipiac and Pawcatuck
102	Housatonic River Basin, Conn.
101	Western Conn. Coastal Area
133	Lower Hudson River - New York Metropolitan Region

FIGURE 2-8 Major Watersheds

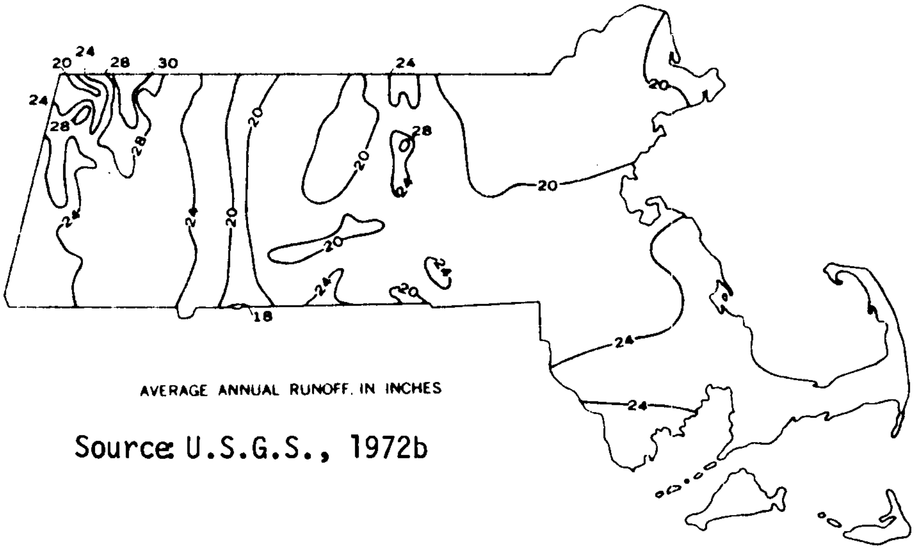
AVERAGE ANNUAL RUNOFF, IN INCHES

Source: U.S.G.S., 1972a



AVERAGE ANNUAL RUNOFF, IN INCHES

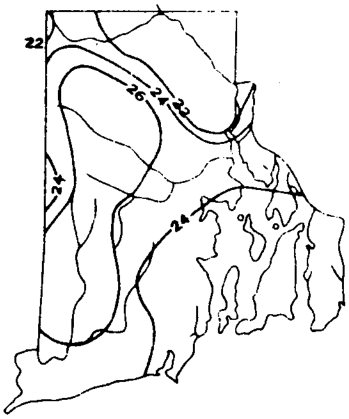
Source: U.S.G.S., 1973a



AVERAGE ANNUAL RUNOFF, IN INCHES

Source: U.S.G.S., 1972b

FIGURE 2-9 Average Annual Runoff



AVERAGE ANNUAL RUNOFF, IN INCHES

Source: U.S.G.S. 1968

AVERAGE ANNUAL RUNOFF IN INCHES

Source U.S.G.S. 1972c

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

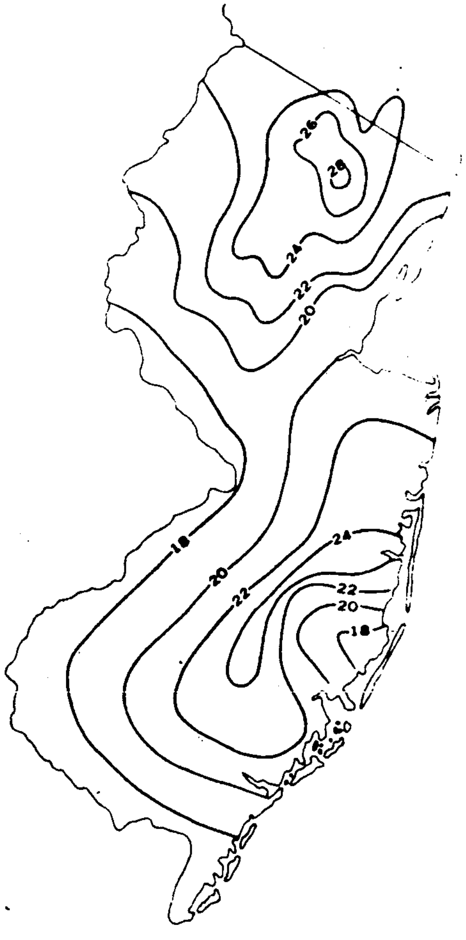
TRIGOM PARC

FIGURE 2-9

Average Annual Runoff

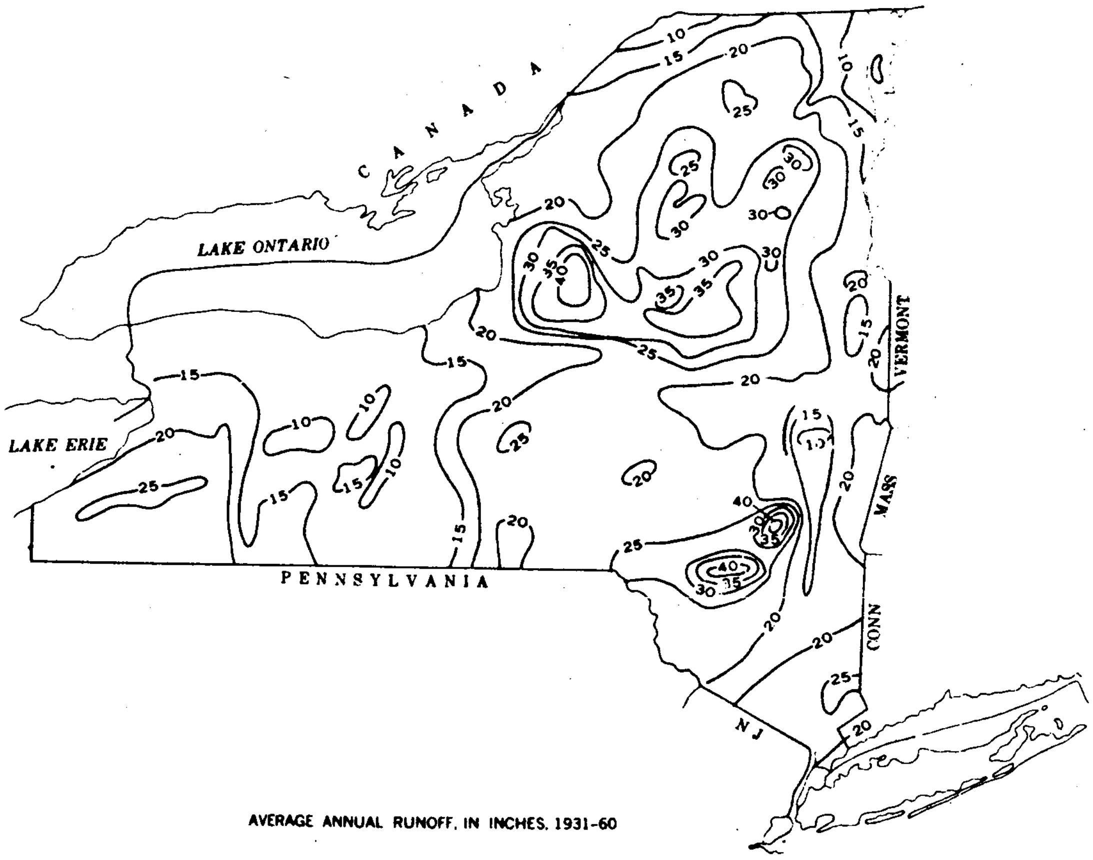
FIGURE 2-9

Average Annual Runoff



AVERAGE ANNUAL RUNOFF, IN INCHES, 1931-60

Source: U.S.G.S., 1972d



AVERAGE ANNUAL RUNOFF, IN INCHES, 1931-60

Source: U.S.G.S., 1973b

Table 2-1 Major rivers, tributaries, and drainage areas

*Basin Code	Water Body	Length (miles)	Drainage Area (square miles)
117	PENOBSCOT RIVER BASIN		
	Penobscot	105	8,570
	West Branch Penobscot	97	2,100
	East Branch Penobscot	47	1,100
	Matawamkeag	48	1,490
	Piscataquis	76	1,454
	Passadumkeag	43	385
	Kenduskeag	33	214
116	KENNEBEC RIVER BASIN		
	Kennebec	145	5,870
	Moose	76	735
	Dead	23	878
	Carrabasett	35	400
	Sandy	69	593
	Sebasticook	48	950
115	ANDROSCOGGIN RIVER BASIN		
	Androscoggin	161	3,450
	Magalloway	47	439
	Ellis	20	163
	Swift	25	125
	Little Androscoggin	46	352
119	ST. CROIX RIVER	77	1,635
118	ATLANTIC COASTAL AREA		
	Machias River	32	450
	Pleasant River	43	332
	Union River	39	497
114	PRESUMPSCOT RIVER BASIN		
	Presumpscot River	24	648
112	SACO RIVER BASIN		
	Saco River	124	1,697
	Ossipee River	18	455
	Little Ossipee River	31	187
110	PISCATAQUA RIVER BASIN		
	Piscataqua River	13	1,022

Table 2-1 (Continued)

*Basin Code	Water Body	Length (miles)	Drainage Area (square miles)
	Salmon Falls River	21	330
	Lamprey River	42	211
	Cocheo River	34	182
109	MERRIMACK RIVER BASIN		
	Merrimack	116	5,010[a]
	Pemigewasset	64	1,021
	Winnipesaukee	23	486
	Contoocook	66	766
	Piscataquog	33	214
	Nashua	34	516
	Concord	16	395
104	CONNECTICUT RIVER BASIN		
	Connecticut	280	11,265
	Passumpsic	23	507
	Ammonoosuc	56	402
	White	58	712
	West	53	423
	Ashuelot	60	421
	Millers	45	392
	Deerfield	73	664
	Chicopee	17	721
	Westfield	57	517
	Farmington	47	602
	Black River	40	202
	Ottauquechee	38	223
106	NARRAGANSETT BAY DRAINAGE		
	Taunton	36	543
	Blackstone	49	540
	Pawtuxet	11	230
103	PAWCATUCK RIVER BASIN		
	Pawcatuck	22	303
108	ATLANTIC COASTAL AREA FROM N.H.-MASS. STATE LINE TO R.I.-CONN. STATE LINE		
	Charles	65	299
105	THAMES RIVER BASIN		
	Thames	51	1,474
	Shetucket	20	1,263
	Quinebaug	76	744

Table 2-1 (Continued)

*Basin Code	Water Body	Length (miles)	Drainage Area (square miles)
102	HOUSATONIC RIVER BASIN		
	Housatonic	131	1,950
	Naugatuck	41	311
	Ten Mile	15	210
	Shepaug	34	158
101	CONNECTICUT COASTAL AREA		
	Quinnipiac River	45	164
131,132,133	HUDSON RIVER BASIN		
	Hudson River	315	12,650
131	Upper Hudson River		
	Schroon River	68	568
	Batten Kill	59	441
	Kayaderosseras Creek	34	252
	Hoosic River	72	730
133	NEW YORK CITY WESTCHESTER COUNTY LONG ISLAND COASTAL	-	1,645[b]
133	NORTHEASTERN NEW JERSEY STREAMS		
	Hackensack River	50	197
	Passaic River	86	935
	Elizabeth River	12	23
	Raritan River	81	1,125

---

* EPA Stored Basin Codes

[a] Includes 114 square miles of Canadian drainage

[b] Total land area in Area 11

SOURCE: U. S. Army Corps of Engineers, North Atlantic Division, 1972, North Atlantic Regional Water Resources Study, Appendix L.

Table 2-2 Average annual runoff, average annual streamflow, minimum flows

AREA		AVERAGE ANNUAL RUNOFF cfs	AVERAGE ANNUAL FLOW, cfs (records thru 1965)	MINIMUM COMBINED STREAMFLOW cfs Monthly	MINIMUM COMBINED STREAMFLOW cfs 7-day
117	Penobscot River Basin	14,930		5,020	3,970
	Penobscot River at West Enfield, Maine		11,560		
116	Kennebec River Basin	10,060		3,200	2,560
	Kennebec River at Bingham, Maine		4,270		
115	Androscoggin River Basin	6,160		2,170	1,730
	Androscoggin River at Auburn, Maine		5,932		
119 118	St. Croix River & Atlantic Coastal Area from International Border to Cape Small, Maine	11,650		2,264	1,585
	St. Croix River at Balleyville, Maine		2,261		
	Machias River at Whitneyville, Maine		933		
114 112 110	Presumpscot, Saco, and Piscataqua River Basins and Atlantic Coastal Area from Cape Small, Maine to New Hampshire-Massachusetts State Line				

114	Presumpscot River Basin	1,495		350	250
	Presumpscot River at Sebago Lake outlet		650		
112	Saco River Basin	3,495		610	490
	Saco River at Cornish, Maine		2,659		
	Ossipee River at Cornish, Maine		863		
110	Piscataqua River Basin	2,150		210	160
	Salmon Falls River at So. Lebanon, Maine		237		
	Lamprey River at Newmarket, New Hampshire		274		
109	Merrimack River Basin	8,330		1,360	820
	Merrimack River at Lowell, Massachusetts		7,077		
	Pemigewasset River at Plymouth, New Hampshire		1,333		
	Contoocook River at Penacook, New Hampshire		1,231		
	Nashua River at E. Pepperell, Massachusetts		526		
104	Connecticut River Basin	18,920		3,720	2,210
	Connecticut River at Thompsonville, Connecticut		16,070		
106 103 108	Narragansett Bay Drainage Pawcatuck River Basin and Atlantic Coastal Area from New Hampshire-Massachusetts State Line to Rhode Island-Connecticut State Line	8,170			

106 103	Narragansett Bay and Pawcatuck River Drainage Basins	4,190		950	555
	Taunton River at State Farm, Massachusetts		480		
	Blackstone River at Woonsockett, Rhode Island		719		
	Pawtuxet River at Cranston, Rhode Island		398		
	Pawcatuck River at Westerly, Rhode Island		560		
108 106	Atlantic Coastal Area, New Hampshire to Connecticut State Line	3,980		830	510
	Ipswich River at Ipswich, Massachusetts		200		
	Charles River at Waltham, Massachusetts		374		
105,102 102	Thames and Housatonic River Basins and Connecticut Coastal Area	7,530			
105	Thames River Basin	3,980		270	140
	Thames River				
	Quinebaug River at Jewett City, Connecticut		1,230		
102	Housatonic River Basin	4,640		540	345
	Housatonic River at Stevenson, Connecticut		2,508		
	Naugatuck River at Beacon Falls, Connecticut		466		

133	Hudson River Basin	20,410		3,710	2,055
	Hudson River at Green Island, New York		12,710		
133	New York City, Westchester Cty., Long Island Coastal	2,950		340	290
133	Northeastern New Jersey Streams	3,990		1,325	1,140
	Raritan River at Manville, New Jersey		732		
	Passaic River at Little Falls, New Jersey		1,160		

Source: U.S. Army Corps of Engineers, 1972
North Atlantic Region Water Resources Study,
App. C

99 times in 100 years with one year 10 percent lower than the minimum, or 98 times in 100 years with two shortages not greater than 7 percent lower than the minimum. Corresponding 7-day minimum flows are considered to have recurrence intervals of about 50 years.

Flood flows are defined and compared to average annual flows on Table 2-3, Average Annual and Peak Discharges. Information was taken only from stations having 20 or more years of record, through 1967.

In northern New England, flooding occurs fairly often on the smaller streams and tributaries, usually as the result of spring rains, snowmelt, and ice jams. Flooding occurs less frequently on major rivers due to the regulatory effect of many natural and man-made lakes.

In southern and central New England, the same phenomena of snowmelt and spring rains result in spring flooding. Additionally, this area is subject to flooding throughout the year from localized storms, and in the coastal areas, from hurricane waves and tides.

Spring flooding is also a problem on the Hudson every few years. Again, the small tributaries are most affected and subject to local flash flooding throughout the year.

In northern New Jersey, streams have had fairly frequent and severe flooding from summer storms, hurricanes, and continental storms. Narrow channels downstream and generally flat slopes result in considerable channel overflow.

The U.S. Geological Survey, in cooperation with various state agencies, carries on a program of monitoring streamflows nationwide. Data are published annually in volumes entitled "Water Resources Data for (state)."

LAKES, PONDS, RESERVOIRS

In addition to flowing surface waters, most of the region, by virtue of its glacial history, contains an abundance of lakes and ponds. Tables 2-4 and 2-5, Land and Inland Water Area of North Atlantic States, indicate the areal extent of these water bodies.

In Maine, a list has been compiled which describes the various studies conducted on Maine lakes and ponds (Wallace and Strunk, 1973). This by no means is a listing of all lakes and ponds, yet it does serve to indicate their abundance as well as the interest they generate in the state. In Washington County, 98 lakes have been studied; in Hancock County, 122 have been studied; in Cumberland and York Counties, over 100, etc. Approximately 120 ponds and lakes larger than 25 acres have been inventoried just in Plymouth County, Massachusetts (McCann, Wood and Kraus, 1972). Likewise, in Rhode Island, 117 lakes and ponds with areas greater than 25 acres have been identified (R.I. Water Resources Board, 1970).

Table 2-3 Average annual and peak discharges (1000 cfs)

Location	Average Annual Discharge	Peak Discharge Frequency Average Recurrence Intervals 100 yrs	50 yrs	20 yrs	10 yrs	2 yrs
Penobscot R. Veazie Dam, Me.		142	128	109	96	63
Kennebec R. Augusta, Me.		185	157	123	101	59
Androscoggin R. Auburn, Me.	6	120	100	75	62	39
Merrimack R. Lawrence, Mass.	7	136	115	95	81	53
Connecticut R. Middletown, Ct.	16	235	210	178	153	101
Housatonic R. Gaylordsville, Ct.	1.5	45	36	26	20	11
Blackstone R. Woonsocket, R.I.	.7	24	19	14	10	5
Hudson R. Hadley, N.Y.	2.8	44	40	34	30	20
Raritan R. Bound Brook, N.J.		48	43	36	32	20

Source: U.S. Army Corps of Engineers, 1972, North Atlantic Region Water Resources Study. App. C.

Table 2-4 Land and inland water area of North Atlantic States (square miles)

	Total	Land	Inland Water
United States	3,615,123.0	3,540,911.0	74,212.0
North Atlantic	114,411.0	109,084.0	5,327.0
Coastal	21,118.0	18,848.7	2,269.3
Inland	93,293.0	90,235.3	3,057.7
Maine	33,215.0	30,933.0	2,282.0
Coastal	8,991.0	7,788.5	1,202.5
Inland	24,224.0	23,144.5	1,069.5
New Hampshire	9,304.0	9,033.0	271.0
Coastal	1,108.0	1,066.1	41.9
Inland	8,196.0	7,966.9	229.1
Massachusetts	8,257.0	7,833.0	424.0
Coastal	3,813.0	3,520.1	292.9
Inland	4,444.0	4,312.0	131.1
Rhode Island	1,214.0	1,049.0	165.0
Coastal	1,214.0	1,049.0	165.0
Inland	---	---	---
Connecticut	5,009.0	4,870.0	139.0
Coastal	2,369.0	2,269.9	99.1
Inland	2,640.0	2,600.1	39.9
New York	49,576.0	47,834.0	1,742.0
Coastal	2,560.0	2,136.3	423.7
Inland	47,016.0	45,697.7	1,318.3
New Jersey	7,836.0	7,532.0	304.0
Coastal (north)	1,063.0	1,018.8	44.2
Other	6,773.0	6,513.2	259.8

Source: U.S. Department of Commerce, Area Measurement Reports, Series GE-20

Table 2-5 Land and inland water area of North Atlantic coast (square miles)

	Total	Land	Inland Water
Total North Atlantic:	21,118.0	18,848.7	2,269.3
Maine:	8,991.0	7,788.5	1,202.5
Washington	2,915.0	2,554.0	361.0
Hancock	1,890.0	1,537.0	353.0
Waldo	777.0	737.2	39.8
Knox	456.0	368.9	87.1
Lincoln	546.0	454.3	91.7
Sagadahoc	303.0	257.1	45.9
Cumberland	1,084.0	878.8	205.2
York	1,020.0	1,001.2	18.8
New Hampshire:	1,108.0	1,066.1	41.9
Strafford	390.0	375.5	14.5
Rockingham	718.0	690.6	27.4
Massachusetts:	3,813.0	3,520.1	292.9
Essex	535.0	493.9	41.1
Middlesex	849.0	825.2	23.8
Suffolk	77.0	55.7	21.3
Norfolk	418.0	394.0	24.0
Plymouth	710.0	654.2	55.8
Barnstable	450.0	393.1	56.9
Nantucket	57.0	46.0	11.0
Dukes	125.0	103.9	21.1
Bristol	592.0	554.1	37.9
Rhode Island:	1,214.0	1,049.0	165.0
Newport	186.0	114.9	71.1
Bristol	45.0	24.9	20.1
Providence	437.0	415.5	21.5
Kent	190.0	172.5	17.5
Washington	356.0	321.2	34.8
Connecticut:	2,369.0	2,269.9	99.1
New London	701.0	667.3	33.7
Middlesex	388.0	371.6	16.4
New Haven	623.0	604.5	18.5
Fairfield	657.0	626.5	30.5
New York:	2,560.0	2,136.3	423.7
Suffolk	1,177.0	928.9	248.1
Nassau	330.0	288.5	41.5
Westchester	487.0	442.9	44.1

Rockland	201.0	176.3	24.7
New York City (5 counties)	365.0	299.7	65.3
New Jersey:	1,063.0	1,018.8	44.2
Bergen	243.0	234.0	9.0
Passaic	202.0	192.9	9.1
Hudson	63.0	47.3	15.7
Essex	132.0	129.5	2.5
Union	105.0	102.7	2.3
Middlesex	318.0	312.4	5.6

Source: U.S. Department of Commerce, Area Measurement Reports, Series GE-20

Included in these inventories are numerous reservoirs and mill dams constructed for various purposes. Table 2-6 lists the existing storage developments in 1972 and the primary uses associated with them.

2.3.2 HYDROGEOLOGY

INTRODUCTION

Ground water resources are most easily described in terms of the geology of the water-bearing formations. The geology of the region in turn may be described in terms of major provinces (see Fig. 2-10). Briefly the New England province is underlaid by crystalline and metamorphic rocks, mainly granite, schist, and gneiss, but also slate, quartzite, and marble. These are largely Pre-Cambrian in age. The Triassic lowlands are underlaid by sandstone, shale, and minor volcanics, while the Ridge and Valley province is underlaid by highly folded and faulted Paleozoic limestone, sandstone, and shale. Highly folded Paleozoic formations make up the Taconic Highlands. The Coastal Plain consists of a thick wedge of sands and clays that were laid down on a bedrock surface which slopes gently seaward.

The region is glaciated as far south as a line drawn along southernmost Long Island and westward through Pennsylvania. In the glaciated area, the consolidated rocks are masked to some degree by till or water-laid sand and gravel deposits.

The following sections typify the water-bearing characteristics of the geologic provinces described above.

GROUND WATER IN COASTAL PLAIN DEPOSITS

The Coastal Plain is a distinct wedge-shaped zone of sedimentary deposits which thins to a vanishing point along the Fall Line and thickens to 8000 feet or more along the coast. Deposited under alternating marine and terrestrial conditions, the sediments consist of both fine and coarse-grained deposits (in general, coarser deposits lie to the west and finer, to the east).

Several major aquifers are known. Three artesian aquifers have been viewed by the Corps of Engineers for potential water supply capabilities: (1) a non-marine cretaceous aquifer about 1200 feet thick in New Jersey, 1700 feet in New York, which outcrops along the Fall Line; (2) the Englishtown Aquifer in New Jersey (150 feet thick); and (3) the Wenonah - Mount Laurel - Monmouth Aquifer in northeastern New Jersey (Corps of Engineers, 1972, NAR report).

Potential yields are estimated below in Table 2-7.

FIGURE 2-10

Major Physiographic Provinces

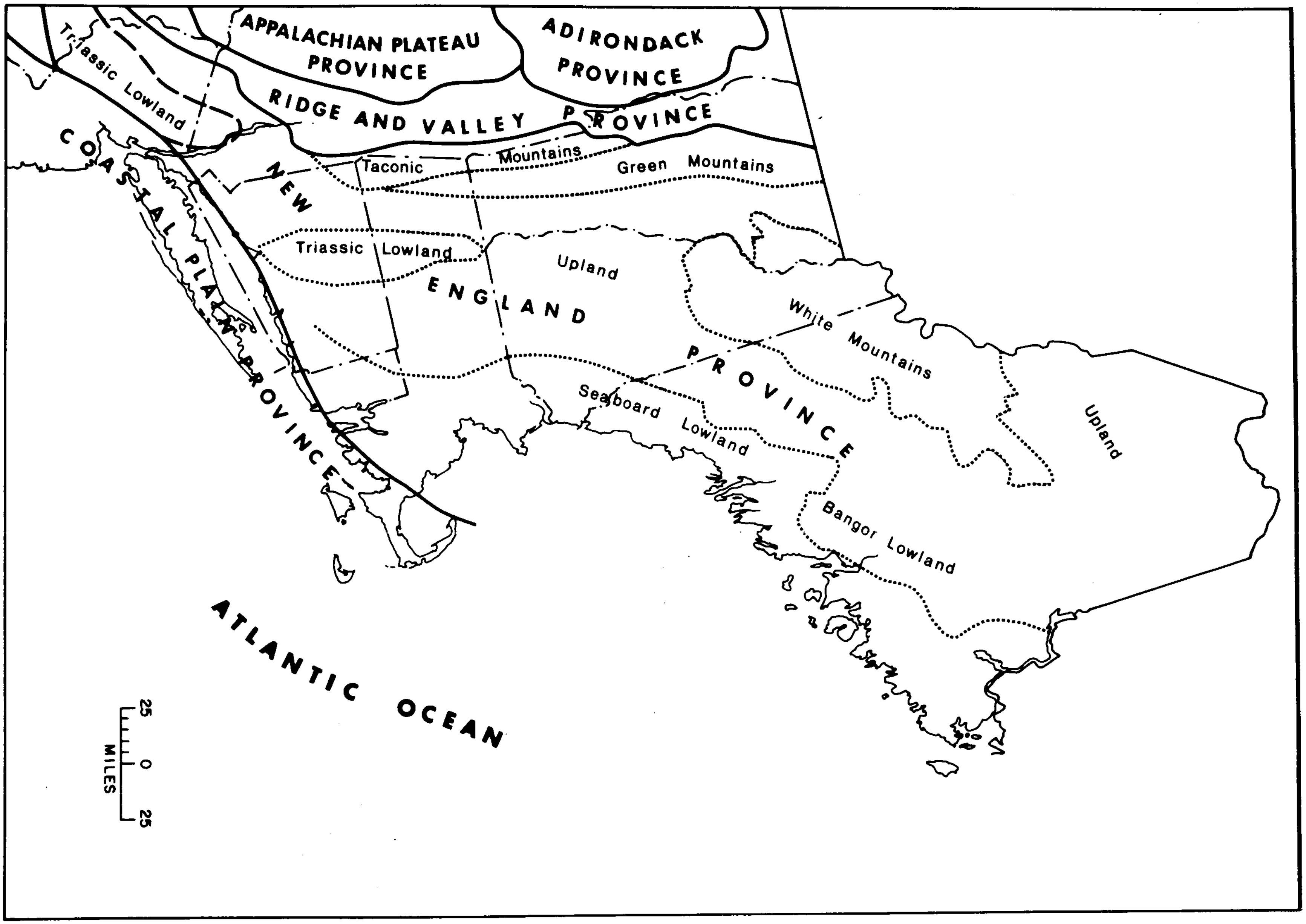


Table 2-6 Storage development 1972

Area		Capacity (1000 acre-feet)	Primary[1] Uses
117	Penobscot River Basin	1,723.9	P
116	Kennebec River Basin	1,386.4	P
115	Androscoggin River Basin	764.4	P
119 118	St. Croix and Atlantic Coastal Area to Cape Small	883.0	PR
110-114	Presumpscot, Saco and Piscataqua, Atlantic Coastal from Cape Small to New Hampshire-Mass. Line	406.9	PR
109	Merrimack River Basin	911.1	MPR
104	Connecticut River Basin	2,609.6	FMPR
106	Narragansett Bay-Coastal Massachusetts	158.7	M
105,102	Thames and Housatonic River Basins	416.8	FPR
131,132,133	Hudson River Basin	2,010.0	FMNP
	New York City-Long Island	89.6	M
	Northeastern New Jersey	401.4	M

[1] F=Flood Control; M=Municipal; N=Navigation; P=Power; R=Recreation.

Source: U.S. Army Corps of Engineers, North Atlantic Regional Water Resources Study, 1972

Table 2-7 Estimated yields from artesian aquifers in the Coastal Plain (New Jersey and New York)

Aquifer	Section	Potential Yields (million gallons/day)
Nonmarine Cretaceous	Long Island	250
	New Jersey	410
Englishtown	New Jersey	55
Wenonah - Mt. Laurel - Monmouth	New Jersey	50

SOURCE: U.S. Army Corps of Engineers, 1972

Hydraulic characteristics of artesian aquifers place constraints on their development, particularly close to the salt water interface where development could result in salt water intrusion and contamination of the ground waters.

Water table aquifers are also extensive in the Coastal Plain. Most of the older aquifers have sandy outcrops. About 90 percent of the surface of Long Island is sandy, and slightly less of the surface in New Jersey. The major aquifers are the Cohansey Formation in New Jersey and the Upper Glacial Sands of Long Island. They contain more usable storage capacity and outcrop area subject to easy recharge than all other coastal plain aquifers combined. Table 2-8 describes the dimensions and production potential of the aquifers.

Table 2-8 Area, thickness, storage capacity, and potential production of the water table aquifers in the Atlantic Coastal Plain - New York and New Jersey. SOURCE: U.S. Army Corps of Engineers, 1972.

	Area (sq. mi.)	Reservoir Thickness		Storage (gals x 10^{12})	Potential Production (Billions of gal/day)
		Total (feet)	Saturated Sand (feet)		
Long Island	722+	[1]176	150	5.63	[2].75
New Jersey	1883	135	90	10.34	1.05

[1] Production from the Magothy and Lloyds aquifers is included.
[2] The water budget area of Long Island considered in N.Y.W.R. bulletin

62 is 760 square miles. King and Queens County and the North and South Forks at the eastern end of the Island are outside the budget area. The water budget figures given are 470 mgd subsurface flow, 320 mgd streamflow, 15 mgd spring flow, a total of 820 mgd, most of which is theoretically recoverable. Considering the areas outside the 760 square mile budget area either as given here by Tarver or that given in Bulletin 62, as well as the very large re-use factor of Long Island water, the figure of 750 mgd available water does not seem large. Further, pumpage in Suffolk and Nassau Counties was already 430 mgd in 1965 without bringing about notable diminution of stream and spring flow. Raising the present pumpage to a possible 750 mgd therefore seems highly conservative.

Significant development of Coastal Plain water table aquifers will affect surface waters flowing across and along the Fall Zone. Water tables may be lowered at times, thus decreasing streamflow and affecting wetlands dependent on certain water table conditions.

GROUND WATER IN GLACIAL DEPOSITS

In terms of ground-water potential, glacial deposits range from till (a compact jumble of unsorted rock, silt, sand, and clay), a poor aquifer, to water-sorted sediments of various grain size, the course sand and gravels being among the best aquifers in the study area. Therefore, understanding the depositional history of an area is necessary before statements regarding its groundwater favorability can be made. Generally, however, highly permeable sands and gravels are present in valleys nearly everywhere at intermediate and low altitudes, and with few exceptions, offer the best opportunities for development of groundwater supplies. Furthermore, large yields are most likely available from wells located along the lower reaches of all the major rivers in the glaciated region. Here an estimated 2 mgd/linear mile would be available, and a relatively rapid recharge assured (dependent on streamflow characteristics). In contrast, localized high yield deposits elsewhere may not receive adequate recharge for intensive development, due to the irregular, patchy configuration of most glacial deposits.

GROUND WATER IN CONSOLIDATED ROCKS

Availability of ground water from consolidated rocks is a function of several factors. Openings produced in the rock formations by fracturing or solution serve as the storage space for groundwater. In rocks that are plastic, such as shales and most schists, fractures produced by earth movements will tend to close up and relatively small quantities of water will be available from wells penetrating them. Brittle rocks, such as sandstone, granite and marble, will tend to remain open. Fractures enlarged by solution, such as limestone, will produce the largest yields.

As with other aquifers, sustained yield depends on the rate of recharge. This is influenced, in consolidated rock aquifers, by climate and the character of materials which overlie it. Those overlaid by well-sorted glacial or alluvial deposits will receive a greater recharge than those overlain by compact glacial till.

The Corps (1972) estimates the recharge rate for limestone and sandstone overlaid by glacial till to be .33 mgd/sq. mile. Crystalline rocks covered by poorly permeable till in the mountainous and submountainous areas in the north have an estimated recharge rate of .25 mgd/sq. mile (Corps of Engineers, 1972, NAR Report). The type and extent of consolidated rock aquifers in the study area, and their potential supply capabilities, are indicated on Table 2-9, Characteristics and Practical Ground Water Development in Consolidated Rock Areas.

SUMMARY OF PRACTICAL GROUND WATER DEVELOPMENTS

Table 2-10 summarizes the volumes of groundwater available for practical development. It is assumed that crystalline and metamorphic rocks, yielding generally less than 100 gallons per minute (gpm) are suitable only for domestic and rural supplies. Further, only one-fifth of the total recharge is assumed developable.

Wells in sandstone, averaging 150 gpm, and wells in limestone, averaging 300 gpm, are assumed viable municipal and industrial sources of water. In most places, three-fourths of the total recharge can be developed.

Streams bordered by glacial sands and gravels are assumed to produce 2 mgd per linear mile.

Coastal Plain artesian aquifers are estimated to yield up to 3 mgd. Limitations exist on the placement of wells as described previously.

GROUND WATER/SURFACE WATER RELATIONSHIPS

Very basically, ground water and surface water systems are interconnected. Streamflow is derived from precipitation, overland runoff, and ground water discharge. Ground water, in the northeastern United States, is a dynamic system which, like surface water, flows from topographic highs to topographic lows, where it is said to "discharge". Discharge areas are lakes, streams, and wetlands. Thus a portion of the surface water system can be attributed directly to this discharge or ground water outflow. In effect, this contribution enables rivers and streams to flow in periods of little or no rainfall.

Ground waters are recharged (replenished) by infiltration of precipitation. This varies according to such factors as slope, permeability of overlying strata, intensity and frequency of rainfall. Recharge

Table 2-9 Characteristics and Practical Ground Water Development in Consolidated Rock Areas

Basin	Area (sq.mi.)	Total Recharge (mgd)	Recoverable M & I* (mgd)	Recoverable Rural** (mgd)
117	7,860			
Crystalline rocks	7,860	1,965		393
116	5,540			
Crystalline rocks	5,540	1,385		277
115	3,200			
Crystalline rocks	3,200	800		160
118, 119	5,420			
Crystalline rocks	5,420	1,355		271
110, 112, 114	3,860			
Crystalline rocks	3,860	915		183
109	4,800			
Crystalline rocks	4,800	1,200		240
104	10,900			
Sandstone	1,100	366	275	
Crystalline rocks	9,255	2,314		463
103, 106, 108	4,120			
Crystalline rocks	3,870	1,290		558
Sand	250	250		200
101, 102, 105	4,380			
Limestone	415	138	69	
Sandstone	175	58	44	
Crystalline	4,380	1,095		219
131, 132, 133	12,830			
Limestone (Taconic)	260	87	65	
Limestone	990	330	248	
Sandstone	15	5	3	
Crystalline rocks and shale	11,225	2,806		561
133	2,300			
Sandstone	1,145	572	429	
Crystalline rocks	700	233		47

* Municipal and Industrial ** Rural and Irrigation

SOURCE: U.S. Army Corps of Engineers, 1972, NAR report.

Table 2-10 Summary of Practical Ground Water Developments

Basin	Municipal and Industrial (mgd)	Rural and Irrigation (mgd)
117		
Consolidated rocks		393
Glacial deposits	640	
116		
Consolidated rocks		277
Glacial deposits	520	
115		
Consolidated rocks		160
Glacial deposits	410	
118, 119		
Consolidated rocks		271
Glacial deposits	60	
110, 112, 114		
Consolidated rocks		183
Glacial deposits	480	
109		
Consolidated rocks		240
Glacial deposits	325	
104		
Consolidated rocks	275	463
Glacial deposits	1,010	
103, 106, 108		
Consolidated rocks		558
Glacial deposits	380	200
101, 102, 105		
Consolidated rocks	113	219
Glacial deposits	320	
131, 132, 133		
Consolidated rocks	316	561
Glacial deposits	840	
133		
Glacial and coastal plain	750	
Consolidated rocks	429	47
Glacial deposits	200	
Coastal plain deposits	29	

SOURCE: U.S. Army Corps of Engineers, 1972, NAR report.

rates for consolidated rock and glacial aquifers were discussed in preceding sections under Hydrogeology.

Water Budget studies attempt to define the percentage or absolute amounts of rainfall which percolate to the ground water table, run off into surface water systems, or evaporate in a given watershed. Such studies are thus descriptive of the interactions of surface and ground water systems. The following is an example, as calculated for Long Island.

Table 2-11 Water Budget - Long Island

(1) Surface Interception =	Surface Evapotranspiration +	Direct Runoff	(2) Infiltration to Water Table =	Water Table Evapotranspiration +	Ground Water Outflow & Underflow
48.75%	47.50%	1.25%	51.25%	0.94%	50.31%
21.45"	20.90"	0.55"	22.55"	0.41"	22.14"

SOURCE: Cohen, Frank, and Foxworth, 1968

It should be noted that the water table evaporation is unusually low in this instance, due to the depth to the water table which is commonly tens of feet. Also, direct runoff is quite low due to the high permeability of the sandy glacial soils overlying the aquifers. Groundwater recharge, 22.55", is equivalent to over 1 million gallons per day/square mile. This compares to .3 mgd/square mile for mountainous, and submountainous regions of sandstone and limestone overlain by glacial till. In the latter areas a larger percentage of rainfall can be attributed to direct runoff and surface evapotranspiration.

From the above, the importance of maintaining the quality of the grounwaters and protecting significant recharge areas can be seen, as a reduction in either ground water quantity or quality will ultimately impinge on the quality and quantity of surface waters available. Significant recharge areas are characterized by high permeability, and are generally upland. A particularly vulnerable case is the aquifer outcrop along the Fall Zone. Within the study area this occurs primarily in Middlesex County, New Jersey, and on Staten Island. Long Island (essentially one big recharge area) is also quite vulnerable to man-induced changes.

2.3.3 SUMMARY OF PROBLEMS/CONFLICTS

WATER SUPPLY

Overall, the area has a relative abundance of surface waters. While containing only 4 percent of the total drainage area of the United States, the area generates nearly 10 percent of the nation's average annual runoff (U. S. Army Corps of Engineers, 1972). However, over 20 percent of the nation's population resides in this region, exerting a disproportionate demand on the available surface water supplies. Furthermore, within the region, water resources are distributed unevenly, and the demand centers do not correspond geographically with the potential supply areas, i.e., those with a relative abundance of water.

As a result, certain areas have encountered local water supply deficiencies. This problem was dramatized in the 1960's when the whole North Atlantic region experienced a prolonged drought. Two areas were particularly hard hit: the Northern New Jersey - New York City - Western Connecticut metropolitan area, and the Eastern Massachusetts - Rhode Island metropolitan complex. These areas are receiving special attention as a result of Congressional action which initiated a yet ongoing water supply study in the Northeast (U.S. Army Corps of Engineers, Northeastern U.S. Water Supply Study, 1971). A more detailed treatment of water demands and use characteristics follows in the section entitled "Land and Water Uses" of Part II: Socio-Economic Inventory and Analysis.

WATER QUALITY

Nearly every watershed in the study area is suffering from water quality degradation, to a greater or lesser degree.

The Federal Water Quality Act of 1965 required states to compile water quality plans for its various river basins. Efforts to satisfy this requirement are in progress in most states, at various stages of completion. These will be discussed in a following section entitled "Environmental Quality." The present discussion will summarize by watershed the general magnitude and character of water quality problems in the area as described by the Corps of Engineers in the NAR Report (1972). Waste loads are based on 1960 data.

In the Penobscot, Kennebec, Androscoggin, and Coastal Watersheds of Maine (areas 115-119), the waste load, in population equivalents (P.E.) of biological oxygen demand (B.O.D.), approximate 10,600,000. Of this, industry contributed 97 percent, with the pulp and paper industry contributing 86 percent. The breakdown, by watershed, is shown on Table 2-12, Estimated Waste Loads by Watershed.

In the area from southwestern Maine to New York City (including the Presumpscot, Saco, and Piscataqua River Basins, the Merrimac, Coastal

Table 2-12 Estimated waste loads

	Basin	Non-Industrial Waste Load (P.E. of B.O.D.)	Industrial Wastes (P.E. of B.O.D.)
1.	Penobscot River	71,000	3,265,000
2.	Kennebec River	75,000	1,586,000
3.	Androscoggin	72,000	2,491,000
4.	St. Croix and Maine Coastal	52,000	955,000
5.	Presumpscot, Saco, and Piscataqua Rivers	190,000	571,000
6.	Merrimack River	391,000	654,000
7.	Connecticut River	849,000	2,381,000
8.	Narragansett Bay-Massachusetts Coastal	2,220,000	2,526,000
9.	Thames and Housatonic Rivers	634,000	176,000
10.	Hudson River	884,000	2,887,000
11.	Long Island Westchester Co. New York City	3,692,000	7,100,000
12.	Northeastern New Jersey	2,169,000	8,170,000

<u>Source</u>: Corps of Engineers, 1972, North Atlantic Water Resources Report, App. L.

Massachusetts, Narragansett Bay, Thames, Connecticut, and Housatonic River Basins, (areas 101-114), waste loads totalled approximately the same, 10,600,000 P.E.'s of B.O.D., with 60 percent contributed by industry and 40 percent by non-industrial sources. Over half of the industrial load can be attributed to textiles, paper, and food industries, with the paper industry again the largest contributor (2,700,000 P.E.). See Table 2-12 for further details. Primary metal industries are a special problem in this region, in that they contain a low B.O.D. but contribute large quantities of toxic materials capable of interfering with or destroying biological life in streams.

In the lower Hudson River Basin and Long Island, about 14,560,000 P.E. of B.O.D. were discharged into the waters. Of this, 10,000,000 or 68 percent were industrial origin and 4,560,000 or 32 percent non-industrial. Approximately 30 percent of the industrial waste load can be attributed to the paper industry. Textile and food industries contributed 40 percent, and chemicals, petroleum, and primary metal industries, the remainder. (See Table 2-12). Again, toxic substances produced by chemical, petroleum, and primary metal industries are a significant problem in addition to B.O.D.

Ultimately, the pollution loads discussed above are discharged into the estuaries and bays downstream. The effects can be seen in every major bay. Raritan Bay, New Jersey, is seriously polluted, with oxygen levels near zero in the Arthur Kill area; Long Island Sound, Moriches Bay and Great South Bay, Long Island, suffer variously, with 4,500 acres of clam flats closed; Narragansett Bay has been closed to shellfish industry in many parts; in Massachusetts, the inner Boston Harbor and the Merrimack Estuary are severely polluted; Great Bay Estuary in New Hampshire has been closed to commercial clam production since 1938 (over 2,800 acres); and in Maine 70,000 acres of shellfish acres were closed as of 1967. A more detailed discussion follows under the "Environmental Quality" section.

SALT WATER INTRUSION

Fresh water aquifers interfacing with salt water reservoirs along the coast present a distinct management problem. Drawdown by intensive well development can upset the equilibrium of the salt-fresh water interface and result in the contamination of fresh water supplies by saline waters. This has, in fact, occurred on Long Island, and to some extent, on the outer reaches of Cape Cod (Provincetown). The Long Island situation has been the subject of intensive research and is well documented in numerous State and Federal (U.S. Geologic Survey) studies, (see MacNish, Heath, Johnson, Wilkens, and Duryea, 1969; Cohen, et al., 1968). In contrast, the problem in Provincetown is relatively new and less studied. A fuller treatment is presented in Part II: Socio-Economic Inventory and Analysis, under "Land and Water Uses."

2.3.4 REFERENCES

Cohen, Philip, O. L. Franke, and B. L. Foxworthy. 1968. An atlas of Long Island's water resources. New York Water Resources Commission Bull., No. 62. Prep. U.S. Geol. Surv. New York Water Res. Comm. 117 pp.

Fenneman, Nevin. 1938. Physiography of Eastern United States. McGraw Hill, New York and London.

MacNish, R. D., R. C. Heath, L. E. Johnson, R. A. Wilkens, R. D. Duryea. 1969. Bibliography of the ground water resources of New York through 1967. Water Res. Comm. Bull. No. 66. N.Y. Cons. Dept. Albany. 186 pp.

McCann, James A., G. E. Wood, and E. E. Kraus. 1972. An inventory of ponds, lakes, and reservoirs of Massachusetts - Plymouth County. Cooperative Extension Ser. Univ. Ma., Amherst. 114 pp.

Rhode Island Water Resources Board. 1970. Rhode Island lakes and ponds. Rhode Island Water Resources Board, Providence. 113 pp.

U.S. Army Corps of Engineers, North Atlantic Division. 1971 - present. Northeastern U.S. Water Supply Study. U.S. Army Corps of Engineers, New York.

__________. 1972. North Atlantic region water resources study. North Atlantic Regional Water Resources Study Coordinating Comm., New York. 25 vol.

U.S. Department of Commerce. Area measurement reports. Series GE-20. Superintendent of Documents, Washington, D.C.

Wallace, Charles F., Jr., and James M. Strunk. 1973. Inventory of lake studies in Maine. Me. State Planning Office, Water Res. Planning Div., Augusta. 305 pp.

2.4 BIOLOGY OF THE NORTH ATLANTIC REGION

An attempt was made in the biological data inventory to organize the information on plants and animals and their environmental relationships by a functional habitat-system approach rather than by taxonomic categories alone. The classification system used was inspired and adapted from Odum, Copeland, and McMahan (unpublished manuscript) who edited in 1969 a three-volume report to the Federal Water Pollution Control Administration, "Coastal Ecological Systems of the United States - a Source Book for Estuarine Planning."

In the Introduction of that report Copeland explains the meaning of an ecological system: "An ecological system consists of populations of organisms, flows of water, invisible pathways of cycling chemical elements and various organizational mechanisms which cause the parts to be interrelated. A bed of underwater eelgrass, with producing plants, micro-organisms and animals, is an ecological system. So is a bay in which water circulates and indigenous microscopic planktonic organisms develop, exchanging minerals from the bottom to the top in continual flows. Wherever there are special conditions, the marvelous self-designing property of ecological systems produces special adaptations, characteristic species of clams and fish and properties that are uniquely characteristic of that special condition." Copeland justifies the use of the system classification as follows: "Classification is necessary in the affairs of man, for where information is diverse and extensive the limits of the human mind require categories and simplified summaries for comprehension. The knowledge and publications on estuaries are so vast that clear perspectives are sometimes drowned in data. Patterns studied in one estuary may not be recognized as similar and recurring in another. As the problems with preservation and development of estuaries become acute with expanding populations, there is increasing need for a classification that has meaning for planning and management."

Further information about the theoretical basis for estuarine systems and how energy is collected, stored, recycled, and transmitted by the biological components of each system can be found in the report edited by Odum, et al. (1969). In some cases, not much information is available to quantify or even to convincingly demonstrate that a particular habitat actually works as a system. Generalization may be very tenuous, and further research may eventually revise much of the classification proposed in this report. However, this functional classification of coastal habitats is more satisfactory than other classification schemes because it embodies the probable energy transfers among organisms based on present knowledge. If a species or group of animals in a particular geographic location become susceptible to an oil spill or other environmental insult, we may infer, by reference to the system dynamics, the probable impact on other species within the same system and perhaps estimate the relative importance of any anticipated pollutional event. Particularly susceptible systems and important habitats can be especially protected against harmful environmental alteration based on our knowledge about system dynamics and required pathways for energy transfers.

We have adapted the Odum et al. (1969) classification system to our purposes for the North Atlantic Inventory. The systems and their location in relation to the shoreline are given in Table 2-13. In addition to the listed systems other biological data were collected under "Shoreline Strand" and "Upland Environments." No attempt was made to describe the details of system dynamics of these latter environments because they are only indirectly affected by the constant flux of tidal

Table 2-13 Coastal biological habitat systems described in North Atlantic inventory

Offshore Region

1. Plankton-based pelagic
2. Offshore bottoms

Major Sounds and Embayments (shallow or intertidal)

1. Mussell/oyster reefs

2. Worm/clam flats

3. Shallow salt ponds

4. Salt marshes

Exposed Shoreline

1. Sandy beaches

2. Rocky shores

Shoreline Strand

Upland-Terrestrial

flows and organisms contained in the marine water column. The terrestrial environment and shoreline strand is largely important to marine systems by contributing nutrients from surface, groundwater drainage and the introduction of man's wastes in the form of sewage, hydrocarbons, pesticides, etc.

Table 2-14 gives the major biotic components of each of the systems as well as their major energy sources, the contiguous or overlapping systems which provide broad energy transfer opportunities, regional variations, and the areal extent of each system. The areal extent and distribution of each of these coastal systems has been prepared on 1:250,000 scale charts for nearshore systems (excluding offshore bottoms and plankton-based pelagic systems which encompass nearly all the subtidal area of the region (Appendix E).

Basically each coastal system is classified according to its major energy source and energy transfer characteristics. Thus in a pelagic plankton-based system, light energy is fixed by phytoplankton which in turn is passed on to small zooplankton, then larger zooplankton and small fish, and finally to larger fish and birds. Death and decomposition, as well as animal excretion, recycle nutrients for augmentation of phytoplankton growth. In another system, such as an intertidal worm and clam flat, energy in the form of organic fuels is carried in from land drainage and from tidal flows. Benthic diatoms growing on the sediment surface also fix light energy. The organic fuels and microscopic plant cells are resuspended by tides that pass over the flat and filtered by clams and certain species of worms. Other worms are deposit feeders which digest the sediment itself by burrowing in the sediment. Energy is passed on to birds and fish which scavenge the flats at low and high tide respectively.

Thus a system includes a characteristic energy source and an assemblage of specialists which perform the work of energy transfer. Some organisms (e.g., small herbivorous zooplankton) are specialized by biological adaptation to process a certain size of phytoplankton cell while others (e.g., carniverous zooplankton) are adapted to prey and process the food accumulated by the smaller species. The significance of diversity of organisms in the biological systems includes the separation and specialization of functions of particular adaptive value.

Besides characteristic horizontal and vertical patterns (lateral dimensions, depth, size, etc.) and unique pathways for the transfer and storage of energy, a system also has its temporal characteristics according to the time of day, tidal cycle, and season. For example, in the North Atlantic, phytoplankton flowers in the spring when sunlight, temperatures, water stability, and nutrient availability are all optimum. The spring bloom is followed by a cycle of zooplankton abundance which are responding to the food availability.

Table 2-14

System Type	Phytoplankton	Zooplankton	Macrophytes	Benthic Invert.	Fishes	Birds	Mammals	Major System Characteristics	Major Energy Sources	Overlapping or Closely-Linked Systems	Comments
Plankton based pelagic	X	X			X	X	X	Surface water column stability	Phytoplankton	Offshore bottoms	Relatively independent of bottom - in deep water
Estuaries	X	X		X	X			Net seaward flow at surface. Large salinity and temperature fluctuations	Phytoplankton	Most of the other systems with offshore bottoms predominating	A special type of plankton-based pelagic with offshore bottoms as a subsystem
Offshore bottom				X	X			Infaunal and epifaunal scavengers and carnivores	Imported detritus from surface	Plankton-based pelagic	Included all of sub-tidal bottoms in region
Mussel/oyster reef	X			X				Filter feeding invertebrates - shallow water	Imported by currents	Rocky shores (north) plankton-based pelagic (north & south)	Special subsystem of offshore bottoms
Worm/clam flat	X			X	X	X		Deposit feeding invertebrates - intertidal exposure	Imported by tidal flows - benthic diatoms	Plankton-based pelagic salt marsh	Important in north. Relatively unimportant subsystem of estuaries and salt pond in south

Table 2-14 (Continued)

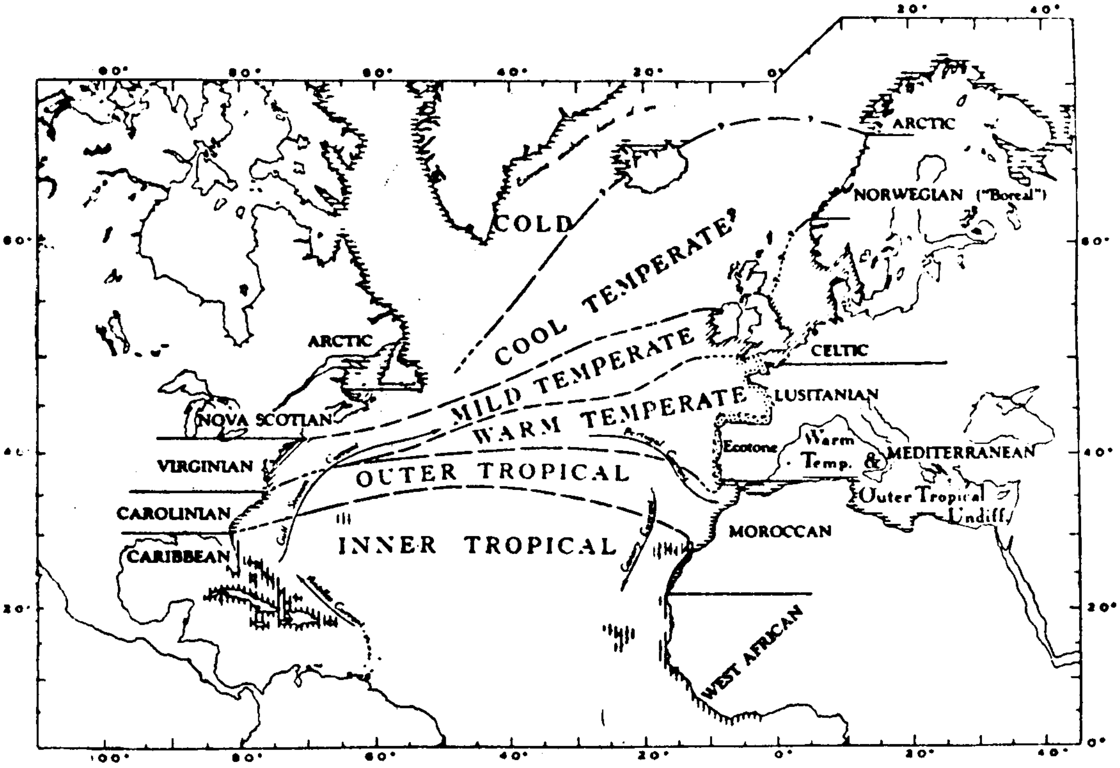
System Type	Phytoplankton	Zooplankton	Macrophytes	Benthic Invert.	Fishes	Birds	Mammals	Major System Characteristics	Major Energy Sources	Overlapping or Closely-Linked Systems	Comments
Shallow Salt Ponds	X	X	X	X	X	X	X	Little tides Shallow water Dense eelgrass and algae mats	Eelgrass and algae mats	Salt marsh	Special kind of estuary in south - not present in north. Often includes Oyster reefs and Salt marsh as subsystems
Salt Marsh			X	X		X	X	Emergent vegetation Detrital sources	Emergent vegetation	Salt pond (south) Worm & clam flat (north)	Often as a subsystem to salt ponds in south or worm & clam flats in north
Sand Beach				X	X	X		High wave energy and transport meiofauna	Imported detritus	Offshore bottom	Interstitial meiofauna & scavenging birds predominate. Detritus collection on backshore
Rocky Shore			X	X	X	X		High wave energy, attached plants and animals	Attached seaweeds	Offshore bottom	Wave energy transports & suspends plankton, detritus to attached plants & filter feeders

The locations and chief attributes of each system are described in some detail later in the report. However, two systems, the pelagic-based plankton and bottom-based systems, are much larger and therefore more important than the others and deserve special mention. In fact, we believe that the two major system-habitats are more like a series of broadly interconnected subsystems, each encompassing somewhat different populations of organisms. However, for the sake of simplicity and due to lack of adequate data, we have described these systems in the broad context.

The plankton-based pelagic system comprises three general areas: (1) An offshore community lying between the edge of the continental shelf and about the 100 m isopleth, which is composed of neritic and oceanic forms, mostly holoplanktonic. Here the bottom is below the zone of effective vertical migration mixing, and energy transfer. (2) An inshore group of neritic plankton which is characterized by a high proportion of meroplankton. Here the sea bottom is an important subsystem with broad energy interchange with the pelagic system. (3) The estuarine water column, inside of headland and river mouths where temperature and salinity fluxes are large, comprising a special kind of plankton-based pelagic system. Hence, the bottom is even more important in transferring energy through reproductive pulses of benthic invertebrates and the incorporation of tychoplankton into the water column (normally bottom living forms), particularly at night. The two-layer transport system and stratification of estuaries define the unique character of the estuarine pelagic system.

In naturally stressed systems such as the inner parts of high latitude estuaries where temperature and salinity changes are large, there tends to be a low diversity of organisms with only a few adapted specialists. Thus the American oyster, for example, is present in a wide latitudinal range of stressed inner estuaries. However, in the mouths of estuaries and on the bottom further offshore, there tends to be a higher diversity of species and a greater tendency for a replacement of species from north to south. Figure 2-11 from Hall (1964) shows the major biogeographic Molluscan provinces of the Atlantic Ocean. Species replacement of benthic invertebrates tends to occur at the edges of these provinces where there are sharp changes of temperature. However the systems themselves tend to be continuous with species which occupy the same ecological role substituting for others. The Cool Temperate and Mild Temperate biogeographic provinces were acknowledged in the coastal system classification, and separate lists of species were collected for areas north and south of Cape Cod. Important species replacements for any one system are noted where appropriate.

The Council on Environmental Quality requested in an earlier report that TRIGOM identify key species for each of the coastal systems. Key species were identified as those organisms that are: (1) known or



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 2-11

Biogeographic Molluscan Provinces of the Atlantic Ocean (Hall, 1964) suspected to be key links in this energy transfer process of this system to the extent that a loss of the species would cause serious damage to the system; (2) important commercial species; (3) rare or endangered species. In some cases key species were selected because much is known about their life history and they are considered to be representative of other species with essentially the same ecological role in the system.

Key species were then linked into food web diagrams with arrows which represent the major known energy transfer pathways. These food web diagrams are intended to illustrate the important relationships in each system and are not in any sense comprehensive. The known life history information is also collected for each key species and summarized according to a number of life history elements. They are: (1) Reproduction, (2) Fecundity and larval life, (3) Growth and longevity, (4) Natural mortality, (5) Migration characteristics, (6) Distribution and niche preference, (7) Population densities, (8) Food, (9) Predation, (10) Competition, (11) Responses to the environment (natural factors, pollutants).

Inasmuch as species in each of the major flora and faunal groups (e.g., birds, phytoplankton, fish) are important components in various coastal systems (Table 2-14), information on each group was also collected in appropriate chapters by specialists in each broad subject category. The chapters contain literature reviews and also checklists of species.

2.4.1 REFERENCES

Hall, C. A., Jr. 1964. Shallow water marine climates and molluscan provinces. Ecology 45(2):226-234.

Odum, H. T., B. J. Copeland, and E. A. McMahan. 1969. Coastal ecological systems of the United States. Unpub. rept. prepared by Inst. Mar. Sci. Univ. of N.C. (recently reprinted by Conserv. Found., 1974)

2.5 CHEMICAL OCEANOGRAPHY OF THE NORTH ATLANTIC REGION

2.5.1 INTRODUCTION

The available chemical oceanographic data on the coastal and continental shelf areas from Sandy Hook, New Jersey, to Eastport, Maine, have been summarized and the following parameters considered:

1. Biologically Active Natural Components
    a. Dissolved gases (oxygen, nitrogen)
    b. Nutrients (phosphate, nitrate, nitrite, ammonia, silicate)
    c. pH
    d. Natural organic compounds (urea, dissolved organic carbon)

2. Suspended matter
    a. Total suspended load by weight
    b. Turbidity
    c. Particulate organic carbon

3. Trace Metals

4. Organic Pollutants
    a. Pesticides (DDT)
    b. Polychlorobiphenyls (PCB's)
    c. Oil

Although a number of these parameters are pertinent to discussions of phytoplankton dynamics or pollution studies in other sections of this report, an inclusion of relevant data will be dealt with here as well. Salinity will be considered under the discussion of physical oceanography and will not be reviewed here except when necessary to aid in understanding chemical parameters.

Of the above parameters, only dissolved oxygen and nutrients have been measured with any amount of detailed coverage. Some estimate of the suspended matter was the next most commonly measured parameter.

There was only limited coverage available for most of the other parameters. Long Island Sound and the New York Bight have been the most studied of the areas and subsequently here the most information is available. The majority of this information comes from the open literature. In addition, data reports and some unpublished data of the section authors who covered the area off the New Hampshire coast are used.

For the purpose of this report we have divided the region into two major areas: South of Cape Cod and North of Cape Cod. Further, there is a separation of Offshore (Section 3.3) and Sound and Embayments (Section 4.3). The coastal and inshore areas south of Cape Cod have been described by Saila (1973) and include Raritan Bay, the New York Bight, Long Island Sound, Narragansett Bay, and Nantucket Sound. We have reviewed these areas, outlining what is already known and bringing the reader up to date. It is, however, the areas on the outer continental shelf south of Cape Cod, the banks to the east and northeast of the Cape, the Gulf of Maine, and the western coastal waters of the Gulf of Maine that comprise the main body of this report. Thus the major sections are as follows:

1. Areas North of Cape Cod

    A. Gulf of Maine
    B. Georges Bank
    C. Coastal Waters

1. Massachusetts Bay
        2. Cape Ann to Cape Elizabeth
        3. Casco Bay to Eastport

2. Areas South of Cape Cod

    A. Continental Shelf
    B. New York Bight
    C. Long Island Sound
    D. Narragansett Bay and Adjacent Waters

2.5.2 PARAMETERS AND UNITS

Over the years the units used to report some oceanographic and chemical data have changed. Where this was the case, a conversion of the units which are used today was made, and are as follows:

(1) Nutrients are reported as the amount of the major element in the species form of the nutrient, such as PO_4-P, NO_3-N, NO_2-N, and SiO_4-Si. The units used are in microgram, atomic weight units per liter, generally abbreviated µg-at/ℓ. This is actually a micro-molar (10^{-6}) quantity and is found by dividing the amount of the element present in micrograms per liter by the atomic weight of the element.

(2) The dissolved oxygen is reported as milliliters of oxygen gas under standard temperature and pressure (0 C and 760 mm Hg pressure) in one liter of seawater at 20-25 C and abbreviated as ml/l.

(3) pH is given in standard pH units which equals the negative log of the hydrogen ion concentration.

(4) Suspended matter is reported as milligrams of dried solid material in one liter of seawater of 20-25 C. Secchi disc measurements are reported in meters or as the reciprocal of the depth (1/D); earlier measurements in inches and feet were converted to meters. Turbidity has also been measured with a transmissometer and these units are in relative percent transmission (%T) or attenuation coefficient (a), or with a photometer with units as extinction coefficient (K).

(5) Most individual trace compounds such as urea and polychlorobiphenyls (PCB) or elements such as zinc and lead are reported as milligrams or micrograms per liter of seawater (mg/ℓ or µg/ℓ) or as parts per million or parts per billion (ppm or ppb). These units are often considered the same (i.e. mg/ℓ≃ppm) although this is not quite the case, since a liter of 35 parts per thousand (ppt) salinity seawater weighs about 1025 grams at 25 C.

2.5.3 FACTORS AFFECTING THE PARAMETERS STUDIED

NUTRIENTS AND DISSOLVED OXYGEN

Because of the location of this region in the mid-temperate latitudes, there is a strong seasonal variation of both nutrients and dissolved oxygen. This variation is the result of the interaction of both physical and biological processes on the continental shelf areas.

The nutrient and dissolved oxygen concentration are inversely related during the processes of both photosynthesis and oxidative decomposition of organic matter. If we assume that the average composition of phytoplankton-produced organic matter is $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)$, then when this is bacterially decomposed or oxidized the following equation results:

$$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138\ O_2 = 106\ CO_2 + 122\ H_2O + 16\ NO_3^- + PO_4^{-3} + 19\ H^+$$

The reverse of this reaction can be considered more or less the equivalent to the photosynthetic production of organic matter. A major point to be noted here is that carbon, phosphorus, and nitrogen are taken up from and released into the water in approximately the same ratios to each other. This ratio of NO_3^--N to PO_4^{-3}-P in the water is about 15 to 1. However, this may vary in coastal waters on a seasonal basis, due to the influence of fresh water input and different rates of regeneration of the NO_3^- and PO_4^{-3} from the organic matter.

The seasonal variations for nutrients and dissolved oxygen in these north temperate, near-shore waters are somewhat as follows:

Winter

During the winter the values of both the nutrients and dissolved oxygen are reasonably high. During the late fall and winter, coastal storms tend to mix the surface layers, both by physical wave action and cooling of the surface waters, causing thermal stratification to break down. This mixing brings up nutrients from the deeper waters, where they have been released by bacterial oxidation of organic matter fallen from the surface layers during the previous summer and fall. The mixing extends to nearly 100 meters depth in the Gulf of Maine by late February-early March, the coldest time period in the Gulf of Maine (Bigelow, 1927).

During the winter most of the inorganic phosphorus is present as a form of orthophosphorus, such as HPO_4^{-2}, PO_4^{-3}, and $H_2PO_4^-$ (Riley and Chester, 1971). The nitrogen is present as nitrate ion (NO_3^-) while dissolved silicate is present as orthosilisic acid ($Si(OH)_4$).

The oxygen concentrations are high as a result of the increased mixing and the fact that the oxygen saturation values for the colder water are much higher than for warm waters. It is for this reason that a knowledge of the percent saturation of oxygen is more useful than just the actual concentrations. The shallow, coastal waters are about 90-100 percent saturated during the winter months.

Spring

Spring, in terms of an initial spring plankton bloom, begins anywhere from late February in sheltered coastal waters, such as parts of Long Island Sound, to late March and April for the open Gulf of Maine waters. During this time, there is an increase in light intensity and duration. This amount of light, coupled with the abundant nutrients in the surface waters, is ideal for a plankton bloom. However, the bloom will not occur until the "critical depth", or depth above which there is a net effective plant production in the water column, is equal to or shallower than the mixed zone. The surface waters must have a certain stability before the bloom occurs. The bloom will usually occur, first near shore or in shallow waters offshore such as Georges Bank, and then farther offshore, as solar heating and spring runoff form a pycnocline which partially stabilizes the surface layers.

During early spring there is a rapid removal of dissolved inorganic nitrogen species (NO_3^-, NO_2^-, NH_4) and orthophosphate from the mixed layer in the eutrophic zone. The phytoplankton are eaten by zooplankton and fish, with nitrogen-containing products returned to the water as excreta. This is in the form of easily assimilated compounds such as urea and ammonia, or as fecal pellets which must be bacterially decomposed before the nitrogen becomes available (Riley and Chester, 1971).

During the early spring there is still enough mixing so that the nutrients do not become limiting. However, by the early summer a strong thermocline between 10-40 meters deep inhibits further vertical mixing and the nutrient concentrations in the surface waters approach zero.

Summer

The surface waters within the mixed zone above the thermocline continue to warm throughout the summer months. The major nitrogen nutrient present is usually ammonia. Phosphorus is mainly tied up in organic compounds and present as particulate organic phosphorus and to a certain extent as dissolved organic phosphorus (Riley and Chester, 1971).

The dissolved oxygen concentration is much lower than in the winter months, but is often at or greater than 100 percent saturation due to the release of oxygen during photosynthesis. In the deeper waters below the thermocline, the oxygen value is below saturation due to respiration by organisms, bacterial utilization, and oxidation of organic matter fallen from the surface. Since the means of replenishment, i.e. mixing from the surface, is not possible because of the stable water column, the concentrations continue to decrease. In near-shore or enclosed areas of water with high productivity, the concentration of oxygen below the mixed zone may approach or reach zero, resulting in anoxic conditions.

By late summer the water column is the most stable and all the nutrients in the surface layer are near zero. These nutrients are tied up in the detritus (either dead organisms or fecal pellets) which has sunk to the thermocline or to the bottom.

Fall

During early fall, storms tend to break down the surface-mixed layer and some of the nutrient-rich water below the thermocline is mixed into the surface layer. If this is early in the fall, it provides nutrients for the "fall bloom". This lasts only a short time because of decreasing light, decreasing temperature, and an increasing depth of the mixed layer as winter approaches.

During the fall the nitrite generally reaches a maximum as the organic matter is broken down and bacterial nitrification occurs, transforming ammonia to nitrite, then to nitrate. This process is usually complete by late fall and early winter, at which time the nitrate values reach their peak. The values for phosphate and silicate also increase during the fall and reach a maximum during the winter.

The dissolved oxygen concentration increases during the fall as the increased cooling and mixing occur. During this time the surface layers tend to be slightly undersaturated to saturated in oxygen as deep waters are mixed with the surface water. In addition, the water column is cooling down, making it possible to hold more oxygen.

SUSPENDED MATTER

Suspended matter includes all particles, organic and inorganic, which have a relatively slow settling velocity, subsequently remaining in suspension for a considerable amount of time without contact with the bottom. This suspended matter may be individual particles of organic matter or inorganic grains of sediment; however, it is more commonly in the form of flocs of clay-sized particles or organically bound aggregates which both contain organic and inorganic particles (Meade, 1972). The size of these suspended particles in coastal waters varies from less than 2 microns to greater than 35 microns in diameter.

Suspended material is derived from land sources by rivers and shore erosion, from biological productivity, and from resuspension of bottom sediments. The population of particles derived from each source tends to have distinguishing characteristics. Particles produced by biological productivity (phytoplankton and zooplankton) are rich in organic matter and have a low bulk density. Particles derived from resuspension of bottom sediments have little organic matter associated with them. Suspended matter derived from river sources has both organic and inorganic fractions of varying proportions.

The amounts of suspended matter in the Gulf of Maine and adjacent waters vary spatially and temporally. Near the coast and in estuaries, concentrations will change over a tidal period, and seasonally. Concentrations in offshore waters will vary seasonally. These changes are a function of the sources of suspended matter and of the density structure of the associated water masses.

Seasonal Cycle of Suspended Matter

The distribution of suspended matter is relatively constant up to 100 meters in depth during the winter months (December to March). It is vertically stratified, with the highest concentrations near the surface and near the bottom, and minimal concentrations at intermediate depths during the summer months (May to October) (Spencer and Sachs, 1970; and Shevenell, 1973).

When the distribution of suspended matter is stratified, the turbid zone near the surface is due to organic-rich material, primarily phytoplankton and suspended matter discharged from estuaries. The bottom turbid layer is due to resuspension of bottom sediments and primarily inorganic. In the late fall (about November) the stability of the water column breaks down with subsequent mixing of these two turbid zones. Although the concentrations with depth are relatively constant, the coastal zone of the Gulf of Maine shows an offshore gradient in turbidity in the winter (Graham, 1970; Shevenell, 1973; and Ward, Anderson, and Shevenell, 1973).

With the establishment of the thermocline and water stability in the early spring (late March to April), the bloom of phytoplankton enriches the surface waters with particulate organic matter. The lack of large-scale vertical mixing will maintain this organic-rich surface layer. The bottom water is most turbid near the coast in the autumn when there is still some vertical stability in the water column, and the frequency of storms to stir up the bottom is high. There does not appear to be this seasonal change in the offshore near bottom waters (Spencer and Sachs, 1970).

The seasonal variability of the sources of suspended material in the surface waters is due to (1) the natural cycle of the phytoplankton populations, (2) the seasonal rates of erosion caused by changes in precipitation and vegetative cover, and (3) seasonal changes in the flushing rates of estuaries due to changes in freshwater discharge.

TRACE METALS

Trace metals in seawater are not conservative elements, and the distribution of their concentrations is affected by geochemical and biological processes. Like the suspended matter distribution, the water circulation and the water mass distribution will play an important role in governing the spatial and temporal variations of trace metal concentrations.

The most important pathways by which trace metals reach the ocean are (1) land runoff, (2) atmospheric fallout and (3) direct injection by man. The amount and types of trace metals supplied to the ocean by rivers will depend on the nature of the rocks and the amount of rainfall in the watershed and man's activities. Trace elements in rivers will be in either a dissolved form or absorbed on fine-grained suspended matter. Lead, primarily from leaded gasoline, is transported to the marine waters through the atmosphere (Chow and Earl, 1970).

Once in the marine environment there are several mechanisms which remove the trace elements from the system. Sediments suspended in river water with absorbed trace metals will settle out in the lower energy, estuarine, and shelf environments. This is probably not a net loss to the system, as resuspension of bottom sediments by storm activity may reintroduce the trace elements into the system (Dow, 1970). Concentration of trace metals by phytoplankton will remove trace elements from solution. When the organism dies and sinks, there will be a net loss of trace elements to the system. Bacterial decomposition of the organic matter will release trace elements to interstitial waters, with subsequent movement to the overlying water or adsorption to sediment particles.

Marine organisms may concentrate trace elements in their skeletal parts, and these will be incorporated into the bottom sediments with a net loss to the system (Riley and Chester, 1971). Because of the complexity of the system, concentrations of trace metals in nearshore waters are extremely variable and are not well established (Rice, Leighty, and McLeod, 1973).

Rice _et al_. (1973) have estimated the concentration ranges in the marine environment for trace metals which will potentially interfere with marine productivity (Table 2-15).

Table 2-15 Trace metal concentrations in seawater potentially harmful to organisms (Rice et al., 1973).

Trace Metal	Range	
	Minimum	Maximum
1. Lead	0.02 μg/ℓ	0.35 μg/ℓ
2. Copper	2.0 μg/ℓ	30. μg/ℓ
3. Cadmium	0.025 μg/ℓ	0.25 μg/ℓ
4. Mercury	0.003 μg/ℓ	0.36 μg/ℓ

2.5.4 REFERENCES

Bigelow, H. B. 1927. Physical Oceanography of the Gulf of Maine: U.S. Bureau Fisheries Bull., v. 40, p. 511-1027.

Chow, T. J. and J. L. Earl. 1970. Lead aerosols in the atmosphere: Increasing concentrations, Science, 169, p. 577.

Dow, R. L. 1970. Maine Coastal Pollution, Department of Sea and Shore Fisheries, Maine, General Bulletin No. 10, 15 p.

Graham, J. J. 1970. Temperature, Salinity, and Transparency Observations, Coastal Gulf of Maine, 1962-1965: United States Fish and Wildlife Service Data Report 42.

Meade, K. H. 1972. Sources and sinks of suspended matter on continental shelves. Shelf Sediment Transport, Swift, Duane, Pilkey (eds.) Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., p. 249-262.

Rice H. V., D. A. Leighty, D. C. McLeod. 1973. The effects of some trace metals on marine phytoplankton. CRC Critical Reviews in Microbiology, Sept. 1973, p. 27-49.

Riley, J. P. and R. Chester. 1971. Introduction to Marine Chemistry, Academic Press, London, 465 pp.

Saila, S. B. (Prog. Coor.). 1973. Coastal and offshore environmental inventory-Cape Hatteras to Nantucket Shoals. University of Rhode Island Mar. Publ. Series No. 2.

Shevenell, T. C. 1973. Distribution and dispersal of particulate matter in a temperate coastal shelf environment. International Symposium on Interrelationships of Estuarine and Continental Shelf Sedimentation, Bordeaux, France, July 1973.

Spencer, D. W. and P. L. Sachs. 1970. Some aspects of the distribution, chemistry, and mineralogy of suspended matter in the Gulf of Maine. Marine Geol., v. 9, p. 117-136.

Ward, L. G., F. E. Anderson, and T. C. Shevenell. 1973. Variation in total particulate matter off the New Hampshire coast. Geol. Soc. of Am. Abstr. Northeast section, p. 235.

Chapter

3 Offshore Region

Page

Chapter 3.1 Geology of Offshore Provinces

3.1 GEOLOGY OF OFFSHORE PROVINCES

3.1.1 INTRODUCTION

The following section deals with the geology of the offshore region which as described in general in the Regional Overview (Chapter 2.1) is roughly delineated as lying beyond the nearshore Sounds and Embayments and in physical terms corresponds to the open ocean.

There is no distinct boundary on which to make the separation from the inshore areas but there is a transition zone ranging from two to ten miles from shore. This rather vague boundary corresponds partly to the biological habitats described in Chapter 2.4 and is used here as a convenient way to view the offshore region and its functions as separate from the inshore-nearshore which are presented in subsequent chapters. As will be seen in the biologic considerations, 3.5 of this chapter, Offshore includes the Offshore Bottom and Pelagic-Based Plankton groups. Both habitats play significant roles in the geology of the sediments.

3.1.2 CONTINENTAL SHELF

The area under study contains two areas with distinct morphology, structure and history. The area south of Georges Bank represents a "normal" continental shelf, with gradually increasing water depth as one approaches the continental slope. This area is underlaid by the Baltimore Canyon Trough and an extensive thickness of post-Cretaceous sediments. The area west of Georges Bank, on the other hand, does not reveal a similar structure or history. This latter area includes the Gulf of Maine, Gulf of Maine Shelf, the Scotian Shelf, and the Georges Bank itself.

3.1.3 GULF OF MAINE

The Gulf of Maine, as defined by the boundaries set in Figure 3-1,includes that portion of the continental shelf seaward of the 100 meter isobath, eastward to the 200 meter isobath along the inner margin of Georges Bank. It includes Northeast Channel and the region southwest of the Scotian Shelf off western Nova Scotia and is the largest and most distinctive geographic unit within the study area. The irregular nature of the region is unlike most inner continental margins that characteristically display a relatively flat seaward sloping surface (continental shelf) which terminates in an abrupt increase in gradient at about 200 meters. This shelf-break forms the border between the continental slope and the shelf proper, and may lie hundreds of meters to hundreds of kilometers from the mainland.

Off the coastline of the United States, only two areas depart from this general scheme; the Continental Borderland off southern California and the Gulf of Maine. In California, the deep basins between the true shelf

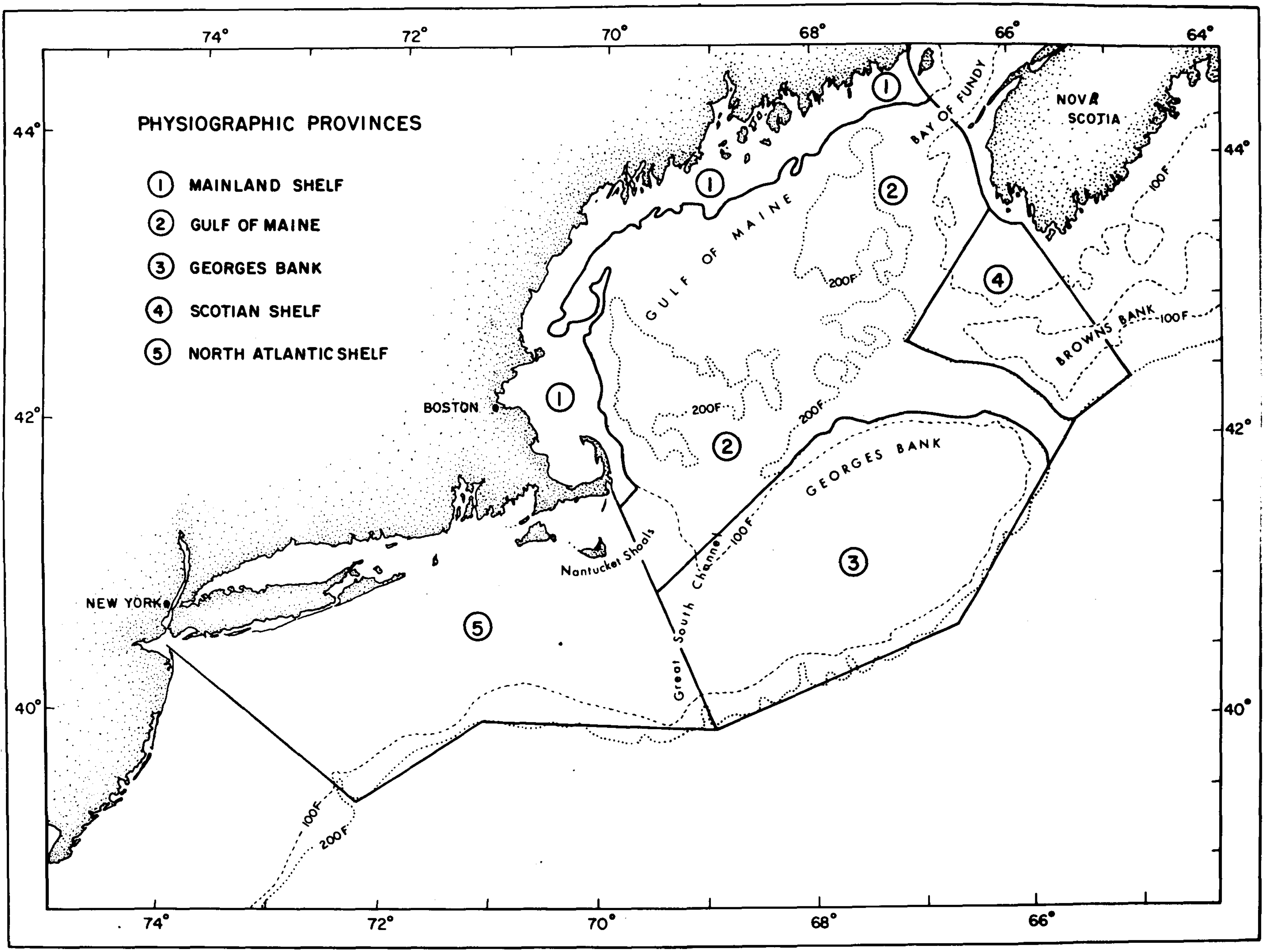


FIGURE 3-1

Offshore Physiographic Provinces in the Study Area edge and the mainland are a result of Tertiary tectonism, but in the Gulf of Maine, the shallow basins reflect the periods of erosion accompanying glacial epochs of the Pleistocene superimposed on a tectonic framework.

BATHYMETRY

The complex bathymetric character of the Gulf of Maine can be categorized by three physiographic subprovinces; the basins, low swells and flat-topped banks. Basins occupy about one-third of the total area of the Gulf; the swells and banks account for the major percentage of relief. Figure 3-2 shows the basin outlines by dashed lines and non-basin areas by slanted lines. The first thorough study of Gulf topography was performed by Murray (1947), but the most recent discussion of the physiographic character of the Gulf, complete with detailed bathymetric charts, will be found in Uchupi (1968).

The central Gulf of Maine displays an elliptical form elongated toward the northeast. This trend, which is consistent with the dominant structural grain of the New England region and some of the larger structural features within the Gulf, is defined by a long linear uplifted basement horst which extends from Cashes Ledge to Yarmouth, Nova Scotia and is covered by less than 100 meters of sediments (Ballard, 1974). This horst divides the Gulf of Maine in half, separating a lowland region to the north associated with Jordan Basin from a similar lowland region to the south beneath Crowell, Rodgers, and Wilkinson Basins. Figures 3-2 and 3-3 show basins, bathymetry, and locations of these features.

Within the Gulf, there are 21 basins with sill depths ranging from 59 to 242 meters. Many of these depressions are compound, that is, they contain several deep sites within one closed depression. The average depth of the Gulf of Maine is 150 meters (Uchupi, 1968), but many individual basins exceed 220 meters in depth, with Georges Basin having the greatest measured depth, 337 m. The most prominent ridge or bank is Cashes Ledge, a north-south trending high which is 57 km long and 8 to 10 km wide. Ammen Rock on the crest of this ledge rises to within 9 meters of the surface, the shoalest point in the Gulf. Gradients between the ledges and basins vary from gentle slopes to steep rock cliffs along the margins of some banks as shown by the contours of Figure 3-3.

The major connection to the sea is via the linear depression separating Georges Bank from the Scotian Shelf. This divide, Northeast Channel, has been studied by Uchupi (1966a) who found a buried trough some 120 meters below the present surface. It was the major point of egress for Wisconsin ice which filled much of the Gulf. The deepest point in this channel is about 270 meters, and in cross section, it displays a broad U-shaped profile characteristic of glaciated valleys. The margins of the channel include gradients of 1:50, but the central portion is essentially flat.

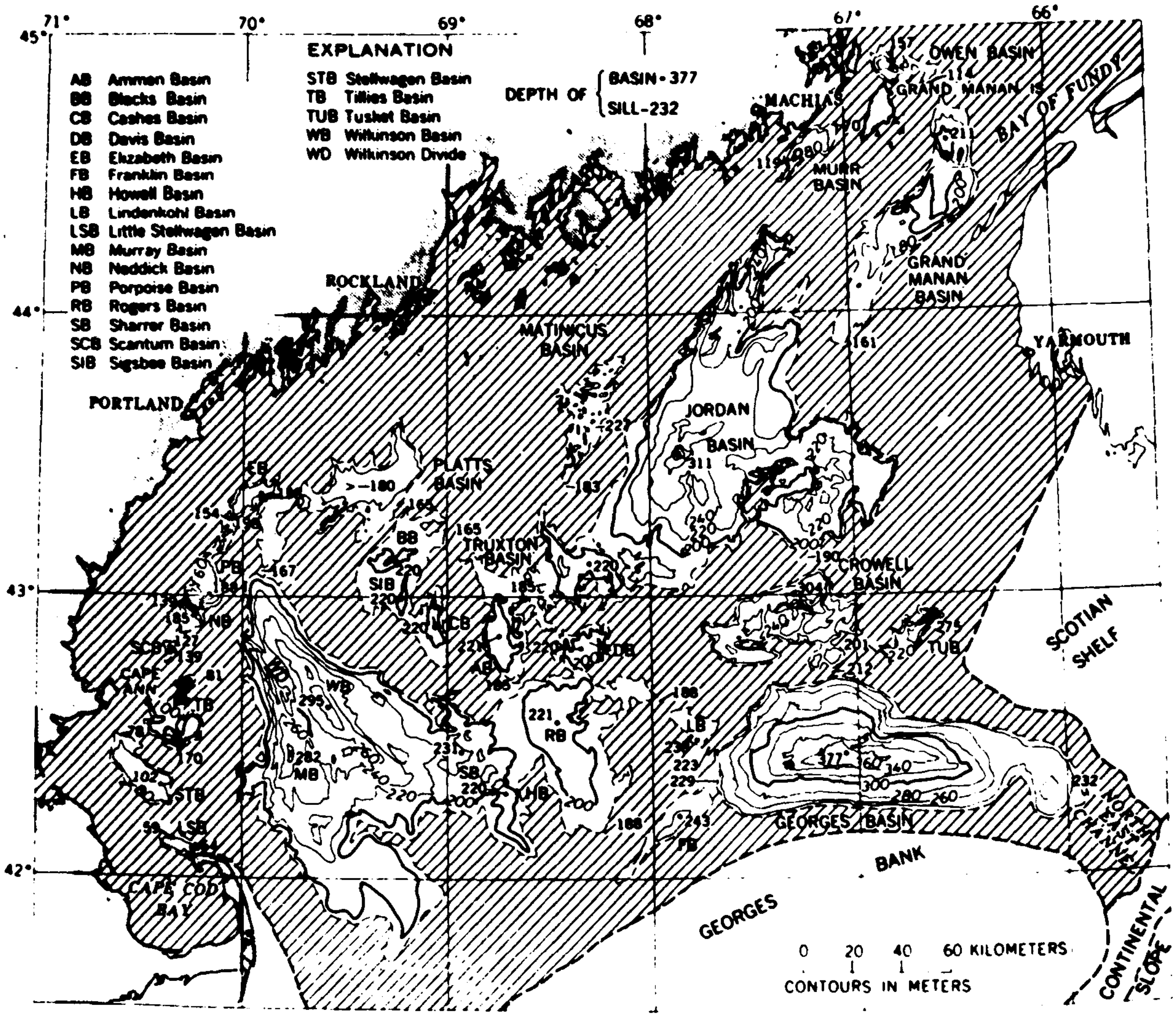


FIGURE 3-2 Basins Within the Gulf of Maine (Uchupi, 1968)

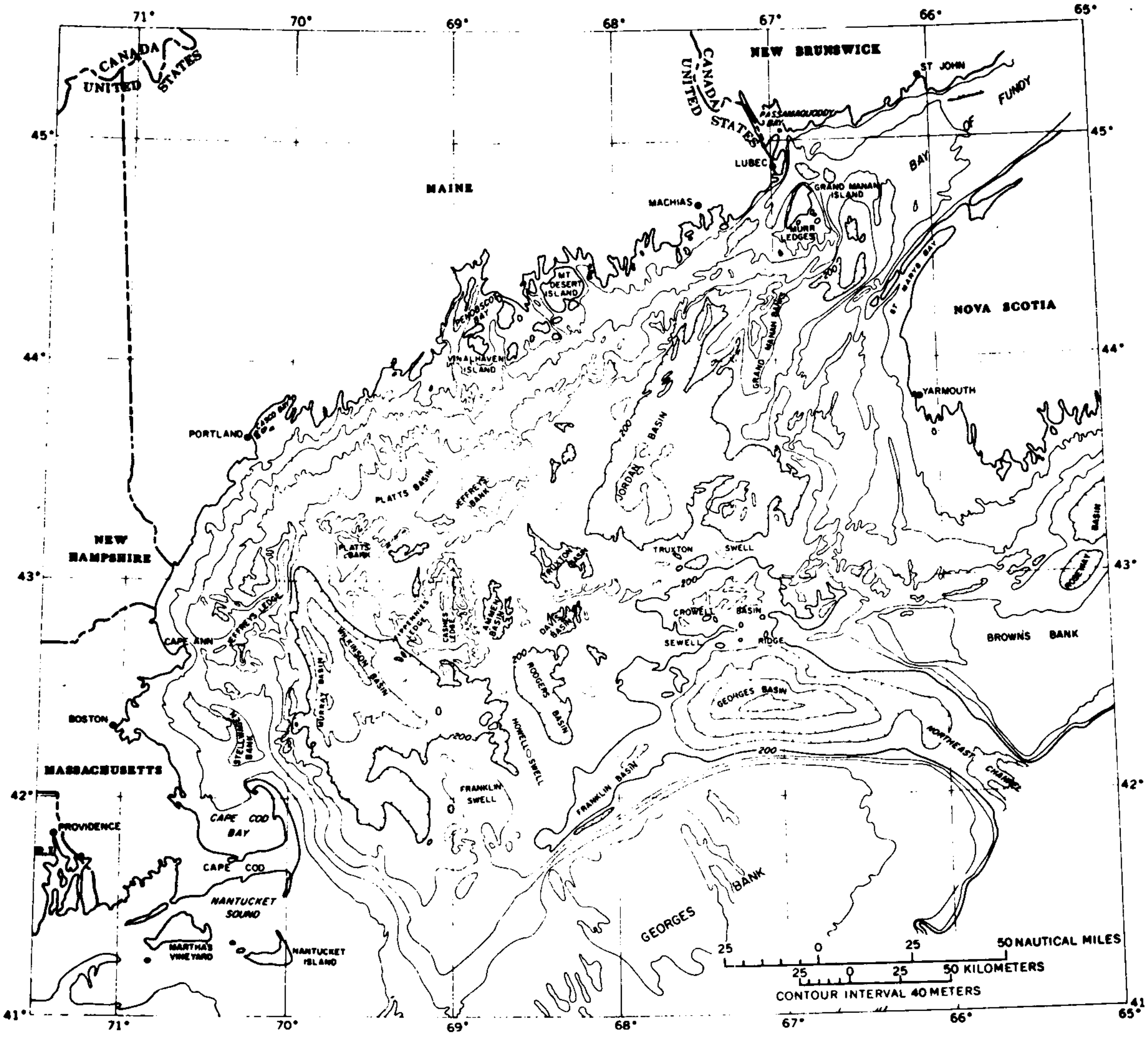


FIGURE 3-3

Bathymetric and Location Map of the Gulf of Maine (Kane et al., 1972 after Uchupi, 1968)

STRUCTURE

As early as 1925, Johnson had proposed that the bathymetric character of the Gulf, as revealed by scattered lead-line soundings, was a result of fluviatile erosion later drowned by the rising Holocene sea. Shepard (1931) proposed a glacial origin for the features, and Murray's initial bathymetric analyses (Murray, 1947) supported this theory. With the advent of seismic profiling techniques, it became possible to study the Gulf in three dimensions, and Drake, Worzel, and Beckman (1954) determined that much of the Gulf was underlaid by Paleozoic basement rocks covered with a thin veneer of recent unconsolidated sediment. As techniques improved, it became obvious that the Gulf contained an assortment of complex tectonic and stratigraphic features. Rather than clarifying the picture, each new survey opened several alternative theories for the structural relationships revealed by seismic reflection, refraction, magnetic and gravity techniques. This brief discussion provides only a summary of the findings, many of which are not conclusive, but taken together provide some appreciation for the nature of the Gulf. References which are indispensible to further study of structural relationships include Uchupi (1966b, 1970), Emery, Uchupi, Phillips, Bowin, Bunce, and Knott (1970), Ballard and Uchupi (1972), Emery and Uchupi (1972), and Kane, Yellin, Bell, and Zietz (1972). A more recent study by Ballard (1974) has synthesized existing and new data into a comprehensive picture of the Gulf.

In the northern portion of the Gulf, geophysical and stratigraphic studies have revealed the presence of a major linear feature termed the Maritime Triassic Basin. This zone, which may be floored by Carboniferous rocks associated with the Fundian Rift system of the same age, extends from the Bay of Fundy southwest into the Gulf for some 120 km. It terminates in the vicinity of Cashes Ledge where a major northwest-trending rift is believed to cross the entire Gulf (see Figure 3-4). Geophysical studies along this trend show generally negative gravity anomalies, a broad and flat magnetic field and relatively low seismic velocities, all of which suggest a fairly thick deposit of sedimentary materials. Much of this area is underlaid by accumulations of sedimentary and volcanic rock of Triassic age, a continuation of the Triassic sequence exposed in the Bay of Fundy.

A series of northwest-trending basins lie between the proposed rift through Cashes Ledge and a zone passing northwest through Cape Cod Bay and Cape Ann as presented in Figure 3-4. Their relationship with these major fractures is not clear, but they are no doubt related to them in both trend and age. They are believed to be fault-bounded depressions containing deformed Triassic volcanics and sediments in a series of depressions on the surface of pre-Carboniferous rocks. Gravity and magnetic data show this region to contain irregular masses of rock having pronounced gravity lows which are either attributed to stratified rocks

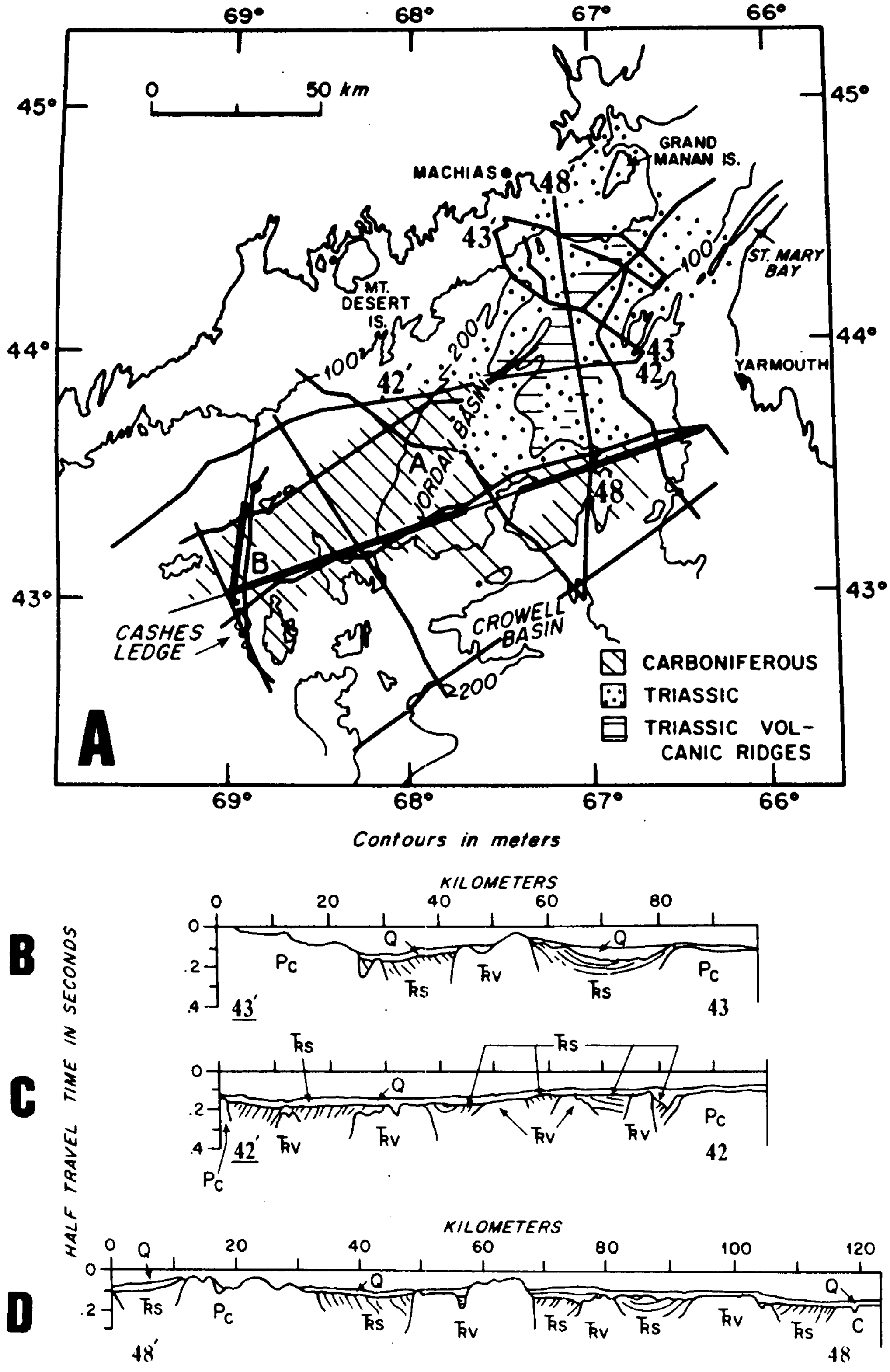


FIGURE 3-4

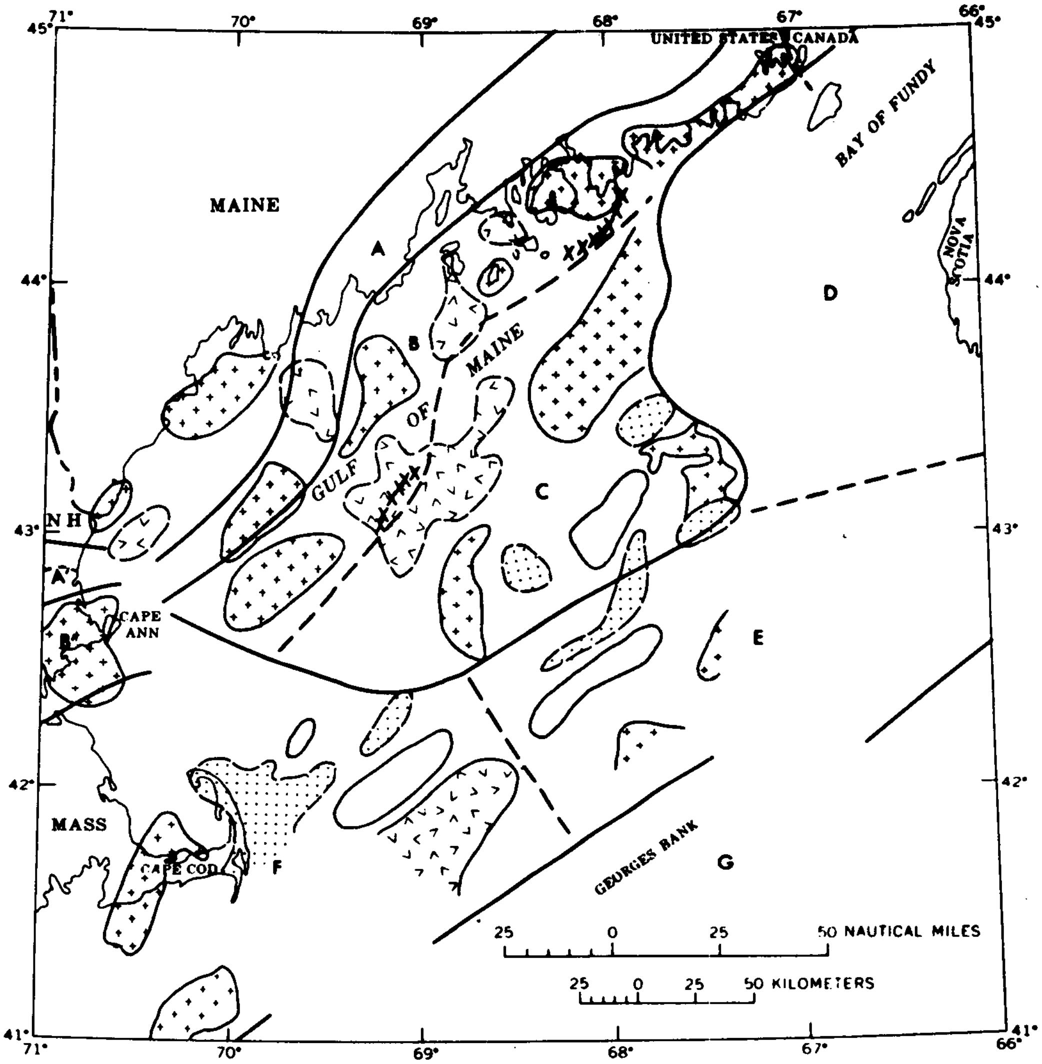
Bathymetric Chart of the North Eastern Part of the Gulf of Maine (Ballard & Uchupi, 1972) or felsic plutonic rocks. Figure 3-5, a lithologic map derived from gravity and magnetic data,shows these lows.

The southwestern margin of this region lies along a second major northwest-trending fracture which contains known and possible Jurassic to early Cretaceous intrusives (an alignment coincident with the "Boston-Ottawa trend"). This regional feature lies within the Mainland Shelf Province of this chapter. The inner Gulf of Maine region may thus be characterized by three crustal blocks separated by northwest-trending fracture zones as we saw previously in Figure 3-4. These features are identified by distortions and dislocations in the magnetic patterns of the Gulf, and by gravity and seismic evidence which identify local density distributions associated with sub-surface depressions or highs. On the basis of several lines of evidence, Ballard and Uchupi (1972) suggest a reconstruction of the region to post-rifting conditions by moving the central block (containing the Murray and Wilkinson Basins) to the northwest by 30 km. If such a crustal dislocation has occurred, it can be attributed to tensional movements associated with the initial motions of the African crustal plate away from the North American block. The ensuing rifting and wrench faulting ended in the early Jurassic at a time when the continental margin of the North American block became "welded" to the spreading Atlantic sea floor. However, the persistent seismic activity along the trend of the southern fracture (through Cape Ann) suggests that welding was incomplete or that more recent stress is precipitating deformation along an old crustal dislocation.

The outer (eastern) half of the Gulf contains several features related to the structure of this Province. Georges Basin is a major depression bordering Georges Bank, and seismic reflection studies have shown it to contain at least 1,600 meters of gently deformed Triassic sediments and volcanic intrusives. The southern margin of these sediments is unclear because of Coastal Plain (post-Triassic) units atop the contact, but to the north, they are clearly bounded by a normal fault juxtaposing them against pre-Carboniferous basement rocks. This fault appears not to affect the Quaternary overburden, and may be related to late Triassic or Tertiary tectonic activity. A series of seismic profiles for the entire Gulf of Maine is presented in Figures 3-6 and 3-7.

3.1.4 GULF OF MAINE SHELF

The Gulf of Maine is surrounded to the north, west, and south by a coastal belt, 30 to 50 km in width, which is primarily a region of massive outcrops of igneous and metamorphic rocks, with sporadic pockets of sediments, mostly less than 100 m thick. This mainland shelf province is outlined in Figure 3-1 and has arbitrarily been established as that region in proximity to the New England Mainland lying between the littoral zone and the 100 meter isobath. It thus includes Jeffrey's Ledge and Stellwagen Bank,



EXPLANATION

▦ Area of pronounced gravity high indicating presence of mafic plutonic rock, or possibly in some places, ultramafic rock

▨ Area of pronounced areally large, aeromagnetic high indicating presence of mafic plutonic rock

☐ Area of moderate gravity high indicating presence of mafic rock, probably of volcanic origin

> ⌃ < Area of pronounced gravity low probably caused by felsic plutonic rock. Broad area in central parts of zones B and C may be underlain in part by stratified rocks

⁘ Area of moderate gravity low indicating presence of thin bodies of felsic composition, or of moderate thicknesses of stratified rocks which are at most partly metamorphosed

A Magnetic zone discussed in text

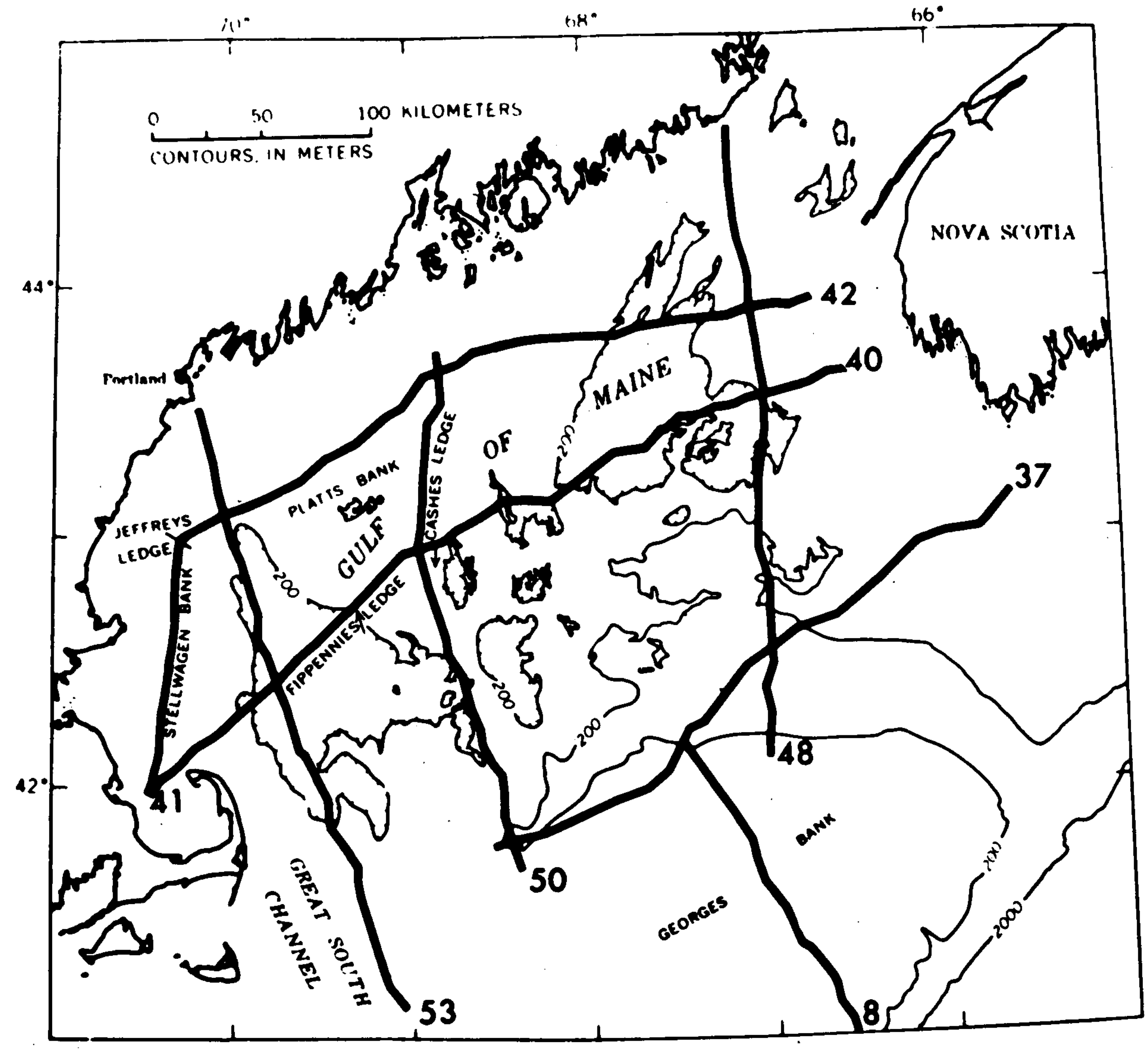
—— Principal magnetic zone boundary

— — — Subordinate magnetic zone boundary

X X X Pronounced linear aeromagnetic high, probably caused by ultramafic rock

FIGURE 3-5

Provisional Lithologic Map of Indurated Bedrock of the Gulf of Maine (Kane et al., 1972)

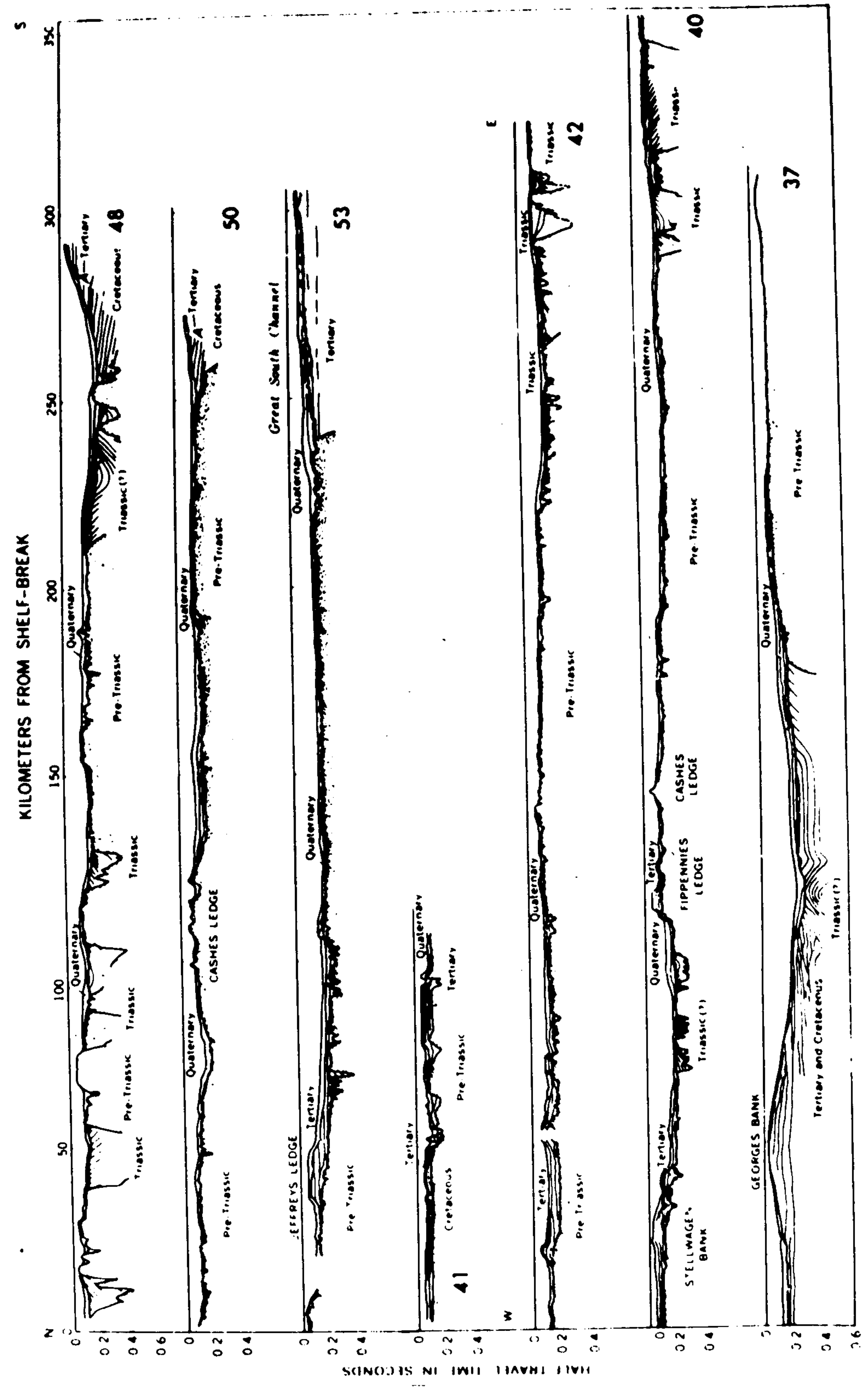


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-6

Location of Seismic Profiles (Uchupi, 1970)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-7

Seismic Profile Interpretations for the Gulf of Maine (Uchupi, 1970) features which are similar in structure to other Banks and Ledges which are placed in the Gulf of Maine Province only because depths greater than 100 meters intervene. The most detailed published analyses of the southern half of the area will be found in Oldale, Uchupi, and Prada (1973), and Uchupi (1970). Their interpretations are based upon extensive surveys employing seismic reflection profiling techniques. Ballard's (1974) study has synthesized data from the northern half of the area.

BATHYMETRY

The mainland shelf province of the Gulf of Maine region is characterized by an extremely irregular surface consisting of narrow basins, linear highs (ledges), flat-topped banks, and isolated pinnacles. The surface is inherited from glacio-fluvial agents associated with the geologically recent retreat of continental ice from the region. The hard rock of coastal New England does not contribute a significant volume of detritus, and what material has found its way to the shelf lies within discontinuous depressions or is spread as a thin veneer over the irregular bedrock.

Two major positive features are Stellwagen Bank, a flat-topped shoal trending north from Cape Cod and reaching to within 40 meters of the surface and Jeffrey's Ledge extending along a trend reaching northeast from Cape Ann. The most extensive smooth area within the province lies within Cape Cod Bay, where only one irregular ledge protrudes through the sedimentary cover. The smooth nature of these three surfaces can be attributed to relatively thick sections of Coastal Plain, Tertiary, and Quaternary sediments which obliterate the underlying relief. Landward of the 20 meter isobath, the general lack of such deposits creates a chaotic surface characterized by exposed bedrock and boulder beds deposited as lag materials washed from glacial drift.

STRUCTURE

Gravity studies (Kane, et al., 1972) suggest that the correspondence between the landward edge of the generally high Bouguer gravity field of the Gulf and the coastline of New England are causally related. The Gulf crustal block is believed to be separated from the mainland block by a fault trending parallel to the general shoreline of the Gulf. A model proposed by Kane, et al., (1972) to account for the regional trend of the increasing gravity field on a trend passing southeast from central New England across the Gulf includes geologic and density data as well as seismic refraction information. This model, shown in Figure 3-8, accounts for all observations by establishing a crustal structure based upon blocks of high density rock (Precambrian basement) with a progressively thinner cover of stratified rocks of Paleozoic age. This model assumes these differences in thickness may cause the gravity field variation. The lateral discontinuities in densities are thus believed to reflect vertical displacement, or faults, between the major crustal blocks. The exact

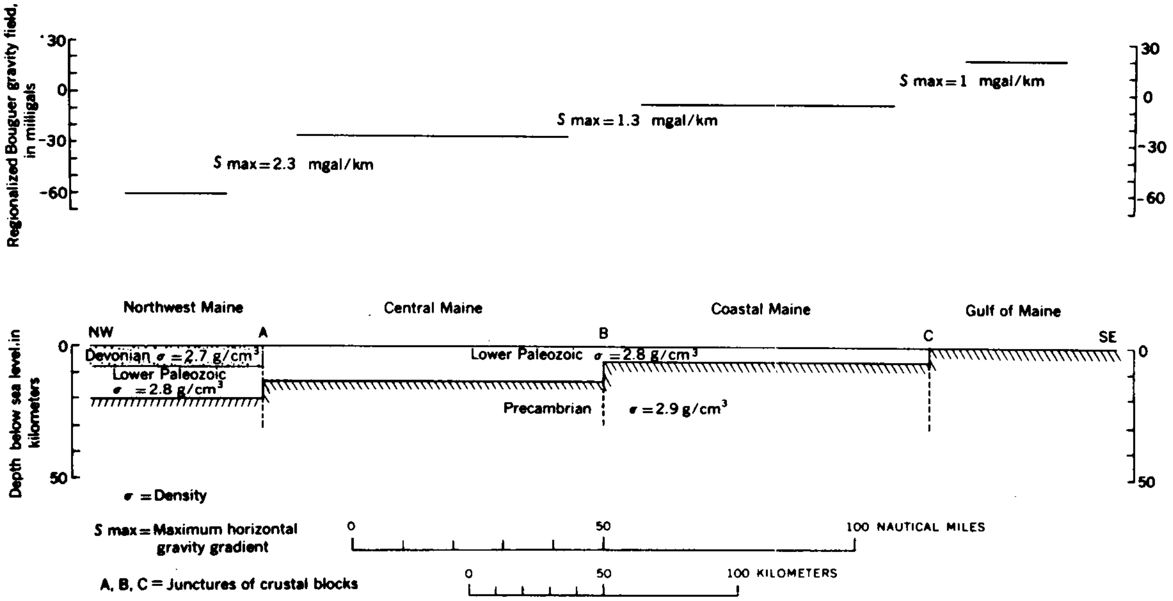


FIGURE 3-8

Regional Bouguer Gravity Field (Kane, et al., 1972) location of such a fault along the coast has not been resolved, but it may be associated with the Cabot Fault, a major feature proposed by Wilson (1962), or the Fundian Fault (Johnson, 1925; Koons, 1941, 1942).

Results of magnetic studies (Kane, et al., 1972) reveal a general absence of large masses of volcanic rock or mafic plutonic rocks. The magnetic field in this region is characterized by a low-gradient flat field generally paralleling the coast until it encounters the disturbed zone at Cape Ann. Here, it is apparently offset to the northwest (refer to Figure 3-5). The flatness of the field is due primarily to the lack of magnetite-rich rocks in the shelf region. These include stratified Paleozoic rocks and felsic intrusives.

The surface of the inner mainland shelf as far south as Plymouth, Massachusetts, is characterized by a series of closely spaced, topographically high "bedrock" outcrops consisting of igneous rocks (primarily granitics), metasediments and metavolcanics. These outcrops are separated by thin (less than 20 feet) lenses of sediment deposited by glacial agents or contributed from coastal tributaries. Seaward of this zone of outcrops and south of Plymouth, the Pleistocene and Recent sediments gradually thicken and obliterate the irregular bedrock surface. Seismic profiles have revealed a network of buried drainage channels which in many cases can be extended onshore where they align with present or buried fluvial channels. They are thus the filled and drowned extension of mainland drainage, some of which are offshore equivalents of preglacial river valleys now buried by glacial drift on land.

Coastal plain sediments of Cretaceous to early Pleistocene age are known to underly many basins and banks of the Gulf of Maine, but they are almost totally lacking in the mainland shelf (Oldale, et al., 1973). They occur in parts of the Cape Cod Bay region, and beneath Stellwagen Bank and Jeffrey's Ledge and Tillies Ledge, and east of Cape Cod peninsula. The combined thickness of inferred moraine and Upper Pleistocene-Holocene deposits varies from zero along the inner shelf to as much as 200 meters on the eastern margin of Stellwagen Bank.

3.1.5 SCOTIAN SHELF

Only a small portion of the Scotian Shelf falls within the region encompassed by the bounds of this study (refer to Figure 3-1). This segment is occupied by Browns Bank, a bathymetric high which is the structural and physiographic equivalent of Georges Bank northeast of the major depression formed by Northeast Channel.

BATHYMETRY

Uchupi (1968) has identified four zones within the Scotian Shelf which can be delineated by characteristic bathymetric features. All four zones are present in the area designated herein as the Scotian Shelf Province.

The first zone occupies an irregular rocky belt that extends some 30 km offshore. Channels having local relief up to 30 meters cross the region and lead into a second zone defined by discontinuous low region having 10 to 60 meters of relief. This region reflects the seaward limit of the irregular rocky area typical of the inner shelf. The third zone consists of a series of basins which parallel the Coastline and deepen to the northeast. Portions of the southernmost depression, Roseway Basin, lie along the edge of the northeastern limit of Province IV. Maximum depth of this basin is 186 meters. Unlike their counterparts in the Gulf of Maine, these basins have gentle slopes with smooth floors. The fourth zone includes the flat-topped banks reaching to the shelf edge. These banks are separated by broad low saddles, quite unlike the relatively deep gap (Northeast Channel) lying between Browns Bank, the southernmost bank of the Scotian Shelf, and Georges Bank. However, the marine processes responsible for the flat-topped shoals affect both Banks alike, and smaller-scale bathymetric features such as sand wave fields and megaripples known to be common to both banks have many similarities.

STRUCTURE

Uchupi (1970) presents a seismic profile from this area which clearly reveals the nature of the Browns Bank region. Reflecting horizons beneath the unconformity separating Quaternary sediments from older units are believed to be Triassic, Cretaceous, and Tertiary formations which terminate against the pre-Triassic "basement" rock which fails to display any internal structure. This unit is probably equivalent to the lower Paleozoic metasediments and igneous rocks forming much of Nova Scotia. However, according to Emery and Uchupi (1972), recent drilling on the Scotian Shelf indicates that this "basement" may be composed of Jurassic limestones and/or Jurassic salt deposits. The high seismic velocity of these materials, previously attributed to Paleozoic intrusives and metamorphic rocks, may instead be related to Mesozoic units of considerable thickness which mask the true igneous basement. Some seismic studies indicate that the Mesozoic units may be as thick as 8 to 12 km in the outer shelf area. The rocks are believed to lie within linear basins extending along continental shelves of Canada and New England.

Younger Quaternary sediments lie atop the Mesozoic and Tertiary sedimentary units as a wedge-shaped deposit which thickens seaward. Reflecting horizons within this wedge are roughly parallel to the present sea floor, and reflect a seaward progradation of these materials through depositional processes of upbuilding and outbuilding. In the vicinity of Browns Bank these sediments are from 20 to 40 meters thick, but increase in thickness to the southwest as they approach Northeast Channel.

The Scotian Shelf appears aseismic with no major earthquake epicenters being located on the shelf off Nova Scotia. One major shock occurred northeast of the shelf in 1929. This event, termed the Grand Banks earthquake, caused massive slumping of sediments on the upper continental slope. Sedimentary conditions at the shelf-break and upper slope off the Scotian Shelf are similar to those off the Grand Banks, and a strong shallow seismic event could promote slumping of equal magnitude.

3.1.6 GEORGES BANK

The second largest Province off New England is Georges Bank, an oval-shaped shoal encompassing more than 35,000 km^2, which forms a major boundary to the continental shelf off New England. Its outer margin (shelf break) is aligned with the outer edge of the Scotian Shelf, and its stratigraphy, structure and sediments are in several ways quite similar. Northeast Channel, the major depression dividing these two Provinces, is also a major boundary between geologic regions. As such, it has been designated a political boundary as well. This factor will be discussed in a later section.

BATHYMETRY

The southern half of the Bank is a smooth plain, similar to that of the continental shelf farther to the west off southern New England (Nantucket Shoals). The boundary between Georges Bank and that shelf has been defined as Great South Channel. This depression is an erosional feature, now partially buried in its outer portions, which trends north-south along an alignment suggesting a previous connection with Hydrographer submarine canyon. The northeastern part of the shoal consists of a shallow platform, generally less than 60 meters deep, upon which several major northwest-trending linear shoals and troughs are superimposed. Many shoals with depths less than 40 meters occur in the northeast corner of Little Georges Bank, and locally depths are less than 20 m. Many of the large features are permanent enough to warrant names (such as Cultivator and Georges Shoals), but a complex second-order set of sand waves is in turn superimposed upon these troughs and shoals. Figure 3-9 shows the distribution of sand waves on Georges Bank with the wave crests.

These are dynamic features as will be discussed later in Section 3.1.8, Sediments, which probably shift position in response to tidal currents and to the storm-generated hydraulic regime. The shoalest point on the Bank, noted as 4 meters (Uchupi, 1968), occupies a sandy crest atop Georges Shoal. According to Chamberlain (1964), this shoal was exposed as an island as late as 1796, when one chronicle indicates a ship's crew held a ball game on this site. Such minimal depths should be considered ephemeral since a severe storm could erase this local high, but it does convey an appreciation for the extent of extremely shallow water along the axis of Georges Bank.

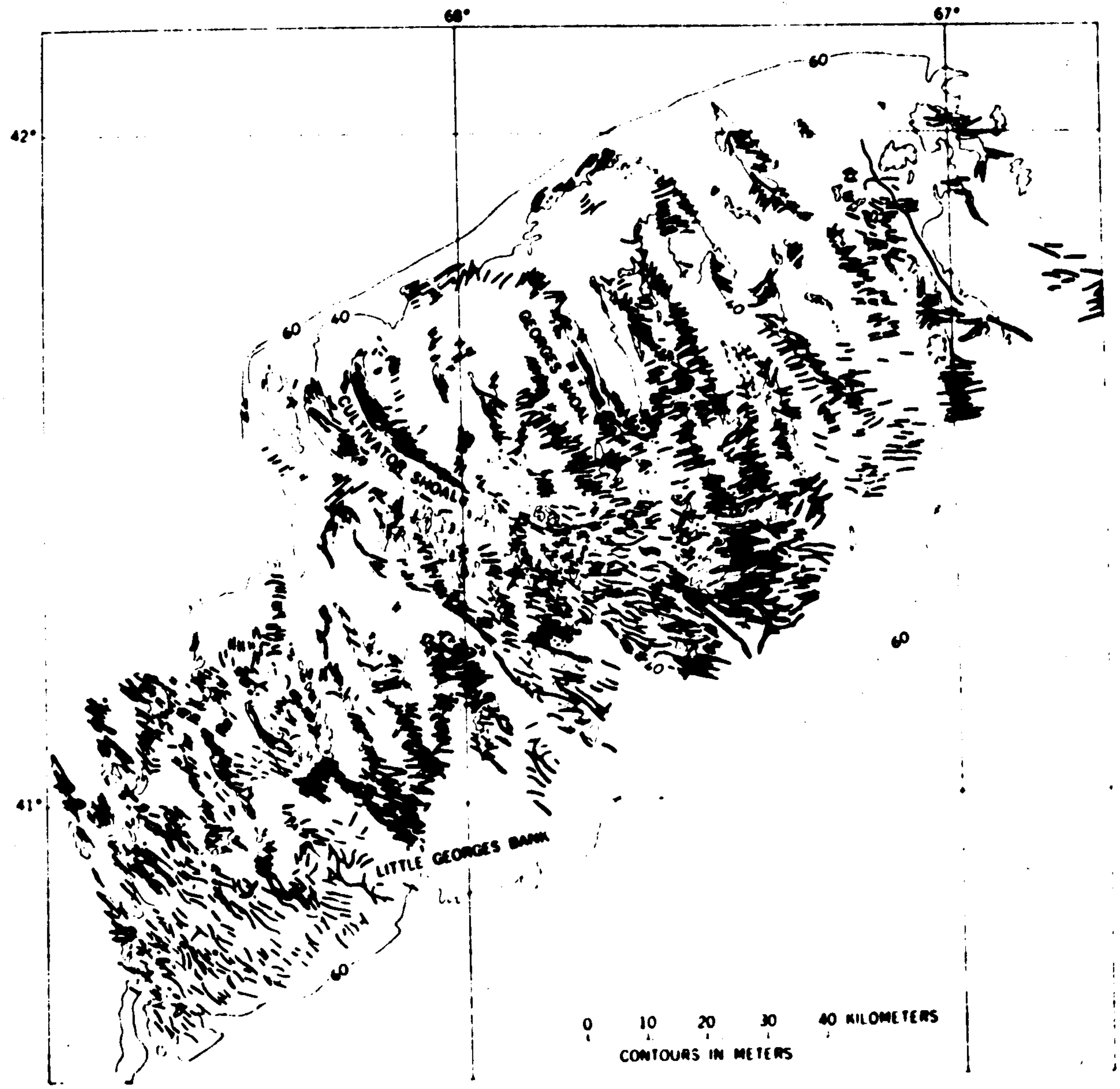


FIGURE 3-9 Distribution of Sand Waves on Georges Bank (Uchupi, 1968)

The steepest slopes on the margins of the Bank occur along the northern border where a gradient of 1:45 is found between the Bank crest and Georges Basin. The outer (seaward) margin displays slightly steeper gradients where the shelf-break is incised by the heads of several major submarine canyons. From north to south, these canyons include Corsair, Lydonia, Gilbert, Oceanographer, Welker and Hydrographer Canyons. All the canyons are cut into the shelf, with the head of Oceanographer being some 20 km landward of the shelf break, and all extend down to the continental rise. Observations from manned submersibles (Ross, 1968; Trumbull and McCamis, 1967; Trumbull and Hathaway, 1968) have given us more detailed insights into the small scale topography, structure, and sedimentary regimes within these canyons.

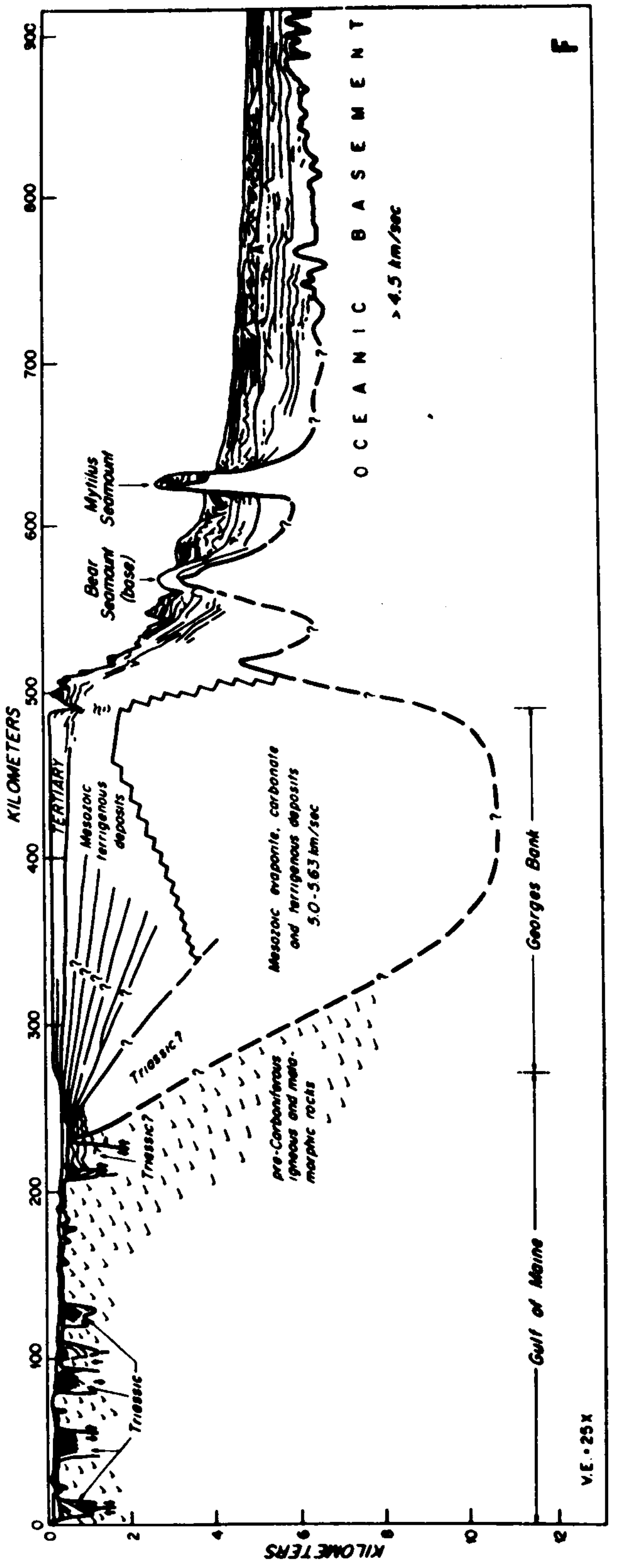
STRUCTURE

It was pointed out in the introduction that the Gulf of Maine region is atypical with regard to the usual bathymetric configuration of the continental margins of the world. This fact was well known to New England geologists, and as early as the 1870's Verrill (1878) published lithologic and paleontologic descriptions of rocks dredged by fishermen from Georges Bank.

Upham (1894) and Dall (1925) followed with additional descriptions, and Johnson (1925), in his major work on New England shorelines, proposed that Georges Bank was a drowned cuesta carved by earlier fluviatile processes. The internal structure of the Gulf was first revealed through seismic refraction by Drake, Worzel, and Beckmann (1954) and Knott, Hoskins and Hartley (1968) employing a continuous seismic profiler to determine details of the uppermost stratigraphic units present on the Bank.

As noted in the section of the Gulf of Maine, Cretaceous sediments are present in Georges Basin. Within that depression, they display a seaward dip, and are thus projected under Georges Bank to the continental slope (Uchupi, 1966a). Dredging by Stetson (1936) along the upper slope south of Georges Bank yielded Upper Cretaceous and Tertiary fossils in rocks recovered from the heads of canyons crossing the shelf-break. The depth of this contact was placed between 480 and 600 meters. Deeper units are believed to consist of a thick series of Mesozoic terrigenous deposits, Triassic redbeds, and at greater depths Mesozoic evaporites, carbonates, and terrigenous deposits (Figure 3-10). The "basement" is thought to consist of pre-Carboniferous igneous and metamorphic rocks similar to those forming the deep foundations of the Gulf of Maine.

Recent gravity and magnetic data reported by Mattick, Weaver, Foote, and Rupple (1973) indicate that the linear ridge at the outer edge of the outer continental shelf is deeper and farther west than reported by Drake, Ewing, and Sutton (1959). It forms the eastward edge of a Mesozoic trough containing relatively undisturbed post-Paleozoic sedi-



TRIGOM PARC

FIGURE 3-10

Structural Section Across Georges Bank, North-South (Emery & Uchupi, 1972) ments. Schultz and Grover (1973) report that the basin beneath Georges Bank may contain more than 7 km of Mesozoic and Tertiary sediments. Geophysical data indicate the presence of about 1,500 meters of Jurassic carbonates, marine shales, and consolidated sands. The basement displays structural deformation in the form of high angle normal faults, with sediment thickness greatest in the down-dropped segments.

On the basis of changes in the magnetic pattern along the northern margin of the Bank, Kane, et al. (1972) suggested that a major fault might be present between Georges Bank and the interior Gulf of Maine. A recent gravity study by Hendricks and Robb (1973) substantiated the suggestion by others that mafic and felsic intrusives lie beneath the northern margin of the Bank. These features appear to be elongate in a northeast direction and are at least 20 km wide. Comparison of the character of the gravity field on the Bank and in the Gulf to the northwest reveals a fairly abrupt transition along the north edge of Georges Bank, supporting the suggestion that a fault may separate Provinces II and III of this chapter.

Tertiary rocks are also present in abundance on Georges Bank, and are separated by a well-defined unconformity from the underlying Cretaceous sedimentary units and are shown in Figure 3-11. Gibson (1965) reports the recovery of Miocene rocks on both the northern and southern margins of the Bank, and Pliocene rocks were dredged from the seaward shelf by Emery and Uchupi (1965). Another prominent reflecting horizon separates the Lower Pleistocene sediments from the Tertiary rocks, and within this upper unit there are five reflectors which suggest a depositional regime associated with successive advances of the continental ice sheets during glacial epochs. Along the northern edge of the Bank, most of these units display mild deformation associated with overburden pressure of encroaching ice, and numerous buried channels imply a period of fluviatile erosion between periods of deposition.

3.1.7 SOUTHERN NEW ENGLAND CONTINENTAL SHELF

The continental shelf between Georges Bank and northern New Jersey is characterized as a broad shelf, up to 200 km wide south of Cape Cod, and a gentle platform with slopes of less than 0°03' off New York. The shelf break generally occurs at a water depth of about 140-160 meters. Like Georges Bank, the outer shelf is incised with a number of prominent canyons, including, Veatch, Atlantis, Alvin, Block, and Hudson Canyons. This latter feature, perhaps one of the most studied canyons in the world, extends across the shelf (where it is called the Hudson Channel or Hudson Shelf Valley) to New York Harbor.

One area of particular interest is Nantucket Shoals, which lies directly southeast of Nantucket Island. This shallow-water area in many ways resembles Georges Bank, although it is located on the inner and middle

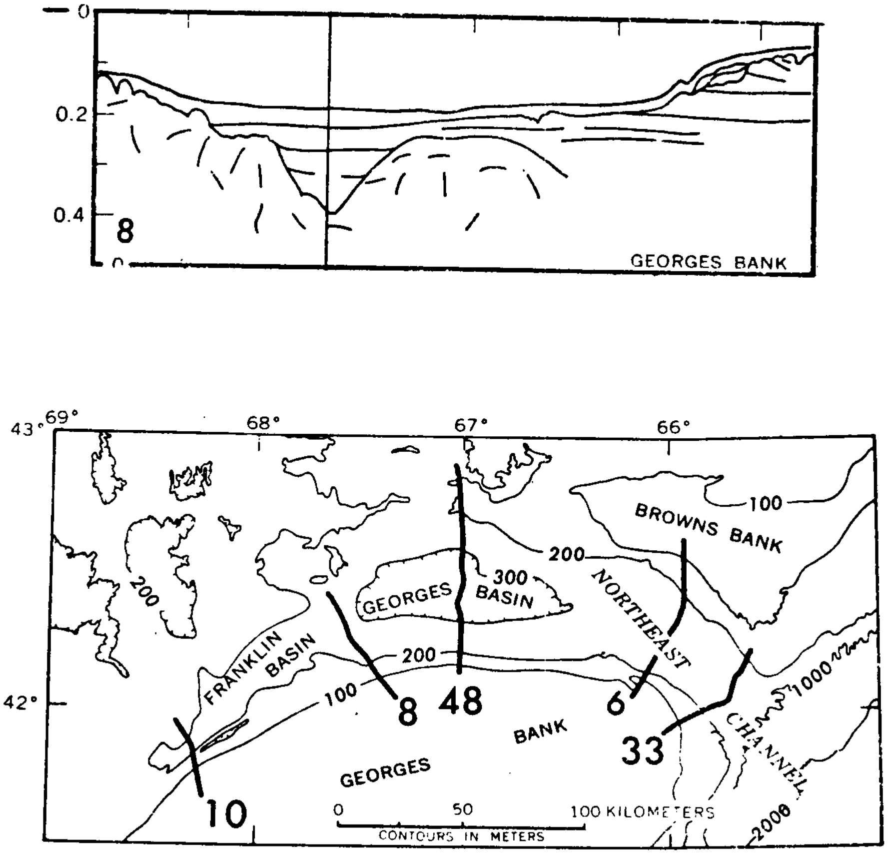


FIGURE 3-11 Profile 8 (Fig. 3-6) Georges Bank Indicating Cretaceous Boundary (Uchupi, 1970)

shelf, not the outer shelf. Like Georges Bank it has shallow depths, generally between 20 and 40 meters, and also is covered with prominent sand ridges (see the following paragraphs). In addition, the Quaternary and pre-Quaternary histories of both areas are quite similar.

The continental shelf off southern New England and New York and New Jersey exhibits a number of distinct morphological features, some of which are erosional and some constructional. Many are remnants of lower stands of sea level while others probably are in equilibrium with modern oceanographic conditions. Probably the most visually characteristic feature is the ridge and swale field which occupies most of the inner shelf (including Nantucket Shoals). Most of these ridges occur in water depths less than 30 m. Most nearshore ridges are linear in configuration, while ridges associated with inlets and capes tend to be arcuate. The ridges off southern New England probably are relict features that have been maintained or slightly altered by tidal activity (Owen, Emery, and Hoadley, 1967; Smith, 1969; Sanders, Emery, and Uchupi, 1969). Most of the sand ridge fields to the south, however, appear to be transgressive Holocene sands which overlie late Pleistocene and early Holocene sediments. These ridges tend to be quite stable, but can migrate more than several hundreds of meters during major storms. For a more complete discussion, the reader is referred to a review paper by Milliman (1974).

The Southern New England shelf is also marked by a number of prominent channels. In addition to Hudson Channel, which obviously was formed by the Hudson River during lower stands of sea level, several other prominent relict river channels occur. Long Island Channel and Block Island Channel both exhibit visually obvious surface topography, but other channels, such as the extensive system off Nantucket Sound (Emery and Uchupi, 1972), Rhode Island (McMaster and Ashraf, 1973a, 1973b) and in Long Island Sound (Tagg and Uchupi, 1967; Grim, Drake, and Heirtzler, 1970), have been buried by late Quaternary sedimentation. Coch (1973) has suggested that modern sand movement is burying former valleys between Long Island and Block Island, but at least some of the burial probably occurred during transgressions and regressions of sea level.

STRUCTURE

At present our knowledge of the deep structure of the northeastern U.S. continental margin is limited by the lack of seismic refraction and reflection data and the near absence of deep drill-hole borings. Most of our insights into the deep structure come from magnetic and gravity data, along with some refraction profiles, a few drill logs, and much imagination. Emery and Uchupi (1972) have summarized most of our knowledge of the area to date.

Two prominent magnetic features occur on the continental slope off southern New England. First is the slope anomaly, which occurs over the outer shelf to upper mid-slope, with values generally greater than 600 gammas. The slope anomaly continues more or less unbroken from Georges Bank to the Blake Plateau, and preliminary calculations (Drake and others, 1959; Drake, Ewing, and Stockard, 1968; Emery, 1968) suggest that this is a buried ridge system behind which much of the continental shelf accreted. Calculations place the magnetic body some 8 to 10 km below the present-day sediment surface, or some 4 to 5 km deeper than the ridge feature commonly seen by seismic profiling under the upper slope off the southeastern U.S.A. This suggests that a considerable amount of sedimentary strata may have accumulated on the ridge before the entire feature was buried (Emery and Uchupi, 1972).

The second major magnetic feature is an E-W magnetic anomaly which may cut the slope anomaly at a latitude of approximately 40°N (Drake and Woodward, 1963). This proposed Cornwall-Kelvin transcurrent fault is suggested to connect the New England Sea Mounts with the proposed fault system in northern New Jersey. According to most workers, this New Jersey fault system was last active in the late Paleozoic. More recent data, however, do not suggest the expected magnetic anomalies proposed by Drake and Woodward (1963), suggesting that perhaps the Cornwall-Kelvin fault does not exist (Taylor, Zietz, and Dennis, 1968).

Shallow structure of the shelf is better known, since existing seismic reflection systems are capable of penetrating the top 1 to 3 km of sediment. Again, however, the lack of stratigraphic control restricts the degree of interpretation of geophysical data.

When the shallow and deep structure data are combined, one can speculate on the history of the southern New England and North Atlantic continental shelf. During the rifting of North America from North Africa, a ridge-trench system formed and became trapped within the westward-drifting North American plate. Fragmentary evidence gathered from seismic refraction velocities and from the logs of test borings suggest that the early sediments which accumulated on and behind this ridge-trench system were evaporites and shallow-water carbonates.

With increased erosion from the Appalachian Mountains, however, terrigenous sedimentation began to mask the non-terrigenous contributions. Maximum accumulation and subsidence occurred along the axis of the Baltimore Canyon Trough. Apparently a basement high (called the Long Island Platform; Ballard, 1974) prevented extensive sediment accumulation off Georges Bank. In contrast, maximum sediment accumulation in the Baltimore Canyon Trough was more than 12 km, most of which was deposited prior to the Tertiary. Sediment accumulations on present-day land areas was sparse, although as much as 2 km did accumulate in the Salisbury Embayment off Maryland (Maher and Applin, 1971).

By the late Cretaceous or early Tertiary, the Baltimore Canyon - Georges Bank Trough was nearly filled with sediment, and excess sediment spilled over the ridge system and accumulated on what is the modern-day continental rise (Emery and others, 1970). A major period of upbuilding and outbuilding of the continental shelf began in the Oligocene, by which a series of deltas prograded seaward across the shelf off Long Island (Garrison, 1970). Off much of southern New England, however, terrigenous sediment mostly escaped to the deep sea; as a result, Cenozoic sediment cover in most of the southern New England shelf is minimal (Moore and Curray, 1963; Hoskins, 1967; Emery and others, 1970).

The best documented history of the southern New England shelf is from the Quaternary, which in most places occupies the upper 40 to 100 m of sediment. In most of this area, the sediment is predominantly glacial moraine and outwash deposited during various Pleistocene glacial advances. (For example, see Zeigler, Hoffmeister, Giese, Tasha, 1960). Drainage systems (as mentioned above), which cut across Coastal Plain strata, were filled and deformed by Pleistocene glaciation. The outer shelf, on the other hand, became the site for a series of prograding deposits. At least 5 Quaternary deltas have been recognized off New Jersey and southern New York (Ewing, Luskin, Roberts, and Hirshman, 1960; Ewing, J., LePichon, and M. Ewing, 1963; Knott and Hoskins, 1968), each one probably representing a different ice age.

3.1.8 SEDIMENTS AND SEDIMENTARY PROCESSES

The sediments within the study area have been discussed in a number of papers originating from data collected during the Woods Hole Oceanographic Institution U.S. Geological Survey study of the eastern continental margin. Included are papers on texture (Schlee, 1973), character of the gravel fraction (Schlee and Pratt, 1970), the light mineral fraction (Trumbull, 1972). heavy minerals (Ross, 1967, 1970), the carbonate fraction (Hulsemann, 1966) and clay mineralogy (Hathaway, 1972). A complete listing of the sedimentological data from this program has been compiled by Hathaway (1971).

One problem in dealing with this sample collection is that it represents only one sample per 320 km^2. One example may indicate the degree of small-scale variability missed in such a sample grid. During a submersible reconnaissance of Browns Bank, Drapeau (1970) reported encountering rounded boulders as large as 2 meters in diameter, often in clusters 5 to 20. Other portions of the Bank inspected consisted of light buff medium to coarse sand which was noted to be well sorted. Intermittent patches of fine, well sorted gravel were noted, some as large as 200 meters in one dimension. In the sandy areas, currents have shaped the loose materials into complex rippled patterns, with larger sand waves and barchan-shaped "dunes" as high as 4 meters. The troughs of the sand waves generally contained coarser materials and shell debris.

Despite the inability of the present sediment sample distribution to take into account such local variations in sediment composition, the broad reconnaissance by WHOI and the USGS does provide the first integrated study of the entire area. The following sections will discuss the general sedimentary parameters and conclusions derived from this study.

SEDIMENT SIZE

Most of the shelf off southern New England, together with Nantucket Shoals and Georges Bank is covered with sand and gravel-size sediments (Figure 3-12); gravels are particularly prominent on Georges Bank and Nantucket Shoals, where local concentrations can exceed 50 percent of the sediment (Figure 3-13). Gravel is even more common on the Scotian shelf and locally is greater than 75 percent. In all these areas mud is a minor component, or is totally absent (especially on Georges Bank and the shelf to the south). The one major exception is the mud-rich area south of Martha's Vineyard, where silt and clay constitute 25 to 90 percent of the total sediment (Figure 3-14).

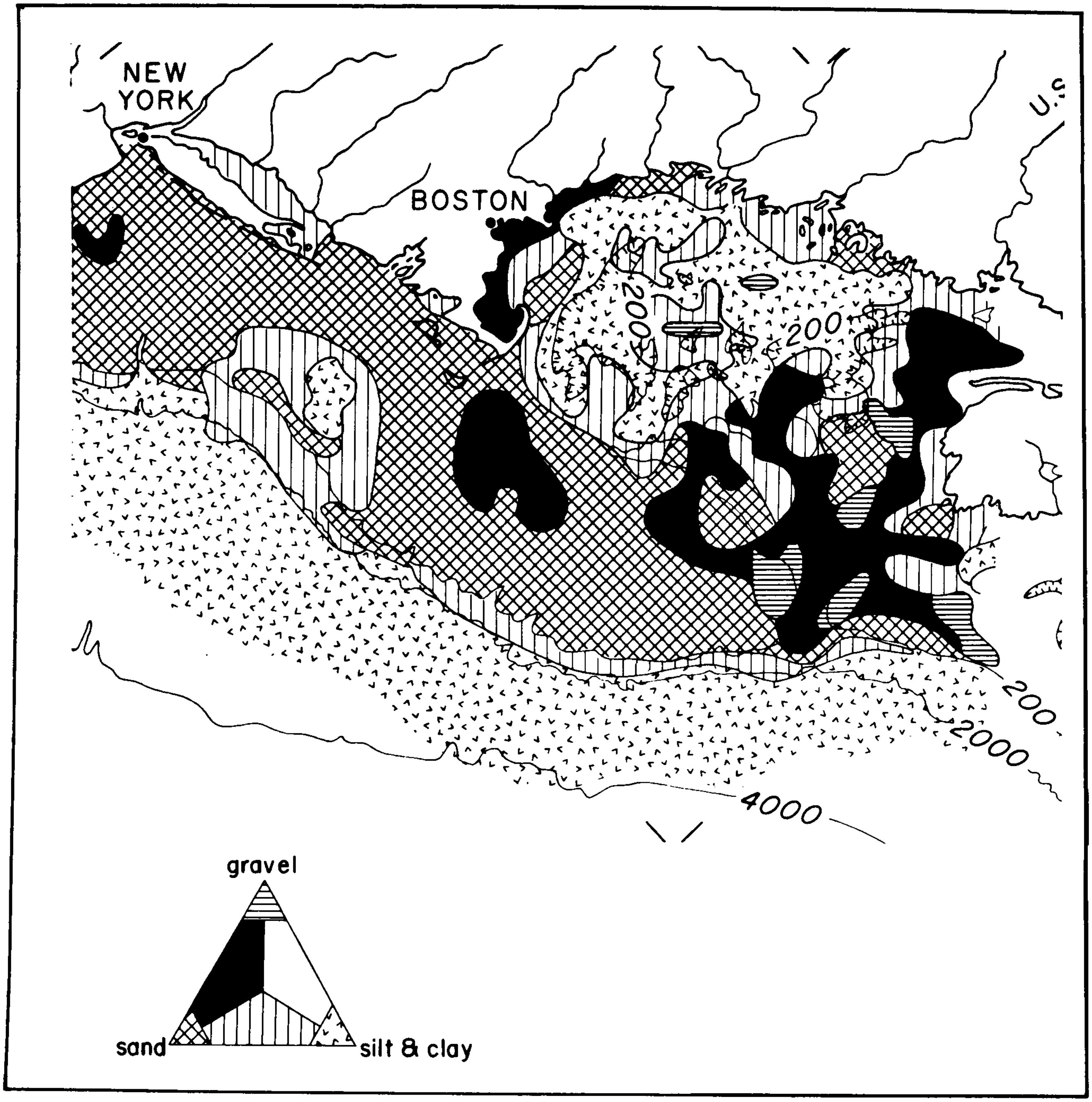
The distribution of sediment types in the Gulf of Maine and adjacent shelf and bank areas is more complex. Generally, however, sands and gravels occur on the banks which separate the various basins within the Gulf, while the basins themselves contain predominantly mud (Figures 3-12 to 3-14). The adjacent inner shelf tends to contain appreciably more mud than does the shelf off southern New England. The source and age of this sediment is discussed in a following section.

IRON STAINING

Iron staining is a common characteristic of many sediments within the study area. Sand-size components south of the Bay of Fundy are particularly well iron stained (Figure 3-15), suggesting an origin of sediment from the iron-rich deposits of Nova Scotia. Sediments over much of the rest of the shelf contain appreciable amounts of iron-stained grains, but seldom more than 50 percent of the sand-size fraction.

CALCIUM CARBONATE CONCENTRATIONS AND ASSEMBLAGES

Most shelf sediments in the study area contain appreciably less than 5 percent calcium carbonate. Notable exceptions occur on Nantucket Shoals, Georges Bank, and the Scotian shelf, where concentrations can exceed 50 percent (Figure 3-16). Shelf carbonates generally are composed of three assemblages, mollusk (containing more than 75 percent mollusk shells), mollusk-echinoids (containing more than 20 to 40 percent of each component) and benthonic foraminifera. The mollusk-echinoid assemblage is most limited to areas south of Georges Bank, while the benthonic foraminifera generally are restricted to those areas containing large quantities of mud, such as the Gulf of Maine basins and the mud patch south of Martha's Vineyard (Figure 3-17). The carbonate-rich sediments of Georges Bank and the Scotian shelf, however, also contain appreciable amounts of barnacles, which distinguish them from the assemblages which characterize



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-12

Sand & Gravel Sediments

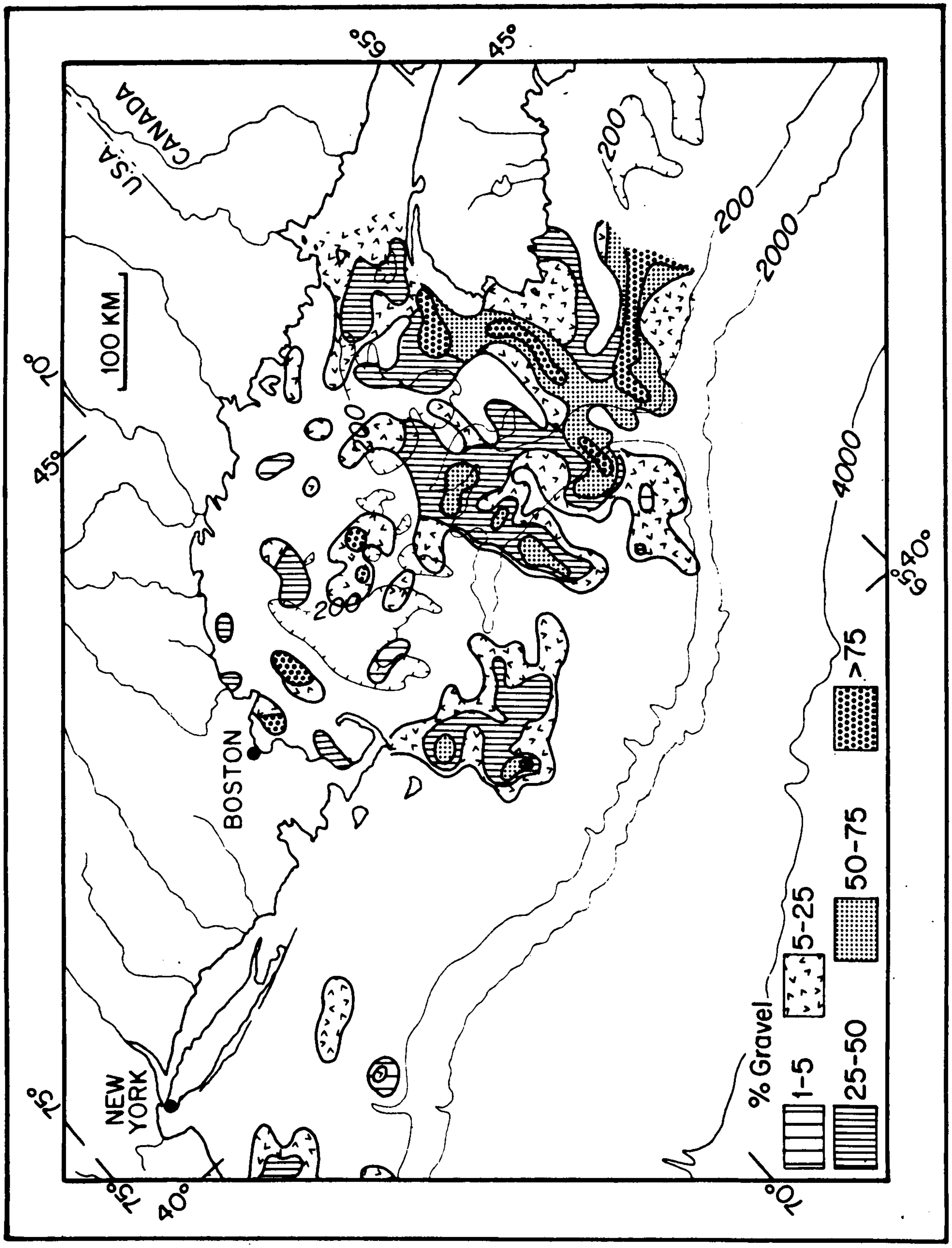
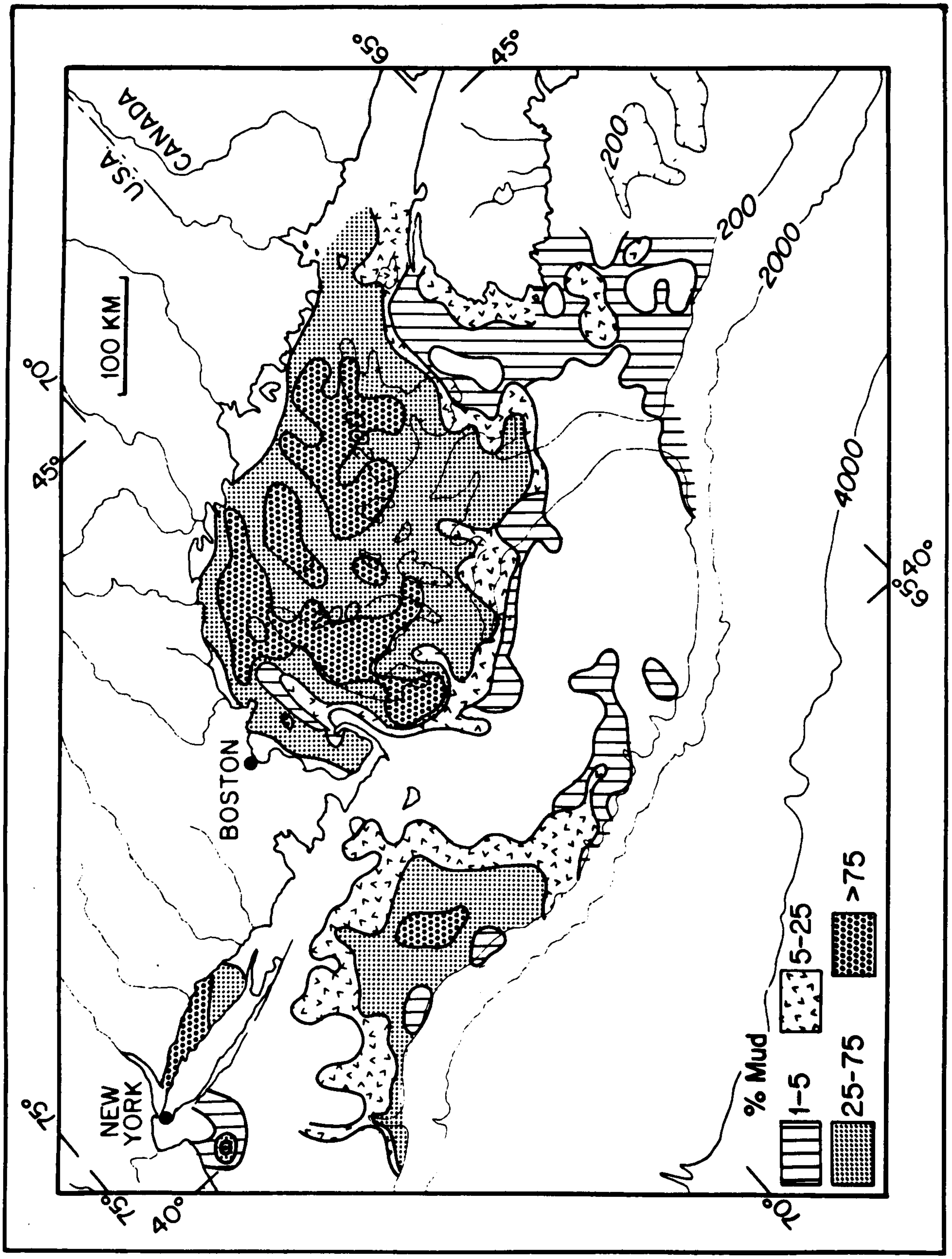


FIGURE 3-13 Gravel Distribution Within the Surface Sediments



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-14

Mud Distribution Within the Surface Sediments

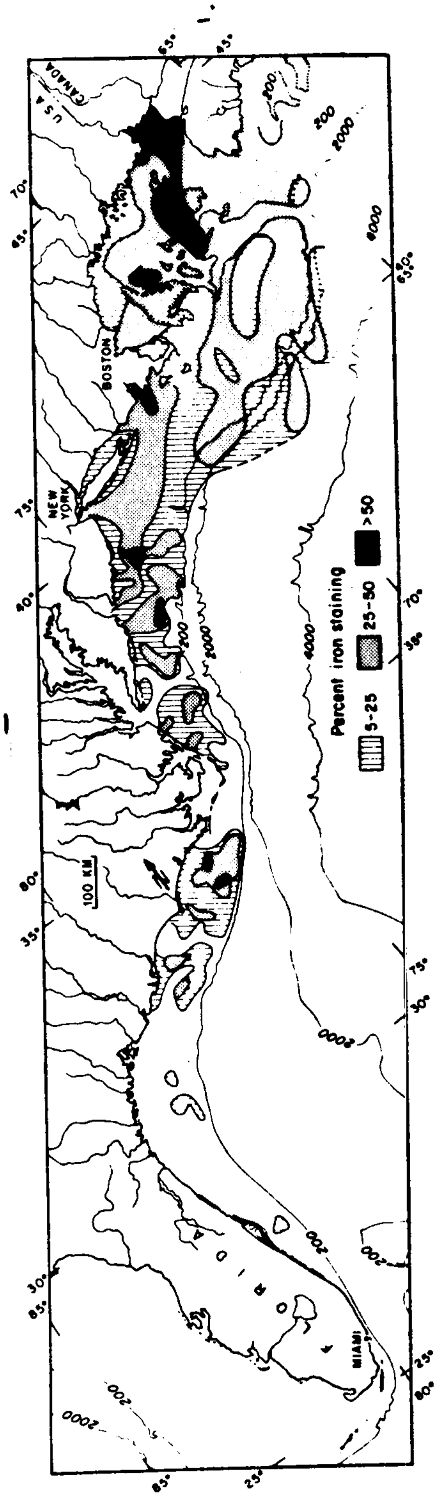
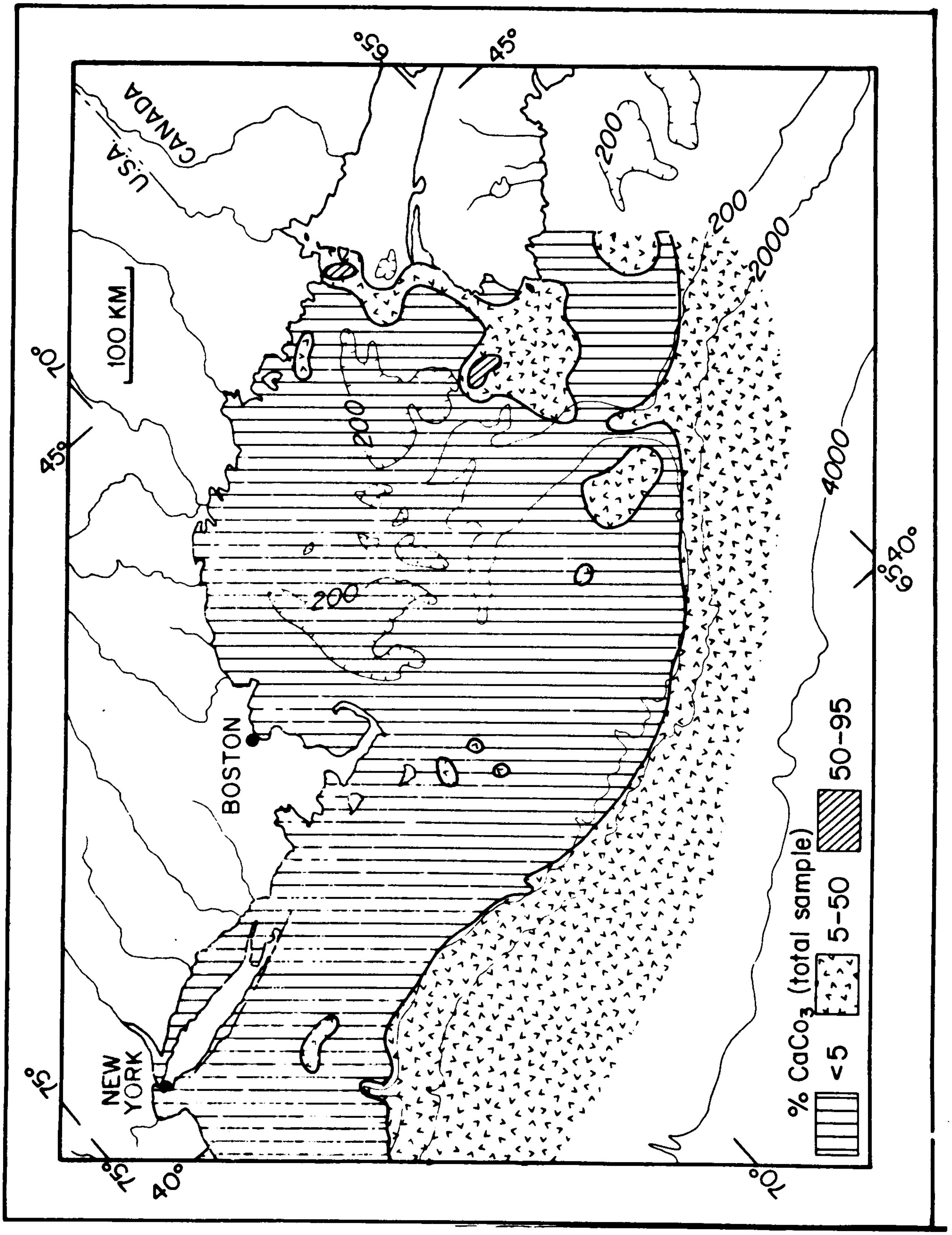


FIGURE 3-15

Iron Staining in the Sand Fraction of the Surface Sediments (Milliman, et al., 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-16

Distribution of Calcium Carbonate

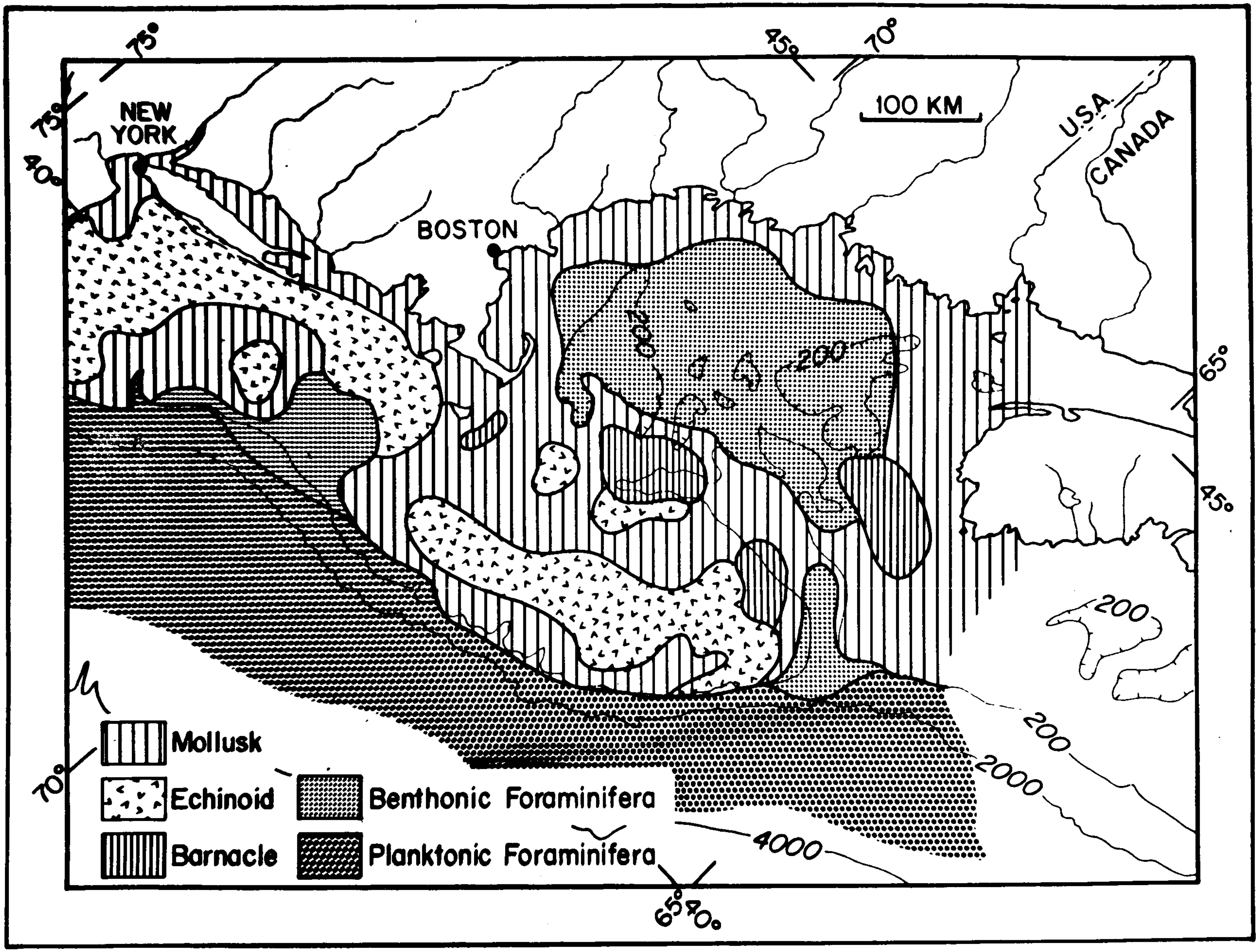


FIGURE 3-17

Carbonate Assemblages on the Continental Shelf and the Upper Slope the other shelf sediments in the area. Slope muds are rich in planktonic foraminifera but contain relatively low concentrations of calcium carbonate (Figure 3-16).

HEAVY MINERALS

Heavy minerals (specific gravity greater than 2.87) generally constitute less than 4 percent of the sand fraction of the shelf and within the Gulf of Maine. Much of the area contains less than 2 percent heavies, and the slope generally less than 1 percent (Figure 3-18). However some areas contain relatively high concentrations (locally greater than 10 percent); such areas include Long Island Sound, the shelf off Penobscot Bay, and several areas of the western Scotian shelf. The limited number of existing heavy mineral data, however, prevents us from delineating possible relict strand lines or placer deposits.

Ross (1970) defined 15 heavy mineral provinces between Long Island and Nova Scotia, only 3 of which (all in the Gulf of Maine) are composed of modern sediments. Sediments within the other 12 provinces are mostly glacial in origin.

Several mineral distributions characterize the non-opaque heavy fraction. Amphiboles are common over much of the inner and outer shelf south of New England and are a prominent component of the Gulf of Maine (Figure 3-19). In contrast, Epidote occurs in only small concentrations throughout much of the Gulf of Maine and adjacent areas, although it is prominent off much of the southeastern Atlantic shelf (Figure 3-20; Milliman, Pilkey, and Ross, 1972). Staurolite is particularly common on Georges Bank and off Long Island, and decreases to both the north and south (Figure 3-21).

The high quantities of altered heavies, amphiboles, garnets (Figure 3-22) and augite in the Gulf of Maine suggests a composition partly related to source and partly to low energy conditions (Ross, 1970), while the staurolite on Georges Bank probably was derived from underlying Coastal Plain strata (Milliman and others, 1972). As stated earlier in this section, most of the other heavy minerals probably were glacially transported during the last glaciation, although as will be discussed in further sections, a fluvial and oceanic transportation probably was also important.

LIGHT MINERALS

Quartz and feldspar dominate the sand grains with specific gravities less than 2.87. One exception is the sand fraction within the Gulf of Maine and the muds south of Martha's Vineyard, both of which contain dominant amounts of fecal pellets composed of silt and clay-size particles (Milliman and others, 1972). Presumably these pellets were formed by some bottom dwelling organism, perhaps a polychaete.

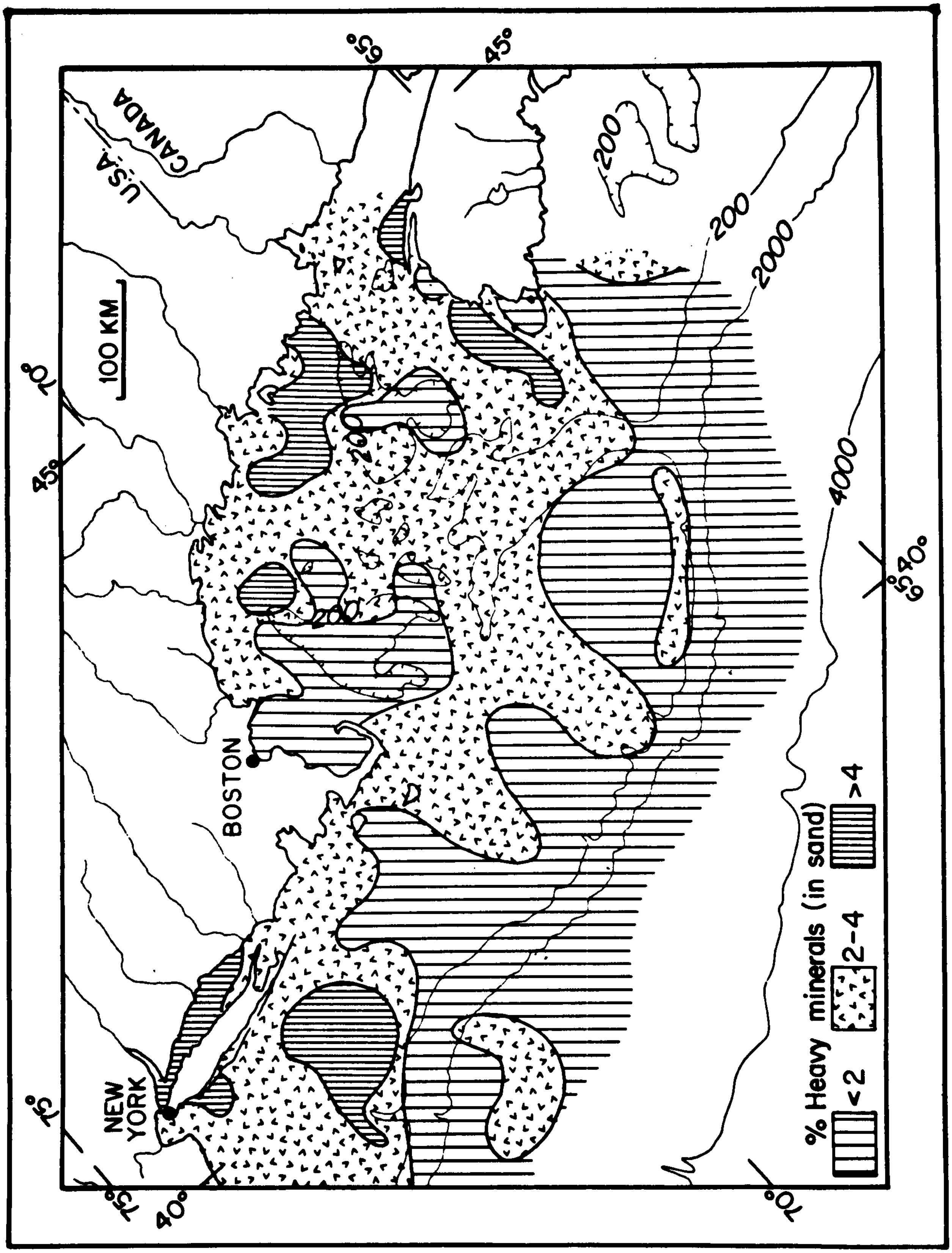


FIGURE 3-18 Heavy Mineral Distribution Within the Sand Fraction

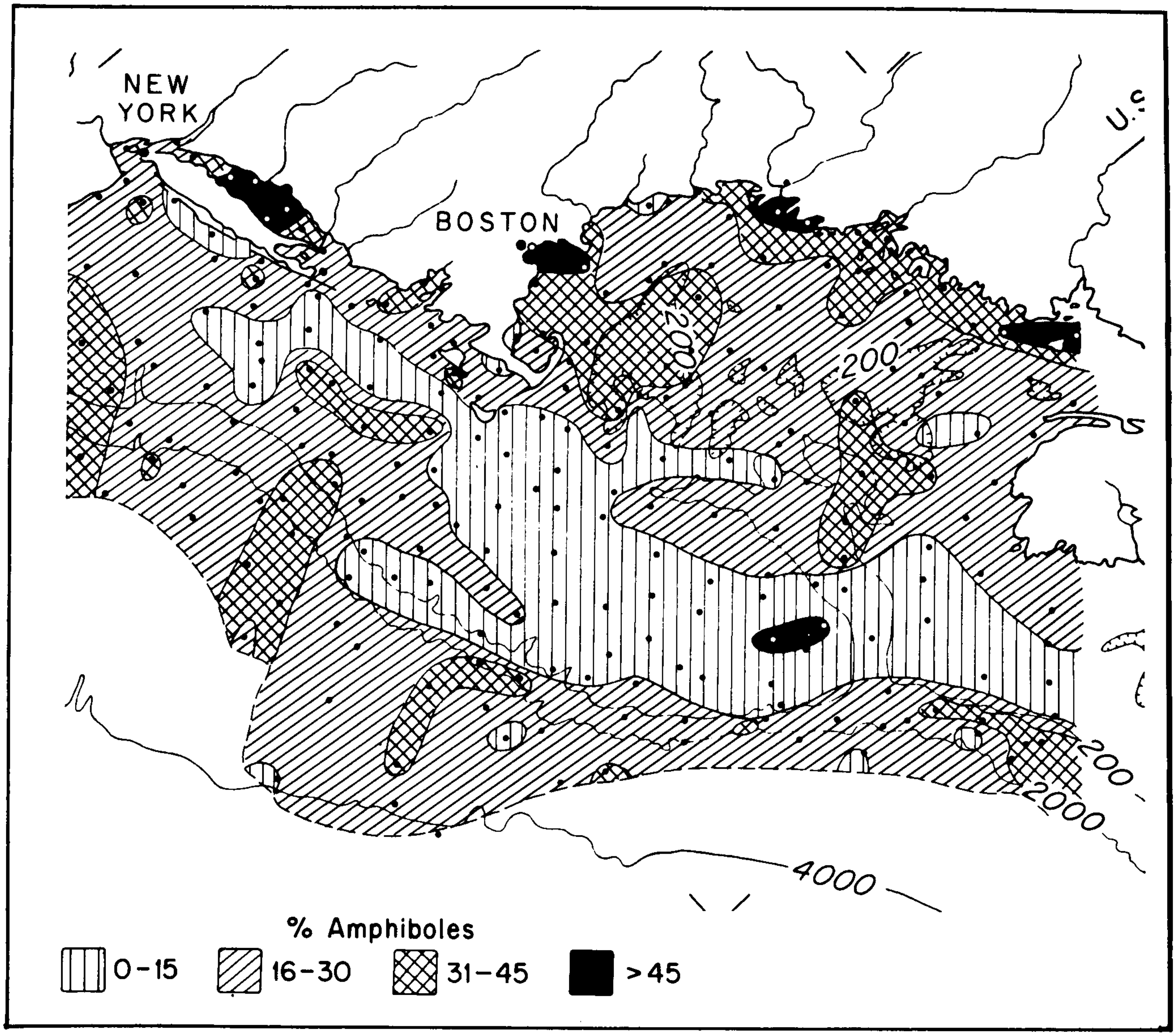
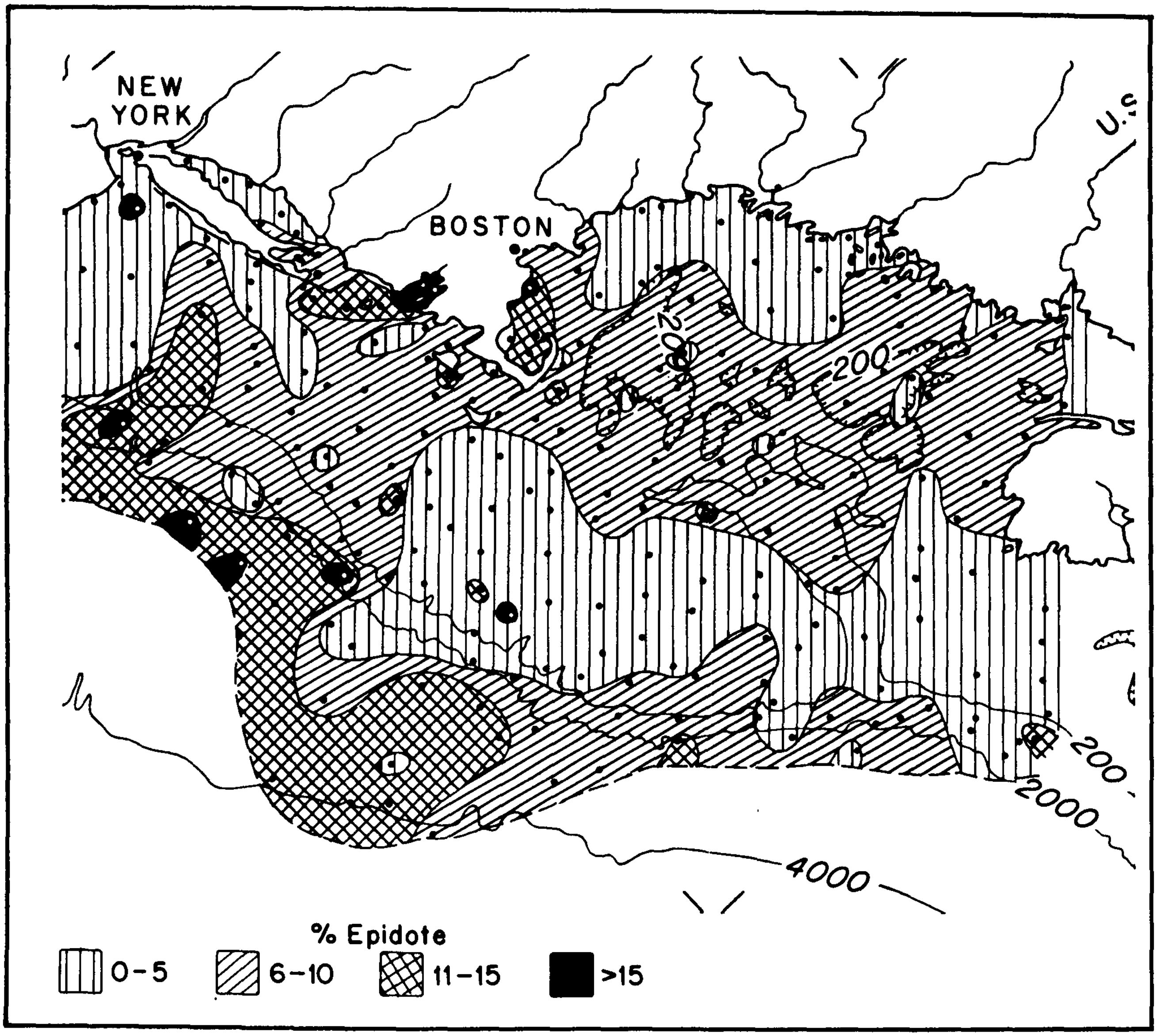


FIGURE 3-19 Amphiboles Within the Non-Opaque Heavy Mineral Fraction (Ross, in preparation)

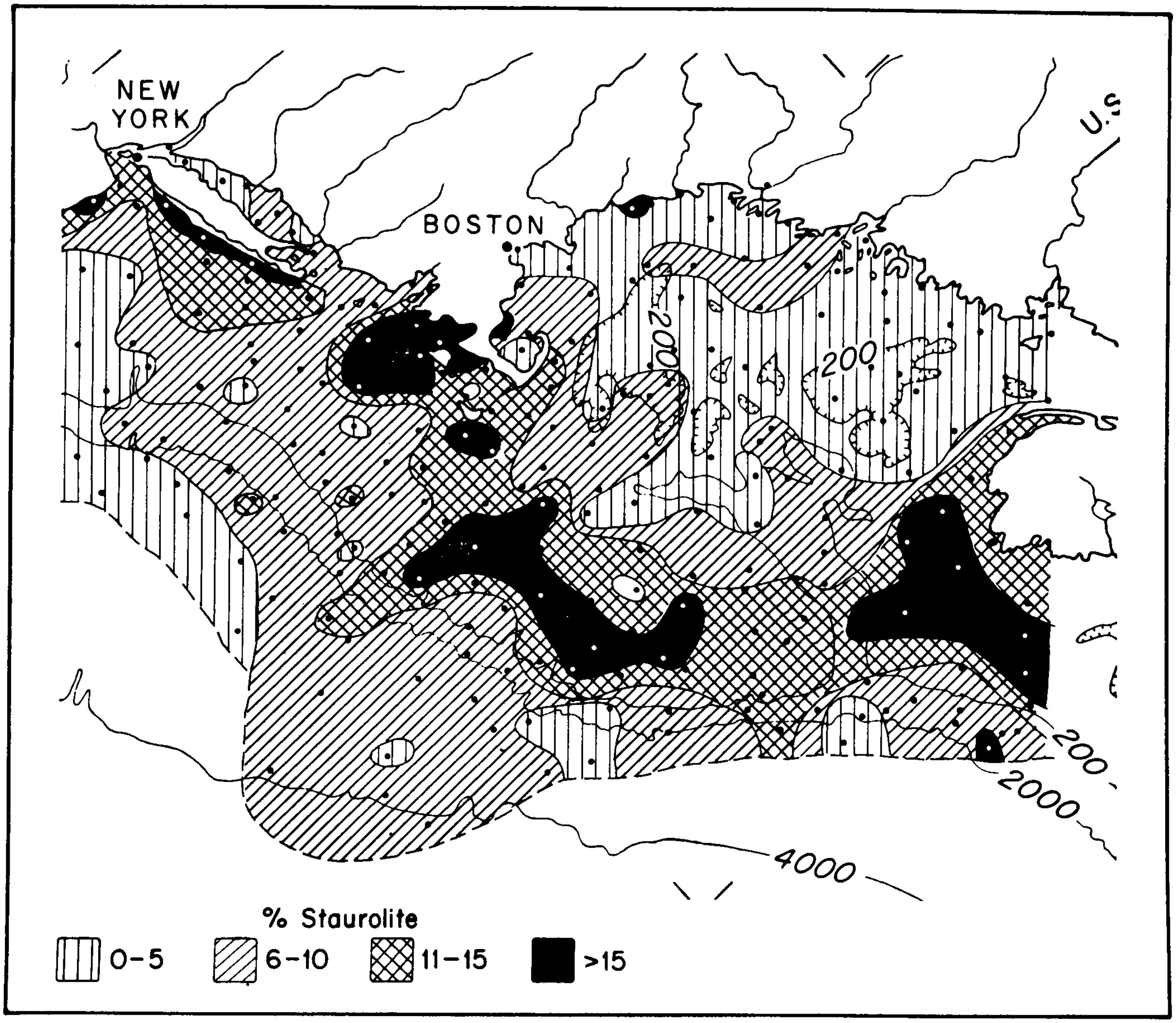


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-20

Epidote Within the Non-Opaque Heavy Mineral Fraction (Milliman and Others, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-21	Staurolite Within the Non-Opaque Heavy Mineral Fraction (Milliman and Others, 1972)

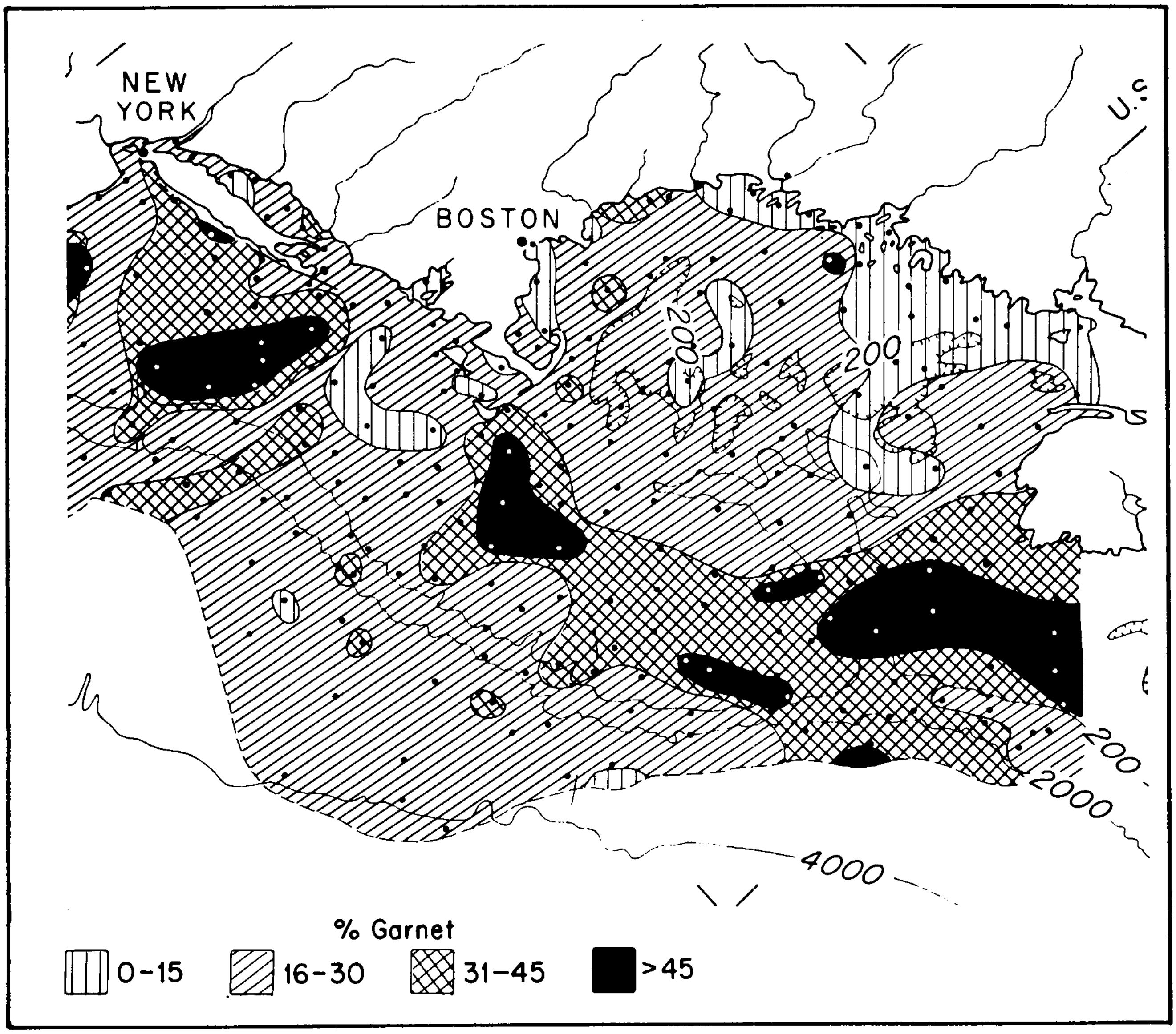


FIGURE 3-22 Garnet Within the Non-Opaque Heavy Mineral Fraction (Ross, in preparation)

The distribution of feldspar relative to quartz is particularly interesting with respect to the source and age of the shelf sands. Two bands of feldspar-rich sands (arkoses, according to Pettijohn, 1957) extend south of Long Island, and most likely coincide with relict river channel sands deposited by the Hudson and Connecticut rivers during the last low stand of sea level (Figure 3-23). In addition, almost the entire Gulf of Maine and much of the Scotian shelf are covered with arkosic sediments. In contrast, much of the shelf south of the Gulf of Maine contains subarkosic sands (10 to 25 percent feldspar) and the shelf from Georges Bank to Martha's Vineyard is suborthoquartzitic (5 to 10 percent feldspar). The only reasonable source for these quartz-rich sands on Georges Bank and Nantucket Shoals must be underlying Coastal Plain strata, since New England river sediments tend to be rich in feldspar.

CLAY MINERALOGY

The mineralogy of the clay fraction (less than 2 microns) of east coast continental margin sediments has been discussed recently by Hathaway (1972) and will be only briefly reviewed here. Gulf of Maine sediments tend to contain mostly illite (average of 60 percent) and chlorite (average of 20-30 percent), with only traces of other minerals. Similar concentrations occur in shelf and slope sediments to the south, although, as mentioned in section Sediment Size, clay-size sediments are not common in most shelf sediments. Undoubtedly the source of these illite and chlorite rich clays is the relatively immature crystalline and metamorphic rocks of northern and southern New England.

ORGANIC MATTER

The quantity of organic matter within a sediment can be expressed in terms of nitrogen content, organic carbon and/or total combustible material. Nitrogen content in the continental shelf sediments is generally less than 0.05 percent and over a large part of the area south of Long Island and on Georges Bank, less than 0.01 percent. Values are distinctly higher in the Gulf of Maine (Figure 3-24) and in other areas with restricted circulation and high concentrations of mud. This pattern is related not to increased productivity but rather to the ability of fine-grained particles to hold higher quantities of organic matter (Kuenen, 1950). When plotted against size, organic nitrogen values in the Gulf of Maine fall almost directly on the regression line for shelf values, although the scatter of values for high-sand sediments is appreciably less (Figure 3-25). A much lower productivity is seen, however, in the slope and rise sediments off New England, as the amount of organic nitrogen for any given size is appreciably less than in the shelf or in the Gulf of Maine.

The ratio of organic carbon to nitrogen has been used to help depict the nature (as well as the age) of the organic material within the sediment. Emery (1960) has suggested that high C/N ratios (greater than 10/1) are

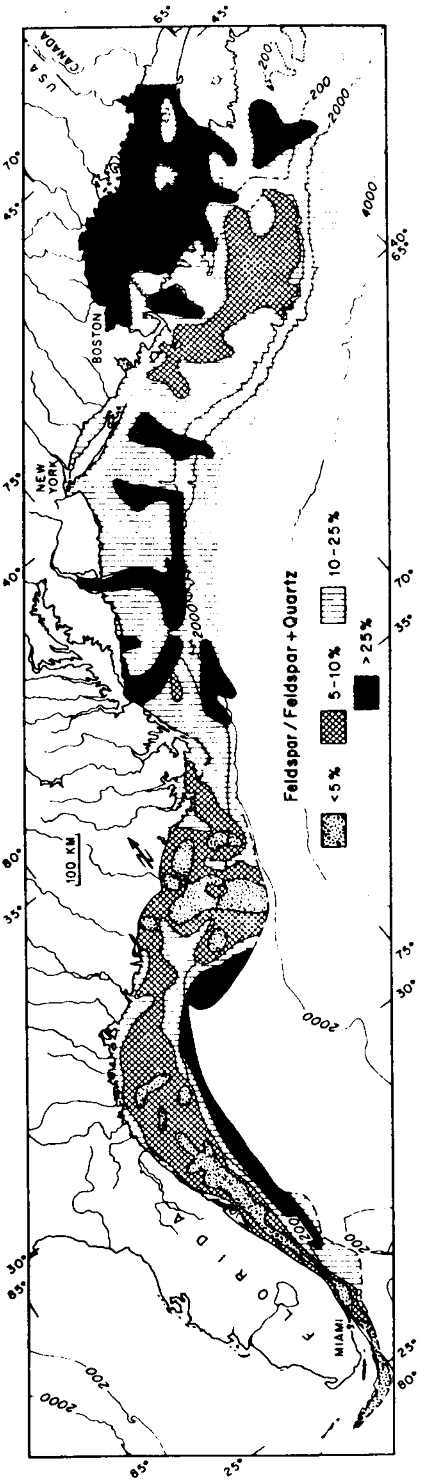


FIGURE 3-23

Ratio of Feldspar and Quartz in the Sand Size Fraction (Milliman and Others, 1972)

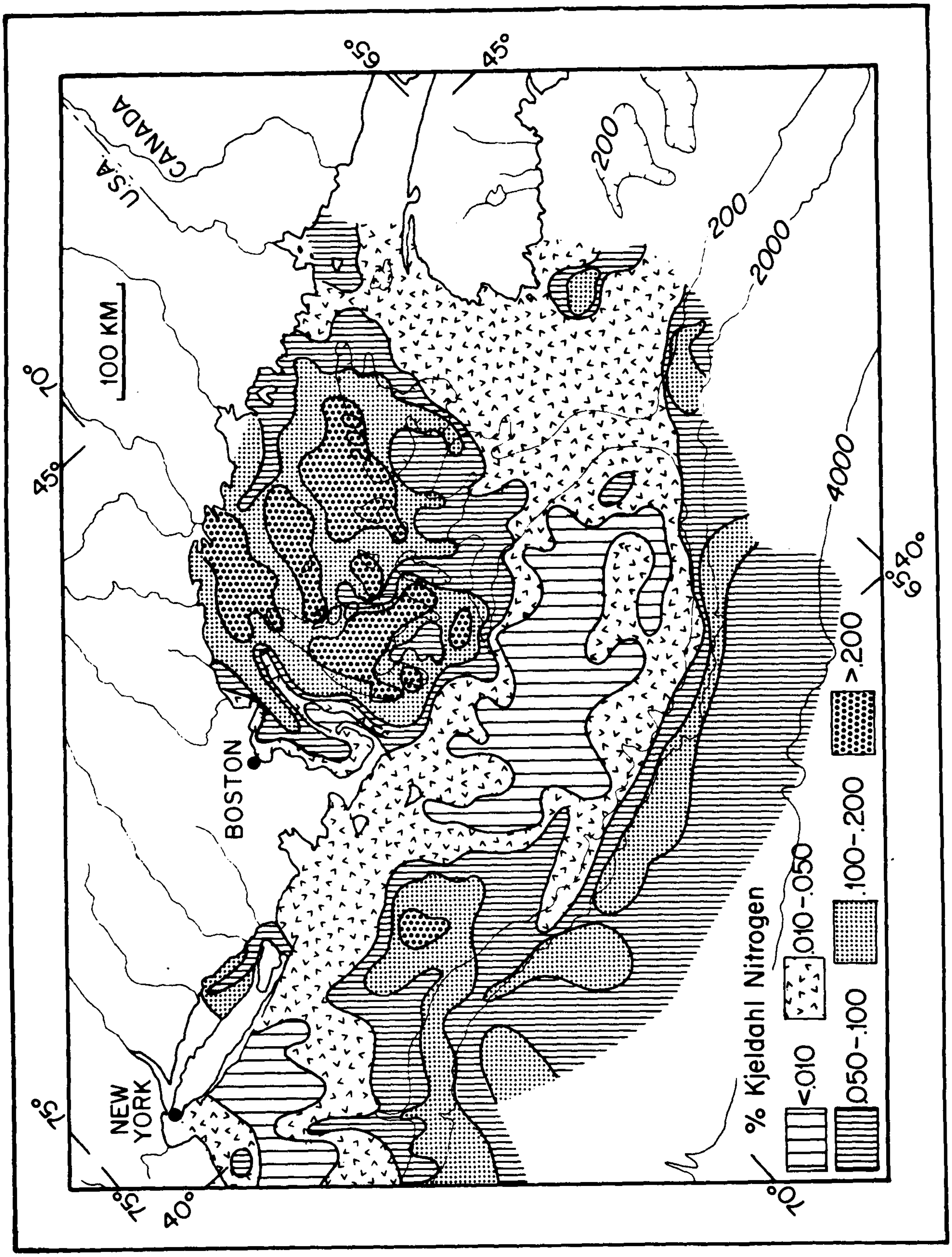
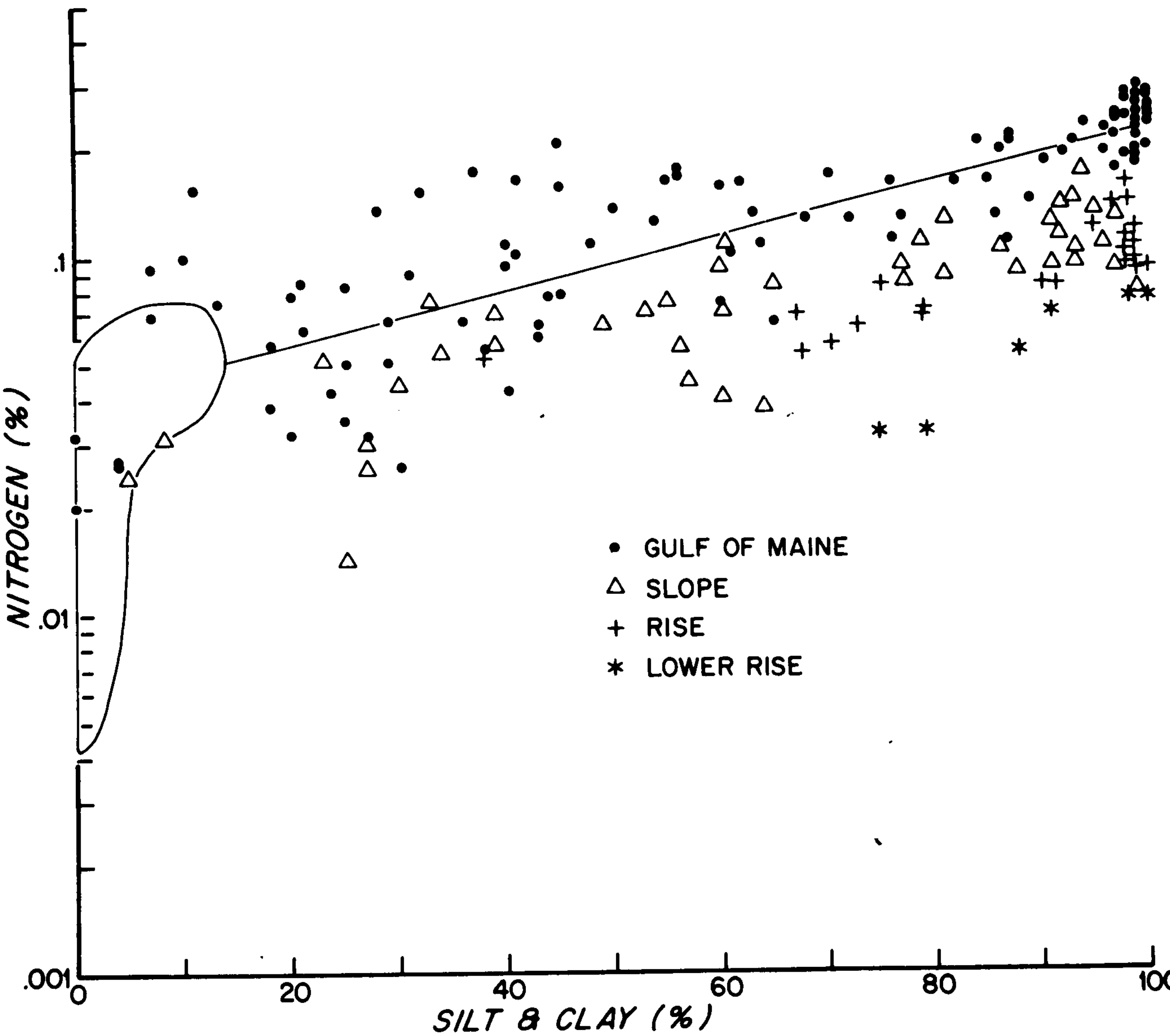


FIGURE 3-24 Distribution of Kjeldahl Nitrogen Within the Surface Sediments



Regression line shows average nitrogen values versus size for southern shelf sediments (exclusive of sand-size sediments).

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-25	Variation of Nitrogen Content with Sediment Size

indicative of terrestrial sources while values less than 5/1 indicate oceanic organic matter. Unfortunately the picture with respect to C/N ratios off New England is not so simple. Most values lie between 6 and 10/1, with a large proportion being between 7 and 8/1. Scattered sediments between Cape Cod and Nova Scotia contain C/N ratios greater than 10/1 as do shelf sediments south of Long Island. In contrast, low values are found on Georges Bank and along much of the inner shelf west of the Gulf of Maine (Figure 3-26).

SEDIMENT SOURCE AND AGE

One usually thinks of mud-size sediments on the continental shelf as being modern in age and sand-size sediments as being relict. Certainly the shelf sands south of New England appear to be relict, as indicated by their coarse size, the presence of relict shallow-water peat deposits and oyster shells (Emery, Wigley, Barlett, Rubin, and Braghorn, 1967; Merrill, Emery and Rubin, 1965) as well as the correlation of feldspar distributions with the channels of probable ancient rivers (see Figure 3-23). No doubt many of these sediments were either deposited originally by glacier and subsequently reworked, or carried to the present-day shelf by glacially influenced rivers during the last ice age (Figure 3-27).

The sands and gravels on Georges Bank and Nantucket shoals, on the other hand, probably were reworked from underlying Coastal Plain strata. This would explain the distinctive heavy mineral suite (rich in staurolite), the quartz-rich light fraction and the presence of mid-Tertiary fossils within the gravel and sand fraction (Stanley and others, 1967). Local concentrations of glauconite (see Milliman and others, 1972) may also be indicative of a Coastal Plain origin. Probably these sediments were reworked during Pleistocene glaciers; Knott and Hoskins (1968) indicate as much as 200 m of unconsolidated reworked sediment overlying apparent Coastal Plain strata on Georges Bank.

The age of the mud belt south of Martha's Vineyard is more difficult to determine. Stetson (1938), Emery (1965a, 1968a) and Trumbull (1973) have considered this to be a modern deposit, but the presence of cold-water mollusks in the sediments (Schlee, 1973) suggests deposition during a colder period, probably during the last glaciation. Perhaps the mud was derived from glacial outwash, or perhaps it was eroded from Nantucket Shoals (McMaster and Garrison, 1967).

The source of the muds within the Gulf of Maine and the muddy sands on the adjoining inner shelf is obvious - the northern New England rocks and sediments. Presumably the sands and gravel banks within the Gulf represent till and moraine deposits (see section Mainland Shelf), but the age of the fine-grained sediments within the basins is open to debate. On the one hand, the fine grained nature suggests a modern age, but the steel blue color is suggestive of glacially deposited mud. This

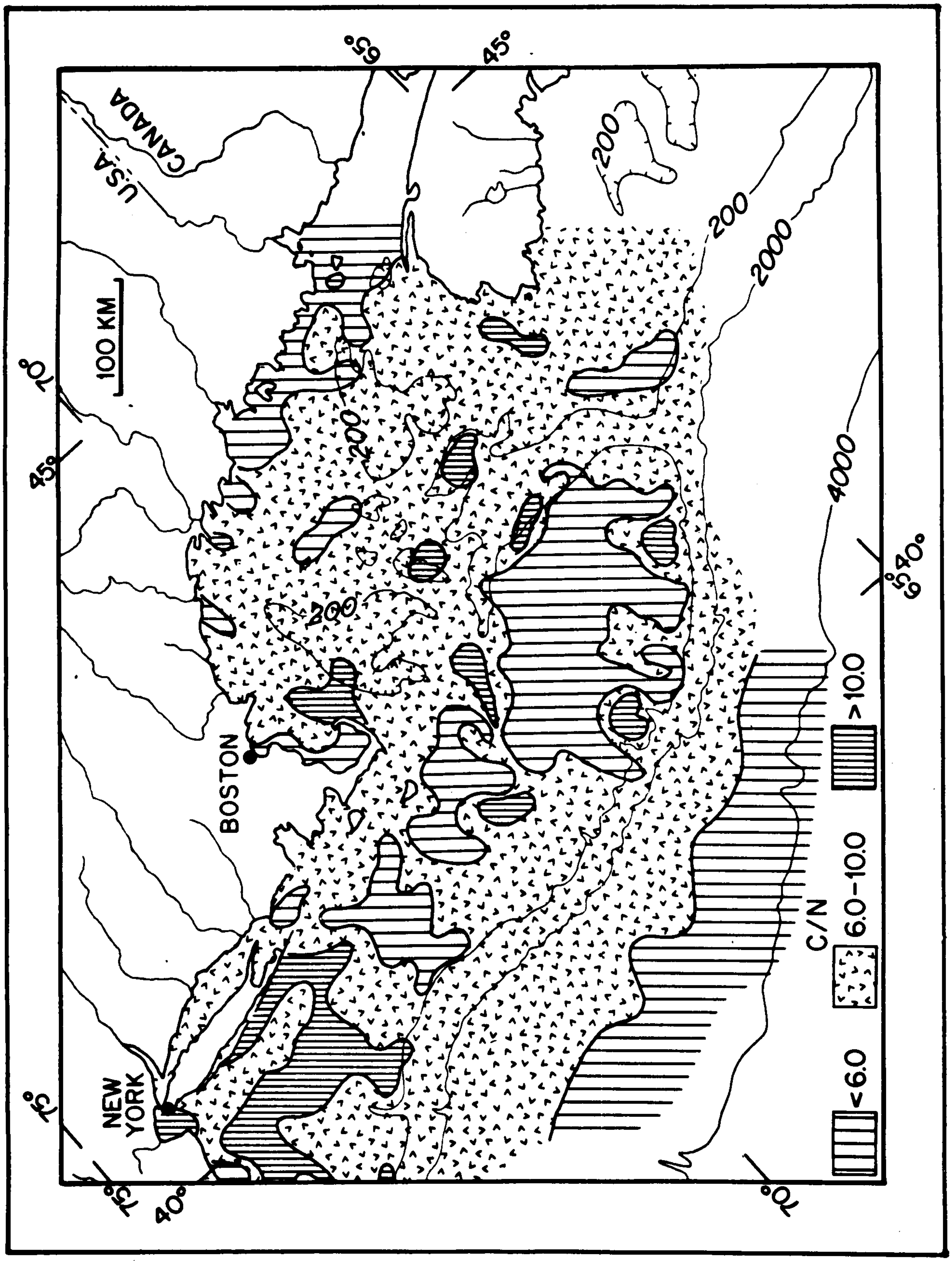


FIGURE 3-26 Distribution of Organic Carbon/Nitrogen (C/N) Ratio Within the Shelf and Slope Sediments

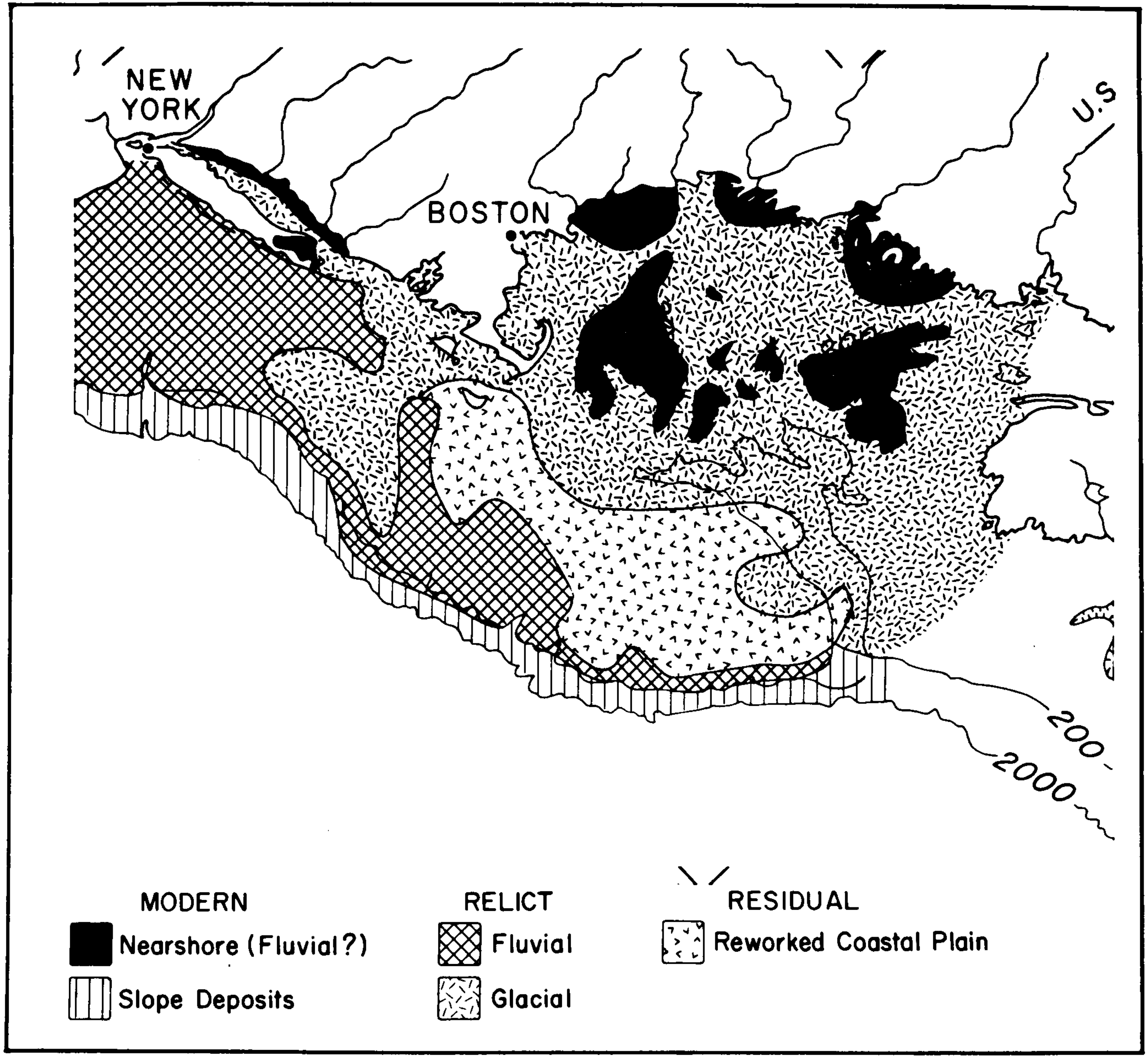


FIGURE 3-27 Distribution of Sediment Types According to Source and Age

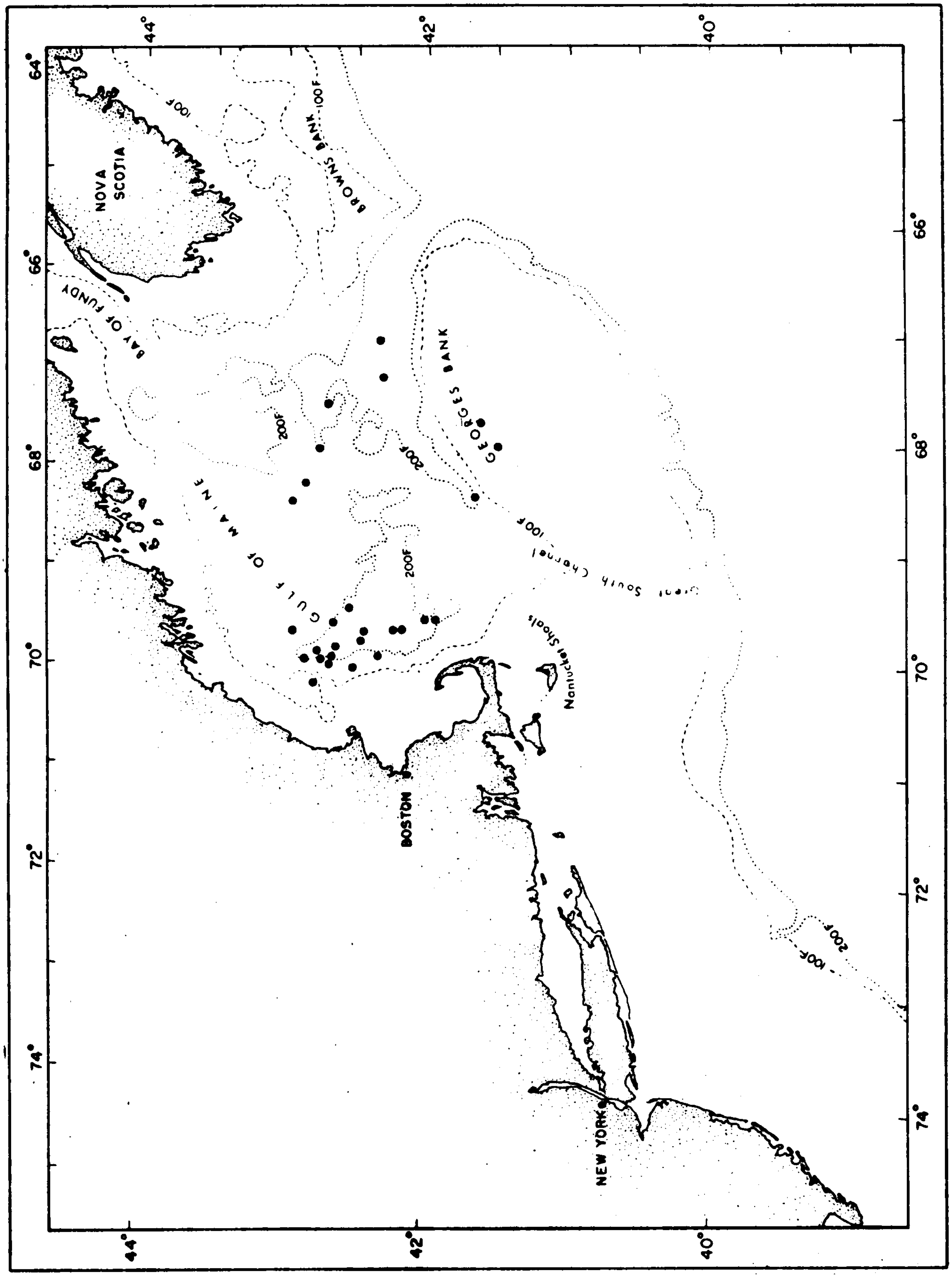
relict origin is supported by the fact that very little suspended sediment is presently being put into the shelf waters from modern rivers (see the following section). Thus it seems possible that much of the sediment within these basins was either deposited in lake-type environments during lower stands of sea level or has been derived from the erosion and transport of fine-grained sediment from neighboring banks.

SUSPENDED MATTER AND SEDIMENTARY PROCESSES

The amount of sediments presently reaching the ocean via New England rivers is probably less than 2 x 10^6 tons per year (Curtis, Culbertson, and Chase, 1973). This low quantity of suspended load is the result of Pleistocene glaciers scraping off erodable sediment and thus leaving only indurated substrate (Meade, 1969a). Not only is the suspended load small, but most of it remains trapped within the modern estuaries. In fact, Meade (1969a, 1972) has speculated that there is actually a net transport of sediment into estuaries, not out of them. Thus, the estimates of suspended load within the rivers are probably much higher than the actual amount that reaches the ocean. In addition, this problem is further complicated by the fact that man's influence upon the river systems has greatly altered the sediment load, both by increasing erosion (for example, by farming) and by decreasing suspended load transport (by constructing dams); Meade (1969b) has estimated that the present suspended loads in rivers is 4 to 5 times that of pre-Columbian streams.

While concentrations of suspended matter in estuaries generally exceed 50 mg/l, nearshore values seldom are greater than 0.125 mg/l (Manheim, Meade and Bond, 1970). Since most of the surface suspended matter on the middle and outer shelf is composed of combustible and non-combustible (for example, diatom frustules) organic matter, the total concentration of terrigenous matter in shelf waters appears to be low. Recent studies within the Gulf of Maine by Spencer and Sachs, 1970 (see Figures 3-28 to 3-31) and off southern New England (Meade and others in preparation), however, indicate that suspended matter concentrations are considerably higher in bottom waters than near the surface. Spencer and Sachs found that the concentrations of non-combustible matter in the deeper waters of the Gulf of Maine is more than 6 times higher than at the surface. Total concentrations of terrigenous matter suspended within the various basins is calculated to be 3.7 x 10^7 tons, which is more than an order of magnitude higher than the annual load of all New England rivers. The close similarity between the composition of this deep suspended matter and the underlying sediments suggests that the material is resuspended bottom sediment and not modern fluvially-derived sediment. Meade and others (in preparation) have made similar conclusions for the suspended matter off southern New England.

If normal river flow does not contribute sediment to the shelf, it is possible that periodic (cataclysmic) storms might contribute large quantities of sediment. However, while such a process might be probable off



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-28

Location of Spencer and Sachs Suspended Sediment Samples (Spencer and Sachs, 1970)

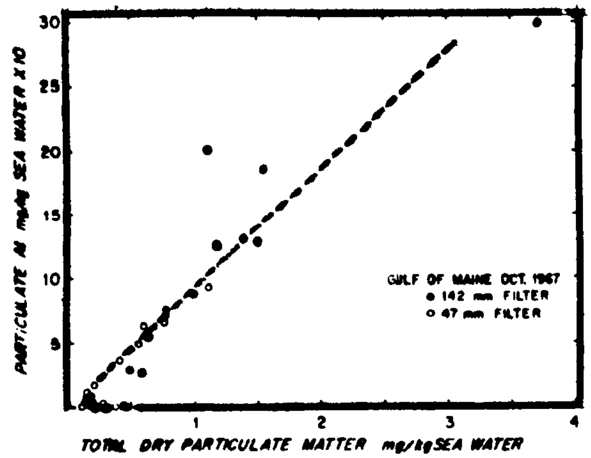
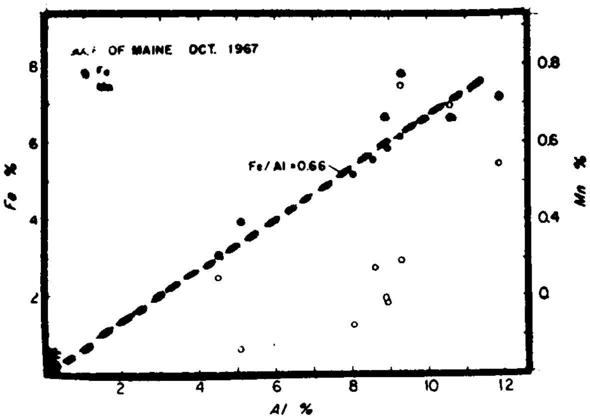


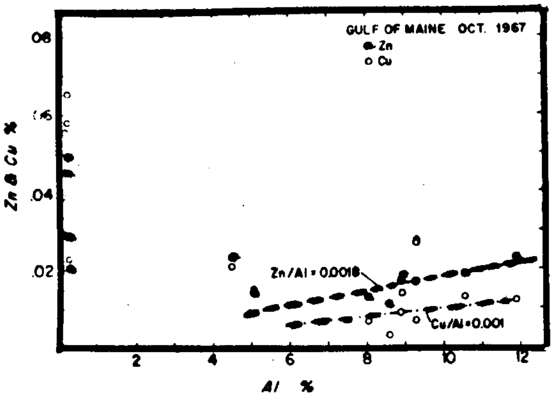
FIGURE 3-29

Co-variation of Particulate Al and Total Dry Particulate Matter (Spencer and Sachs, 1970)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-30	Relationship of Suspended Fe and Al; Mn and Al (Spencer and Sachs, 1970)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-31	Relationship of Suspended Particles of Zn and Al; Cu and Al (Spencer and Sachs, 1970)

the southern U.S., the absence of erodable strata and the present-day low suspended loads seem too low even if cataclysmic floods were invoked. More likely, most fine grained sediments within the shelf (and particularly within the Gulf of Maine) probably have been reworked from nearby transgressional sediments (for example, the shelf) or from till and moraine sediments (for example, the banks in the Gulf of Maine) and deposited in deeper basins (for instance, the Gulf of Maine). Apparently high energy in some areas (such as Georges Bank and Nantucket Shoals; witness the coarse sediment size and migrating sand shoals) and the generally low sediment input have precluded sedimentation over much of the shelf area.

3.1.9 ECONOMIC ASPECTS

For purposes of this chapter, economic deposits in the region offshore from New England may be grouped under two major headings; fossil fuels and sediment. Placers of heavy mineral concentrates do not appear to be present in significant quantities in the Gulf of Maine, although one site at Harborside, Maine,has an intertidal open pit mine which suggests that some economic deposits lie in close proximity to the coastline. (This mine, belonging to Callahan Mines, was closed in 1972). Petroleum is by far the most important offshore resource, and will be discussed first.

PETROLEUM - FOSSIL FUELS

The Atlantic continental margin of the North American continent contains four deep basins which are considered potential sources of petroleum. The southernmost, the Blake Plateau Trough, is also in the deepest water. The north-trending oval depression lies some 280 km east of northern Florida at water depths from 2000 to 5000 meters. The water depth over this feature will pose a major problem in the development of this structure should petroleum be found in the Mesozoic carbonates, evaporites and possible terrigenous rocks contained within the basin.

The Baltimore Canyon Trough off New Jersey, Delaware,and Maryland is a narrow deep depression trending north-northeast along the outer continental shelf. Its maximum depth is about 5,000 meters at a point 75 km off of Delaware Bay, and the basin is defined by a closed 3,000 meter contour. Prospects for development of this structure are good.

The Georges Bank Trough, as defined by Maher and Applin (1971) lies along a northeast trend just west of the center line of the Bank. This elongate depression is defined by a closed 3,000 meter contour, but its depth does not reach 4,500 meters. Later work figured by Emery and Uchupi (1972; Figure 3-10 this chapter) shows a much deeper basin underlying all of Georges Bank and the upper portion of the continental slope. Mattick, et al. (1973) state that more than 8 km of sedimentary rock lies beneath the bank. Prospects appear excellent for this basin, and it will be discussed in greater detail in this section.

The northernmost significant basin of the continental margin lies on the Scotian Shelf in Canadian waters. This is Emerald Bank Trough, again an elongate structural depression trending northeast. Only the southern half of the basin has been figured (Maher and Applin, 1971), but this depression is also defined by a proposed closure of the 3,000 meter contour. The basin is at least as deep as 4,300 meters, and is thought to contain Triassic or Paleozoic consolidated sediments. They may be similar to those in the Georges Bank Basin to the southwest.

In all likelihood, the Baltimore Canyon Trough contains the greatest potential for petroleum production on the east coast. As mentioned in North Atlantic Shelf, the sediment thickness exceeds 12 km in the trough's axis, and the steeply pitching beds on either side may provide excellent stratigraphic traps. Recent work by Mattick and others (1974) describes these sediments. The maximum sediment thickness, however, is considerably to the south of the study area (off Maryland) and thus the potential off southern New England may be somewhat less. It should be noted that the northern end of Baltimore Canyon Trough was cited as being hazardous for drilling (CEQ, 1974).

With the exception of Baltimore Canyon Trough, the Georges Bank Basin Trough is perhaps the most promising site for petroleum exploration on the Atlantic continental margin. According to Maher and Applin (1971), the pre-Mesozoic ("basement") rocks probably have poor reservoir characteristics due to metamorphism. Elsewhere, these rocks appear highly indurated and folded. The Triassic rocks are at least in part continental redbeds and conglomerates which could only be potential reservoirs if migration from marine oil-bearing strata occurred. That is, they may be good reservoir rocks but poor source rocks. On the other hand, more recent seismic refraction data interpretation, suggests that the lower half of the sedimentary strata may contain highly indurated carbonates, which could severely limit any petroleum potential (Ballard, 1974).

The best prospects for petroleum lie in the Lower Cretaceous and Upper Jurassic (Neocomian) rocks. The combined thickness of rocks of this age may be as great as 10 km. However, as Emery and Uchupi (1972) point out, a profile across the Gulf of St. Lawrence and down the axis of the Laurentian Channel indicates that Carboniferous limestone forms the core of the outer shelf, and if a comparable series of strata lie in the Georges Bank Basin, the promising Mesozoic section would be much thinner, but still attractive for exploration.

Two of the best locations may be 1) along the southeast and east flank which appears to be fault controlled. Up-dip faulting into the early Cretaceous may provide the section with numerous stratigraphic traps. 2) The southern part of the Trough is flanked on the south by another possible basement high associated with the east coast slope anomaly.

This high is a fault-controlled basement horst, which may also have had active faulting associated with its formation during the early Cretaceous, thus providing possible stratigraphic traps in the overlying section (Ballard, 1974).

Inasmuch as the subsurface structure off Nova Scotia may be quite similar to that under Georges Bank, it is appropriate to note a description of the stratigraphy of the continental shelf in this Canadian Province as summarized by McIver (1973). The oldest stratigraphic unit recognized from about 30 offshore drill sites and seismic data is an evaporite of possible early Jurassic age. Carbonates lie atop this unit, and above these beds are feldspathic sedimentary rocks which disconformably overlie both the carbonates and the regional basement rocks of metasediments and granitics. A marine transgression is marked by a sequence of limestone and shales which in turn is overlain by about 1,000 meters of deltaic and sands and shales of late Jurassic and early Cretaceous age. From mid-Cretaceous through much of the Tertiary, the deposition of silty sandstones, limestones and chalk indicate fairly deep water covered the site. Pliocene uplift caused dissection of these rocks, and the highly variable Pleistocene materials form the present shelf surface. The Oligocene marine regression noted by Emery and Uchupi (1972) is not apparent in the Nova Scotian section.

Schultz and Grover(1973) have summarized the stratigraphic record of Georges Bank Basin, and have pointed out the overall similarity of many units to those in the adjacent Scotian Shelf. However, Jurassic salt drapers present off Nova Scotia were not detected in Georges Bank Basin, but perhaps 2,000 meters of Jurassic carbonates, shales and sands are believed to be present, some of which lie in faulted basins within this structure. By comparison of seismic velocity data with that from the Scotian Shelf where drillers logs confirm lithology, Schultz and Grover state that the Georges Bank Basin may contain more than 7,500 meters of Mesozoic and Cenozoic sediments. The most promising Lower Cretaceous and Jurassic rocks within the basin account for a volume of about 120,000 km^3 of potential source rock. (An example of the driller's log from Nova Scotia is shown in Appendix A.1, unpublished data).

One potential economic deposit which is not frequently mentioned on the continental shelf is coal. Yet refraction and gravity data in the northwestern portion of the Gulf of Maine indicate a major Carboniferous basin extending from Boston to Jeffrey's Ledge. Since coal measures are known to be associated with this basin onshore, it is reasonable to suggest their presence within the Gulf.

SAND AND GRAVEL - SEDIMENTS

The economic potential of sand and gravel is often overlooked by those considering marine mineral commodities. It is thus interesting to note that next to petroleum, the most profitable mineral resource recovered from many continental shelf areas is sand and gravel (Emery, 1965b). These deposits are often concentrated in regions where glaciation has localized massive deposits of sand and gravel in moraines and outwash plains, and the Gulf of Maine includes a number of such areas. Because of the relatively low cost at the source of aggregate per ton (about $1 to $2/ton), the major expense in production is that of transportation to a marketing point. Thus, in the exploitation of an offshore sand and gravel deposit, the distance to a port or aggregate yard can be the most important factor in determining the economics of recovery. For this reason, extensive deposits of sand and gravel on Georges Bank cannot at present be considered an economic deposit, while beds which might contain lower quality material near Boston are under study as sources for immediate or near-term recovery.

Manheim(1972) estimated a total sand deposit of the northeastern U.S. of 400 billion tons. While many deposits are not now (or in the foreseeable future) exploitable, they may become important as the Boston-Washington megalopolis expands over present continental sand and gravel deposits.

An analysis of sand and gravel resources for the northeastern part of the Atlantic continental margin was presented by Schlee and Pratt (1970). They point out that for metropolitan areas such as Boston and Portland, offshore deposits of sand are not as extensive as those on the southern New England Shelf (off Long Island, Rhode Island, etc.). Sands in the Gulf of Maine are generally restricted to isolated banks and nearshore regions such as Cape Cod Bay. Along much of the inshore(Mainland) shelf the sands are covered by a thin blanket of Holocene muds (Oldale, et al., 1973) which constitute undesirable "overburden" with regard to exploitation. They point out that the best areas for recovery of such materials would be the upper surfaces of banks and ledges in the nearshore regions of the Mainland Shelf and the Gulf of Maine.

An inventory of gravel deposits (Schlee and Pratt, 1970) indicates that these materials are more restricted in their distribution than the sands. The distribution of gravel can be related to bathymetry to some degree, but the visual and photographic observations which reveal the discontinuous nature of many gravel areas delineated by bottom grab samples should temper the calculation of volumes based only on spot samples. In the Gulf of Maine, patchy distributions of gravels are known from the region off Boston and Plymouth, but in general the gravels are disseminated as thin, discontinuous patches in the nearshore regions along the New England coast. In the basins offshore from the Mainland Shelf, gravels are almost non-existent.

A recent evaluation of nearshore aggregate resources of the inner Massachusetts Bay area has been reported by Bell, Cook, Willett, Wilkins, and Jackimovicz (1973) and documented by Cook, et al. (1973, in press). They have delineated 15 sand and gravel bodies which, on the basis of seismic profiles, a side-scan sonar, cores, grabs, and bottom photographs, could be considered as having potential economic significance. These irregular masses have a general trend of northwest-southeast and are concentrated seaward of the Boston Basin at depths from 18 to 36 meters. Their areas are as large as 9 km^2 and maximum thicknesses approach 10 meters. The largest deposits may be drumlins which, in the course of the last marine transgression, have been partially destroyed and winnowed to produce lenses of sands and gravels.

In summary, the offshore sand and gravel deposits within the Gulf of Maine are either small local deposits which would provide a temporary source of aggregate, or are large deposits, such as the Georges Bank surface, whose distance from a marketing point relegate them to a status of a marginal resource. The expenditure of energy to recover the transport sea floor aggregate to a coastal market will probably be greater than an equivalent (or lesser) expenditure of energy on land to reach the same market. In view of the resources present on land, it is doubtful that a submarine resource could compete in the aggregate market for construction in the coastal zone. However, beach replenishment, a major problem in some areas of the Atlantic coast, may be more economic via hydraulic dredge and piped discharge than from vehicular hauling, and the nearshore submarine resource may be more economic for this purpose than onshore sand and gravel pits.

MUD

Few people think of mud as a marketable resource, and yet Manheim (1972) has pointed out that D. C. Rhoads and his co-workers at Yale University have made usable bricks out of high-temperature fired organic muds. At present this scheme is more science-fiction than reality, but if certain technological and marketing difficulties can be overcome, the vast amounts of mud within the nearshore waters of New England, not to mention the Gulf of Maine basins, could provide a valuble resource in this area.

3.1.10 ENVIRONMENTAL ASPECTS: HAZARDS AND IMPACTS

Development of the resources of the Outer Continental Shelf (OCS) in the New England area must proceed on a carefully planned basis, taking into consideration the various factors present in the marine environment. Some of these factors are quite sensitive, especially in the biological realm where some species are of economic importance, and others are essential links in the food chain. Many of the geological factors are relatively insensitive, but consideration of several aspects presented in this chapter is essential to the proper planning for structures or practices.

For purposes of discussion, we may define a hazard as a potentially detrimental situation or condition having an effect on a structure, and classify impacts as the effect that a structure has on the marine environment. In the case of practices, the discussion may only include consideration of the impact. For example, there is little hazard in sea floor mineral recovery, but the impacts may be serious. This section will examine several types of structures which will probably be placed in the New England OCS within this decade, and will also examine several practices such as ocean dumping and mineral recovery (dredging). Prior to that discussion, a brief outline of potential regional hazards created by seismicity of the region and the tsunami potential is presented. The effects of severe storms and wave hazards are presented in the chapter on Oceanography.

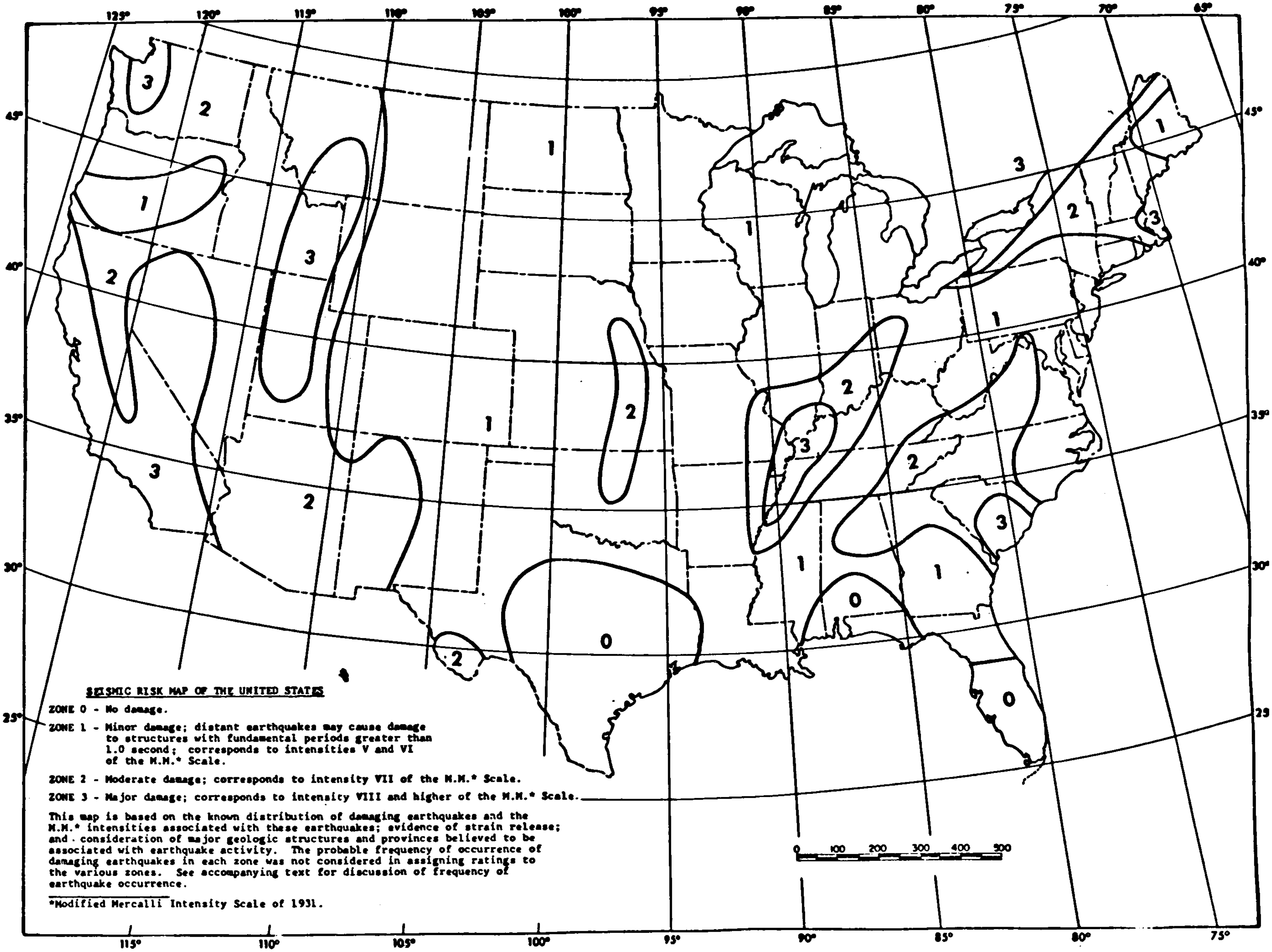
SEISMICITY

The east coast of the United States and Canada are generally considered to be aseismic, that is, relatively free from major earthquake activity. However, two of the largest recorded earthquakes in the U.S. occurred on the eastern coastline, one at Charleston, South Carolina (1886) and another at Cape Ann, Massachusetts (1755). The latter is of interest here, and it will be discussed in greater detail.

The Cape Ann earthquake was rated at an intensity of VIII on the modified Mercalli scale. This intensity has been described as "Destructive" in the sense that poor or old construction is liable to collapse under seismic stress. The ground acceleration associated with intensity VIII shocks is about 0.1 gravity, that is, the ground acceleration is about one meter per second per second (98 cm/sec/sec). Because of this shock, the Seismic Risk Map for the United States (Figure 3-32) places the Massachusetts and New Hampshire coastlines in Zone 3, where major destructive earthquakes may occur. The southern coast of Maine lies in Zone 2 where moderate damage may occur and the northern Maine coast is in Zone 1 with only minor damage possible. As pointed out in the discussion on geologic setting of New England, the Cape Ann epicenter lies along a northwest-trending zone of activity which passes across Massachusetts Bay and can be traced to the vicinity of Ottawa. A projection of this trend to the southeast crosses the central portion of Georges Bank. In his maps of seismic activity for the period 1928-1959, Smith (1966) shows no epicenter located along this trend, and one would assume that shocks at sea would have been recorded as well as those on land. Only one small intensity epicenter is shown in the vicinity of Georges Bank, and that lies on the continental slope at a depth of about 2,500 meters. We may assume, since Smith's map shows offshore epicenters in other regions, that Georges Bank is not an active seismic region.

FIGURE 3-32

Seismic Risk Map (NOAA, 1973)



SEISMIC RISK MAP OF THE UNITED STATES

ZONE 0 - No damage.

ZONE 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 second; corresponds to intensities V and VI of the M.M.* Scale.

ZONE 2 - Moderate damage; corresponds to intensity VII of the M.M.* Scale.

ZONE 3 - Major damage; corresponds to intensity VIII and higher of the M.M.* Scale.

This map is based on the known distribution of damaging earthquakes and the M.M.* intensities associated with these earthquakes; evidence of strain release; and consideration of major geologic structures and provinces believed to be associated with earthquake activity. The probable frequency of occurrence of damaging earthquakes in each zone was not considered in assigning ratings to the various zones. See accompanying text for discussion of frequency of earthquake occurrence.

---

*Modified Mercalli Intensity Scale of 1931.

TSUNAMI

Unlike the Pacific Coast of North America, the possibility of a destructive seismic sea wave (tsunami) along the Atlantic coastline is practically nil. The only occurrence which can be substantiated was that which followed the 1929 Grand Banks earthquake. A wave struck the south end of Newfoundland, and because of unusually high tide at the time of arrival, some damage and loss of life ensued. The passage of this wave was measured as a tidal fluctuation on gauges along the New Jersey coast, but it was not recorded in Boston. A tsunami struck Saint Martin's Harbor in the West Indies in November 1755, and it has been attributed by some to the Cape Ann earthquake (18 November). However, there are no records of the passage of such a wave from any eastern seaport, and it is likely that the wave, which did considerable damage, can be attributed to the tsunami generated by the catastrophic Lisbon earthquake just 17 days prior to the Cape Ann event and resulting confusion in recording a precise date.

HAZARDS AND IMPACTS FOR STRUCTURES

For purposes of this chapter, we may define a structure as a large man-made object placed on, and often extending above, the sea floor. This category would include drilling platforms, pipelines, production facilities (sea floor wellheads), and breakwaters. Each is in contact with the surface of the sea floor. It does not include anchors for buoys or floating mooring facilities. Again, we will define a <u>hazard</u> as an adverse environmental effect <u>on</u> a structure and an <u>impact</u> as an adverse effect of the structure <u>on</u> the environment.

Table 3-1 cites several hazards, their causes and some of the data necessary for formulating design criteria or remedial action. Table 3-2 lists several impacts of structures on the environment, with causes and data necessary for analyses. By our definition, structures are features in contact with the sea floor (either resting upon it, embedded in it or anchored to it). Thus, the <u>cause</u> of a hazard or impact is generally related to the physical properties of the sea floor and the forces which act upon it (waves and currents, and, to a lesser degree, organisms). The remainder of this section will be devoted to a discussion of the hazards and impacts related to structures, and the chapter will conclude with a review of the effects of practices.

Because we are concerned with both materials and forces in the consideration of structures, and because both factors are a function of location within the Gulf of Maine, it will be convenient to examine the hazards and impacts of structures on the basis of Province, as delineated in Figure 3-1. Province IV, the Scotian Shelf, lies beyond the jurisdiction of Federal agencies or policies of the United States. It is not appropriate at this point to discuss hazards and impacts in an area where the

Table 3-1 Hazards to structures: Environmental effects on objects

STRUCTURAL HAZARD	CAUSE	DATA REQUIRED FOR DESIGN OR REMEDIAL ACTION
Submarine slumps	Liquifaction of soils due to earthquakes, storm waves, structural motion (wind, machinery), erosion	Wave spectra, current data, soils information on cohesion, friction angle, ground acceleration
Scour	Wave-induced surge, tidal currents, bio-excavation	Wave and current data, sediment properties, benthonic biota data
Failure of soils under load	Insufficient shear strength of soils	Cohesion, density, shear strength, friction angle
Settlement	Variations in soil properties under structure, compressible soils, seismic loading	Density, bearing capacity, consolidation data
Excessive lateral loads	Waves, winds, currents	Oceanographic data (waves, currents)
Pullout (breakout)	Low shear strength	Cohesion data, density friction angle

Table 3-2 Impacts of structures: Object effect <u>on</u> <u>environment</u>

EFFECT	CAUSE	DATA REQUIRED FOR ANALYSES
Regional erosion or deposition	Alteration in local current regime (littoral drift, wave refraction).	Wave and current data, textural data for sediments, structural configuration, bathymetry
Localized scour (erosion)	Obstruction of local flow, placement of discharges	Flow rate (current data), object geometry, discharge rate and orientation, sediment texture, bathymetry
Localized deposition	Obstruction of local flow, dumping of spoil or other solids	Sediment texture,, current and wave data, volume of material, bathymetry, toxicity
Spills	Accidental discharge of materials	Nature of materials, currents, waves, volume of material, buoyancy, toxicity

state or Federal government cannot comment upon design or construction of offshore structures. However, the discussion of hazards and impacts for the Georges Bank Province has direct application to the Browns Bank region of the Scotian Shelf, and can generally be extended to include that province.

Province I: Mainland Shelf

Hazards. The sediments (soils for the purposes of most engineering discussions) atop the Mainland Shelf area are generally fine-grained except along the littoral zone where sandy beaches may extend onto the shelf surface. Their thickness is often less than 10 meters, and in some cases these units contain boulders and/or gravel lenses. Both are troublesome where piles are to be driven, and the proximity of bedrock to the sea floor surface gives little in the way of support for lateral loads typically imposed by inshore waves and currents. In addition, the sandy soils lack cohesion necessary for frictional support for vertical and lateral loads.

The fine-grained soils are generally found in depressions and low-energy regions, and since they reflect Holocene deposition, they have not been consolidated by ice overburden pressures and are, therefore, quite weak. Nearshore sediments may thus be considered to be susceptible to slumping under loads, scour, liquifaction under seismic loads, settlement and low pullout characteristics.

Because the Mainland Shelf Province lies on the inner edge of an extensive Gulf whose floor is characterized by an assortment of bathymetric highs and lows, the wave energy arriving at the shoreline represents a confused set of wave trains whose interference tends to reduce their energy. Short period waves are present, especially under conditions of "northeasters" when the extensive fetch of the Gulf permits buildup of local seas, but the long period swell from the North Atlantic cannot propagate directly across much of the Gulf proper (see Chapter on Oceanography for discussion).

The short period waves are effective in shoreline erosion and deposition through littoral drift associated with longshore currents. This current can cause scour and deposition in the vicinity of structures, especially pipelines and outfalls which might traverse the shallow areas of the inner shelf. Similarly, breakwaters and groins are subject to these strong currents. Local effects of coastal topography may enhance or retard the effects of longshore currents, but directional wave spectra should be developed for adequate planning.

In the immediate area of the coast (beaches, bays, etc.) attention should be directed to the effects of ice grounding upon inner shelf sediments. Ice heave and push along the shoreline can be quite destructive, and a structure exposed to zones where ice could accumulate should be designed to withstand such pressure. This factor is most critical to pipelines or outfalls which must cross the zone of most severe structural stress from grounded ice. Consideration of ice problems must be included in buoy design (single point mooring for fluid cargoes) since ice heave and push on both buoys and anchor lines can be significant. Rock bolts or other embedment techniques for anchors should be considered.

Impacts. Structures with small cross-sectional areas will have little or no regional effect, but may cause significant modification in local sedimentological regimes. Pipelines are a major factor in deflecting currents, and severe scour may occur in the vicinity of exposed pipes and outfalls. The latter are generally more vulnerable, because they are often shorter and depend upon exposure for efficient operation. Severe scour problems with outfalls have occurred in California, and the problems created by ice in the New England region further complicate design of these features.

Detached breakwaters, either for shore protection or the containment of an offshore facility, pose a major problem where bottom currents are sufficient to move local sediment. Scour in the vicinity of the toe of these features is common, and deposition in the "energy shadow" (lee) of large structures may create local problems from undesirable sedimentation.

Both the hazards and impacts cited above are not all-inclusive, and each structure must be evaluated on the basis of local conditions. Local effects of structural operations, such as thermal plumes, discharges of effluents, etc., must be scrutinized from the standpoint of biological impact as well as geological effects. Proper design can minimize both the hazard and impact aspects of man-made objects placed on the Mainland Shelf of the Gulf of Maine.

Province II: Gulf of Maine

Hazards and impacts to structures in the Gulf of Maine must be discussed with regard to bathymetry. The irregularity of the sea floor within this province requires separate consideration for banks as opposed to basins. The bathymetric highs, or Banks and Ledges, will be examined first. As is the case with the Mainland Shelf Province, wave refraction is a significant parameter over much of the Gulf since the oceanic swell must pass over shoals prior to entering the Gulf proper.

Banks and Ledges. Except for Jeffreys Ledge and Stellwagen Bank, the thickness of sediments atop the bathymetric highs within the Gulf of Maine is minimal. In these two features, which are marginal to both the Gulf and the Mainland Shelf Provinces, sediment thickness in the Coastal Plain (Cretaceous and Tertiary) units and the moraine deposits may reach a combined thickness of up to 200 meters (see discussion under Mainland Shelf, this chapter). However, the sedimentary units lying upon positive features in the Gulf, are generally much thinner. These units have, in some cases, been subjected to ice loading which resulted in consolidation of the sedimentary units herein described as glacial till and outwash. The uppermost units atop positive features are generally finer grained and consist of loose materials winnowed from an assortment of glacial materials and deposited in low energy environment.

Hazards to structures located on these features are similar to those associated with the unconsolidated materials of the Mainland Shelf Province. All of the items listed as Structural Hazards in Table 3-1 apply to the superficial unconsolidated materials of the upper units on Banks and Ledges. In areas where consolidated materials (till, etc.) lie at shallow depths, additional bearing capacity, shear strength and friction angle can afford greater structural integrity to pile-supported or bottom-supported structures than can the less-dense sediments at the surface.

Due to the unconsolidated nature of many surfaces on bathymetric highs, scour will be a major consideration for bottom-supported structures. Lateral loads due to waves will be greater than the Mainland Shelf, but less than Georges Bank. Due to the proximity of non-productive basement rock to the sea floor surface, it is doubtful that drilling for petroleum would take place within the Gulf. Offshore energy terminals are perhaps more likely structures for this Province, and these would require enclosing breakwaters for floating facilities or retaining walls for artifical islands constructed of hydraulic fill. Water depths in this Province seem excessive for both concepts which, although of proven structural competence in shallow water (less than 15 meters), have yet to be applied to deeper sites where a fraction of a meter in depth is equivalent to millions of dollars in quarry stone, rubble or cast forms. It is more likely that single point mooring systems might be established in the Gulf.

Moored terminals are now proven devices for the trans-shipment of liquid cargoes, and in the near future solids cargoes may be transferred via floating terminals of relatively small dimensions. Such structures require strong moorings, and hazards associated with breakout forces should be analyzed for sites under consideration. The unconsolidated sediments are poor risks, and driven anchors may be required for adequate mooring line support. Embedment in a deeper, more competent bed might be possible where these units lie close to the surface.

Impacts of structures established on bathymetric highs are minor, unless an alteration in sedimentation regimes could affect a fishery. Displacement of bottom materials associated with scour would merely relocate materials, and in light of the distance from shore, such effects should be inconsequential.

Basins. Basins within the Gulf of Maine Province are probably the least sensitive to development of any segment of the outer continental shelf. The basins are the sinks of the region, and as such are not contributors to the sediment flux associated with displacement of sea floor materials due to man's activities. Again, consideration of possible hazards and impacts of structures to basins can be accomplished with reference to Tables 3-1 and 3-2, but it should be noted that the water depth and lack of economic importance (save perhaps fisheries) will result in little structural activity in these regions.

Most basins have a relatively thick (tens of meters) deposit of fine materials swept from the higher portions of the Gulf and deposited in the lower energy regime of the deeper basin waters. A series of investigations in the "geotechnical range" established by Perlow and Richards (1972; 1973) and the reports by Parker (1973) and Faas, Nittrouer, and Toth (1973) in the Wilkinson Basin can provide some perspective in an assessment of the hazards and impacts of basin regions.

Hazards may be considered from the standpoint of the physical properties of sediments. Shear strength generally increases with depth in relatively undisturbed cores which sampled the upper 1.5 meters of basin sediments. Bulk density and water content were nearly uniform at depths greater than about 0.5 meters, suggesting that for the upper layers of sediments the clays and silts are not appreciably different in their physical properties. Remoulded samples of the sediments (a measure of the effect of disturbance on sediment character) indicated that shear strength was reduced by about 75 percent following disturbance (such as would be encountered in driving, jetting, explosive embedment, etc.) in the sediments. Breakout forces for these materials would be greater than those in cohesionless (sandy) sediments, but only after a period of settlement and adjustment of the soil mass had occurred.

The only conceivable structure which might require foundations in the basins of the Gulf of Maine are pipelines. Hazards associated with pipelines at this depth can be related to two processes. One, currents, may not be important, but in the absence of current meter data from the basin floors it is difficult to determine adequate design criteria for pipeline supports. Currents of sufficient speed and proper orientation to the axis of the pipe might initiate and maintain scour, and remove much of the supporting soils beneath the pipes. It is fruitless to speculate on the effects without additional data. The second hazard is related to biologic activity (burrowing) which might occur beneath a soil-supported pipe. Limited studies to date (Muraoka, 1970) have shown some settlement of structures due to the activity of infauna off southern California. A survey of benthonic organisms typical of the Gulf of Maine would provide some insight into the probability and magnitude of this potential hazard.

Impacts. Embedment of anchors in basin sediments would create minor disturbances on the environment, and this along with local scour deposition could be considered the only impact which might occur on the sea floor. The fine-grained nature of these materials would provide a relatively high breakout force to moorings placed within the sediments.

Georges Bank and the Southern New England Shelf

The greatest potential for destructive hazards within the entire Gulf of Maine area occurs on Georges Bank. Here the oceanic swell first encounters a shoal, and much of the energy is dissipated on the outer margin as these waves shoal. Extreme currents recorded by Stewart and Jordan (1964) have been described. These currents lead to chaotic turbulence, termed "overfalls", in which the sea surface is characterized by a series of standing waves where the water rushes over the sand waves atop the Bank. Hazards, aside from those created by wind loads on structures, may be restricted to scour phenomena.

Hazards. In light of the unusually high, and essentially constant, flow of water over the surface of Georges Bank, the scour potential is always quite high. The surface consists of unconsolidated sediments ranging from boulders through gravels to sand, with fine sediments only present in the deeper portions of the Bank margins. These granular materials are constantly shifting, as shown by the series of sand waves on the two major shoals (see Figure 3-9). Borings on the central portion of the Bank in support of Texas Tower studies reveal nearly 40 meters of Pleistocene and Holocene gravels and sands with no indication of a bedrock (Tertiary sediments) which might afford a more rigid foundation (Emery and Uchupi, 1972). An example of the severity of scour can be provided from the experience of a platform which attempted to drill on the nearby Scotian Shelf.

The Sedco-H semi-submersible drilling rig was leased to drill an exploratory hole in 30 meters of water on the Nova Scotian Shelf. Maximum normal tidal current in the area is about 0.8 meters/sec. Because this rig has large-diameter pontoons (26 meters in diameter) concern was voiced regarding scour under them due to restriction of flow in the remaining 4 meters. Such scour could endanger the stability of the rig. Model studies showed that this could indeed occur, and a protective nylon mesh skirt was deployed around and beneath each pontoon. Normal tidal scour resulted in modest erosion, but in 13-meter waves accompanying a major storm, the rig began to pitch and settle. Divers' examination the following day revealed extensive destruction to the mats, and excessive scour (2 meters) beneath the pontoons. The operation was abandoned (Wilson and Abel, 1973).

Prevention of scour is a major problem in shallow water operations, and it must be considered in the design of any structures to be placed on Georges Bank. Some scheme of immobilization of the sea floor materials is essential, unless extremely long piles are used.

The Scotian Shelf storm just described should not be considered an exceptional situation, since maximum wave heights for the Georges Bank region for the year 1970 (Neu, 1972) reveal waves of 10-12 meters height were recorded. Calculations for a "design wave", or the maximum wave height to be expected in a one-hundred year period, yield heights of from 17 to 20 meters on the Bank. Under such conditions, waves within the Gulf of Maine might reach 16 meters. Typical wave statistics for the region are provided by Drapeau (1970), whose data show waves 4-6 meters in height are common. These data reduced to wave-induced surge spectra (frequency of bottom currents in cm/sec), show that for 16 percent of the time, regional waves can move bottom sands at a depth of less than 50 meters. Thus, the combination of scour potential and wave loads on structures such as pipelines and drilling rigs in the Georges Bank region create a high risk region with regard to marine environments hazards. More wave data appear in Section 3.2 as part of Physical Oceanography.

Perhaps an equally pressing problem is the periodic migration of the ridge and swale features along the inner shelf and Nantucket Shoals and Georges Bank. During major storms, many of these features move up to several hundred meters. What may today be buried under as much as 10 meters of sediment, may be exposed or only partly buried tomorrow. Similarly, a structure exposed to the bottom waters could be buried by a vast quantity of sediment after a severe storm. What impact the presence of an offshore structure or pipeline may have upon such a phenomenon is as unknown as the forces and actual water-particle interactions that take place on the sea floor.

Impacts. Impacts of structures will be slight with regard to alteration to bottom sediments or topography. Material scoured from the vicinity of supports will be deposited in the region, but will be redistributed by the local current regime.

PRACTICES

Under practices, we will include dumping and dredging. Under dumping we can include the discharge of dredge spoil, sewage sludge, demolition debris and cellar dirt, and other particulate matter which might be barged or piped to sea. Inasmuch as such practices generally take place in the inner continental shelf, we will assume that the discussion applies most directly to the Mainland Shelf Province.

Dumping

Proper disposal of particulate matter in the marine environment requires a knowledge of the wave and current regime at the disposal site. Generally, such data are not available in sufficient quantity or quality to permit predictions for seasonal changes in both the motions of the water mass and its vertical structure. Diffusion of the discharged materials will depend on many variables (wind, water structure, specific gravity of solids, waves and currents, etc.) and thus the site of ultimate deposition on the sea floor cannot be predicted. Geological factors to be taken into consideration are local bathymetry, both in major character and microtopography, and sediment texture. A cooperative study between physical oceanographers and geologists will permit estimation of the potential for resuspension once materials reach the sea floor.

Large objects, such as containerized wastes now being deposited in Stellwagen Basin, will remain in place and if sufficiently negative in buoyancy, will tend to bury themselves should scour occur. Additional discussion on ocean disposal is found in Chapter 17.4.

Dredging

Sediment "pollution" as a result of hydraulic dredging can create undesirable deposition in areas down-current from the activity. Inasmuch as aggregate recovery from offshore areas is a possibility, attention to currents throughout the water column must precede dredging activities. As is the case with dumped particulate materials, wind, waves, currents, and other oceanographic parameters must be estimated for the region prior to operations. It may be possible to schedule dredging for periods when hydrologic conditions favor the diffusion and transport of turbid waters away from sensitive regions.

3.1.11 REFERENCES

Ballard, R. D. and Elazar Uchupi. 1972. Carboniferous and Triassic rifting: a preliminary outline of the Gulf of Maine's tectonic history: Geol. Soc. America Bull., v. 83, p. 2285-2302.

Ballard, R. D. 1974. Unpubl. Ph.D. Thesis, University of Rhode Island.

Bell, D. L., D. O. Cook, C. F. Willett, R. L. Wilkins and J. Jackimovicz. 1973. Nearshore marine geology of Massachusetts Bay. ECS, Trans. Amer. Geophys. Union, v. 54, p. 335 (abs.).

Chamberlain, Barbara B. 1964. These fragile outposts - a geological look at Cape Cod, Martha's Vineyard, and Nantucket: Garden City, N. Y., Natural History Press, 327 p.

Coch, N. K. 1973. Morphology and sediment distribution in deep channels connecting Long Island and Block Island Sounds, New York (abst.). Symposium Intern., Relations Sedimentaires entre Estuaires et Plateaux Continentaux Bordeaux, p. 24.

Cook, D. O., D. L. Bell, C. F. Willett, R. L. Wilkins, and J. Jackimovicz. 1973. Geologic framework and aggregate deposits of inner Massachusetts Bay. Unpublished manuscript (in press), 25 p.

Curtis, W. F., J. K. Culbertson and E. B. Chase. 1973. Fluvial-sediment discharge to the oceans from the conterminous United States. U.S. Geol. Survey Circular 670, 17 p.

Dall, W. H. 1925. Tertiary fossils dredged off the northeastern coast of North America: Am. Jour. Sci., 5th ser., v. 10, p. 213-218.

Drake, C. L., J. L. Worzel, and W. C. Beckmann. 1954. Gulf of Maine, Part 9 of Geophysical investigations in the emerged and submerged Atlantic Coastal Plain: Geol. Soc. America Bull., v. 65, No. 10, p. 957-970.

Drake, C. L., M. Ewing and G. H. Sutton. 1959. Continental margins and geosynclines: the east coast of North America north of Cape Hatteras, in Physics and Chemistry of the Earth, vol. 3, New York, Pergamon Press, p. 110-198.

Drake, C. L. and H. P. Woodward. 1963. Appalachian curvature, wrench faulting, and offshore structures. New York Acad. Sci. Trans. Ser. 2, 26:48-63.

Drake, C. L., J. I. Ewing, and H. Stockard. 1968. The continental margin of the eastern United States. Can. Jour. Earth Sci., 5:993-1010.

Drapeau, G. 1970. Sand waves on Browns Bank observed from the Shelf Diver, Maritime Sediments, v. 6, p. 90-101.

Emery, K. O. 1960. The sea off southern California: A modern habitat of petroleum. New York, John Wiley and Sons, 366 p.

__________ 1965a. Geology of the continental margin off eastern United States. Proc. Symp. Colston Res. Soc., 17:1-20.

__________ 1965b. Some potential mineral resources of the Atlantic continental margin. U.S. Geol. Survey Prof. Paper 525-C, p. C157-C160.

Emery, K. O. and Elazar Uchupi. 1965. Structure of Georges Bank: Marine Geology, v. 3, no. 6, p. 349-358.

Emery, K. O., R. L. Wigley, A. S. Bartlett, M. Rubin and E. S. Braghoorn. 1967. Freshwater peat on the continental shelf. Science, 158:1301-1307.

Emery, K. O. 1968. Relict sediments on the continental shelves of the world. Amer. Assoc. Petroleum Geologists Bull., 52:445-464.

Emery, K. O., E. Uchupi, J. D. Phillips, C. O. Bowin, E. T. Bunce, and S. T. Knott. 1970. Continental rise of eastern North America. Amer. Assoc. Petroleum Geologists Bull., 54:44-108.

Emery, K. O. and E. Uchupi. 1972. Western North Atlantic Ocean: Topography, rocks, structure, water, life and sediments. Memoir 17, Amer. Assoc. Petroleum Geologists, Tulsa, 532 p.

Ewing, J., B. Luskin, A. Roberts and J. Hirshman. 1960. Sub-bottom reflection measurements on the continental shelf, Bermuda Banks, West Indies Arc and in the west Atlantic basin. Jour. Geophys. Res., 64:2849-2859.

Ewing, J., X. LePichon and M. Ewing. 1963. Upper stratification of Hudson apron region. Jour. Geophys. Res., 68:6303-6313.

Faas, R. W., C. A. Nittrouer, D. J. Toth. 1973. Fine grained sediment distribution in the Wilkinson Basin, Gulf of Maine. Northeast Section, Geol. Soc. of Amer. (abstract).

Garrison, L. E. 1970. Development of continental shelf south of New England. Amer. Assoc. Petroleum Geologists, Bull. v. 54, p. 109-124.

Gibson, T. G. 1965. Eocene and Miocene rocks off the northeastern United States: Deep-Sea Research, v. 12, p. 975-981.

Grim, M. S., C. L. Drake and J. R. Heirtzler. 1970. Sub-bottom study of Long Island Sound. Geol. Soc. Amer. Bull., 81:649-666.

Hathaway, J. C. 1971. Data file, continental margin program, Atlantic coast of the United States. Vol. 2, Sample collection and analytical data. Woods Hole Oceanographic Institution Tech. Rept. 71-15, 496 p. (unpubl. ms.).

__________ 1972. Regional clay mineral facies in the estuaries and continental margin of the United States east coast. Geol. Soc. Amer. Memoir 133.

Hendricks, J. D. and J. M. Robb. 1973. Gravity measurements in the vicinity of Georges Bank. Geol. Soc. America Bull., v. 84, p. 3911-3916.

Hoskins, H. 1967. Seismic reflection observations on the Atlantic continental shelf, slope and rise southeast of New England. Jour. Geol., 75:598-611.

Hulsemann, J. 1966. On the routine analysis of carbonates in unconsolidated sediments. J. of Sedimentary Petrol. Vol. 36: 622-625.

__________. 1967. The continental margin off the Atlantic coast of the United States; carbonate in sediments, Nova Scotia to Hudson Canyon. Sedimentol., v. 8, p. 121-145.

Johnson, D. W. 1925. The New England-Acadian shoreline: New York, John Wiley & Sons, 608 p.

Kane, M. F., M. J. Yellin, K. G. Bell, and Isidore Zietz. 1972. Gravity and magnetic evidence of lithology and structure in the Gulf of Maine region: U.S. Geol. Survey Prof. Paper 726-B.

Knott, S. T., and Hartley Hoskins. 1968. Evidence of Pleistocene events in the structure of the continental shelf off the northeastern United States. Marine Geology, v. 6, p. 5-43.

Koons, E. D. 1941. The origin of the Bay of Fundy and associated submarine scarps. Jour. Geomorphology, v. 4, no. 3, p. 237-240.

_________. 1942. The origin of the Bay of Fundy: A discussion. Jour. Geomorphology, v. 5, no. 2, p. 143-150.

Kuenen, P. H. 1950. Marine Geology. New York, John Wiley and Sons, 568 p.

Maher, J. C. with E. R. Applin. 1971. Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf. U.S. Geol. Survey Prof. Paper 659, 98 p.

Manheim, F., R. H. Meade, and G. C. Bond. 1970. Suspended matter in surface waters of the Atlantic continental margin Cape Cod to the Florida Keys. Science, v. 167, p. 371-376.

Manheim, F. T. 1972. Mineral resources off the northeastern coast of the United States. U.S. Geological Survey Circular 669, 29 p.

Massachusetts Institute of Technology. 1974. Primary physical impacts of offshore petroleum developments. MIT Sea Grant Report No. MITSG - 74-20.

Mattick, R. E., N. L. Weaver, R. Q. Foote, and B. D. Ruppel. 1973. Preliminary report on the U.S. Geological Survey Geophysical studies of Atlantic outer continental shelf. (abs.), Amer. Assoc. Petroleum Geologists Bull., v. 57, p. 2147.

McIver, N. L. 1973. Stratigraphy of the continental shelf, offshore Nova Scotia. Amer. Assoc. Petrol. Geologists Bull., v. 57, p. 2146-2147 (abs.).

McMaster, R. L. and L. E. Garrison. 1967. A submerged Holocene shoreline near Block Island, Rhode Island. Jour. Geology, v. 75, p. 335-340.

McMaster, R. L. and A. Ashraf. 1973a. Subbottom basement drainage system of inner continental shelf off southern New England. Geol. Soc. Amer. Bull., 84:187-190.

__________. 1973b. Extent and formation of deeply buried channels on the continental shelf off southern New England. Jour. Geol., 81:374-379.

Meade, R. H. 1969a. Landward transport of bottom sediments in estuaries of the Atlantic Coastal Plain. Jour. Sedimentary Petrology, 39:222-234.

__________. 1969b. Errors in using modern stream-load data to estimate natural rates of denudation. Geol. Soc. Amer. Bull., 80:1265-1274.

__________. 1972. Transport and deposition of sediments in estuaries. Geol. Soc. Amer. Memoir 133, p. 91-120.

Merrill, A. S., K. O. Emery, and M. Rubin. 1965. Ancient oyster shells on the Atlantic continental shelf. Science, 147:398-400.

Milliman, J. D. 1974. Marine geology of the Middle Atlantic Bight. Marine Publ. Series No. 3, Univ. Rhode Island, 89 p.

Milliman, J. D., O. H. Pilkey and D. A. Ross. 1972. Sediments of the continental margin off the eastern United States. Geol. Soc. Amer. Bull., 83:1315-1334.

Moore, D. G. and J. R. Curray. 1963. Sedimentary framework of continental terrace off Norfolk, Virginia and Newport, Rhode Island. Amer. Assoc. Petroleum Geologists Bull., 47:2051-2054.

Moore, S., G. R. Chirlin, C. J. Puccia, and B. P. Schrader, 1974. Potential biological effects for hypothetical oil discharge in the Atlantic Coast and Gulf of Alaska. MIT Sea Grant. Report No. MITSG - 74 - 19.

Muraoka, J. J. 1970. Animal undermining of naval seafloor installations. U.S. Naval Civil Engr. Lab. Tech. Note N-1124, 18 p.

Murray, H. W. 1947. Topography of the Gulf of Maine, field season of 1940. Geol. Soc. America Bull., v. 58, no. 2, p. 153-196.

Neu, H. J. A. 1972. Extreme wave height distribution along the Canadian Atlantic Coast. Ocean Industry, July, p. 45-49.

Oldale, R. N., E. Uchupi and K. E. Prada. 1973. Sedimentary framework of the western Gulf of Maine and the southeastern Massachusetts offshore area. U.S. Geol. Survey Prof. ppr. 757, 10 p.

Owen, D. M., K. O. Emery and L. D. Hoadley. 1967. Effects of tidal currents on the sea floor shown by underwater timelapse photography. In J. B. Hersey (ed.), Deep-Sea Photography. Baltimore, Johns Hopkins Press, p. 159-166.

Parker, A. 1973. Some chemical, mineralogical, and geotechnical analyses of four cores from the Wilkinson Basin. Deep-Sea Research, v. 20, p. 551-554.

Perlow, M., Jr. and A. F. Richards. 1972. In-Place Geotechnical Measurements from submersible Alvin in Gulf of Maine Soils. Offshore Technology Conference Preprints, 1, p. 333-340.

Perlow, M., Jr. and A. F. Richards. 1973. Geotechnical variability measured in place from a small submersible. Marine Technology Society Journal, 7(4), p. 27-32.

Pettijohn, F. J. 1957. Sedimentary rocks. New York, Harper and Bros., 718 p.

Ross, D. A. 1967. Heavy-mineral assemblages in the nearshore surface sediments of the Gulf of Maine in Geological Survey research 1967. U.S. Geol. Survey Prof. Paper 575-C, p. C77-C80.

__________ 1968. Current action in a submarine canyon. Nature, 218: 1242-1245.

__________ 1970. Source and dispersion of surface sediments in the Gulf of Maine - Georges Bank area. Jour. Sed. Petrology, v. 40, 906-920.

__________ 1970. Atlantic continental shelf and slope of the United States -- Heavy minerals of the continental margin, southern Nova Scotia to northern New Jersey. U.S. Geol. Survey Prof. Paper 529-G, 40 p.

Sanders, J. E., K. O. Emery and E. Uchupi. 1969. Microtopography of five small areas of the continental shelf by side scanning sonar. Geol. Soc. Amer. Bull., 80:561-572.

Schlee, J. and R. M. Pratt. 1970. Atlantic continental shelf and slope of the United States - Gravels of the northeastern part. U.S. Geol. Survey Prof. ppr. 529-H, 39 p.

Schlee, J. 1973. Atlantic continental shelf and slope of the U.S. -- Sediment texture of the northeastern part. U.S. Geol. Survey Prof. ppr. 529-L, 61 p.

Schultz, L. K. and R. L. Grover. 1973. Geology of Georges Bank Basin. (abs.), Amer. Assoc. Petroleum Geologists Bull., v. 57, p. 2149.

Shepard, F. P. 1931. Glacial troughs of the continental shelves. Jour. Geol., v. 39, p. 345-360.

Smith, J. D. 1969. Geomorphology of a sand ridge. Jour. Geol., 77:39-55.

Smith, W. E. T. 1966. Earthquakes of eastern Canada and adjacent areas, 1928-1959. Dominion Observatory Ottawa Pubs., v. 32, p. 87-121.

Spencer, D. W. and P. L. Sachs. 1970. Some aspects of the distribution, chemistry and mineralogy of suspended matter in the Gulf of Maine. Marine Geol., v. 9, p. 117-136.

Stanley, D. J., D. J. P. Swift and H. G. Richards. 1967. Fossiliferous concentrations on Georges Bank. Jour. Sedimentary Petrology, 37:1070-1083.

Stetson, H. C. 1936. Geology and paleontology of the Georges Bank canyons. Geol. Soc. Amer. Bull., 47:339-366.

____________. 1938. The sediments of the continental shelf off the eastern coast of the United States. Mass. Inst. Tech. and Woods Hole Oceanog. Inst. Papers in Phys. Oceanog. and Meteorol., 5(4): 5-48.

Stewart, H. B., Jr. and G. F. Jordan. 1964. Underwater sand ridges on Georges Shoal, In R. L. Miller, Ed., Papers in marine geology, Shepard commemorative volume: New York, Macmillan Co., p. 102-114.

Tagg, A. R. and E. Uchupi. 1967. Subsurface morphology of Long Island Sound, Block Island Sound, Rhode Island Sound and Buzzards Bay. U.S. Geol. Survey Prof. paper 575-C, p. 92-96.

Taylor, P. T., Isidore Zietz, and L. S. Dennis. 1968. Geologic implications of aeromagnetic data for the eastern continental margin of the United States. Geophysics, v. 33, p. 755-780.

Trumbull, J. V. A. and M. J. McCamis. 1967. Geological exploration in an East Coast submarine canyon from a research submersible. Science, 158:370-372.

Trumbull, J. V. A. and J. C. Hathaway. 1968. Further exploration of Oceanographer Canyon. Woods Hole Oceanographic Institution Ref. No. 68-37, 57 p.

Trumbull, J. V. A. 1972. Atlantic continental shelf and slope of the United States - Sand-size fraction of bottom sediments, New Jersey to Nova Scotia. U.S. Geol. Survey Prof. Paper 529-K, 45 p.

Uchupi, Elazar. 1966a. Topography and structure of Northeast Channel, Gulf of Maine. Am. Assoc. Petroleum Geologists Bull., v. 50, no. 1, p. 165-167.

___________. 1966b. Structural framework of the Gulf of Maine. Jour. Geophys. Research, v. 71, no. 12, p. 3013-3028.

___________. 1968. Atlantic continental shelf and slope of the United States - Physiography. U.S. Geol. Survey Prof. Paper 529-C, 30 p.

___________. 1970. Atlantic continental shelf and slope of the United States - Shallow structure. U.S. Geol. Survey Prof. ppr., 529-I, 44 p.

Upham, Warren. 1894. The fishing banks between Cape Cod and Newfoundland. Am. Jour. Sci., 3d ser., v. 47, p. 123-129.

Verrill, A. E. 1878. Occurrence of fossiliferous Tertiary rocks on the Grand Bank and Georges Bank. Am. Jour. Sci., ser. 3, 16:323-324.

Wilson, J. T. 1962a. Cabot fault, an Appalachian equivalent of the San Andreas and Great Glen faults and some implications for continental displacement. Nature, v. 195, p. 135-138.

___________. 1962b. Some further evidence in support of the Cabot fault, a great Paleozoic transcurrent fault zone in the Atlantic provinces and New England. Royal Soc. Canada Trans., v. 61, p. 31-36.

Wilson, N. D. and W. Abel. 1973. Seafloor scour protection for a semi-submersible drilling rig on the Nova Scotia Shelf. Offshore Technology Conf. Preprints, v. 2, p. 631-646.

Zeigler, J. M., W. S. Hoffmeister, G. Giese and H. Tasha. 1960. Discovery of Eocene sediments in subsurface of Cape Cod. Science, 132:1397-1398.

Chapter

3 Offshore Region

Page

Chapter 3.2 Physical Oceanography

3.2 PHYSICAL OCEANOGRAPHY

3.2.1 INTRODUCTION

This section includes the physical oceanography of the offshore region as defined and is separate from the nearshore and coastal processes discussed in Chapter 4.2, Major Sounds and Bays. The dividing boundary is generally several kilometers offshore and in most cases away from immediate fresh water and estuarine effects. However, both the Gulf of Maine and the area south of Cape Cod are somewhat under the effect of the coastal fresh water regime and are not typical of open ocean North Atlantic. The following discussion is considered to typify the Gulf of Maine oceanography and is a summary of the physical processes from the literature. The most complete review of the history of the oceanography of the Gulf of Maine is found in a document by Colton (1964). The general area included is shown in Figure 3-33 Since the Gulf of Maine is considered by many to be a separate area physically, the following sections 3.2.2 to 3.2.4 will treat the physical oceanography of this area only. A similar presentation of the region south of Cape Cod is presented in Sections 3.2.6 to 3.2.9.

3.2.2 WAVE CLIMATE

The surface of the Gulf of Maine appears confused if one simply observes waves and attempts to discern individual wave trains. Waves in the Gulf of Maine, as elsewhere, represent three different sets of waves: (1) waves generated by the presently operating winds, (2) waves generated by previously operating winds, and (3) waves generated by storms outside the area, which propagate through the area.

The greatest amount of wave data from the Gulf of Maine comes from shipboard observations and two wave gauges operated by the U. S. Army Corps of Engineers. Thompson and Harris (1972) have constructed a wave height distribution function based on shipboard observations in SSMO Area 4, the Gulf of Maine which is shown in Figure 3-34. Their calculations show that waves greater than seven meters occur only one-tenth of one percent of the time; greater than one meter, 50 percent of the time; and greater than 0.5 meters, 80 percent of the time. Emery and Uchupi (1972) report that data from the Office of Climatology and Division of Oceanography (1959, chart 137) agree well with the wave distribution function reported by Thompson and Harris only for the lower wave heights. Emery and Uchupi report that wave heights greater than 3.5 meters occur ten percent of the time, while Thompson and Harris calculate that they occur only two percent of the time; the latter also indicate that observations of the higher wave heights may be as much as 50 percent in error.

Wave patterns and winds observed December 17-20, 1964 (Emery, 1965a) are shown in Figure 3-35a. (A) Flight path and observation points at two-minute intervals (about 10 km apart). (B) Wind streamlines inferred from slicks on sea surface. Streamlines closely fitted those developed from isobaric maps on same days. (C) Wave trains and their direction of movement. Note that one train on each day is approximately at right angles to wind streamlines. (D) Western margin of Gulf Stream (wide line) bordered by zone of transition to shelf water. Water color is indicated as present yellow (Forel scale).

Figure 3-35b from Emery and Uchupi (1972) shows wave patterns and winds observed July 19-21, 1965. Finally, Figure 3-36 presents average winter winds and waves. The top: Frequency of winds. Narrow lines denote percentage frequency of observations showing winds equal to or greater than Wind Force 4 (20 km/hour, or 11 knots); wide lines show frequency of winds equal to or greater than Wind Force 8 (63 km/hour, or 34 knots). From Chief of Naval Operations (1955, charts 16, 17). Bottom: Frequency of waves. Narrow lines denote percentage frequency of observations showing waves higher than 1.5 m, and wide lines showing frequency of waves higher than 3.5 m. From Office of Climatology and Division of Oceanography (1959).

Wave data gathered for 1970 in the Gulf of Maine by Neu (1972) indicate the one year maximum wave within the Gulf is nine meters, while over Browns Bank and Georges Bank the one-year maximum height is 11 to 12 meters. The 100-year wave heights are 16 and 19 meters, respectively, for the two areas. During the winter months waves approach from the south through the northwest quadrant to the northeast quadrant. Wave energies are greater from a northwesterly direction. During the summer months the waves are from the southwest and the east-northeast, the former being prevalent (Neu, 1972). Figures 3-37a, 3-37b, 3-37c show these characteristics.

Wave data from the two U.S. Army Corps of Engineers' wave stations coupled with direction hindcasts from synoptic weather charts are available in the Gulf of Maine. One station is located 50 miles due south of Mt. Desert Island, the other 15 miles east on Nauset on Cape Cod. Both wave stations show that the major wave-approach directions are from the southerly and easterly directions. The dominant waves are from the east-northeast and the east, reflecting the importance of northeast storms. The largest waves, five meters and over, approach from the east-northeast. The prevailing wave directions are also from the easterly direction, but waves from the south and southeasterly directions occur about 30 percent of the year. Northeasterly waves occur principally during the winter months because northeast storms occur frequently during the winter, but they are not limited to the winter season. Wave approach from the south quadrant occurs principally during the summer months. Figures 3-38 and 3-39 present wave roses for each of the stations.

The inner continental shelf of the Gulf of Maine is characterized by dominant northeast waves generated by storms within the Gulf of Maine. The outer shelf, on the other hand, is dominated by northwest waves generated by strong northwest winds. The New England landmass prevents northwest waves from being generated along the inner Gulf by limiting the fetch, but unrestricted fetch from the inner shelf to the Atlantic Ocean allows northwest waves to dominate on the outer shelf. Georges Bank and Browns Bank protect the inner Gulf of Maine from long-period, high waves from the Middle Atlantic (Emery and Uchupi, 1972) while strong northwest winds and waves aid to oppose and diminish the Atlantic waves on the outer shelf (Neu, 1972).

ADDITIONAL WAVE DATA

The term waves, as applied to the sea surface, refers to the general field of perturbations caused by wind action. When the term <u>wave height</u>, i.e., the vertical distance from trough to crest, is applied to ocean waves its meaning must be defined. In general wave height means the average height of some selected sample of waves. If the sample includes the highest waves observed during a period of time, then the measurement is properly termed the <u>mean maximum wave height</u>. All wave heights referred to in this report are mean maximum wave heights.

<u>Wave period</u> refers to the length of time for successive wave crests (or troughs) to pass a fixed observation point. This again is an average of many separate waves and is sometimes termed the <u>predominant wave period</u>.

There are a variety of ways to display wave data. In this report data will be presented in two forms: wave period-height graphs and period-duration graphs and persistence of favorable and unfavorable seas.

Figure 3-40 is a location chart for wave period-height and period-direction graphs. The seasonal data for area 1, essentially the study area, and area 2, its southwestern extension, are given in Figures 3-42 and 3-43. Figure 3-41 is the legend for 3-43.

A great deal of information is contained in each of these graphs. As shown in the legend, Figure 3-41, there are five curves drawn and three roses. The ordinate is percent of observations, the number of which are in the upper left-hand corner. The abscissa gives the heights of the waves. Each of the curves is a cumulative percentage curve for the labelled period. For example, point A on the graph refers to waves of all periods and heights equal to or greater than 1.5 meters. It shows that 60 percent of all observations reported wave heights equal to or greater than 1.5 meters. The three roses display the directional characteristics of the waves as a function of wave period.

To illustrate the use of these graphs an example will be worked using the winter season data for area 1 (Gulf of Maine and the Grand Banks). There were 2,877 observations, 2 percent of which showed no sea (calm) and 9 percent of which were indeterminate. The maximum height observed was 9 meters. The roses show that the most common direction from which waves came was between west and north. Five percent of all waves were higher than 1.5 meters and 8 percent were higher than 3.5 meters. Thirty percent of all waves were of periods greater than 7 seconds. These graphs can also be used to determine the percentage of the time that waves were between a specified height and period range. For example, to determine the percentage of the time that waves with periods between 7 and 9 seconds and simultaneously heights between 1 and 2.5 meters occurred, we read the following data from the graphs: greater than 7 seconds and greater than 1 m, 27 percent; greater than 7 seconds and greater than 2.5 m, 18 percent; greater than 9 seconds and greater than 1 m, 11 percent; and greater than 9 seconds and greater than 2.5 m, 9 percent. Therefore, for periods greater than 7 seconds we have 27 percent minus 18 percent or 9 percent of the observations showing waves with periods greater than 7 seconds and heights between 1 and 2.5 m. Similarly, for waves with periods greater than 9 seconds the result is 2 percent of the observations with periods greater than 9 seconds and heights between 1 and 2.5 m. The difference between 9 percent and 2 percent is the desired result: 7 percent of the observations during the winter in the Gulf of Maine indicated waves with periods between 7 and 9 seconds and heights between 1 and 2.5 m.

The data relating to the persistence of favorable and unfavorable seas is shown in Figures 3-46 to 3-51b. The location chart for these data is given as Figure 3-44. Figure 3-45 provides the legend. These graphs can only be obtained where data is continuously recorded by a wave meter for a period of at least three years. Adequate data in the study area are only available for the permanent light ships at the following locations: Portland, Maine; Pollock Rip, Massachusetts; Buzzards Bay, Massachusetts; Nantucket Shoals, Massachusetts; Ambrose Channel, New York; and Barnegat, New Jersey. The use of these graphs can be illustrated by reference to the legend, Figure 3-45. In the upper right hand corner of each graph are given the total number of observations and beneath that the average number of occurrences of seas rising or falling past 1 m during the season. This number, 16, is the base number for all subsequent calculations. Each curve on the graph refers to a particular height value, e.g., 3.5 m. To determine the persistence of a given condition, say, seas greater than 3.5 m for a period greater than 40 hours, we extract from the unfavorable seas graphs at 40 hours and 3.5 m the value of 28 percent. This means that on 0.28 x 16 occasions, i.e. about five occasions, the seas rose to above 3.5 m and remained there for longer than 40 hours. The total number of occasions during which the seas rose above 3.5 m is read from the left-hand end of the 3.5 m line. The percent value here is 108 and applying this to the base of 16 gives 17 occasions when seas rose above 3.5 m. Above we calculated that on 5 of these occasions it remained above 3.5 m for more than 40 hours. Therefore, the probability of seas remaining above 3.5 m for longer than 40 hours, given that they rise above 3.5 m is 5/17 or about 30 percent. Put another way, if the seas rise above 3.5 m there is a 30 percent probability that they will remain above 3.5 m for at least 40 hours.

For the case of favorable seas we can determine the probability of seas dropping below 3.5 m, given that they are above 3.5 m, and remaining below 3.5 m for longer than, for example, 80 hours. The intersection of 3.5 m and 80 hours is 50 percent. Applying this to the base value of 16 we have eight occasions during which the seas dropped below 3.5 m for longer than 80 hours. The total number of occurrences of seas greater than 3.5 m was previously determined to be 17. Therefore, of the 17 seas observed above 3.5 m, eight fell below 3.5 m and remained there for a period of more than 80 hours. The probability is therefore 8/17 or 45 percent that when seas fall below 3.5 m they will remain below 3.5 m for at least 80 hours. Conversely, if seas fall below 3.5 m there is a 55 percent probability that they will exceed 3.5 m again sometime in the next 80 hours.

Below each pair of graphs is a bar graph giving the percent of time seas were observed within specified height range. These data are somewhat different from the data in Figures 3-42 and 3-43 which apply to large sea areas. Figures 3-46 through 3-51 only apply strictly speaking to the light ships. However, the general indication can be applied to somewhat larger areas.

In addition to mean wave conditions it is also of interest to consider the probability of extreme events such as extraordinary (solitary) waves. Extreme-wave height return period, i.e. the length of time on the average for the same event to re-occur, can be estimated from the data below (U.S. Department of Commerce, 1973). No analysis was performed for the Gulf of Maine but analyses were done for the sea areas to the southwest and east of the study area. Interpolation gives the following results for the study area:

	Return Period (years)				
	2	5	10	25	50
wave height	15	20	24	27	30

These figures have been taken from U.S. Department of Commerce (1973) and are based on data and analyses in U.S. Navy (1963).

3.2.3 CURRENTS

Off the continental slope, the Gulf Stream forms a narrow current about 90 km across, flowing eastward (Fig. 3-52). The Gulf Stream is characterized by multiple currents, countercurrents, and discrete zones of rapid flow sometimes reaching 7 to 9 km/hr with meanders and eddies. Adjacent to the north side of the stream is a second eastward flow, known as the Slope Water Current. Closer to the Continental Slope this current reverses forming an oblong eddy with its northern limb moving westward according to Sverdrup, Johnson, and Fleming (1942) (Figure 3-53). This westward moving water is joined by the southern limb of the Georges Bank eddy which moves along the southern edge of the Bank. One limb of the westward drift continues across Great South Channel and then across the shelf to the offing of southern Rhode Island. The other limb diverges northward to join the flow moving eastward across the northern edge of Georges Bank. A southerly flowing limb closes the eddy at the eastern edge. The Georges Bank eddy develops seasonally. The eddy develops over the bank during spring, but by summer the flow at the eastern edge is southerly and offshore and by autumn the flow over the western edge moves westerly and southerly. The entire drift over the bank in winter is, in general, southerly.

North of the Georges Bank a second eddy encompasses the entire Gulf of Maine. The southern limb of the Gulf eddy joins the eastward moving limb of the Bank eddy during spring. An indraft of water from the Scotian Shelf and Browns Bank flows westward entering the counterclockwise eddy and either moves northward into the Bay of Fundy or continues westward to the western coast of the Gulf of Maine. Water encountering the coast turns southerly and follows the contour of the coast eventually either entering Massachusetts Bay or turning eastward to again cross the northern edge of Georges Bank. The eddy slows by early summer and during autumn and winter the southern limb dissipates into a southern drift across Georges Bank as the eddy withdraws into the northern corner of the Gulf.

An approximation of minimal current velocities at the surface can be obtained from the drift bottle atlas of Bumpus and Lauzier (1965). During the winter and spring months currents vary from 1.8 to 7 nautical km per day. In June following the spring addition of estuarine water from the western coast of the Gulf of Maine, flows of 13 to 15 km per day were recorded in some places. Currents did not exceed 9 km per day during July and August. With the advent of autumn and winter winds, velocities of 9 and 11 km per day sometimes occurred and in one instance a value of 16 km per day was recorded south of the Bay of Fundy in November.

The surface circulation is largely caused by winds and dynamic pressure gradients. The direction of the current in a given area or region is determined by Coriolis force, the apparent effect resulting from the rotation of the earth, as well as by the contours of the bottom and shore. Bumpus (1960) stated that the circulation of the offshore region may be modified at any time by winds or river runoff. Offshore winds tend to disrupt the Georges Bank eddy when they are from the northeast. Even short term winds from the northeast speed up the northern segment of the Gulf of Maine eddy and push water through the South Channel.

Surface drifts, determined from dynamic pressure gradients, agree generally with those obtained from drift bottle experiments (Bigelow 1927: Bumpus and Lauzier 1965). The two major eddies are indicated, one in the Gulf of Maine and the other over Georges Bank. Dynamic gradients and their inferred currents in turn may be correlated with the drift of organisms which are assumed to be transported passively. Redfield (1941) and Redfield and Beal (1940) show such correlations for the Calanoid community and Chaetognaths in the Gulf of Maine. Also, intrusions of oceanic water over Georges Bank and into the Gulf of Maine have been traced through the occurrence of oceanic copepods in these areas by Colton, Temple, and Honey (1962).

Day (1958) showed the effect of Coriolis force in deflecting the net drift of surface water to the right of the wind direction in offshore Gulf of Maine. Bigelow (1927) also showed this effect for autumn and summer currents at the Portland lightship and Graham (1970a) demonstrated this effect at the lightship for all four seasons. Since water is added to the periphery of the Gulf of Maine eddy, one might expect the estuarine water of generally lower salinity to flow outward from the coast. However, this flow, developed from dynamic pressure gradients, is also deflected by Coriolis force. Thus, as the water moves offshore the current is directed to the right following closely the coastline and the counterclockwise motion of the Gulf of Maine eddy. In general, currents follow the bottom contours in the region. Therefore, the Gulf of Maine eddy flows along the periphery of the coast following the general contours of the bottom and shore and the Georges Bank eddy encircles the periphery of the bank. The movement of water northward from the Gulf into the Bay of Fundy is increased by winds from the west and southwest. On the western side of the Gulf the eddy is strengthened when fresh water is added from the estuaries; but this eddy declines during periods of drought.

The bottom drift as indicated by the use of sea bed drifters, is shoreward from the 100 m isobath along the western coast of the Gulf of Maine. The drift is also shoreward south of the Nova Scotia coast, but at depths down to 300 meters. At that depth, Lauzier (1967) shows a demarcation zone that divides the Northeast Channel into one drift onto Browns Bank and the southern coast of Nova Scotia and the other drift onto Georges Bank to the south (Figure 3-54). A second zone of divergence of bottom flows occurs in the deep trough which extends into the Bay of Fundy between Grand Manan Island and the western coast of Nova Scotia. The zone sharply separates an easterly inflowing drift from a westerly outflowing drift. In the deeper water of the Gulf of Maine the direction of flow is similar to that at the surface. A similar agreement exists on Georges Bank (Bumpus, MS).

The minimal velocities with which the bottom drifts transport sea bed drifters are considerably less than that indicated by surface drift bottles. Along the coasts the bottom drift average .09 to 1.2 nautical km per day (Graham 1970a and Lauzier 1967). In the deeper portions of the Gulf drifts are less than two km per day, while on Georges Bank they are faster, generally about one km per day (Bumpus MS). The movement of drifters does not appear to have a marked seasonality. Figure 3-54a shows all bottom measurements on record. The table immediately following Figure 3-54a lists these measurements.

OFFSHORE TIDAL MEASUREMENTS

A brief summary of tidal gauge measurements made in the offshore area is presented by Emery and Uchupi (1972). In addition to major stations used for prediction by the coast and geodetic survey there were data from Texas Tower 2 on Georges Bank and Tower 3 off Nantucket for up to 15 months as well as two bottom mounted stations. The Gulf of Maine tidal range is about 4 meters at the entrance to the Bay of Fundy inshore of Nova Scotia. At the head of the Bay spring tides reach 14.5 meters. According to Emery and Uchupi (1972) the tide slows as it crosses Georges Bank due to the shallow area.

OFFSHORE TIDAL CURRENTS

Measurements of tidal currents by Haight (1942) showed all stations with a clockwise rotation, except sites possibly influenced by local topography at Portland, Maine and Mount Desert Island. Figure 3-55 shows these clockwise rotations as tidal ellipses for the offshore area. Maximum velocities of more than 2 km/hour occur over Georges Bank and along the shallow shelf from Long Island to Nova Scotia, and separates the open ocean from the Gulf of Maine. Current speeds in the Great South Channel and Northeast Channel, the two principal entrances to the Gulf of Maine, were reported to be 43 cm/second and 32 cm/second respectively according to Emery and Uchupi (1972).

3.2.4 TEMPERATURE AND SALINITY

There are two water masses located to the north of the Gulf Stream. These are the Slope Water and Coastal Water as shown in Figure 3-52. Slope Water is formed primarily by water added from the oceanic side and the coastal side. The formation of Slope Water is described by McLellan (1957). Because these additions and other factors are relatively constant this water mass retains its characteristics. Coastal Water on the other hand is formed largely by (1) the addition of Slope Water on the southern edge, (2) a movement of water from over the Scotian Shelf which enters through the Northeast Channel, and (3) the addition of estuarine water at the shoreward boundary. Occasionally, meanders from the Gulf Stream current intrude, extending over the southern edge of Georges Bank on the southern boundary of the Coastal Water (Colton, Temple, and Honey (1962). Thus, the characteristics of the two water masses may be altered but not sufficiently for them to lose their identities which are apparent in the descriptions of temperature and salinity in subsequent sections.

An excellent atlas of temperature regimes existing in this region is given by Colton and Stoddard (1972). Figure 3-56 shows the areas (1-6) and tracks (A-H) used to construct temperature profiles. The Bay of Fundy (Area 1), Georges Bank (Area 3), the Gulf of Maine basin (Area 4) and the Slope Water (Area 5) are of special interest here. The authors state that the Bay of Fundy and Georges Bank are areas of intense tidal mixing and thus are less thermally stratified in summer than waters over the deep Gulf basin where tidal flows are weak (Figure 3-57). The higher degree of stratification and temperatures shown for Area 5 are typical for Slope Water.

At any time of year a large range in surface temperature exists from the Slope Water to inshore Coastal Water (Figure 3-58). In the winter, most of the gradient exists in the Slope Water and it is not until summer that the gradients are also well developed in the Coastal Water which is more affected by seasonal events and local regional climatic conditions. With the advent of autumnal cooling and mixing by winds, these gradients are destroyed and in winter vertical mixing is complete and the water column is thermally homogeneous (Figure 3-59 and 3-60).

Bigelow (1927) described summer surface temperatures as decreasing from southwest to northeast offshore of the western coast of the Gulf of Maine and increasing near the bottom in the same direction. At 40 meters temperatures were uniform. This reversal of surface and bottom temperature gradients was related to greater stratification in the southwest and greater mixing in the northeast section and the Bay of Fundy. A comparison of Figures 3-58 and 3-61 suggests that this phenomenon extends over most of the Gulf. But, near the northern edge of Georges Bank in summer (August, Fig. 3-58) intense tidal mixing and the eddying of water around the bank causes sharp gradients normal to the edges of the bank. This and other features of the temperature regimes are apparent in the vertical profiles shown in Figures 3-63 to 3-66.

Bottom temperatures usually vary with depth; thus, isotherms closely parallel the contours of the coast and banks. Colton and Stoddard (1973) present an atlas of mean bottom temperatures for the continental shelf including the present study region. Those for the months of February, May, August, and November are shown in Figures 3-67 to 3-70. In addition, charts of maximum and minimum temperatures also from Colton and Stoddard (1973) are shown in Figures 3-71 and 3-72. Because shallow water more quickly reflects seasonal changes than deep water, the higher maximum temperatures occur on banks and near the coast and higher minimum temperatures occur in the basins and deepening offshore water.

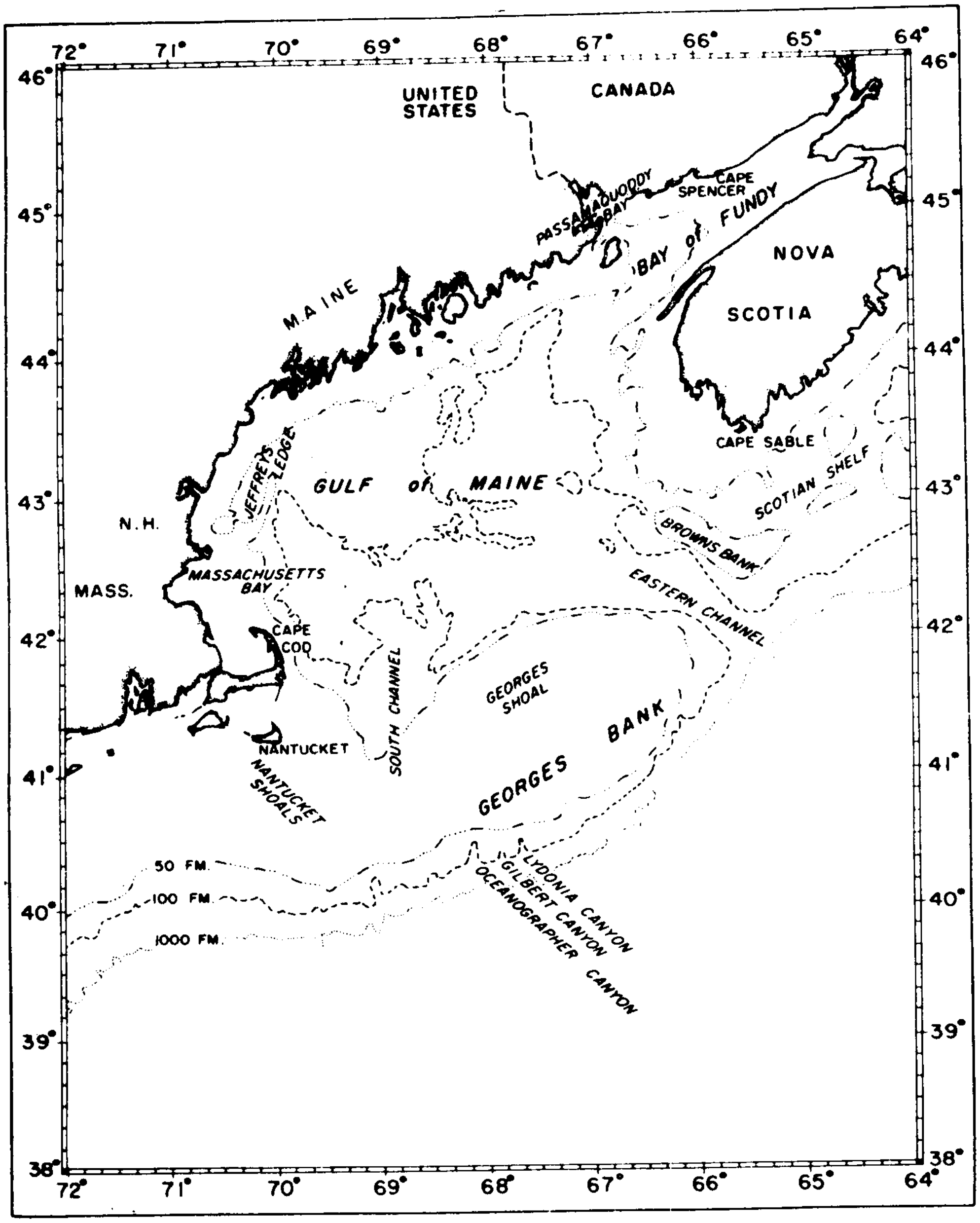
Another atlas, published by Colton et al. (1968), contains plots and profiles of temperature, salinity, dissolved oxygen, and chlorophyll; only those pertaining to salinity will be considered here. The area covered (Figure 3-73) is similar to that in the atlas of surface temperatures (Colton and Stoddard, 1972). Surface salinity is relatively uniform over the surface in winter (Figure 3-74) except offshore within the Slope Water. In December, 1965 this offshore gradient in salinity is especially pronounced compared to December, 1964. According to Bigelow (1927) during winter the lower salinity waters off southern Nova Scotia have moved westward and into the Gulf of Maine. This intrusion is marked by the 31.5 ^{o}/oo and 32 ^{o}/oo isohalines. Water of slightly lower salinity derived from coastal estuarine waters extends around the periphery of the Gulf of Maine bordering the northern edge of Georges Bank: Note the distribution of the 32.5 ^{o}/oo isohaline. Conditions are somewhat similar in March (Figure 3-75); possibly the beginning of early spring discharge is noticeable in the 32 ^{o}/oo isohaline encompassing stations along the southwestern coast of the Gulf of Maine. Freshening of coastal water is more apparent in data from the late spring to early summer cruises (Fig. 3-76) shown by Colton, Marak, Nickerson, and Stoddard (1968). Salinity is generally lower over the region except in the Slope Water where a strong gradient exists. In September (Figure 3-77) salinity is higher over the region following the summer decrease in freshened water discharged from the coast. The intrusion of the 32 ^{o}/oo isohaline into the Gulf from the western coast reflects the Gulf of Maine eddy established in the late spring and summer.

In the winter the vertical distribution is relatively uniform to depths of 40 or 50 meters (Bigelow, 1927) from the coast to offshore until the Slope Water is reached. This is indicated within the vertical profiles of salinity (Figures 3-78 to 3-82) given by Colton, et al. (1968) for tracks B-F (Figure 3-73). Such conditions also prevail during March (Figures 3-83 to 3-87). In late spring increased river discharge stratifies the upper waters (Figures 3-88 to 3-92). This stratification is increased by September, probably by the distribution of lower salinity water about the Gulf by currents. However, over the shoal areas such as Georges Bank intense tidal mixing obliterates the stratification observed elsewhere.

At 100 meters and in deeper water salinity tends to increase from west to east. Bigelow (1927) showed a tongue of saltier water entering the eastern channel, then extending toward the Bay of Fundy (Figure 3-93). Perhaps some of this water entered the Bay. The gradient from west to east persisted at 150 m. Within the deeper basins, 200 m to 250 m, salinity usually varied from 34 to 34.5 ^{o}/oo.

The variation in salinity between basins may be related to differences between sill depths of the basins and the underflow of Slope Water entering the Gulf of Maine from the Northeast Channel. This relation is shown by Emery and Uchupi (1972) for a southern series of basins extending from the Northeast Channel. Salinity in Georges Basin (Figure 3-94) is higher than that in the more southern basins which also have shallower sills. The authors postulate a flow of Slope Water from basin to basin, the direction of flow depending upon progressively shallower sill depths in a landward direction (Figure 3-95). Only a small portion of the flow of the Labrador Current enters the Gulf as it passes southward along the

Scotian shelf. This flow is in the spring and summer (Bigelow, 1927). The river runoff to the Gulf is a minor contribution of 0.003 million cubic meters per second. Bigelow states the major source is an under flow from the Slope Water derived from Gulf Stream water mixing with shelf water resulting in salinities of about 34 $^{o}/oo$.

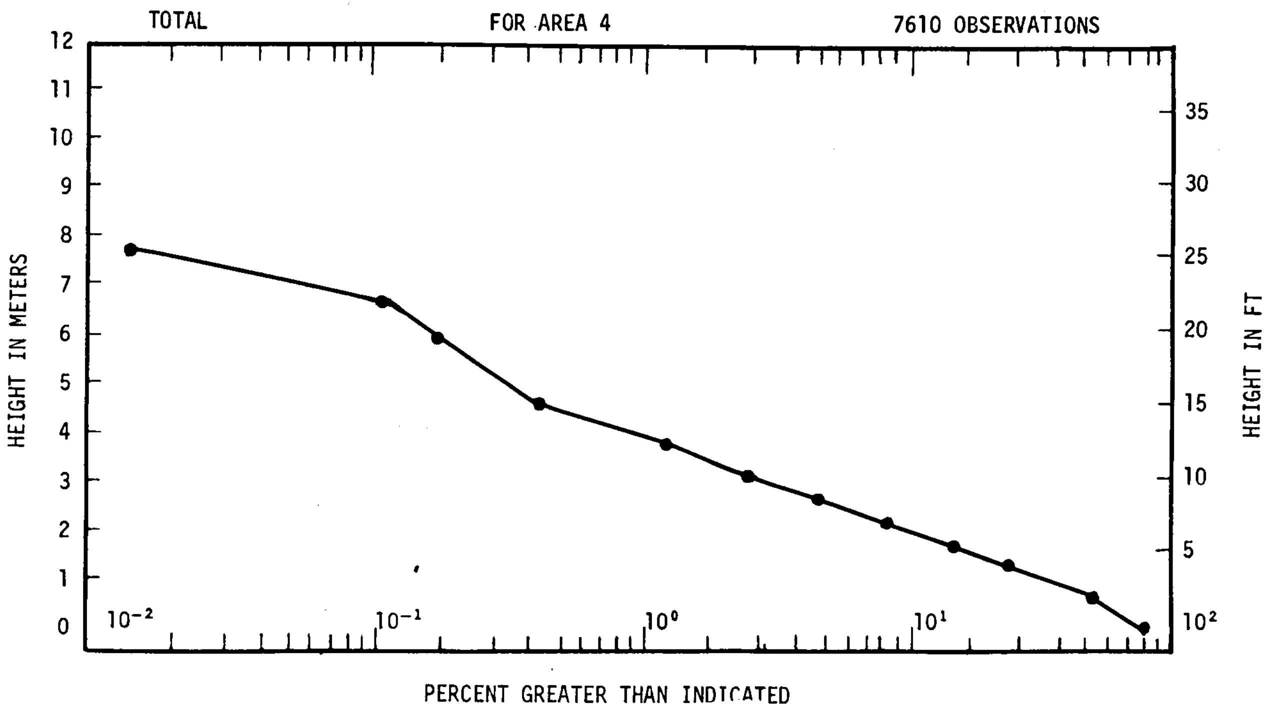


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-33

Orientation Chart of Gulf of Maine
(Colton, 1964)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-34

Wave Height Distribution Function
(Thompson and Harris, 1972)

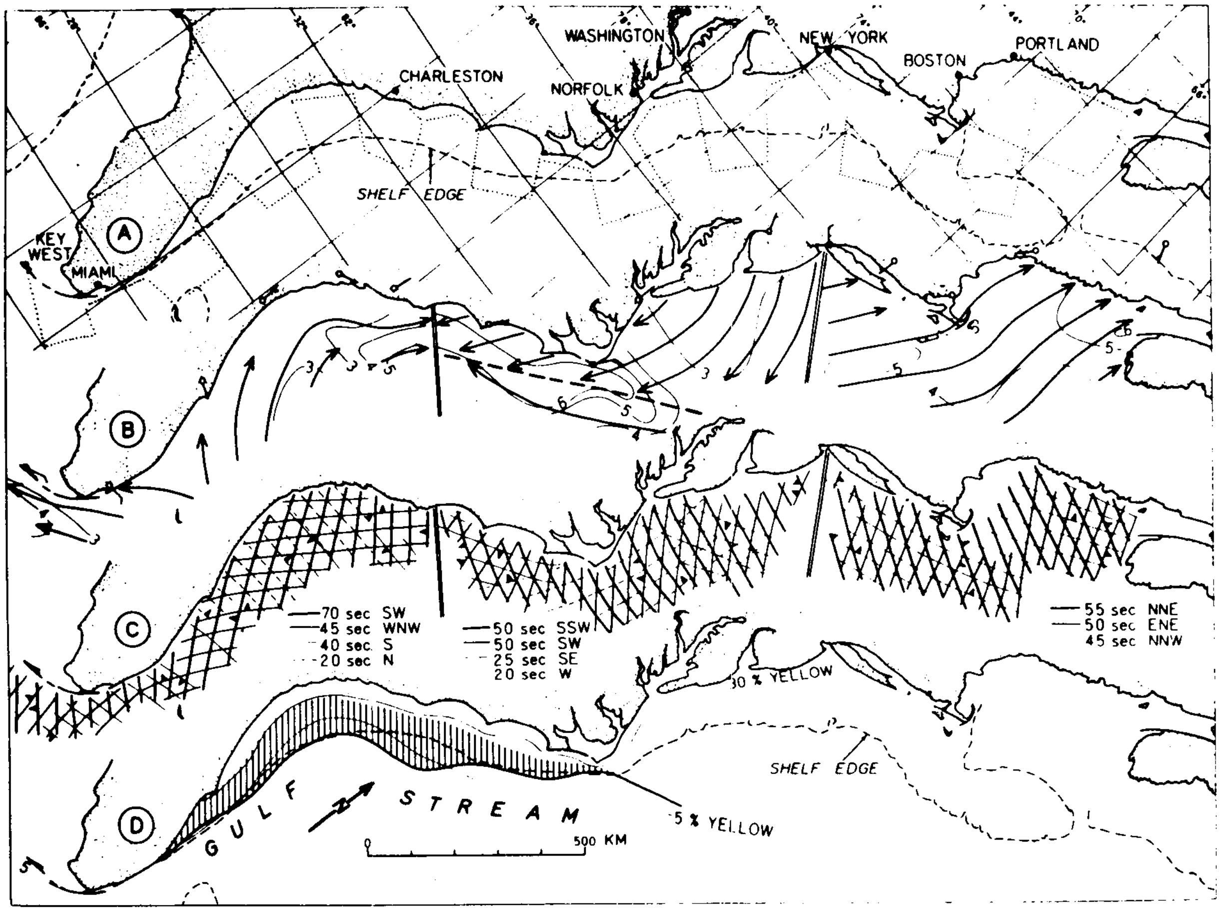


FIGURE 3-35a Wave Patterns and Winds - Dec. 17-20, 1964 & July 19-21, 1965 (Emery, 1965 & Uchupi, 1972)

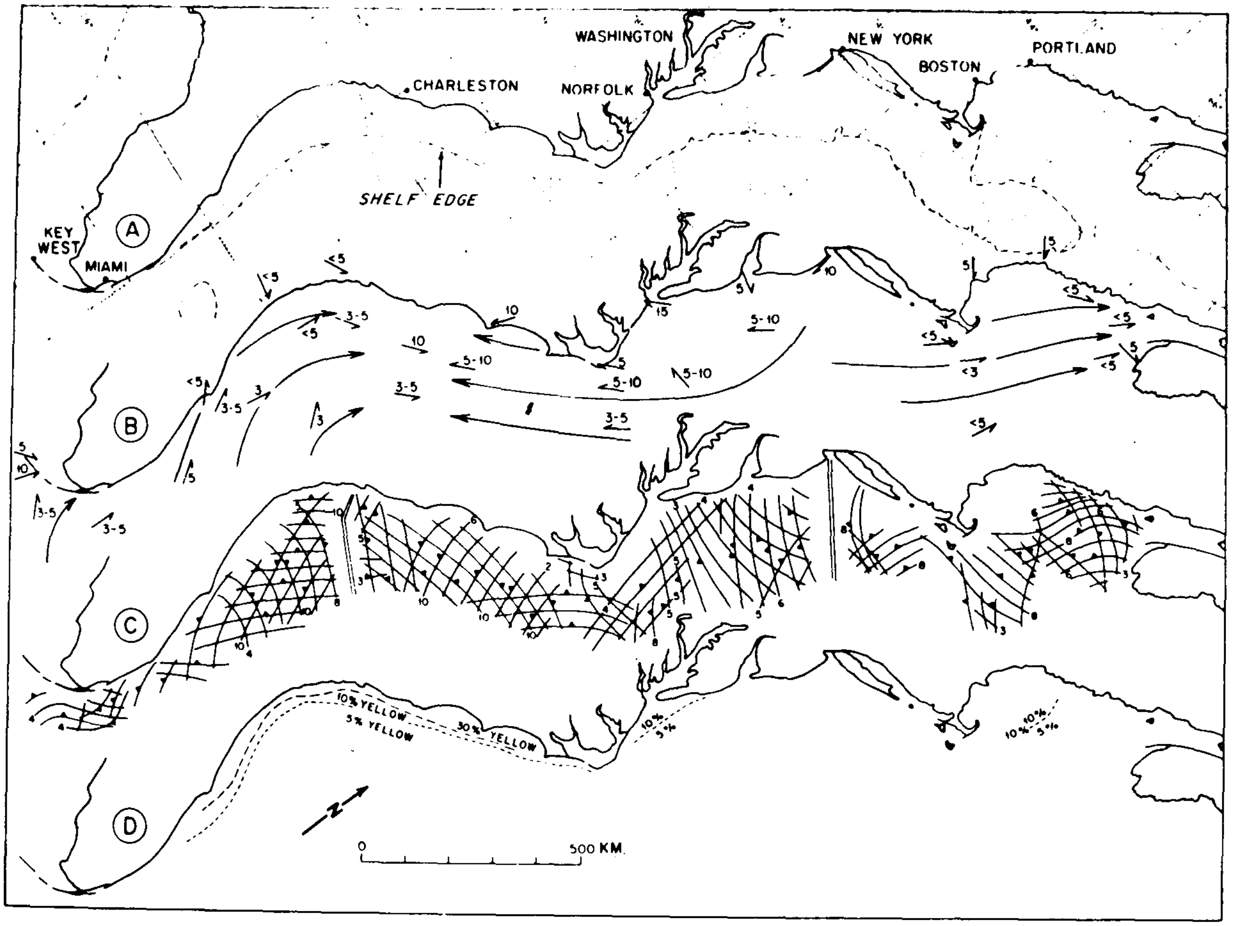


FIGURE 3-35b Wave Patterns and Winds - Dec. 17-20, 1964 & July 19-21, 1965 (Emery, 1965 & Uchupi, 1972)

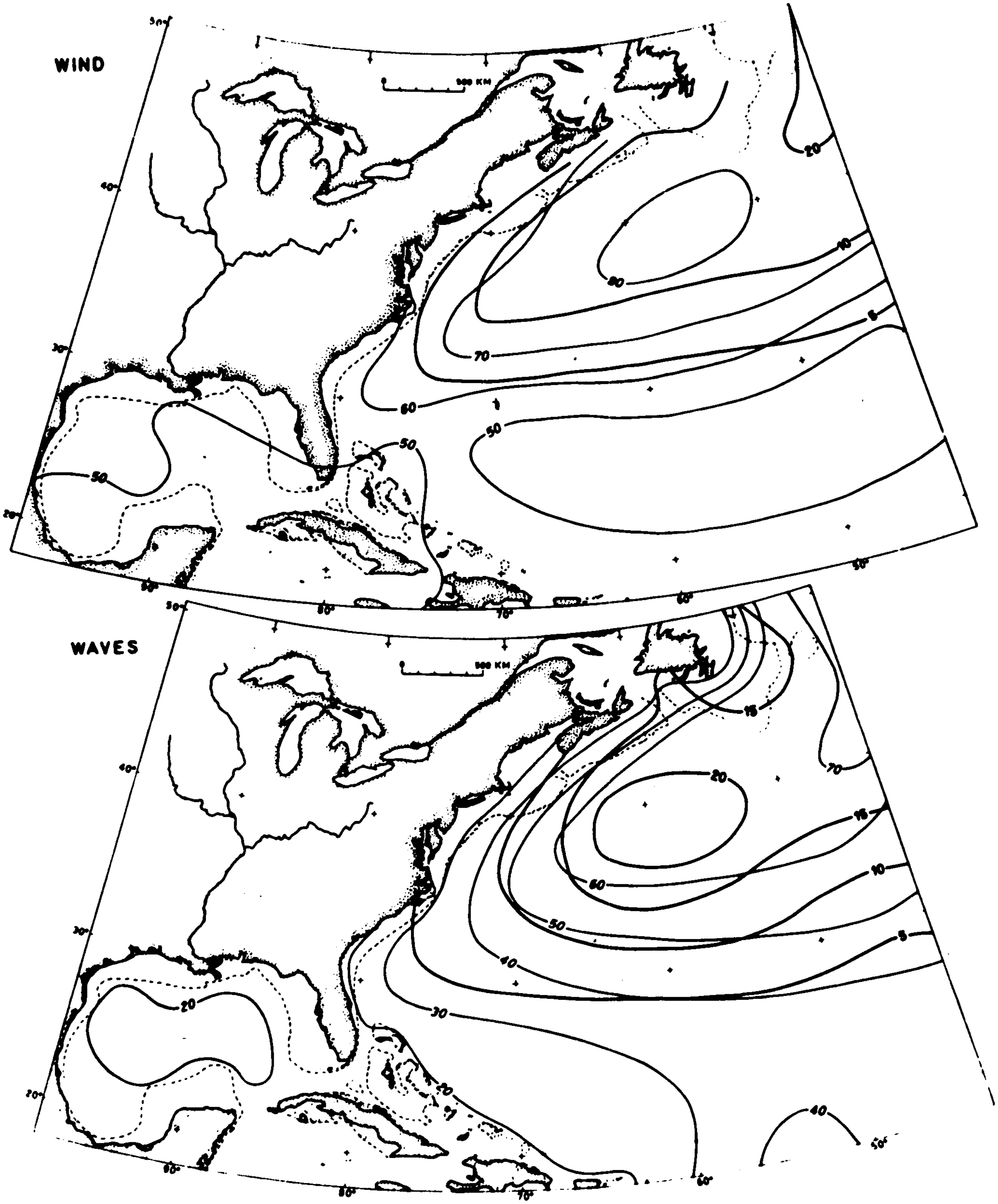
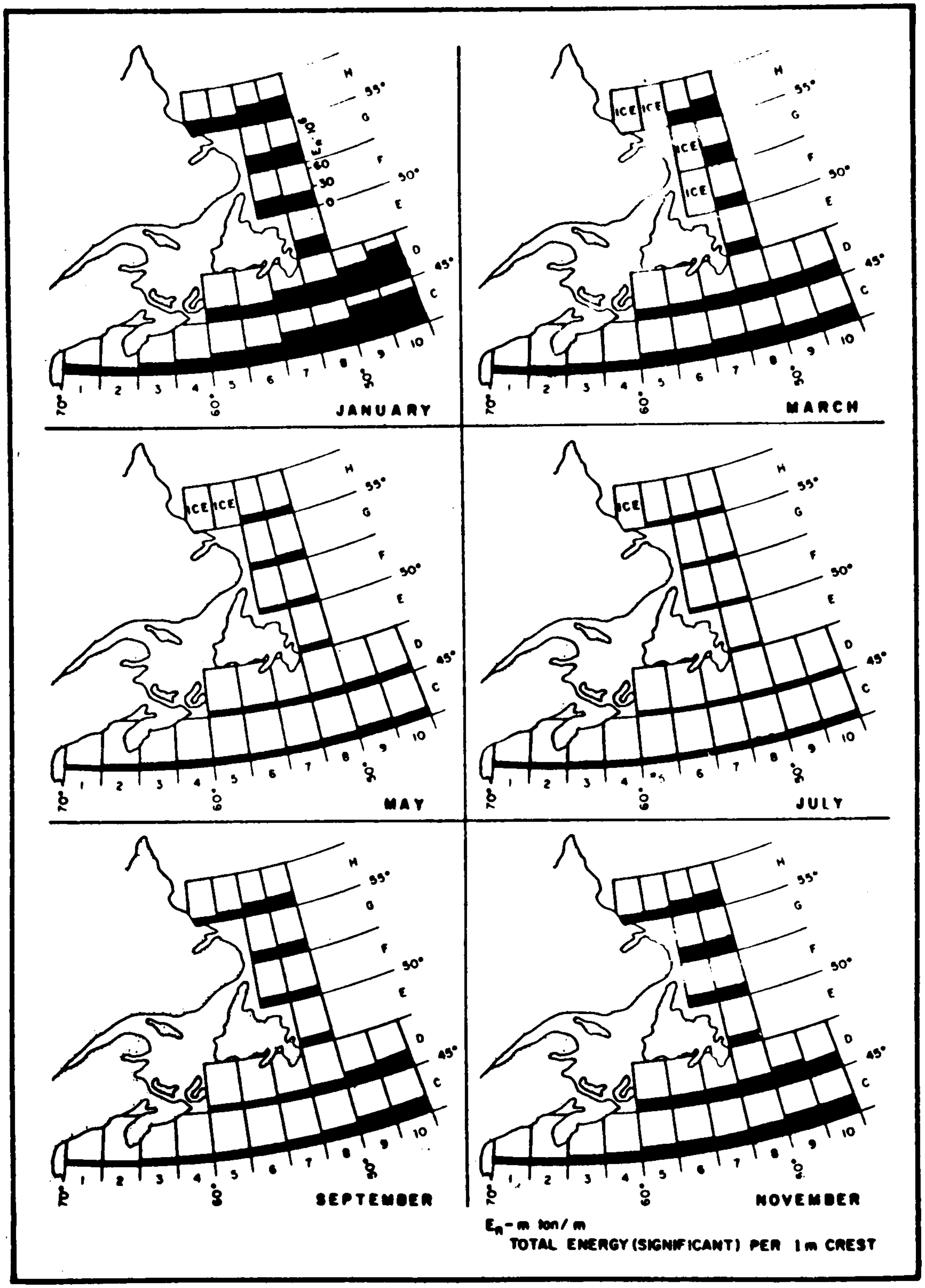


FIGURE 3-36 Average Winter Winds and Waves (Emery and Uchupi, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-37a

Bimonthly Nondirectional Wave Energy Spectra (Neu, 1972)

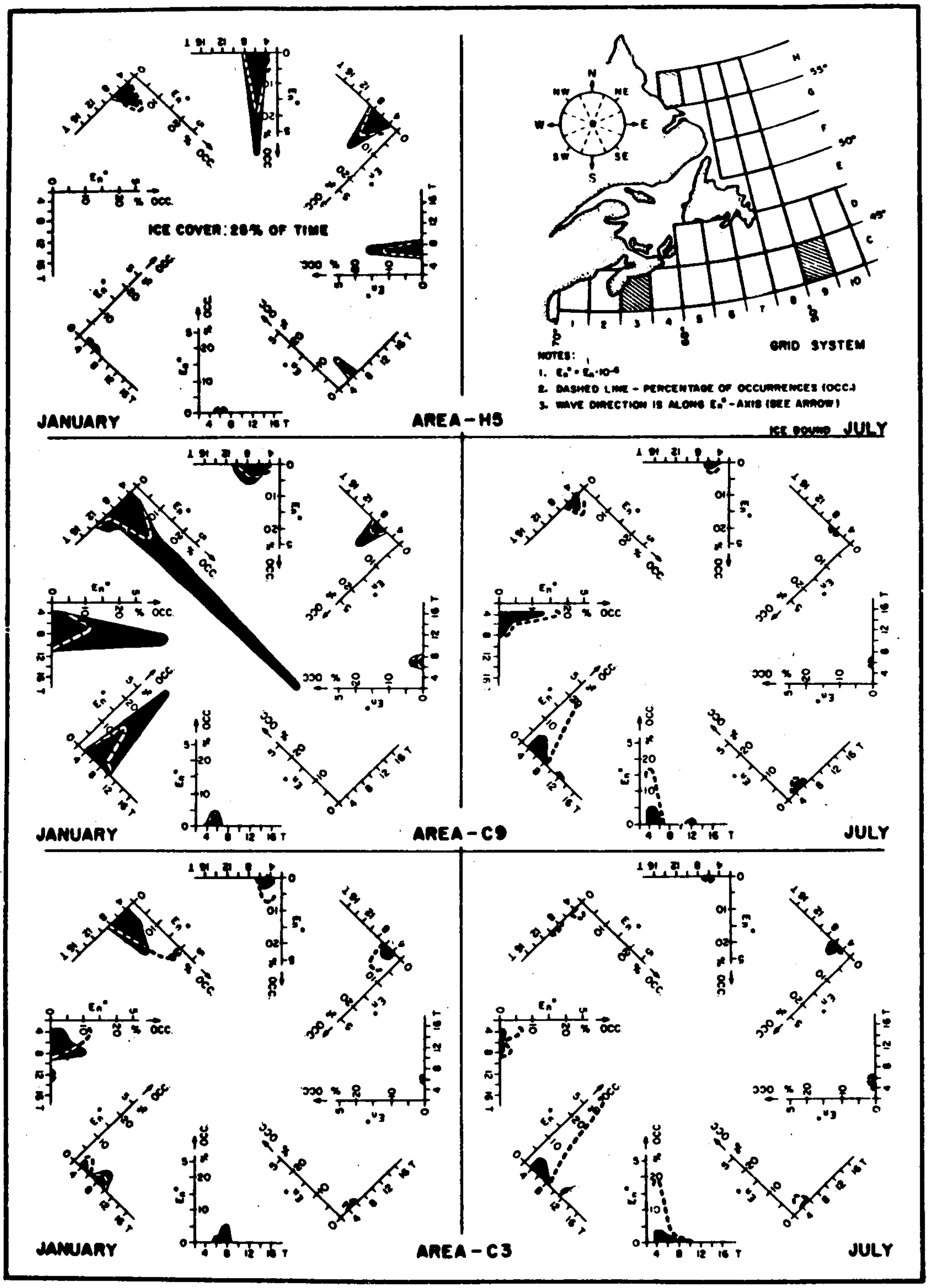
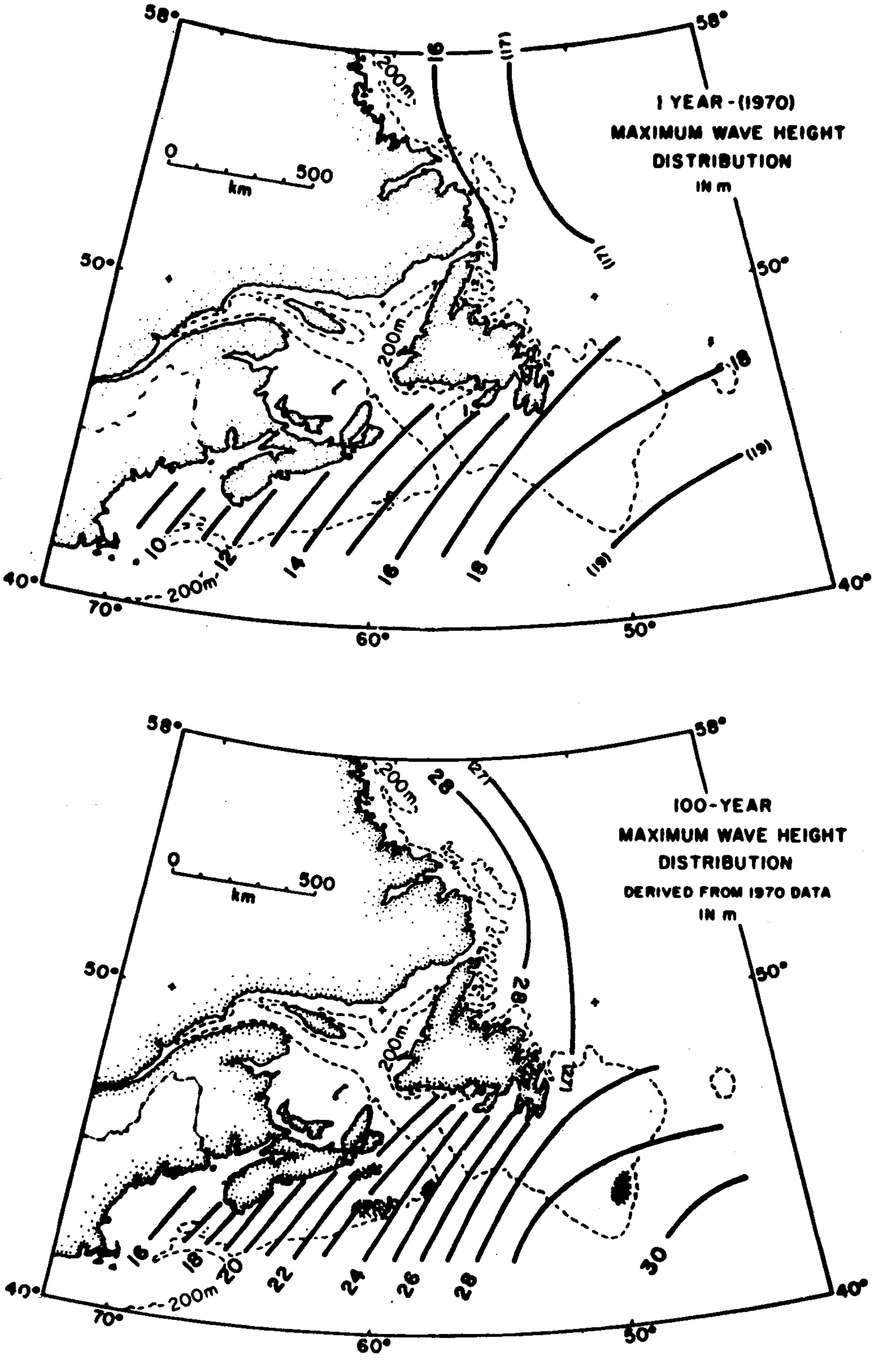


FIGURE 3-37b Samples of Monthly Directional Energy Spectra (Neu, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-37c

One Year Maximum Wave Height and 100 Year Design Wave Distribution (Neu, 1972)

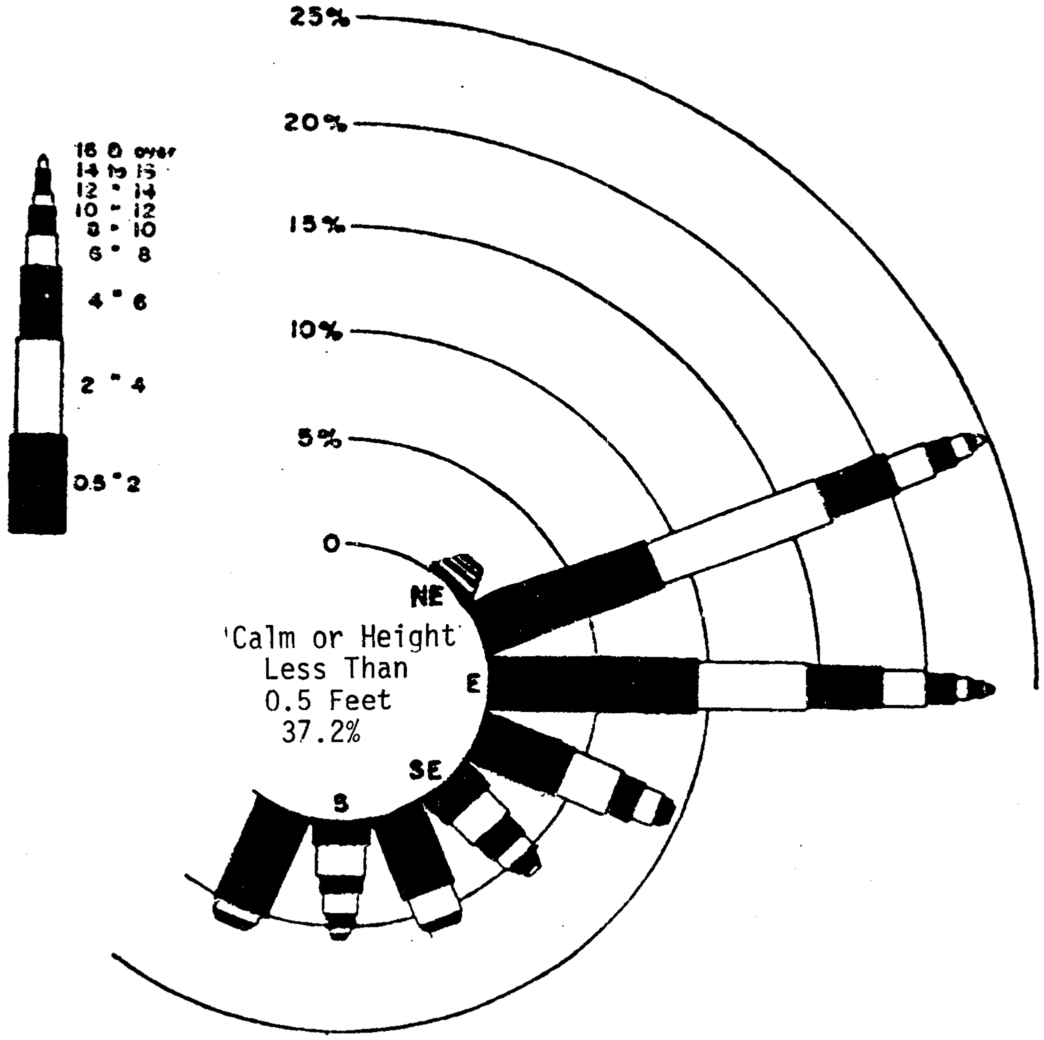


FIGURE 3-38 Wave Diagram Off Penobscot Bay, Maine

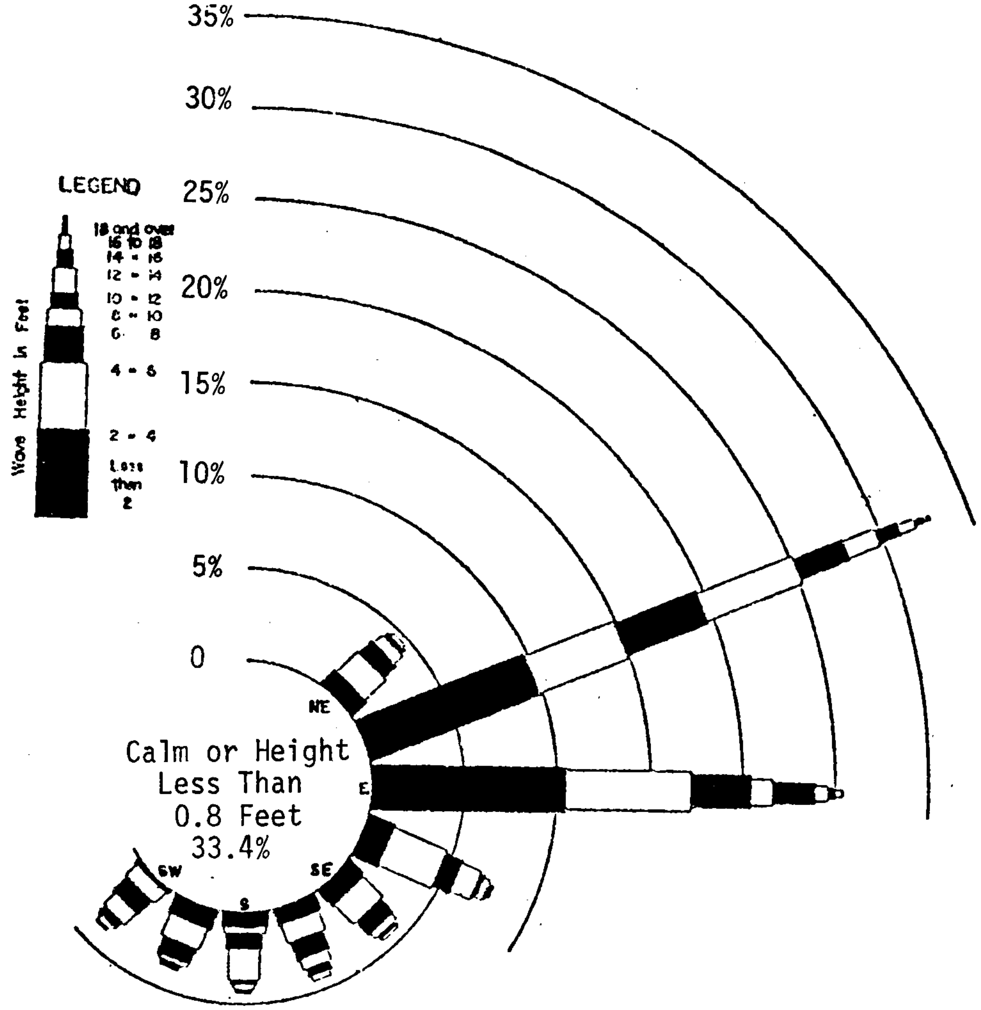
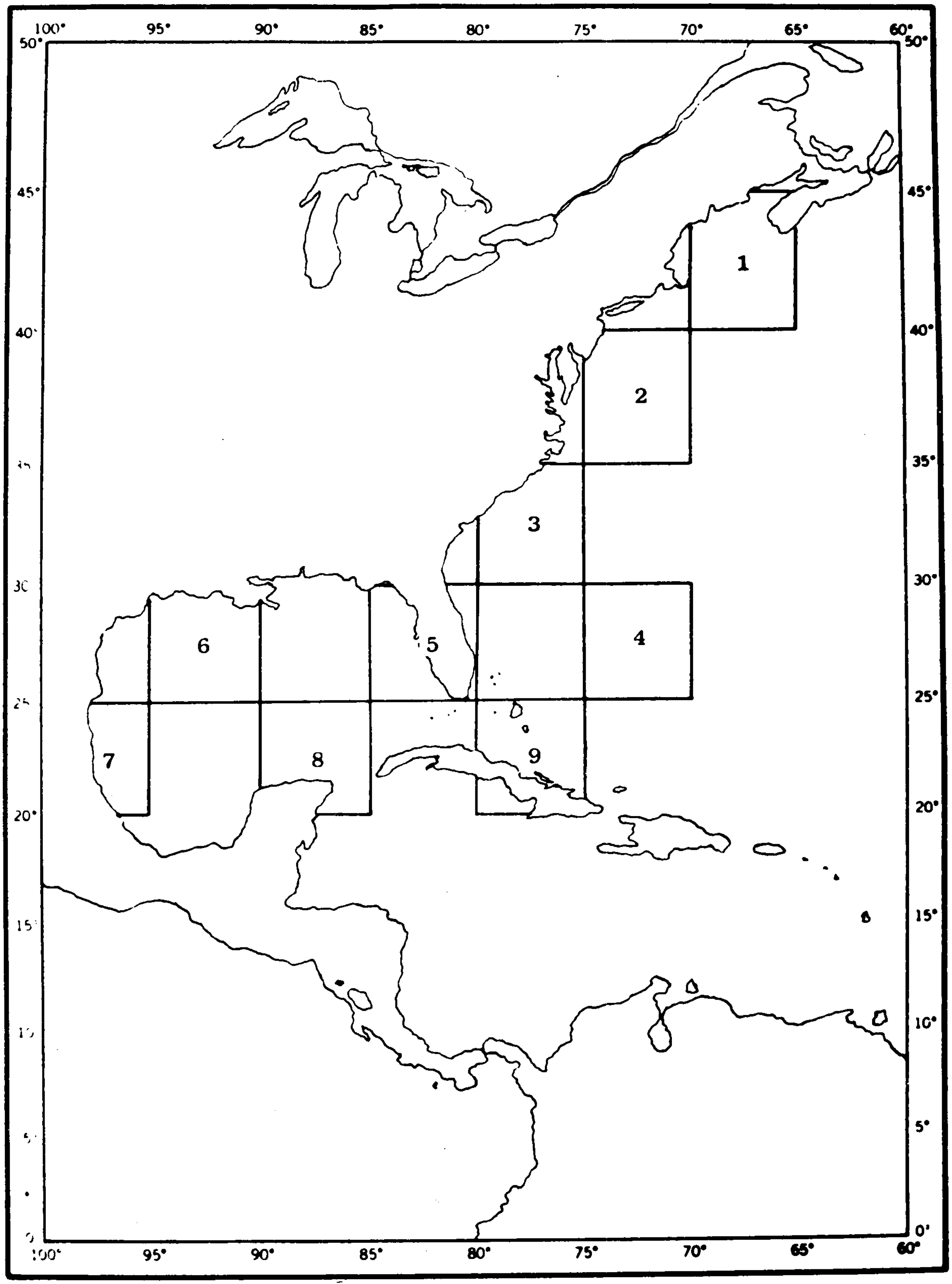


FIGURE 3-39 Wave Diagram Off Nauset Beach, Cape Cod



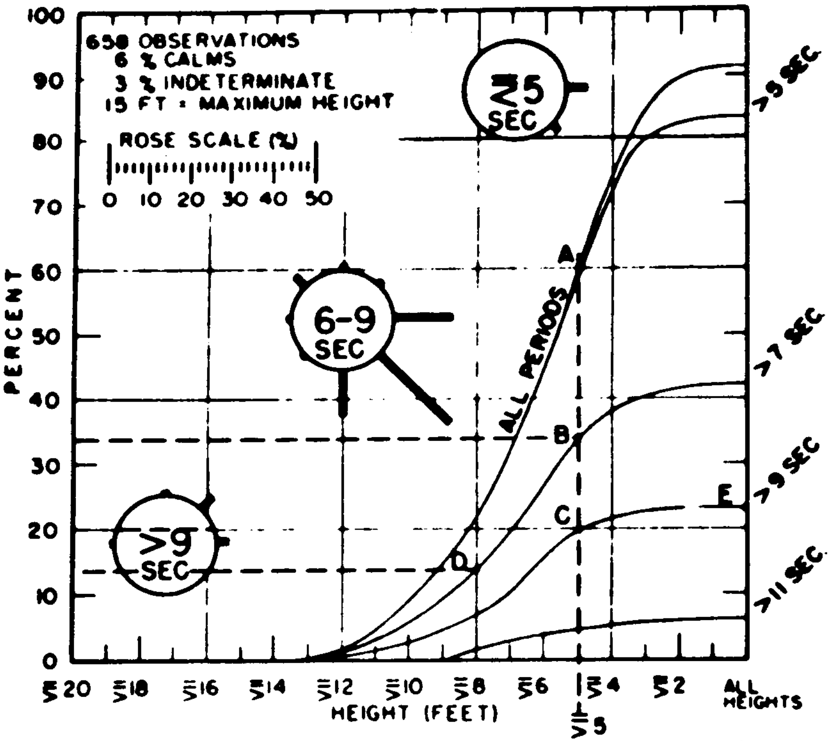
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-40

Location Chart for Wave Period-Height and Period-Directional Graphs. (U.S. Dept. of Commerce, 1973)

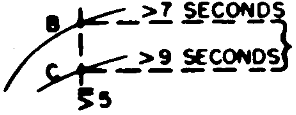
LEGEND



A POINT ON THE GRAPH SHOWS THE PERCENTAGE OF ALL WAVES OBSERVED WITH PERIODS EXCEEDING, AND HEIGHTS EQUAL TO OR EXCEEDING, CERTAIN VALUES

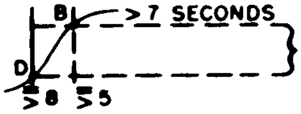
POINT A 60 % OF ALL WAVES WERE ≥5 FEET
" B 34 % OF ALL WAVES WERE >7 SECONDS, ≥5 FEET
" E 23 % OF ALL WAVES WERE >9 SECONDS

AN INTERVAL BETWEEN TWO POINTS OF THE SAME HEIGHT CATEGORY SHOWS THE PERCENTAGE OF ALL WAVES OF THAT HEIGHT CATEGORY WITHIN A CERTAIN RANGE OF PERIODS



14 % OF ALL WAVES WERE 7-9 SECONDS, ≥5 FEET

AN INTERVAL BETWEEN TWO POINTS ON THE SAME PERIOD CURVE SHOWS THE PERCENTAGE OF ALL WAVES REPRESENTED BY THE CURVE WITHIN A CERTAIN RANGE OF HEIGHTS



20% OF ALL WAVES WERE 5-8 FEET, >7 SECONDS

AN ARM OF A ROSE INDICATES THE PERCENTAGE OF ALL OBSERVATIONS WHICH ARE IN THE GIVEN PERIOD-DIRECTION CATEGORY

25% OF ALL WAVES OBSERVED HAD PERIODS OF 6-9 SECONDS AND CAME FROM THE SOUTHEAST

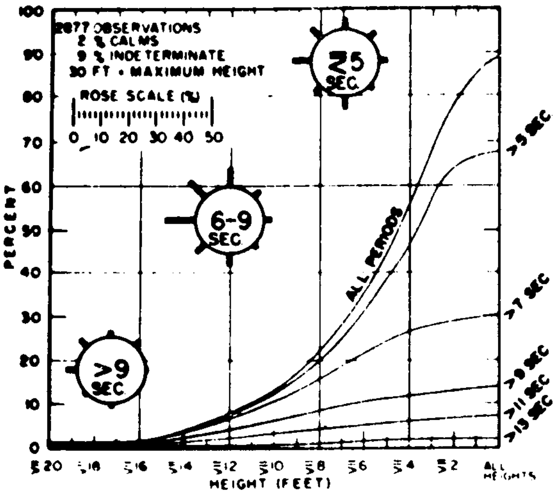
15% OF ALL WAVES OBSERVED CAME FROM THE SOUTH. 12% OF THESE WAVES HAD PERIODS OF 6-9 SECONDS AND 3% HAD PERIODS >9 SECONDS.

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

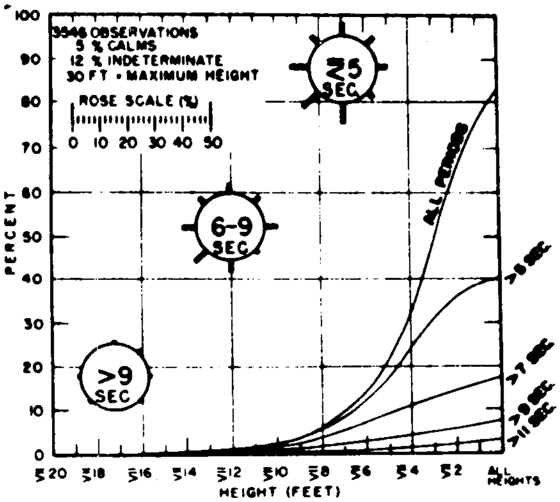
TRIGOM PARC

FIGURE 3-41

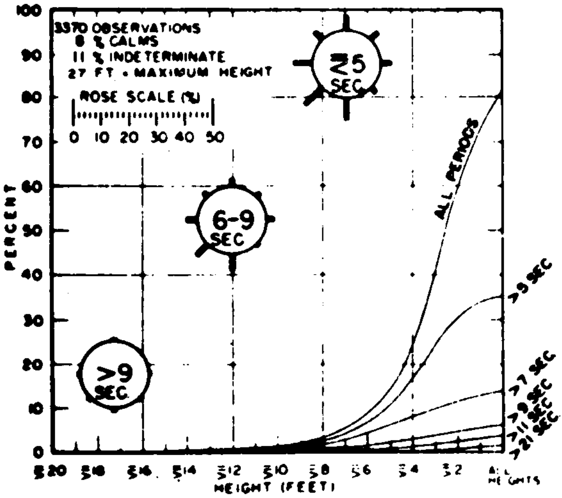
Legend for Period-Height and Period-Directional Graphs (U.S. Dept. of Commerce, 1973)



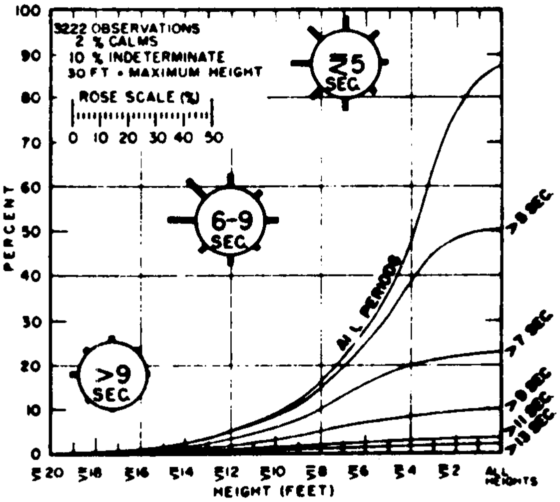
WINTER
(JAN. FEB. MAR.)



SPRING
(APR. MAY JUN.)



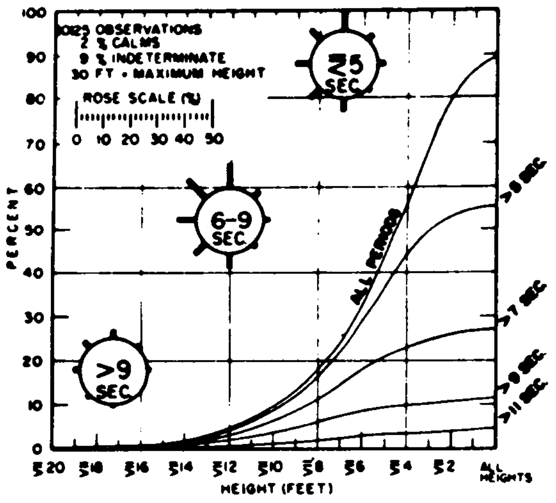
SUMMER
(JUL. AUG. SEP.)



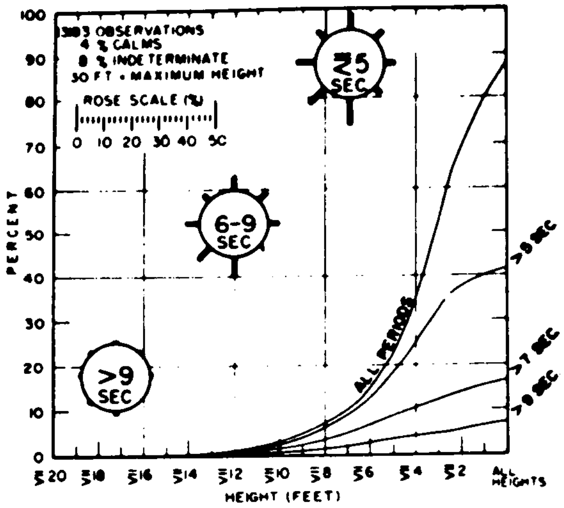
AUTUMN
(OCT. NOV. DEC.)

FIGURE 3-42

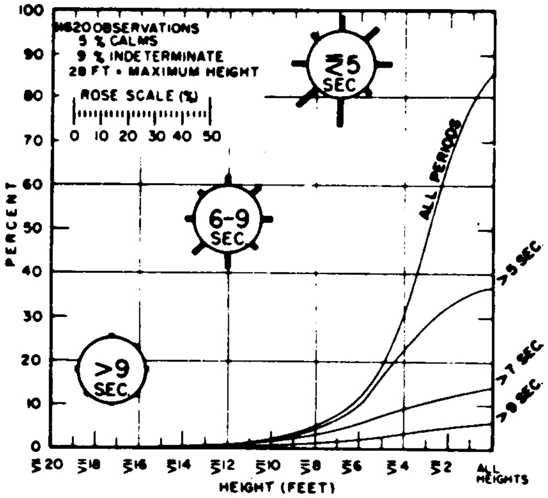
Wave Period-Height and Period Direction Graph Area 1 (U.S. Dept. of Commerce, 1973)



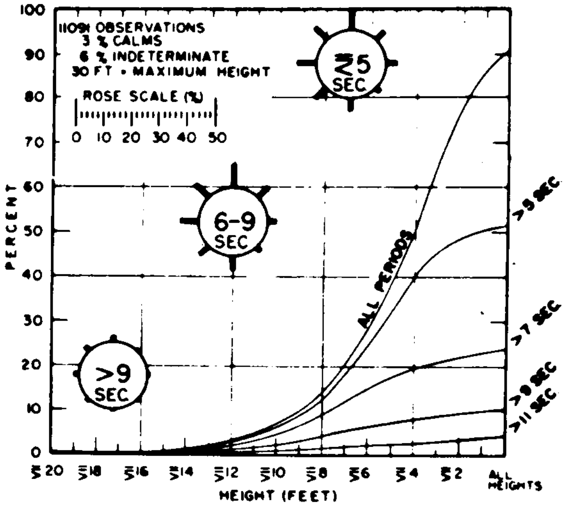
WINTER
(JAN. FEB. MAR.)



SPRING
(APR. MAY JUN.)



SUMMER
(JUL. AUG. SEP.)



AUTUMN
(OCT. NOV. DEC.)

FIGURE 3-43

Wave Period-Height and Period Direction Graph Area 2 (U.S. Dept. of Commerce, 1973)

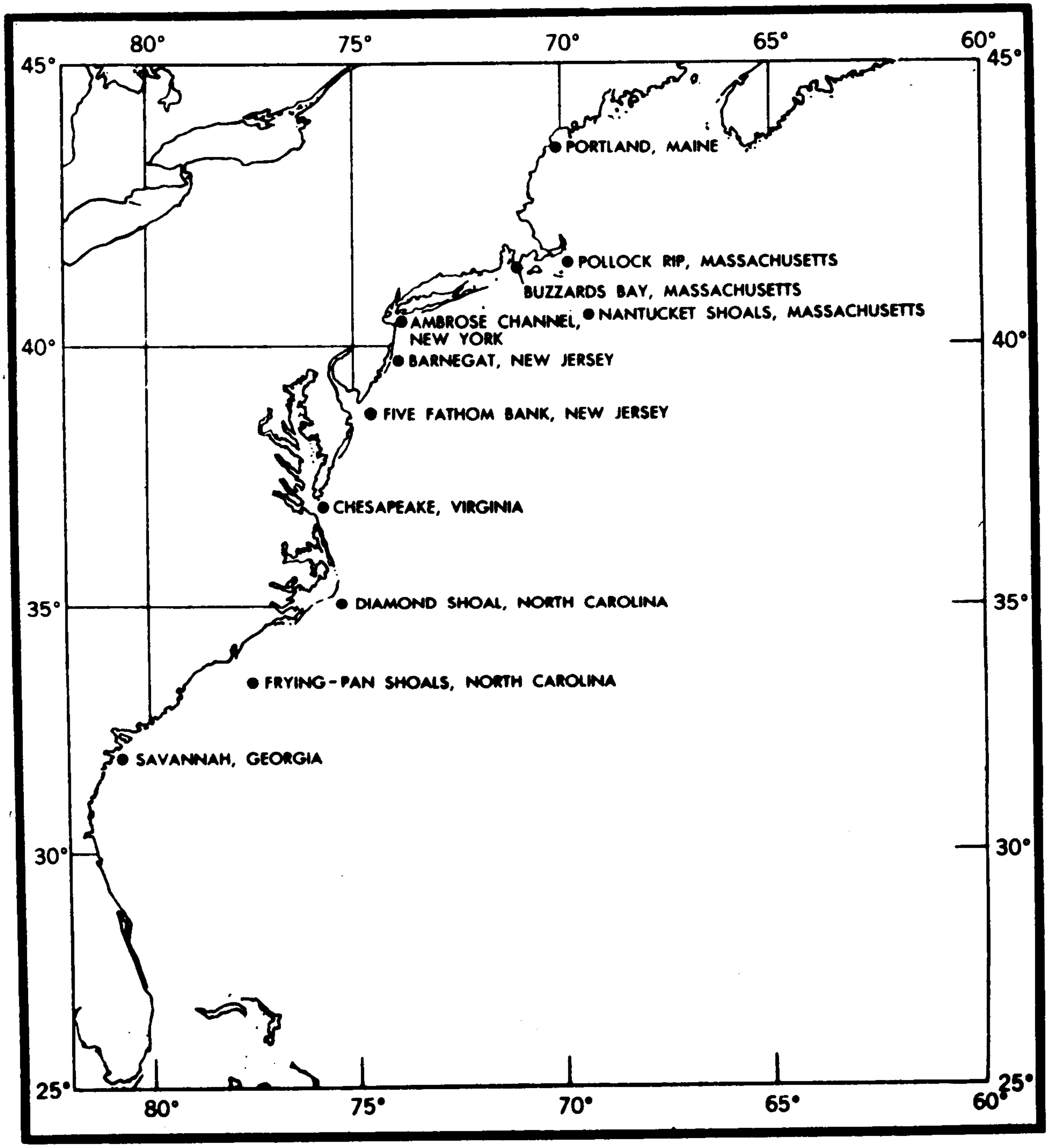
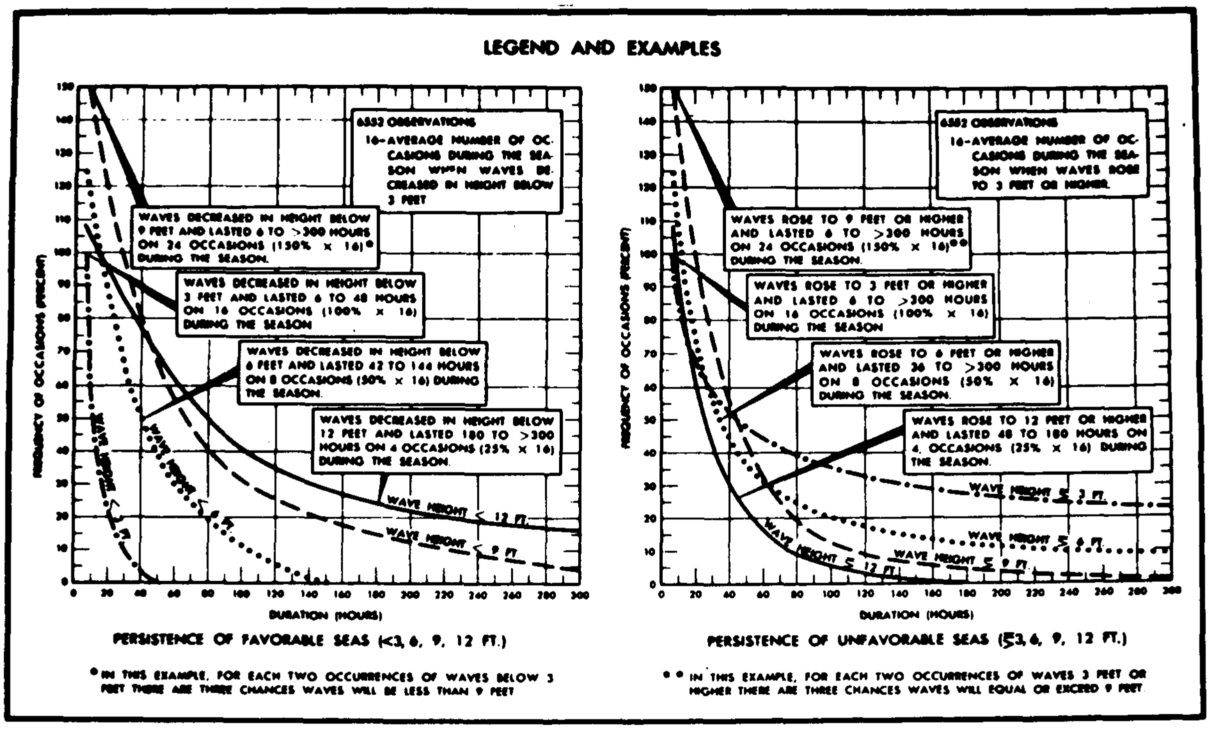
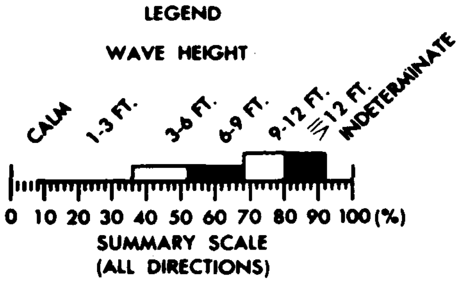


FIGURE 3-44 East Coast Lightships (U.S. Dept. of Commerce, 1973)





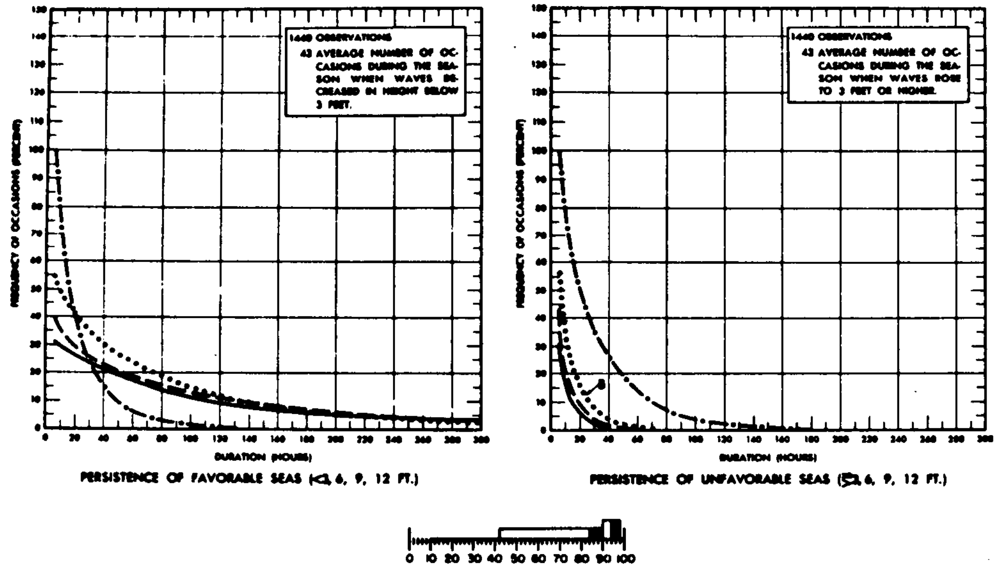
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM
PARC

FIGURE
3-45

Persistence of Favorable and Unfavorable Seas at East Coast Lightships (U.S. Dept. of Commerce, 1973)

JANUARY, FEBRUARY, MARCH



APRIL, MAY, JUNE

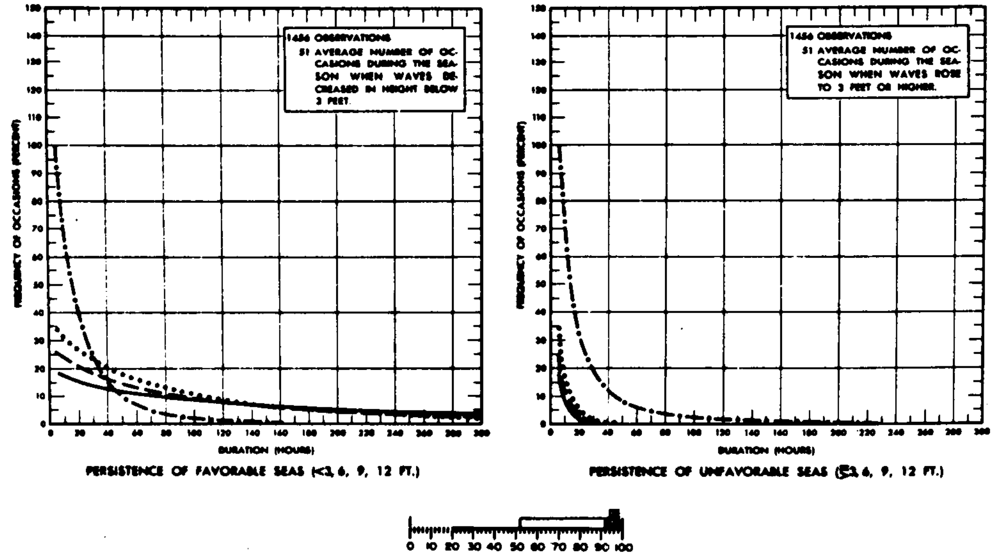
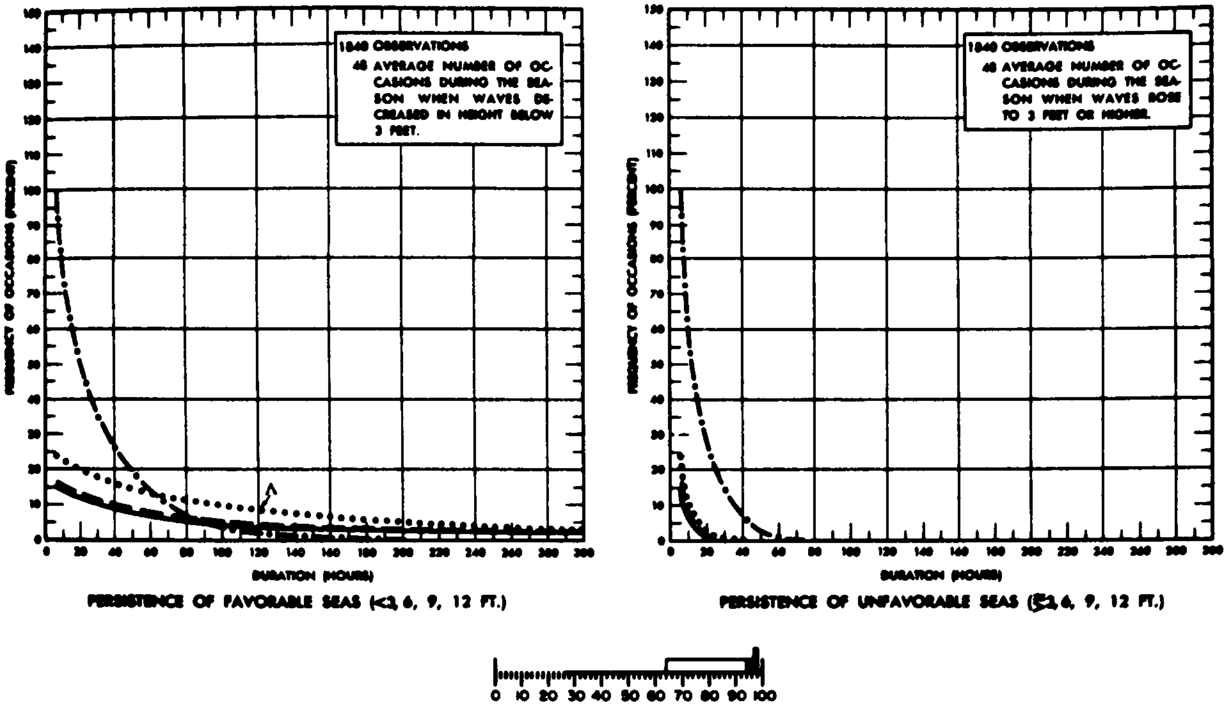


FIGURE 3-46 Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Portland, Maine (U. S. Dept. of Commerce, 1973)

JULY, AUGUST, SEPTEMBER



OCTOBER, NOVEMBER, DECEMBER

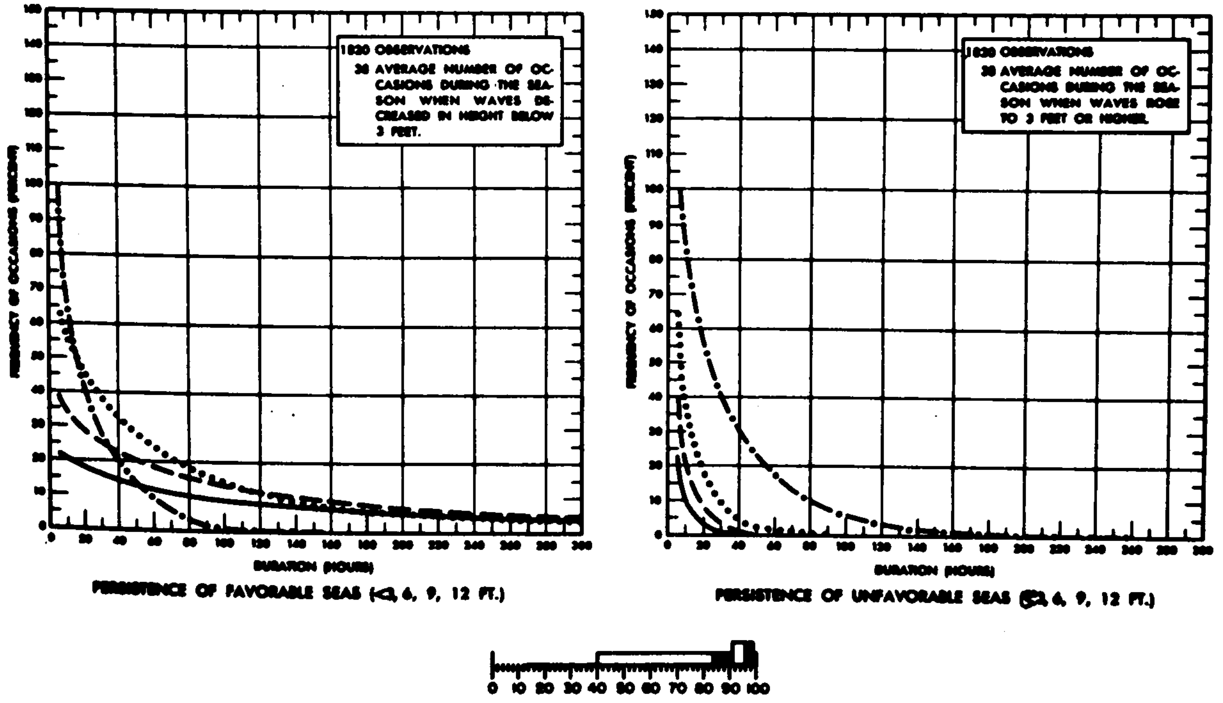
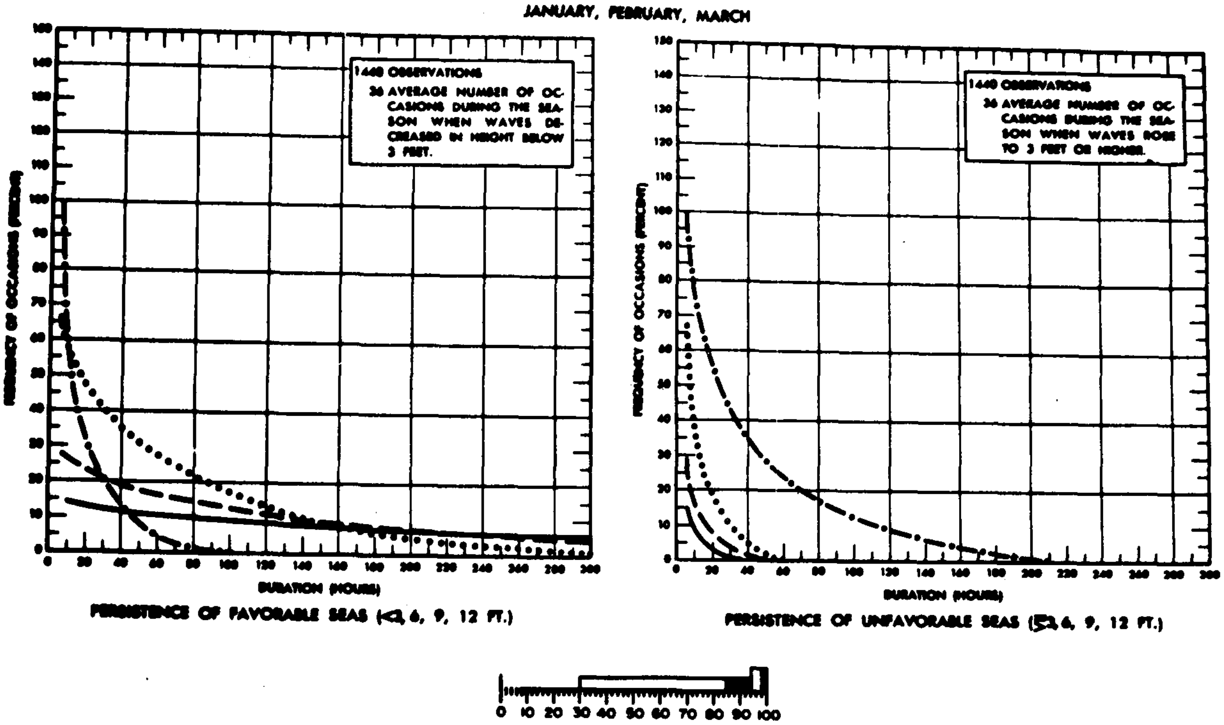


FIGURE 3-46b Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Portland, Maine (U.S. Dept. of Commerce, 1973)

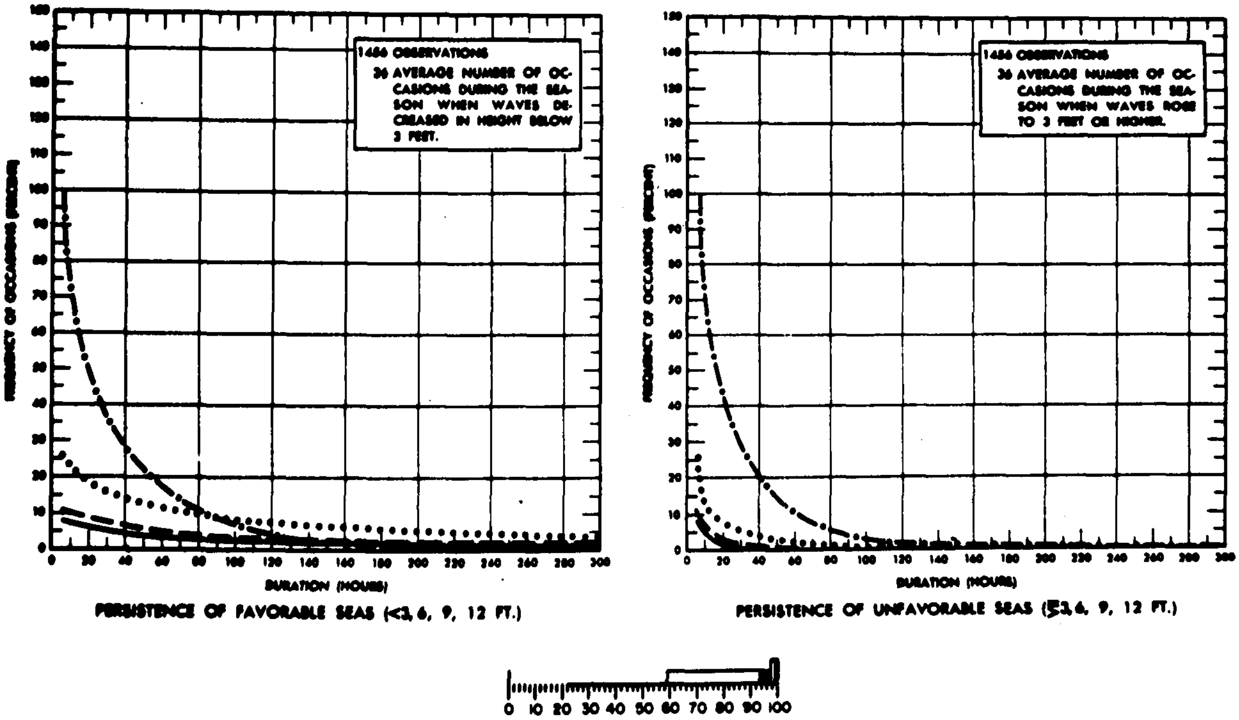
JANUARY, FEBRUARY, MARCH



PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE SEAS (≥3, 6, 9, 12 FT.)

APRIL, MAY, JUNE



PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

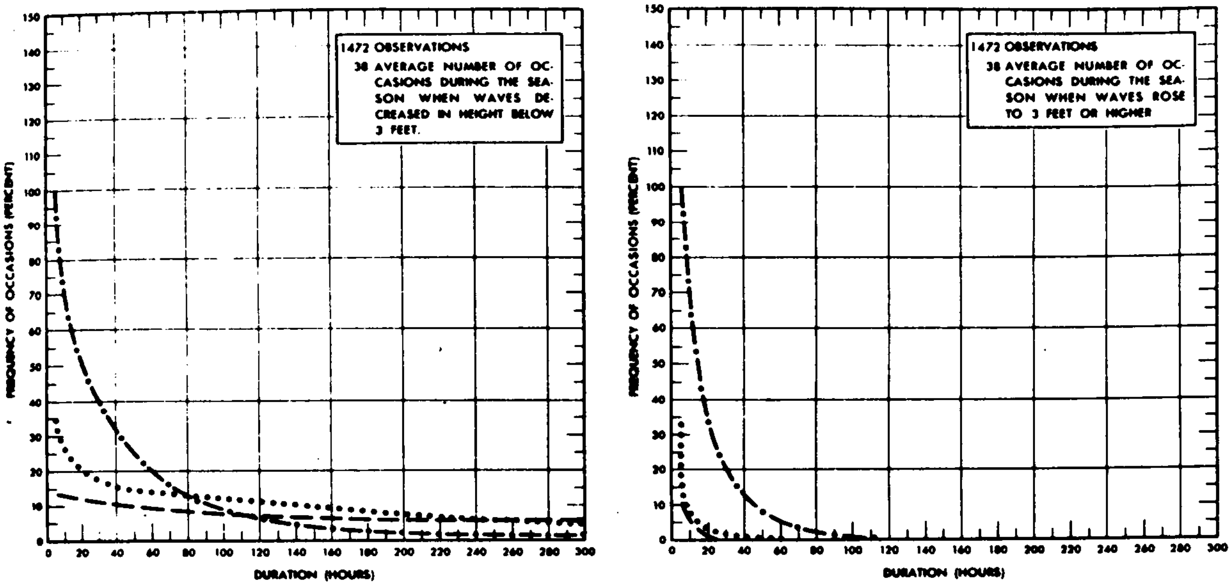
PERSISTENCE OF UNFAVORABLE SEAS (≥3, 6, 9, 12 FT.)

POLLOCK RIP, MASS. 41°36.1'N., 69°51.1'W.

FIGURE 3-47a

Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Pollock Rip, Mass. (U.S. Dept. of Commerce, 1973)

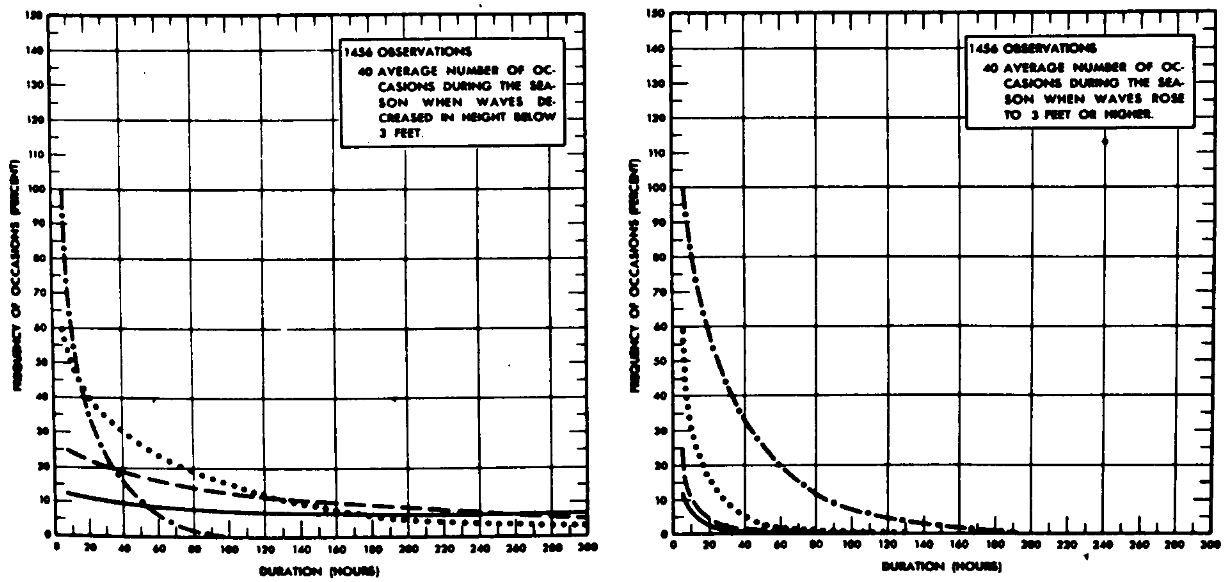
JULY, AUGUST, SEPTEMBER



PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE SEAS (≧3, 6, 9, 12 FT.)

OCTOBER, NOVEMBER, DECEMBER



PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE SEAS (≧3, 6, 9, 12 FT.)

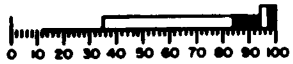
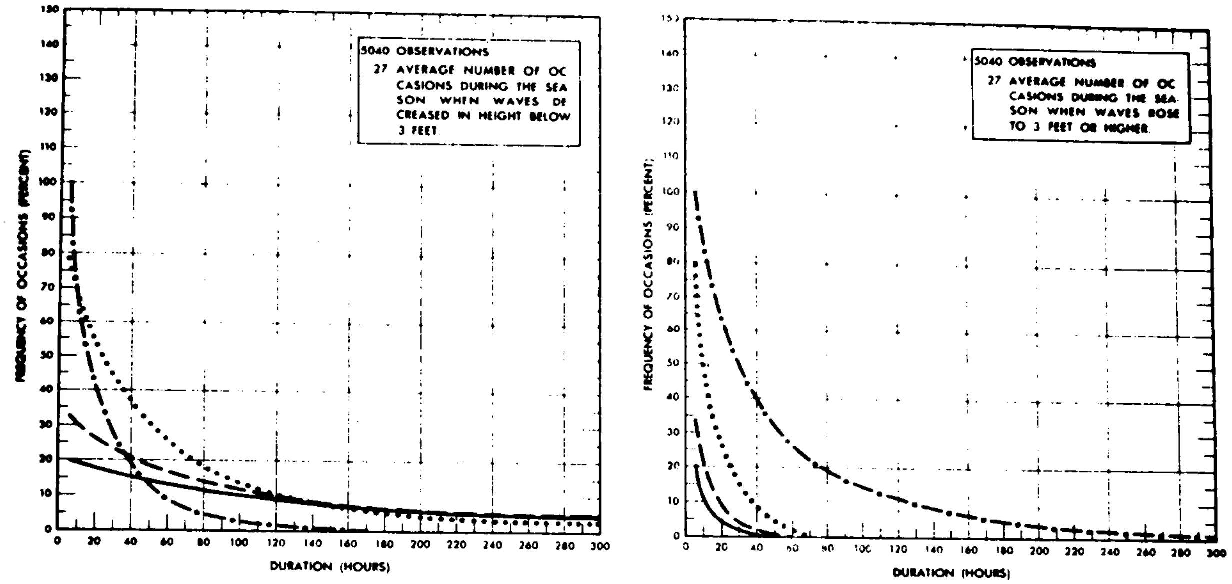


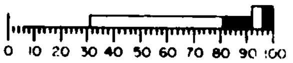
FIGURE 3-47b Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Pollock Rip, Mass. (U.S. Dept. of Commerce, 1973)

JANUARY, FEBRUARY, MARCH

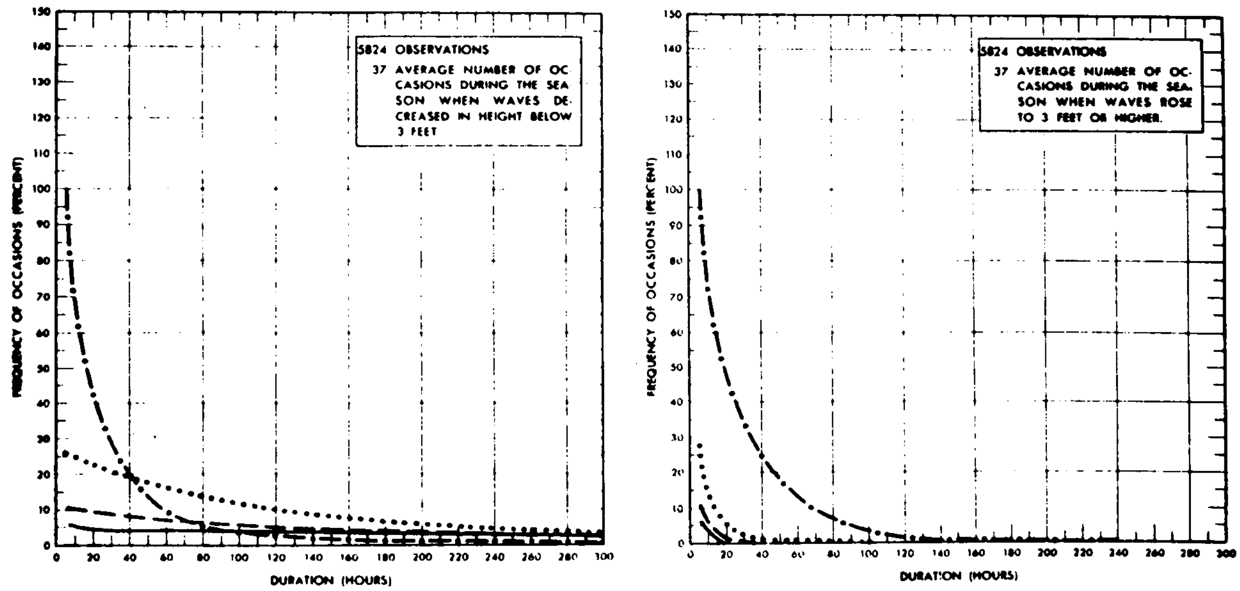


PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE WAVES (≧3,6, 9, 12 FT.)

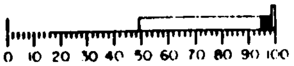


APRIL, MAY, JUNE



PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)

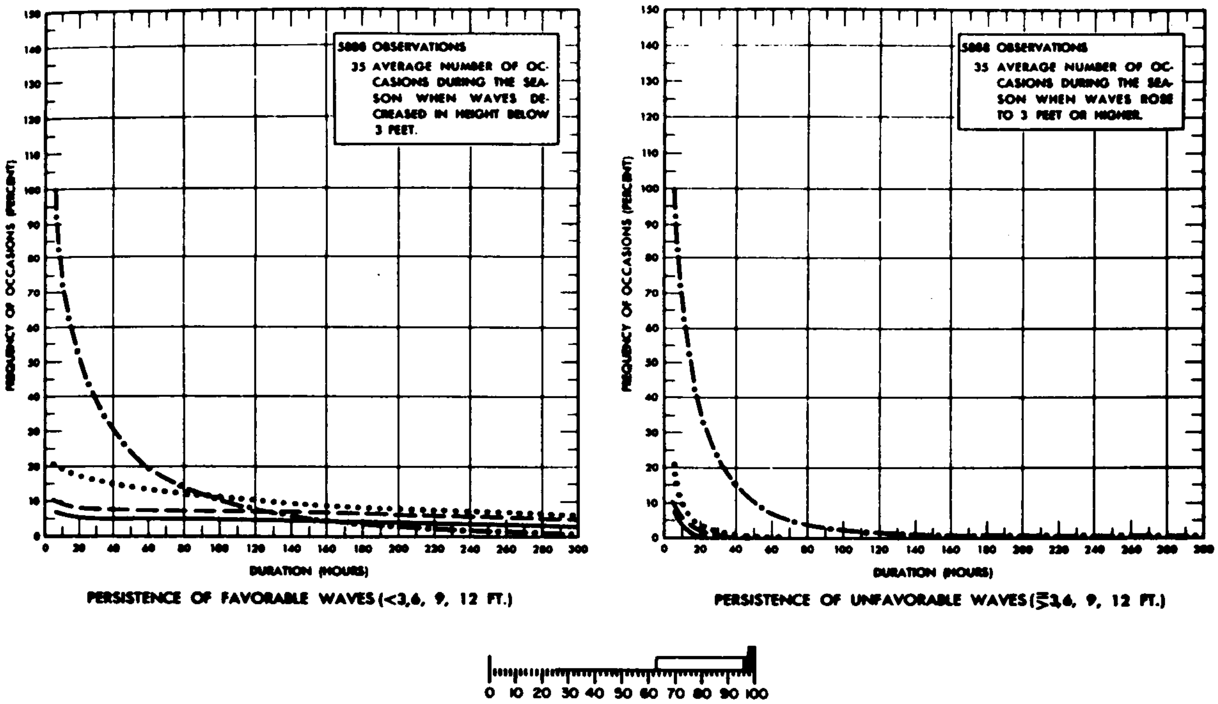
PERSISTENCE OF UNFAVORABLE WAVES (≧3,6, 9, 12 FT.)



NANTUCKET SHOALS, MASS. 40°37.0'N., 69°18.5'W.

FIGURE 3-48a Persistence of Favorable and Unfavorable Seas at East Coast Lightship - Nantucket Shoals, Mass. (U.S. Dept. of Commerce, 1973)

JULY, AUGUST, SEPTEMBER



OCTOBER, NOVEMBER, DECEMBER

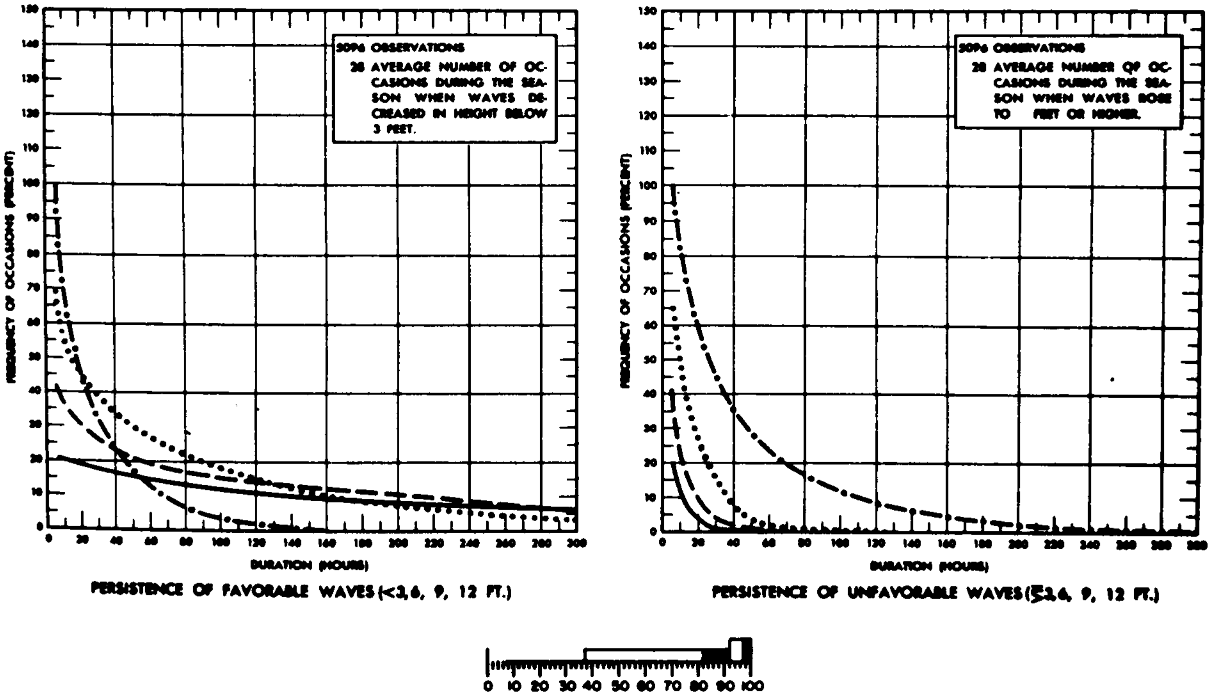
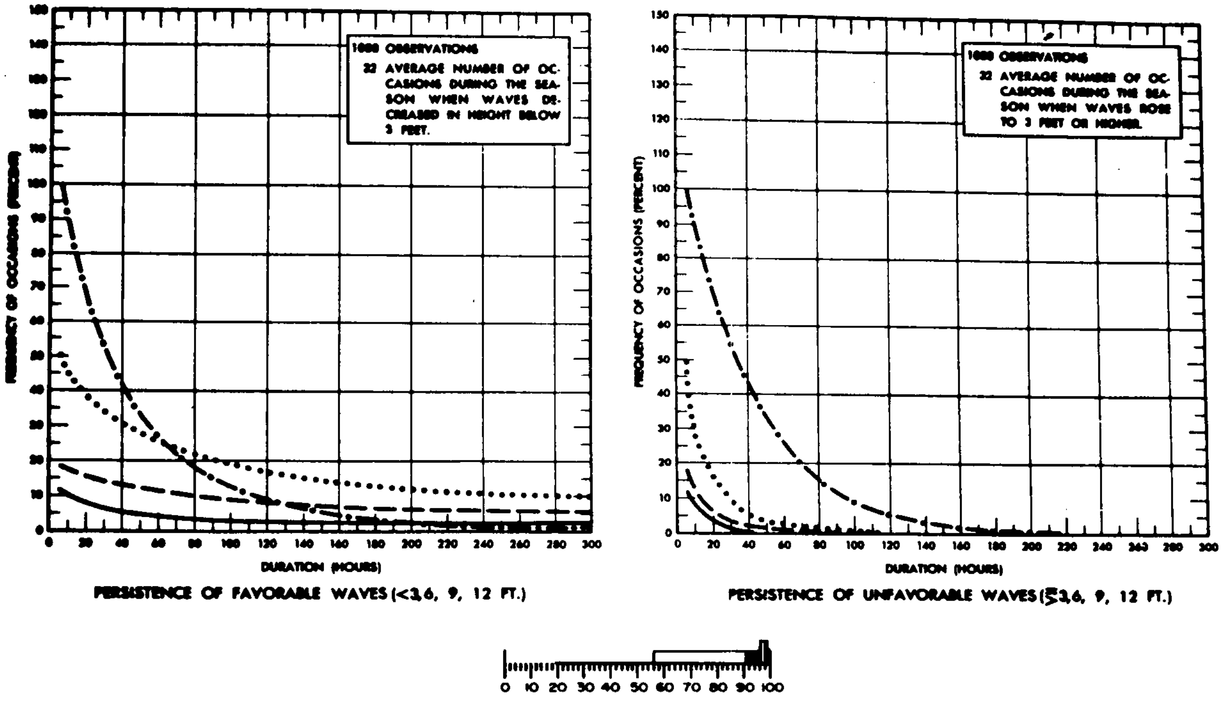


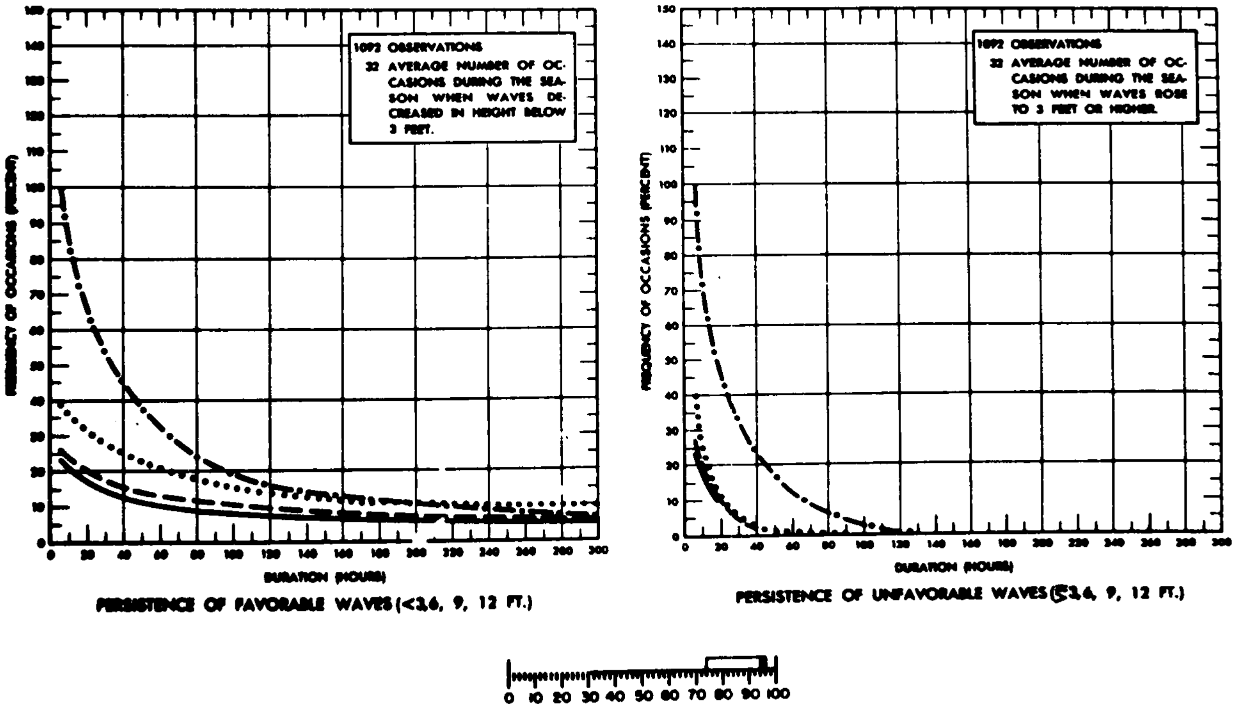
FIGURE 3-48b

Persistence of Favorable and Unfavorable Seas at East Coast Lightship - Nantucket Shoals, Mass. (U.S. Dept. of Commerce, 1973)

JANUARY, FEBRUARY, MARCH



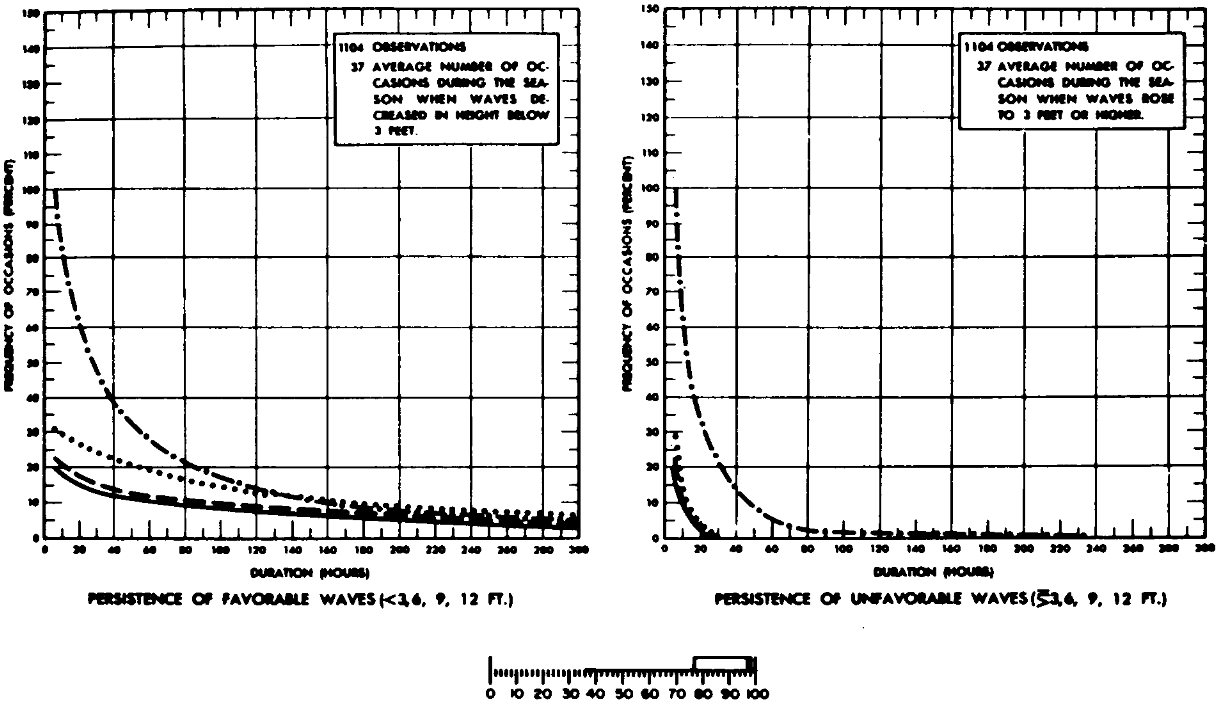
APRIL, MAY, JUNE



BUZZARDS BAY, MASS. 41°24.0'N., 71°3.0'W.

FIGURE 3-49a Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Buzzards Bay, Mass. (U.S. Dept. of Commerce, 1973)

JULY, AUGUST, SEPTEMBER



OCTOBER, NOVEMBER, DECEMBER

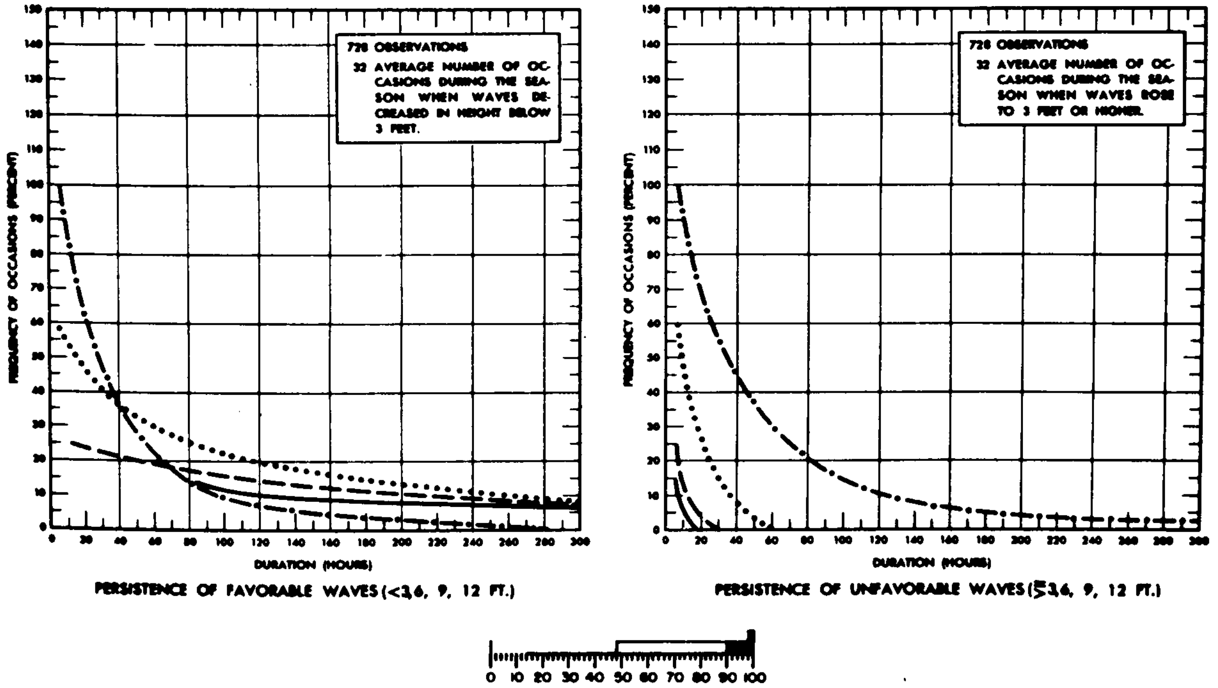
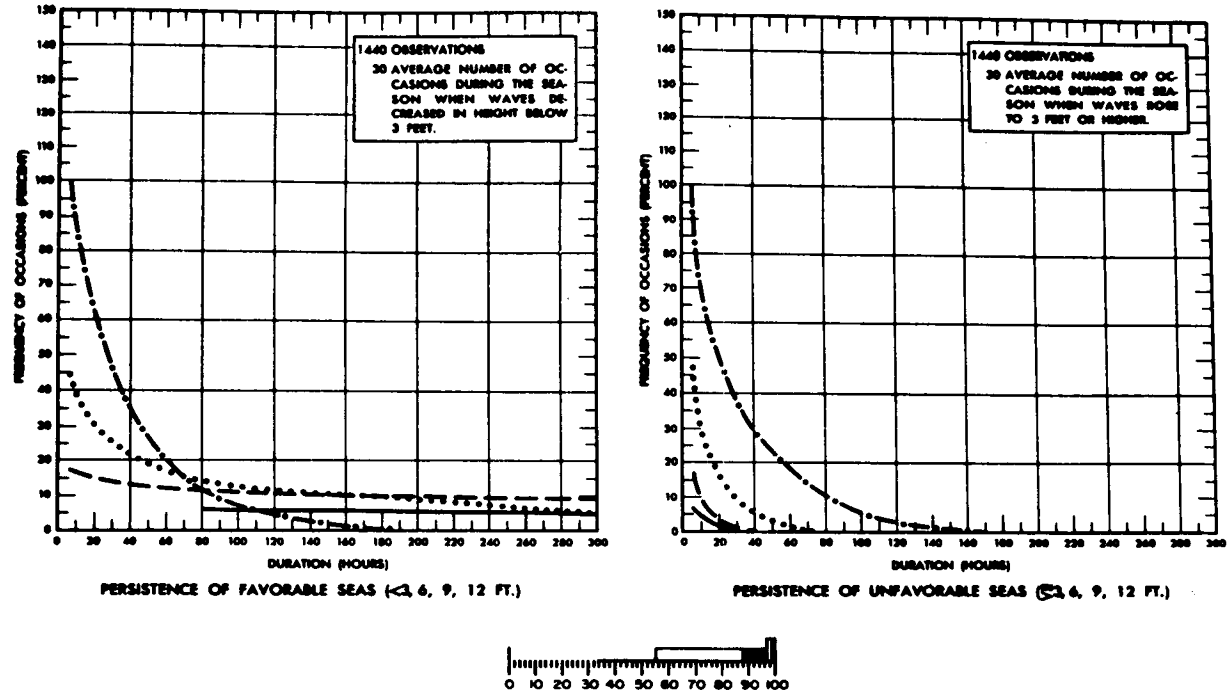
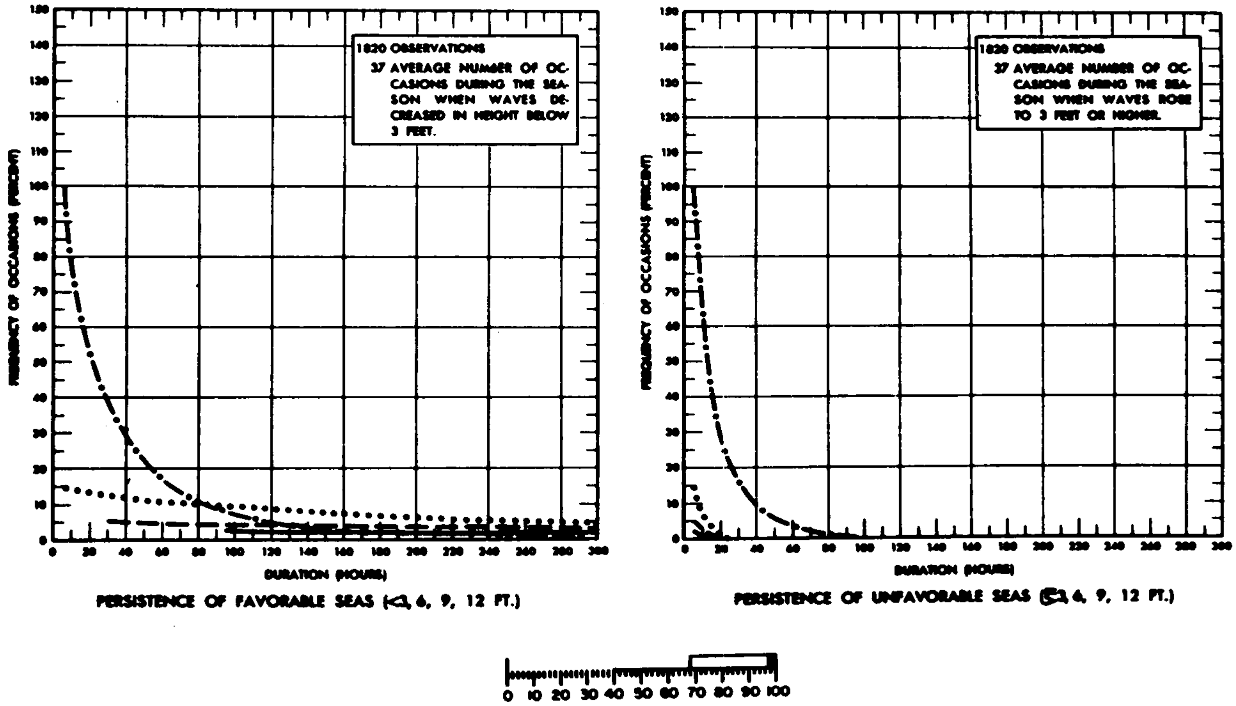


FIGURE 3-49b Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Buzzards Bay, Mass. (U.S. Dept. of Commerce, 1973)

JANUARY, FEBRUARY, MARCH



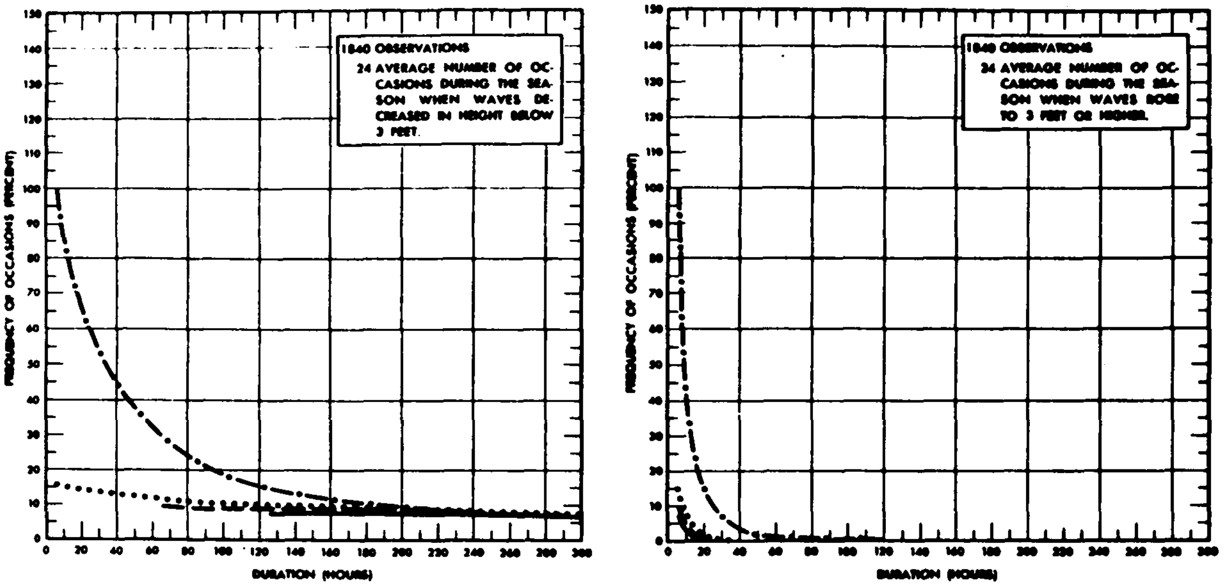
APRIL, MAY, JUNE



AMBROSE CHANNEL, N. Y. 40°27.1'N., 73°49.4'W

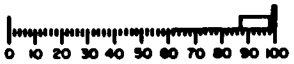
FIGURE 3-50a Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Ambrose Channel, N.Y. (U.S. Dept of Commerce, 1973)

JULY, AUGUST, SEPTEMBER

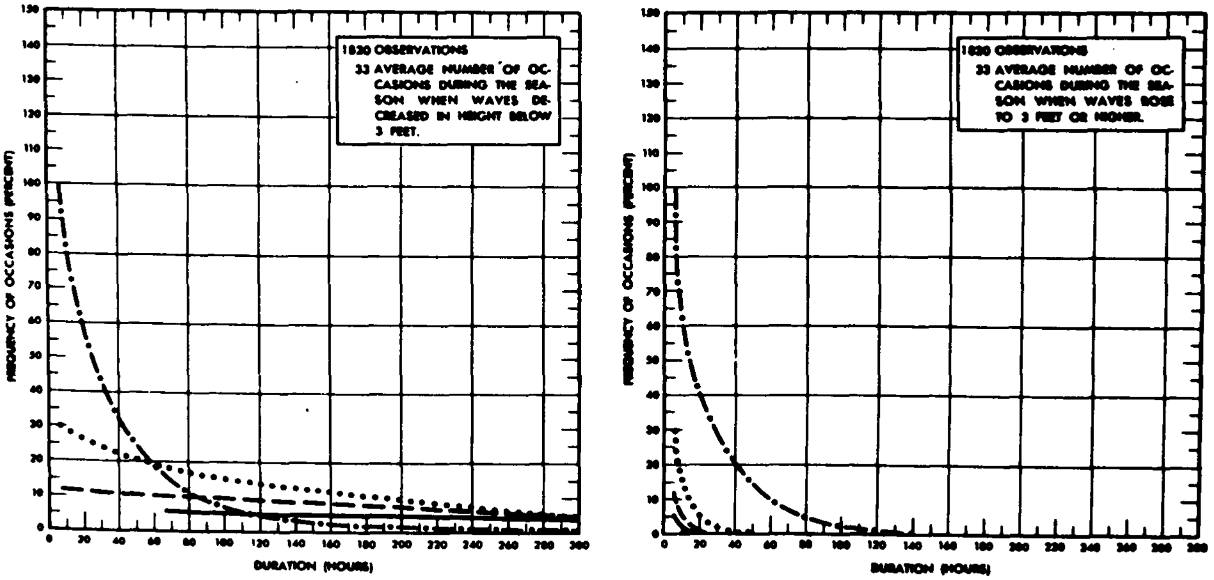


PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE SEAS (≥3, 6, 9, 12 FT.)



OCTOBER, NOVEMBER, DECEMBER



PERSISTENCE OF FAVORABLE SEAS (<3, 6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE SEAS (≥3, 6, 9, 12 FT.)

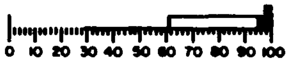
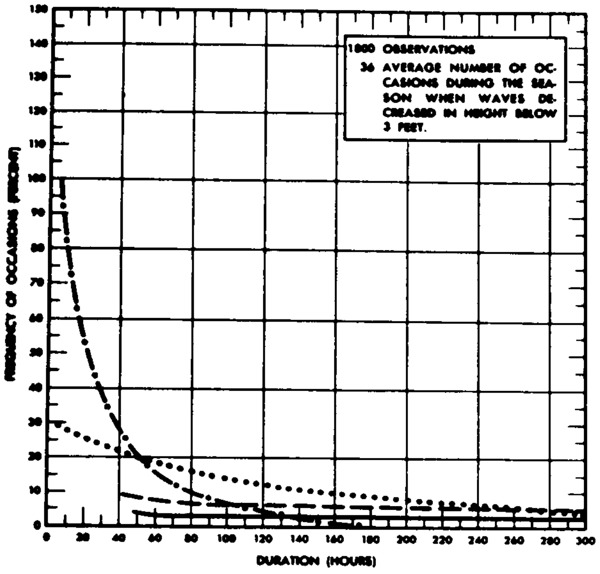
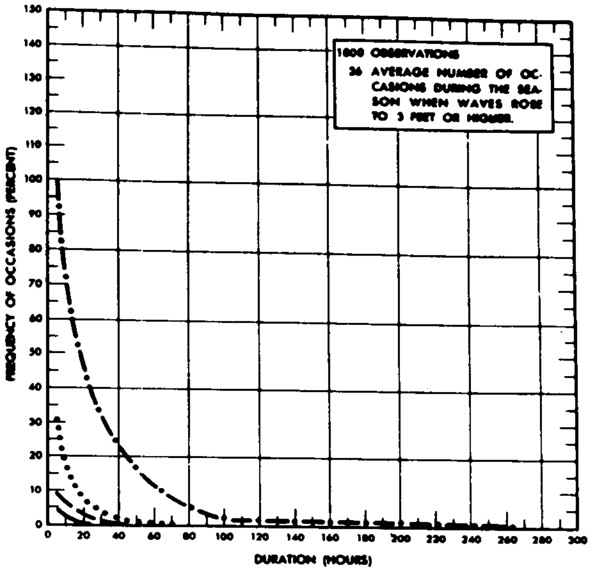


FIGURE 3-50b Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Ambrose Channel, N.Y. (U.S. Dept. of Commerce, 1973)

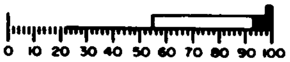
JANUARY, FEBRUARY, MARCH



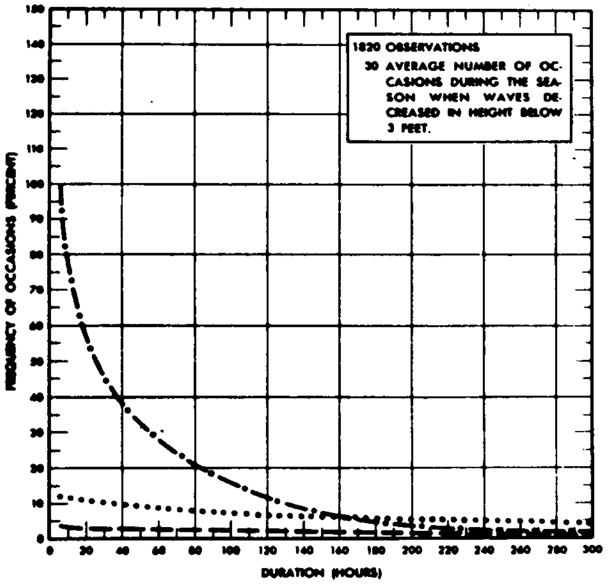
PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)



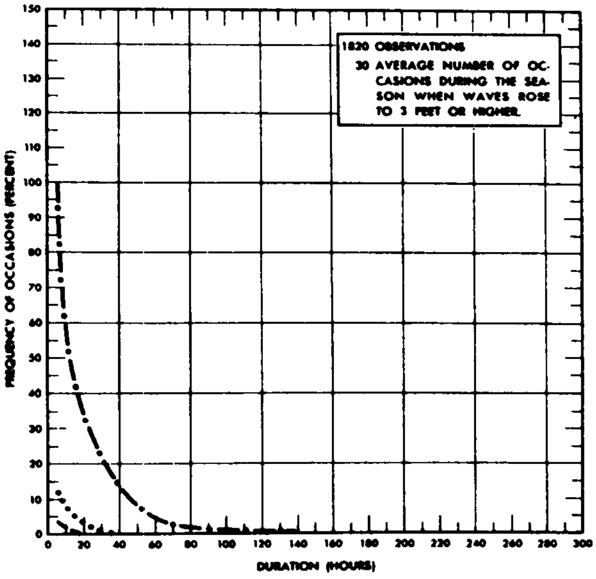
PERSISTENCE OF UNFAVORABLE WAVES (≧3,6, 9, 12 FT.)



APRIL, MAY, JUNE



PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)



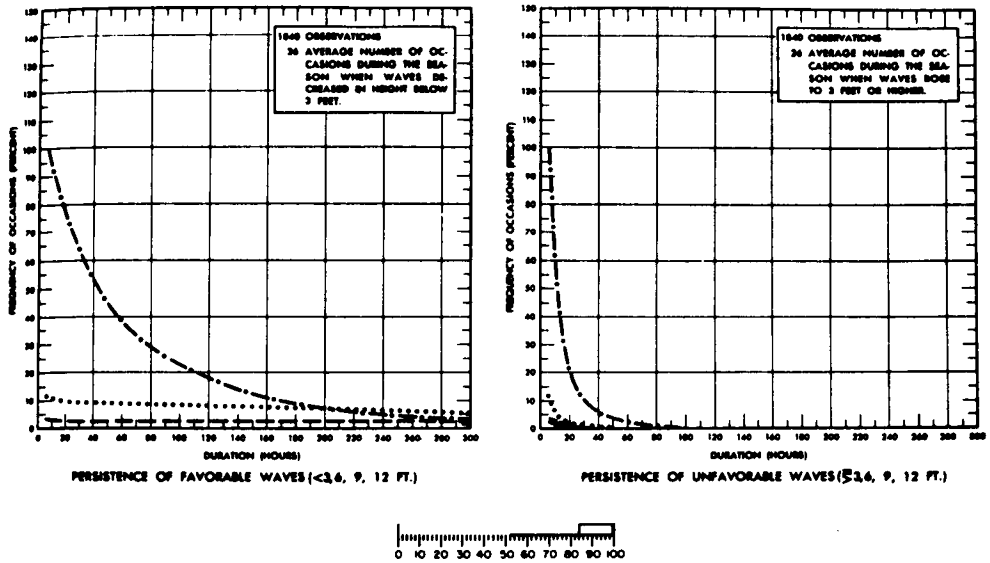
PERSISTENCE OF UNFAVORABLE WAVES (≧3,6, 9, 12 FT.)

BARNEGAT, N. J. 39°45.8'N., 73°56.0'W.

FIGURE 3-51a

Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Barnegat, New Jersey (U.S. Dept. of Commerce, 1973)

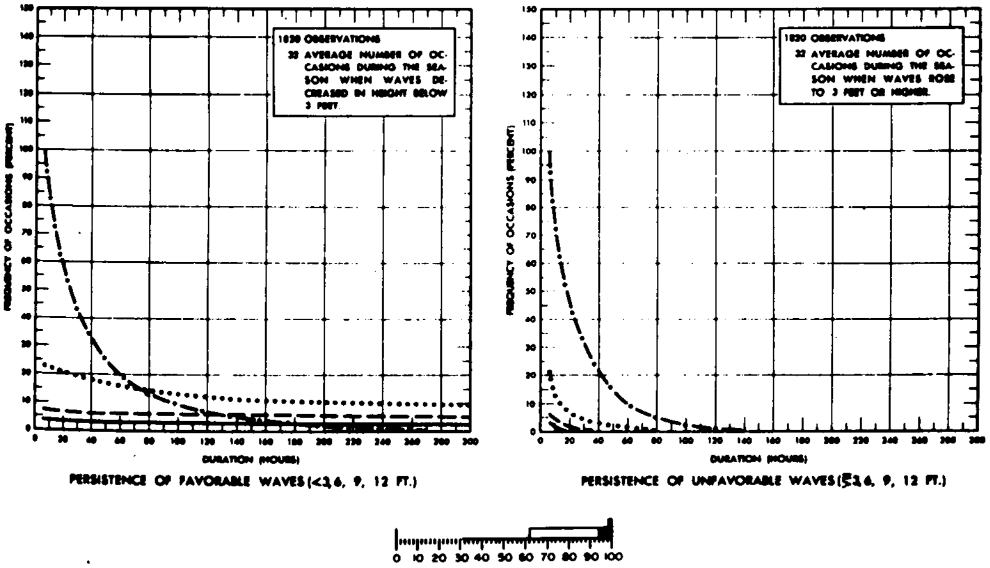
JULY, AUGUST, SEPTEMBER



PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE WAVES (≥3,6, 9, 12 FT.)

OCTOBER, NOVEMBER, DECEMBER

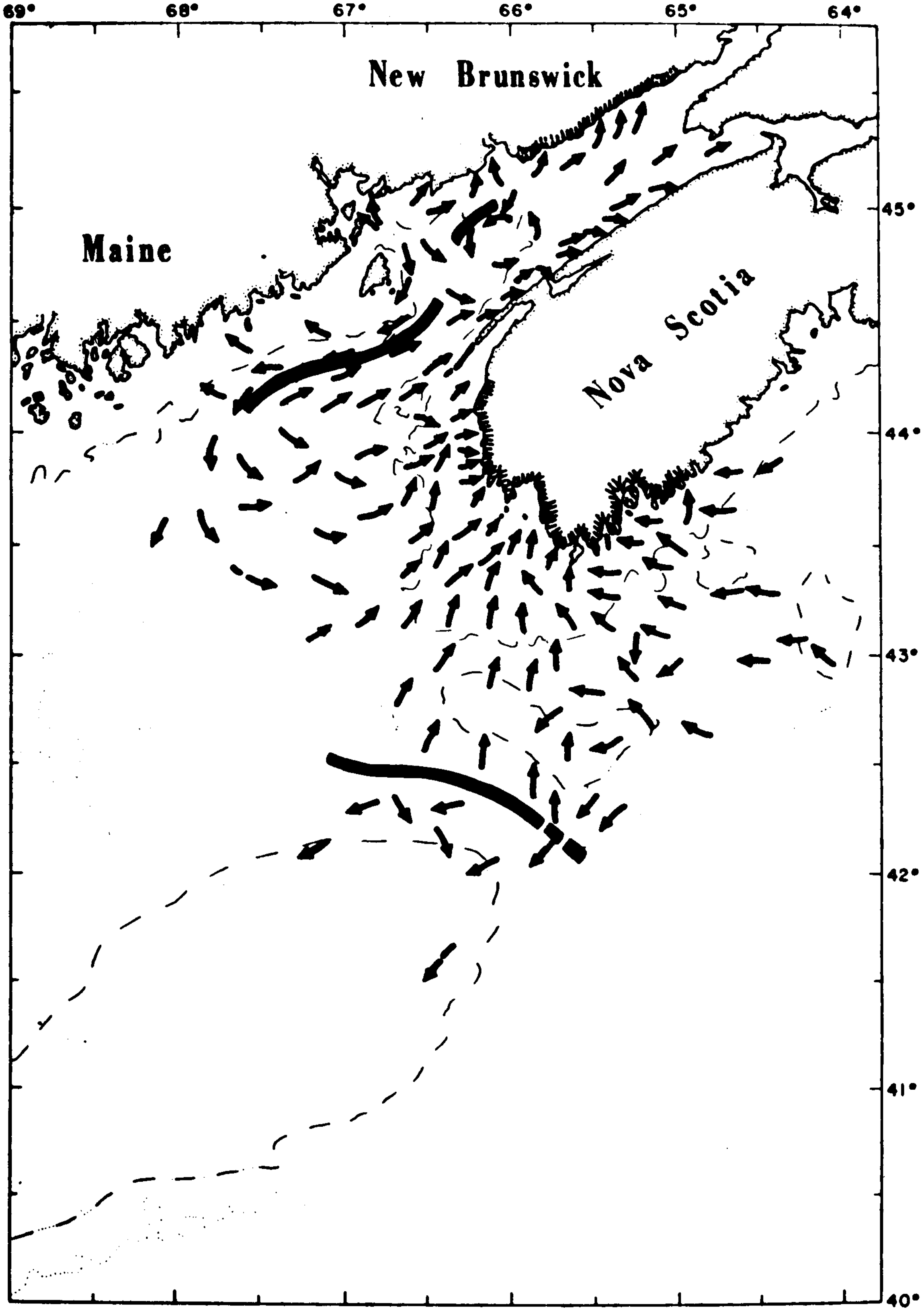


PERSISTENCE OF FAVORABLE WAVES (<3,6, 9, 12 FT.)

PERSISTENCE OF UNFAVORABLE WAVES (≥3,6, 9, 12 FT.)

FIGURE 3-51b

Persistence of Favorable and Unfavorable Seas at East Coast Lightships - Barnegat, New Jersey (U.S. Dept. of Commerce, 1973)



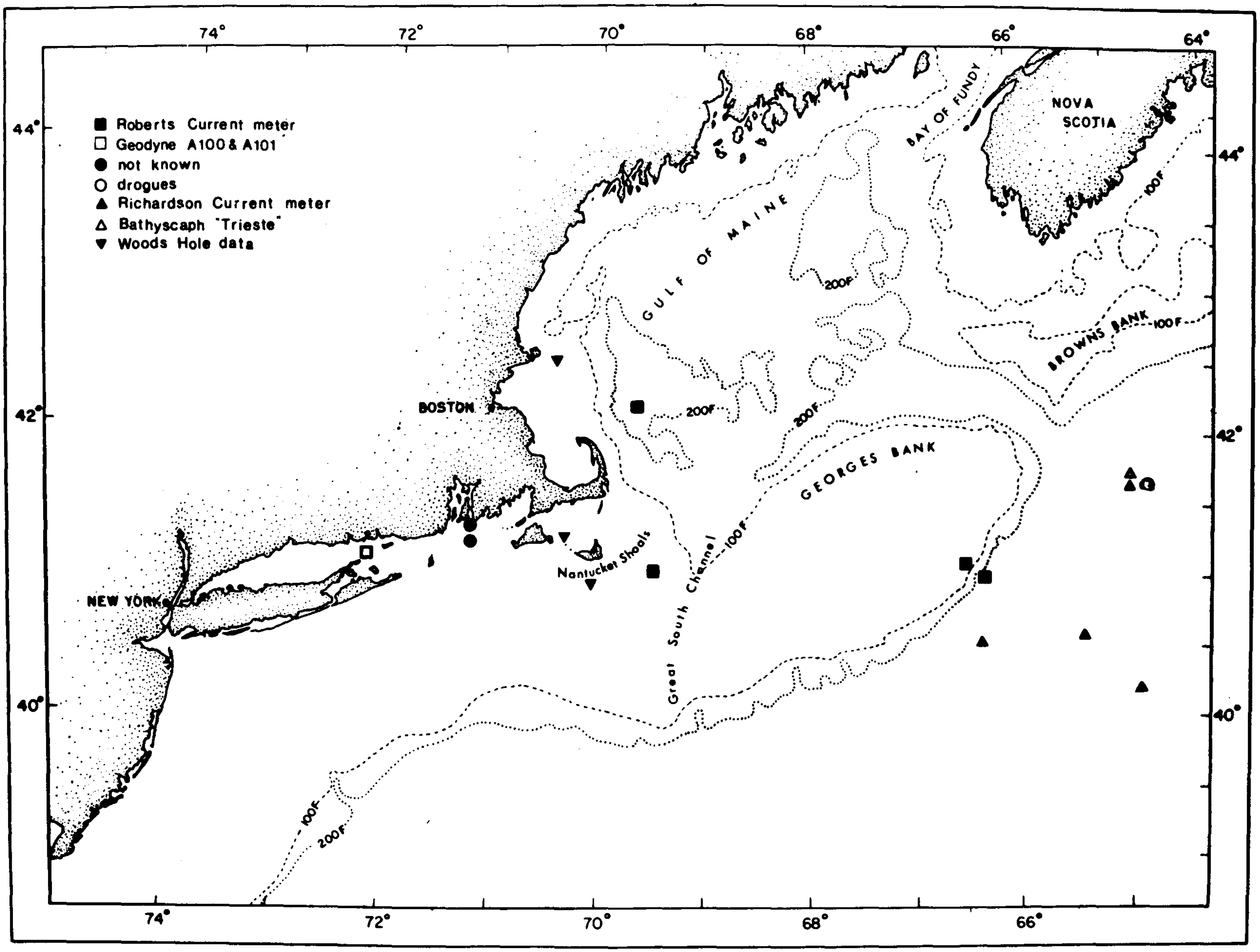
TRIGOM PARC

FIGURE 3-54

Inferred Residual Bottom Drift-S.W. Nova Scotia to Bay of Fundy (Lauzier, 1967)

FIGURE 3-54a

Bottom Current Data



BOTTOM CURRENT DATA FROM NODC 1974

LATITUDE DEGREES	LONGITUDE DEGREES	BOTTOM DEPTH (M)	CURRENT DEPTH (M)	SPEED (KTS) OBS.	MEAN	MAX.	DIRECTION DEGREES TRUE		METHOD	RELIABILITY	MONTH	YR	SR NUMBER	STATION NUMBER
40.3	- 64.9	4394.0	4392.0		.19		226		21	3	6	969	59	METE
40.6	- 65.5	3640.0	3638.0			.39	148		21	3	6	969	59	0000
40.6	- 65.5	3638.0	3636.0		.38		148		21	3	6	969	59	METD
41.7	- 65.0	2300.0	2300.0		.25		125*	270	24	2	6	963	116	0000
41.7	- 64.9	2400.0	2400.0		.40		45		20	3	5	963	115	0000
41.7	- 65.0	2550.0	2500.0		.82		23		21	2	5	963	116	0000
41.0	- 66.4	100.0	95.0		.80	1.40	182		6	3	8	958	117	0000
41.1	- 66.7	79.0	72.0		.60	1.00	68	180	6	2	8	958	61	0000
41.0	- 69.7	39.0	34.0		1.62*	2.40	212	24	6	2	8	960	193	STA8
42.2	- 69.8	229.0	218.0		.44	.90	154	163	6	2	10	959	192	STA3
42.2	- 69.8	229.0	214.0		.37	.50	139		6	2	4	961	193	STA3

AVAILABLE DATA WITHIN MARSDEN SQUARE NO. 152

LATITUDE DEGREES	LONGITUDE DEGREES	BOTTOM DEPTH (M)	CURRENT DEPTH (M)	SPEED (KTS) OBS.	MEAN	MAX.	DIRECTION DEGREES TRUE		METHOD	RELIABILITY	MONTH	YR	SR NUMBER	STATION NUMBER
41.3	- 72.1	21.0	20.0		.10	.65	345	110	8	2	6	972	185	STA2
41.3	- 72.1	21.0	20.0		.10	.60	3	115	8	2	6	972	185	STA1
41.3	- 72.1	14.0	13.0		.10	.65	224	110	8	2	8	972	185	STA3
41.3	- 72.1	14.0	13.0		.10	.75	309	90	8	2	8	972	185	STA4
41.4	- 71.4	40.0	38.0		.90	1.70	360	180	9	1			20	0056
41.5	- 71.4	15.0	15.0		.50	.70	360	180	9	1			20	0123

LEGEND

125* mean or single observed. 270 dir. of maximum current

1.62* mean speed. 240 max

METHOD

■	6 Roberts Current meter
□	8 Geodyne A100 & A101
●	9 not known
○	20 drogues
▲	21 Richardson Current meter
△	24 Bathyscapth "Trieste"

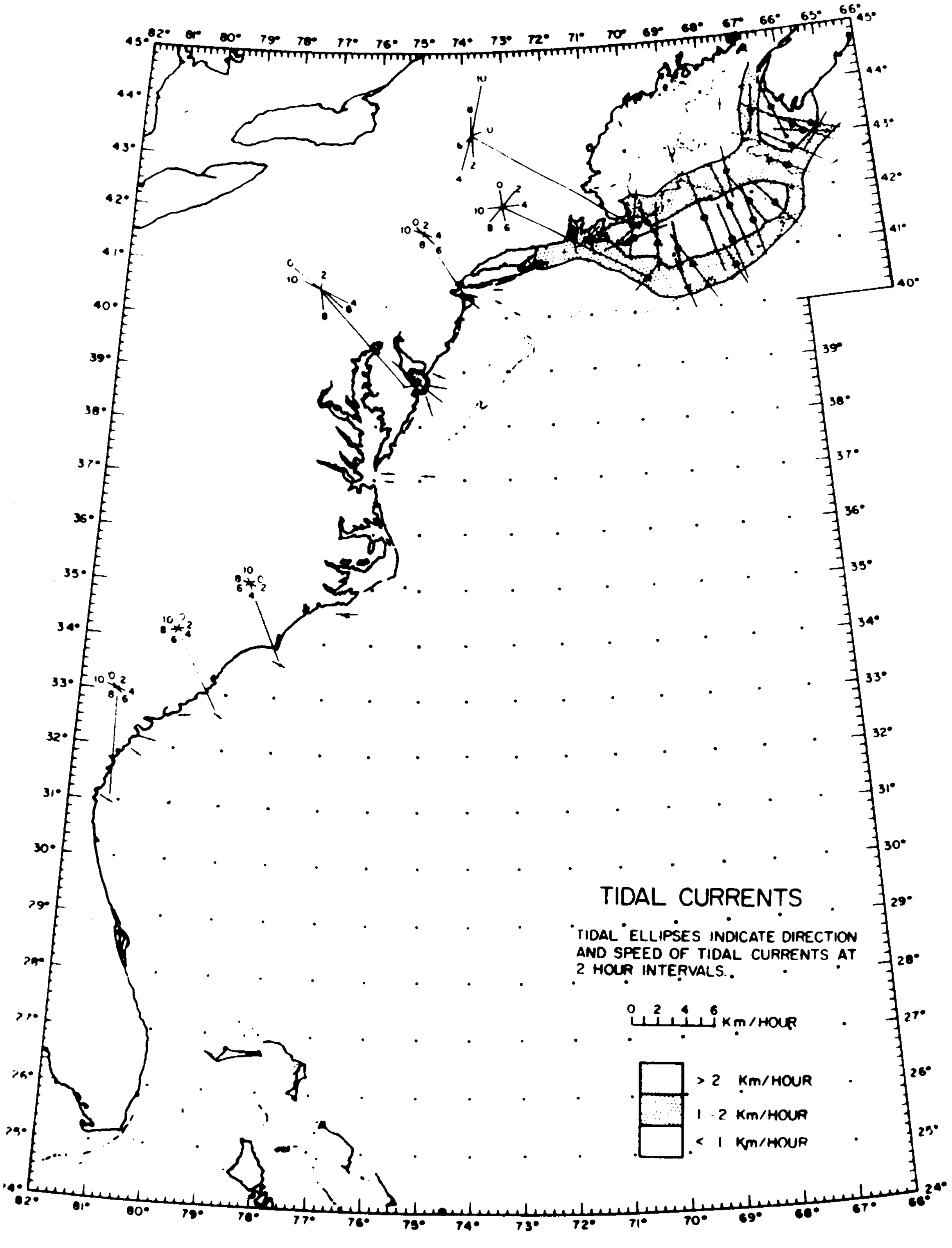
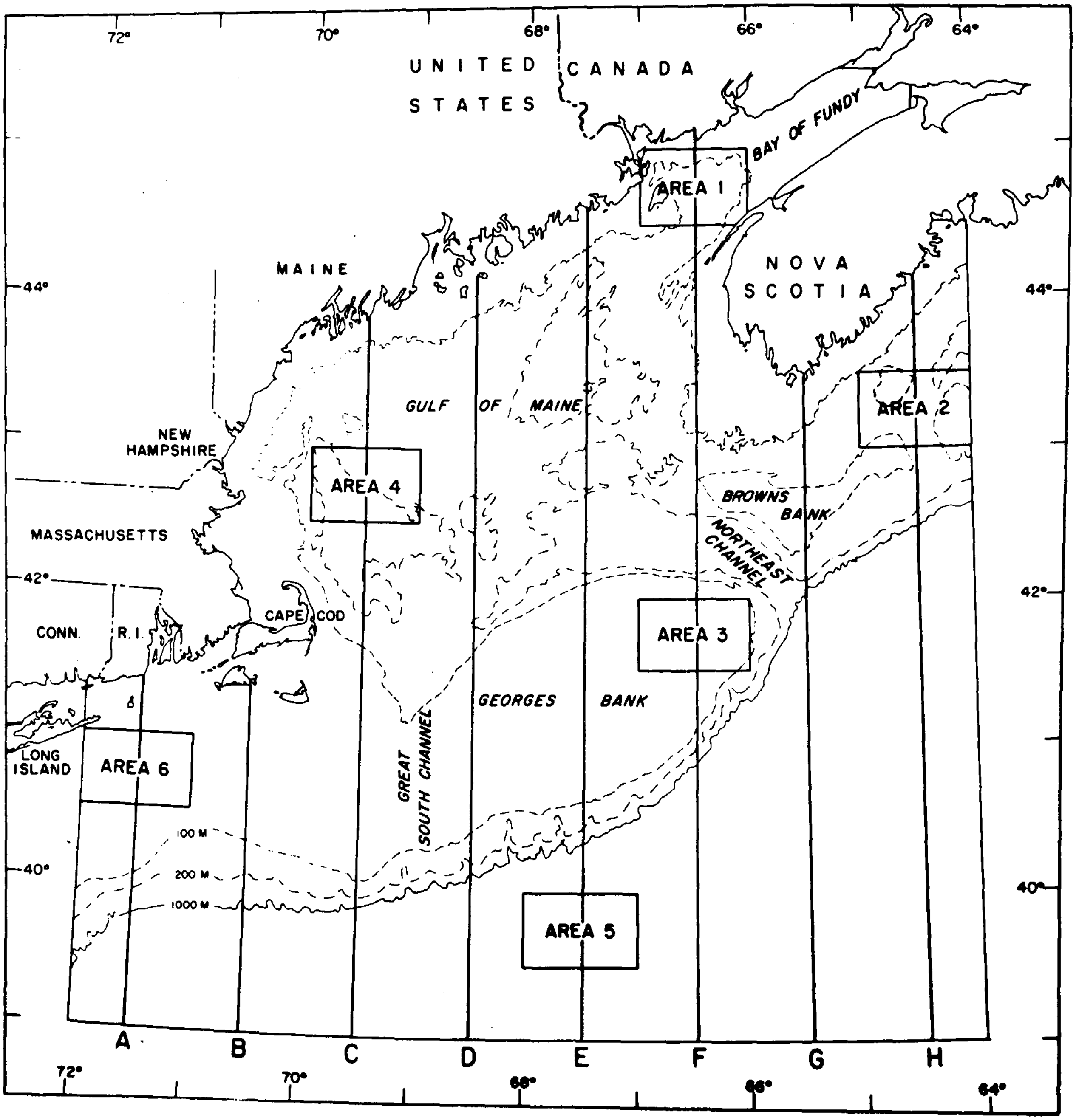


FIGURE 3-55

Surface Tidal Currents Offshore Over the Continental Shelf (Haight, 1942; Emery & Uchupi, 1972)

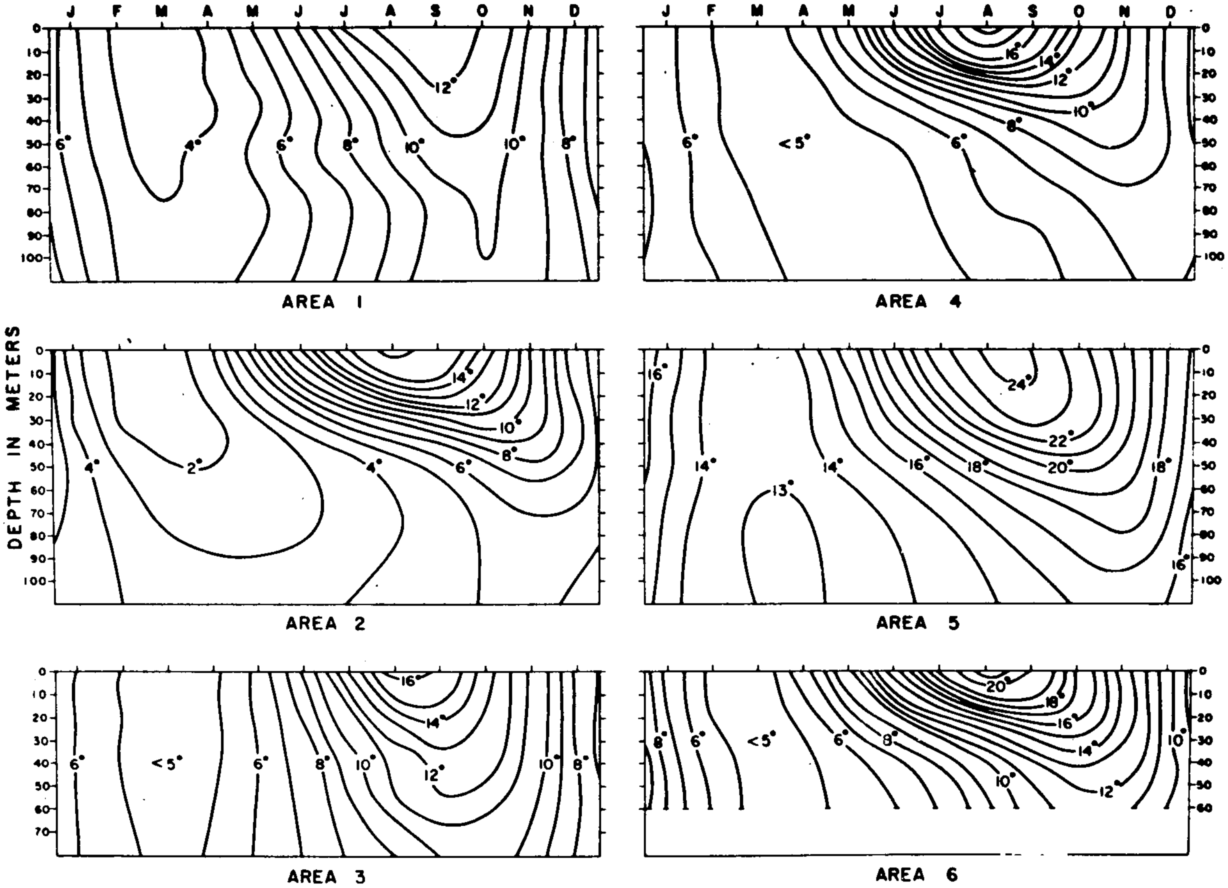


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-56

Location of Areas and Profiles (Colton and Stoddard, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-57

Monthly Temperature Progressions in Areas Shown in Fig. 3-56 (Colton and Stoddard, 1972)

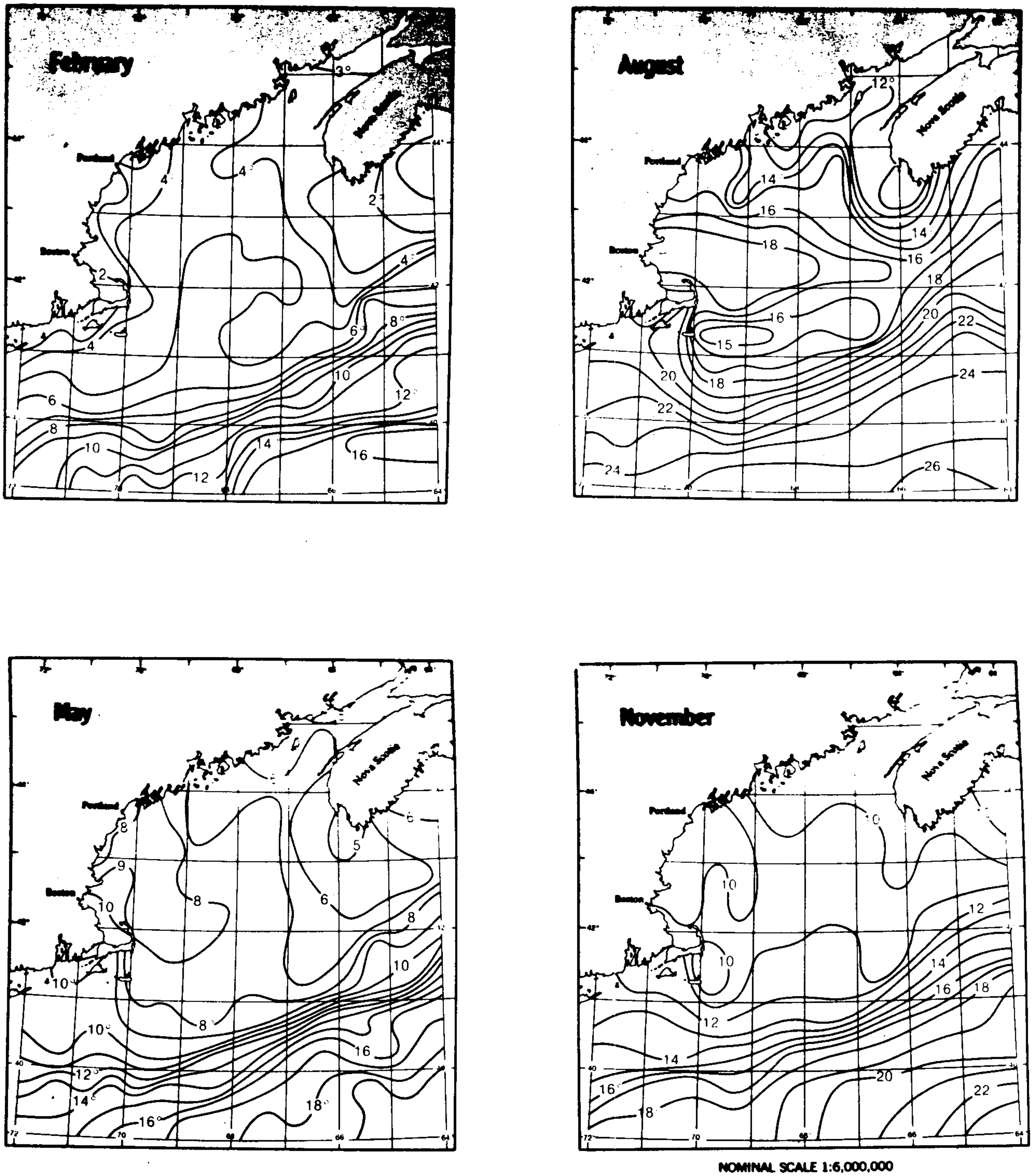
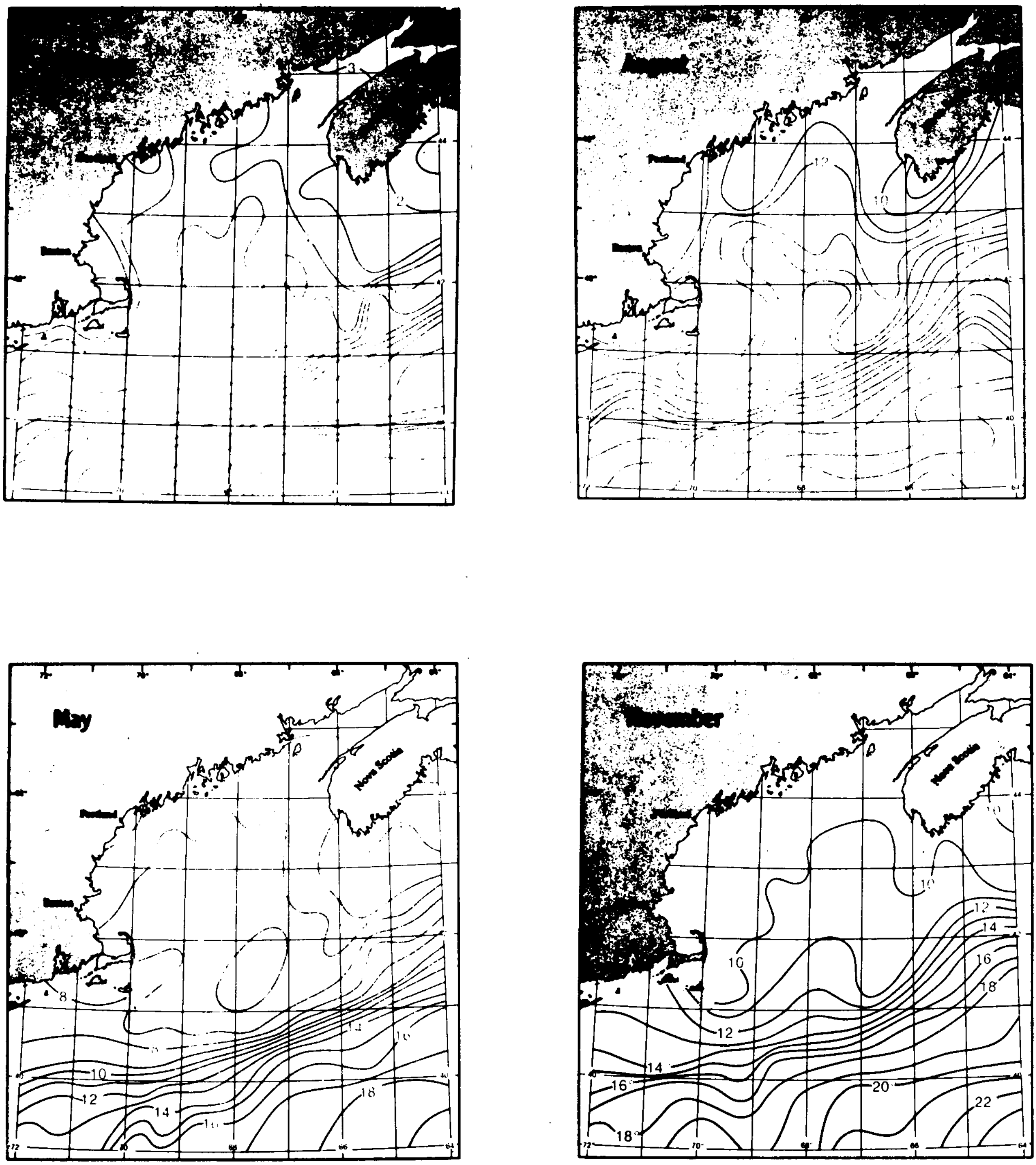


FIGURE 3-58

Average Monthly Temperatures at the Surface (Colton and Stoddard, 1972)



NOMINAL SCALE 1:6,000,000

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-59

Average Monthly Temperatures at 20 Meters (Colton and Stoddard, 1972)

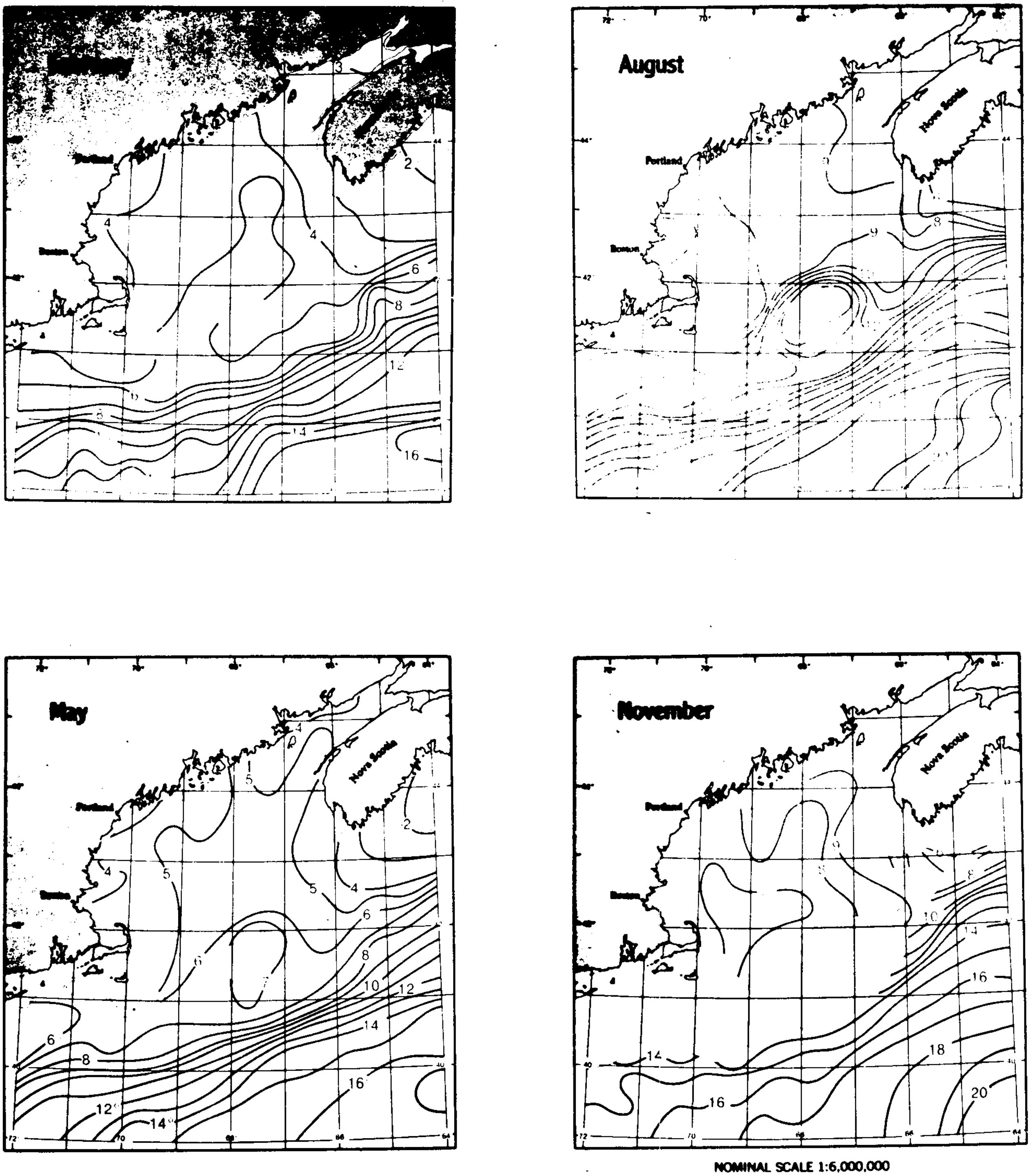
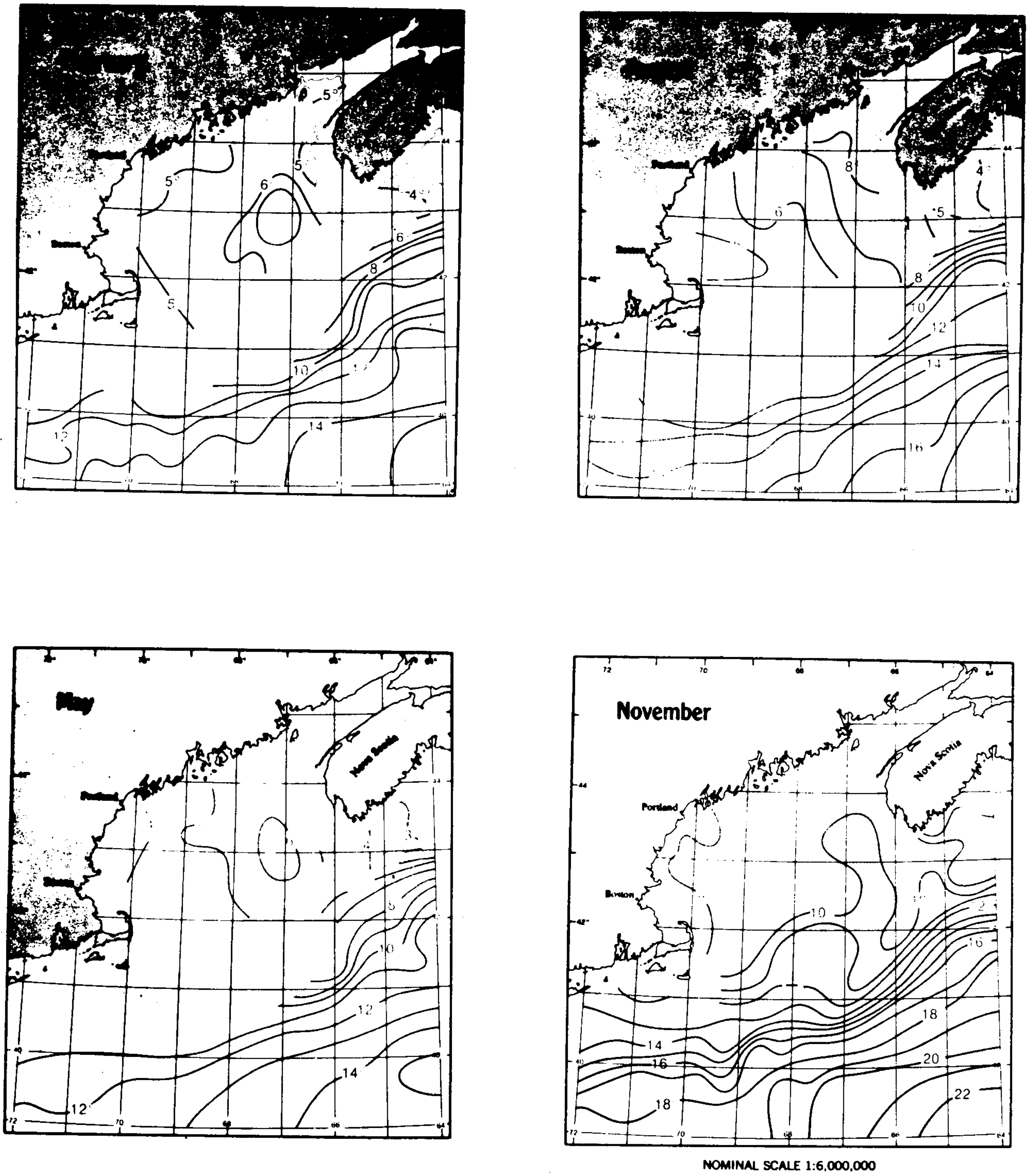


FIGURE 3-60 Average Monthly Temperatures at 40 Meters (Colton and Stoddard, 1972)

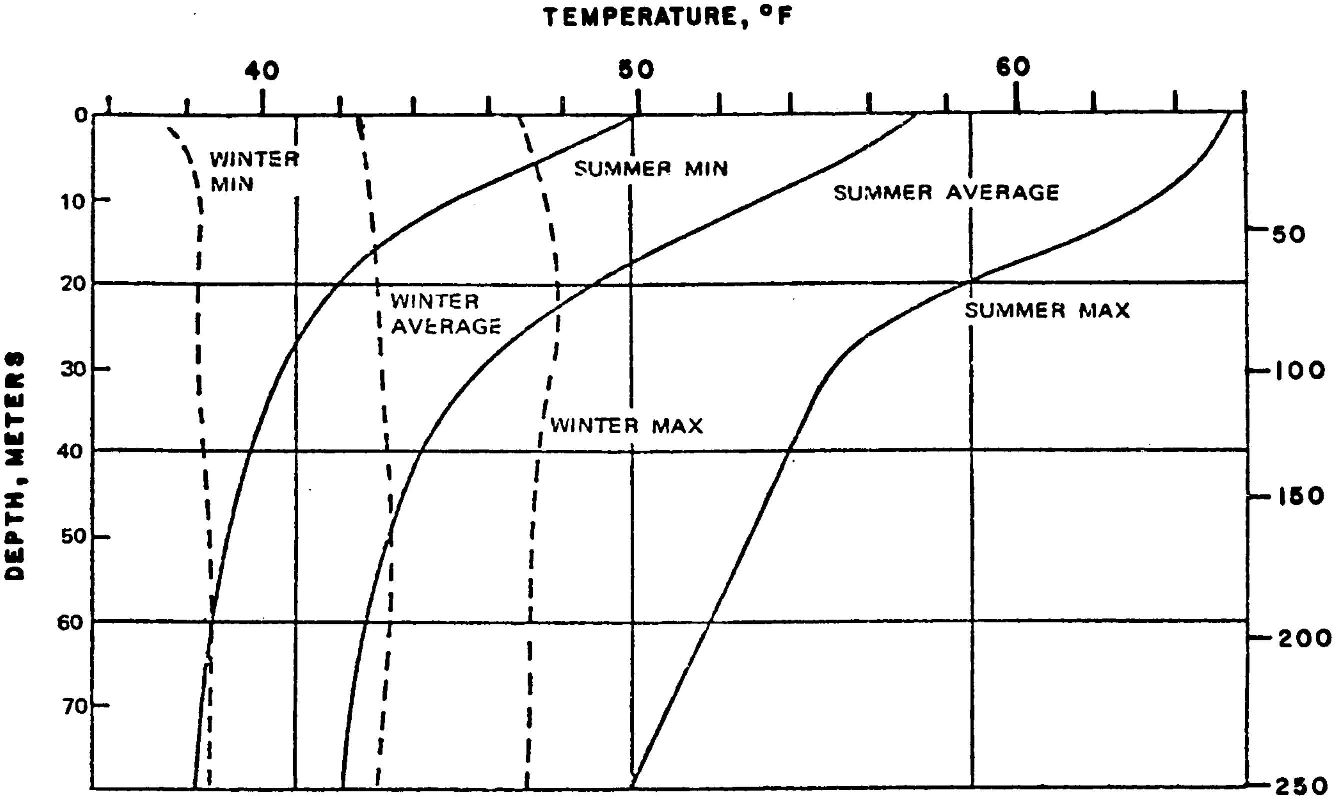


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-61

Average Monthly Temperatures at 100 Meters (Colton and Stoddard, 1972)

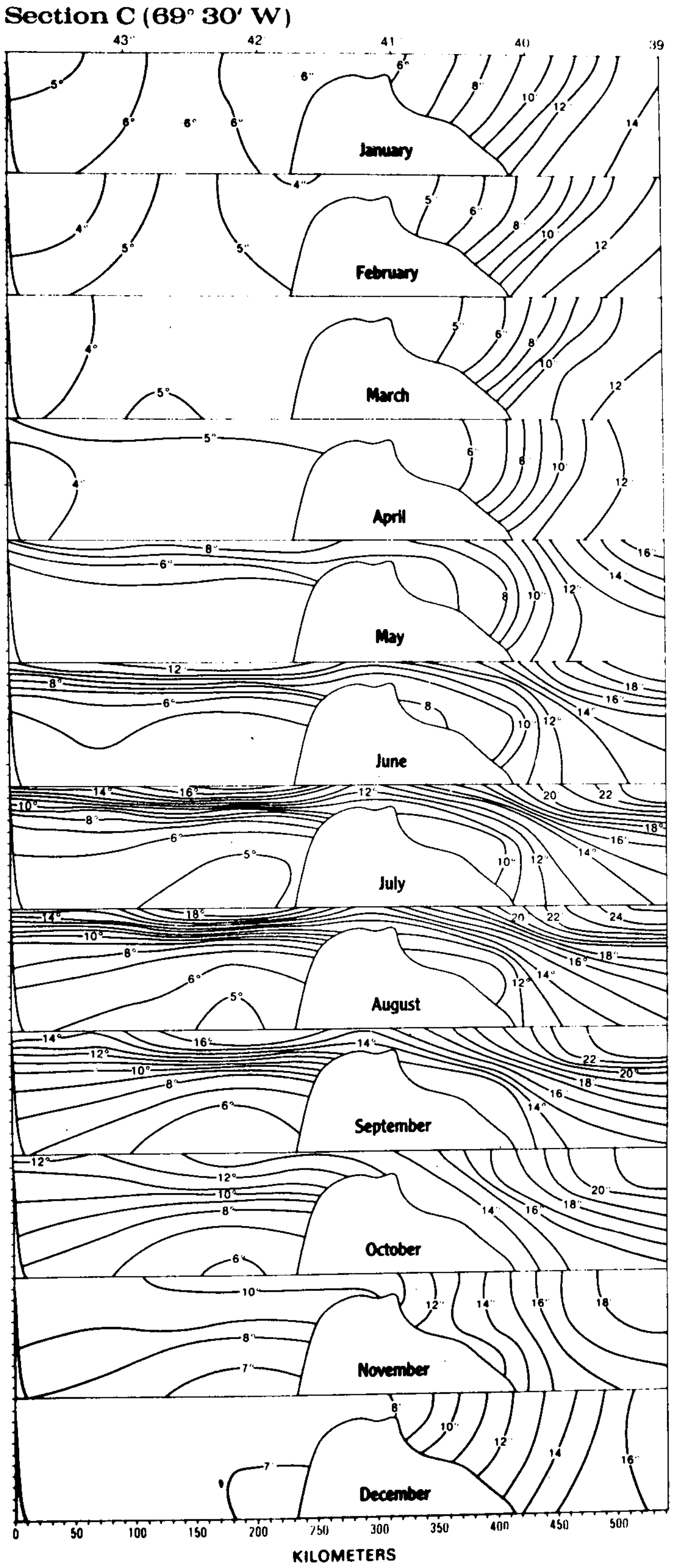


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-62

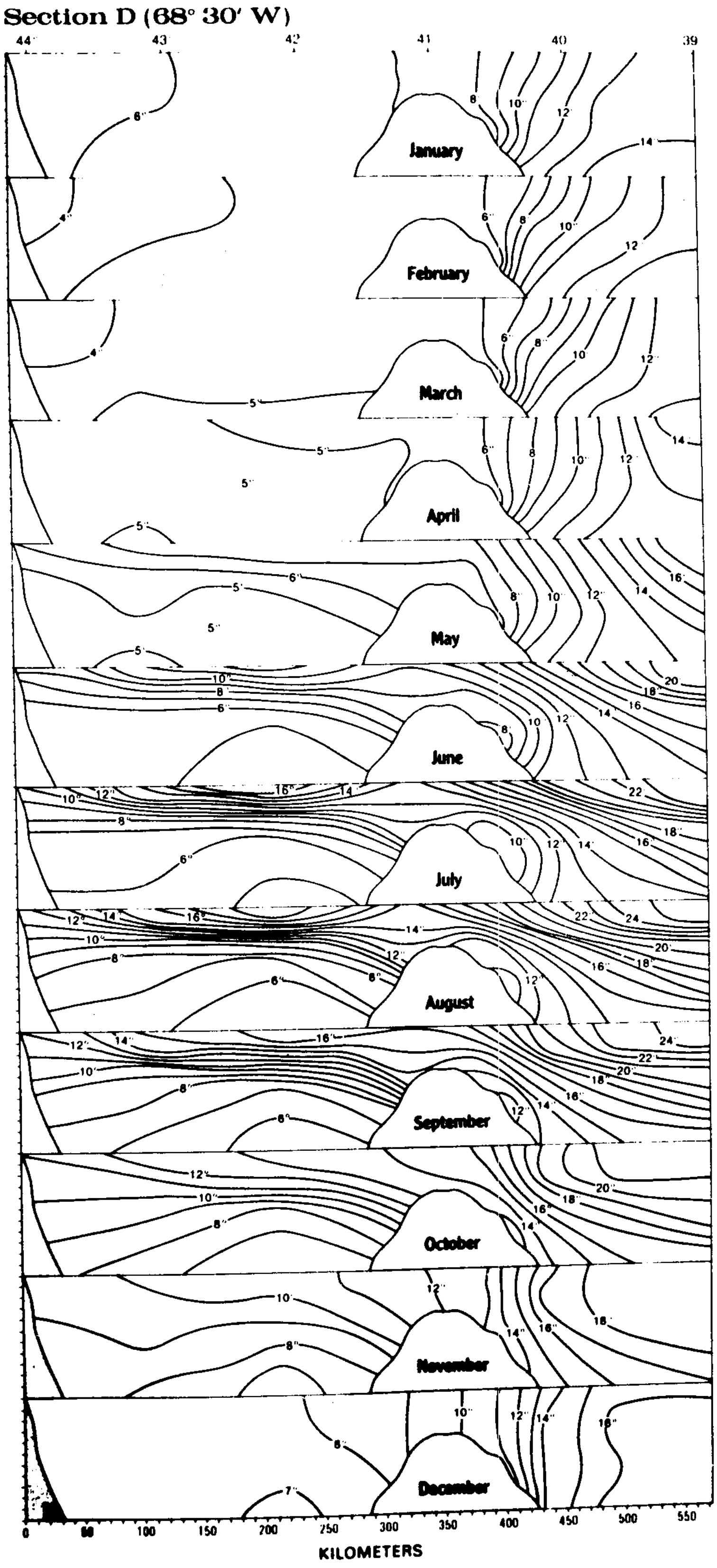
Summer and Winter Temperature Profile in the Gulf of Maine (PSNH, 1972)



TRIGOM PARC

FIGURE 3-63

Temperature Profiles for Section C in Fig. 3-56 (Colton and Stoddard, 1972)

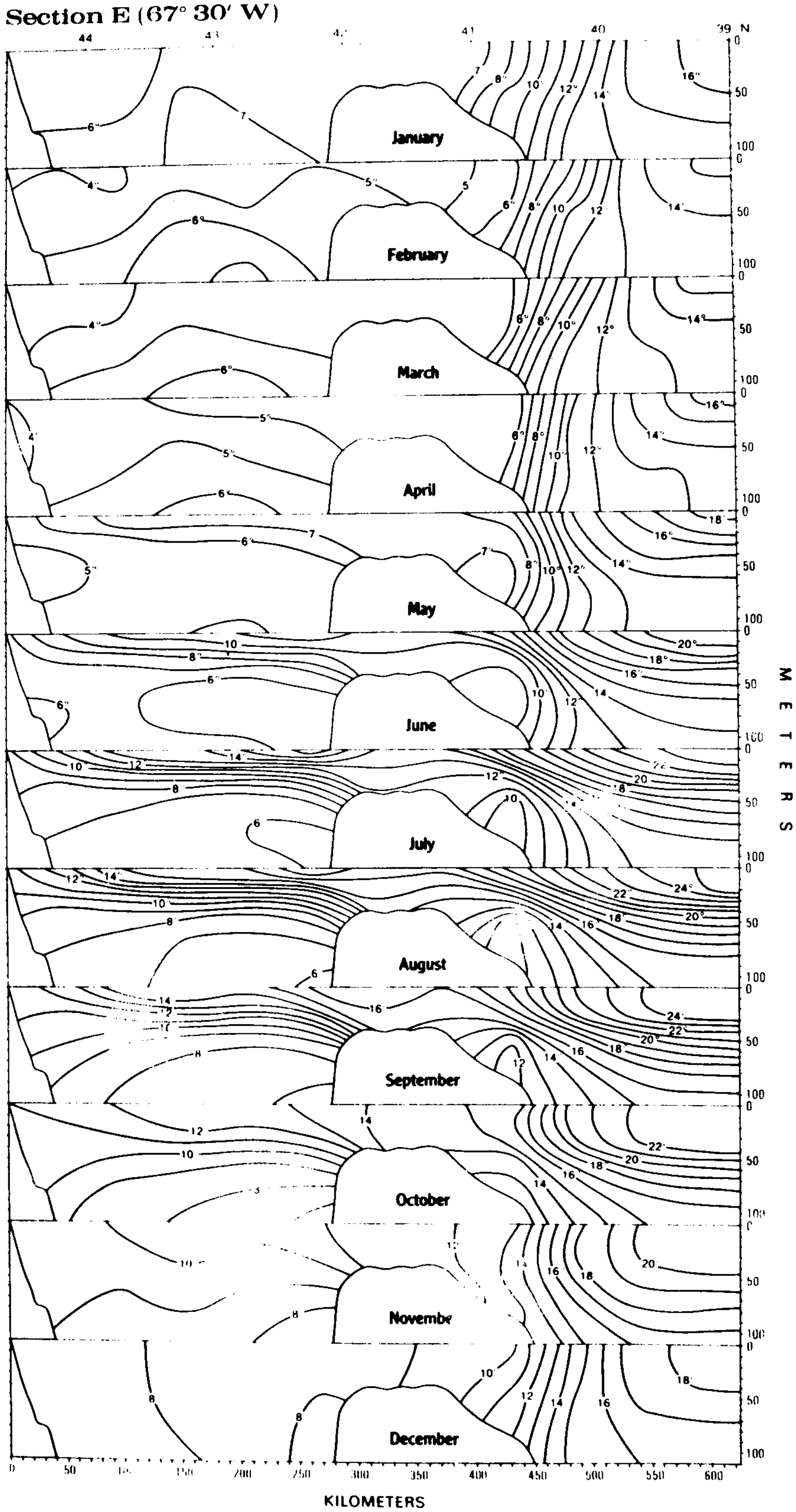


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-64

Temperature Profiles for Section D in Fig. 3-56 (Colton and Stoddard, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-65

Temperature Profiles for Section E in Fig. 3-56 (Colton, et al., 1972)

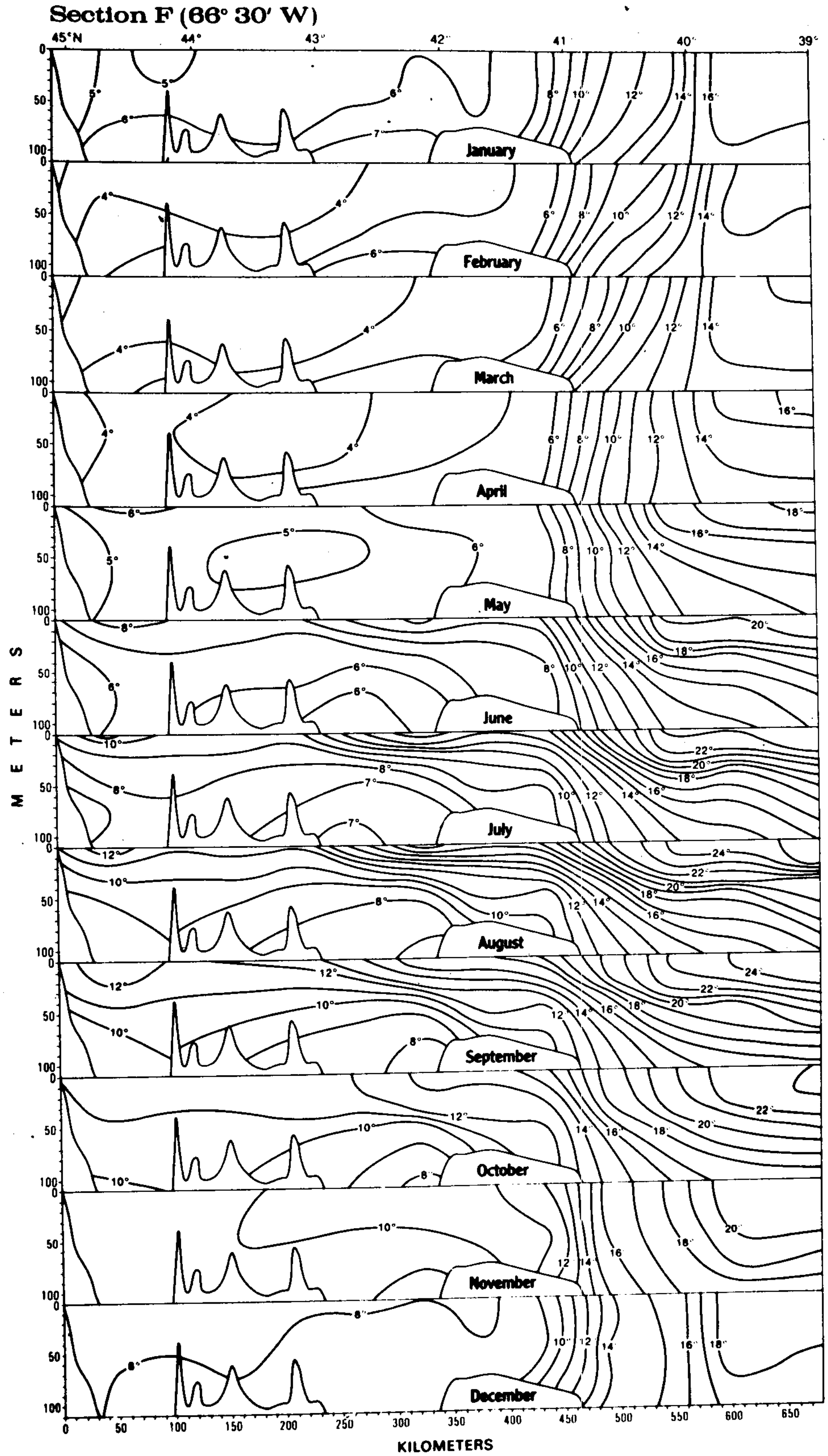
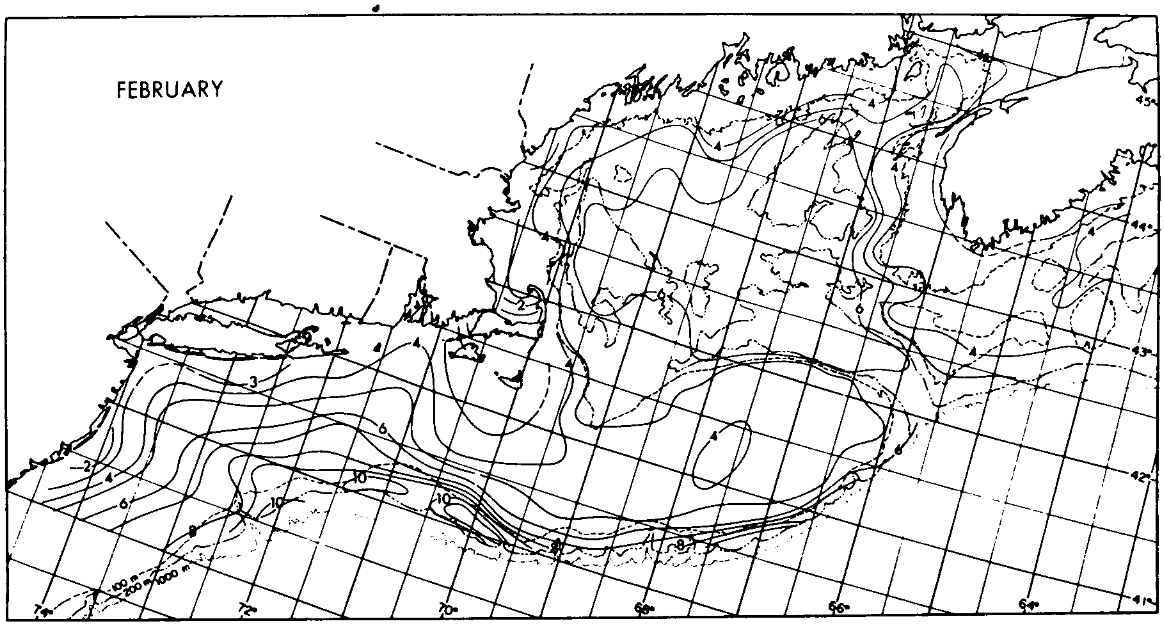


FIGURE 3-66

Temperature Profiles for Section F in Fig. 3-56 (Colton, et al., 1972)

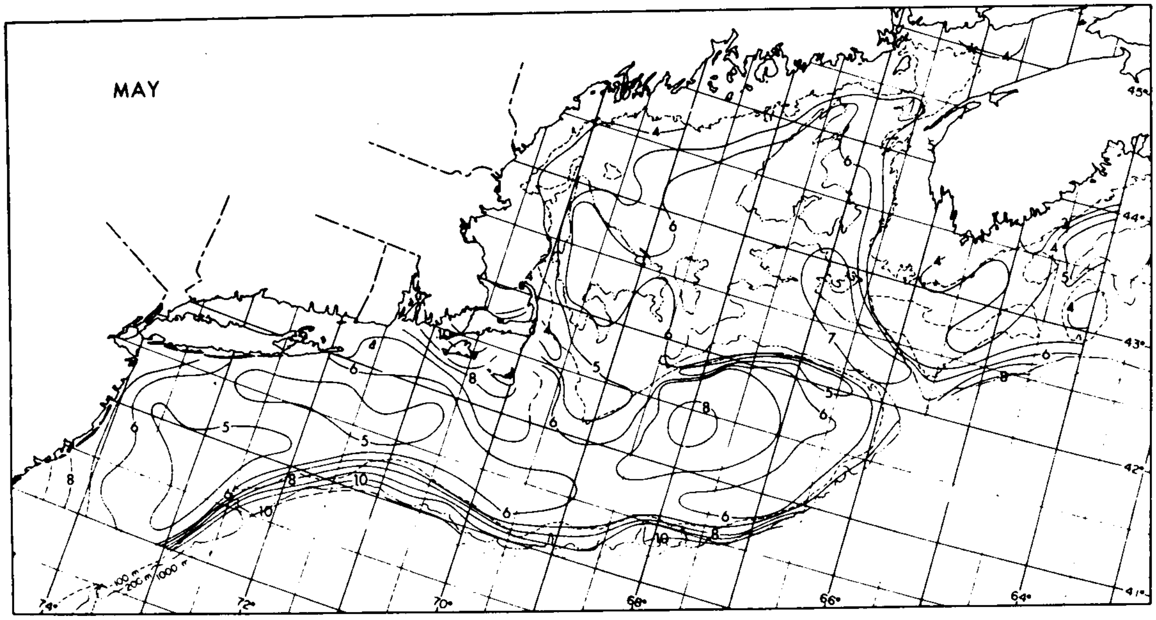


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-67

Bottom Isotherms in February
(Colton and Stoddard, 1973)

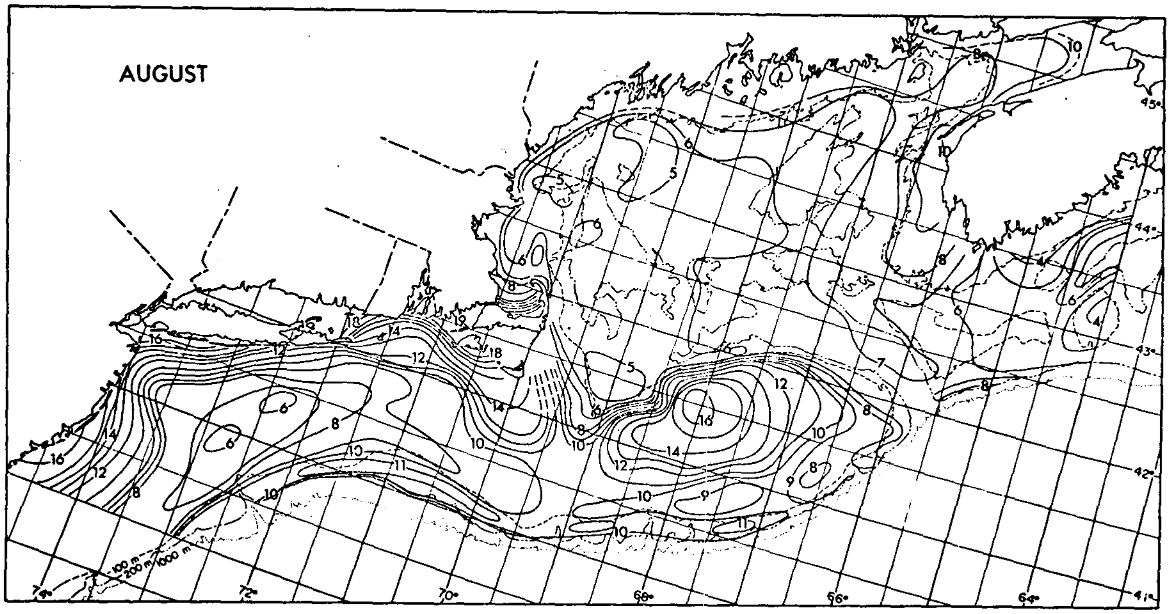


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

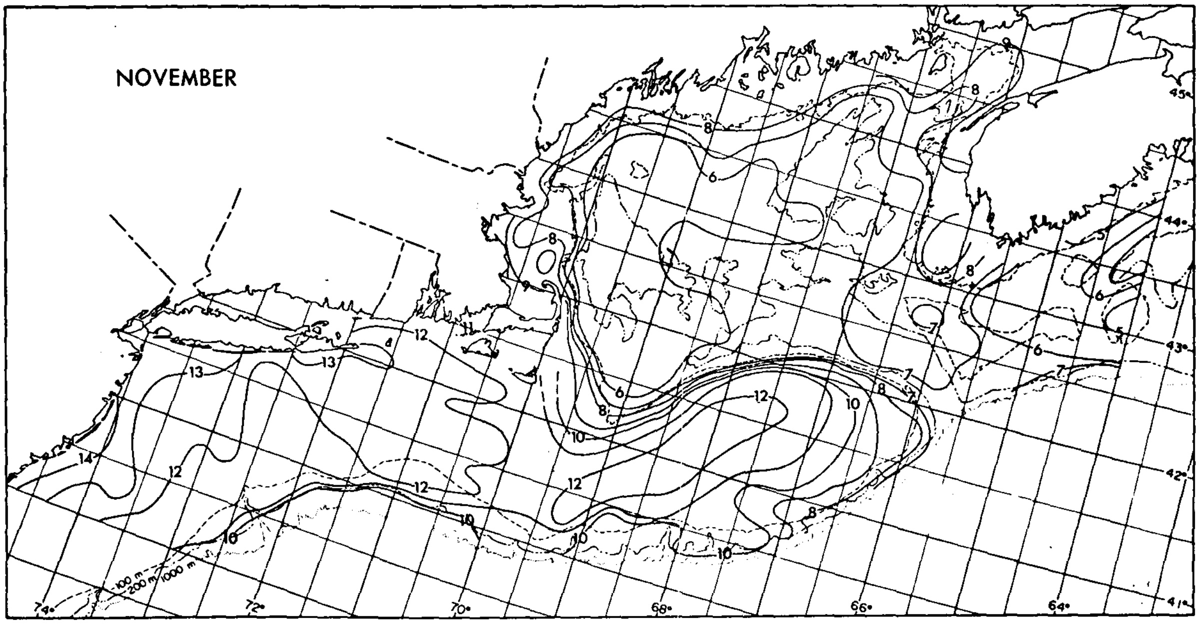
FIGURE 3-68

Bottom Isotherms in May
(Colton and Stoddard, 1973)



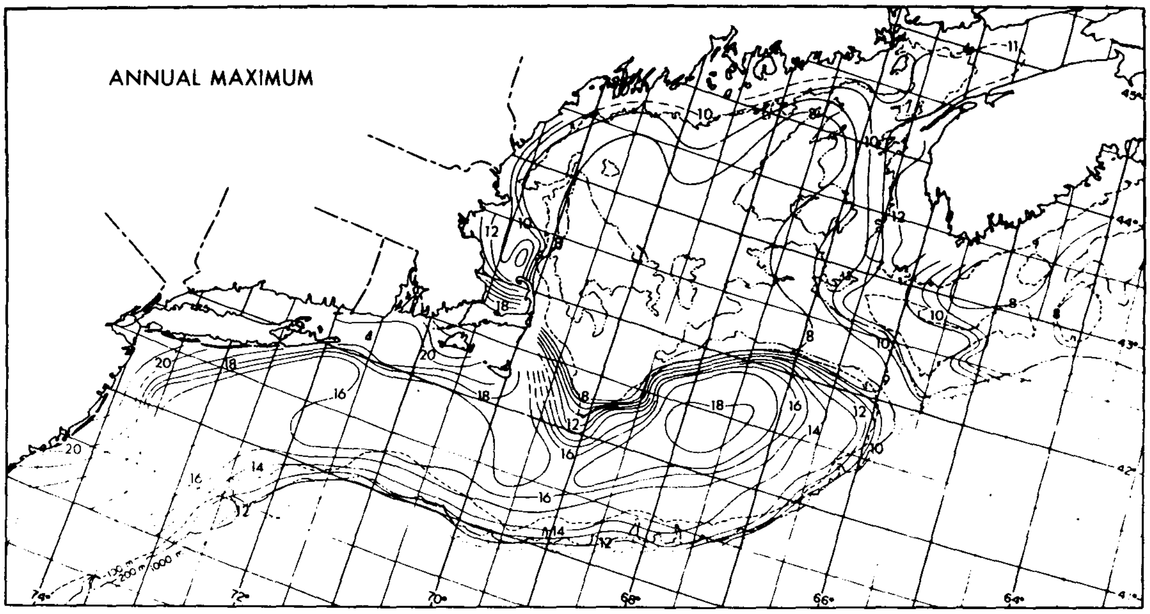
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-69	Bottom Isotherms in August (Colton and Stoddard, 1973)



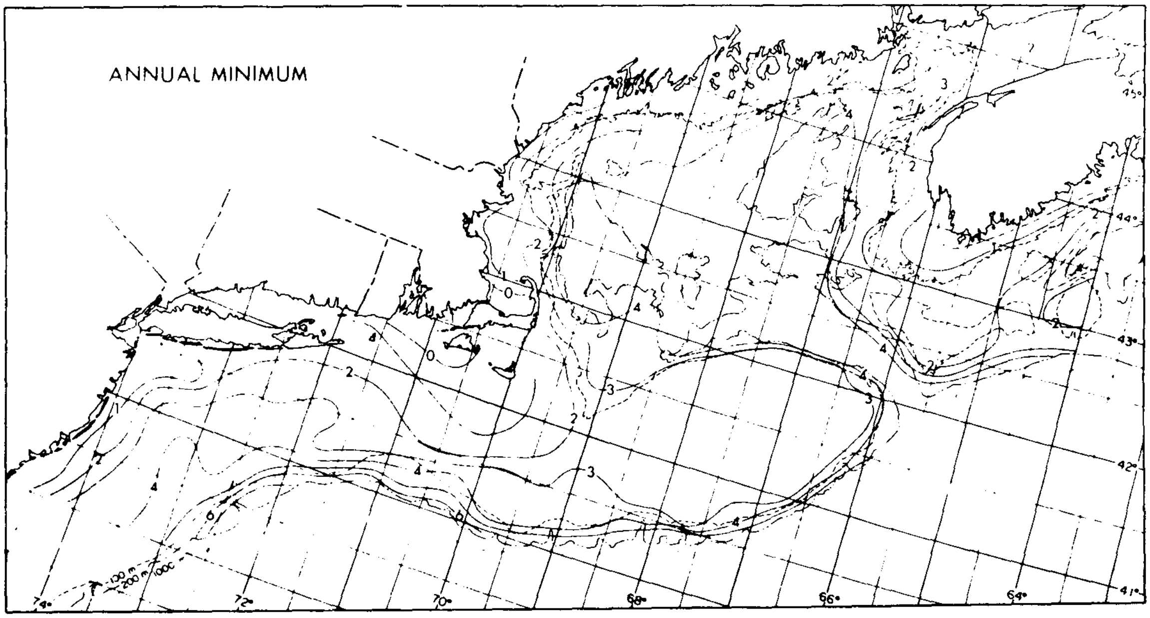
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-70	Bottom Isotherms in November (Colton and Stoddard, 1973)



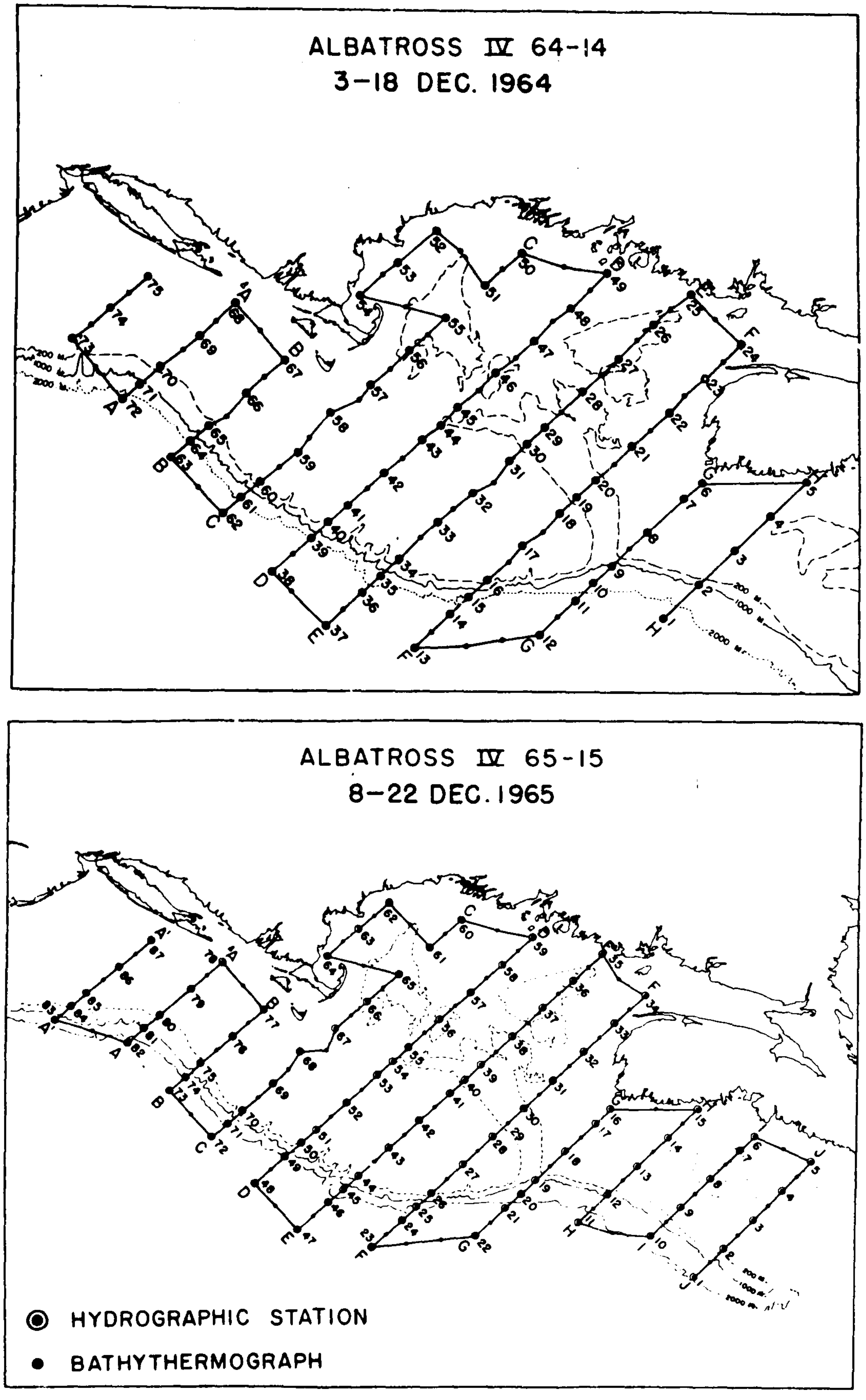
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-71 | Annual Maximum Bottom Isotherms (Colton and Stoddard, 1973)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-72 | Annual Minimum Bottom Isotherms (Colton and Stoddard, 1973)


ALBATROSS IV 64-14
3-18 DEC. 1964

ALBATROSS IV 65-15
8-22 DEC. 1965

FIGURE 3-73 Examples of Cruise Tracks and Stations-Albatross IV (Colton, et al., 1968)

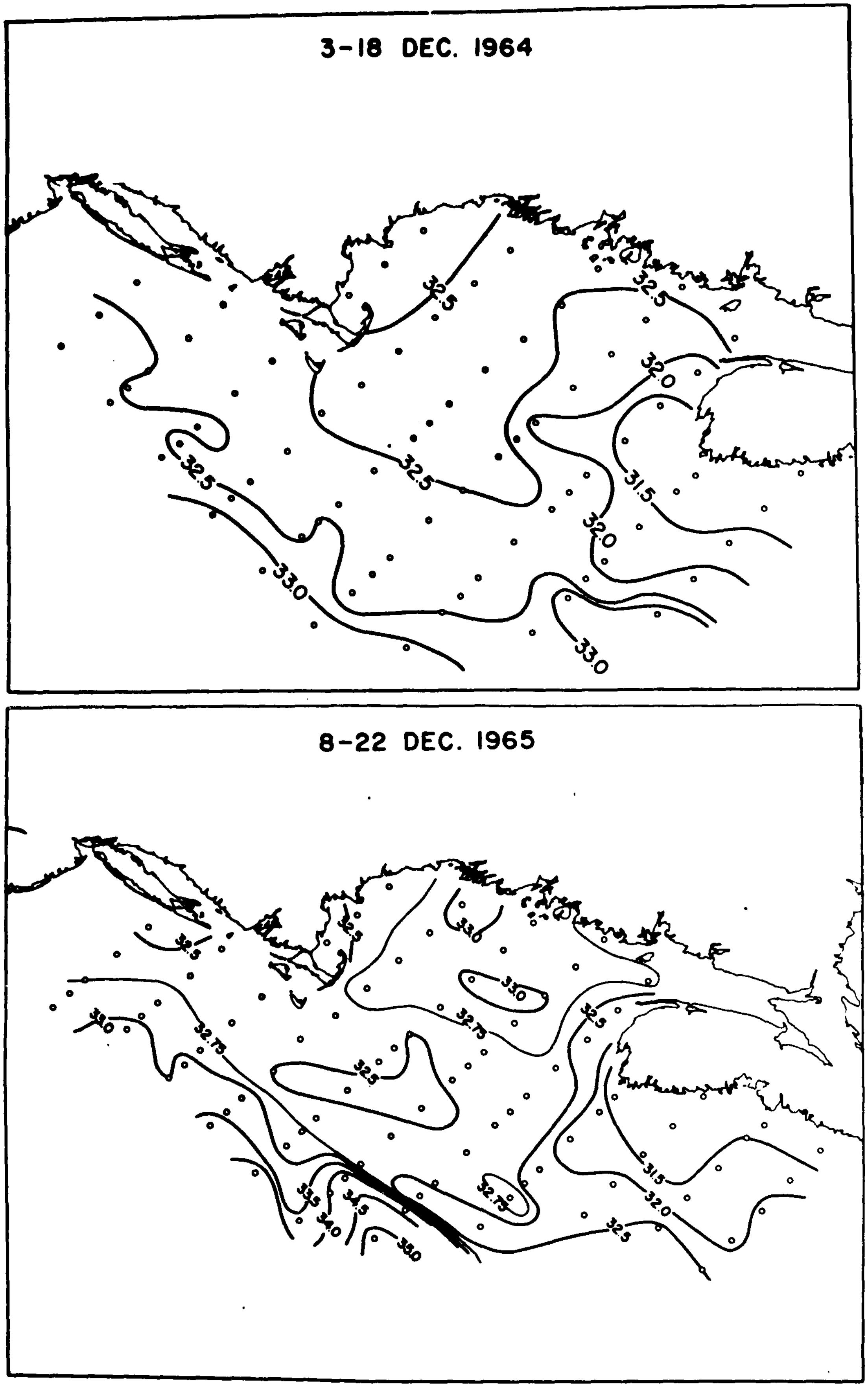
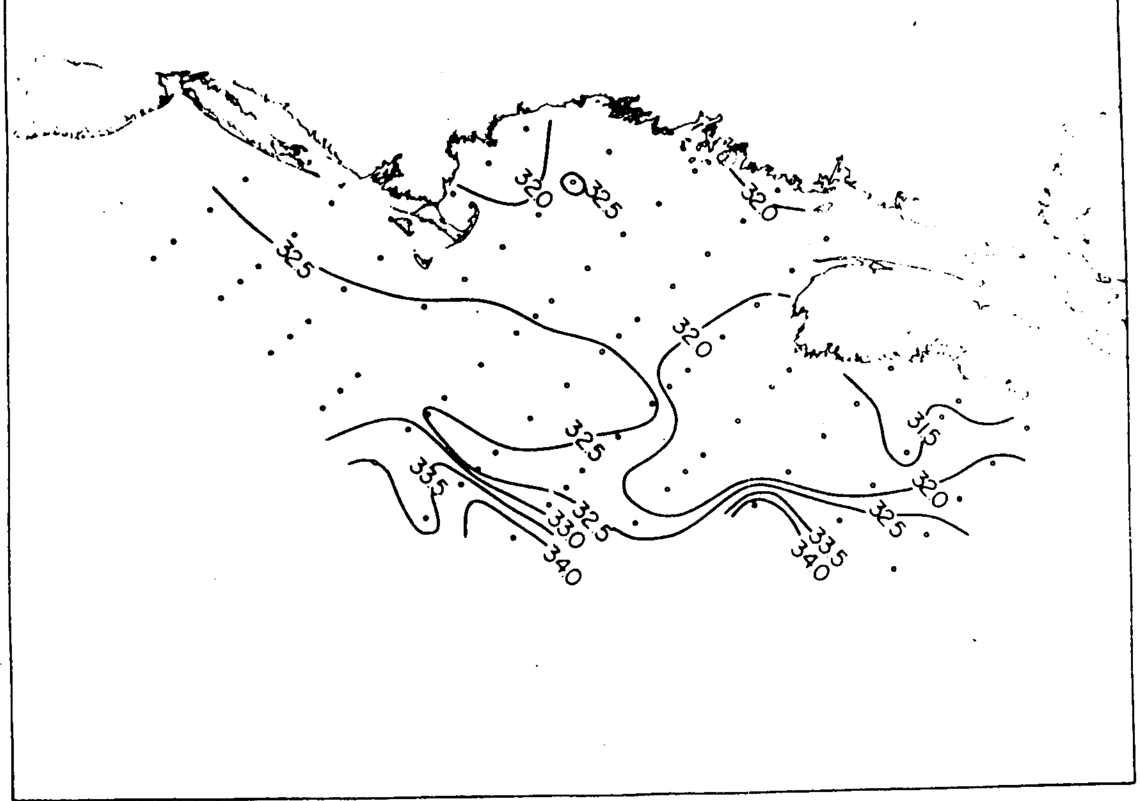


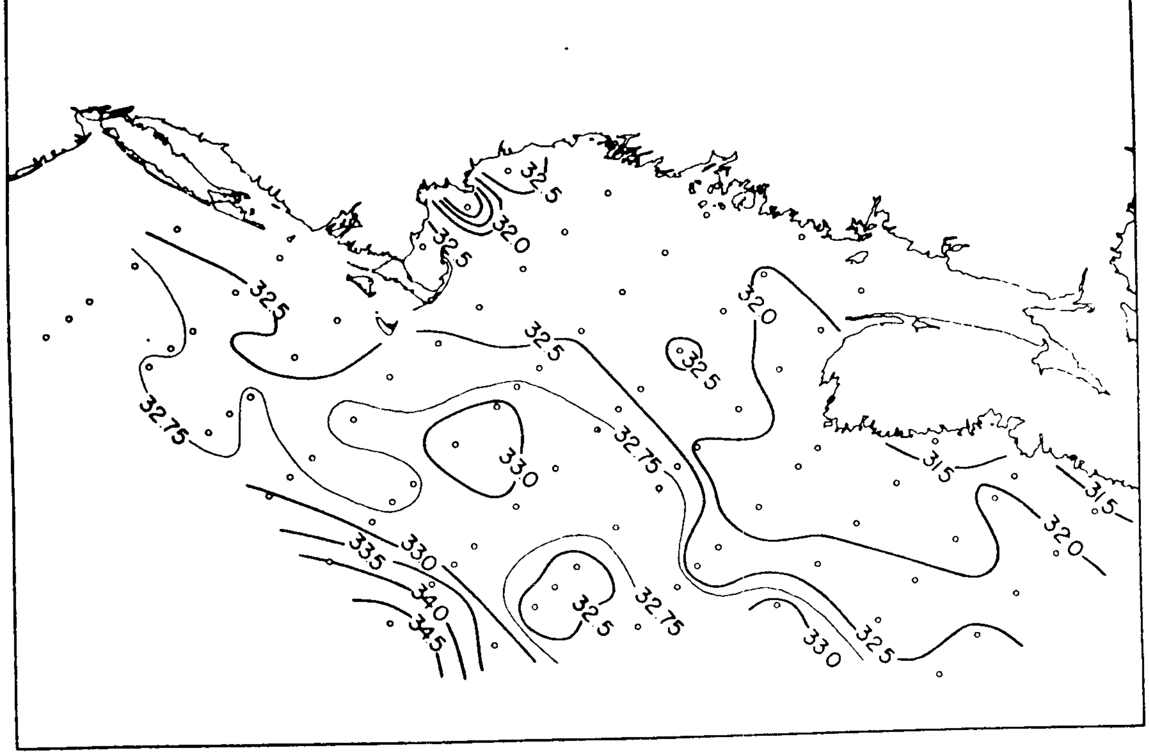
FIGURE 3-74

Surface Isohalines in December (Colton, et al., 1968)

9-20 MAR. 1965



2-14 MAR. 1966

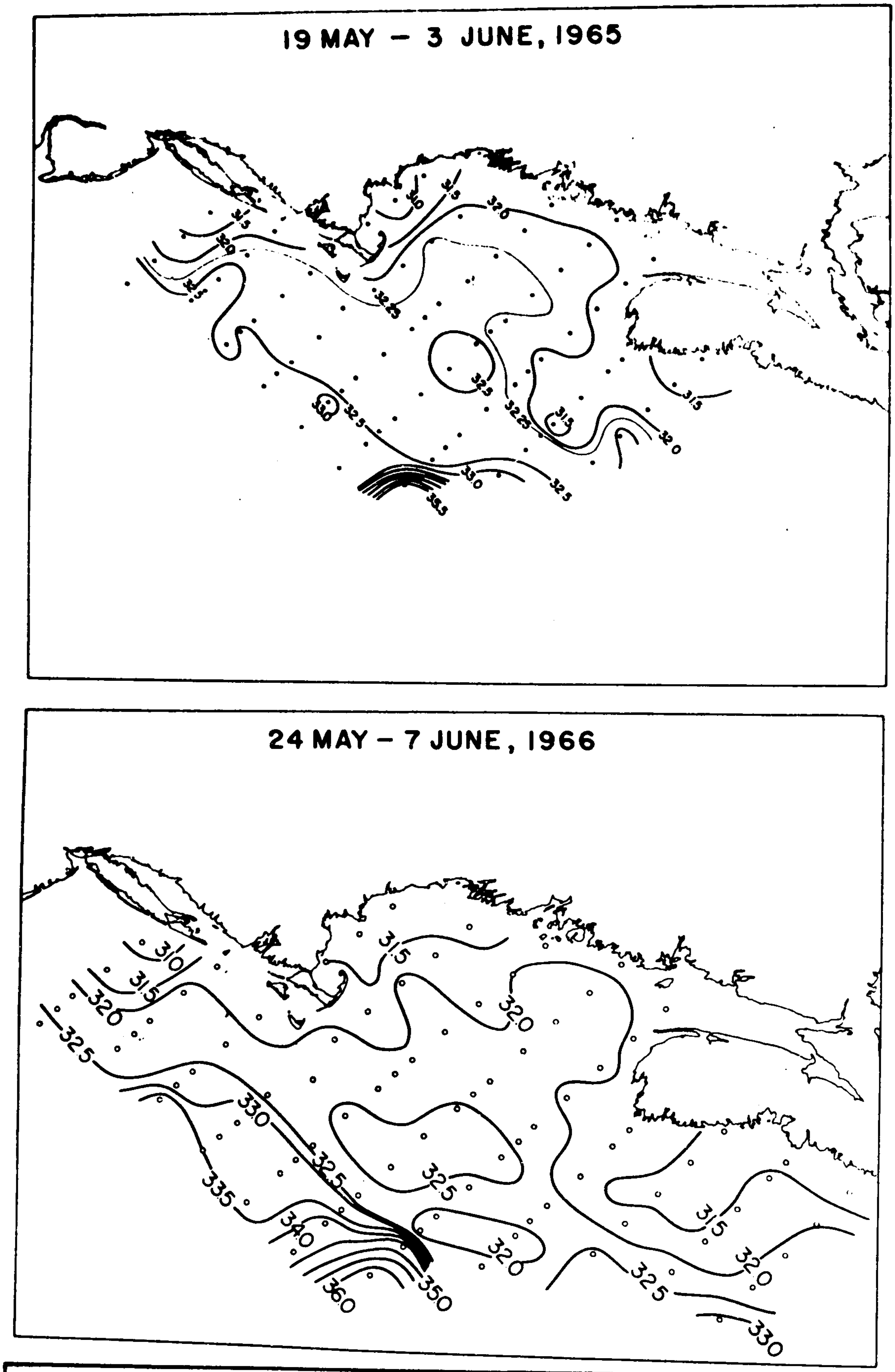


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-75

Surface Isohalines in March
(Colton, et al., 1968)


19 MAY – 3 JUNE, 1965

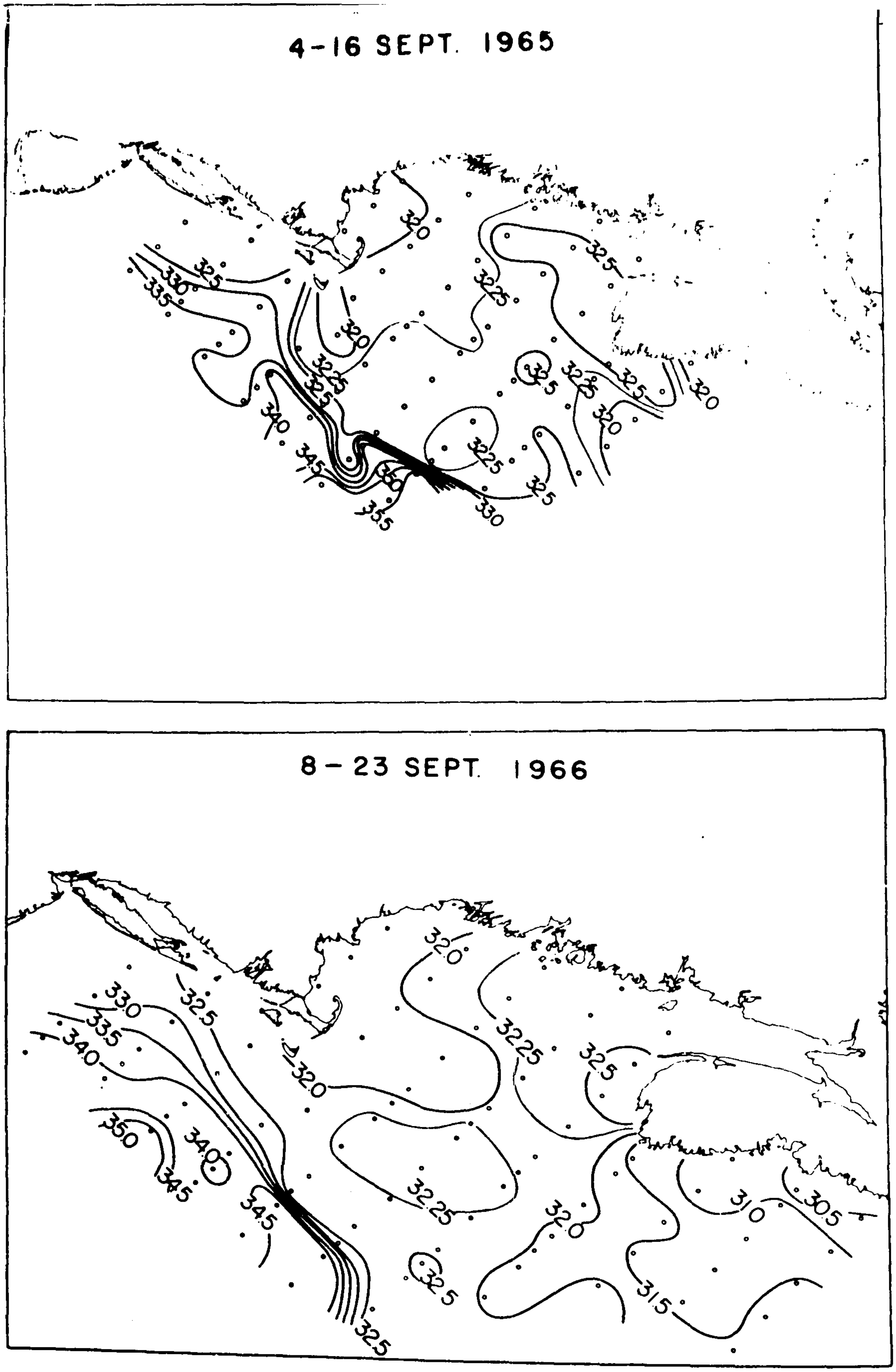
24 MAY – 7 JUNE, 1966

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-76

Surface Isohalines in May-June
(Colton, et al., 1968)



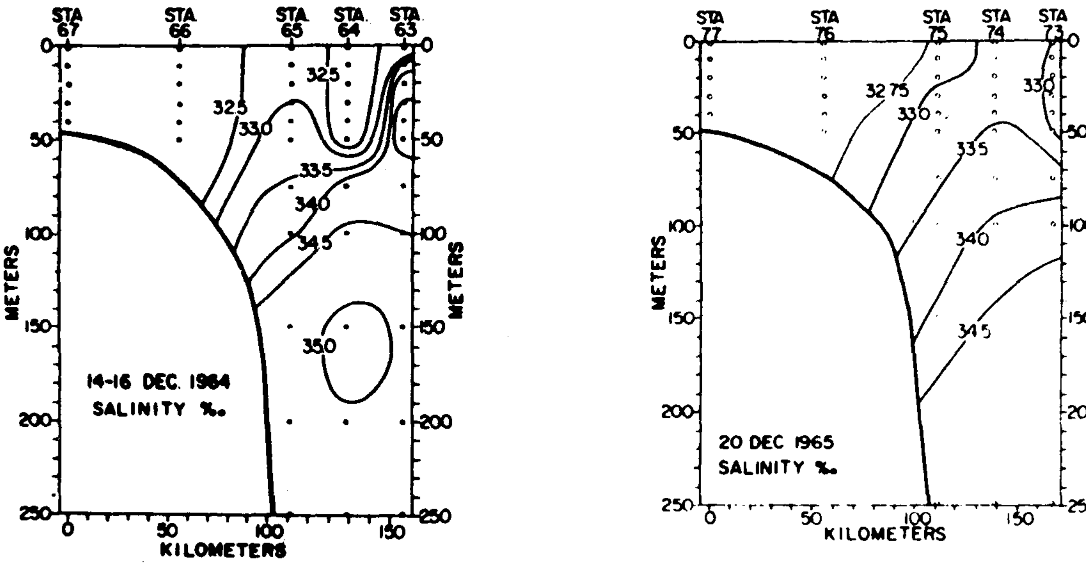
4-16 SEPT. 1965

8 – 23 SEPT 1966

TRIGOM PARC

FIGURE 3-77

Surface Isohalines in September
(Colton, et al., 1968)



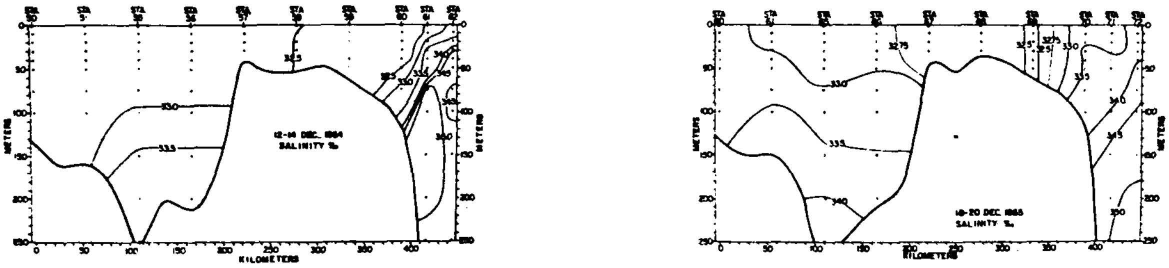
SECTION B

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-78

Salinity Profiles for Sections in Figure 3-56



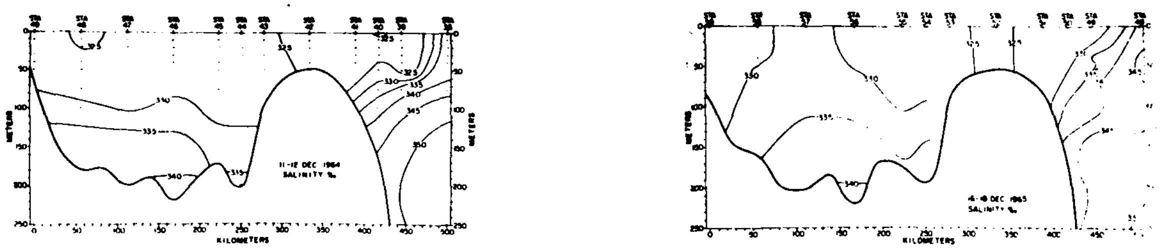
SECTION C

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-79

Salinity Profiles for Sections in Figure 3-56



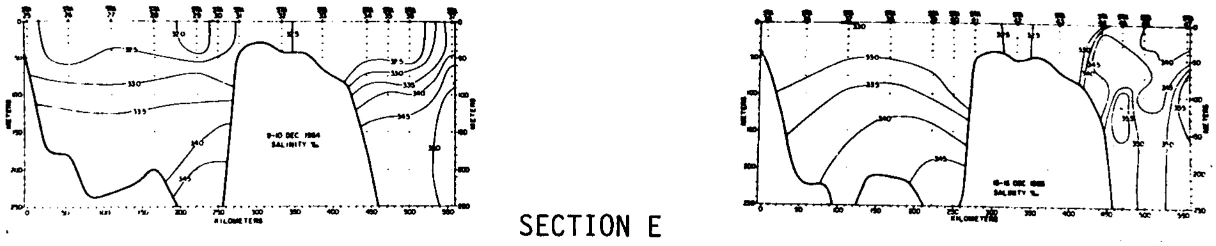
SECTION D

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

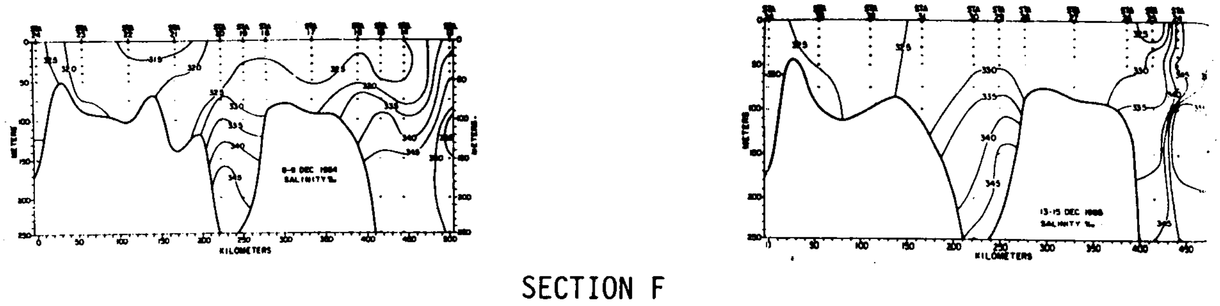
FIGURE 3-80

Salinity Profiles for Sections in Figure 3-56



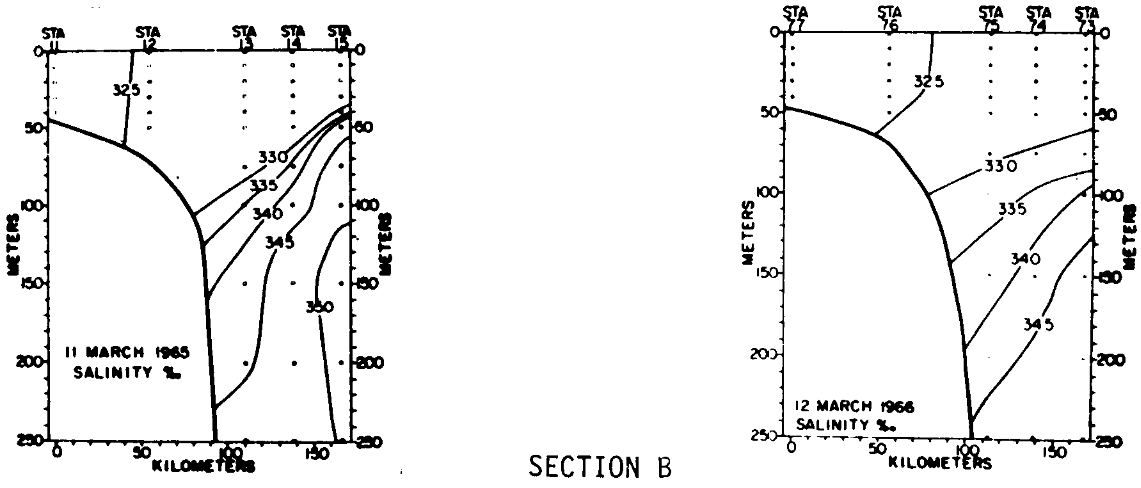
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-81 | Salinity Profiles for Sections in Figure 3-56



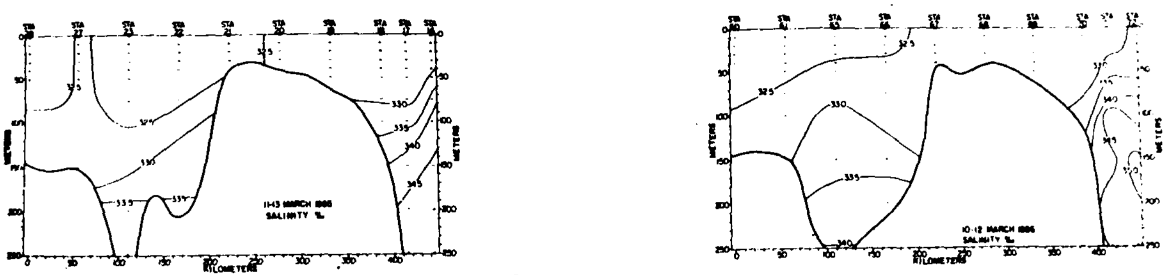
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-82 | Salinity Profiles for Sections in Figure 3-56



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

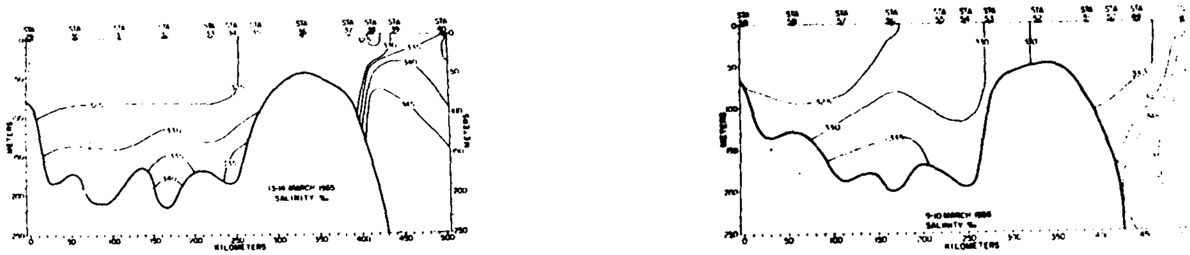
TRIGOM PARC | FIGURE 3-83 | Salinity Profiles for Sections in Figure 3-56



SECTION C

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-84	Salinity Profiles for Sections in Figure 3-56



SECTION D

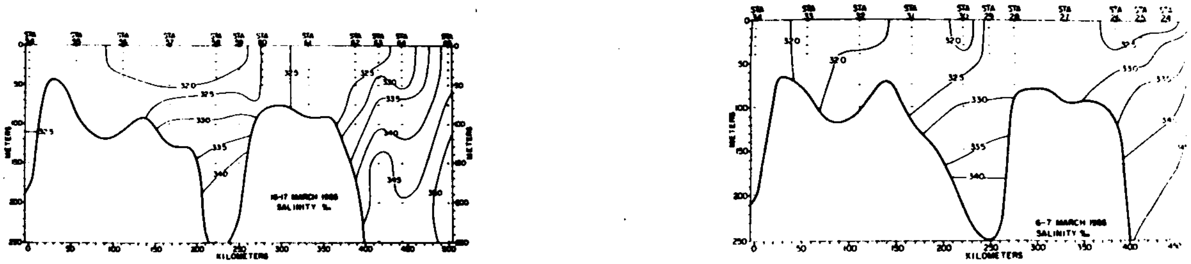
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-85	Salinity Profiles for Sections in Figure 3-56

SECTION E

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

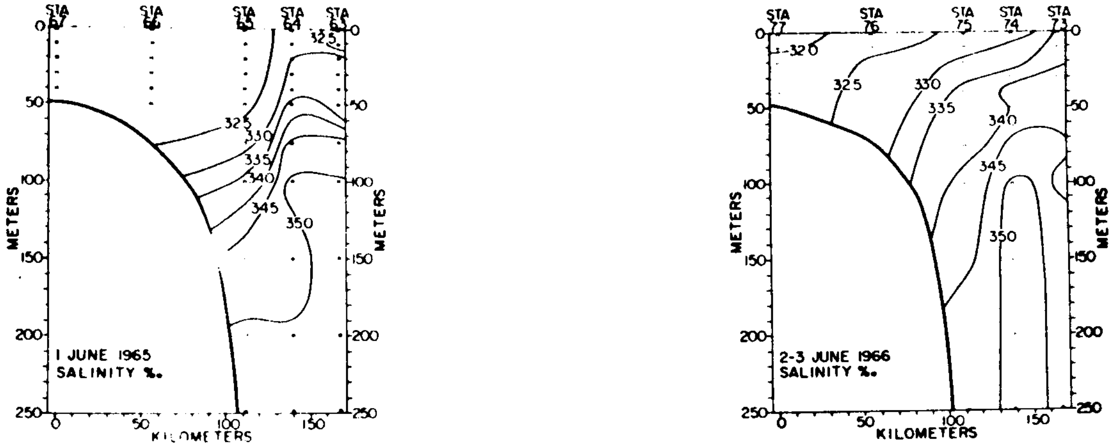
TRIGOM PARC	FIGURE 3-86	Salinity Profiles for Sections in Figure 3-56



SECTION F

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

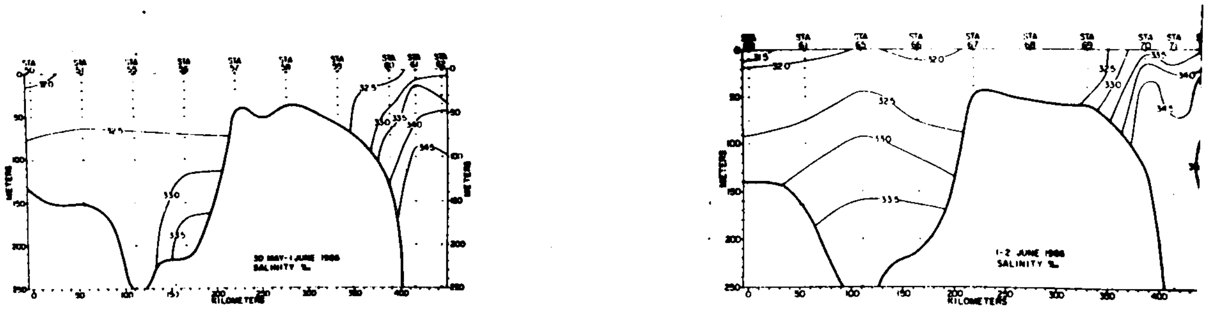
TRIGOM PARC	FIGURE 3-87	Salinity Profiles for Sections in Figure 3-56



SECTION B

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

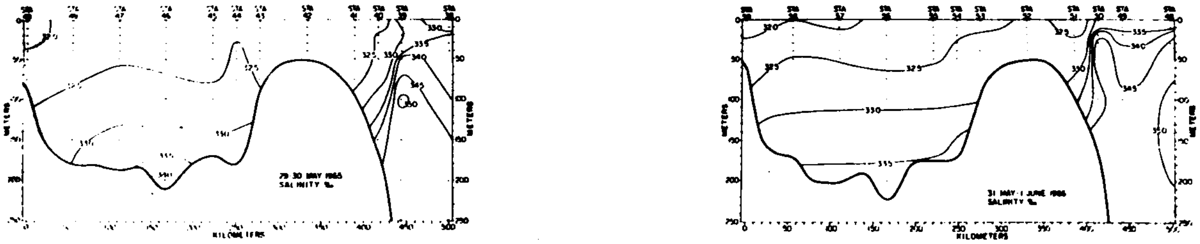
TRIGOM PARC	FIGURE 3-88	Salinity Profiles for Sections in Figure 3-56



SECTION C

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-89	Salinity Profiles for Sections in Figure 3-56



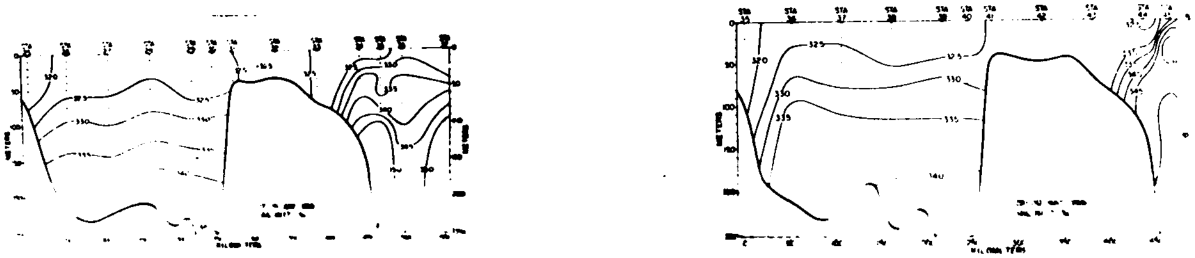
SECTION D

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-90

Salinity Profiles for Sections in Figure 3-56



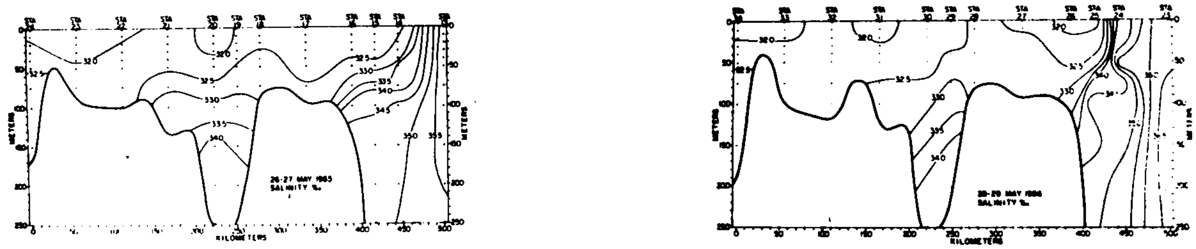
SECTION E

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-91

Salinity Profiles for Sections in Figure 3-56



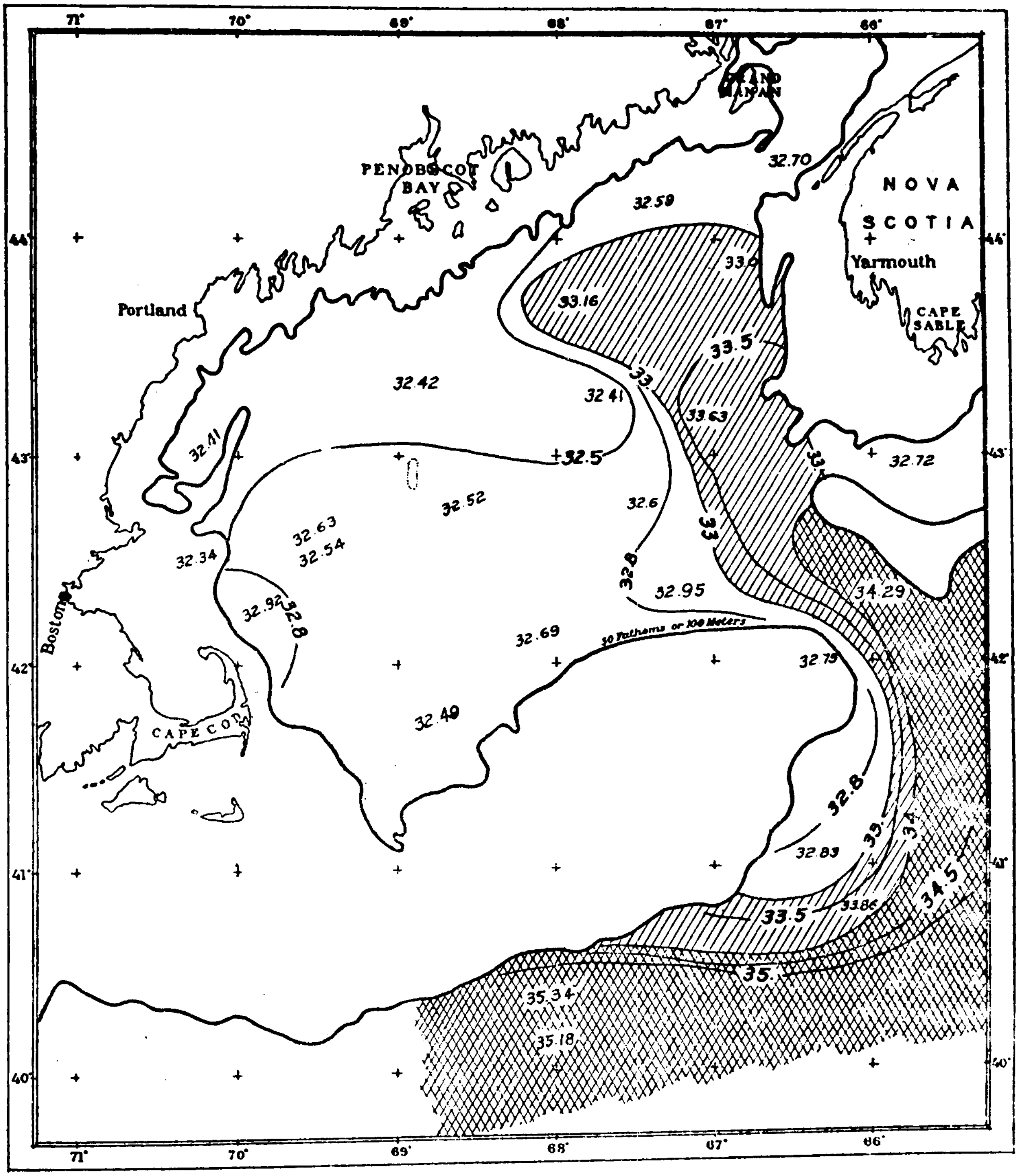
SECTION F

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-92

Salinity Profiles for Sections in Figure 3-56



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-93

Salinity at 100 Meters (Bigelow, 1927)

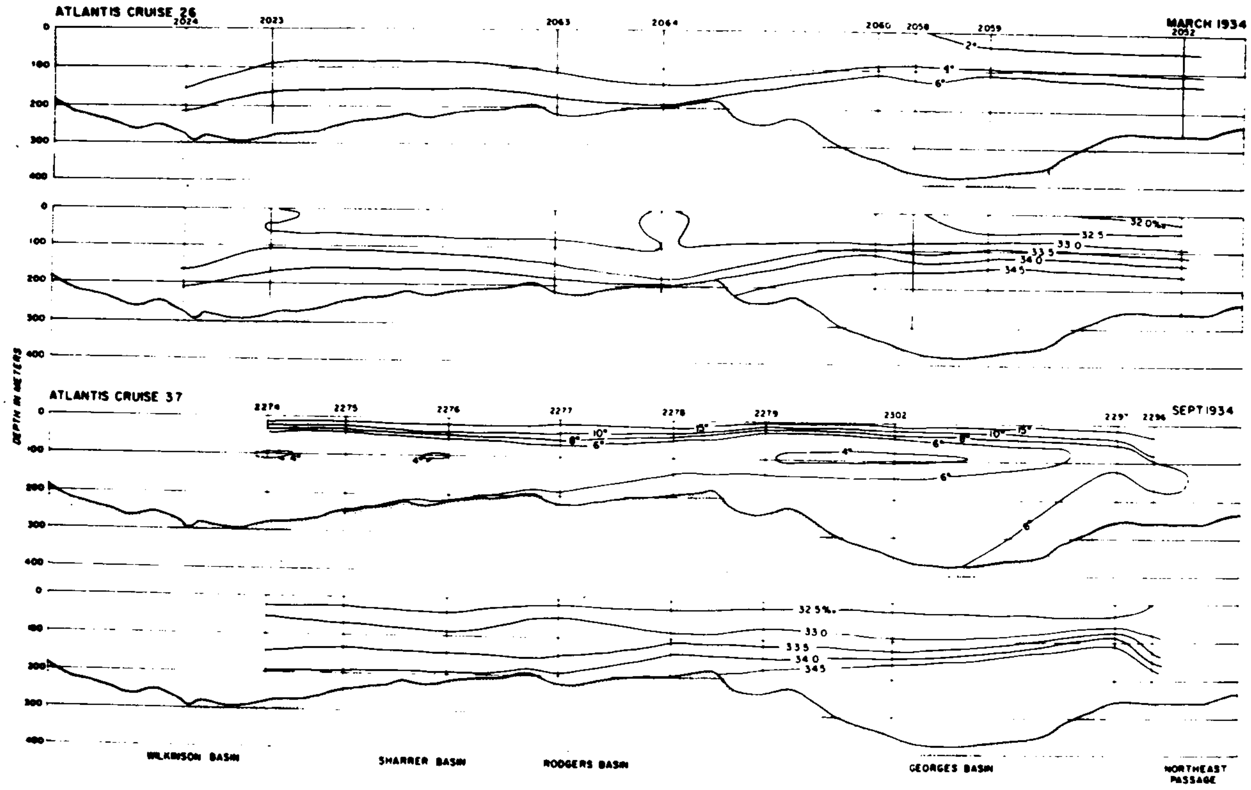
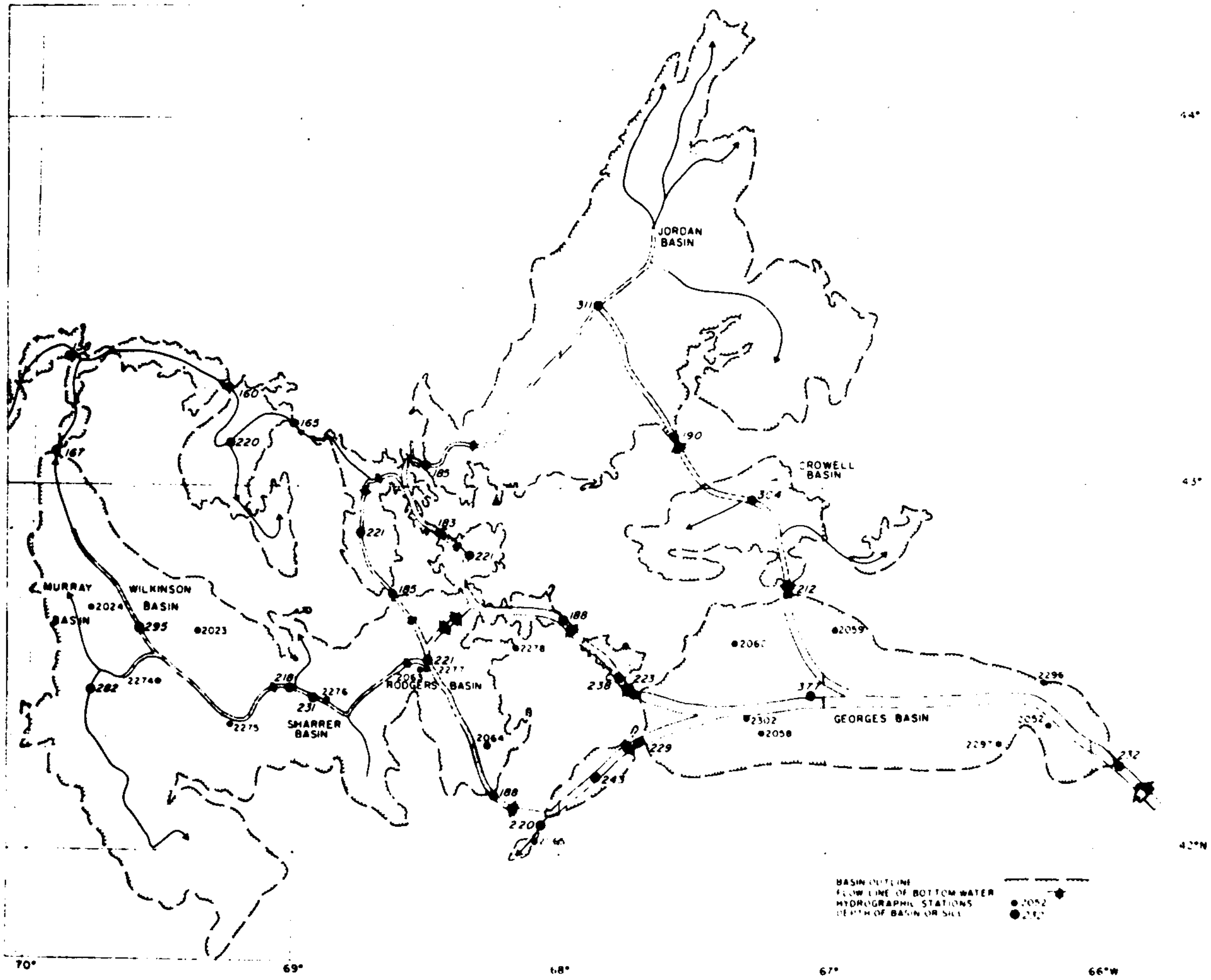


FIGURE 3-94

Vertical Sections of Temperature and Salinity Along a Southern Series of Basins in the Gulf of Maine (Emery and Uchupi, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-95

Flow of Bottom Water from Basin to Basin in the Gulf of Maine (Emery and Uchupi, 1972)

3.2.5 REFERENCES

Bigelow, H. B. 1927. Physical oceanography of the Gulf of Maine. Fish. Bull. U.S., 40:511-1027.

Bumpus, D. F. MS. A description of the circulation on the continental shelf of the east coast of the United States. Woods Hole Ocean. Inst. 84 p.

_______. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Bd. Canada, 17(6): 181-197.

Bumpus, D. F. and L. M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Am. Geogr. Soc. Ser. Atlas, Marine Environment, Folio 7: 4 p. 1 Table.

Colton, John B., Jr. 1964. History of oceanography in the offshore waters of the Gulf of Maine: Spec. Sci. Rep., U.S. Fish. Wildl. Serv. - Fish., No. 496, 18 p.

Colton, John B. Jr., Robert R. Marak, Samuel Nickerson and Ruth F. Stoddard. 1968. Physical, chemical and biological observations on the continental shelf, Nova Scotia to Long Island, 1964-66. U.S. Fish and Wildlf. Serv., Data Rept. 23, Microfiche, 1 p.

Colton, John B. Jr., and Ruth R. Stoddard. 1973. Bottom water temperatures on the continental shelf, Nova Scotia to New Jersey. U.S. Dept. Comm., NOAA Techn. Rep. NMFS - 376:55 p.

________. 1972. Average monthly sea-water temperatures, Nova Scotia to Long Island. 1940-1959. Amer. Geog. Soc., Folio 21, 2 p. Appendix, 10 plates.

Colton, John B., Jr., Robert F. Temple and Kenneth A. Honey. 1962. The occurrence of oceanic copepods in the Gulf of Maine - Georges Bank area. Ecology, Vol. 43, No. 1, 166-171.

Day, C. G. 1958. Surface circulation in the Gulf of Maine. Spec Sci. Rep. U.S. Fish and Wildl. Serv., Fish., No. 496, 18 p.

Emery, K. O. 1965a. Geology of the continental margin off the eastern United States. Proc. Symp. Colston Res. Soc., 17: 1-20.

Emery, K. O. and Elazar Uchupi. 1972. Western North Atlantic Ocean: topography, rocks structure, water, life and sediments. Amer. Assoc. Petr. Geol., Memoir 17:532 p.

Graham, J. J. 1970a. Coastal currents of western Gulf of Maine. Intern. Comm. Northwest Atl., Fish. Res. Bull. 7:19-31.

Haight, F. J. 1942. Coastal currents along the Atlantic coast of the United States. U.S. Dept. Comm. Coast and Geodetic Survey. Spec. Publ. 230:73 p.

Lauzier, L. M. 1967. Bottom residual drift on the continental shelf area of the Canadian Atlantic coast. J. Fish. Res. Bd. Canada, 24 (9):1845-59.

McLellan, H. J. 1957. On the distinctness and origin of the slope water of the Scotian Shelf and its easterly flow south of the Grand Banks, J. Fish. Res. Board, Can., 14:213-239.

Neu, H. J. A. 1972. Extreme wave height distribution along the Canadian Atlantic coast. Ocean Industry, July, p. 45-49.

Normandeau Associates, Inc. 1972. Seabrook Station: environmental report, construction state. For: Public Service Company of New Hampshire.

Redfield, Alfred C. 1941. The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. Biolo. Bull. Vol. 80, No. 1:86-110.

__________, and Alice Beal. 1940. Factors determining the distribution of Chaetognaths in the Gulf of Maine. Biol. Bull. Vol. 79, No. 3: 459-487.

Sverdrup, H. U., M. W. Johnson, and R. A. Fleming. 1942. The oceans: their physics, chemistry, and general biology. Prentice-Hall, Inc., New York, New York 1087 p.

Thompson, E. P. and D. L. Harris. 1972. A wave climatology for U.S. coastal waters. Coastal Eng. Res. Center Reprint p. 1-72.

U.S. Department of Commerce. 1973. Environmental conditions within specified geographical regions, 735 pp.

U. S. Navy. 1955. Marine climatic atlas of the world. Vol. 1, North Atlantic Ocean. Commander, U. S. Naval Weather Service Command, Washington, D.C.

U. S. Navy/U. S. Weather Bureau. 1959. Climatological and oceanographic atlas for mariners. Vol. 1, North Atlantic Ocean.

U.S. Navy. 1963. Oceanographic atlas of the North Atlantic Ocean, Section IV, Sea and swell. H. O. Pub. 700.

3.2.6 PHYSICAL OCEANOGRAPHY OF NEW ENGLAND COASTAL WATERS, CAPE COD, MASSACHUSETTS TO SANDY HOOK, NEW JERSEY

INTRODUCTION

The New England shoreline, with its complex series of islands, embayments and headlands, emerges from a broad continental shelf which stretches as much as 200 miles offshore (Figure 3-96). The coastline runs essentially northeast-southwest from Maine to the Cape Cod-Nantucket Island area, where it veers sharply to the west. The outer edge of the continental shelf is smoother in profile, but reflects the general directional trends of the emergent shoreline.

Classified by geologists as a glaciated and drowned coast, it reflects its dynamic history in the deep fjord-type bays and rocky shores north of Cape Elizabeth, Maine (Bigelow, 1924). To the south, the remains of two terminal moraines contribute substantially to the coastal structure. The Nantucket Island, Martha's Vineyard, Block Island, Montauk Point-Long Island areas comprise the visible portions of the Ronkonkoma-Nantucket moraine, while the Cape Cod, Elizabeth Islands, Point Judith, Fishers Island, Orient Point-Long Island areas constitute remains of the Harbor Hill moraine (McMaster, 1960).

In this section, Offshore Shelf will refer to areas south of the Ronkonkoma-Nantucket moraine, while Inshore will refer to the series of sounds stretching from east to west along the coast, defined to a large extent by the exposed and submerged morainal remnants.

The continental shelf averages only 185 km in width south of Cape Cod. It has a generally smooth and gentle slope when compared with the banks and basins of the Gulf of Maine. The slope breaks at 120-160 m. A general review of the physical oceanography of the shelf area is given in Bumpus, Lynde, and Shaw (1973), and the relationship of this area to the rest of the east coast shelf is given in Bumpus (in press).

3.2.7 WAVE CLIMATE

Waves are caused by wind, and hence the meteorological conditions of the area will determine the wave climate. The energy content of a wave is a function of its height and its speed of propagation, properties which are determined by the velocity of the wind, its duration, and the fetch (distance over which it blows) as shown in Figure 3-97. The relationship between wind velocity and wave height (hence energy) has been illustrated in Figure 3-36 where isopleths for the frequency of occurrence of strong winds show markedly similar patterns to those for the frequency of high waves (Emery and Uchupi, 1972). Off southern New England, waves are higher during November to February when the 30 percent isocline for waves exceeding 1.5 meters in height moves inshore (Figure 3-98), even as far west as the Block Island Sound area (Bumpus, et al., 1973).

Although direct observational data from the area are sparse (Navy ocean station vessels all occupy positions beyond the Middle Atlantic Bight), these and other extrapolations based on OSV's and ships' logs estimate that wave heights in winter exceed 6 m about 2 percent of the time, and that waves exceeding 13 m could be expected once every 2 years, while those exceeding 31 m could be expected once in 50 years. The median significant wave height (significant wave height is the average height of the highest third of the waves during an observation period) is 1.2 m in winter and 0.7 m in summer.

Due to Coriolis force, the direction of propagation of wind-driven waves in the northern hemisphere (when not affected by an intervening land mass) will be at 45° to the right of the downwind direction at the surface, and this angle will increase with depth to 180° at the depth where the wind no longer moves the water (Ekman flow), producing a mean transport at 90° to the surface direction of the wind. Seasonal wind direction will therefore greatly influence the direction of wave propagation and the resulting net movement of the water mass, often to considerable depths. Although SW winds predominate from May through August, and NW winds from September through April, reversals do occur, and even over periods as short as 12 to 24 hours they can have profound effects on the direction of water movement (Bumpus, et al., 1973).

The effects of wind on wave propagation off New England has been given in Figures 3-35a and b showing a well-developed NE set in December and a less distinct, somewhat confused pattern in July. There appears to be a sharp break in conditions north of New York Harbor during both seasons. In winter the New York Bight area appears to be fairly homogeneous with the Gulf of Maine, but in summer a definite transition occurs off Nantucket. This transition is also reflected in current patterns and in temperature and salinity as shown in later sections.

3.2.8 CIRCULATION

The net circulation on the shelf is the resultant of both tidal and net tidal components, both of which become weaker with distance from shore and with depth. Tidal components are generally less than 2 km/hr on the shelf (Table 3-3). Maximum velocities within the tidal cycle are plotted for several stations on Figure 3-99. The significantly turbulent area of Nantucket Shoals logged the greatest offshore velocity of those measured (Bumpus, et al., 1973). Non-tidal components are of the order of 9 nautical km per day (.37 km/hr) while bottom drift is generally measured in tenths of a nautical km per day (Figure 3-100). Thus they are generally one to several orders of magnitude less than the tidal component and easily masked by wind and wave conditions.

Non-tidal drift results from wind and geostrophic factors (pressure or density gradients) as modified by Coriolis force and the geomorphology

Table 3-3 Hourly tidal current velocities at selected locations. (From Haight, 1942)

Location		Hours after Greenwich transit of the moon												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Nantucket Shoals **40°37.1'N 69°37.1'W**	Kts. °T	0.71 355	0.80 015	0.84 038	0.75 056	0.67 086	0.61 128	0.69 166	0.80 193	0.83 215	0.80 233	0.69 260	0.62 308	0.67 344
Vineyard Sound **41°22.8'N 71°00.0'W**	Kts. °T	0.22 030	0.20 097	0.36 138	0.48 152	0.52 163	0.42 181	0.24 208	0.24 265	0.26 311	0.36 327	0.43 344	0.42 355	0.29 020
U.S.S. Finch **40°04.3'N 72°43.4'W**	Kts. °T	0.05 065	0.10 085	0.14 104	0.14 122	0.13 128	0.07 152	0.07 203	0.12 257	0.10 295	0.10 291	0.11 307	0.09 345	0.10 025
Five Island **40°28.7'N 73°11.4'W**	Kts. °T	0.00 --	0.08 073	0.11 090	0.15 093	0.14 098	0.11 100	0.04 115	0.04 255	0.11 271	0.13 277	0.12 280	0.10 285	0.02 330
U.S.S. Cardinal **40°16.0'N 73°15.5'W**	Kts. °T	0.07 308	0.03 045	0.09 095	0.09 109	0.12 112	0.12 115	0.09 132	0.00 --	0.09 257	0.11 281	0.11 292	0.11 297	0.08 305
Ambrose Channel **40°28.0'N 72°50.0'W**	Kts. °T	0.24 283	0.15 280	0.02 282	0.10 100	0.18 093	0.24 092	0.28 096	0.21 101	0.06 120	0.08 270	0.17 272	0.24 277	0.25 292
Ambrose Channel **40°27.1'N 73°49.4'W**	Kts. °T	0.23 285	0.15 295	0.06 292	0.04 090	0.11 090	0.17 090	0.22 095	0.21 106	0.16 121	0.00 --	0.14 262	0.24 278	0.24 282
Scotland **40°26.6'N 73°55.2'W**	Kts. °T	0.41 312	0.26 327	0.12 024	0.21 079	0.41 111	0.60 127	0.65 133	0.44 144	0.10 190	0.24 287	0.42 295	0.49 298	0.45 308
Barnegat **39°45.9'N 73°56.0'W**	Kts. °T	0.03 020	0.02 083	0.03 119	0.05 130	0.05 141	0.04 152	0.03 204	0.02 272	0.04 301	0.05 321	0.05 335	0.05 343	0.04 004
U.S.S. Falcon **39°04.5'N 73°25.5'W**	Kts. °T	0.06 015	0.06 029	0.04 059	0.04 091	0.05 147	0.06 146	0.05 183	0.04 221	0.06 240	0.07 259	0.04 293	0.04 302	0.06 000
Northeast End **38°57.8'N 74°09.6'W**	Kts. °T	0.10 329	0.06 039	0.12 086	0.19 102	0.22 110	0.20 119	0.13 140	0.07 197	0.11 261	0.20 280	0.23 290	0.20 300	0.13 317
Five Fathom Bank **38°47.3'N 74°34.6'W**	Kts. °T	0.22 304	0.06 005	0.11 073	0.23 099	0.29 103	0.30 112	0.26 125	0.15 158	0.10 217	0.20 268	0.29 284	0.32 295	0.26 301
Overfalls **38°47.9'N 75°01.4'W**	Kts. °T	1.37 306	0.85 317	0.38 015	0.32 087	1.21 117	1.40 126	1.23 131	0.88 136	0.44 173	0.25 252	0.92 297	1.38 300	1.43 303
Fenwick Is. Shoal **38°27.4'N 74°46.7'W**	Kts. °T	0.24 346	0.18 354	0.08 025	0.10 088	0.19 126	0.27 145	0.27 158	0.22 176	0.14 208	0.09 259	0.16 308	0.23 329	0.25 343
Winter Q'tr Shoal **37°55.4'N 74°56.4'W**	Kts. °T	0.07 000	0.06 030	0.06 062	0.06 090	0.05 121	0.06 154	0.07 185	0.06 206	0.06 235	0.06 266	0.06 290	0.06 323	0.06 350
U.S.S. Brant **37°04.6'N 74°51.1'W**	Kts. °T	0.08 358	0.11 042	0.16 061	0.19 083	0.19 106	0.15 133	0.11 183	0.12 237	0.15 261	0.16 273	0.16 292	0.17 326	0.10 335
Cape Charles **37°05.3'N 74°43.5'W**	Kts. °T	0.30 264	0.20 263	0.10 228	0.05 144	0.19 090	0.27 089	0.29 086	0.22 080	0.10 055	0.03 340	0.19 265	0.26 268	0.30 264
Chesapeake **36°58.7'N 75°42.2'W**	Kts. °T	0.15 279	0.13 278	0.06 271	0.03 335	0.10 093	0.14 095	0.15 094	0.13 100	0.09 106	0.00 --	0.06 272	0.13 281	0.15 278
Tail of Horseshoe **36°58.8'N 76°00.4'W**	Kts. °T	0.56 312	0.90 312	0.95 312	0.64 312	0.12 312	0.50 126	1.04 126	1.40 126	1.50 126	1.29 126	0.85 126	0.21 126	0.36 312
Diamond Shoal **35°05.3'N 75°19.7'W**	Kts. °T	0.04 035	0.04 072	0.04 116	0.04 140	0.04 165	0.04 205	0.03 237	0.03 266	0.03 293	0.03 321	0.03 337	0.03 341	0.03 024

of the area. The effect of wind friction on water movement was discussed in the previous section on waves. Pressure gradients may be set up by differences in the height of the sea surface through several mechanisms: prevailing winds may pile up the water, especially in coastal areas; localized barometric pressure differentials may produce a similar effect (although it probably accounts for less than 3 cm of the observed differences in the northwestern Atlantic); river runoff may effect a higher volume along the coast; and in situ density characteristics may operate. Emery and Uchupi (1972) reported that in situ density curves were closely correlated with curves for sea level. Temperature and salinity changes in the water itself change the density and hence the pressure structure. Onshore-offshore temperature gradients typically reverse themselves seasonally, and salinity changes are most pronounced in the spring with increased runoff which also affects coastal sea levels. Unseasonably warm, cold, rainy, dry or windy weather would modify expected patterns. Apparently wind-induced advection is more effective in changing water temperatures than is simple atmospheric influence (Day, 1963). When only the pressure gradient and its Coriolis component are involved, the resultant balanced flow is called a geostrophic current, and its direction will be 90^{o} to the right of the decreasing pressure gradient (in the northern hemisphere).

Emery and Uchupi (1972) describe an increasing slope to the sea surface from Key West to Portland of 0.58 m or 0.24 mm/km resulting from water piling up against the coast and high runoff from the northeastern states (Table 3-4). The influence of runoff on salinity (hence density) on the shelf is shown in Table 3-5 and Figure 3-101.

This slope would produce a movement of shelf and inner slope water at a velocity of ca 0.10 cm/sec (.037 km/hr) to the Southwest, and is steep enough so that seasonal variations in the temperature and salinity gradients along the coast would not normally be sufficient to reverse the direction of flow. Transient nearshore current reversals have been recorded during spring and summer in years of prevailing southerly winds and low river flow (Bumpus, 1969). Usually, however, estuarine runoff increases sea level and hence produces even faster nearshore currents in some places.

There is indeed a westerly to southwesterly drift of surface water south of New England as shown in Figures 3-102 and 3-103. These figures show a winter pattern of general offshore movement, partially in response to winter northeast storms. A very light inshore current moves into Rhode Island Sound and Vineyard Island Sound. By spring the offshore current reverses and flows northward into Rhode Island Sound, while an easterly component develops along the south shore of Long Island. Water leaving Lond Island Sound moves west and south or turns easterly to Rhode Island Sound. There is a strong inshore component in toward New York Harbor and a strong offshore countercurrent for the length of New York Bight.

Table 3-4 Stream flow into Atlantic Coastal Waters from 3 areas, showing basis for classification of shelf area south of Cape Cod in New England as a salt wedge estuary by Bumpus (from Bumpus, *et al*., 1973).

STREAM FLOW INTO THE THREE MAJOR SEGMENTS OF THE ATLANTIC COAST BETWEEN THE ST. CROIX RIVER AND CAPE SABLE, FLORIDA, 1931-1960

	Stream flow (m^3/sec)	Length of coastline (km)	Stream flow per length of coastline ($m^3 sec^{-1} km^{-1}$)	Stream flow ($10^9 m^3$/yr)	Area of shelf to (100 m isobath) ($10^9 m^1$)	Stream flow per unit area of shelf (m/yr)
Gulf of Maine	1676.6	735	2.28	52.8	152.6	*0.35
Middle Atlantic Bight	4977.8	1060	4.70	156.8	97.5	1.61
South Atlantic Bight	3290.0	1510	2.18	103.6	100.4	1.03

*Bigelow (1927) estimated 0.79 m/yr for the whole Gulf of Maine
Stream flow data from Bor (1970).
Note that the stream flow/length of coastline for the Middle Atlantic Bight is more than two times that for the Gulf of Maine and the South Atlantic Bight; the stream flow area of shelf for the Gulf of Maine is one-third that for the South Atlantic Bight and ≃ one-fifth that for the Middle Atlantic Bight

Table 3-5

Mean salinity of coastal waters compared to the monthly mean flow of the Connecticut River at Thompsonville, Connecticut, and to the mean flow for the six months prior to the observation of salinity

Date	Mean salinity (‰)	River flow*			
		Monthly mean		6-month mean	
		(ft^3/sec)	(m^3/sec)	(ft^3/sec)	(m^3/sec)
1956					
10 Sept	32.300	3,232	92	22,572	639
28 Nov	34.054	10,420	295	8,880	252
1957					
12 Feb	32.920	13,330	378	9,590	272
21 Mar	32.712	21,130	598	13,160	373
29 Apr	32.703	24,820	703	16,050	455
10 July	32.858	7,042	199	15,370	435
16 Sept	33.619	3,705	105	10,210	289
18 Nov	33.249	11,010	312	6,250	177
1958					
21 Jan	33.508	17,460	495	11,420	323
6 Mar	32.899	12,890	365	12,830	363
12 May	32.503	63,410	1,796	24,880	705
7 July	32.191	10,360	293	25,605	725
5 Sept	31.964	6,512	184	22,890	648
8 Dec	33.106	12,120	343	8,500	241
1959					
25 Feb	33.221	10,030	284	9,620	272
18 May	32.394	14,290	405	19,000	538
12 Aug	32.331	5,357	152	17,754	503
21 Sept	32.691	4,990	141	14,870	421

* For cruises after the 15th of the month, the river flow data for the same month are used; for those prior to the 15th the data for the previous month are used.

By summer both nearshore and offshore waters travel west-southwest south of Long Island. Water enters Rhode Island Sound from the south and east. By autumn the winter offshore component begins to develop. The longshore current south of Long Island continues into New York Harbor, and Long Island Sound water flows west with the current south of Long Island. There still persist components in toward Rhode Island and Vineyard Sounds and New York Harbor.

On the inner shelf movement takes place as a series of 3 to 4-day cells or gyres off the major estuaries as shown in Figure 3-104. The offshore flow splits and one portion enters Rhode Island and Block Island Sounds to the east of Block Island, entraining with a major counterclockwise gyre around Block Island. A second portion continues westward to join the clockwise eddy off the entrance to Long Island Sound. From this eddy water travels westward hugging the shore to join 3 more eddies, a clockwise gyre between Moriches and Shinnecock Inlets, a counterclockwise cell of Great South Bay, and then another clockwise eddy between there and New York Harbor. A countercurrent in New York Bight splits the effluent from New York Harbor into another counterclockwise eddy, and more eddies continue south along the coast. These eddies provide a major mechanism for the entrainment of offshore water and its movement inshore.

Seabed drifters released on the shelf off southern New England showed a consistent residual bottom drift shoreward from the inner 2/3 of the shelf area (Figures 3-105 and 106). Outside of this, the bottom water moved seaward, carrying the drifters off the shelf. The isohalines of vertical cross-sections of the shelf from shore to slope in this area dip downward toward shore in the area of shoreward drift, and downward toward the ocean in areas of seaward drift, although data from Ketchum and Corwin (1964) show this structure only for winter conditions.

Bumpus (personal communication) regards the entire shelf south of New England dynamically like a salt-wedge estuary. The wedge of high salinity water on the bottom moves inward toward shore, especially toward the mouths of estuaries. Seaward of this, the dynamic gradient moves bottom water in the opposite direction. The magnitude of this drift varies from less than 0.1 to 1.3 nautical km per day, usually in the range of 0.2 to 0.5 or 0.4 to 1.0 cm/sec. The shoreward drift is much weaker in winter (Bumpus, 1965a). The dynamics of this system are controlled by the volume of river runoff, thus introducing the seasonal component (Figures 3-104 and 3-105, Table 3-5).

3.2.9 TEMPERATURE AND SALINITY

A considerable amount of data have been compiled for temperature, salinity,and density over the Northwestern Atlantic shelf. Seasonal profiles of both horizontal and vertical gradients are given in Section 3.2-9A. These figures have been annotated to provide interpretation and comparisons for detailed study, and only generalizations are discussed here.

Water temperatures on the shelf reach a minimum in late February or early March, when the onshore-offshore gradient ranges from 4-10 C, the warmer water lying offshore (Figure 3-110). Out to the 100 m depth, the water column is homogeneous (Figure 3-123), while on the slope there is a wedge of warmer water at the 45 to 75 m depth which reaches the surface off Nantucket (Figure 3-143).

In spring, the onshore-offshore gradient is reduced to about 2 C (Figure 3-153) until late April or early May, the entire water column warms together, but after that a thermocline develops as the inshore surface water heats up more rapidly (Figure 3-158). The cold wedge of bottom water is pushed seaward (Figure 3-157), and an abrupt temperature transition zone develops over Nantucket Shoals, where water remains colder by 4-5 C than that to the westward. By June, rapid summer warming takes place, and a thermocline develops throughout the area except over the Shoals where the high degree of mixing reflects the transition zone discussed in the section on wind and waves (Figures 3-115 to 3-117). A cold belt of bottom water occupies the mid-shelf zone throughout the year, with a warmer water mass on either side (Figure 3-142).

Autumn cooling is locally variable, being much slower over Nantucket Shoals until late October, thus eliminating the sharp summer gradient between the Shoals and the areas to the westward. Temperatures equalize with depth throughout the area so that the thermocline disappears and the onshore-offshore gradient is lost as a step in its reversal (see December, Figures 3-157 and 3-158). The entire water column then cools again to its February minimum.

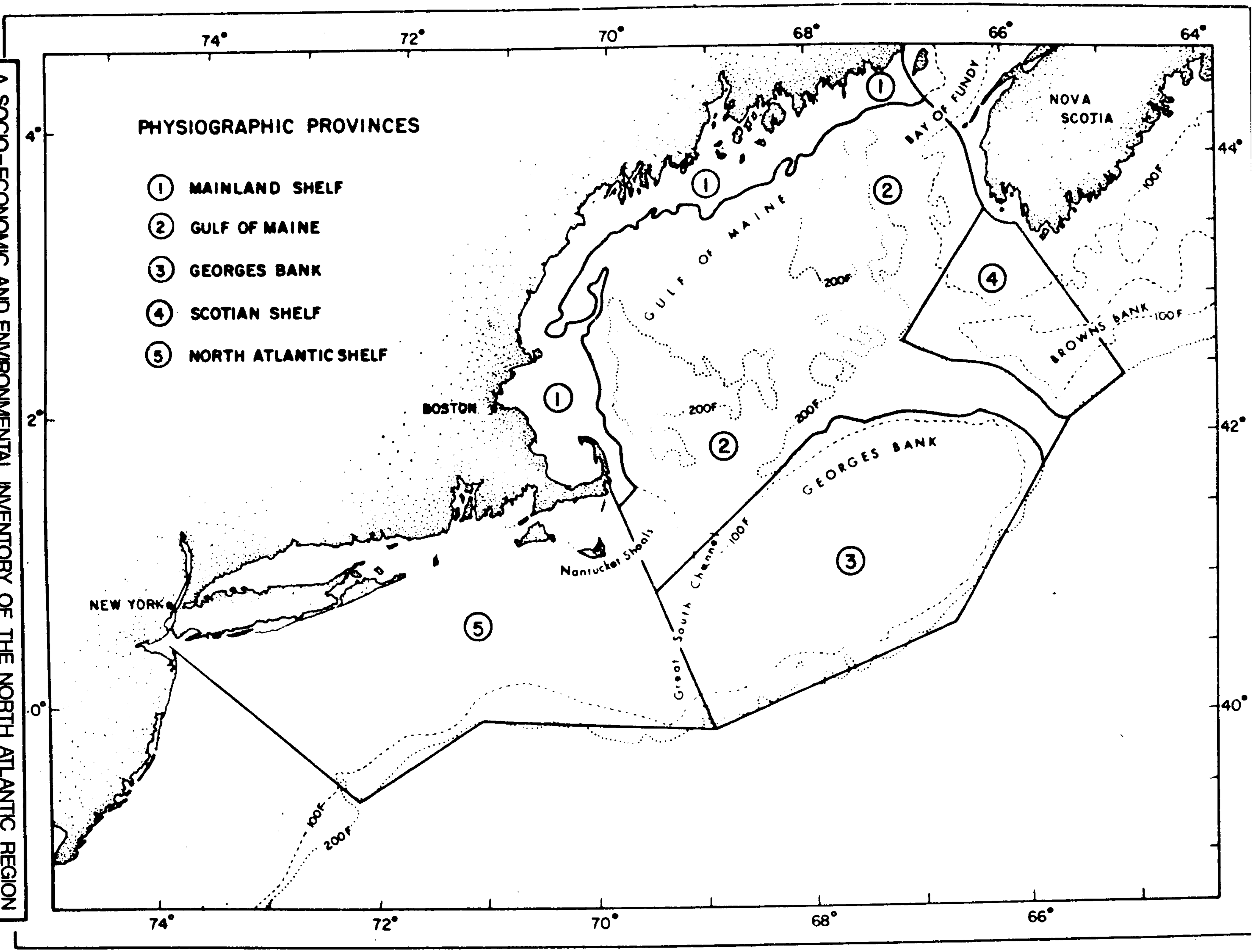
Salinities generally increase with distance from shore, with isohalines running generally parallel to the edge of the Continental Slope (Figures 3-311, 3-112). This gradient persists throughout the year except that salinities are slightly lower on the inner shelf in May and June as a result of higher river discharge. The high correlation between fresh water runoff and shelf salinities has already been discussed (Table 3-5, Figure 3-101); Ketchum and Corwin (1964) have stated that salinities on the shelf south of Montauk Pt., Long Island may be predicted within 3 percent accuracy from the Connecticut River Runoff, allowing for the lag time.

Salinities also increase with depth showing a salt wedge along the bottom of the shelf (3-130, 3-132), which is particularly well defined in winter. The combination of salinity and temperature produces a high-density area about 2/3 of the way out on the shelf, which Bumpus (1965b) cites as the reason for the split in the net direction of movement on the bottom. The onshore-offshore gradients are steeper than gradients with depth, but the entire range (ca 2 ^{o}/oo) is very small compared with inshore waters.

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-96



Physiographic Provinces in the Study Area

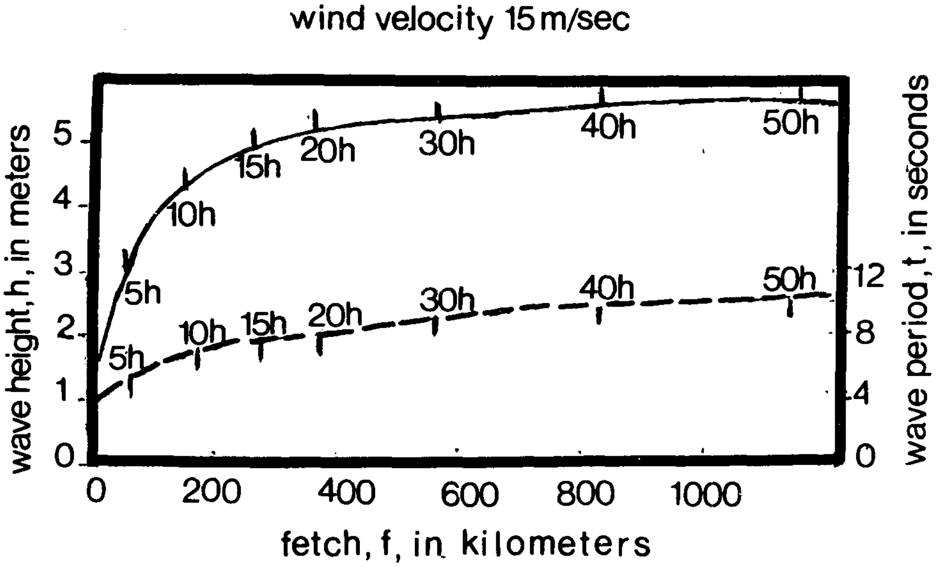


FIGURE 3-97 Relationship Between Wave Height and Period with Fetch Over Time (Sverdrup, et al., 1942)

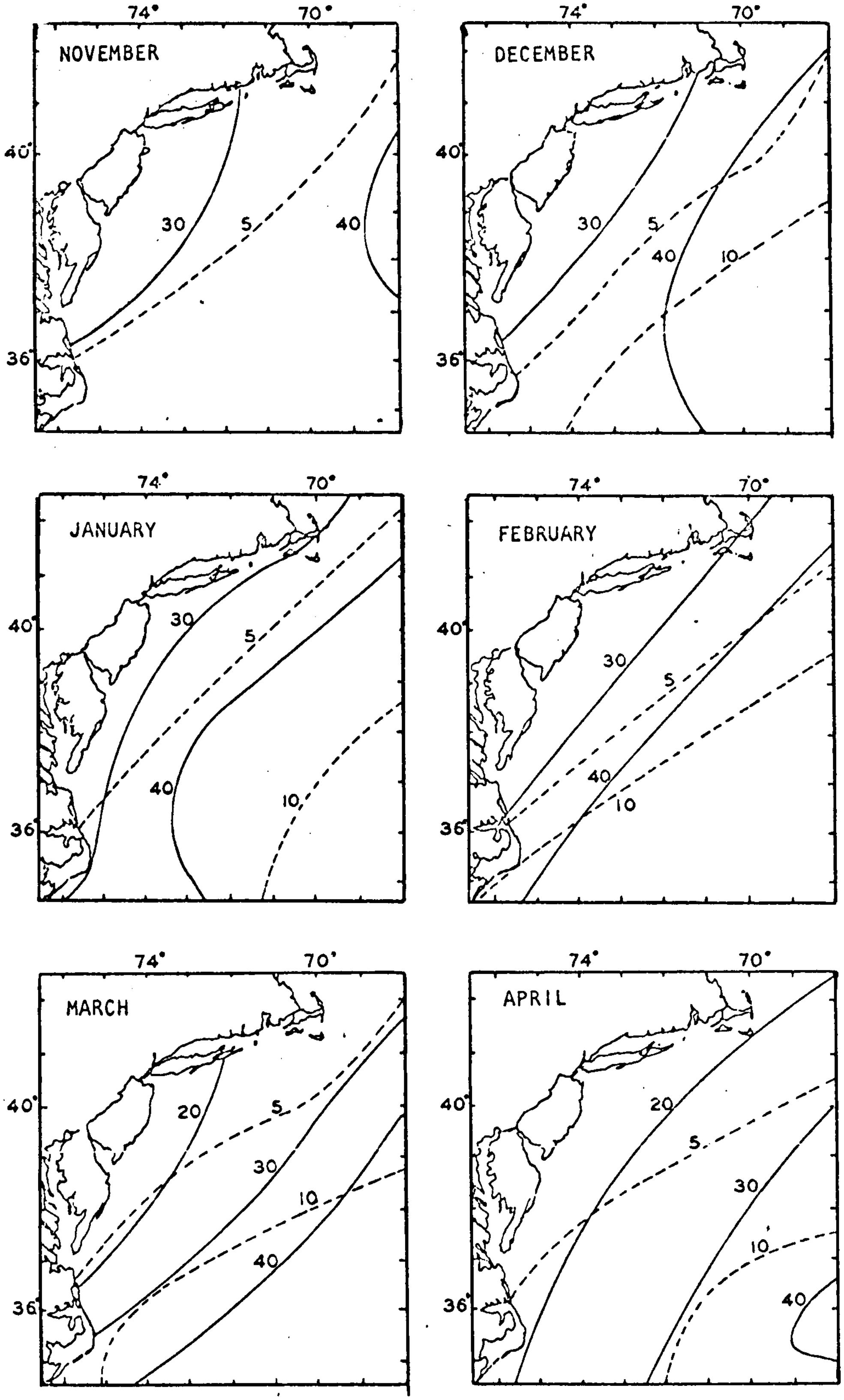


FIGURE 3-98a Percentage Frequency of Waves ≥ 12' (dashed lines) and ≥ 5' (solid lines) (Bumpus, et al., 1973)

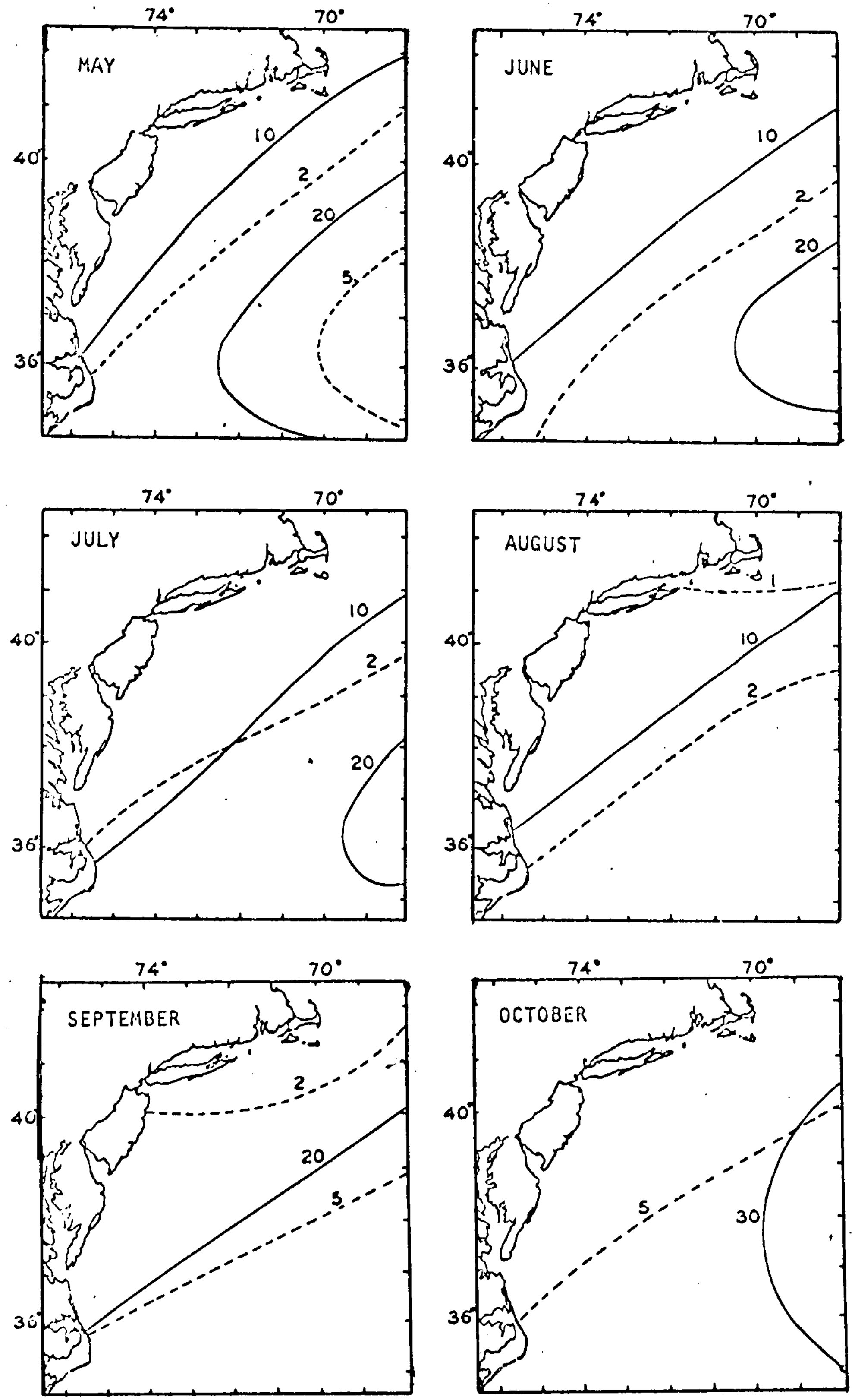
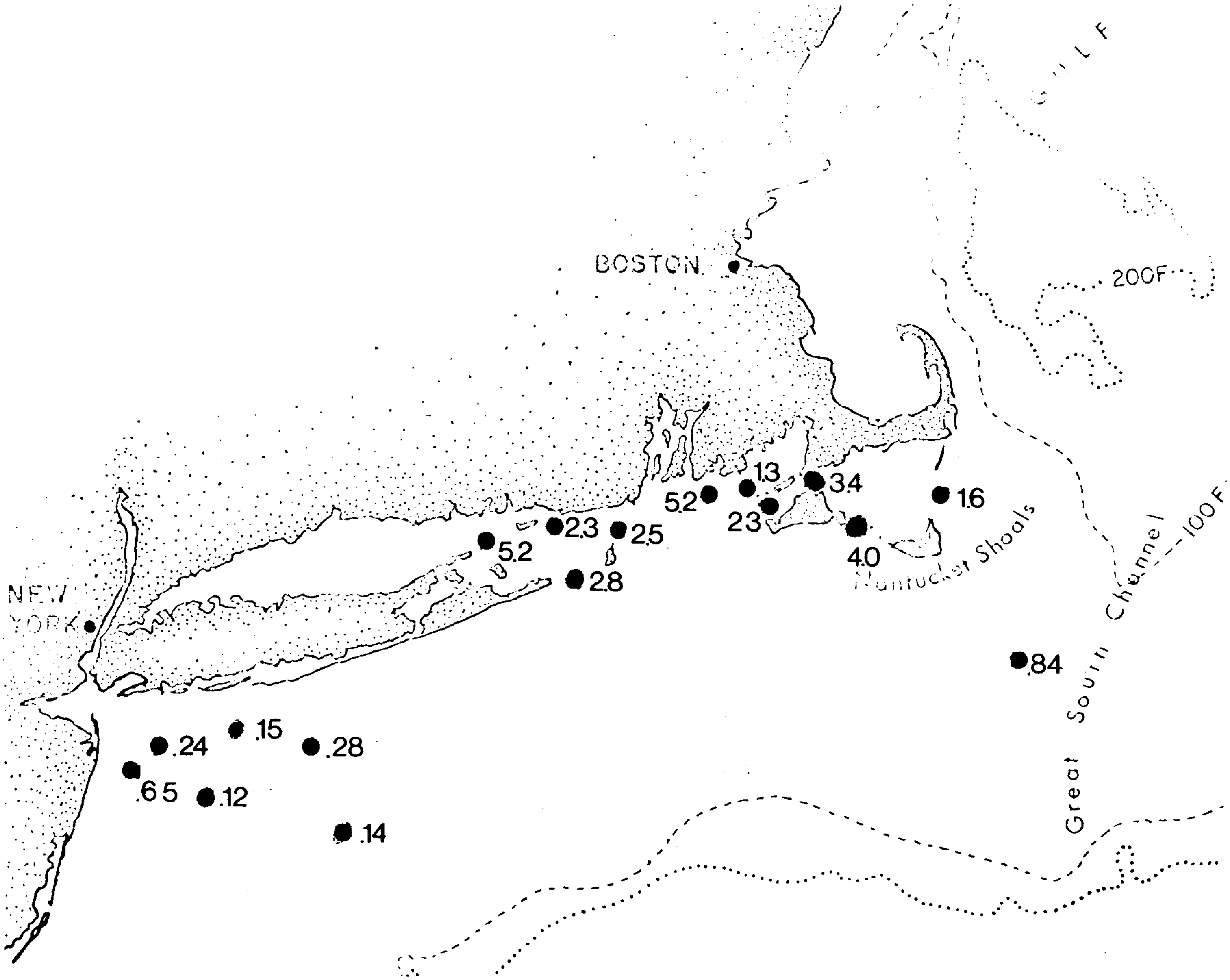


FIGURE 3-98b

Percentage Frequency of Waves ≥ 12' (dashed lines) and ≥ 5' (solid lines) (Bumpus, et al., 1973)



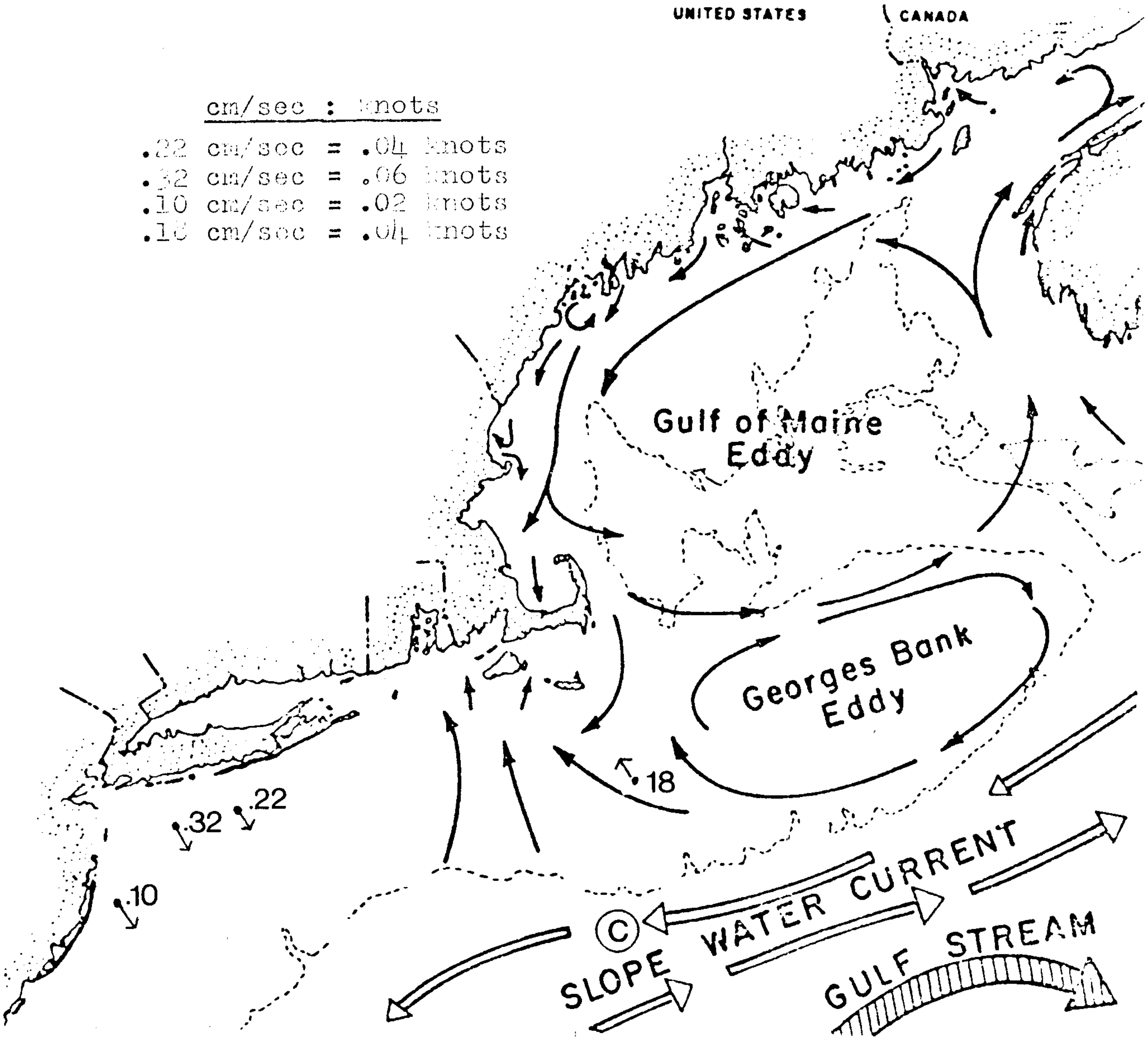
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-99

Maximum Velocities (in knots) Within the Tidal Cycle for Selected Stations cm/sec : knots

.22 cm/sec = .04 knots
.32 cm/sec = .06 knots
.10 cm/sec = .02 knots
.18 cm/sec = .04 knots



Depth profile at C

10 m 13 cm/sec = .26 knots
100 m 7 cm/sec = .14 knots
500 m 3.6 cm/sec = .08 knots
1000 m 3.6 cm/sec = .07 knots
2000 m 1.6 cm/sec = .03 knots

TRIGOM PARC

FIGURE 3-100 Some Recorded Magnitudes of Non-Tidal Drift Currents on the Shelf and a Velocity Profile

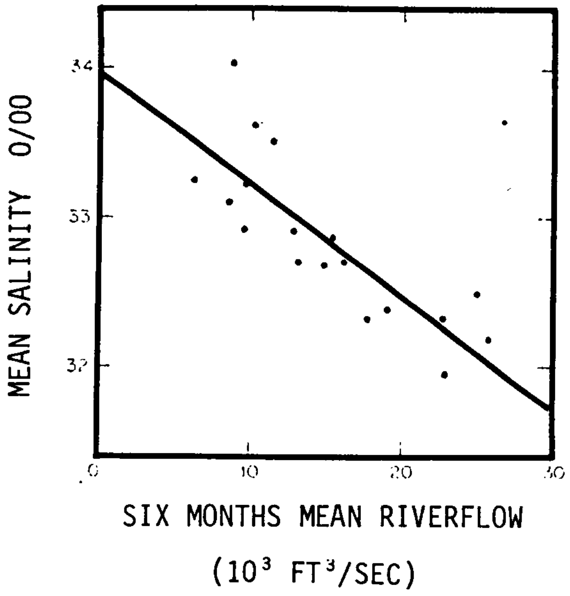


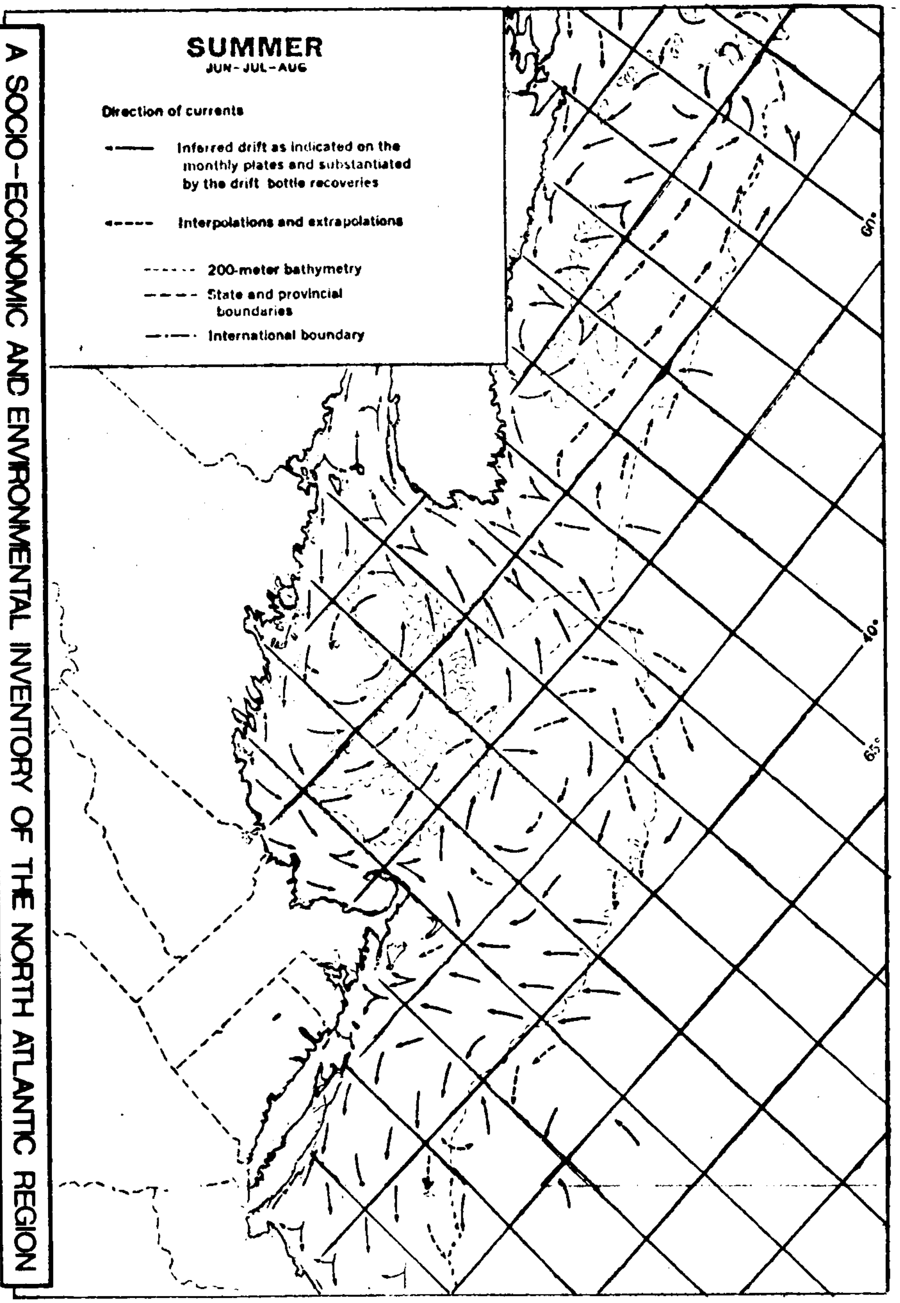
FIGURE 3-101 The Relationship Between the Mean Salinity of the Water on the Continental Shelf to a Depth of 60 m. (Ketchum and Corwin, 1965)

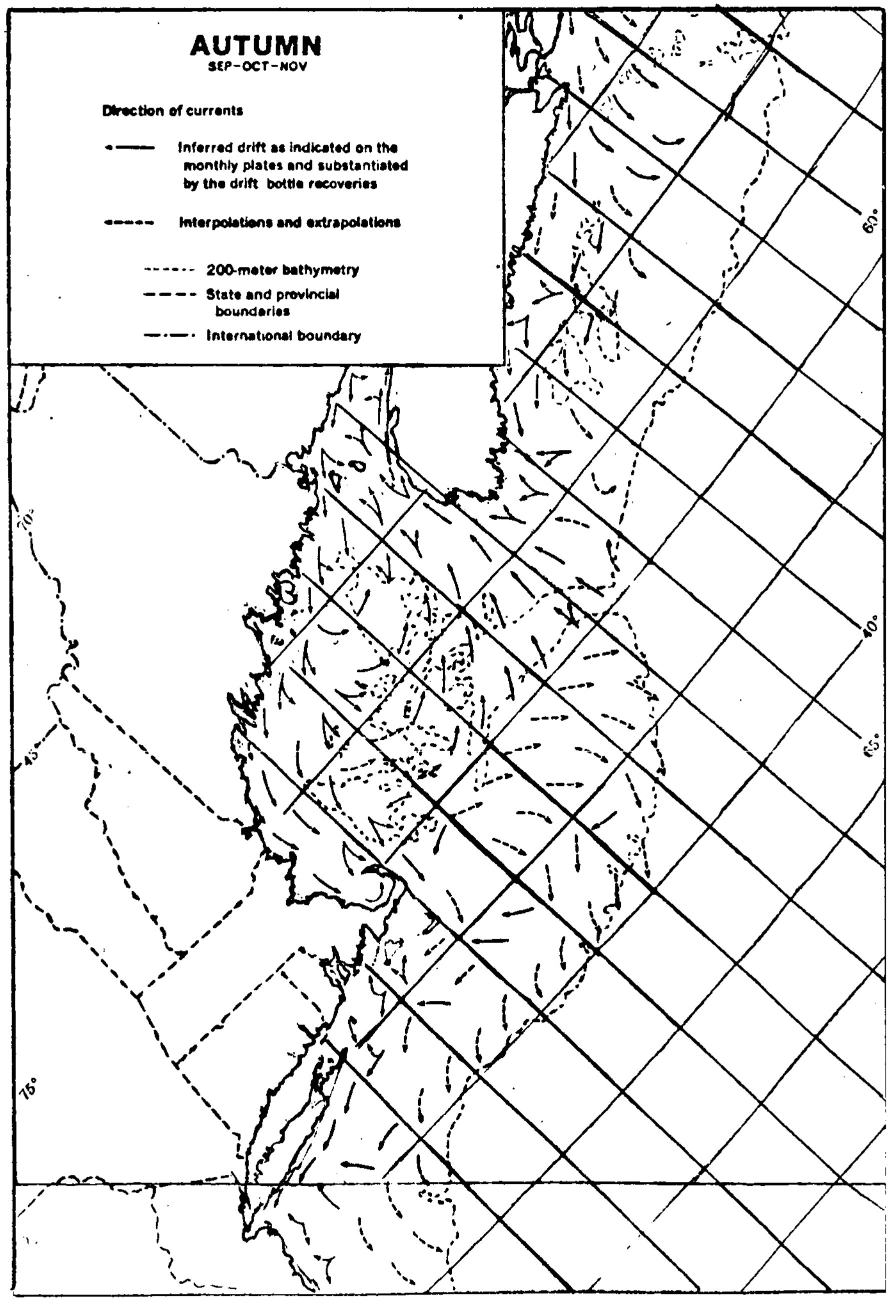
TRIGOM PARC

FIGURE 3-102

Summer-Autumn Surface Circulation

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION



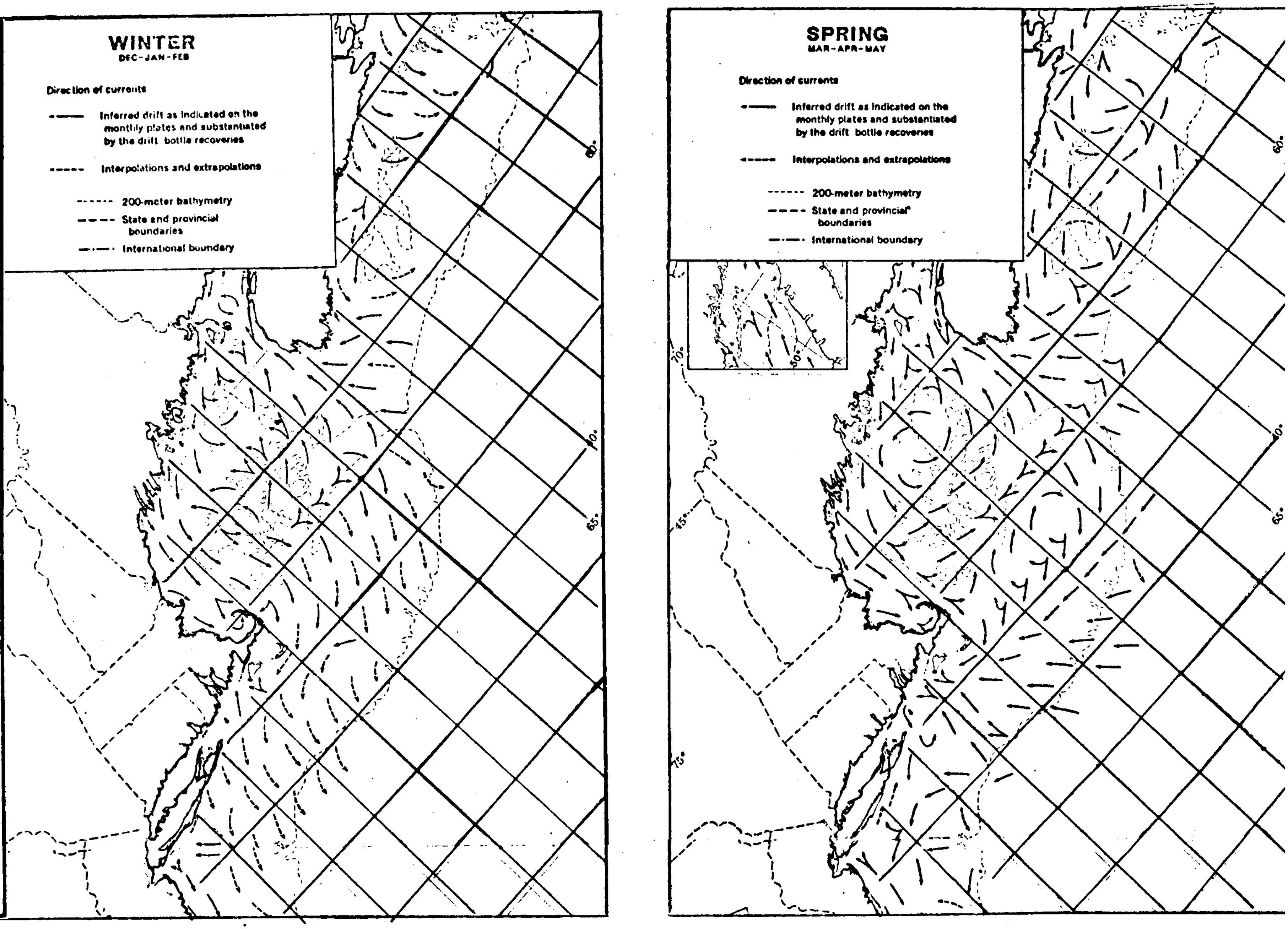


NOMINAL SCALE 1:5,000,000

TRIGOM PARC

FIGURE 3-103

Winter-Spring Surface Circulation



NOMINAL SCALE 1:5,000,000

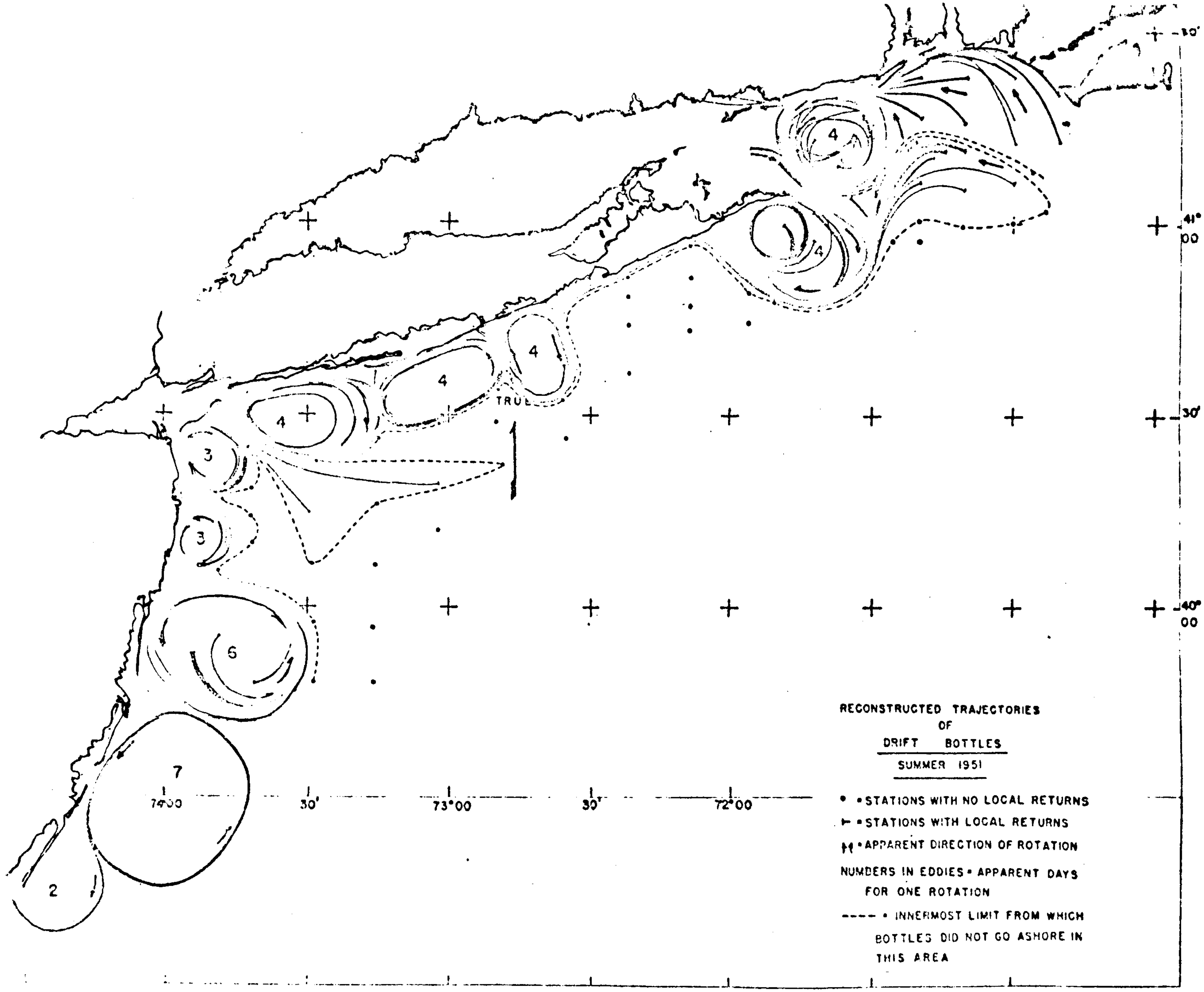


FIGURE 3-104

Three and Four Day Eddy Structures for Inshore Areas Along the Coast

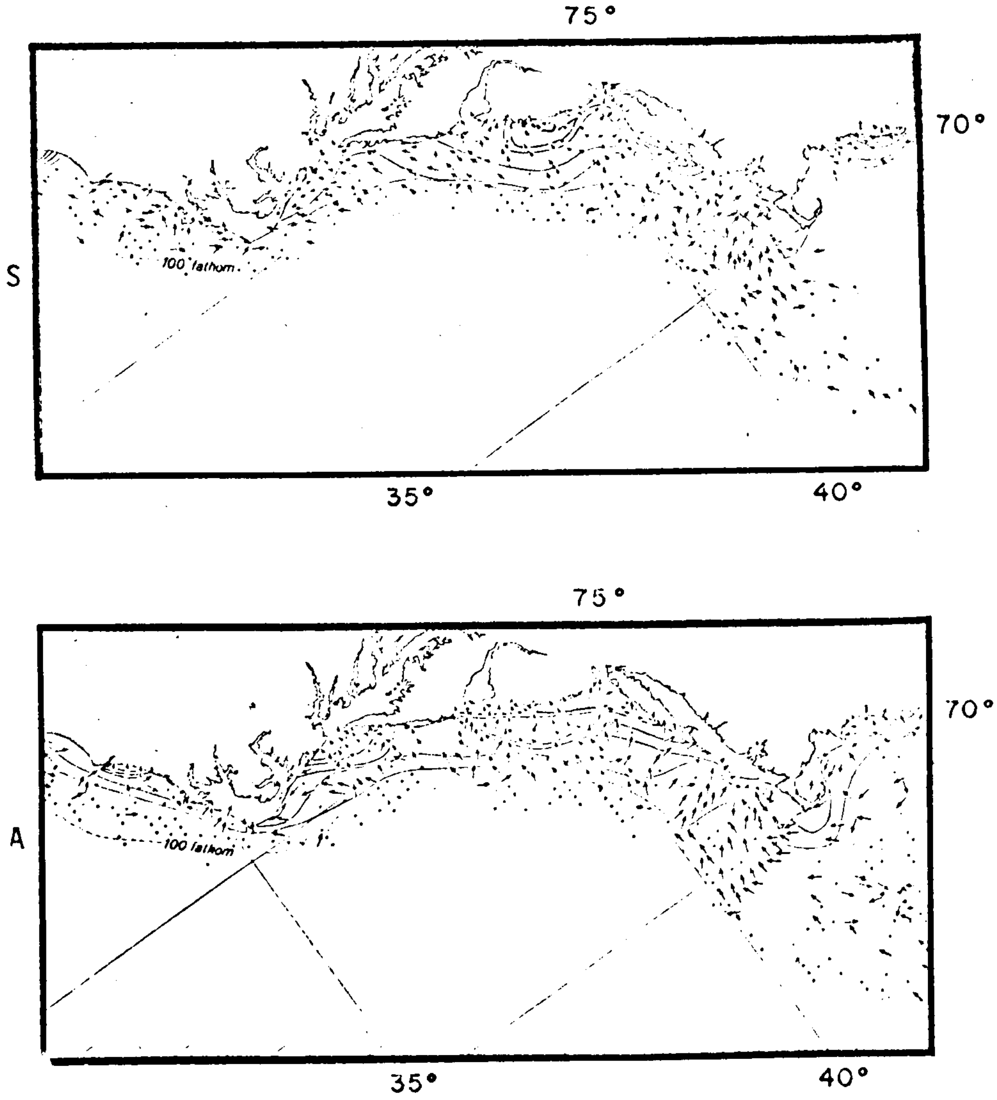


FIGURE 3-105

Summer and Autumn Circulation Patterns for Bottom Water Off New England Shelf (Bumpus, et al., 1973)

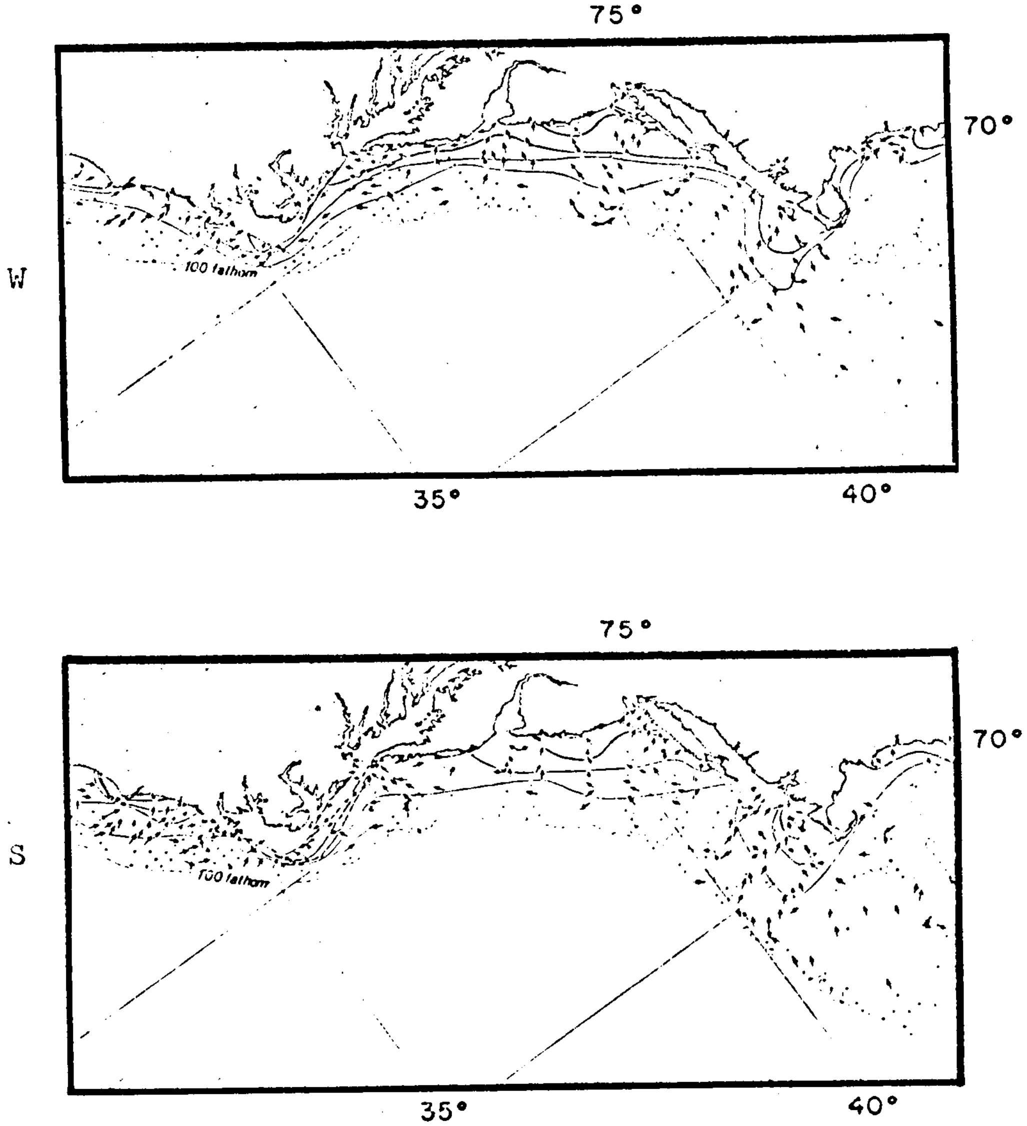
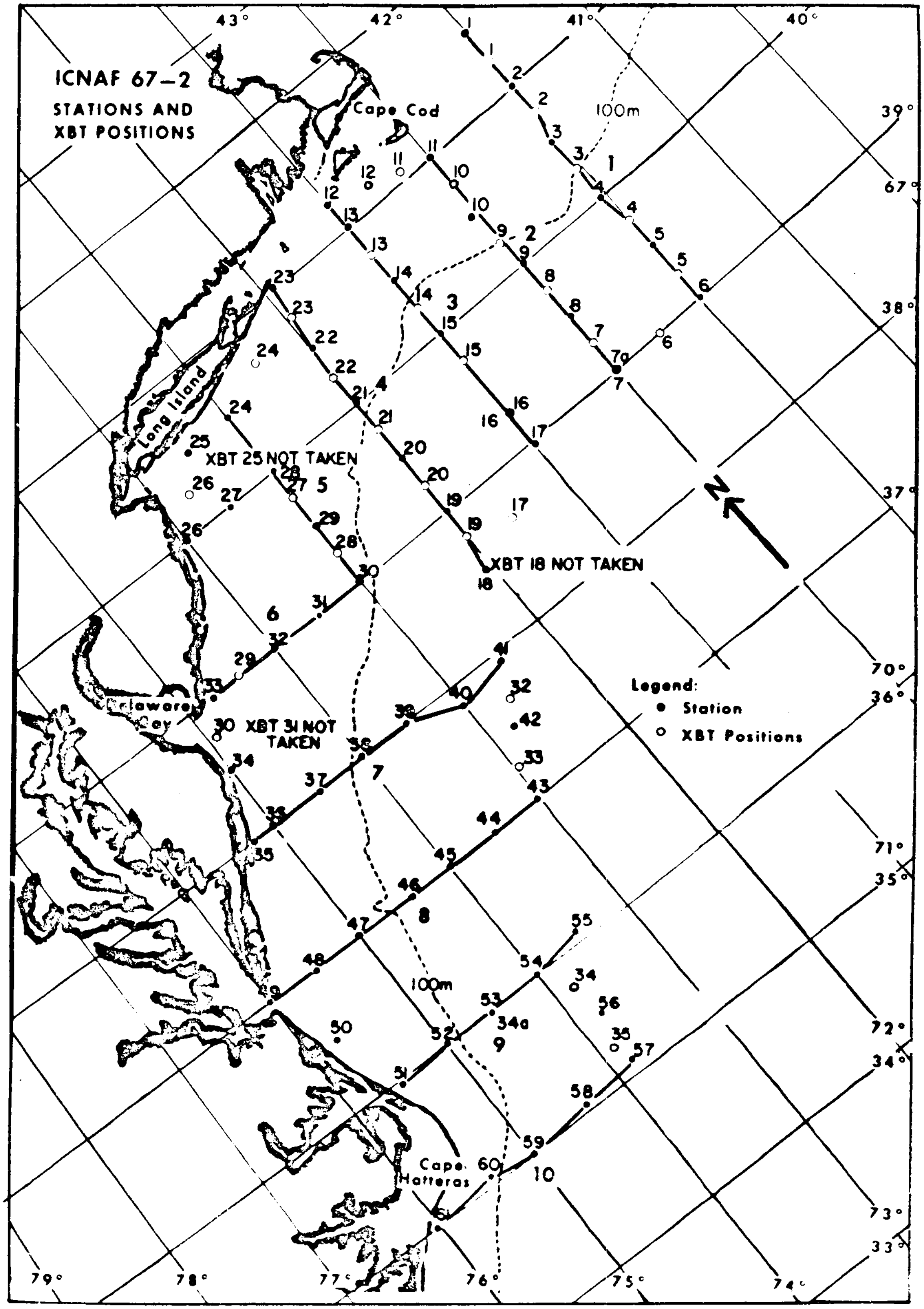


FIGURE 3-106 Winter and Spring Circulation of Bottom Water (Bumpus, et al., 1973)

3.2.9A PART I

Summer (September) and winter (December) conditions in the offshore area, including both the shelf and slope, south of New England. Figures are taken from Whitcomb (1970).

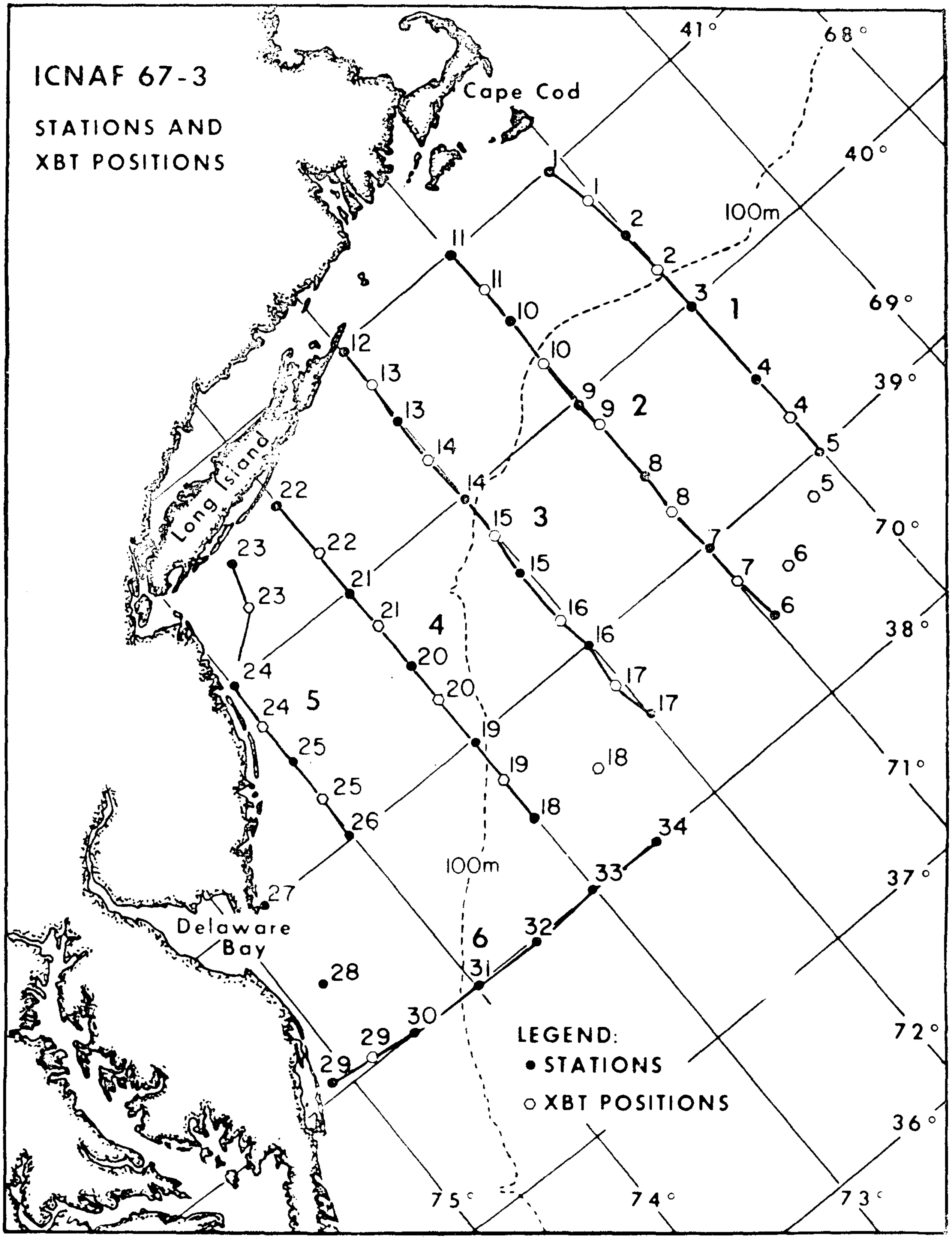


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-107

Transect and Station Location - September 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-108

Transect and Station Location - December 1967 (ICNAF)

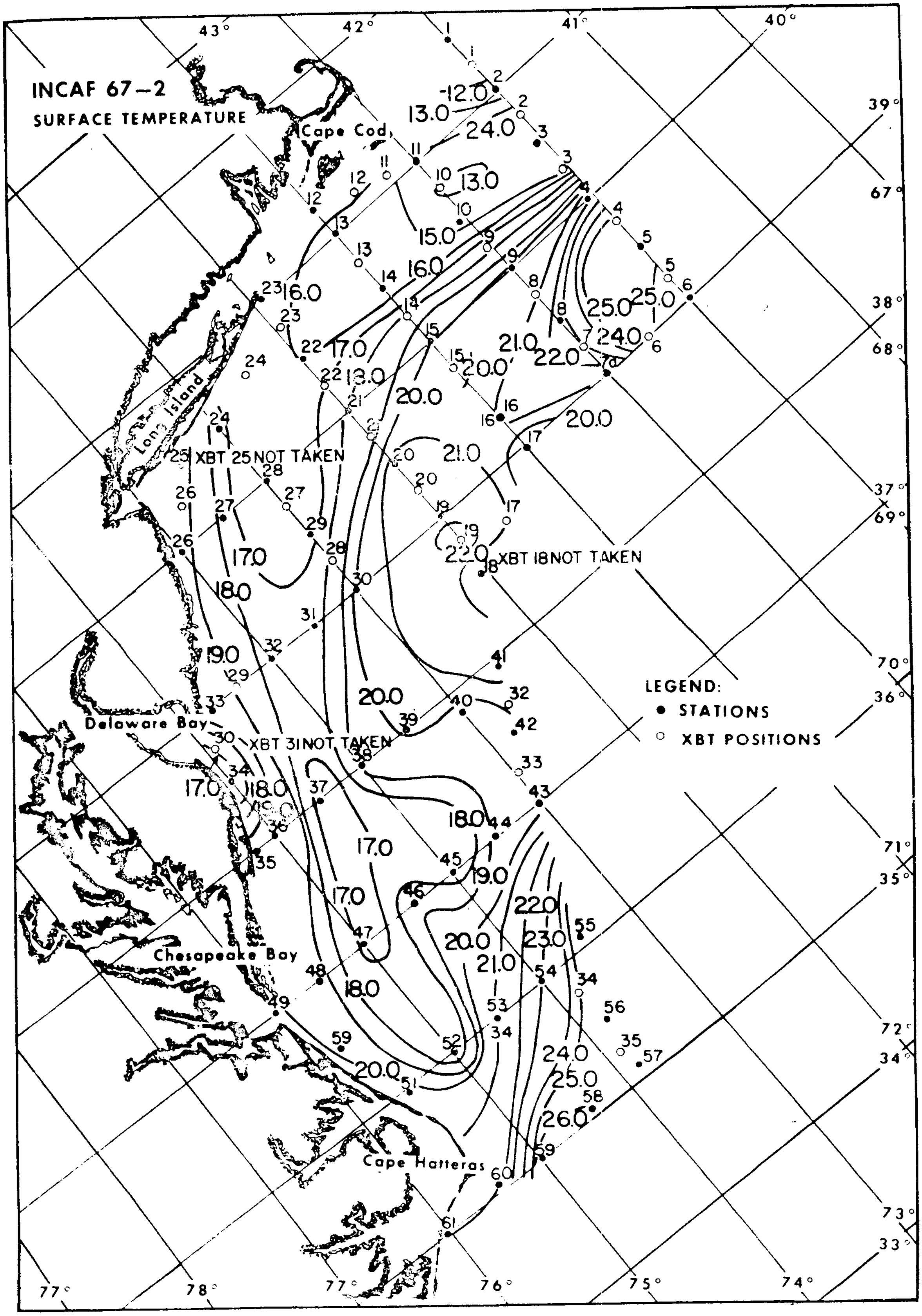
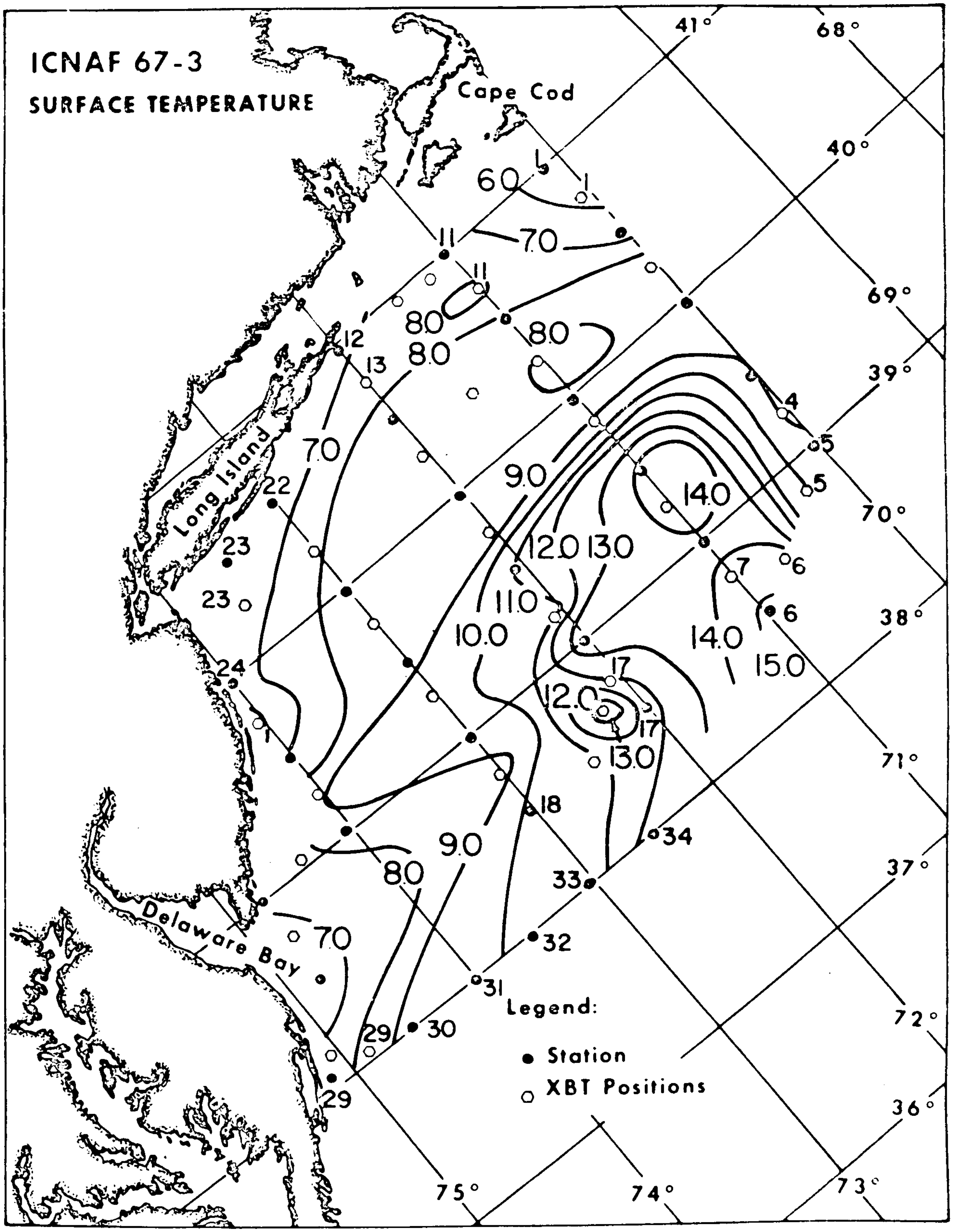


FIGURE 3-109 Surface Isotherms (^{0}C) September (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-110

Surface Isotherms (°C) December (ICNAF)

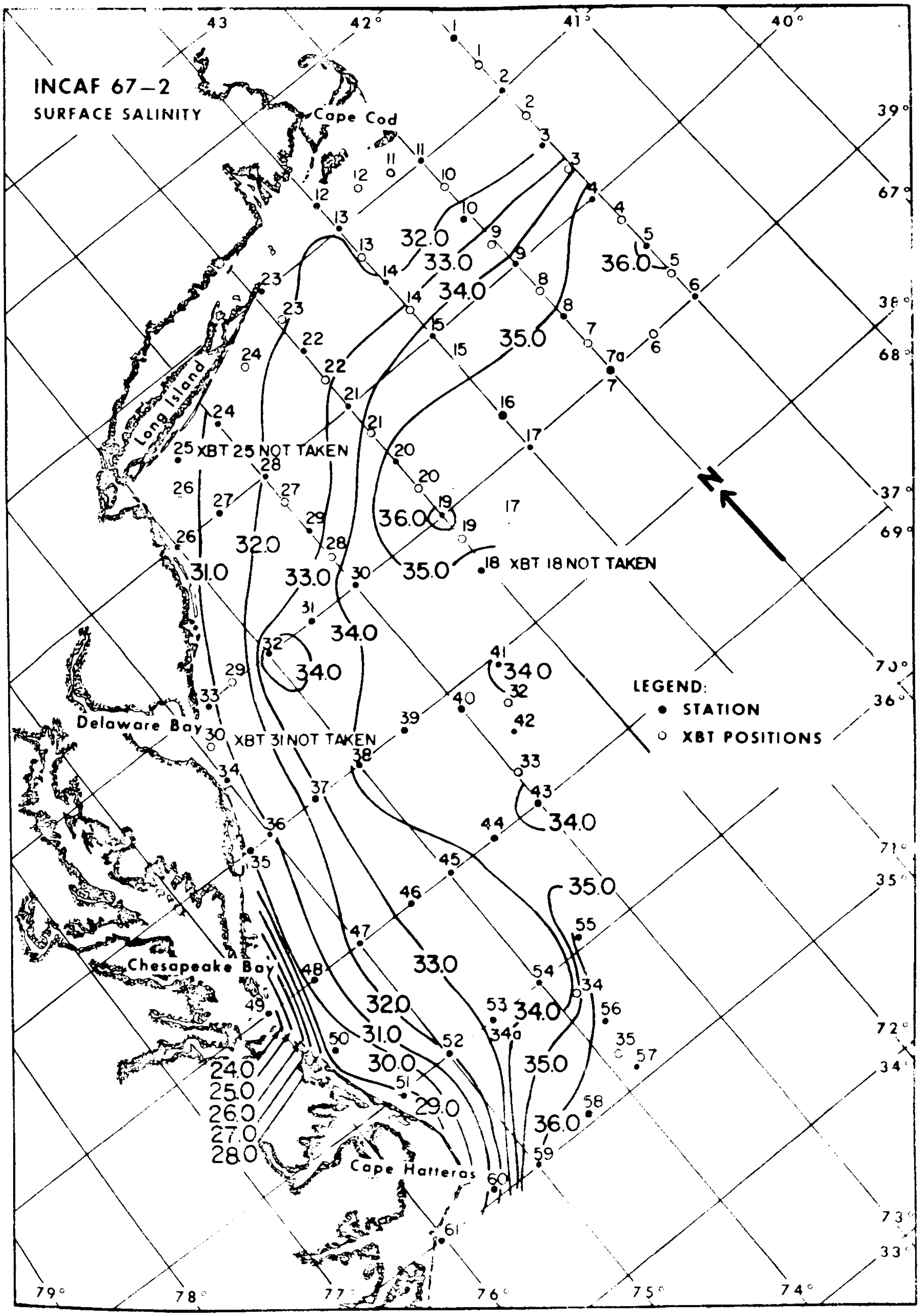


FIGURE 3-111 Surface Isohalines (^{0}/oo) September (ICNAF)

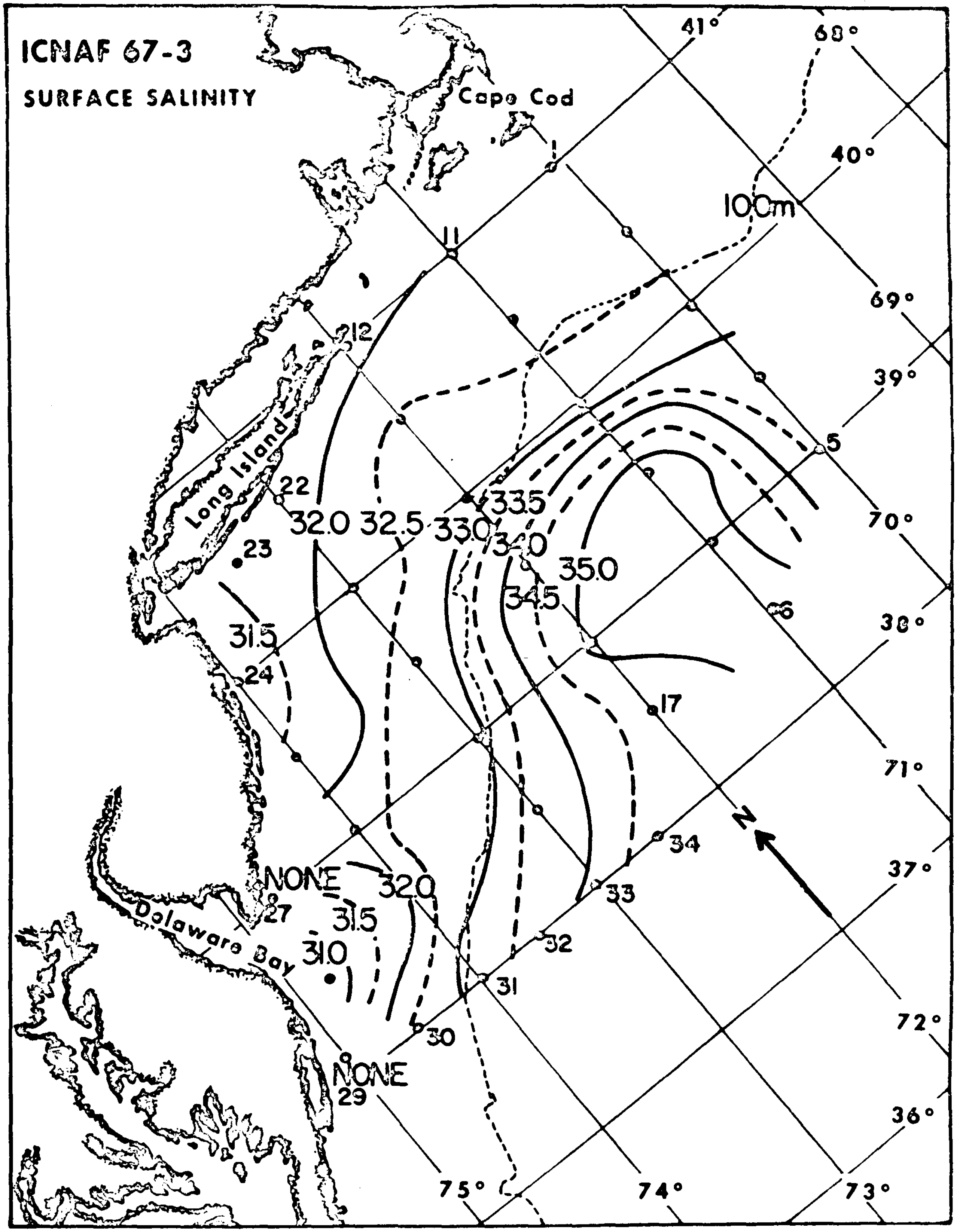
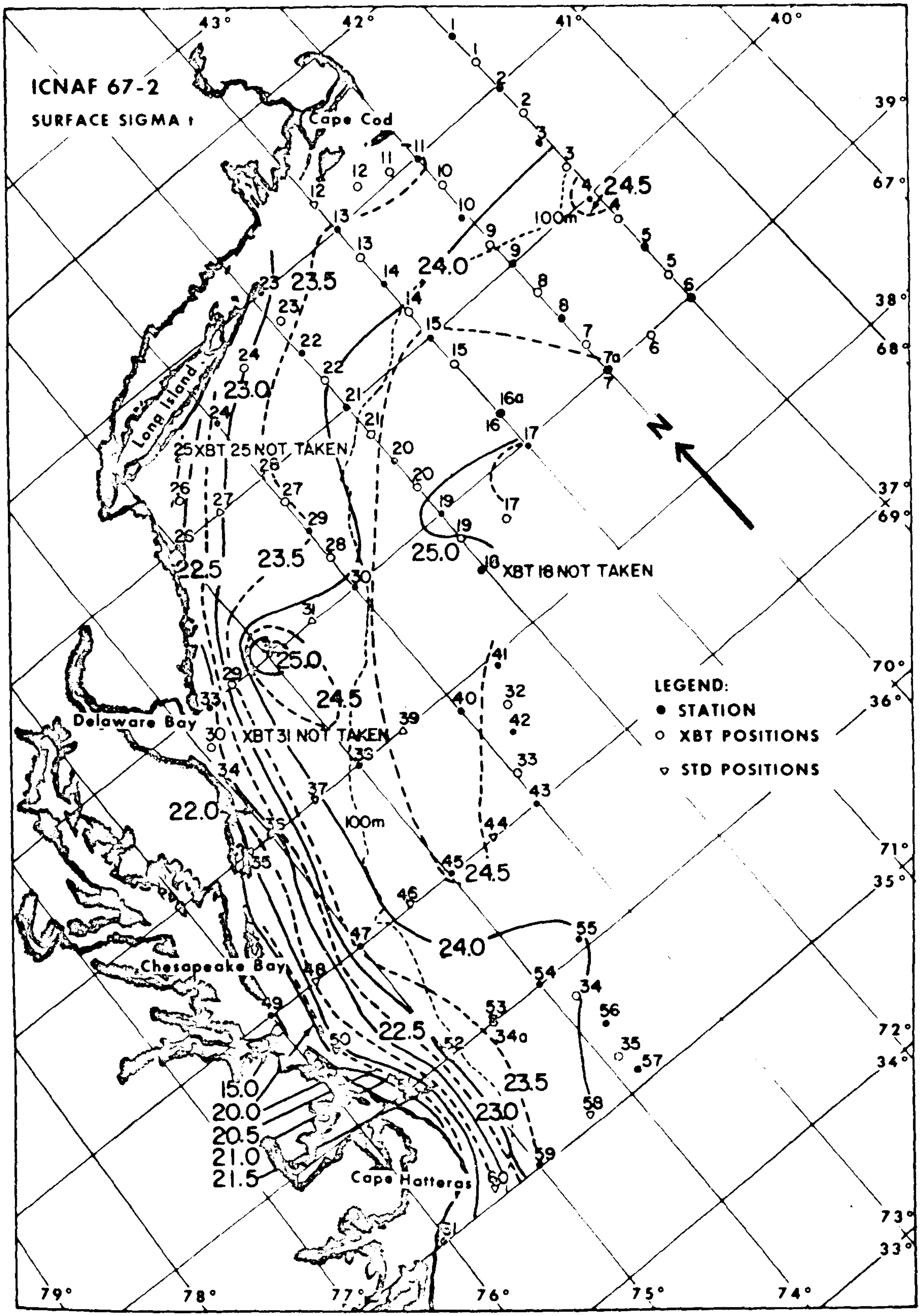


FIGURE 3-112 Surface Ishoalines (o/oo) December (ICNAF)

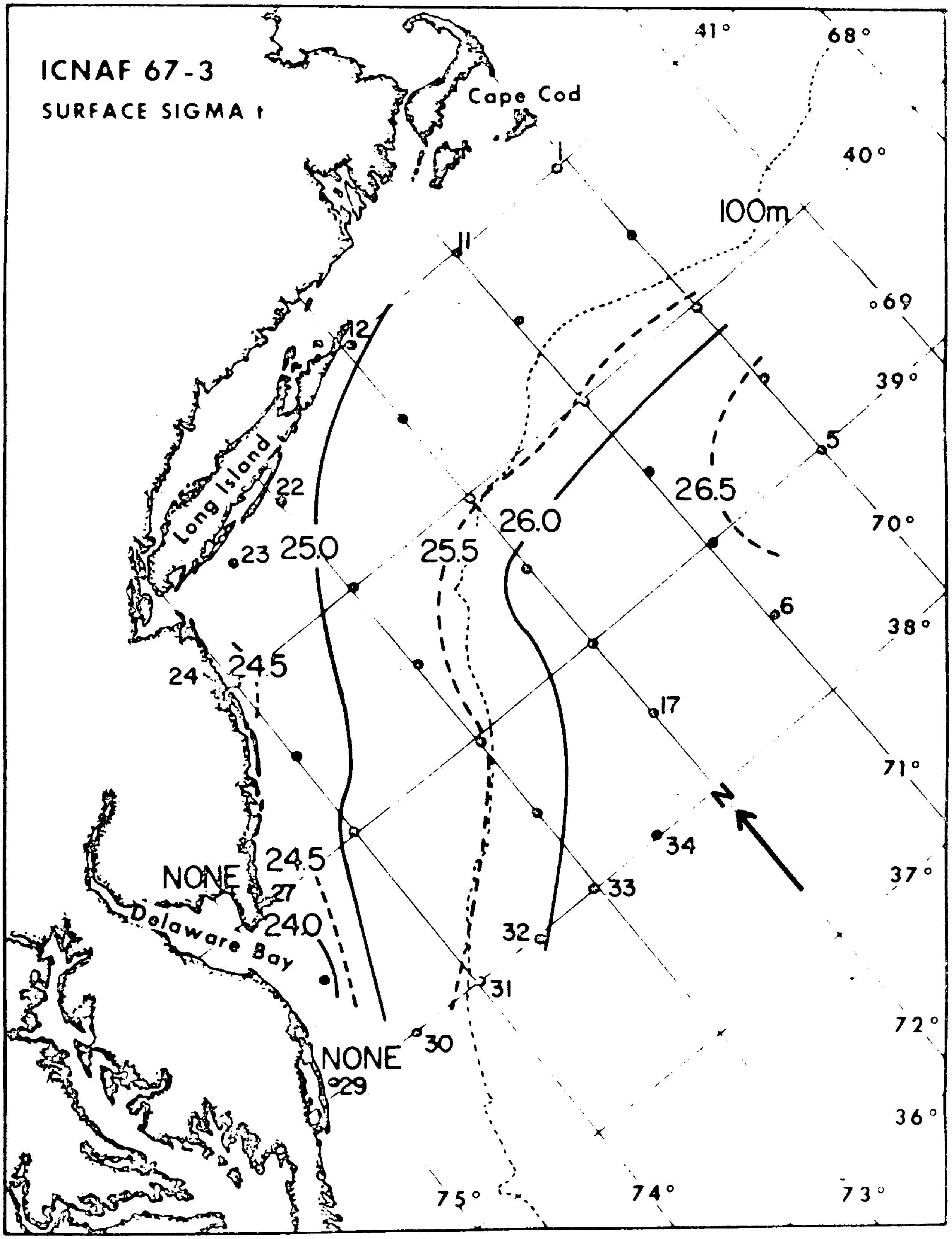


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-113

Surface Density (σt in g/l) September (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-114 Surface Density (σt in g/l) December (ICNAF)

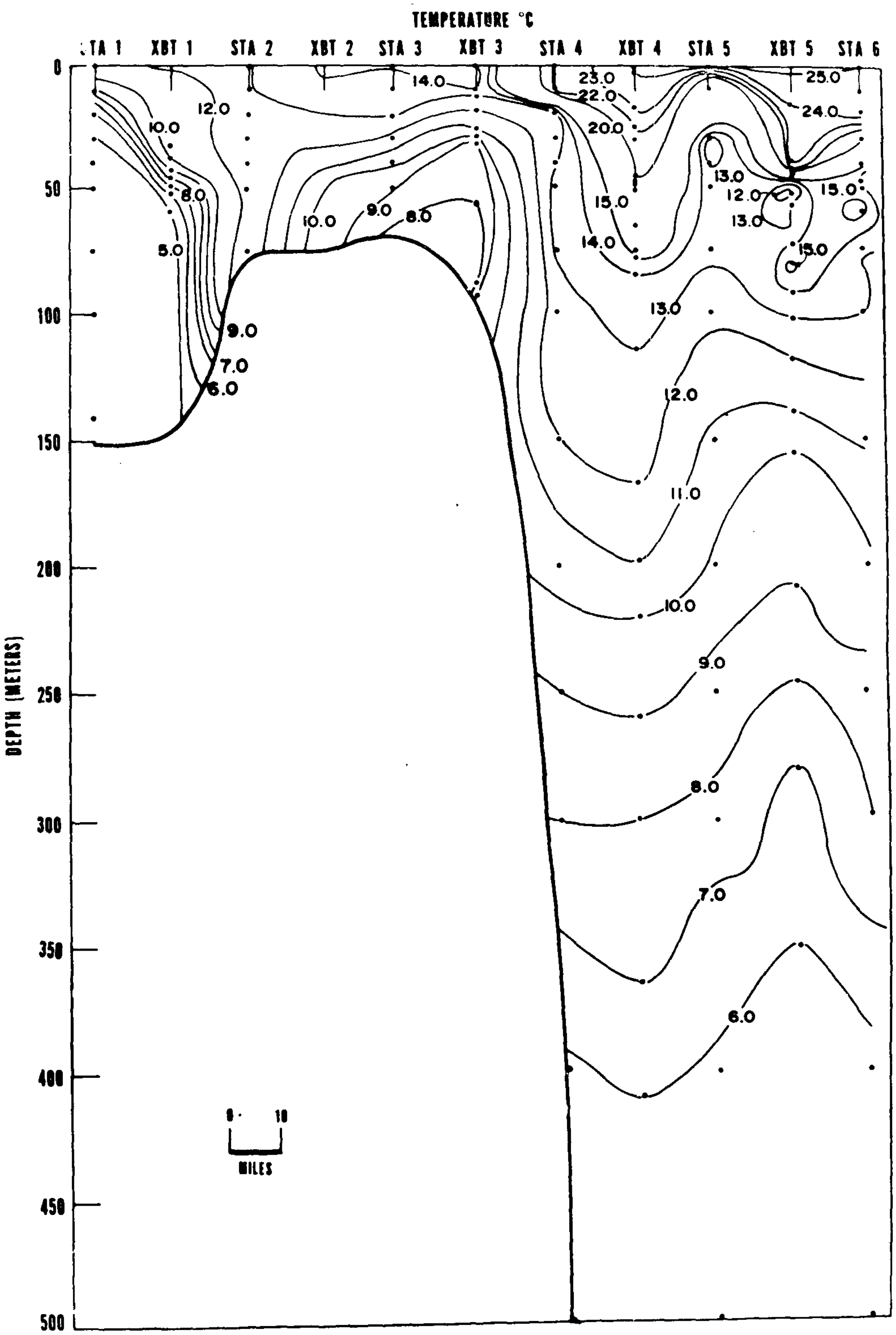


FIGURE 3-115

Vertical Distribution of Temperature (°C) - Section 1 September (ICNAF)

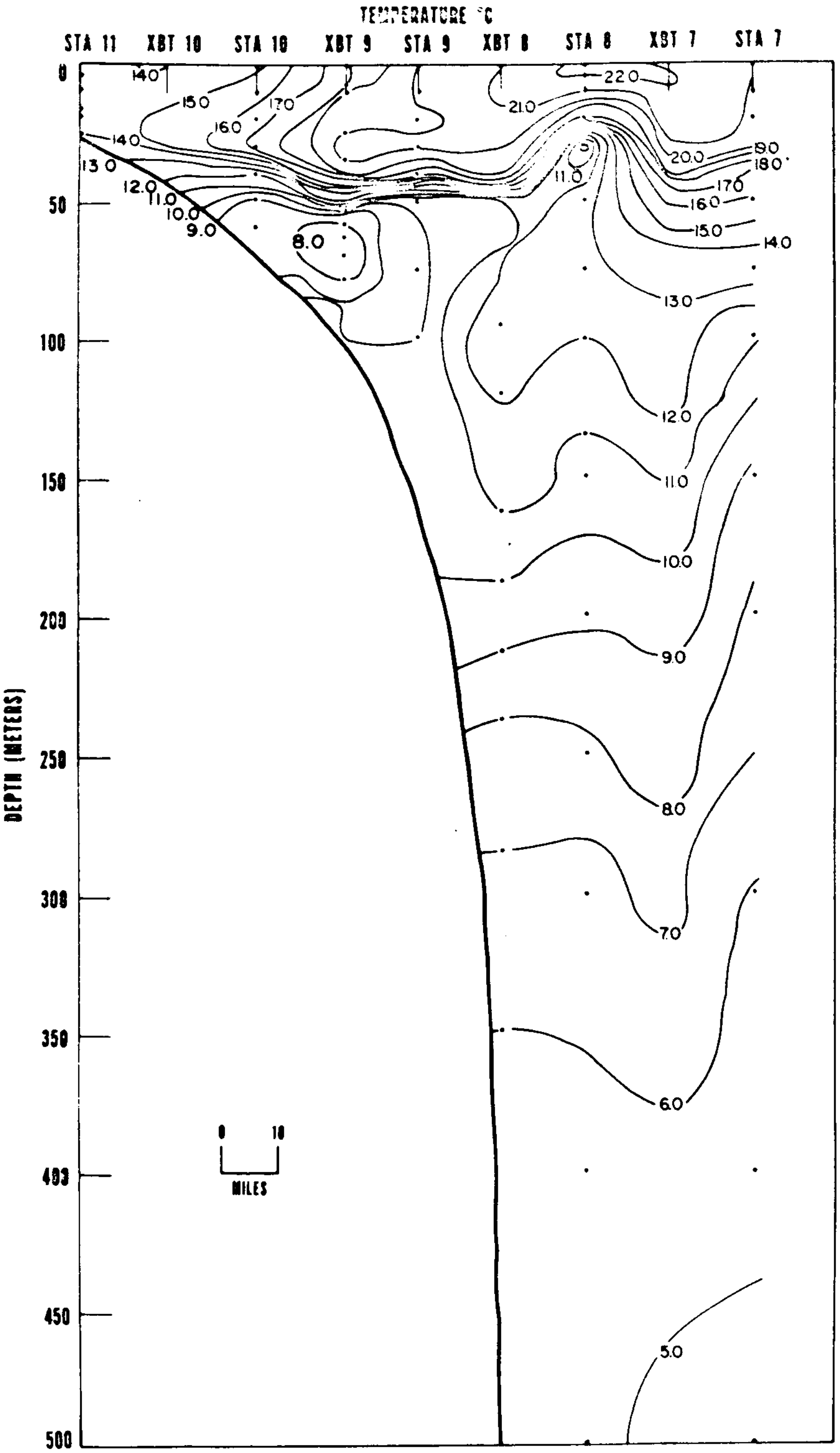
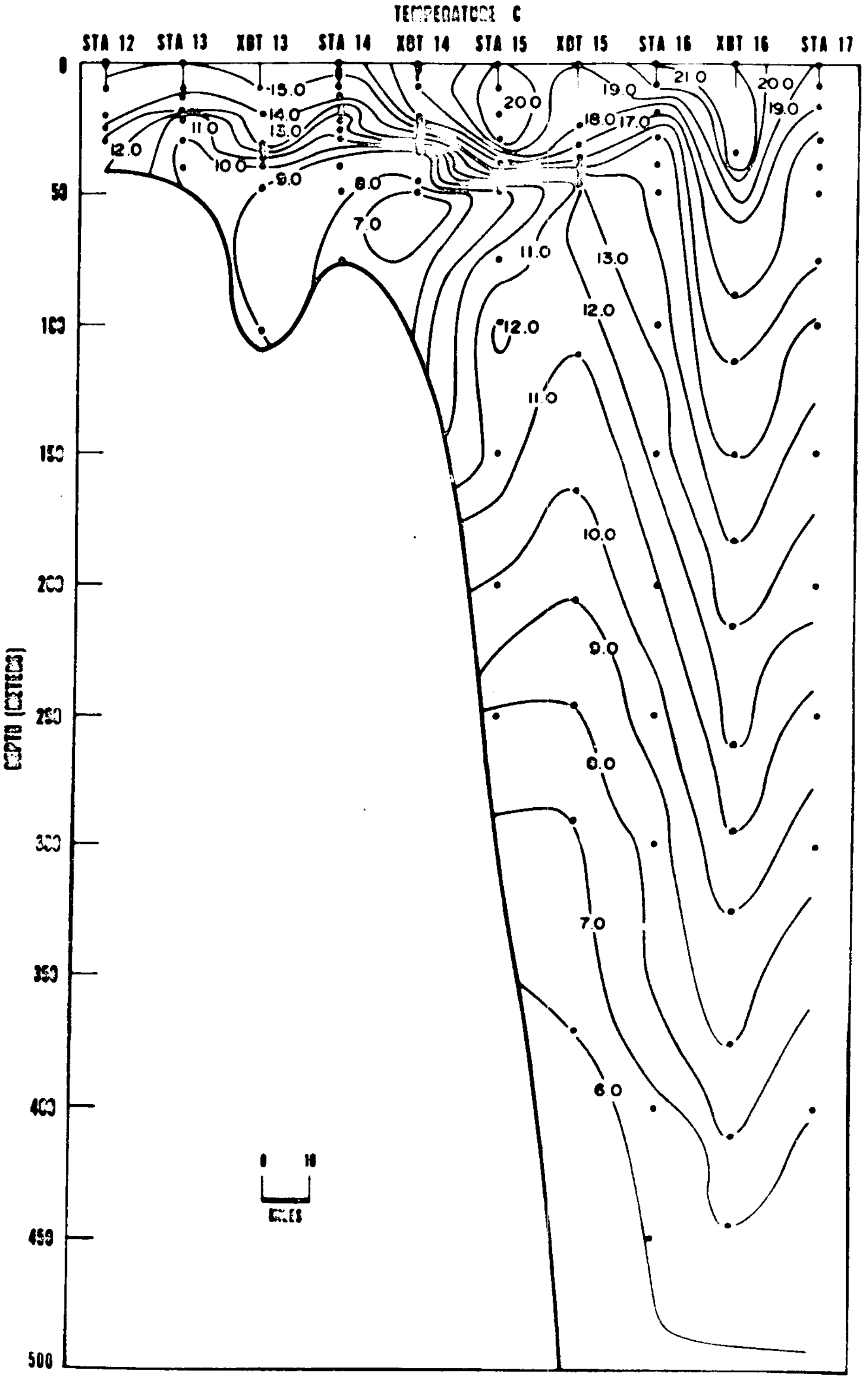


FIGURE 3-116

Vertical Distribution of Temperature (°C) - Section 2
September (ICNAF)

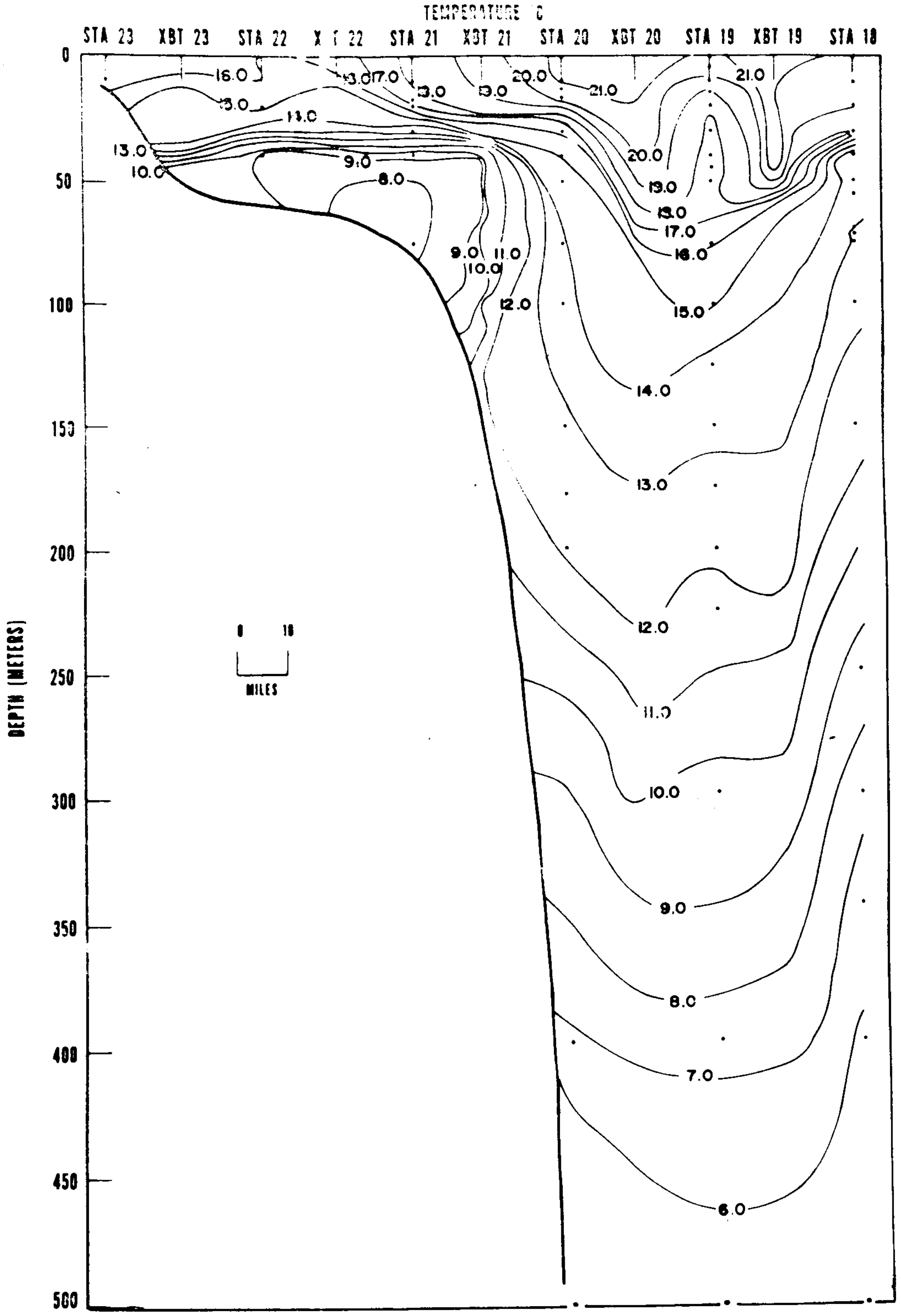


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

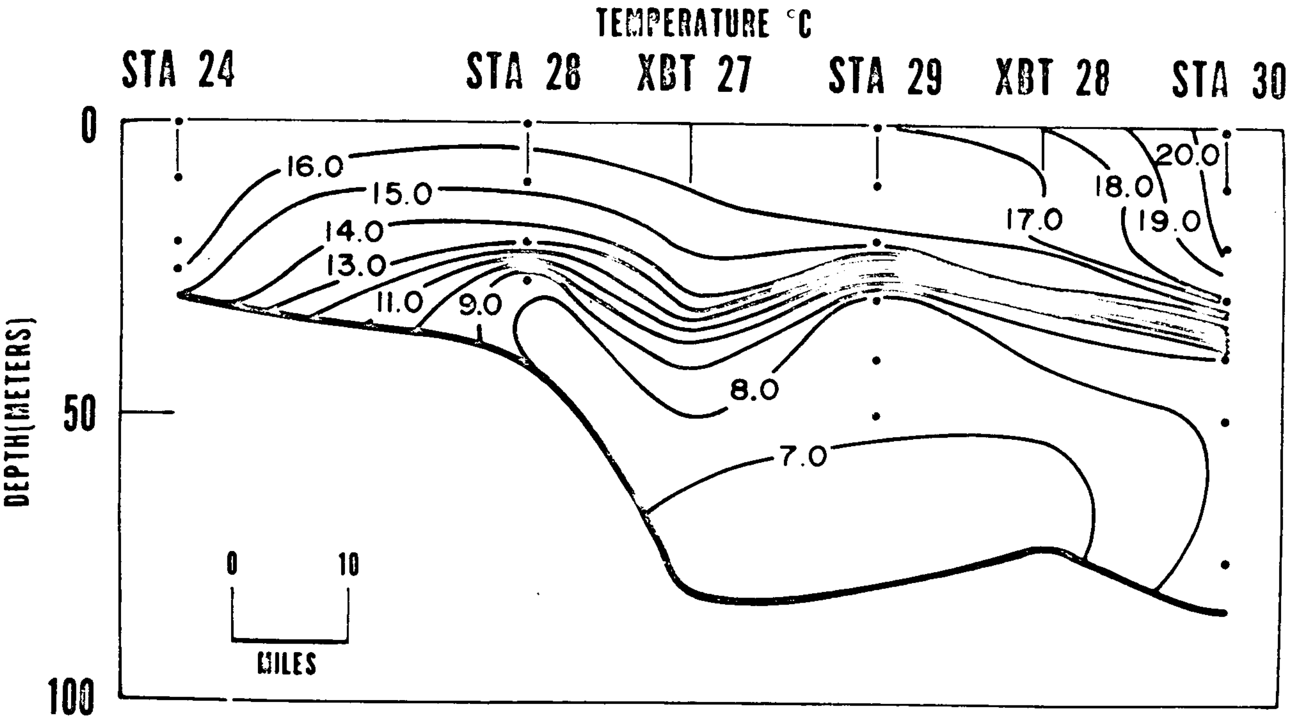
FIGURE 3-117

Vertical Distribution of Temperature (°C) - Section 3 September (ICNAF)



TRIGOM PARC

FIGURE 3-118 Vertical Distribution of Temperature (^{o}C) - Section 4 September (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-119

Vertical Distribution of Temperature (°C) - Section 5 September (ICNAF)

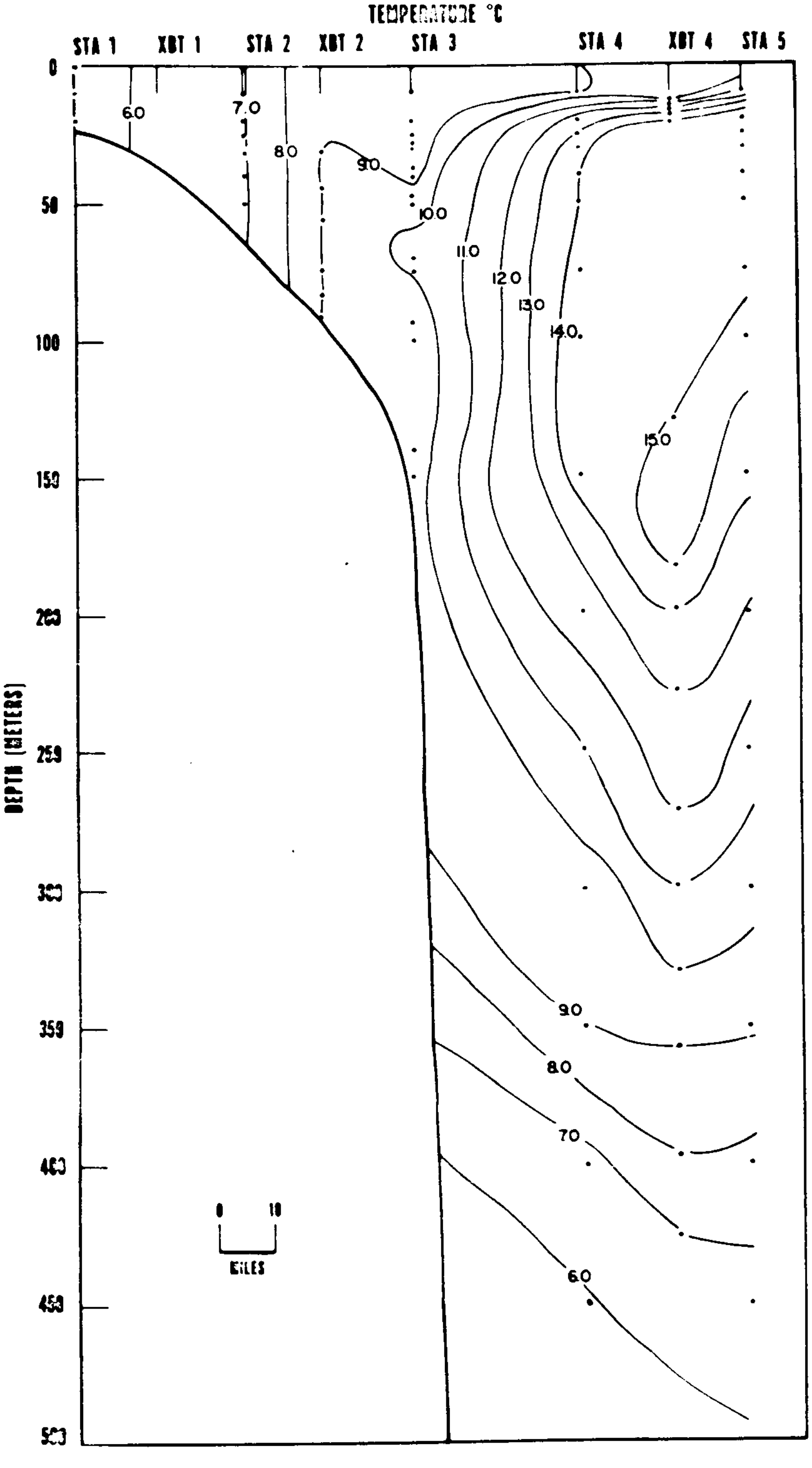
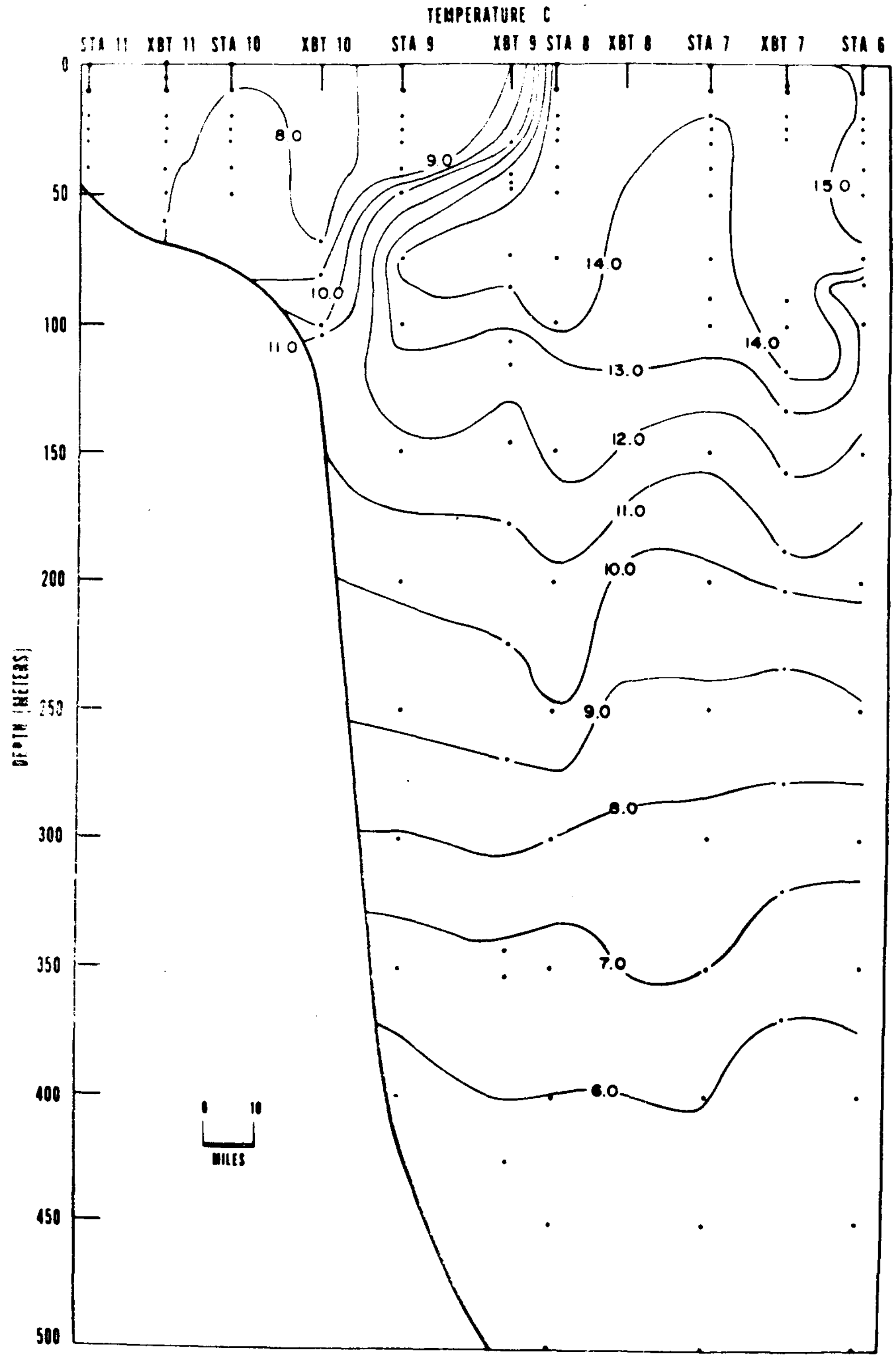


FIGURE 3-120 Vertical Distribution of Temperature (°C) - Section 1 December (ICNAF)

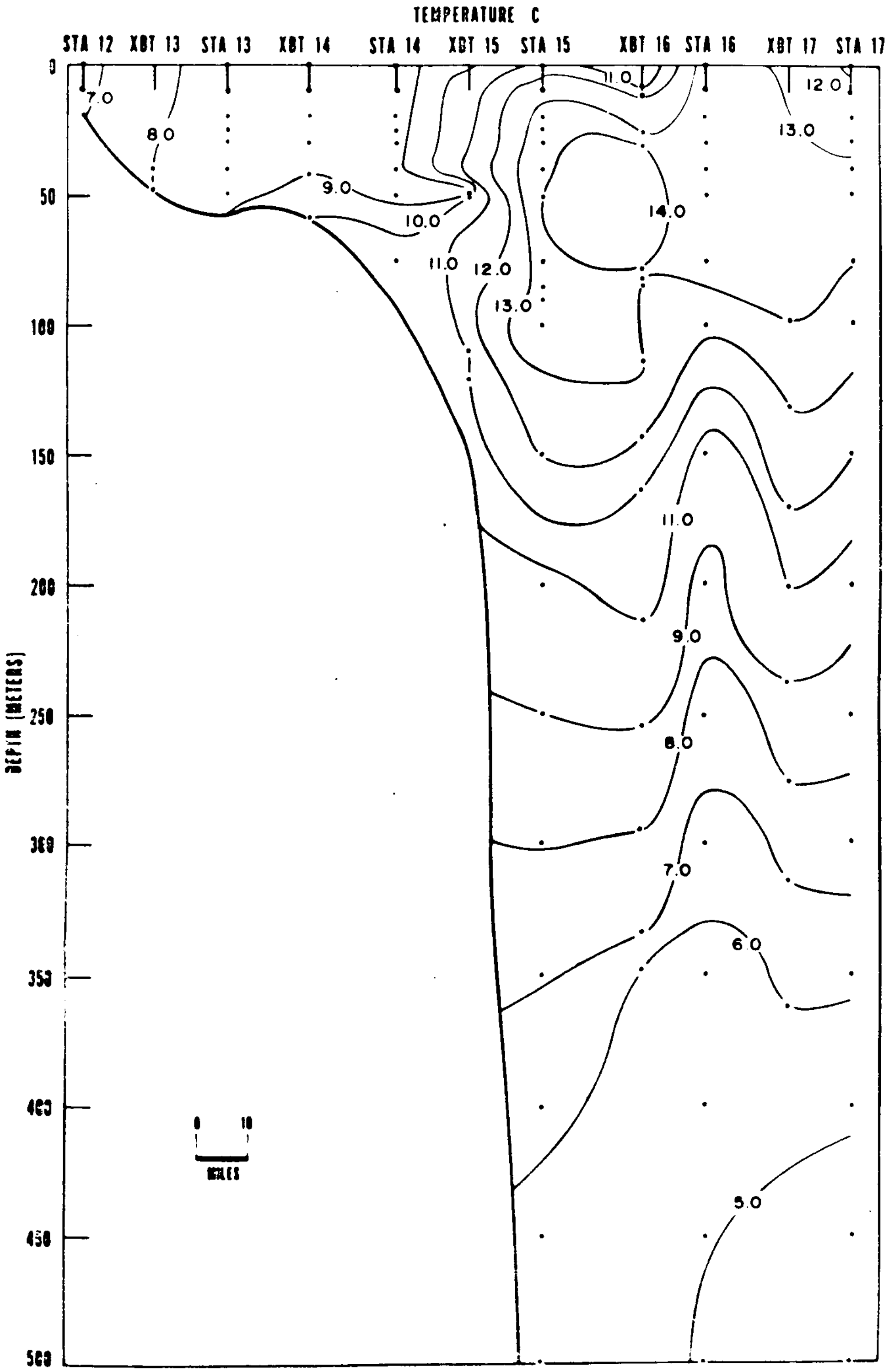


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-121

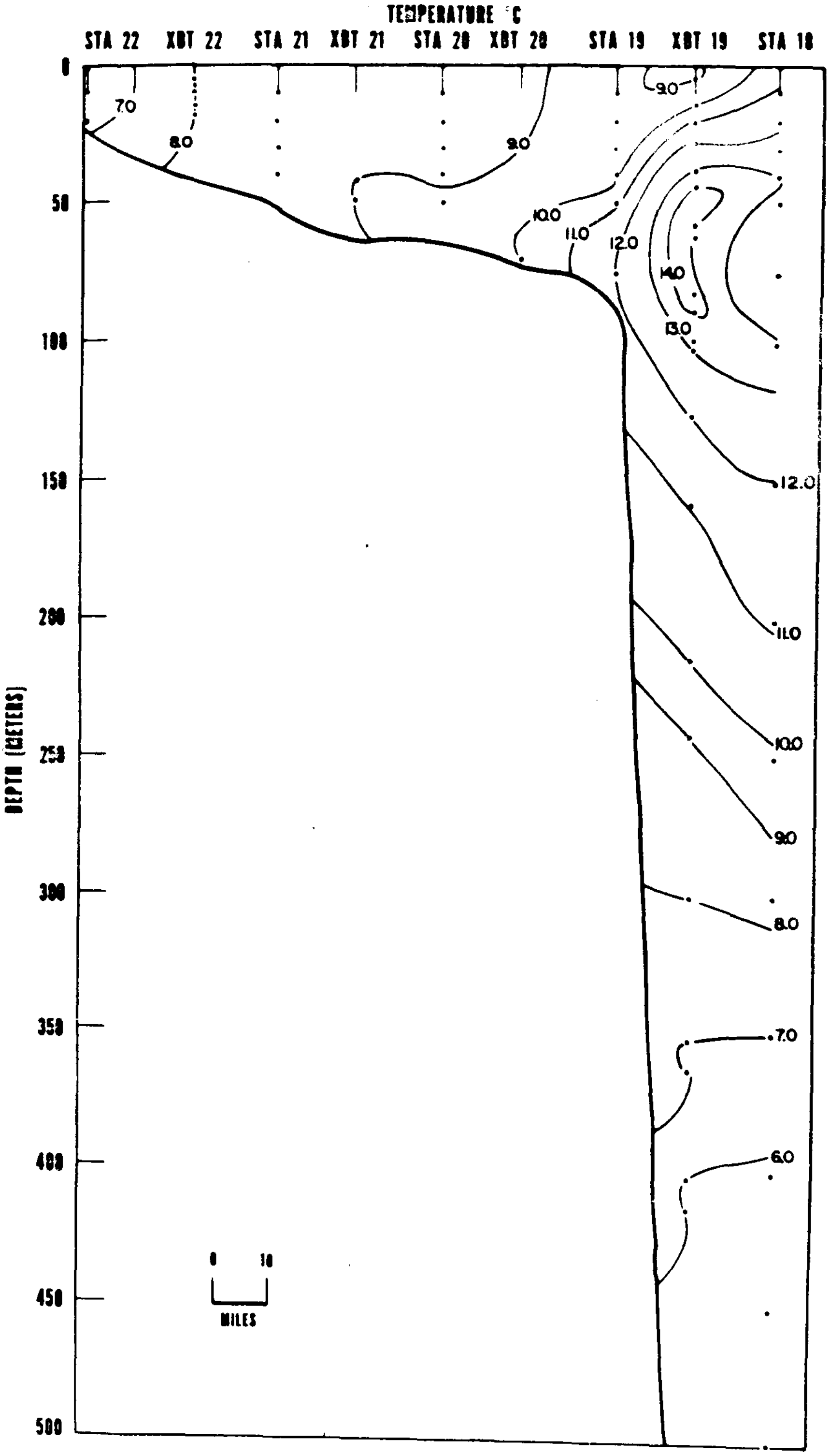
Vertical Distribution of Temperature (°C) - Section 2 December (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-122 Vertical Distribution of Temperature (^{o}C) - Section 3 December (ICNAF)

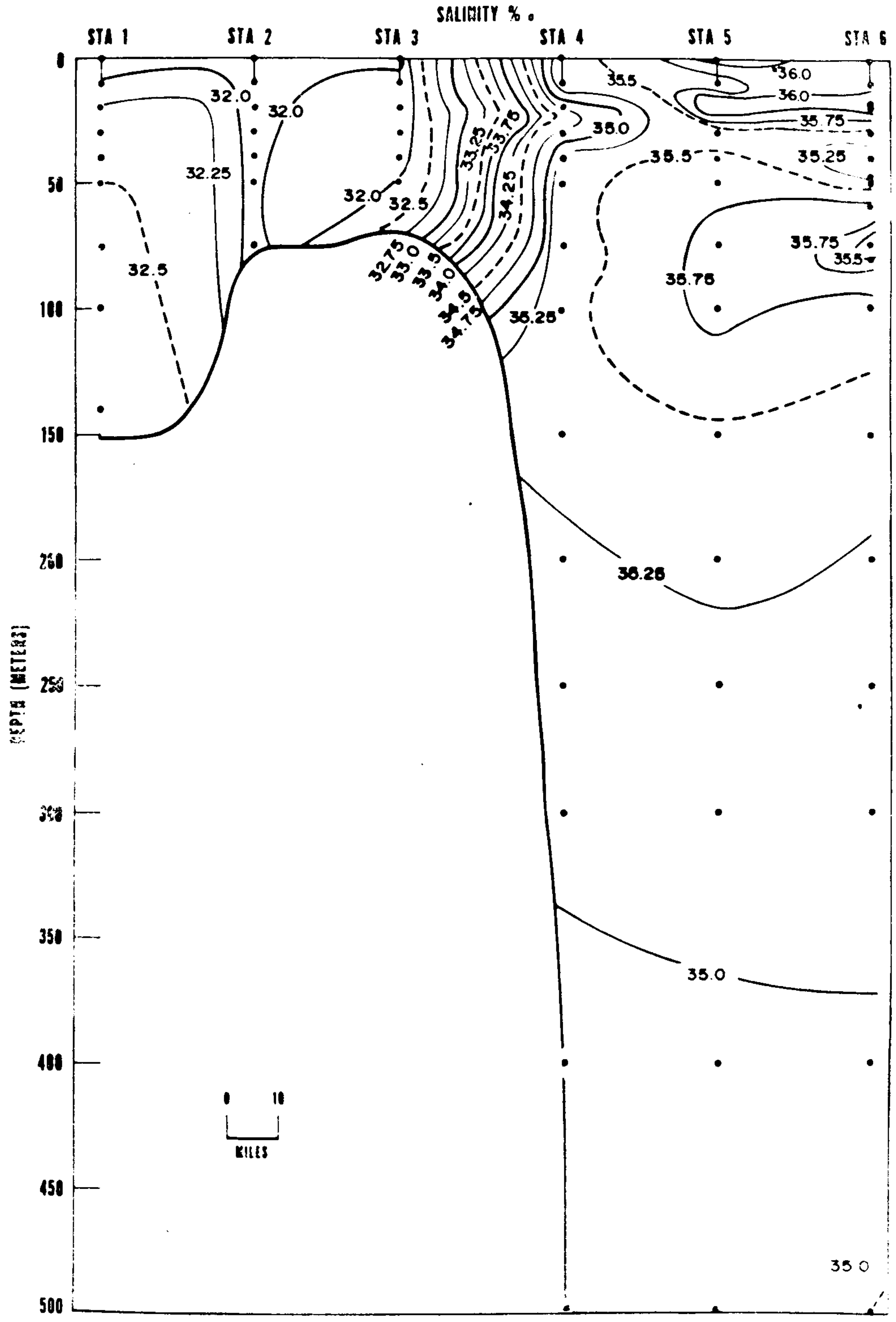


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-123

Vertical Distribution of Temperature (°C) - Section 4 December (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-124

Vertical Distribution of Salinity (^{0}/oo) Section 1 September 1967 (ICNAF)

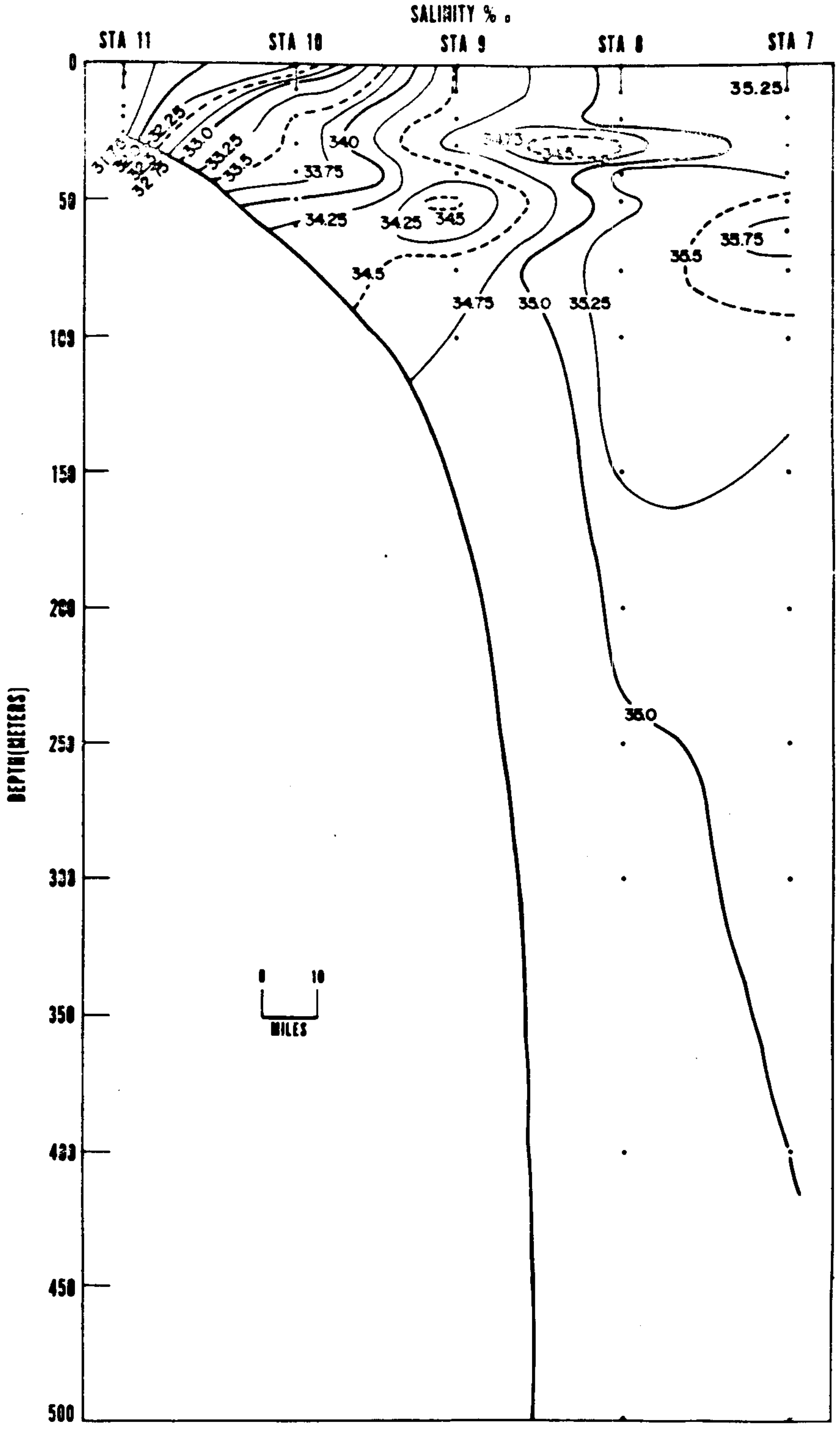
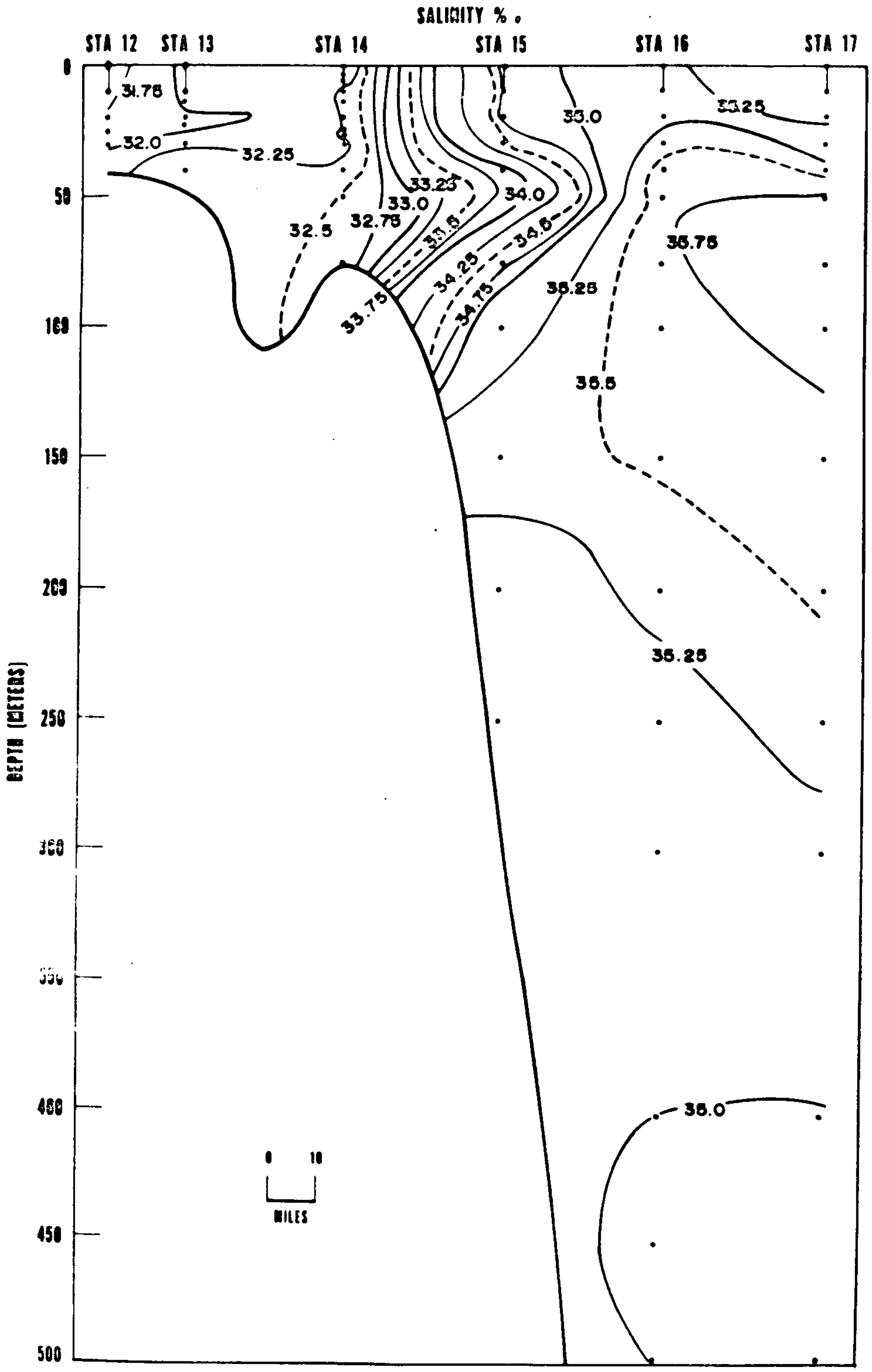


FIGURE 3-125 Vertical Distribution of Salinity (^{0}/oo) Section 2 September 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-126

Vertical Distribution of Salinity (⁰/oo) Section 3 September 1967 (ICNAF)

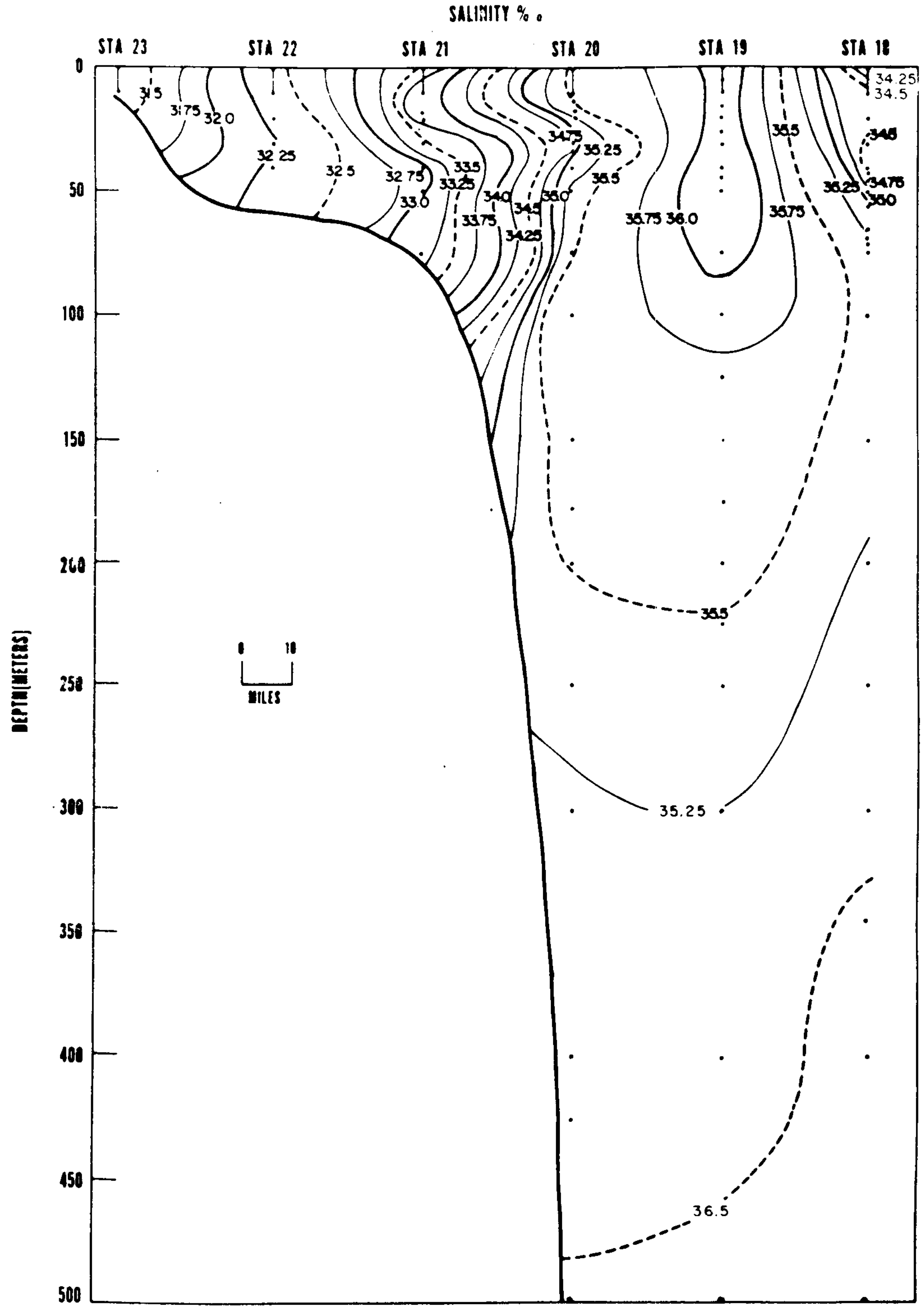


FIGURE 3-127 Vertical Distribution of Salinity (0/oo) Section 4 September 1967 (ICNAF)

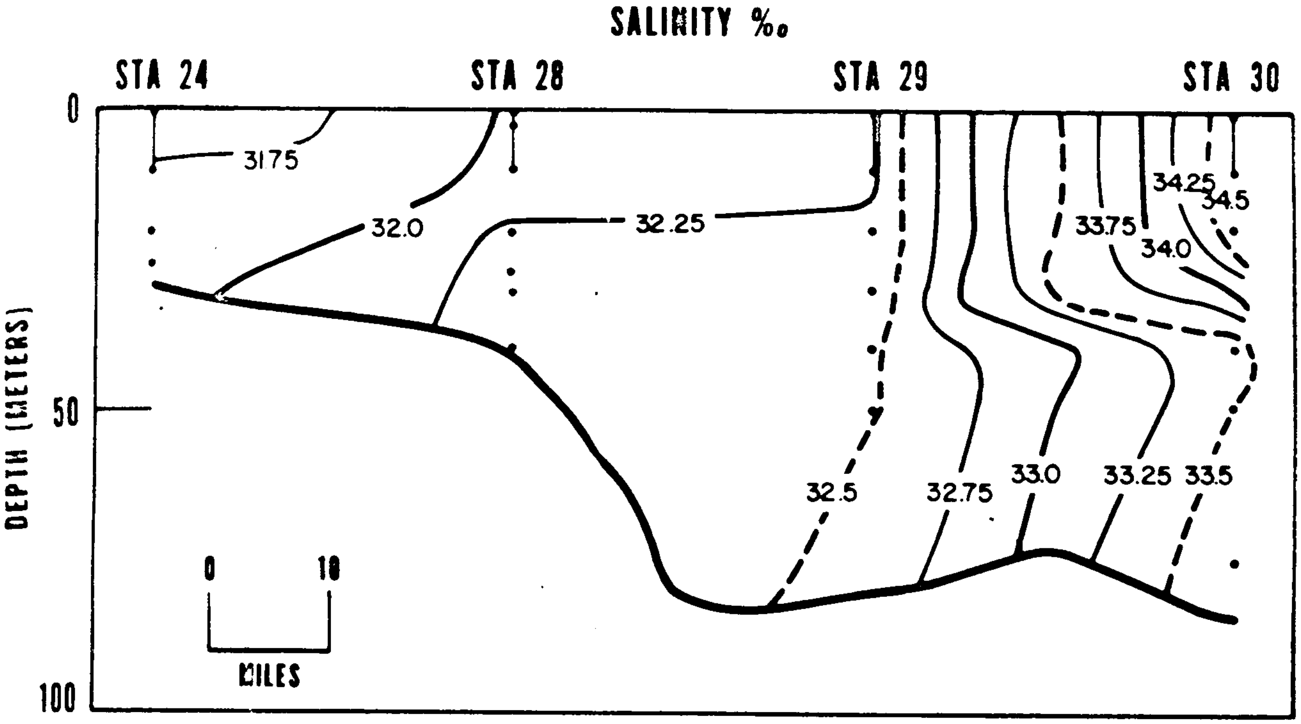


FIGURE 3-128

Vertical Distribution of Salinity (o/oo) Section 5
September 1967 (ICNAF)

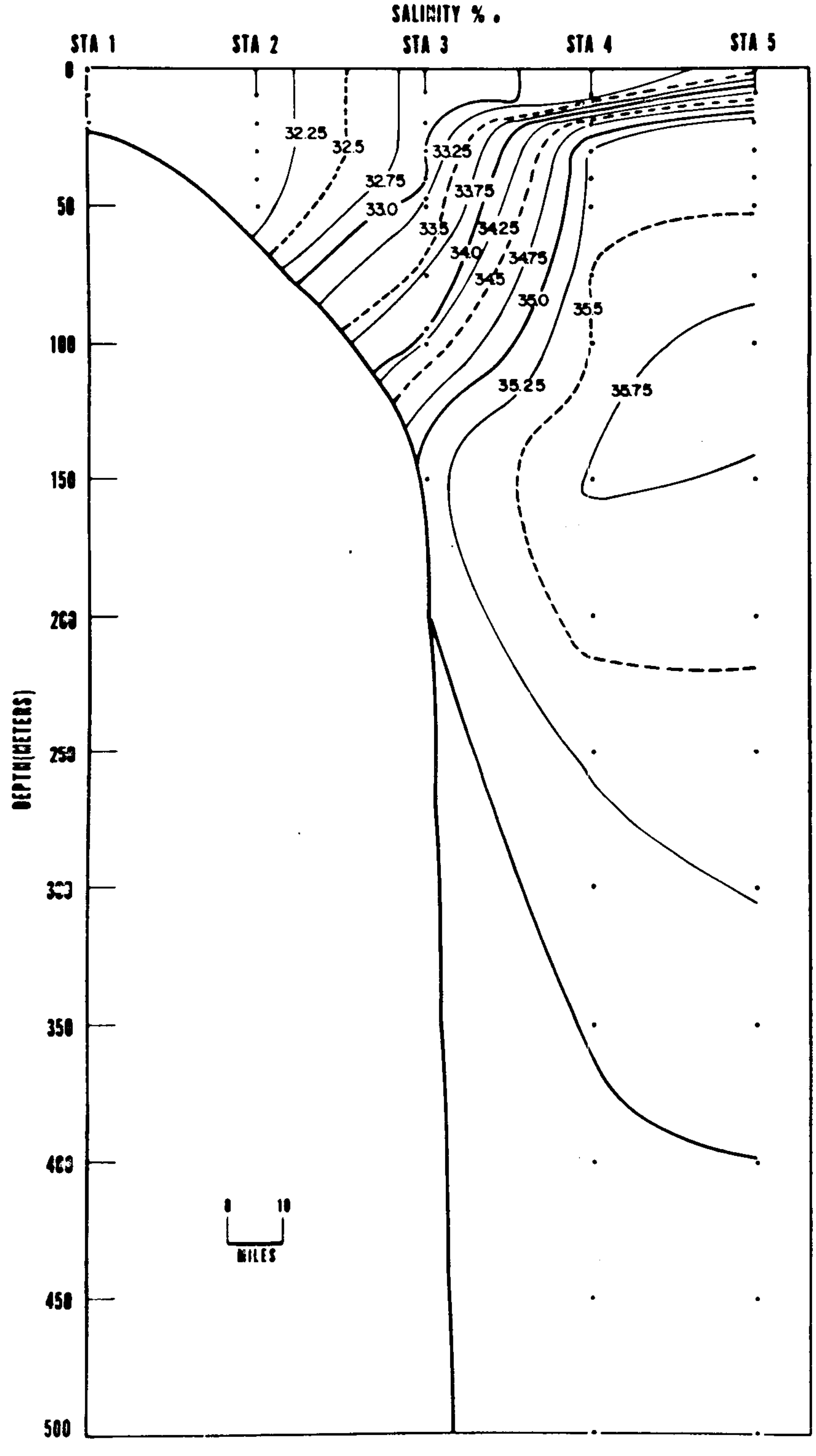
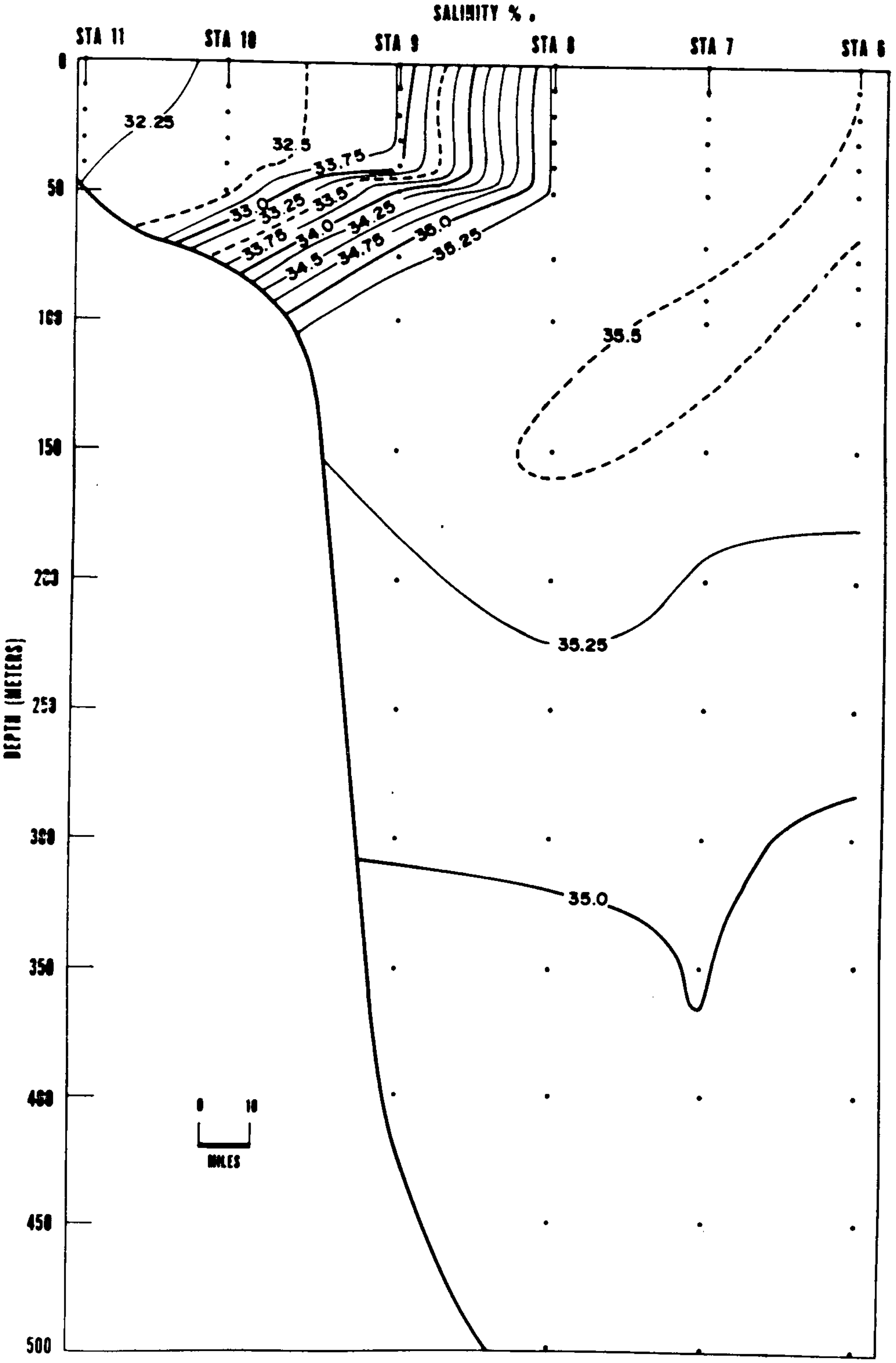


FIGURE 3-129

Vertical Distribution of Salinity (^{0}/oo) Section 1
December 1967 (ICNAF)

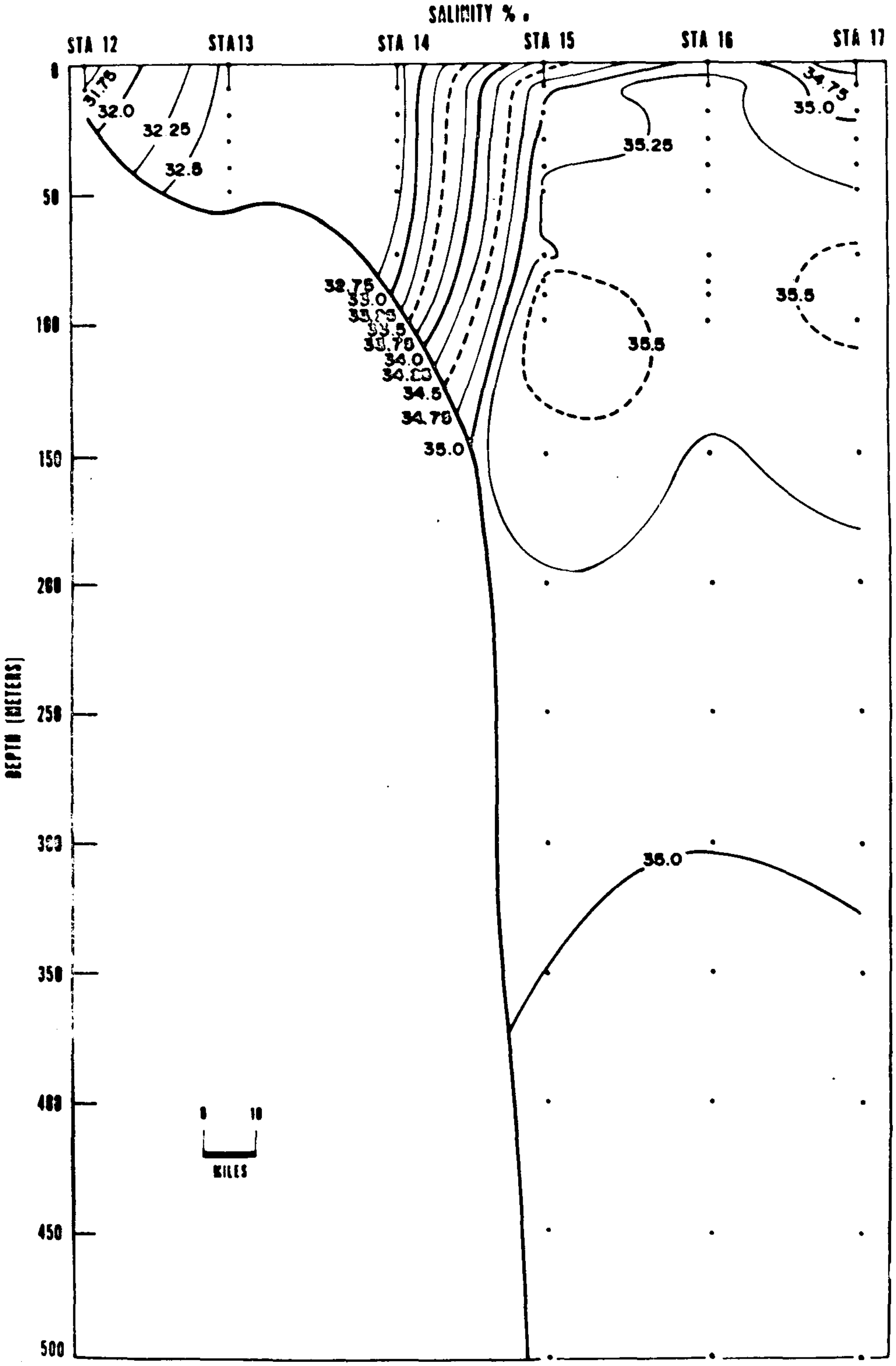


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-130

Vertical Distribution of Salinity ($^{0}/oo$) Section 2 December 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-131

Vertical Distribution of Salinity (o/oo) Section 3 December 1967 (ICNAF)

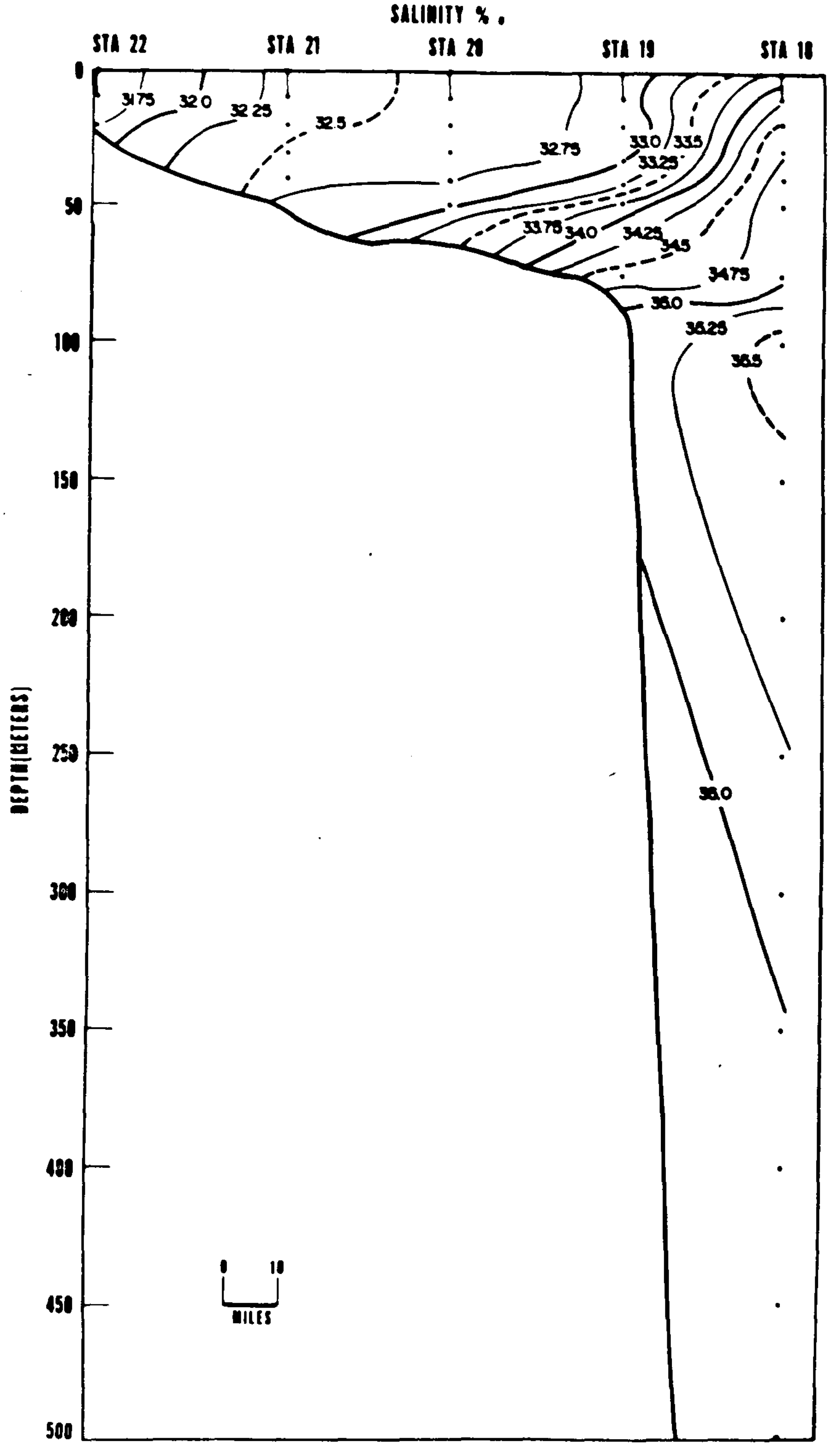
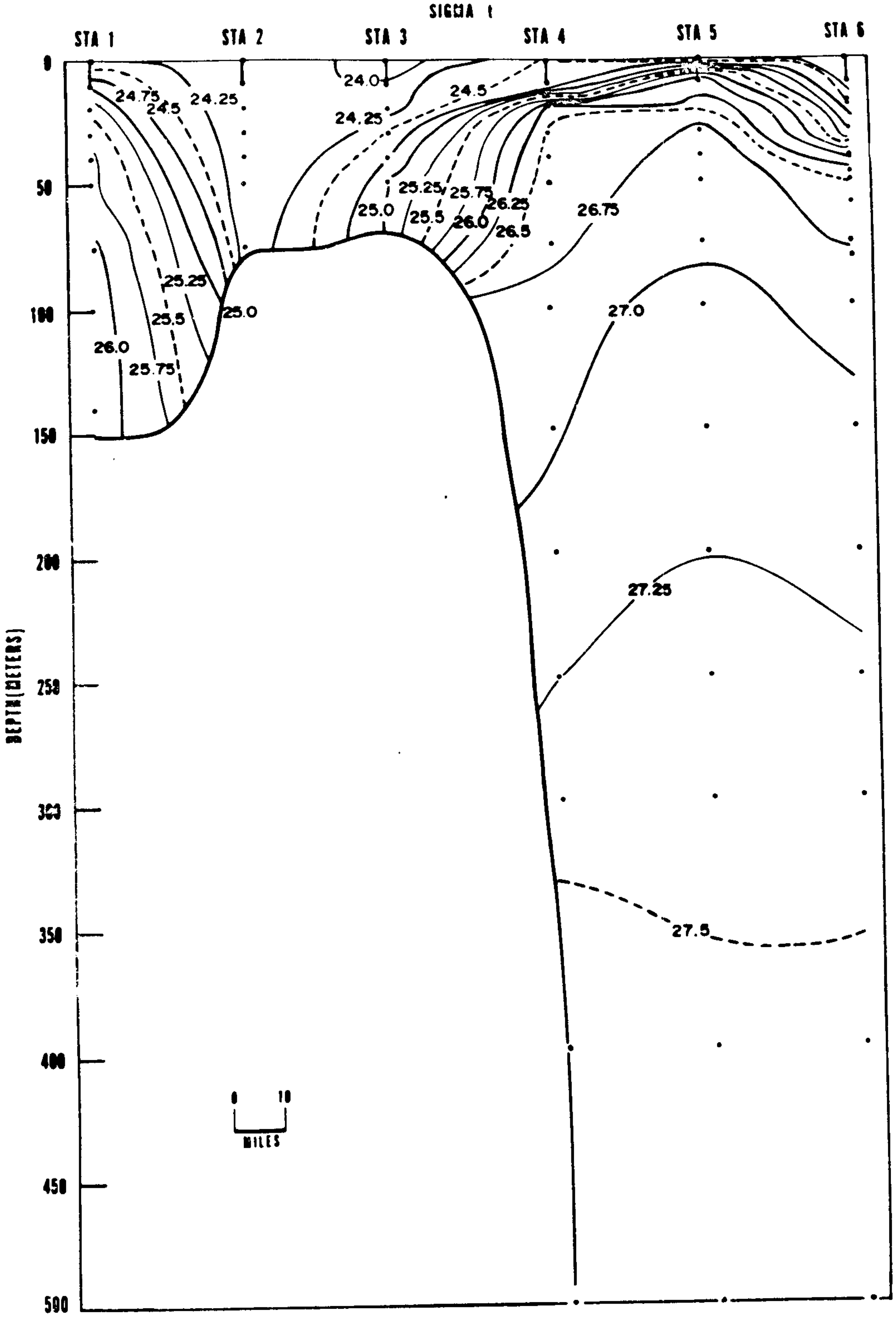


FIGURE 3-132 Vertical Distribution of Salinity (^{o}/oo) Section 4 December 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-133

Vertical Distribution of Density (σt in g/l) - Section 1 - September 1967 (ICNAF)

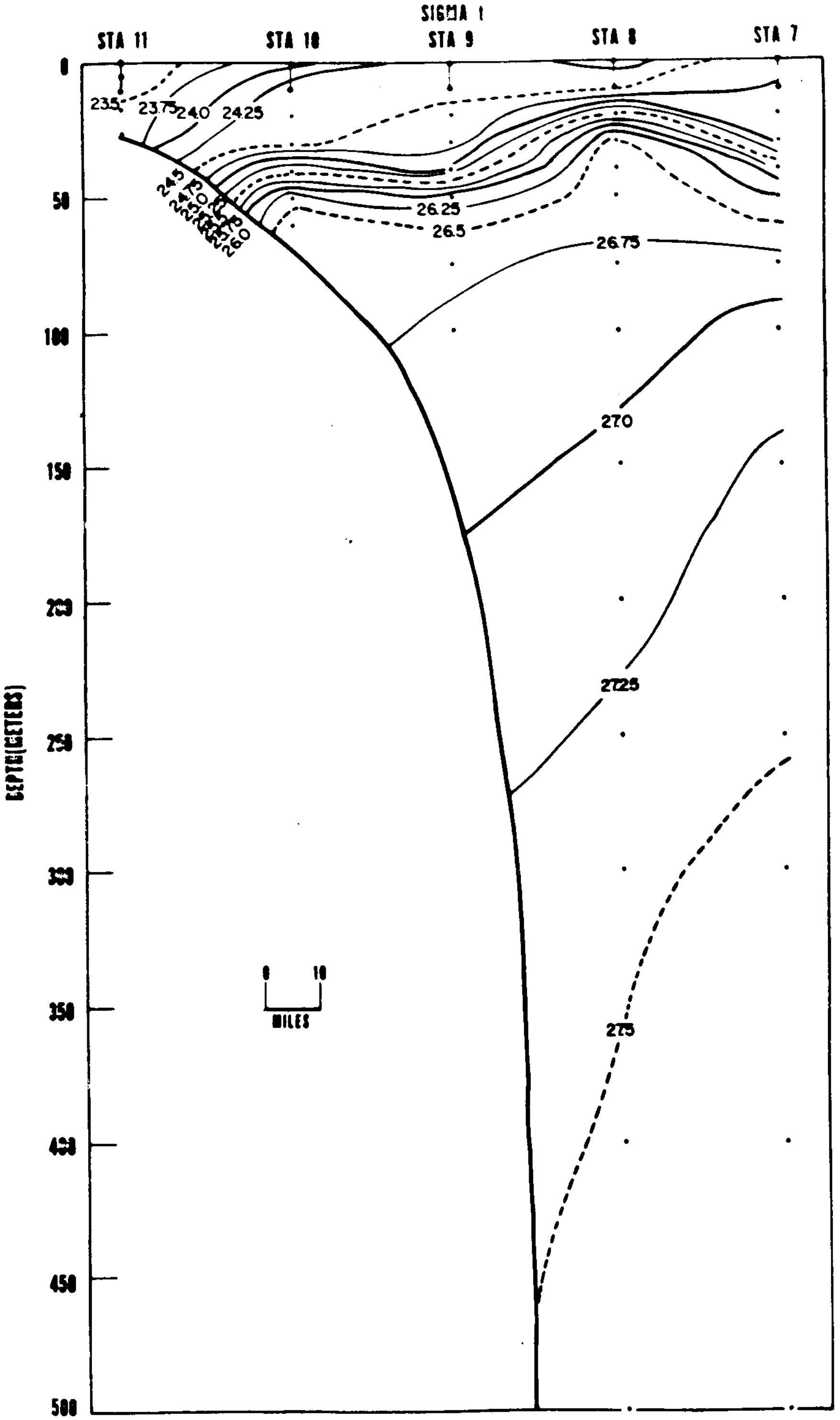


FIGURE 3-134

Vertical Distribution of Density (σt in g/l) - Section 2 - September 1967 (ICNAF)

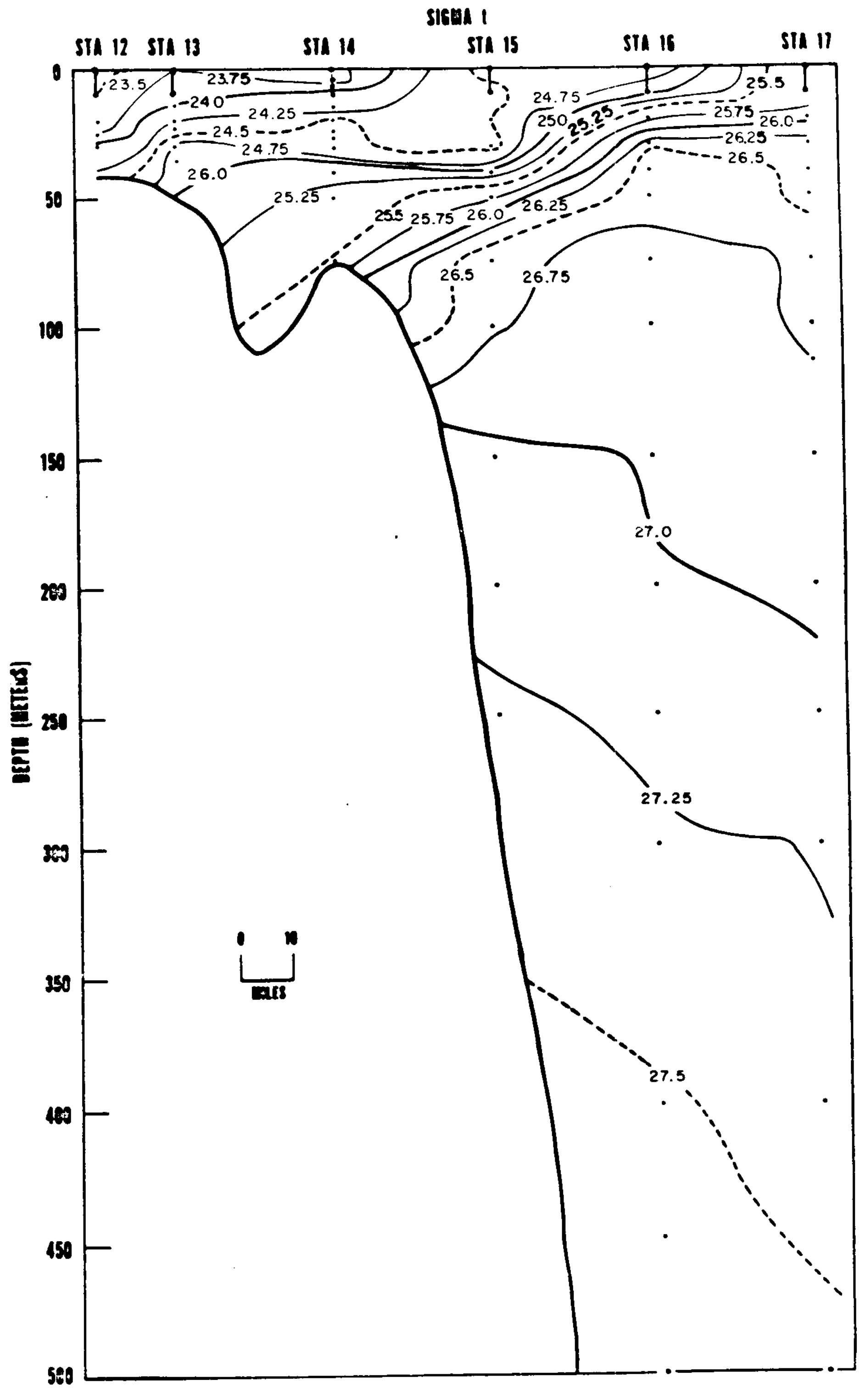


FIGURE 3-135

Vertical Distribution of Density (σt in g/l) - Section 3 - September 1967 (ICNAF)

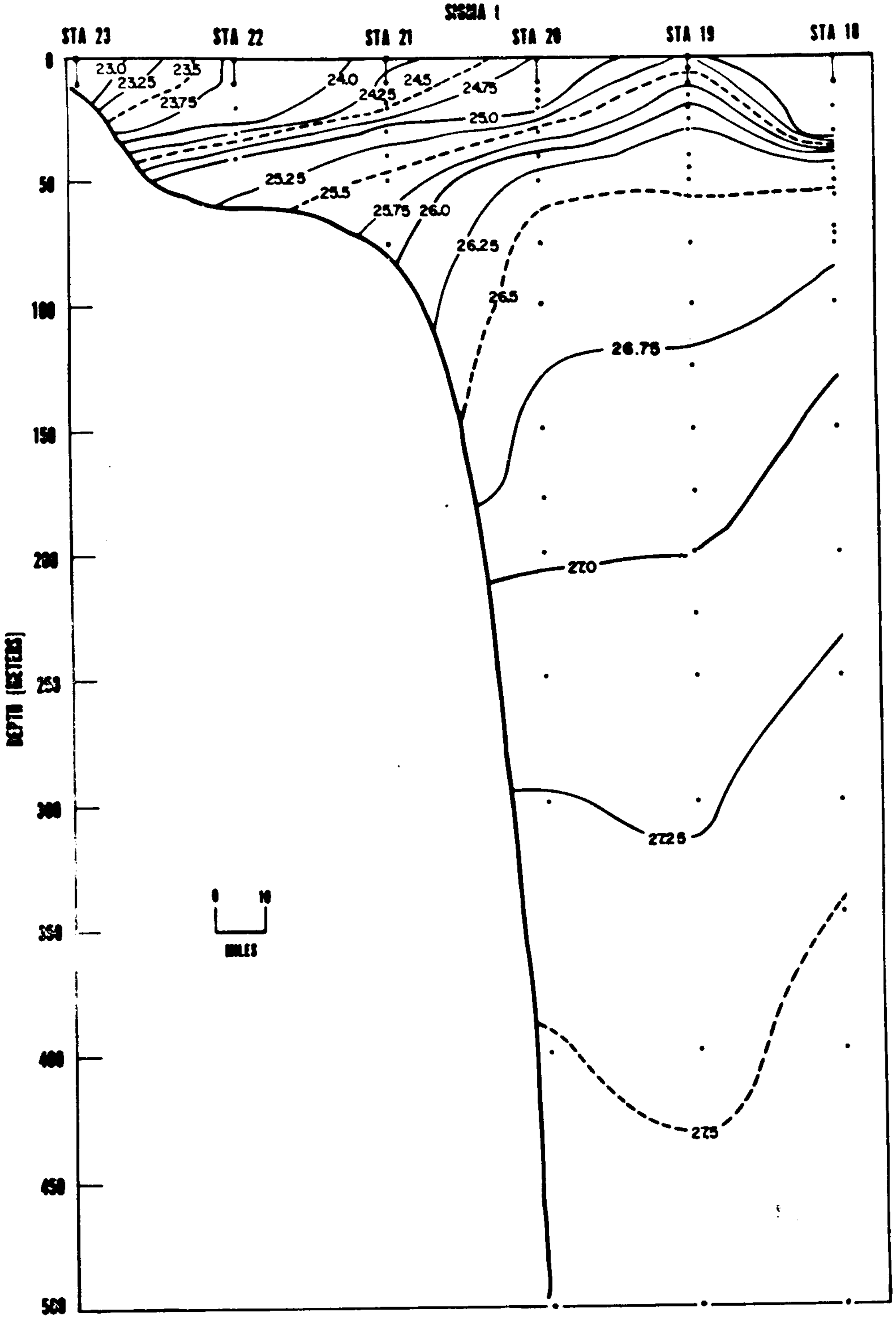
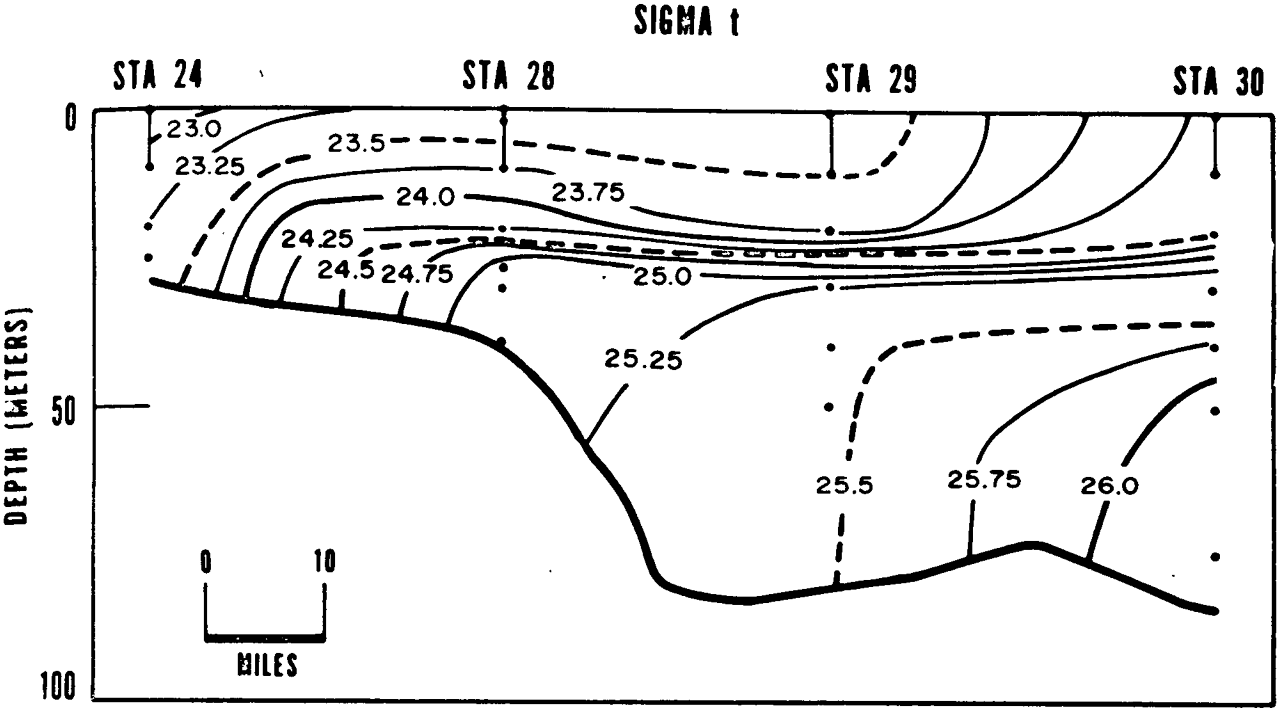


FIGURE 3-136

Vertical Distribution of Density (σt in g/l) - Section 4 - September 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-137

Vertical Distribution of Density (σt in g/l) - Section 5 - September 1967 (ICNAF)

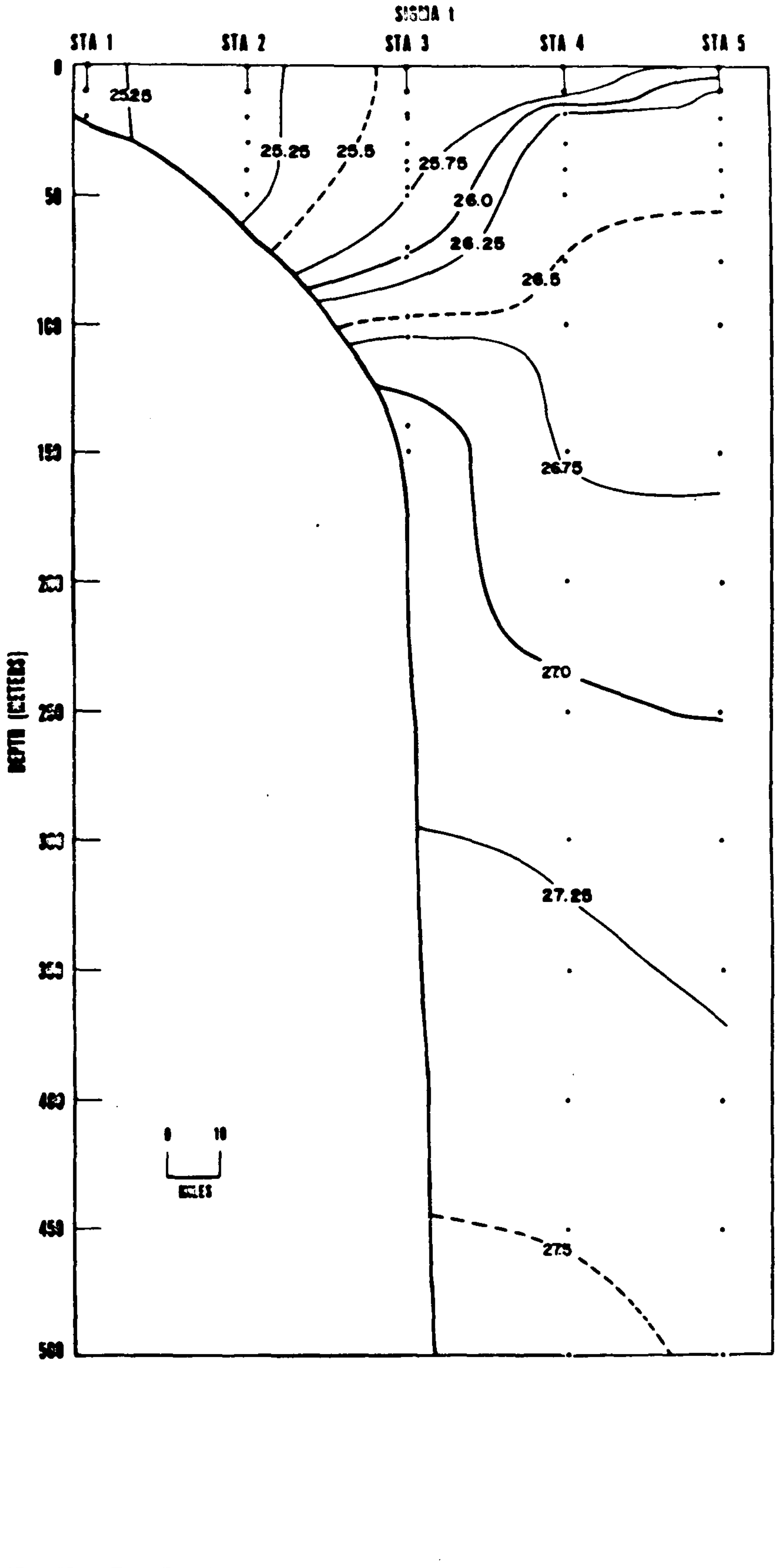


FIGURE 3-138

Vertical Distribution of Density (σt in g/l) - Section 1 - December 1967 (ICNAF)

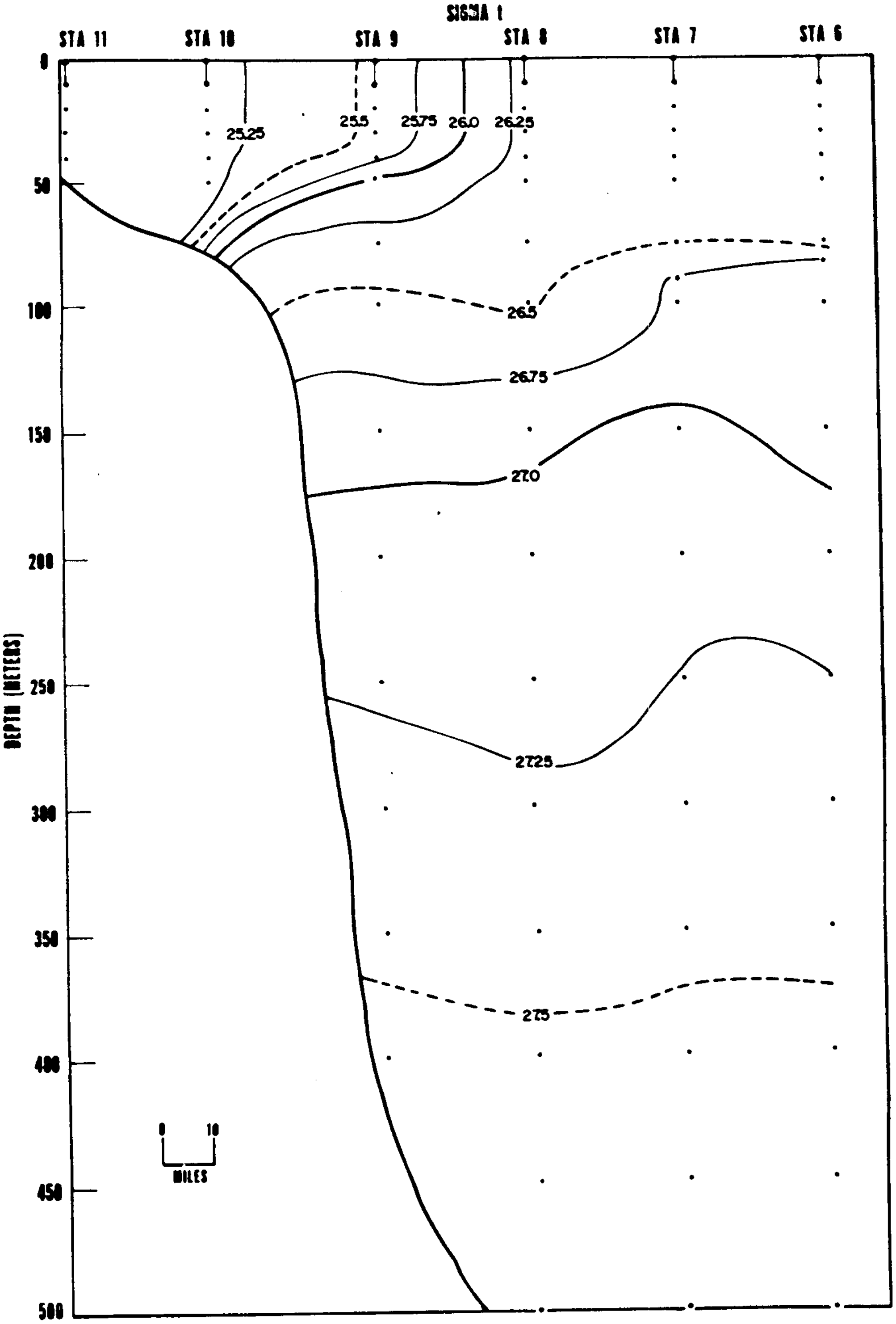


FIGURE 3-139

Vertical Distribution of Density (σt in g/l) - Section 2 - December 1967 (ICNAF)

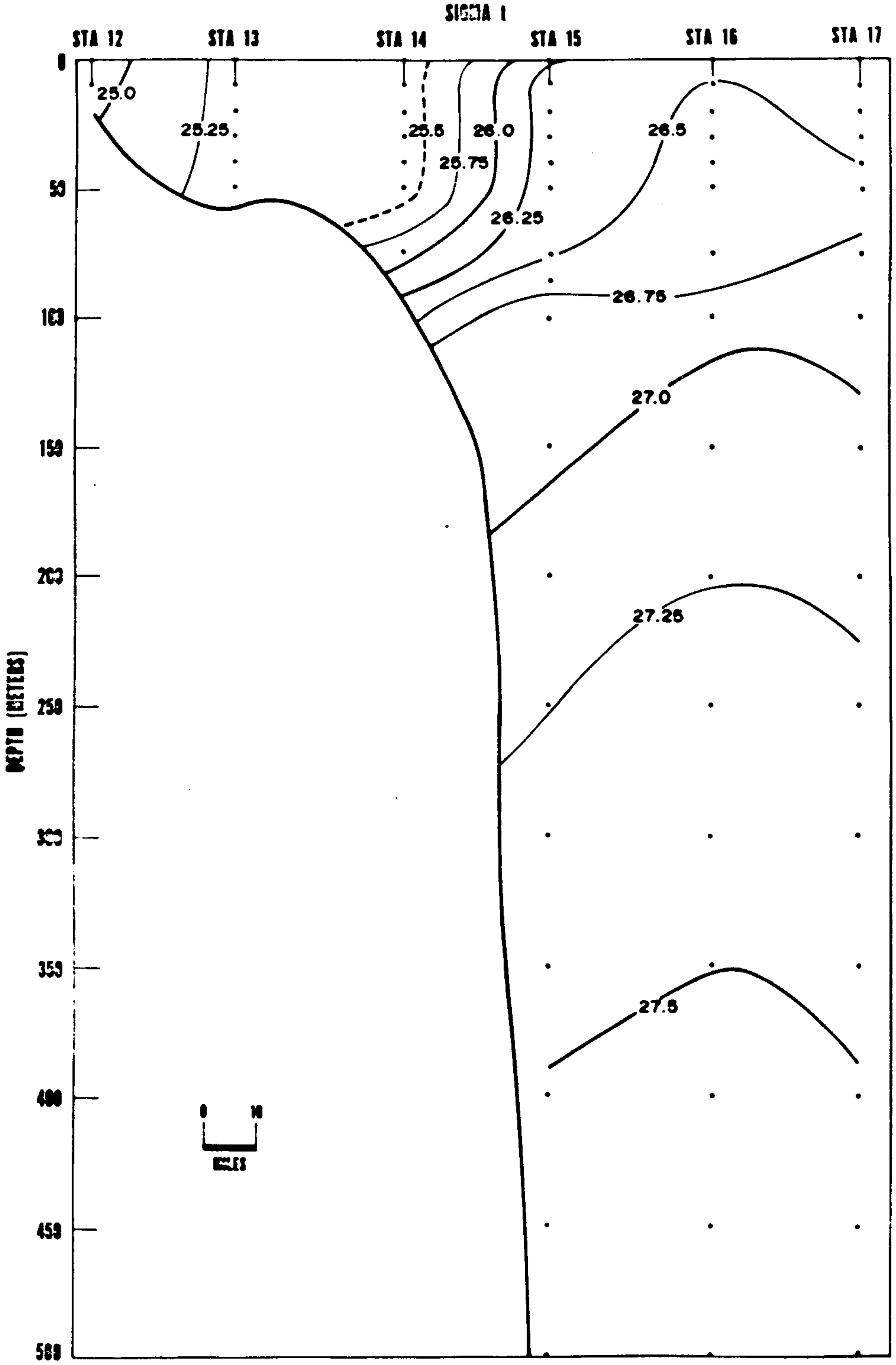
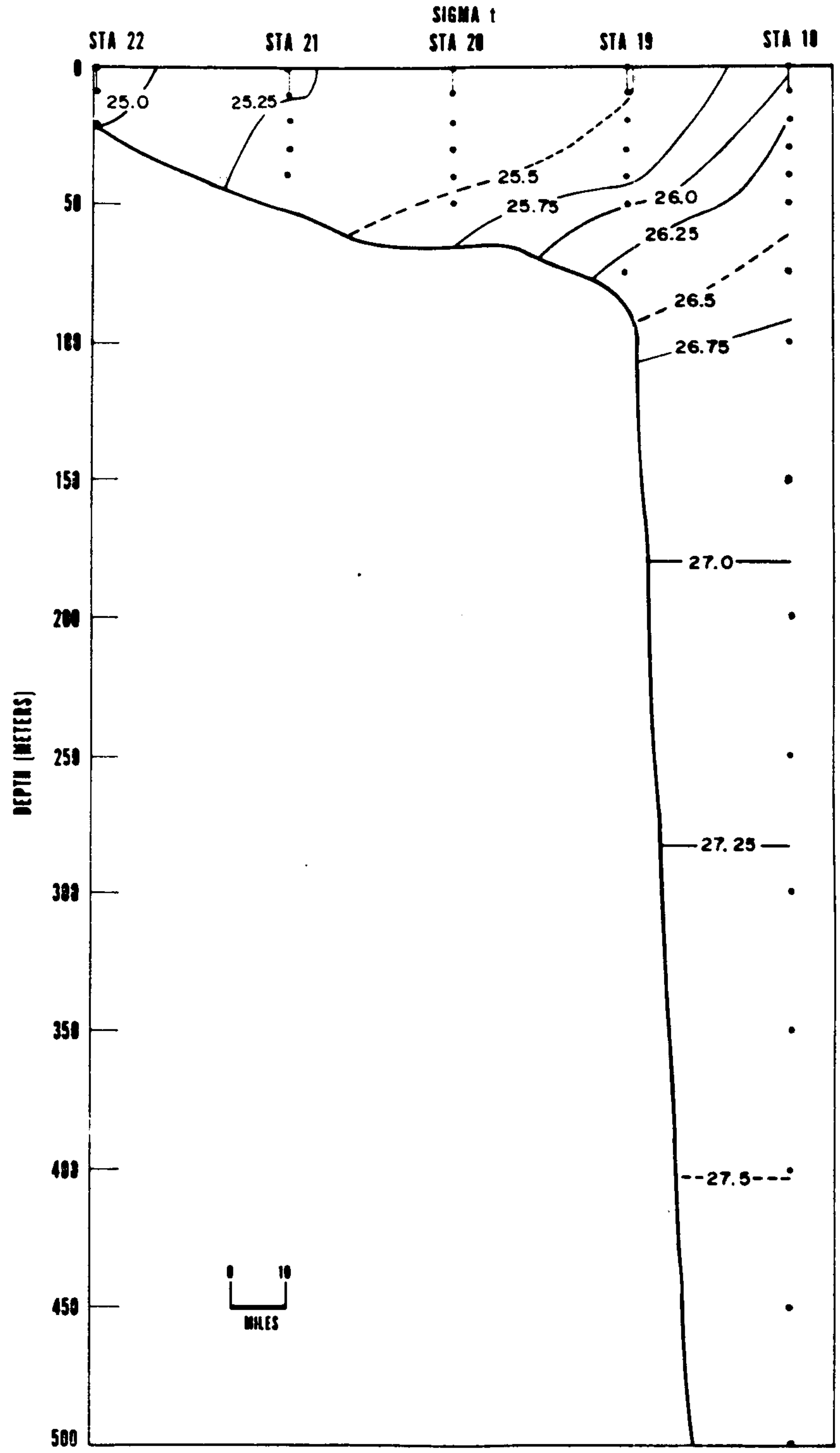


FIGURE 3-140

Vertical Distribution of Density (σt in g/l) - Section 3 - December 1967 (ICNAF)

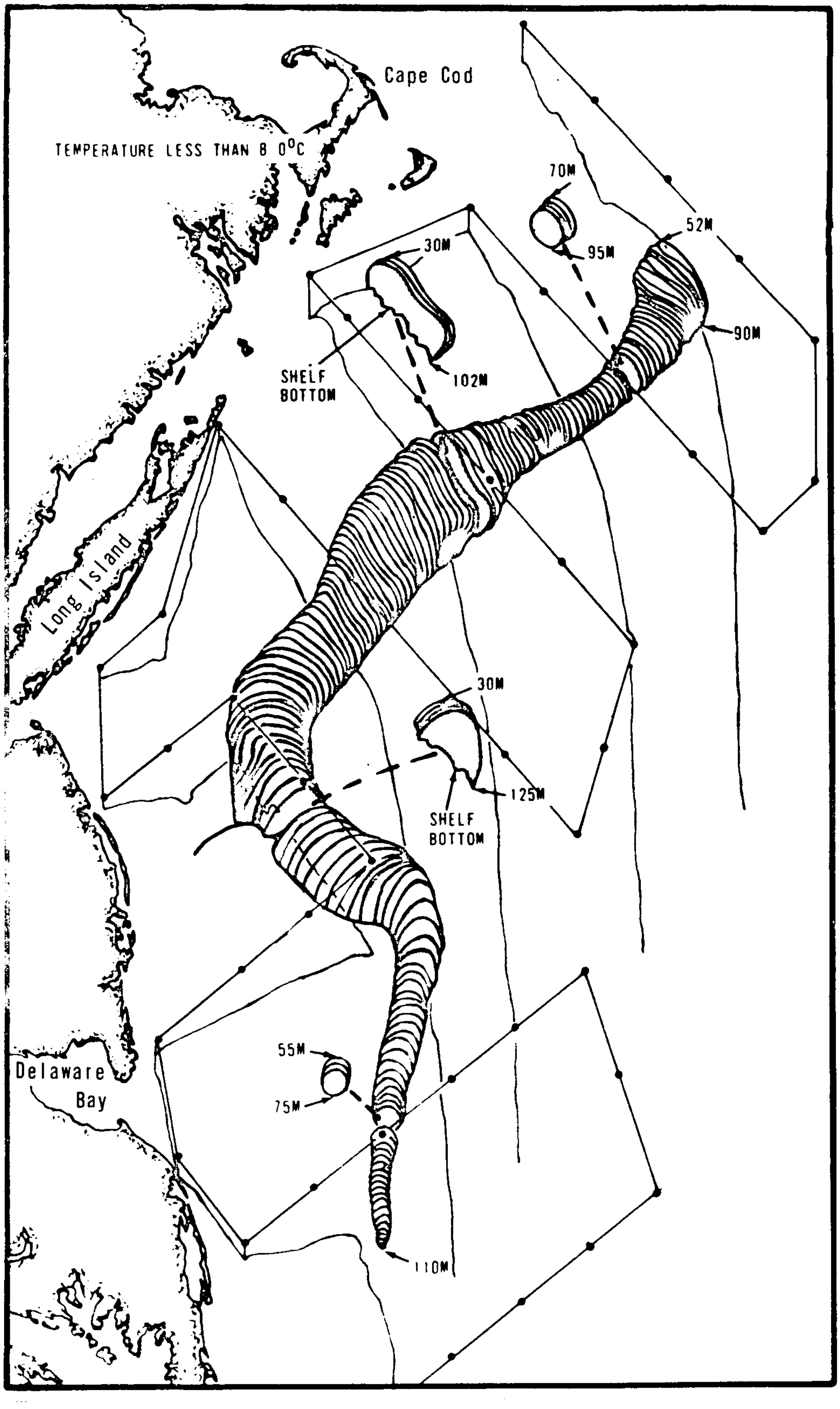


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-141

Vertical Distribution of Density (σt in g/l) - Section 4 - December 1967 (ICNAF)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-142 Three Dimensional Representation of Cold Bottom Water Core Along the Shelf in September (ICNAF)

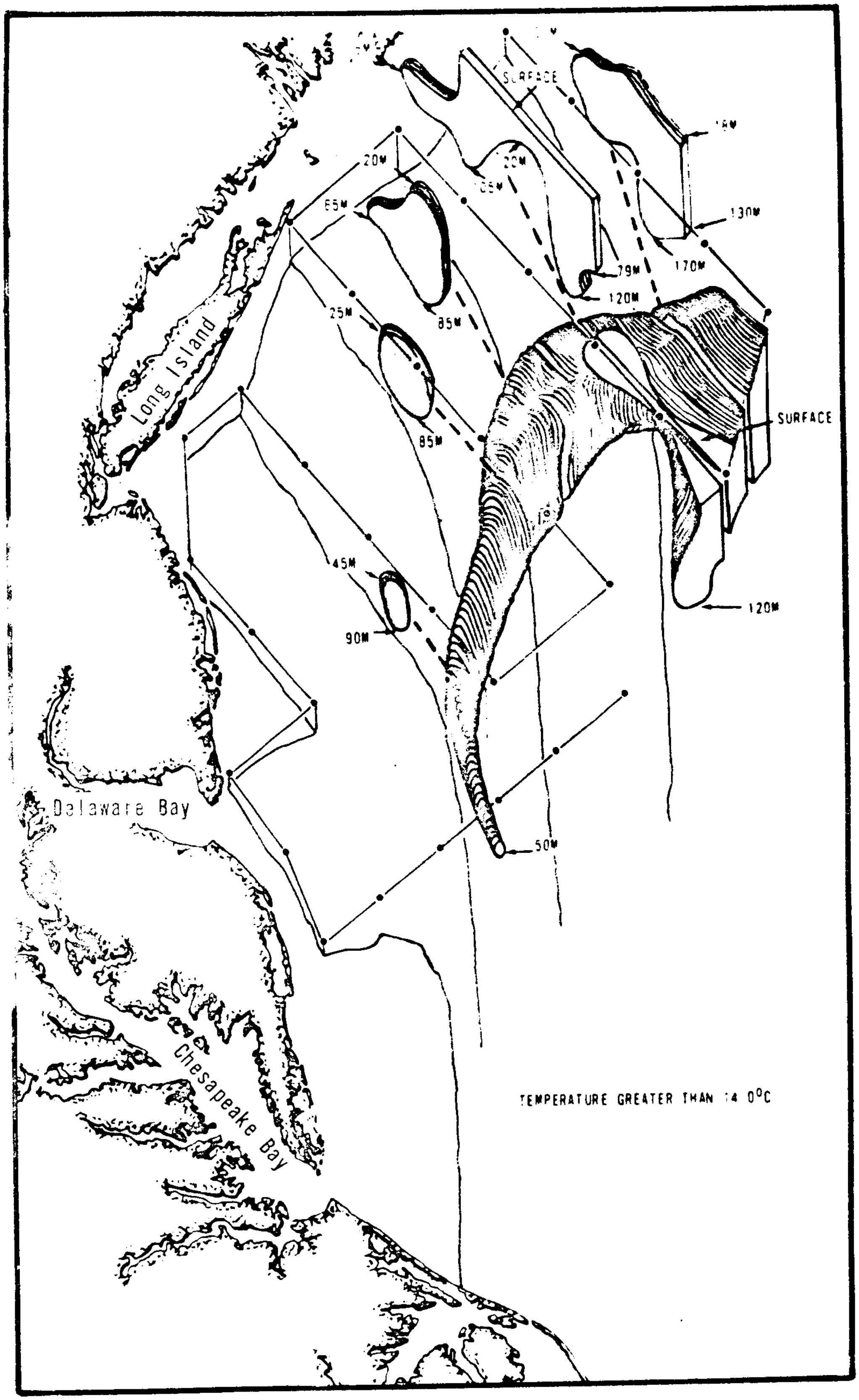


FIGURE 3-143

Three Dimensional Representation of Warm Slope Water in December (ICNAF)

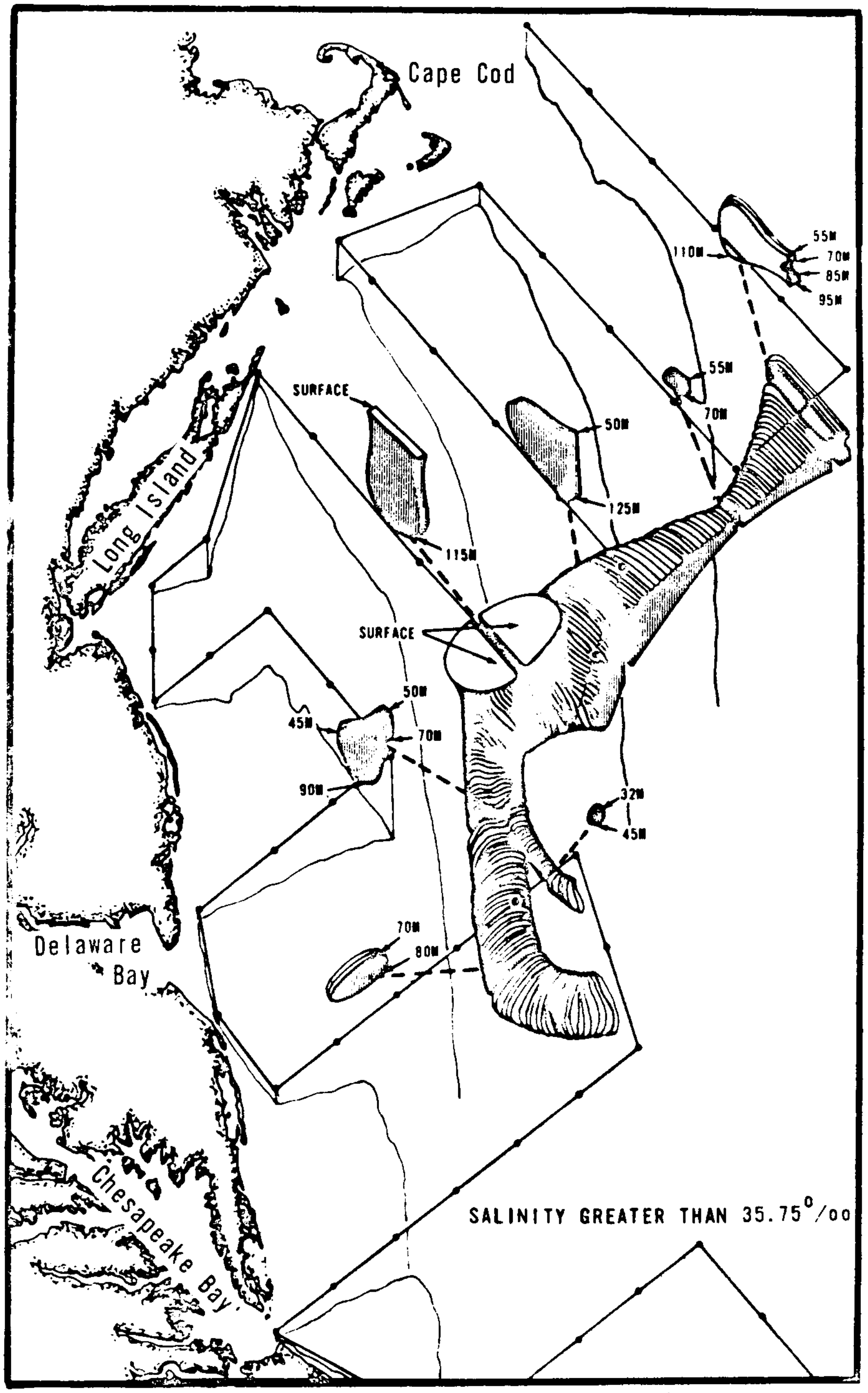


FIGURE 3-144 Three Dimensional Representation of High Salinity (>35.5%) Core of Slope Water in September (ICNAF)

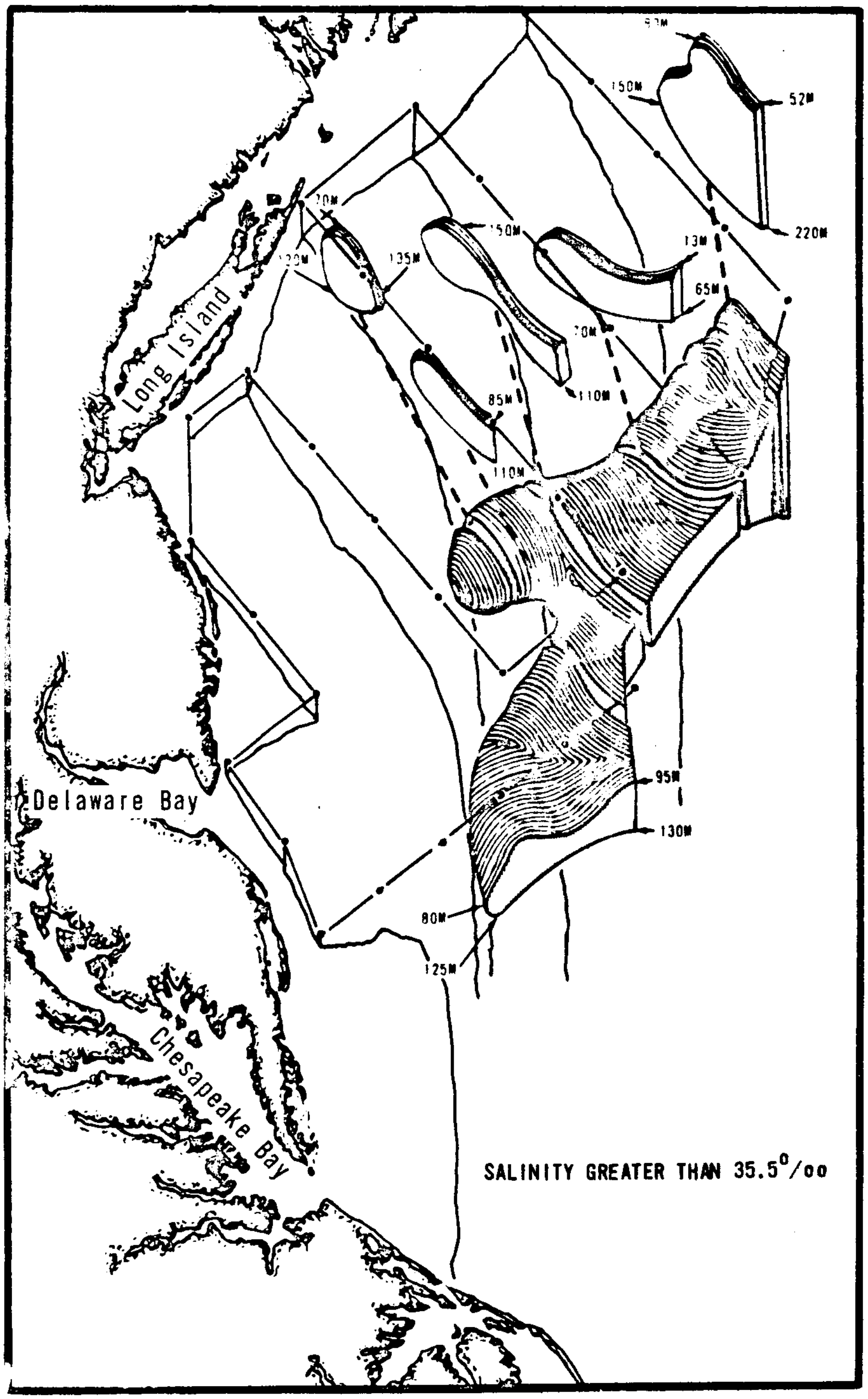


FIGURE 3-145 Three Dimensional Representation of High Salinity (>35.5%) Core of Slope Water in December (ICNAF)

Table 3-6

—Observed and interpolated oceanographic data taken by USCGC Evergreen, 19–29 September 1970, on ICNAF Cruise 67–2; prepared from NoDC Listing No. 31–8023.

Reference Ctry Code	Reference ID. No.	Ship Code	Latitude ° 1/10	Longitude ° 1/10	Drift Indctr	Marsden Square 10°	Marsden Square 1°	Station Time (GMT) Mo	Station Time (GMT) Day	Station Time (GMT) Hr. 1/10	Year	Originator's Cruise No.	Originator's Station Number	Depth to Bottom	Max. Depth of S'mpl's	Wave Observations Dir.	Wave Observations Hgt	Wave Observations Per	Wave Observations Sea	Weather Code	Cloud Codes Type	Cloud Codes Amt		NODC Station Number
31	8023	EV	4130 N	06900 W		151	19	09	19	020	1967	102	001	0151	01	21	0	2		X0				0001

Water Color Code	Water Trans (m)	Wind Dir.	Wind Speed or Force	Barometer (mbs)	Air Temp. °C Dry Bulb	Air Temp. °C Wet Bulb	Vis. Code	No. Obs. Depths	Special Observations
07	50	24	510	142	155	144	7	09	

Messengr Time or T Hr 1/10	Cast No.	Card Type	Depth (m)	T °C	S ‰	Sigma-T	Specific Volume Anomaly×10⁵	Σ Δ D Dyn. M. × 10³	Sound Velocity	O₂ ml/l	PO₄-P µg-at/l	Total-P µg-at/l	NO₂-N µg-at/l	CHL—A	SiO₄-Si µg-at/l	pH	SCC
		STD	0000	1145	3187	2428	0036525	0000	14916	683							
020		OBS	0000	1145	31865	2428			14916	683				114			
		STD	0010	0850	3201	2488	0030858	0034	14811	686							
		OBS	0010	0850	32008	2488			14811	686				143			
		STD	0020	0579	3226	2544	0025525	0062	14709	667							
000		OBS	0020	0579	32259	2544			14709	667				033			
		STD	0030	0490	3232	2559	0024106	0087	14675	665							
		OBS	0030	0490	32320	2559			14675	666				023			
		OBS	0040	0439	32505	2579			14658	663				011			
		STD	0050	0435	3250	2579	0022211	0133	14658	655							
		OBS	0050	0435	32500	2579			14658	655				005			
		STD	0075	0410	3276	2602	0020028	0186	14655	608							
		OBS	0075	0410	32760	2602			14655	608				000			
		STD	0100	0410	3298	2619	0018384	0234	14662	577							
		OBS	0100	0410	32981	2619			14662	577				000			
		STD	0125	0410	3299	2620	0018350	0280	14666								
		OBS	0140	0410	32992	2620			14669								

Reference Ctry Code	Reference ID. No.	Ship Code	Latitude ° 1/10	Longitude ° 1/10	Drift Indctr	Marsden Square 10°	Marsden Square 1°	Station Time (GMT) Mo	Station Time (GMT) Day	Station Time (GMT) Hr. 1/10	Year	Originator's Cruise No.	Originator's Station Number	Depth to Bottom	Max. Depth of S'mpl's	Wave Observations Dir.	Wave Observations Hgt	Wave Observations Per	Wave Observations Sea	Weather Code	Cloud Codes Type	Cloud Codes Amt		NODC Station Number
31	8023	EV	4100 N	06900 W		151	19	09	19	050	1967	102	002	0078	01	21	0	2		X0				0002

Water Color Code	Water Trans (m)	Wind Dir.	Wind Speed or Force	Barometer (mbs)	Air Temp. °C Dry Bulb	Air Temp. °C Wet Bulb	Vis. Code	No. Obs. Depths	Special Observations
DT	SD	28	515	139	150	144	7	07	

Messengr Time or T Hr 1/10	Cast No.	Card Type	Depth (m)	T °C	S ‰	Sigma-T	Specific Volume Anomaly×10⁵	Σ Δ D Dyn. M. × 10³	Sound Velocity	O₂ ml/l	PO₄-P µg-at/l	Total-P µg-at/l	NO₂-N µg-at/l	CHL—A	SiO₄-Si µg-at/l	pH	SCC
		STD	0000	1290	3196	2408	0038394	0000	14967	599							
050		OBS	0000	1290	31962	2408			14967	599				082			
		STD	0010	1290	3197	2409	0038394	0038	14969	599							
		OBS	0010	1290	31965	2409			14969	599				081			
		STD	0020	1290	3197	2409	0038417	0077	14971	604							
000		OBS	0020	1290	31965	2409			14971	604				093			
		STD	0030	1290	3197	2409	[illegible]	0115	14972	605							
		OBS	0030	1290	31965	2409			14972	605				079			
		OBS	0040	1290	31965	2409			14974	[illegible]				078			
		STD	0050	1290	3197	2409	[illegible]	0192	14976	606							
		OBS	0050	1290	31965	2409			14976	606				088			
		STD	0075	1290	3197	[illegible]	[illegible]	[illegible]	[illegible]	606							
		OBS	0075	1290	[illegible]	[illegible]			[illegible]	[illegible]				085			

3.2.9A PART II

Surface salinity gradients on the continental shelf SE and E of New England as determined for winter (March), spring (May-June), summer (September) and fall (December) over 2 years (1965-66) by Colton, Marak, Nickerson and Stoddard (1968). Transects are not coincident with Whitcomb (1970) in **Section A, Part I.**

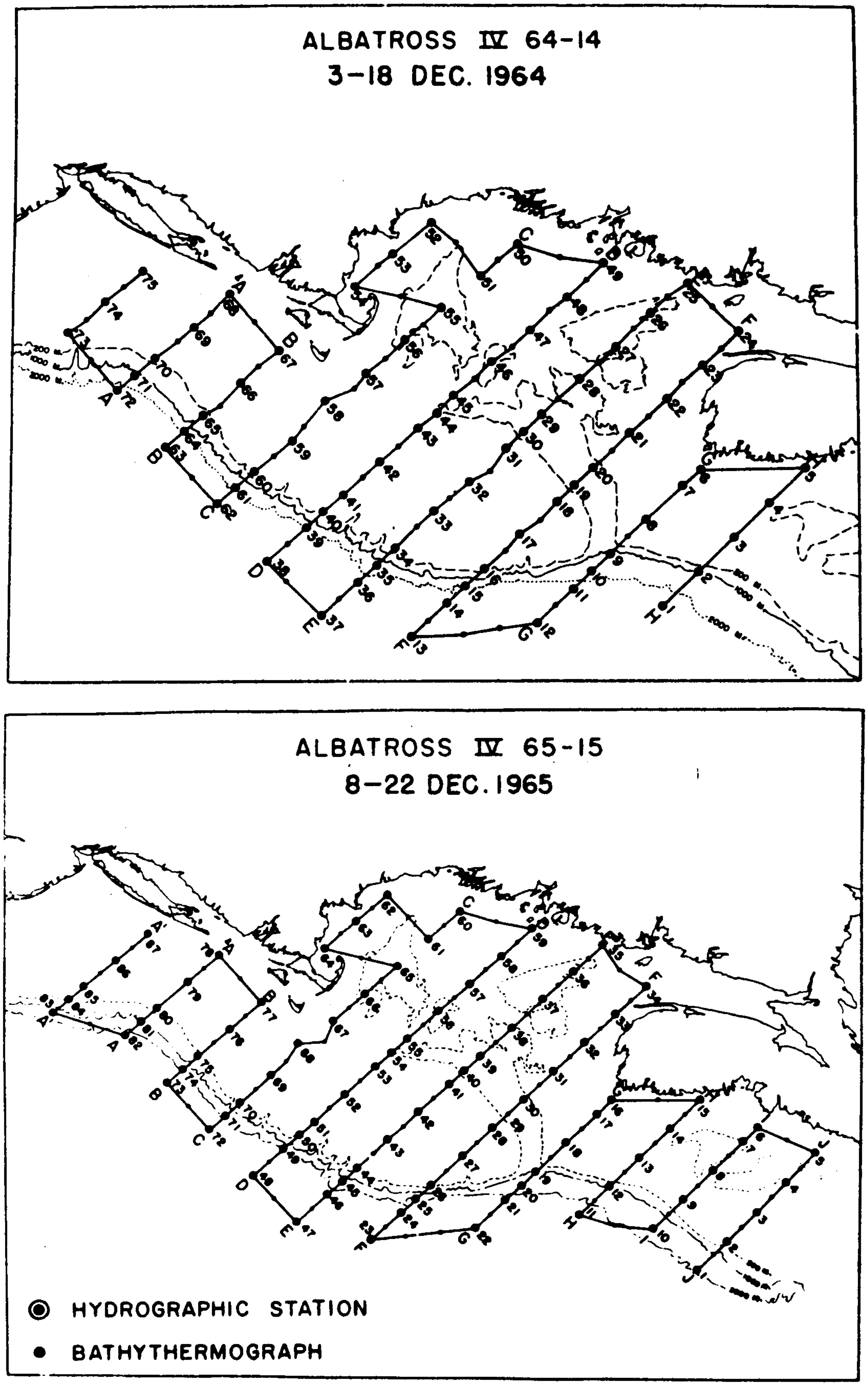
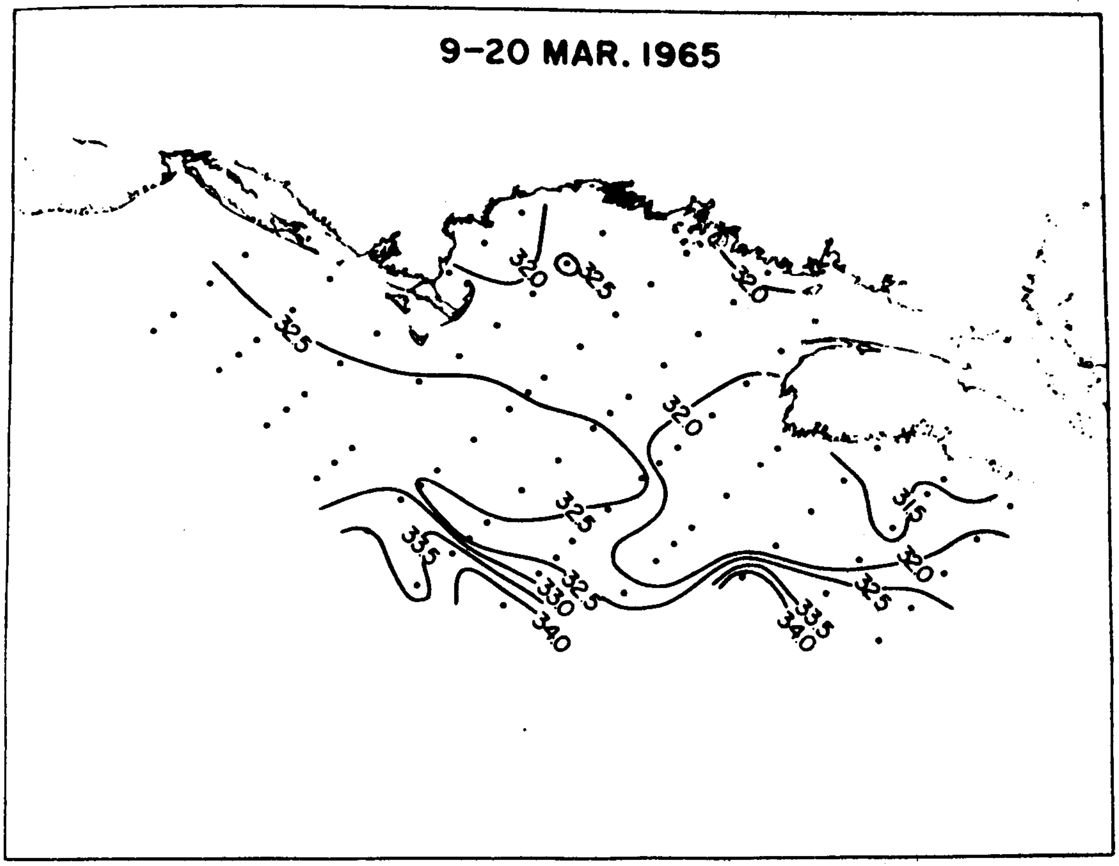
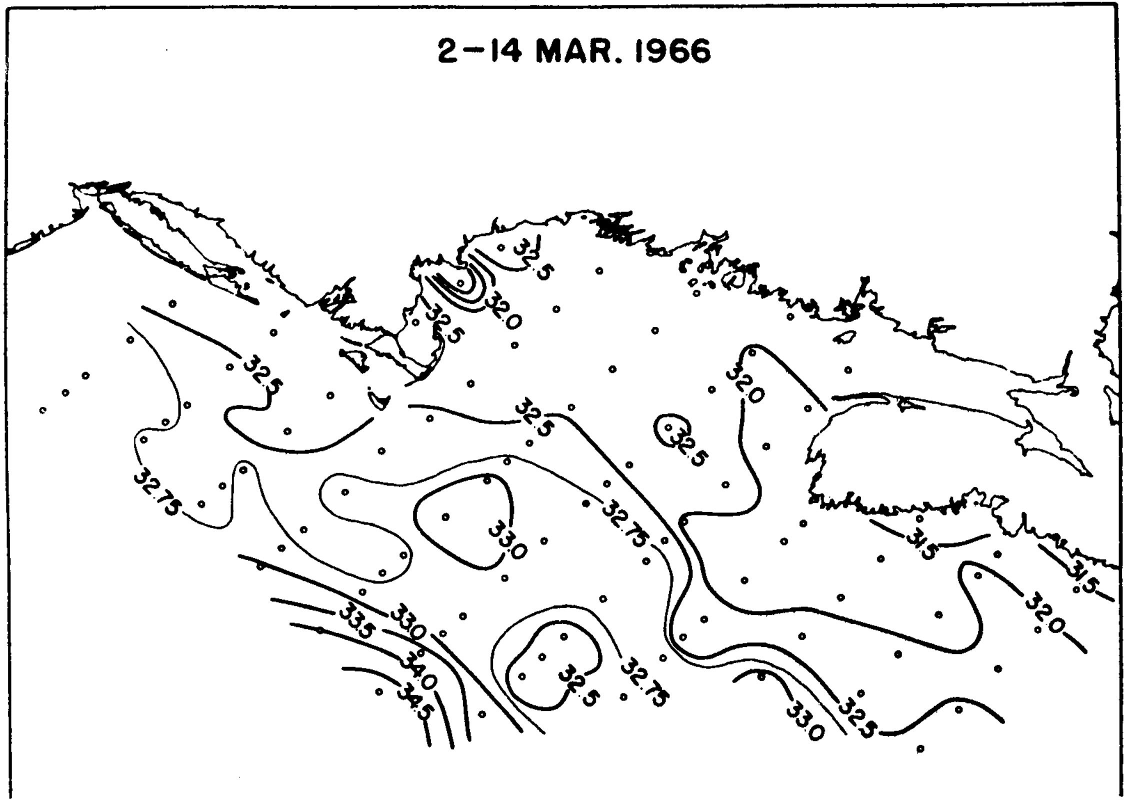


FIGURE 3-146 Cruise Tracks and Stations for the Albatross IV (Colton et al., 1968)



9-20 MAR. 1965



2-14 MAR. 1966

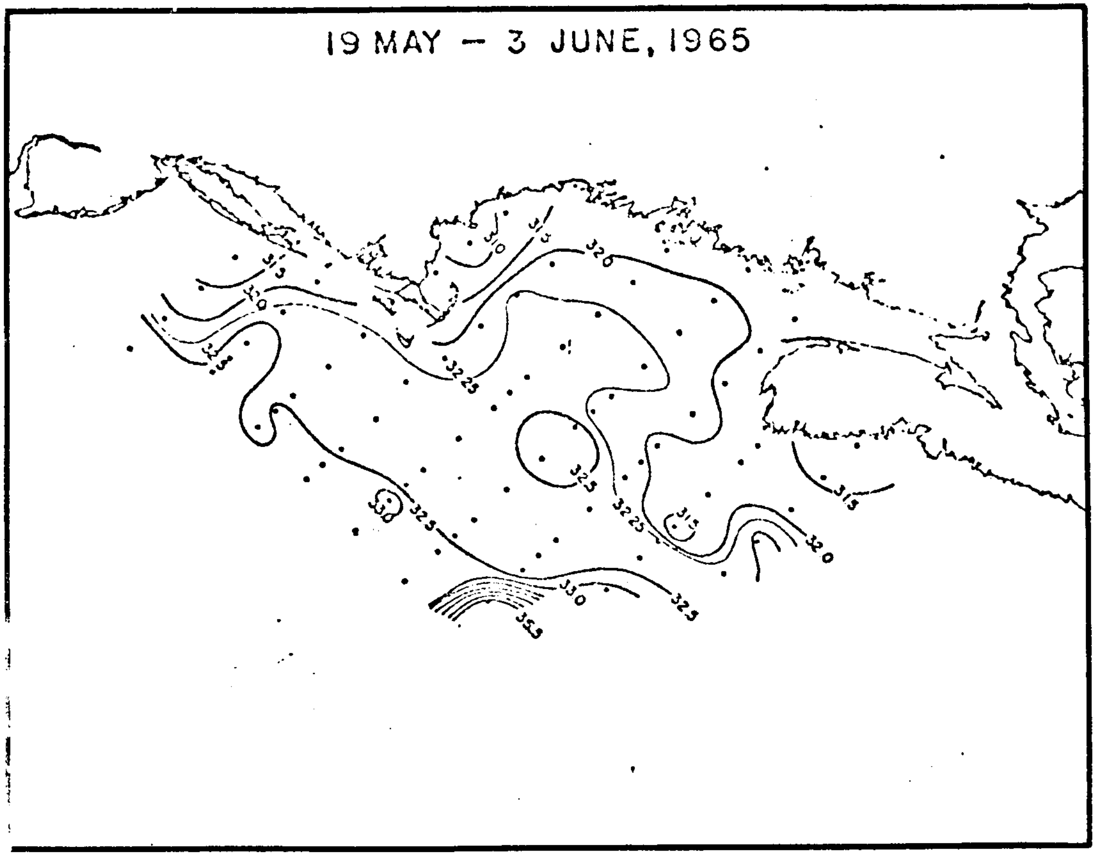
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-147

Surface Isohalines - March (Colton et al., 1968)

19 MAY – 3 JUNE, 1965



24 MAY – 7 JUNE, 1966

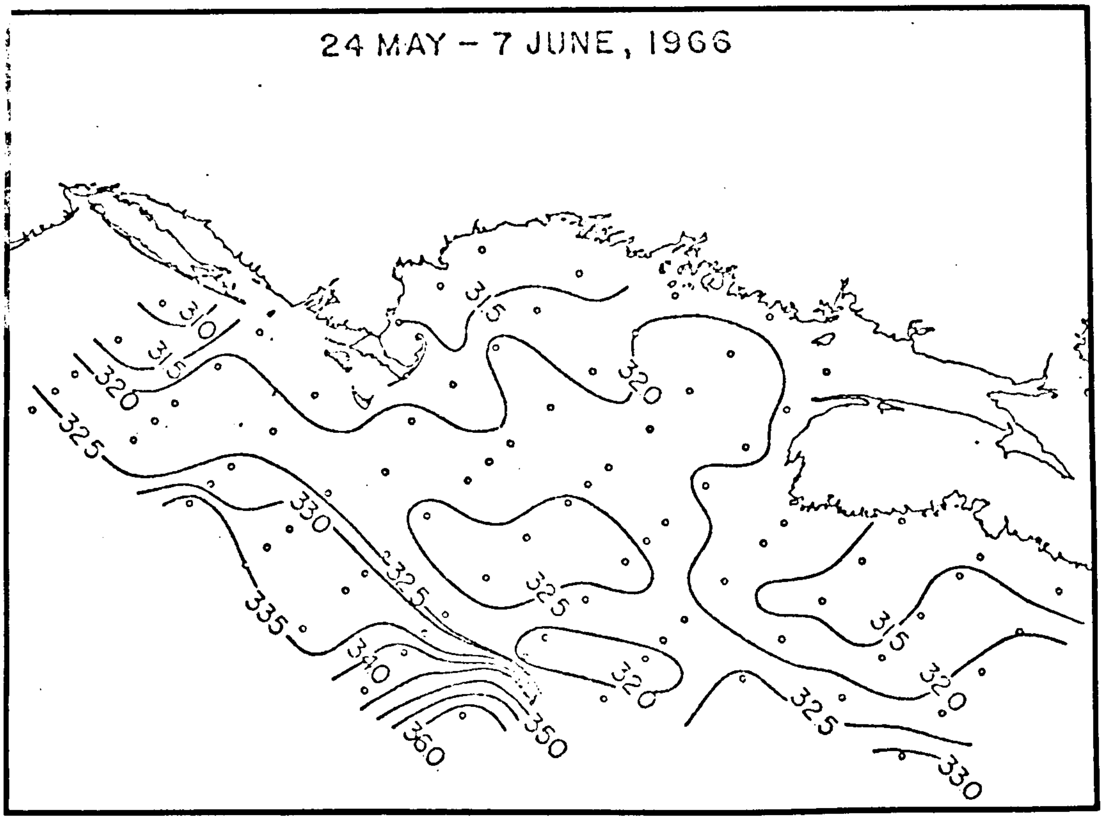


FIGURE 3-148 Surface Isohalines - May-June (Colton et al., 1968)

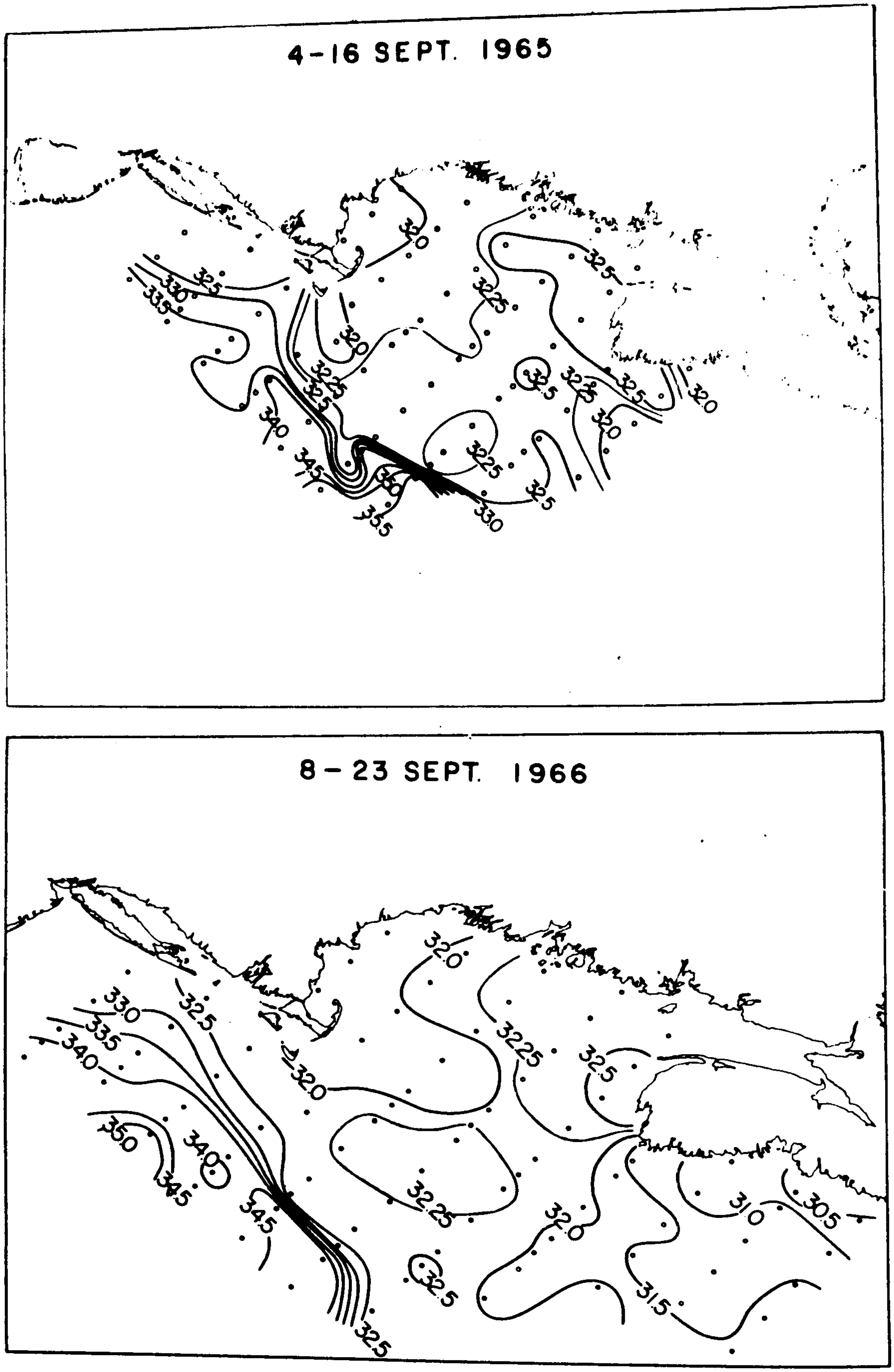
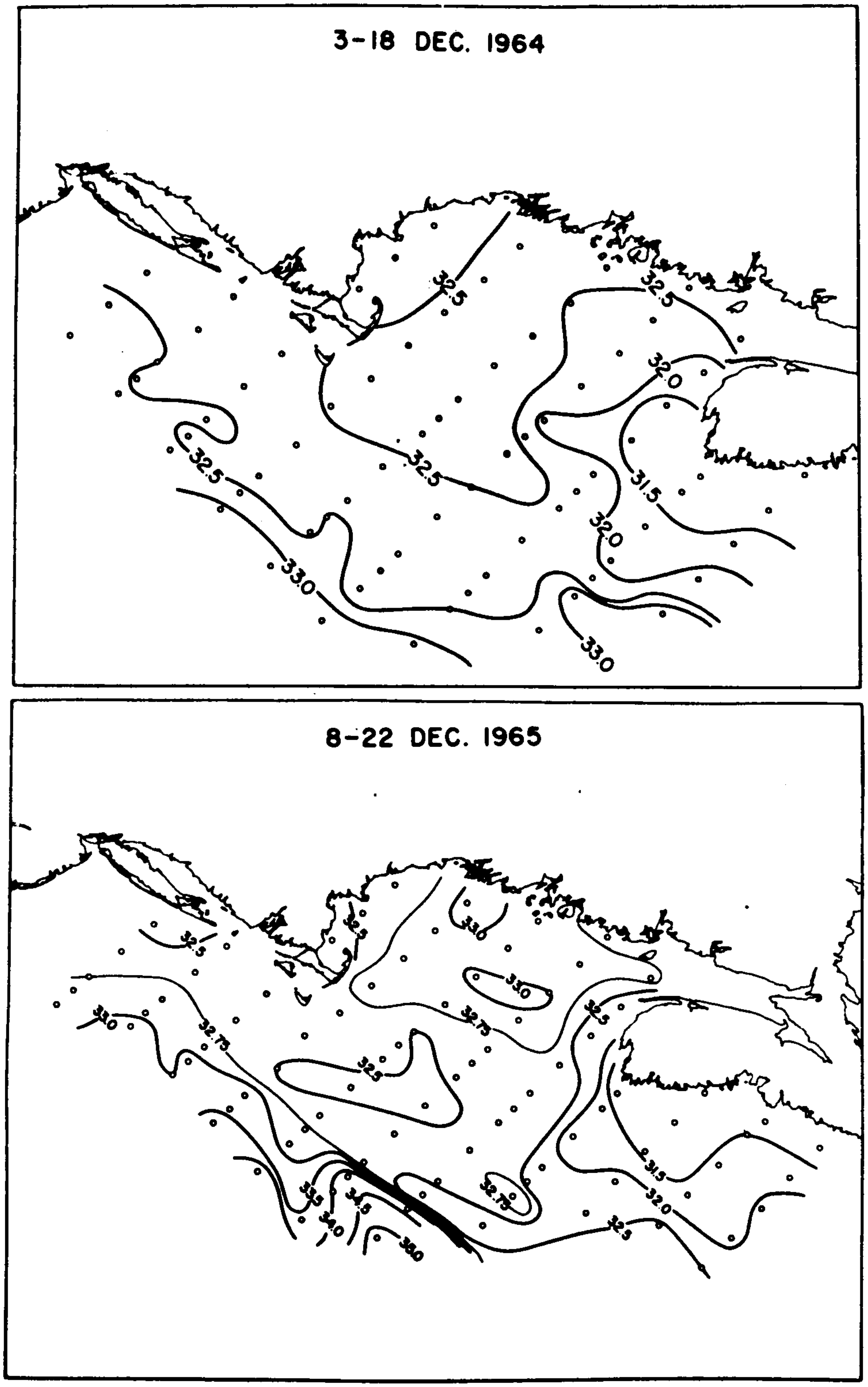


FIGURE 3-149 Surface Isohalines - September (Colton et al., 1968)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-150 Surface Isohalines - December (Colton et al., 1968)

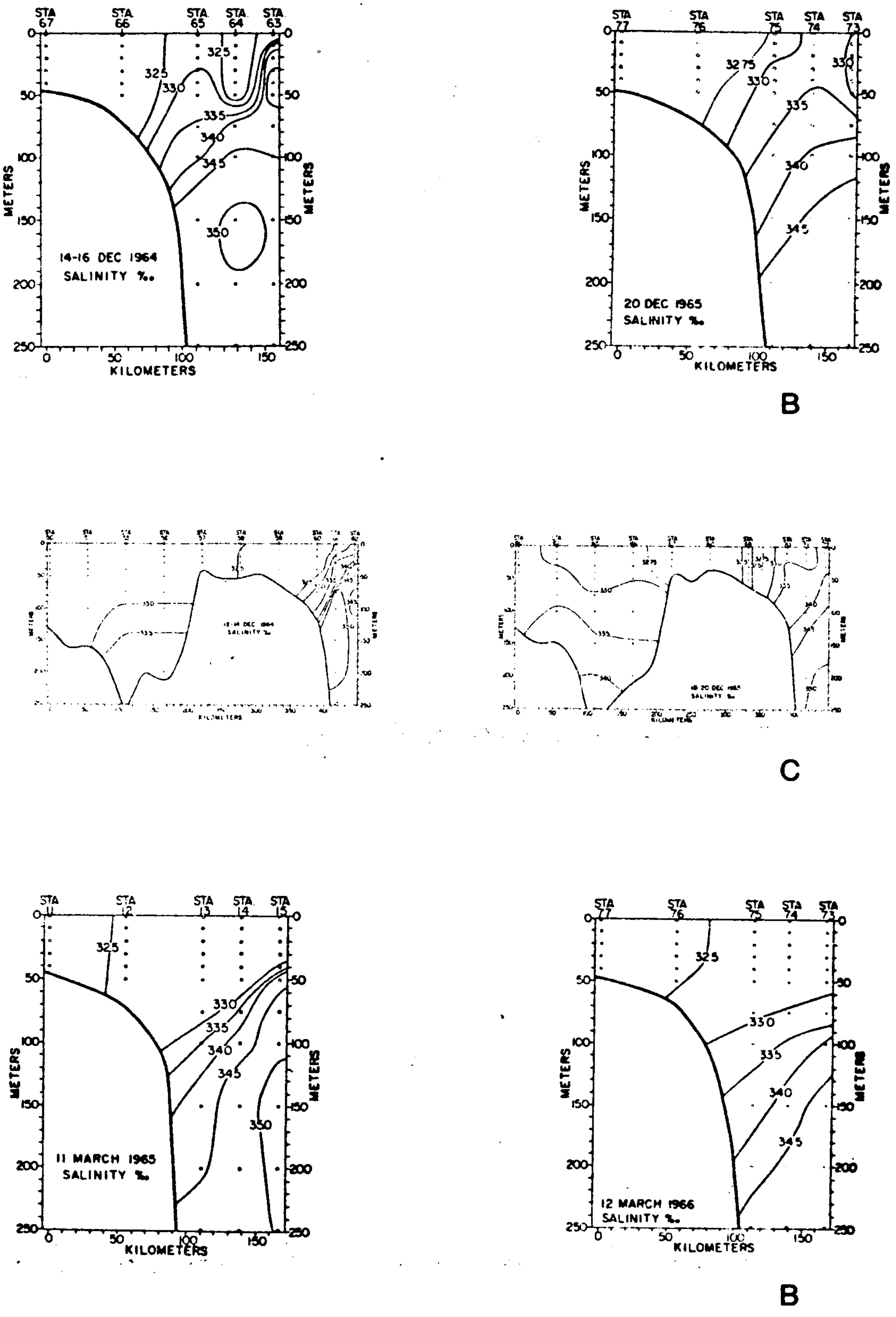
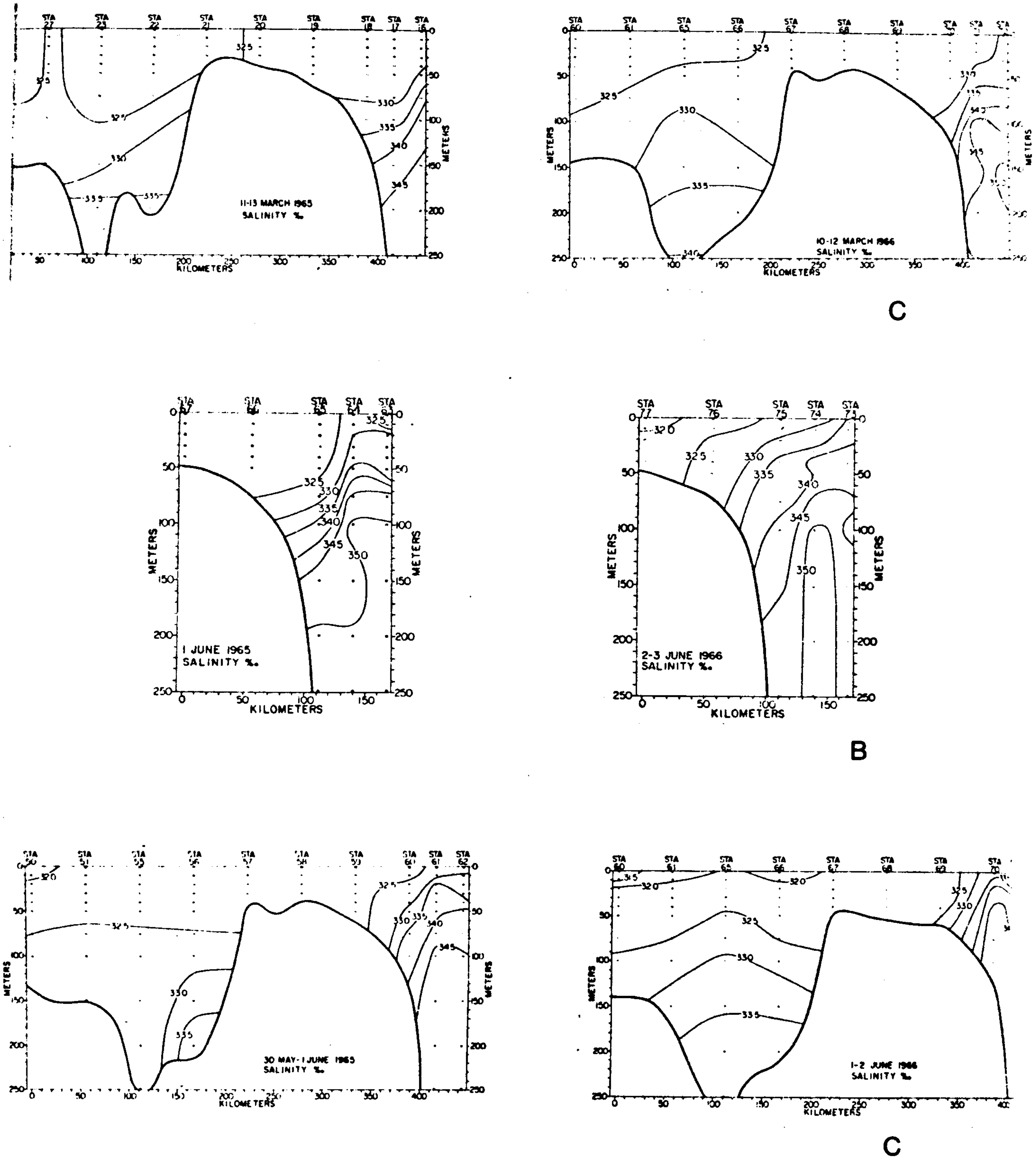


FIGURE 3-151 a

Vertical Salinity Profiles for Sections B and C (Colton et al., (1968)



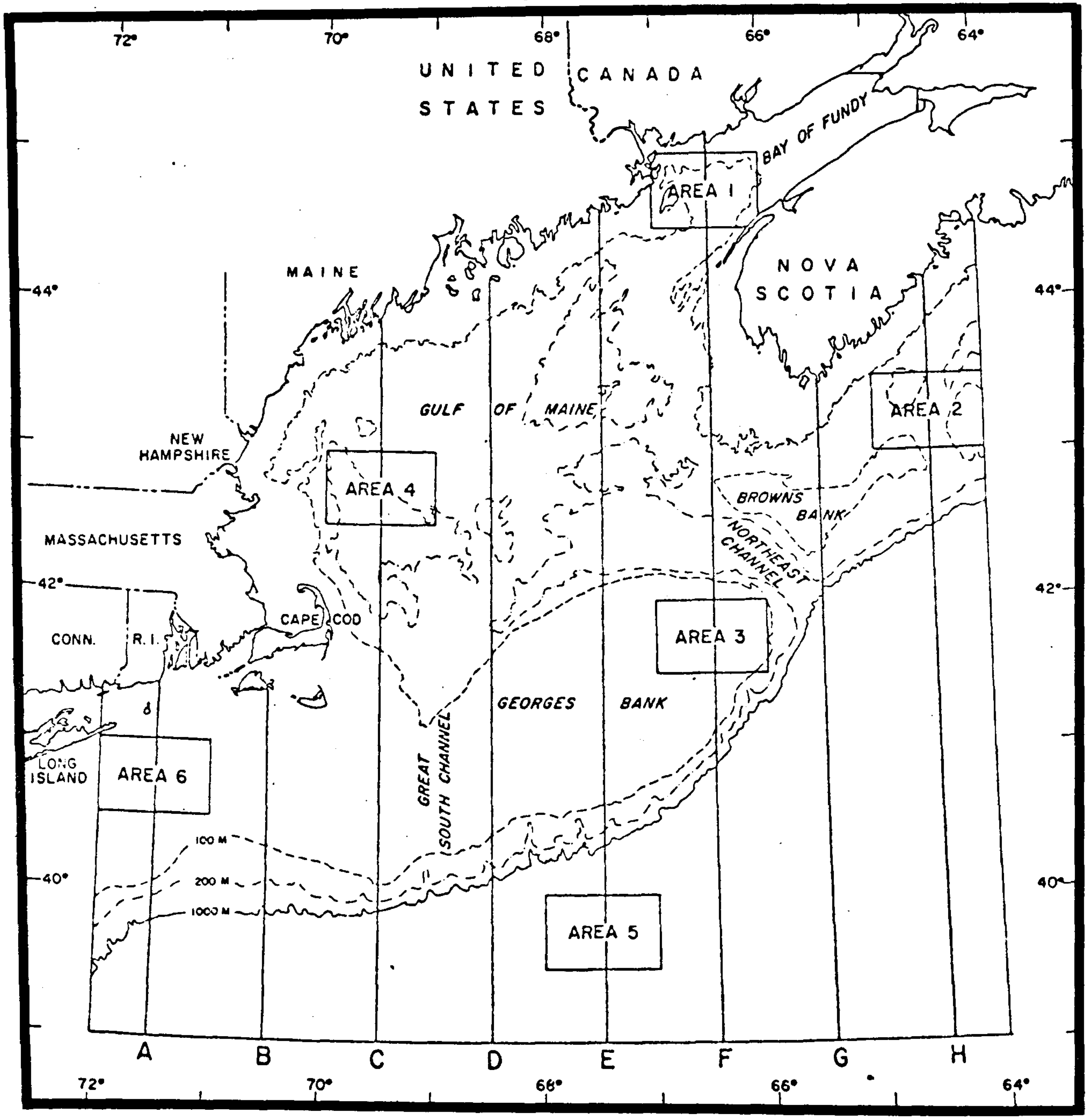
TRIGOM PARC

FIGURE 3-151 b

Vertical Salinity Profiles for Sections B and C (Colton et al., 1968)

3.2.9A PART III

Horizontal temperature gradients by season (February-August-May-November), monthly vertical profiles, and dynamic profiles over time for continental shelf areas east and southeast of New England as shown in Figure 3-152. Figures are from Colton and Stoddard (1972, 1973). Transects appear to be coincident with Colton, *et al*. (1968).



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-152

Locations of Areas and Profiles (Colton and Stoddard, 1972)

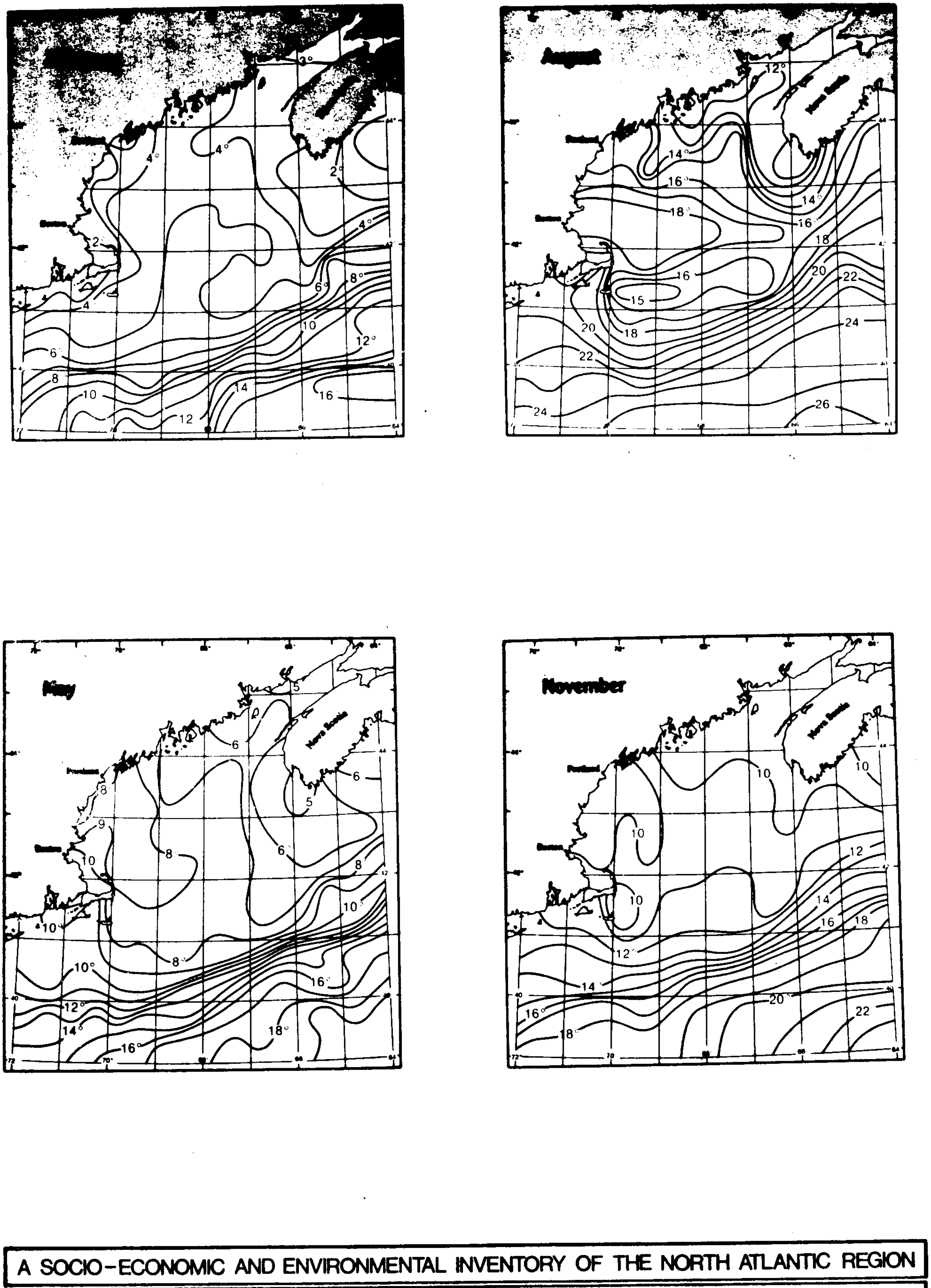


FIGURE 3-153

Average Monthly Surface Isotherms
(Colton and Stoddard, 1972)

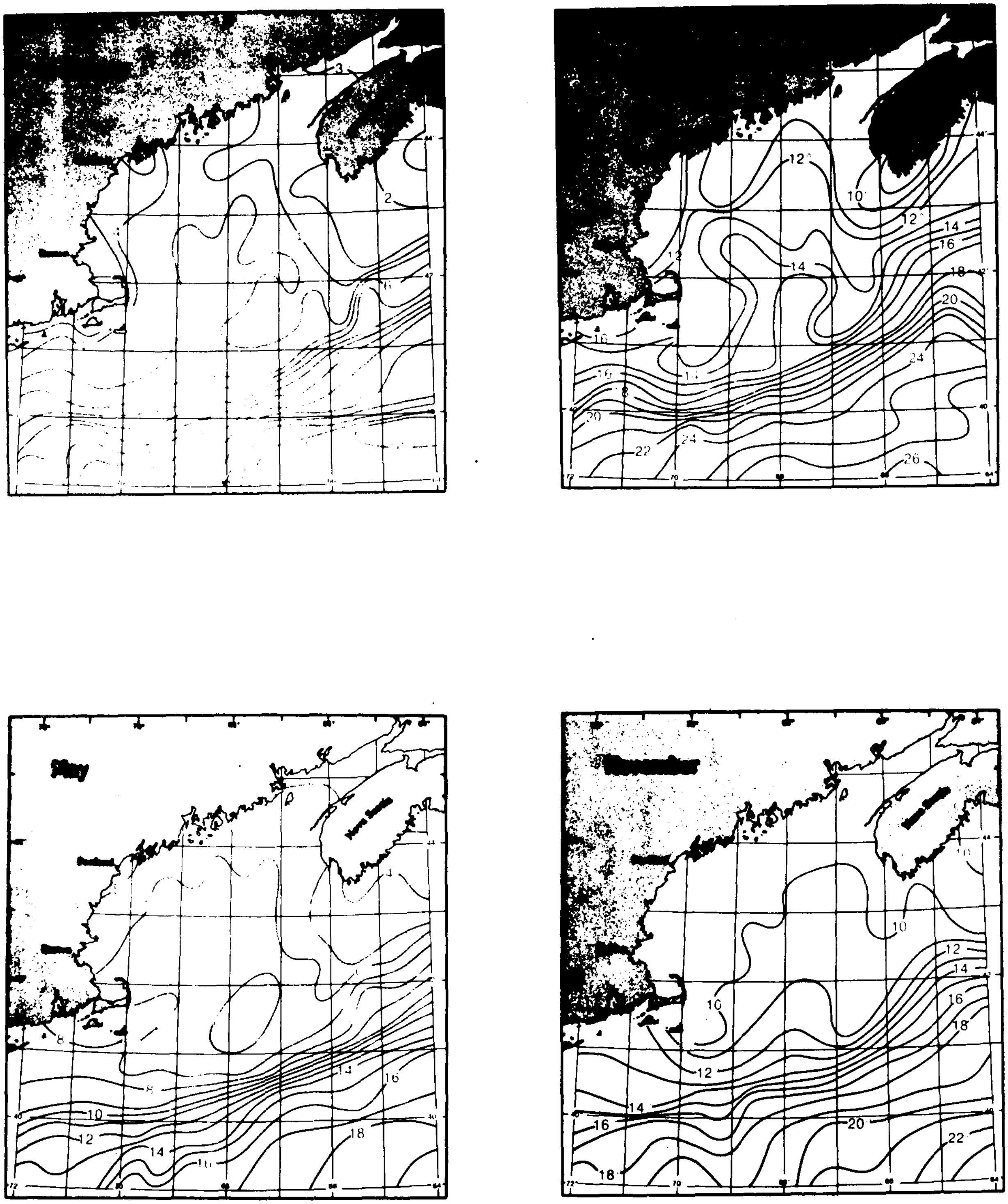


FIGURE 3-154 Average Monthly Isotherms at 20 Meters (Colton and Stoddard, 1972)

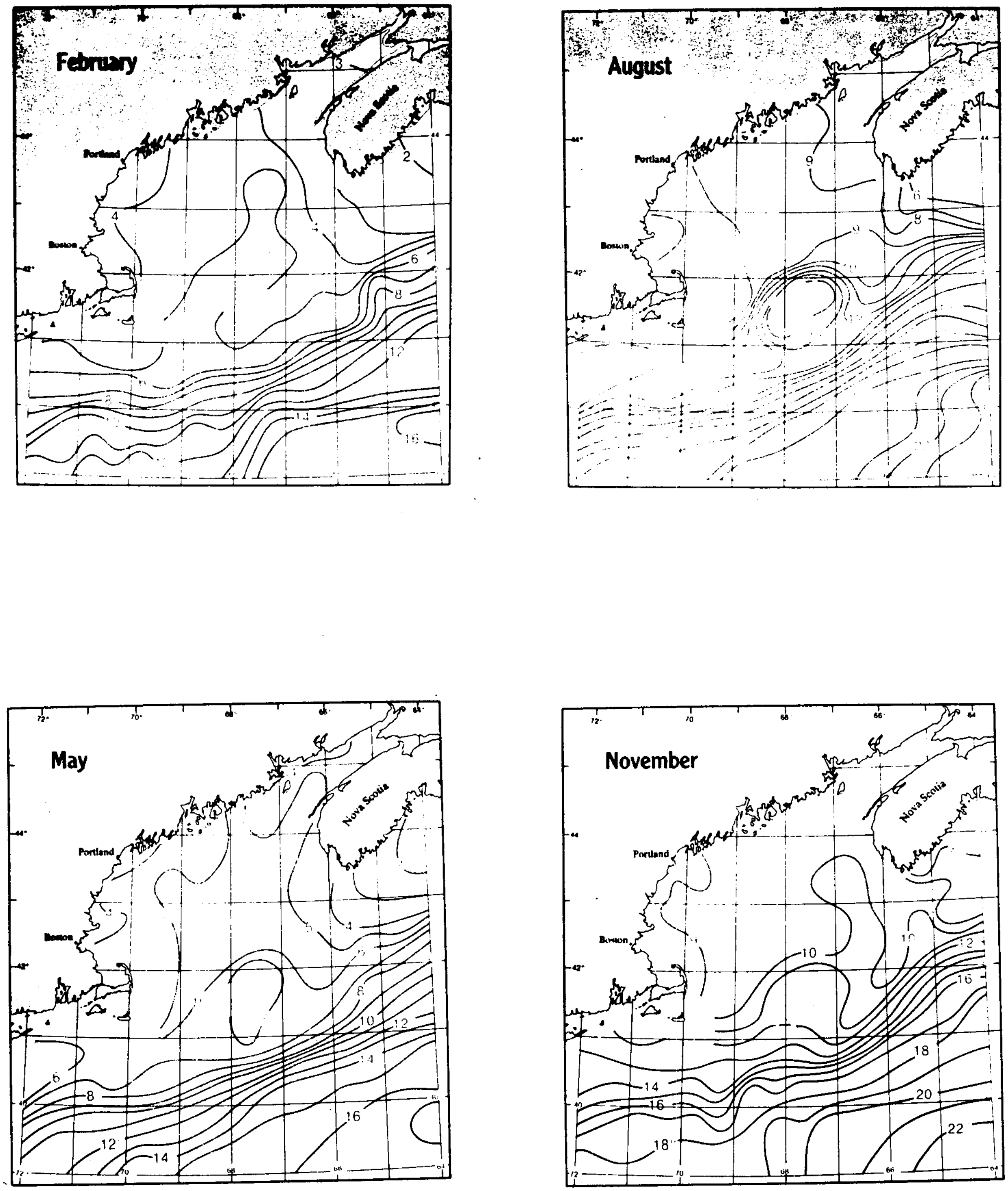


FIGURE 3-155 Average Monthly Isotherms at 40 Meters (Colton and Stoddard, 1972)

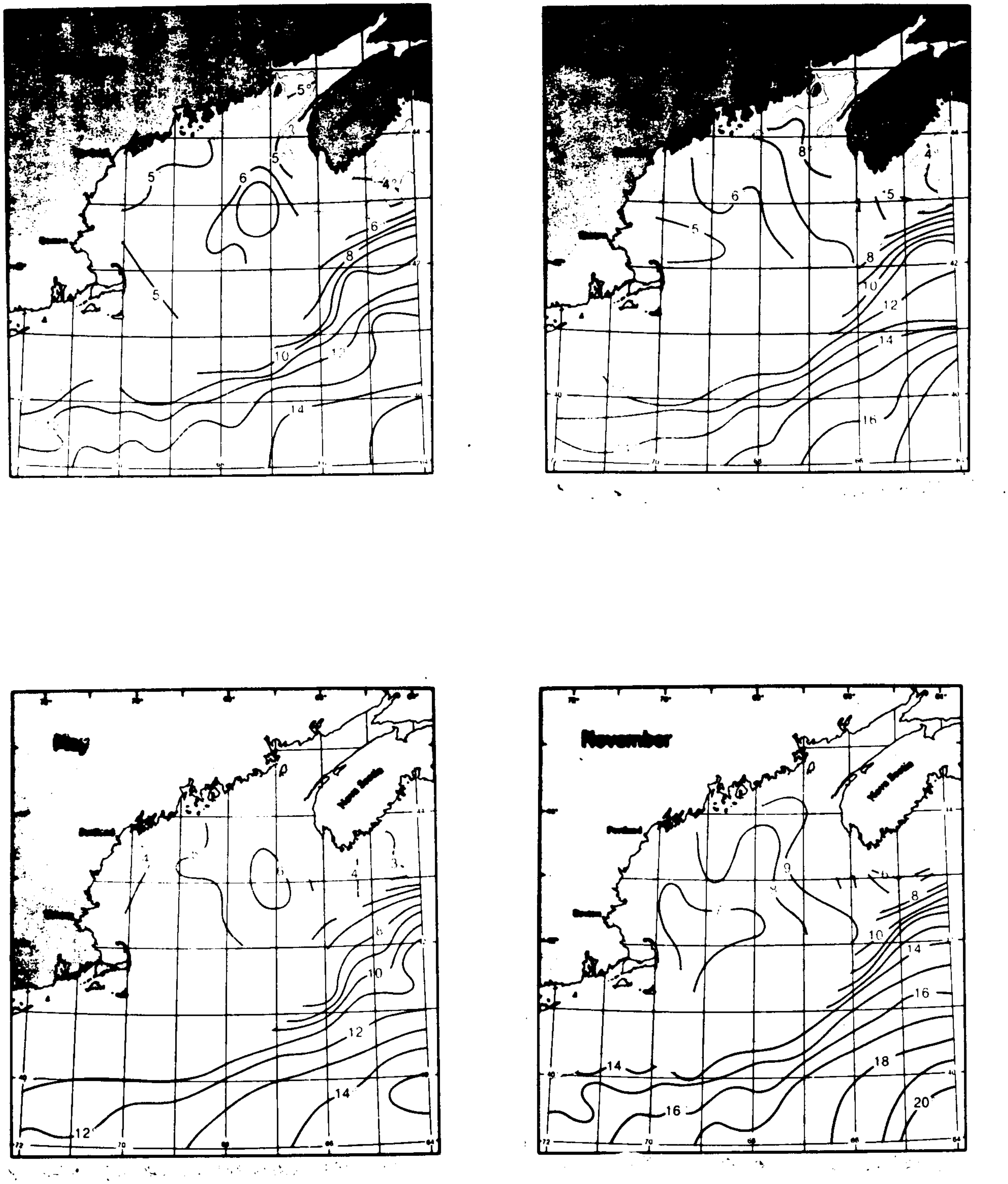


FIGURE 3-156

Average Monthly Isotherms at 100 Meters (Colton and Stoddard, 1972)

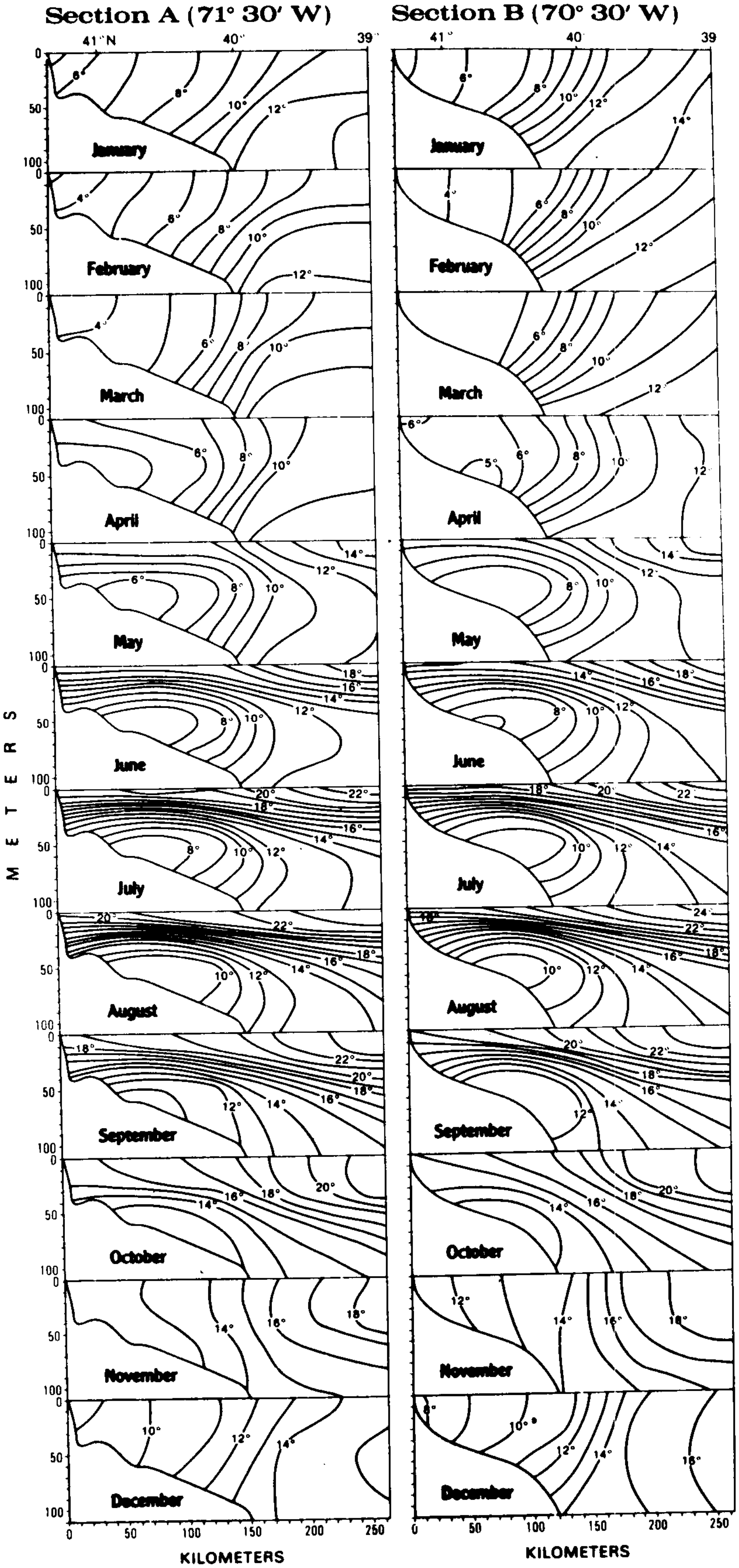
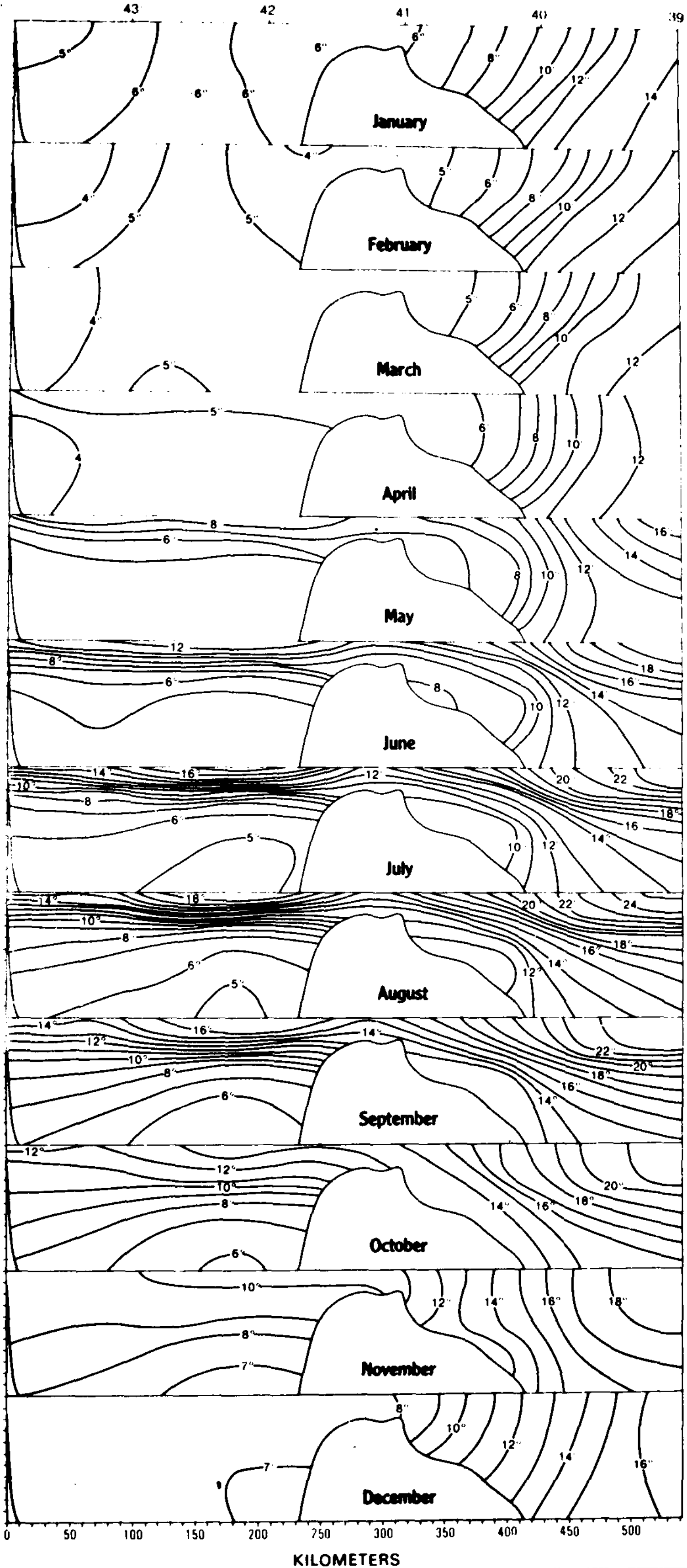


FIGURE 3-157

Vertical Temperatures Profiles (Colton and Stoddard, 1972)

Section C (69° 30′ W)



TRIGOM PARC

FIGURE 3-157

Vertical Temperatures Profiles
(Colton and Stoddard, 1972)

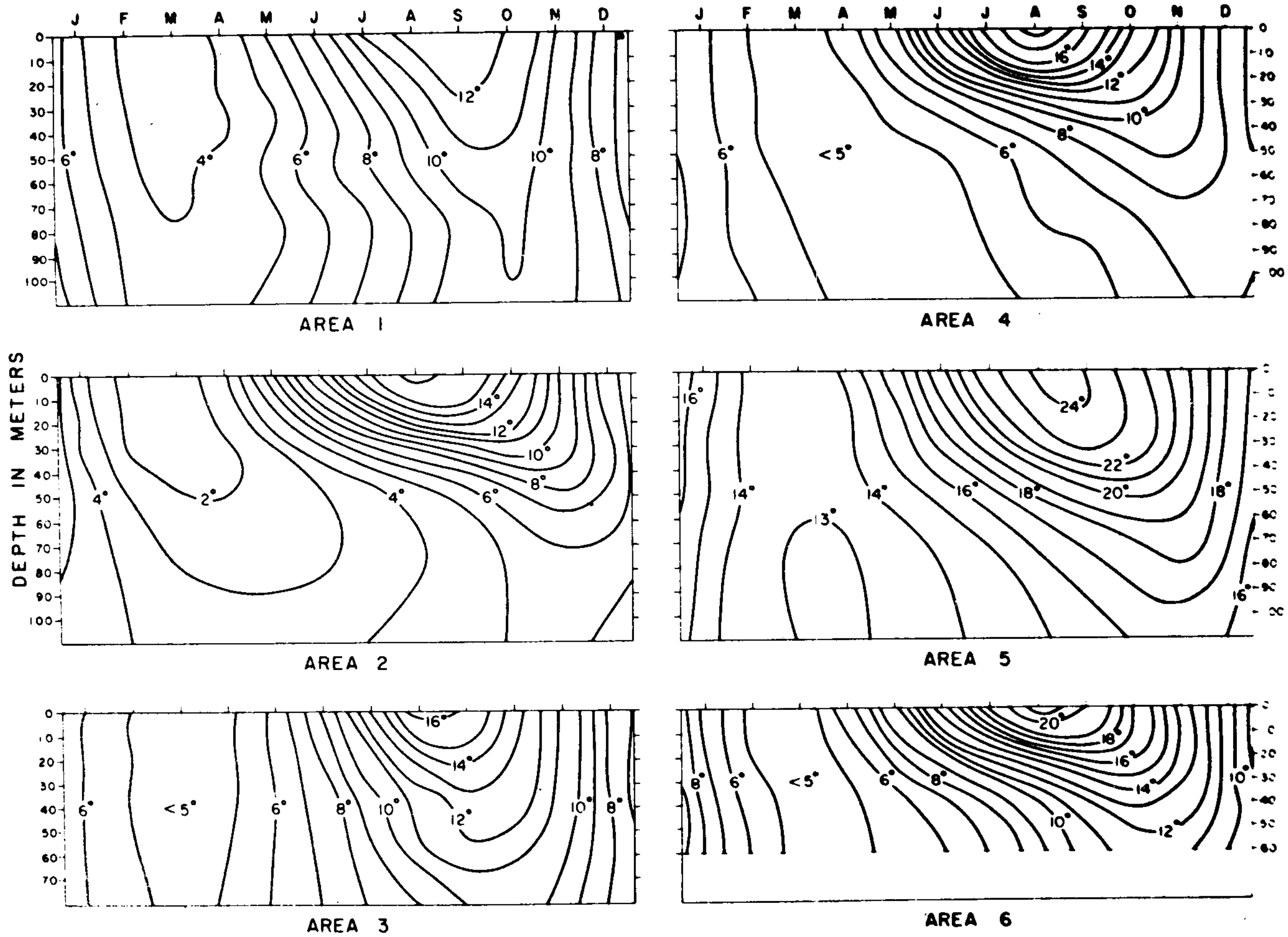
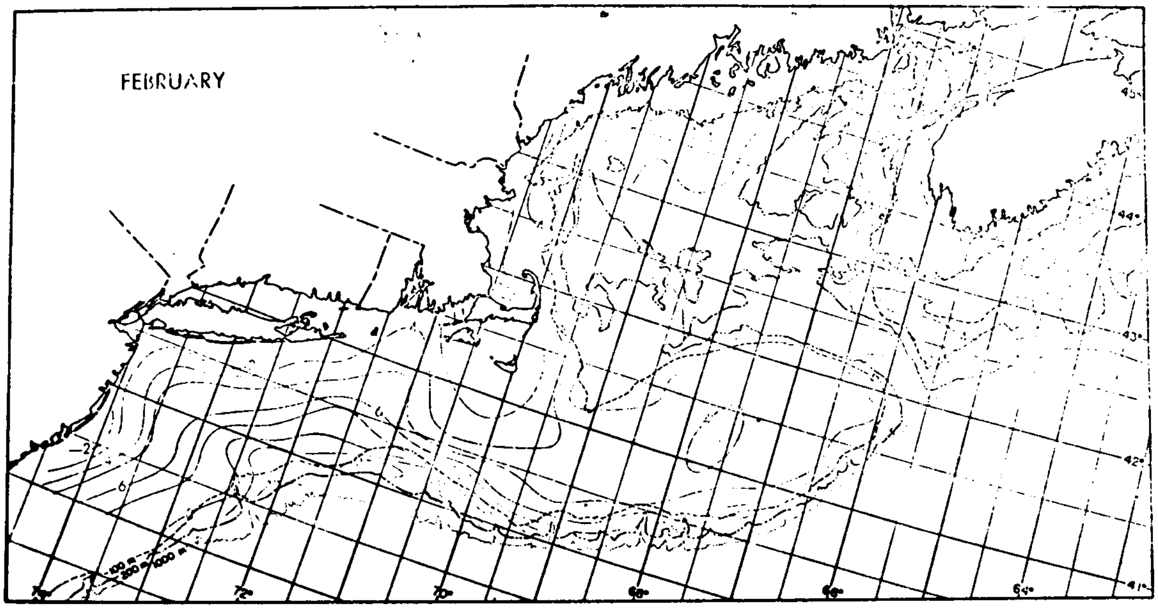


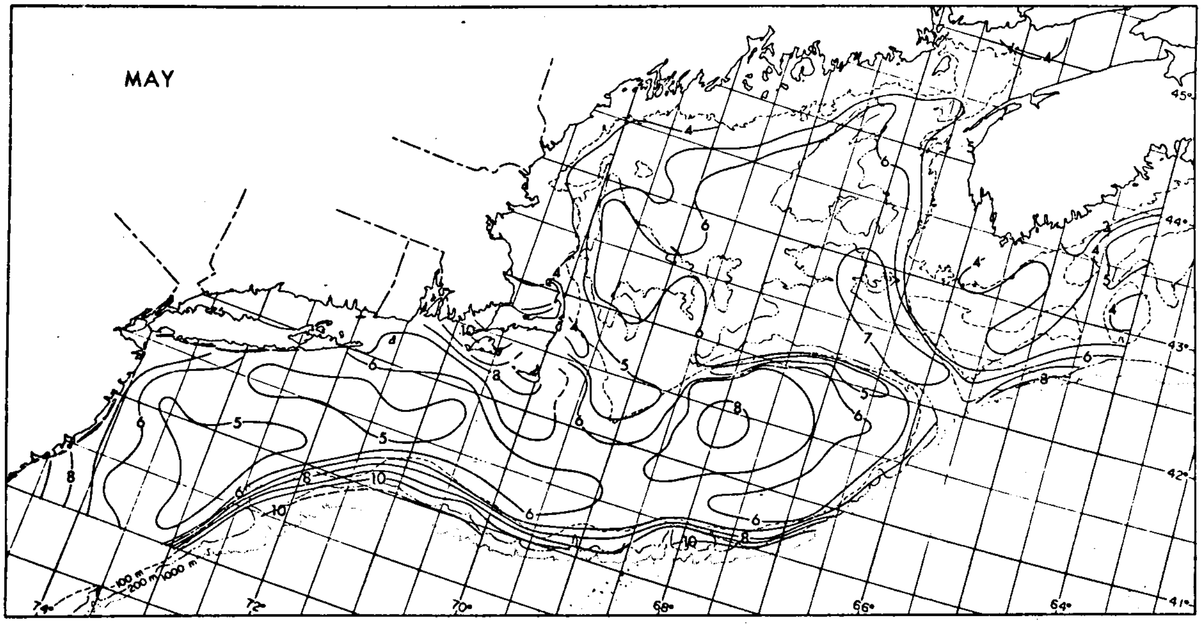
FIGURE 3-158

Monthly Progression of Temperature - in Fig. 3-152 (Colton and Stoddard, 1972)



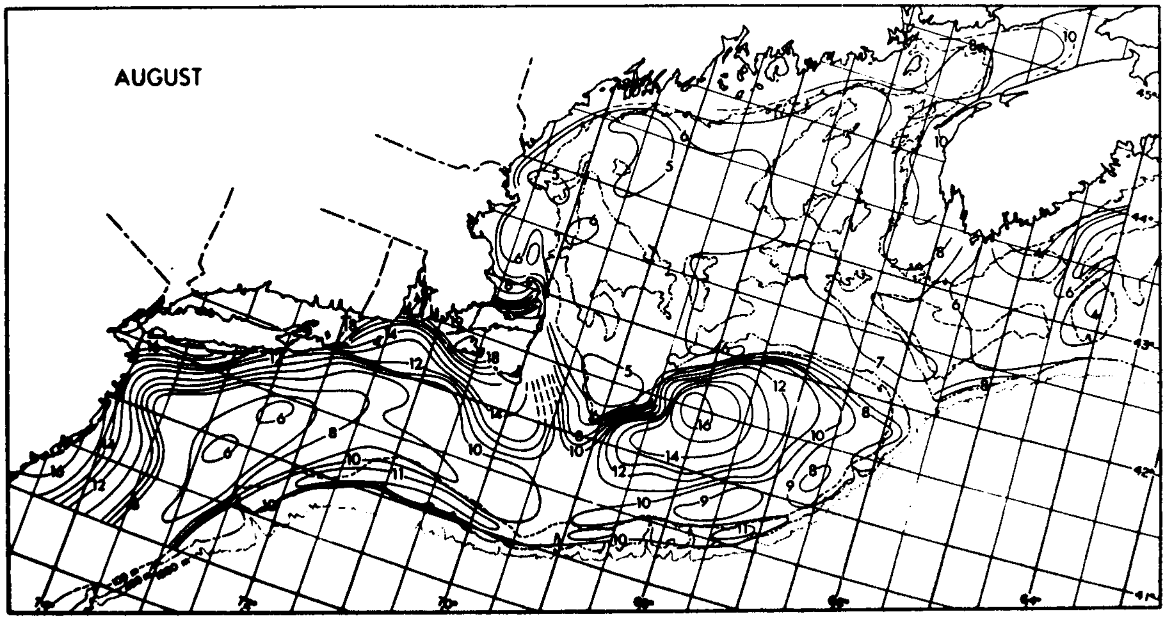
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-159 | Bottom Water Isotherms (°C) - February (Colton and Stoddard, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 3-160 | Bottom Water Isotherms (°C) - May (Colton and Stoddard, 1972)

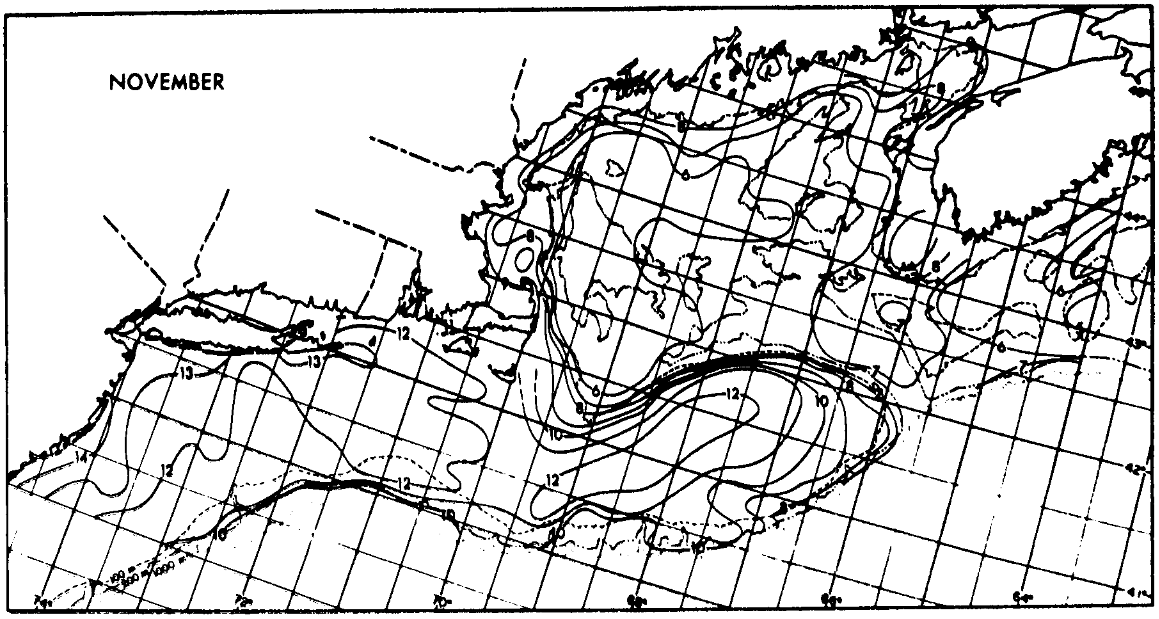


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-161

Bottom Water Isotherms (°C) - August
(Colton and Stoddard, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

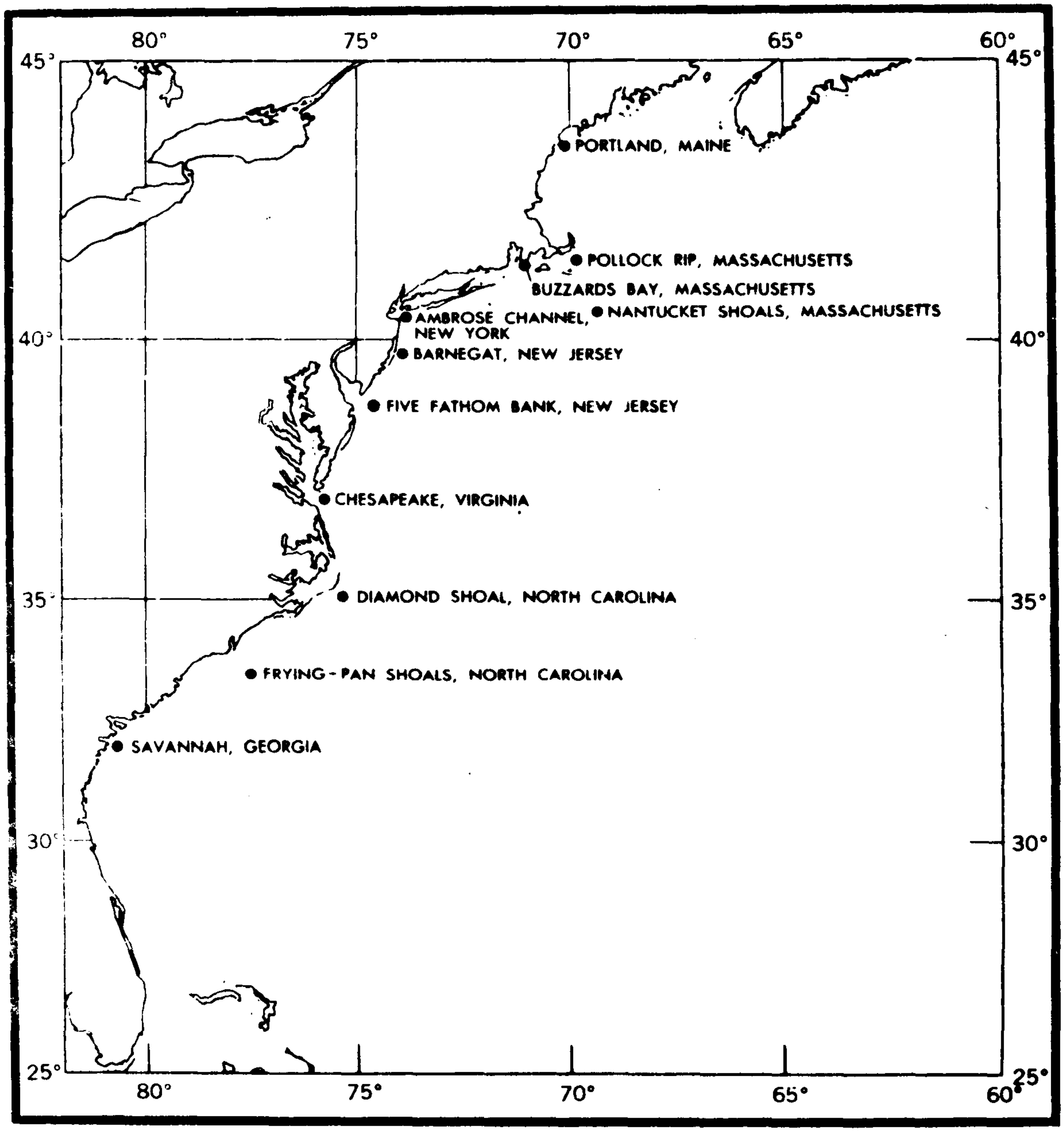
TRIGOM PARC

FIGURE 3-162

Bottom Water Isotherms (°C) - November
(Colton and Stoddard, 1972)

3.2.9A PART IV

Data for temperature and salinity collected for LOSAMP (Light Vessel/ Light Station Oceanographic Sampling Program) as reported in Kangas (1973).



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-163

Location of East Coast Lightships

Table 3-7 Surface water temperatures (°C)-monthly and annual means, 1971

	Mt. Desert Rock Light Station	Portland Lightship	Boston Lightship	Nantucket Shoals Lightship	Woods Hole, Massachusetts	Buzzards Bay Entrance Light Station	Ambrose Channel Light Station	Five Fathom Bank Lightship	Chesapeake Light Station	Diamond Shoal Light Station	Frying Pan Shoals Light Station
Jan.	4.5	4.0	4.2	6.0	-0.4	1.6	4.0	(5.9)	-	11.7	(14.8)
Feb.	3.5	2.9	2.1	3.6	-0.5	0.7	2.4	(4.5)	4.8	11.4	13.5
Mar.	3.8	2.8	2.8	4.2	2.1	1.8	3.9	-	6.6	14.2	13.6
Apr.	4.8	4.8	4.7	4.9	5.6	4.4	6.3	7.5	9.3	13.1	16.7
May	6.1	9.5	8.9	7.3	10.3	8.9	10.4	12.7	15.1	19.3	19.7
Jun.	8.8	13.6	15.2	11.5	16.8	14.2	17.3	-	21.8	24.0	24.4
Jul.	12.1	16.3	14.7	16.1	20.7	-	20.6	-	24.3	26.8	26.3
Aug.	13.9	16.3	17.0	18.1	21.8	16.3	21.4	-	23.6	26.7	27.4
Sep.	12.4	(14.4)	17.2	18.7	20.6	16.4	20.5	21.5	23.8	27.2	26.8
Oct.	11.8	11.7	14.0	16.8	17.4	16.2	17.9	19.5	20.9	23.6	25.2
Nov.	9.8	9.8	10.6	13.9	11.0	12.5	12.7	-	15.7	19.2	22.2
Dec.	6.9	7.6	6.9	9.5	5.6	7.1	8.7	(9.8)	10.6	17.5	(19.7)
Mean	8.2	9.5	9.9	10.9	10.9	(9.1)	12.2	(11.6)	(16.0)	19.6	20.9

Table 3-8 --Nantucket Shoals Lightship: temperature (°C) and salinity (°/₀₀), 1971 (40°30.0'N, 69°28.0'W; water depth: 60 meters) --Continued

Month and day	Temperature at depth of--						Salinity at depth of--	
	0 m	9 m	15 m	30 m	46 m	60 m	0 m	60 m
SEPTEMBER								
1	18.4	17.8	16.7	13.3	10.4	9.7	32.09	
2	18.1	16.9	15.1	10.9	9.7	9.6	-	
3	18.1	16.8	15.0	10.8	9.6	9.6	32.07	32.64
4	18.6	18.1	17.0	12.3	8.9	8.9	32.10	
5	18.7	17.8	16.1	12.2	9.2	9.2	32.08	
6	19.0	18.5	17.2	13.2	9.8	9.5	32.03	32.56
7	18.9	17.6	15.5	10.8	10.6	10.6	31.98	
8	19.4	16.7	12.8	11.9	11.2	11.1	31.99	
9	19.5	14.7	13.4	11.8	11.2	11.1	31.88	
10	15.6	12.9	12.7	12.6	11.7	11.6	31.91	32.23
11	13.8	13.6	13.1	12.6	11.8	10.8	32.08	
12	(16.7)	-	-	-	-	-	31.92	
13	19.4	16.3	14.2	13.3	12.8	12.2	31.98	32.82
14	20.1	17.8	15.0	12.4	12.2	12.1	32.26	
15	19.7	18.9	15.6	12.8	12.7	12.0	31.29	
16	-	-	-	-	-	-	-	
17	19.8	18.9	16.4	12.7	12.8	12.2	32.29	32.44
18	21.1	18.4	16.9	12.6	12.3	12.2	32.58	
19	20.5	20.4	18.4	12.2	11.8	11.8	32.60	
20	18.2	15.1	14.0	12.8	11.8	(11.7)	32.34	32.56
21	19.0	17.8	15.1	12.0	11.6	11.6	32.32	
22	18.6	18.5	16.8	12.2	11.5	11.6	32.08	
23	18.0	16.3	14.7	11.8	11.3	11.3	32.40	
24	-	-	-	-	-	-	-	
25	18.2	19.1	19.1	12.7	11.6	11.2	32.94	
26	19.3	19.4	19.6	14.4	11.2	11.2	33.37	
27	19.5	19.6	19.8	15.1	11.3	11.1	33.72	32.71
28	18.5	18.8	19.3	13.6	12.2	12.0	33.11	
29	18.4	18.4	18.8	16.1	12.2	11.3	33.47	
30	19.2	19.6	19.5	15.6	12.2	11.5	33.51	
MEAN	18.7	17.6	16.2	12.8	11.4	11.2	32.38	32.57

Table 3-9

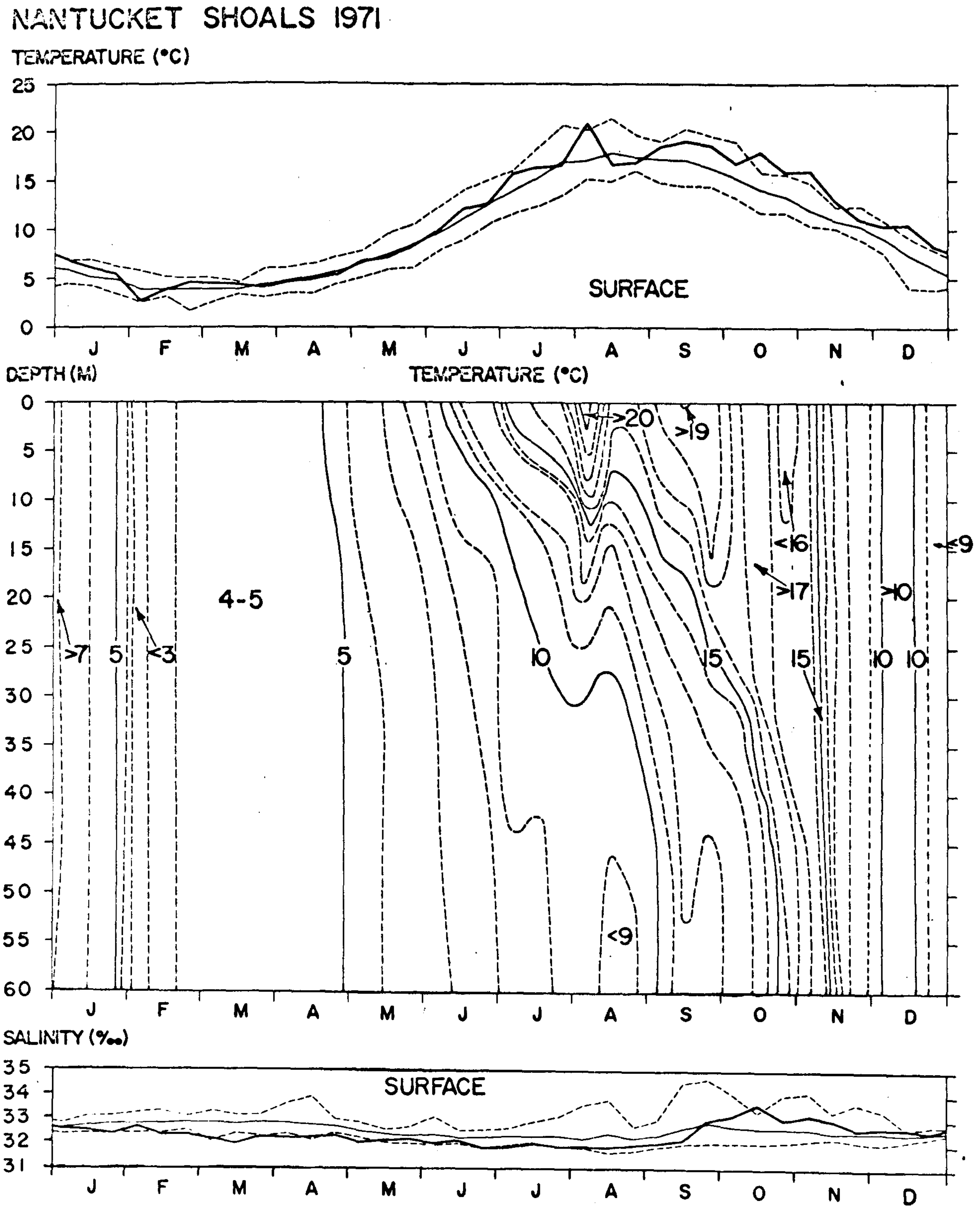
MEAN SURFACE WATER TEMPERATURES (T) AND DENSITIES (D)

Stations	Years	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec		Mean	
		(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}
Cape Cod Canal (E. ent.), Mass. (41°46'N., 70°30'W.)	16	1.1	23.5	0.4	23.5	1.8	23.4	5.3	23.3	9.4	23.1	12.8	23.2	14.7	23.4	16.2	23.4	15.9	23.4	13.3	23.5	9.4	23.4	4.7	23.5	8.8	23.4
Cape Cod Canal (W. ent.), Mass. (41°44'N., 70°37'W.)	15	0.8	23.2	0.4	23.2	2.2	23.1	6.1	22.9	10.4	22.9	15.0	23.0	17.6	23.2	18.7	23.3	17.4	23.3	13.9	23.3	9.6	23.2	4.3	23.2	9.7	23.2
Woods Hole, Mass. (41°31'N., 70°40'W.)	27	1.2	23.2	0.5	23.2	2.4	23.1	6.8	23.2	11.8	23.3	17.0	23.5	20.9	23.6	21.6	23.5	19.7	23.6	15.6	23.6	10.5	23.5	4.9	23.3	11.1	23.4
Newport, R. I. (41°30'N., 71°20'W.)	16	2.3	22.7	1.6	22.5	3.1	22.5	6.3	22.3	10.9	22.8	16.3	23.1	19.8	23.5	20.6	23.4	18.6	23.5	15.3	23.4	11.3	23.1	5.8	22.9	11.0	23.0
New London, Conn. (41°22'N., 70°06'W.)	24	2.8	13.6	2.4	12.4	4.3	10.1	9.3	9.2	14.3	10.4	19.2	13.9	22.1	17.4	22.5	18.7	20.3	19.2	16.2	18.7	10.9	16.2	5.5	14.1	12.5	14.5
Bridgeport, Conn. (41°10'N., 73°11'W.)	7	3.9	19.5	3.6	18.4	5.8	18.1	10.1	17.7	15.7	17.6	21.7	18.0	24.8	19.1	26.3	19.8	24.4	19.9	19.6	20.1	13.9	20.0	8.0	19.7	14.8	19.0
Plum Island (L. I. Sound), N. Y. (41°10'N., 72°12'W.)	10	2.9	21.6	1.3	21.6	2.4	21.4	5.6	20.9	9.7	20.8	14.6	21.3	18.8	21.8	20.3	22.2	19.3	24.7	15.8	22.4	11.5	22.0	6.4	21.8	10.7	21.9
Montauk (Fort Pond Bay), N. Y. (41°03'N., 71°58'W.)	23	2.2	22.5	1.5	22.4	3.1	22.3	6.6	21,7	10.8	21.8	16.1	22.2	20.1	22.6	21.1	22.8	19.6	23.1	15.9	23.1	11.0	22.9	5.7	22.6	11.1	22.5
Willets Point (E. River), N. Y. (40°48'N., 73°47'W.)	39	1.9	18.8	1.0	18.5	2.8	18.3	7.0	17.7	12.2	17.7	17.1	18.1	20.3	18.6	22.1	19.1	21.2	19.2	16.8	19.0	11.1	19.0	5.1	18.8	11.6	18.6
New York (The Battery), N. Y. (40°42'N., 74°01'W.)	44	2.8	15.5	2.0	15.4	3.7	13.6	7.6	12.1	12.9	13.7	18.3	15.7	21.9	17.0	22.9	17.5	21.4	17.5	16.8	17.3	11.4	16.2	6.0	15.3	12.3	15.6
Bear Mountain (Hudson R.), N. Y. (41°19'N., 73°59'W.)	5	0.7	-0.6	0.4	-0.8	1.8	-0.7	7.6	-0.8	14.1	-0.9	20.6	-0.8	24.2	-0.4	25.2	-0.2	23.8	0.2	17.8	0.0	10.8	-0.5	3.8	-0.5	12.6	-0.5
New York (Fort Hamilton), N. Y. (40°37'N., 74°02'W.)	12	2.1	16.6	1.2	17.3	2.4	14.8	6.5	12.5	11.8	15.2	17.0	17.0	20.8	18.1	21.8	19.0	19.8	18.7	15.3	17.9	9.8	16.8	4.9	16.5	11.1	16.7
Sandy Hook, N. J. (40°28'N., 74°01'W.)	33	1.4	17.0	1.4	16.9	4.1	15.9	9.1	14.9	14.6	16.2	20.2	17.7	23.4	19.0	23.5	19.1	20.8	19.2	15.1	19.1	9.4	18.4	3.8	17.5	12.2	17.6

F (Fahrenheit) = 1.8C (Celsius) + 32

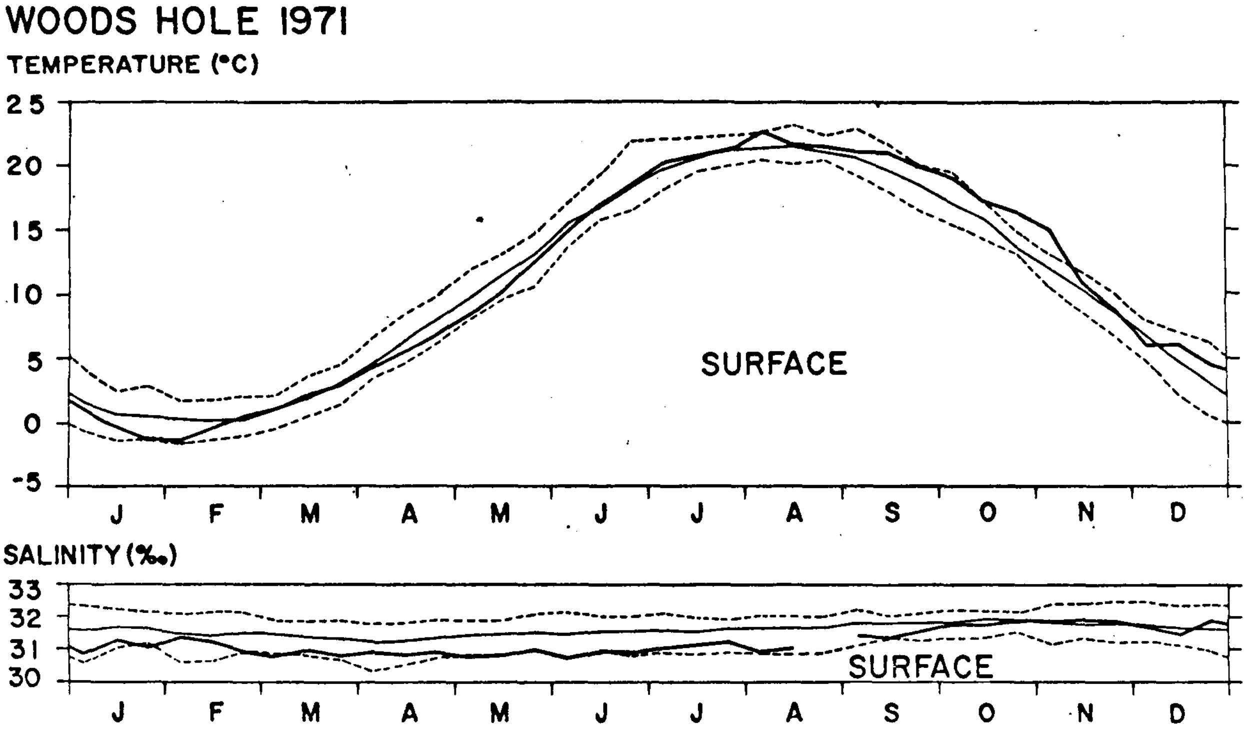
Density as used in this table is the specific gravity of the sea water or the ratio between the weight of a sea-water sample and the weight of an equal volume of distilled water at 15°C (59°F). These figures representing density at 15°C (ρ_{15}) are expressed in terms of sigma-t (σ_t) where t = 15°C and $\sigma_{15} = (\rho_{15} - 1)\,1000$. Thus, for $\rho_{15} = 1.0238$, $\sigma_{15} = 23.8$. Obtain the pamphlet, "Surface Water Temperature and Density, Atlantic Coast, North and South America, C&GS Publication 31-1", for greater detail; for sale by Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, price $1.00.

(After National Ocean Survey, 1972)



TRIGOM PARC

FIGURE 3-164 Annual Changes in Surface Temperatures and Salinity - Nantucket Shoals


WOODS HOLE 1971

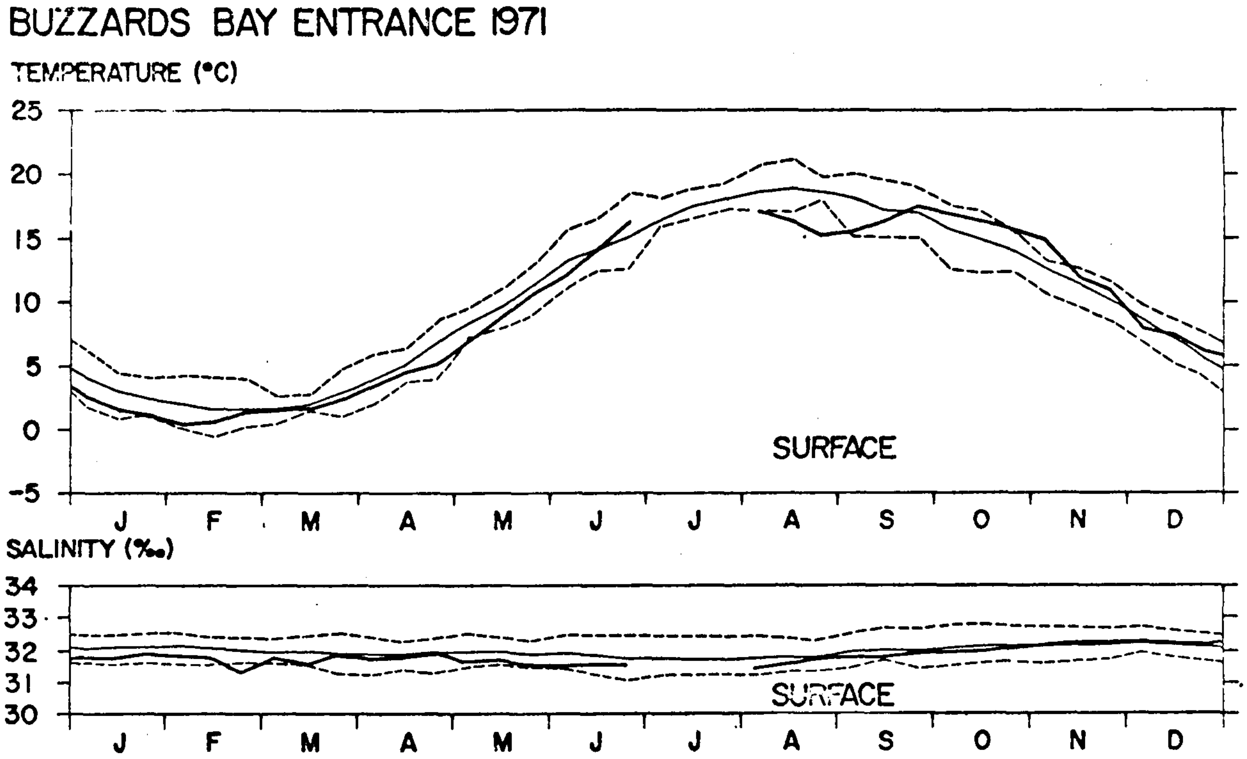

BUZZARDS BAY ENTRANCE 1971

FIGURE 3-164a

Annual Changes in Surface Temperatures and Salinity - Woods Hole and Buzzards Bay Entrance

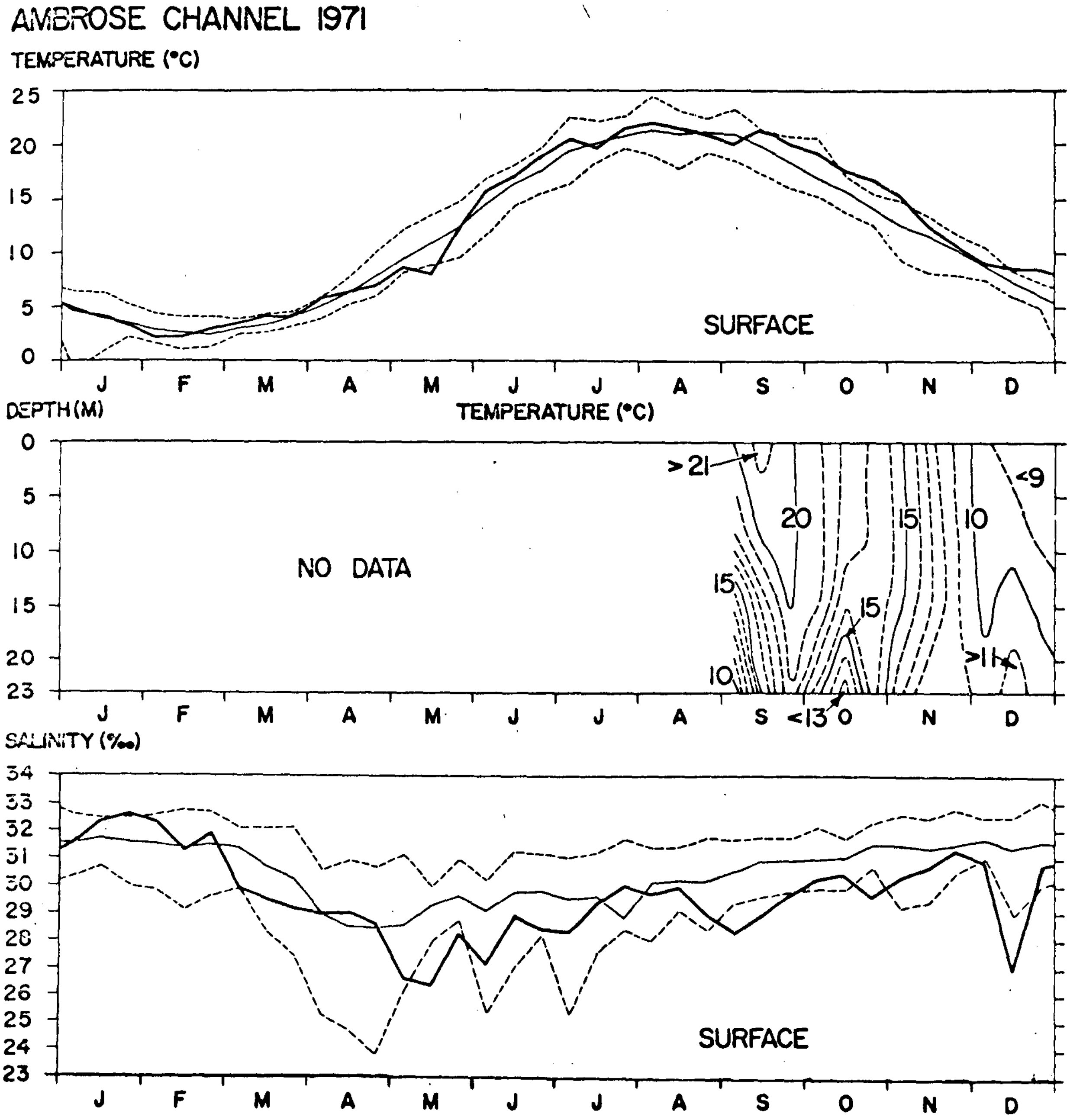


FIGURE 3-164b Annual Changes in Surface Temperatures and Salinity - Ambrose Channel

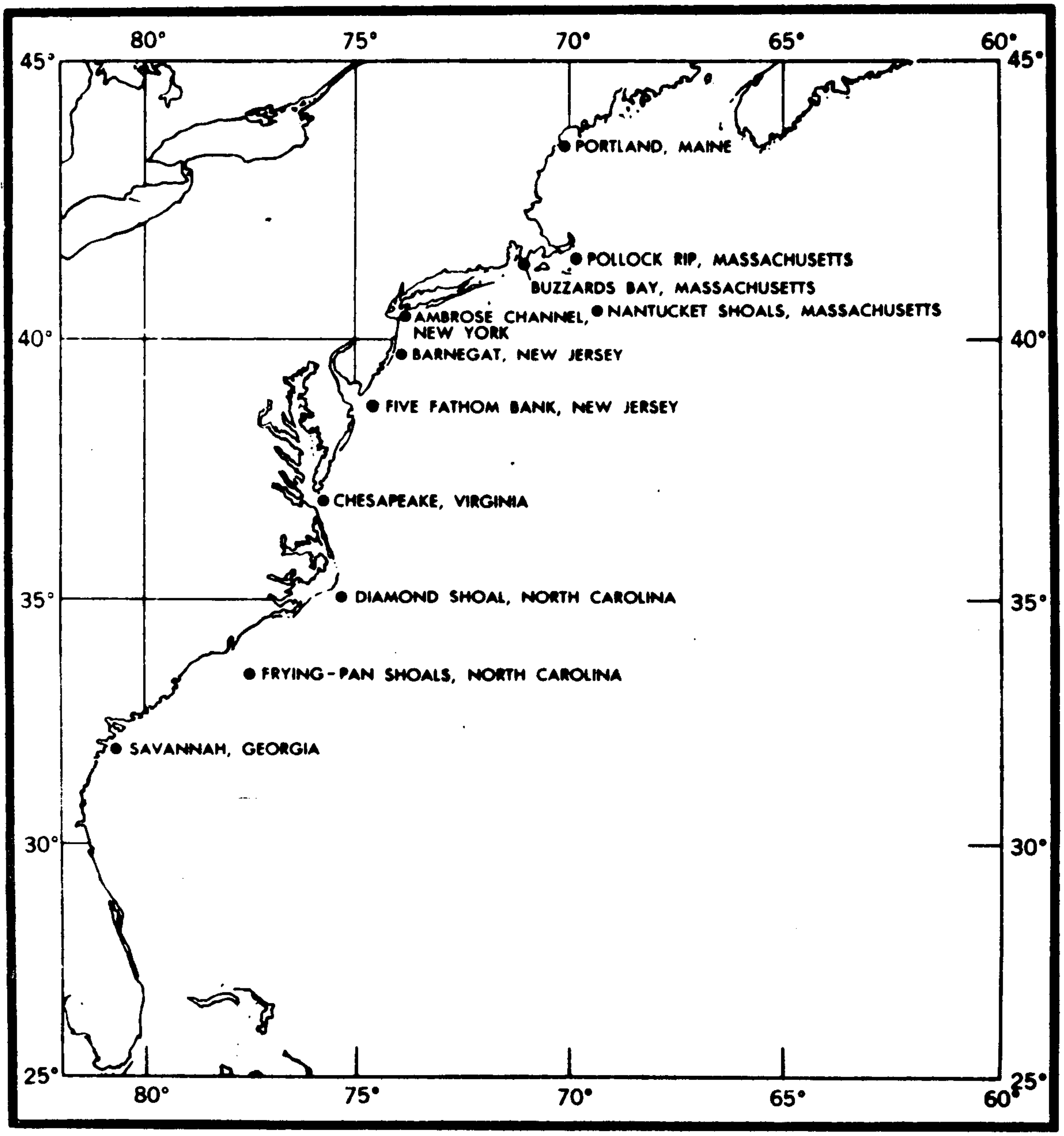
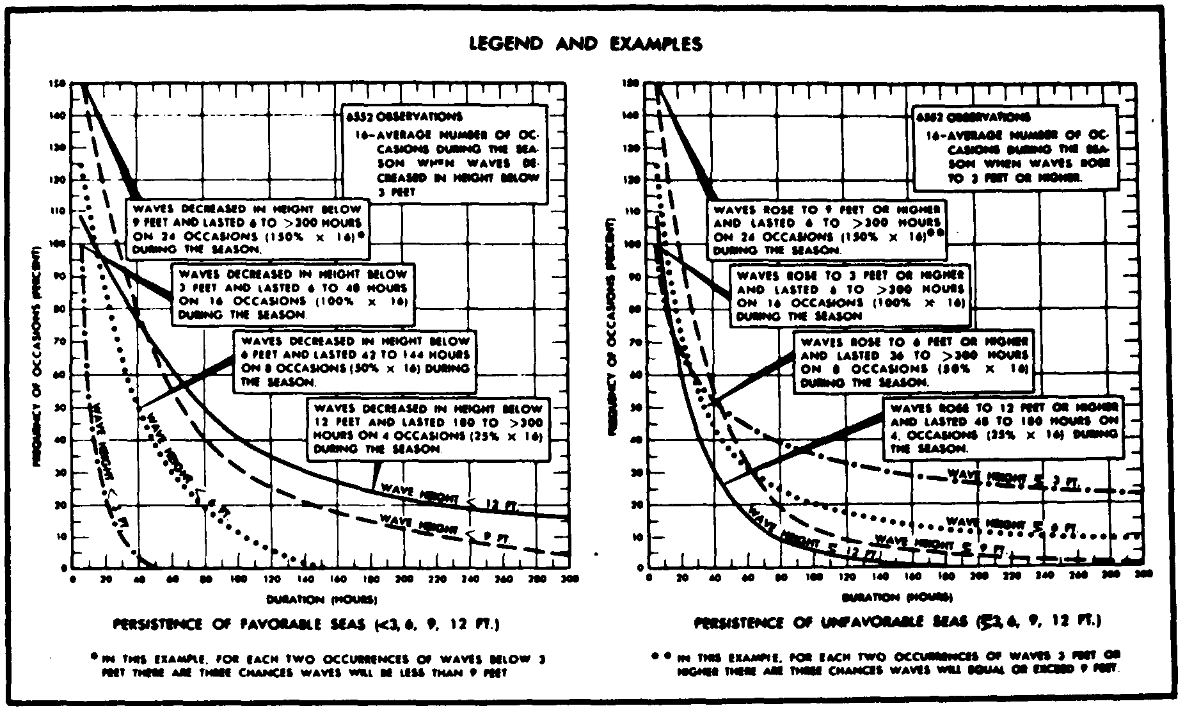
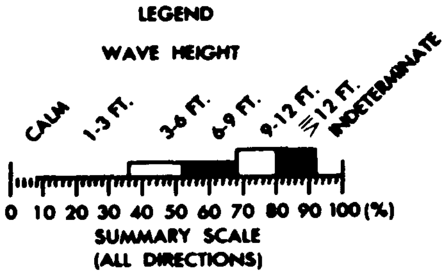


FIGURE 3-165 Location of East Coast Lightships





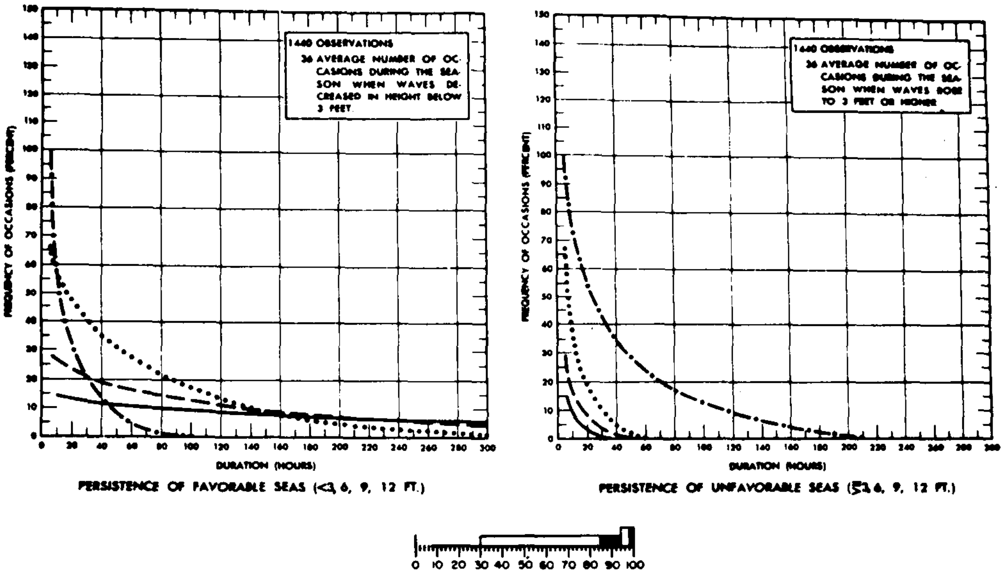
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

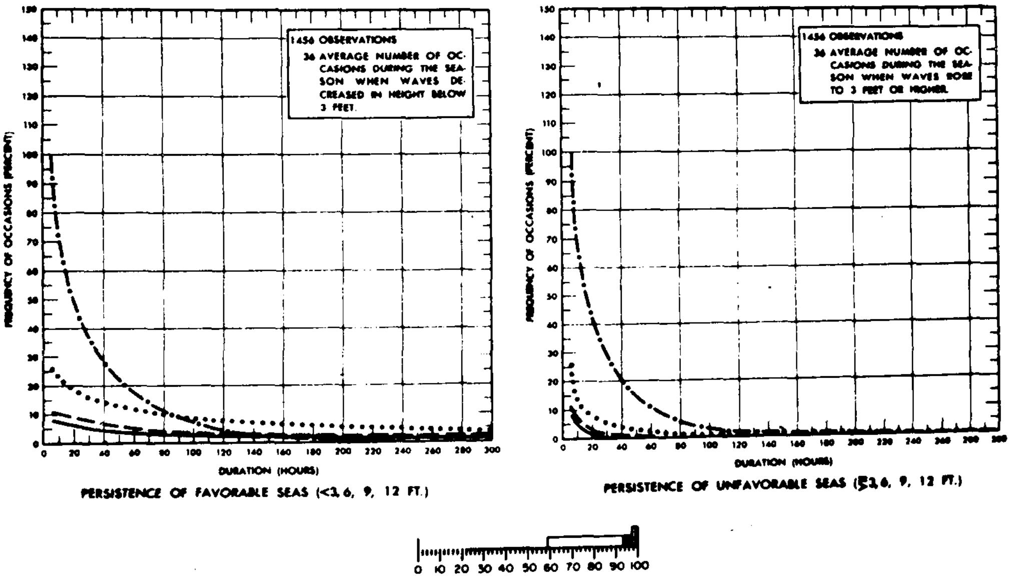
FIGURE 3-166

Legend for Persistence of Favorable and Unfavorable Seas at East Coast Lightships

JANUARY, FEBRUARY, MARCH



APRIL, MAY, JUNE

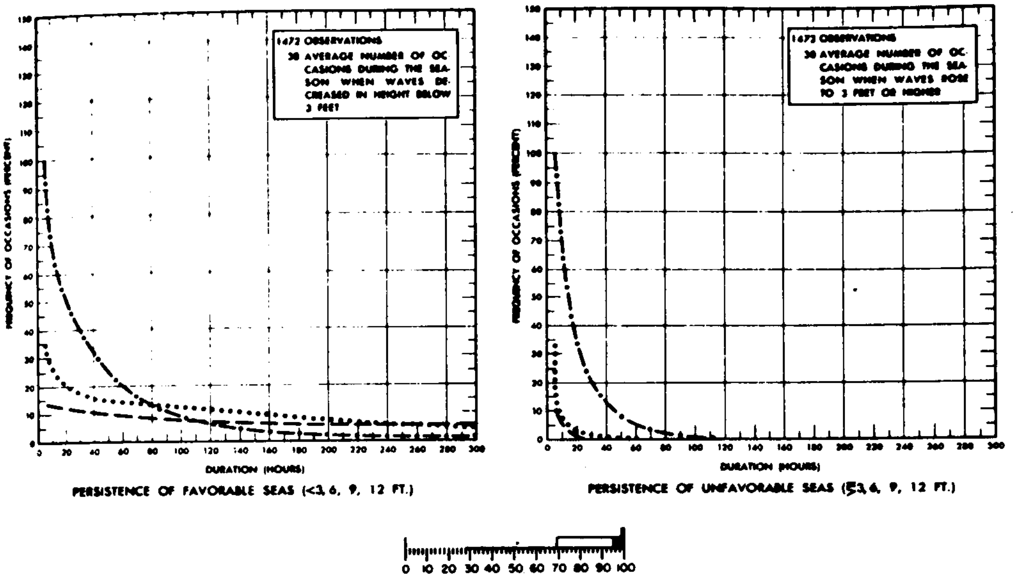


POLLOCK RIP, MASS. 41°36.1'N., 69°51.1'W.

FIGURE 3-167a

Persistence of Favorable and Unfavorable Seas
Pollock Rip Lightship, Mass.

JULY, AUGUST, SEPTEMBER



OCTOBER, NOVEMBER, DECEMBER

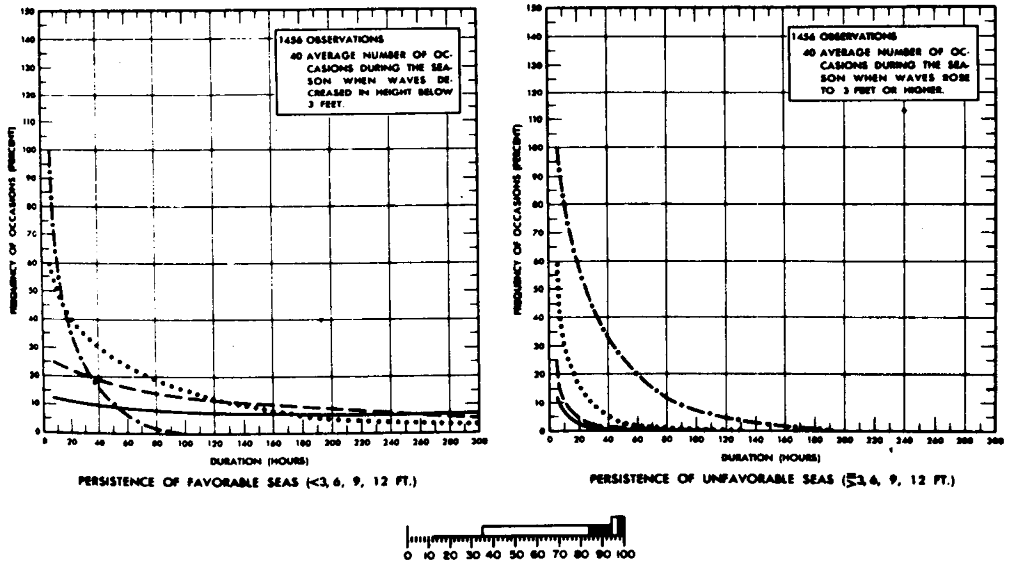
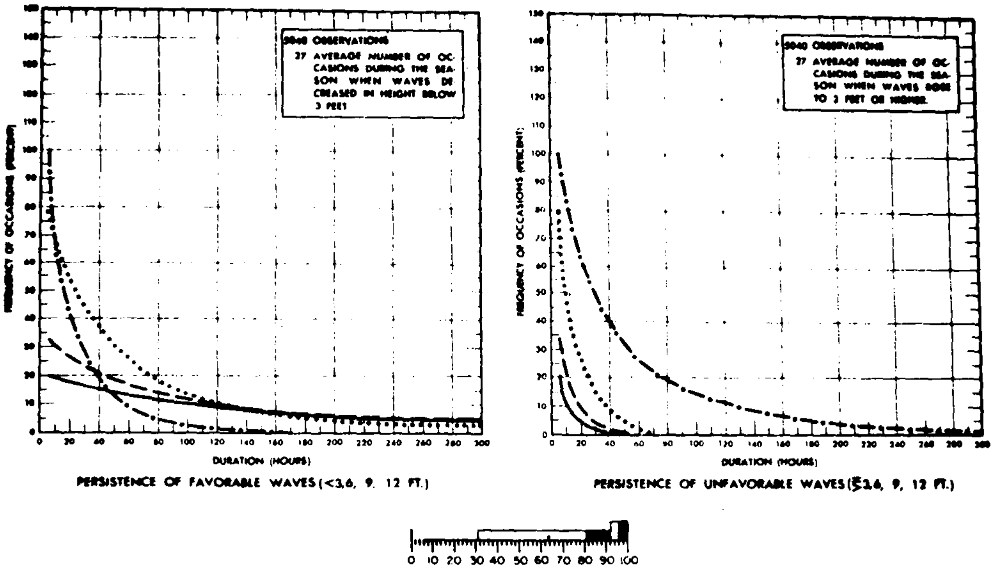


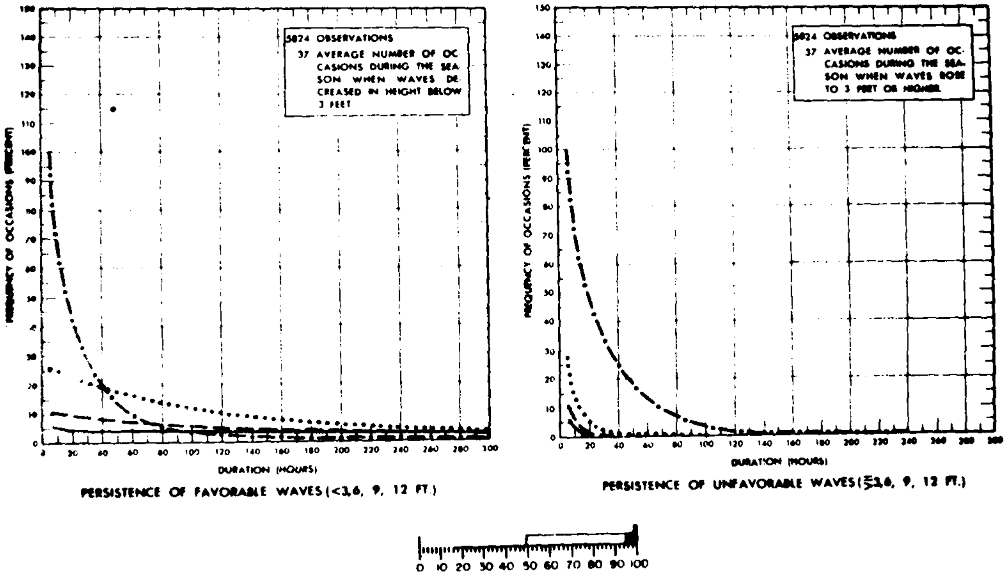
Figure II-27.—Continued.

Persistence of Favorable and Unfavorable Seas
Pollock Rip Lightship, Mass.

JANUARY, FEBRUARY, MARCH



APRIL, MAY, JUNE

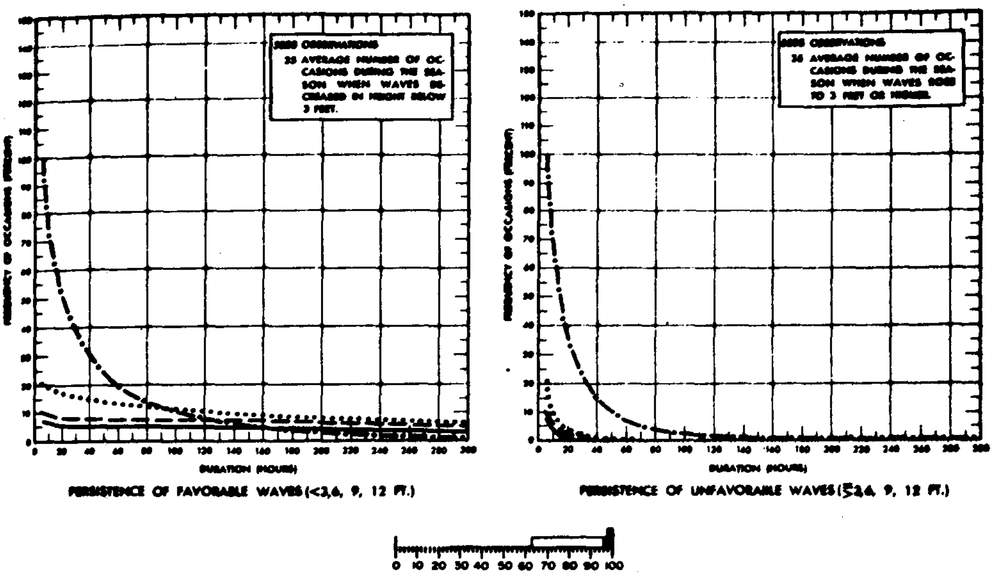


NANTUCKET SHOALS, MASS. 40°37.0'N., 69°18.5'W.

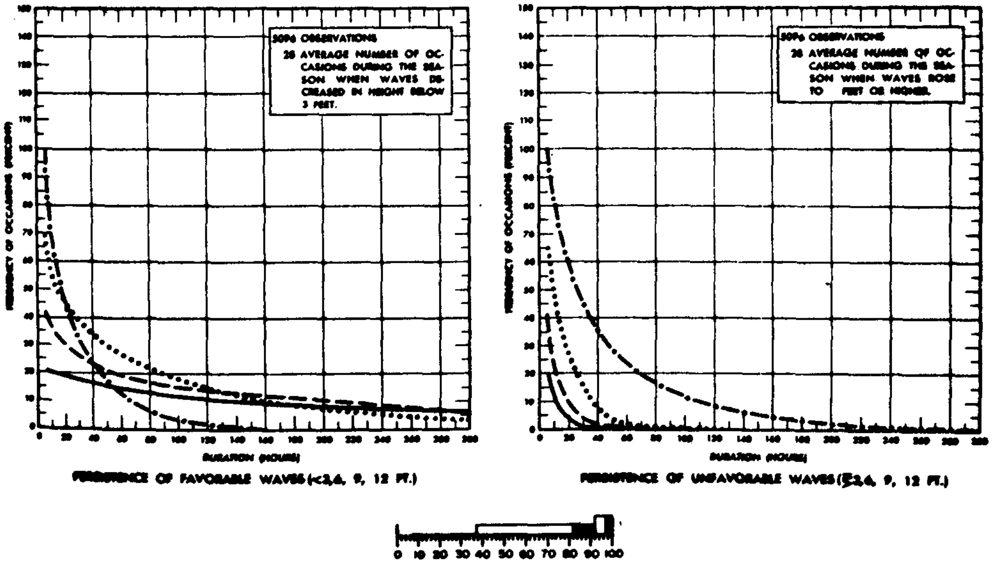
FIGURE 3-168a

Persistence of Favorable and Unfavorable Seas
Nantucket Shoals Lightship, Mass.

JULY, AUGUST, SEPTEMBER



OCTOBER, NOVEMBER, DECEMBER



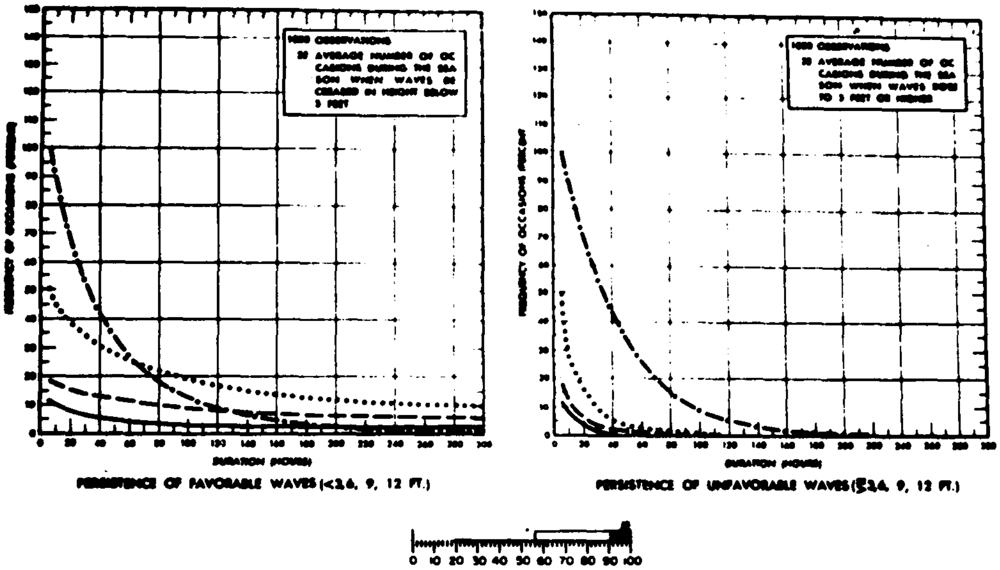
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

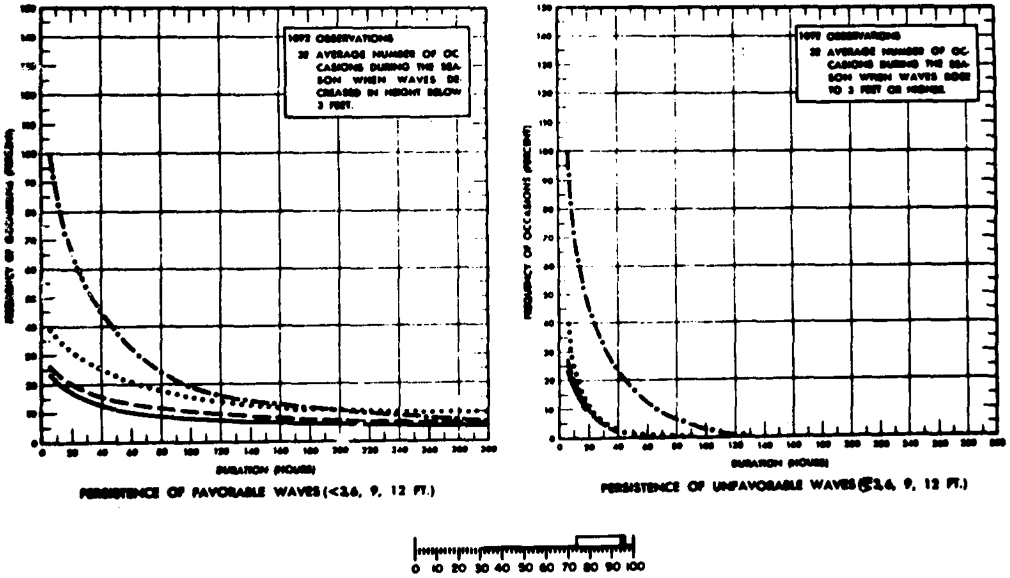
FIGURE 3-168b

Persistence of Favorable and Unfavorable Seas
Nantucket Shoals Lightship, Mass.

JANUARY, FEBRUARY, MARCH



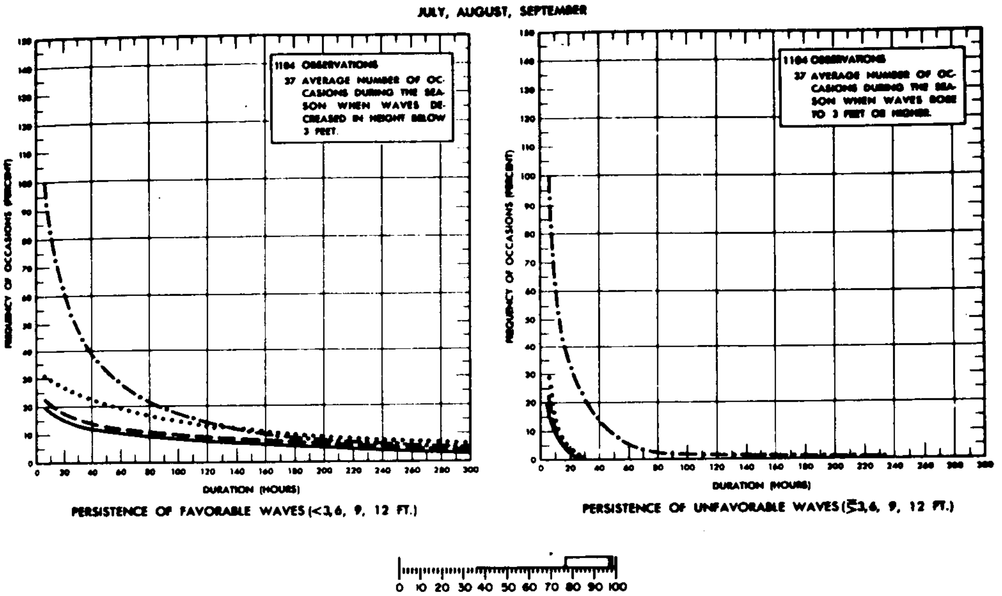
APRIL, MAY, JUNE

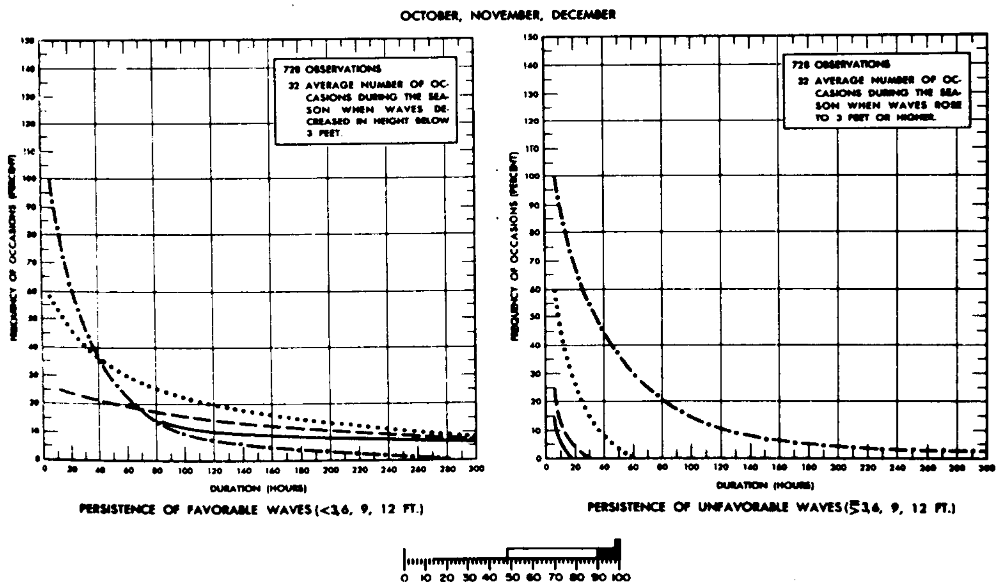


BUZZARDS BAY, MASS. 41°24.0'N., 71°3.0'W.

FIGURE 3-169a

Persistence of Favorable and Unfavorable Seas
Buzzards Bay Lightship, Mass.





A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-169b

Persistence of Favorable and Unfavorable Seas
Buzzards Bay Lightship, Mass.

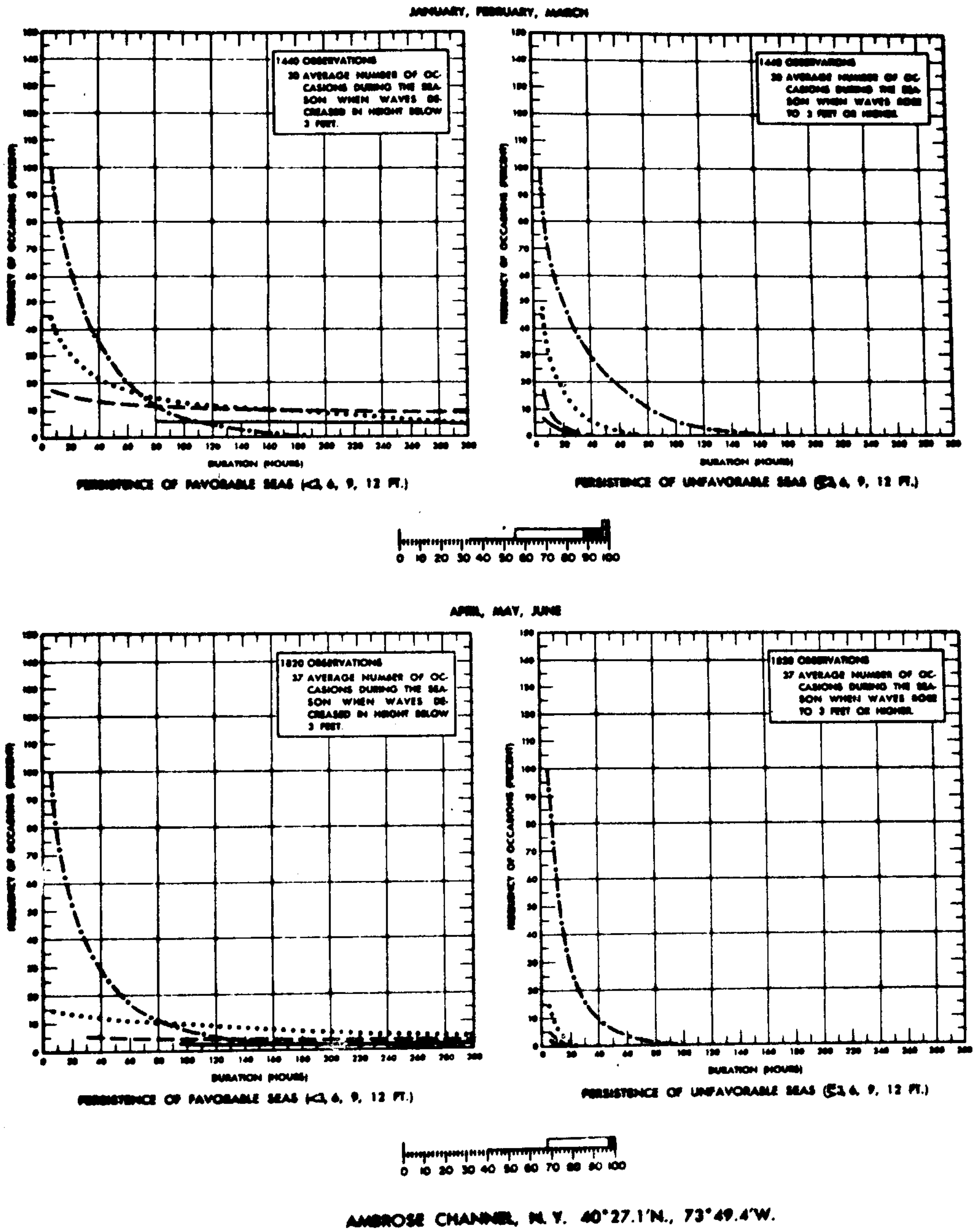
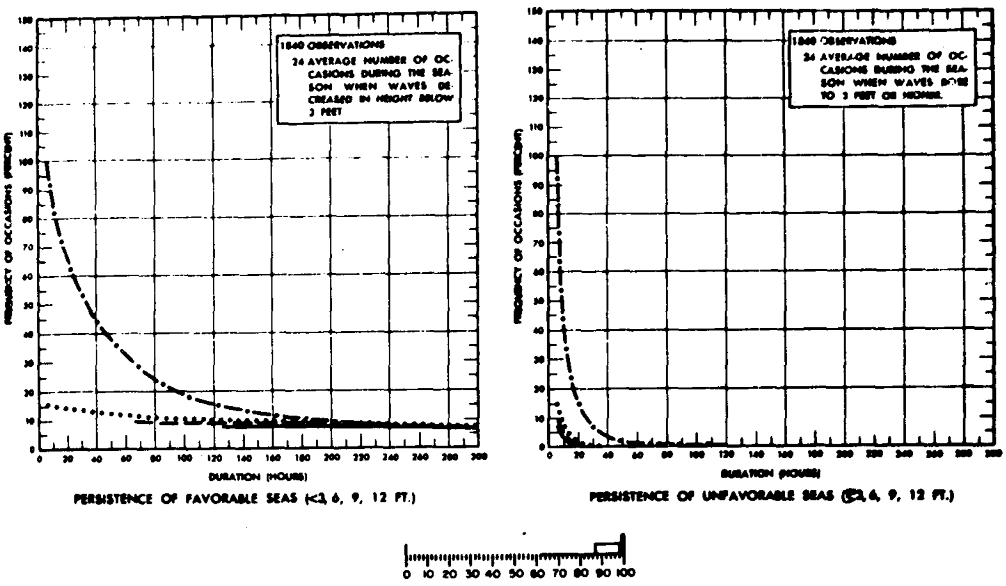
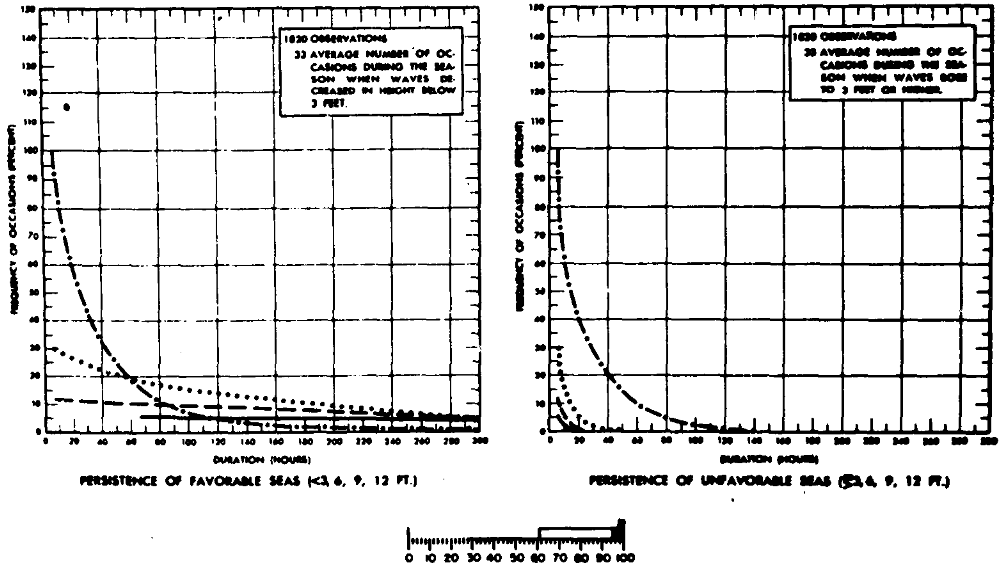


FIGURE 3-170a Persistence of Favorable and Unfavorable Seas Ambrose Channel Lightship, New York

JULY, AUGUST, SEPTEMBER

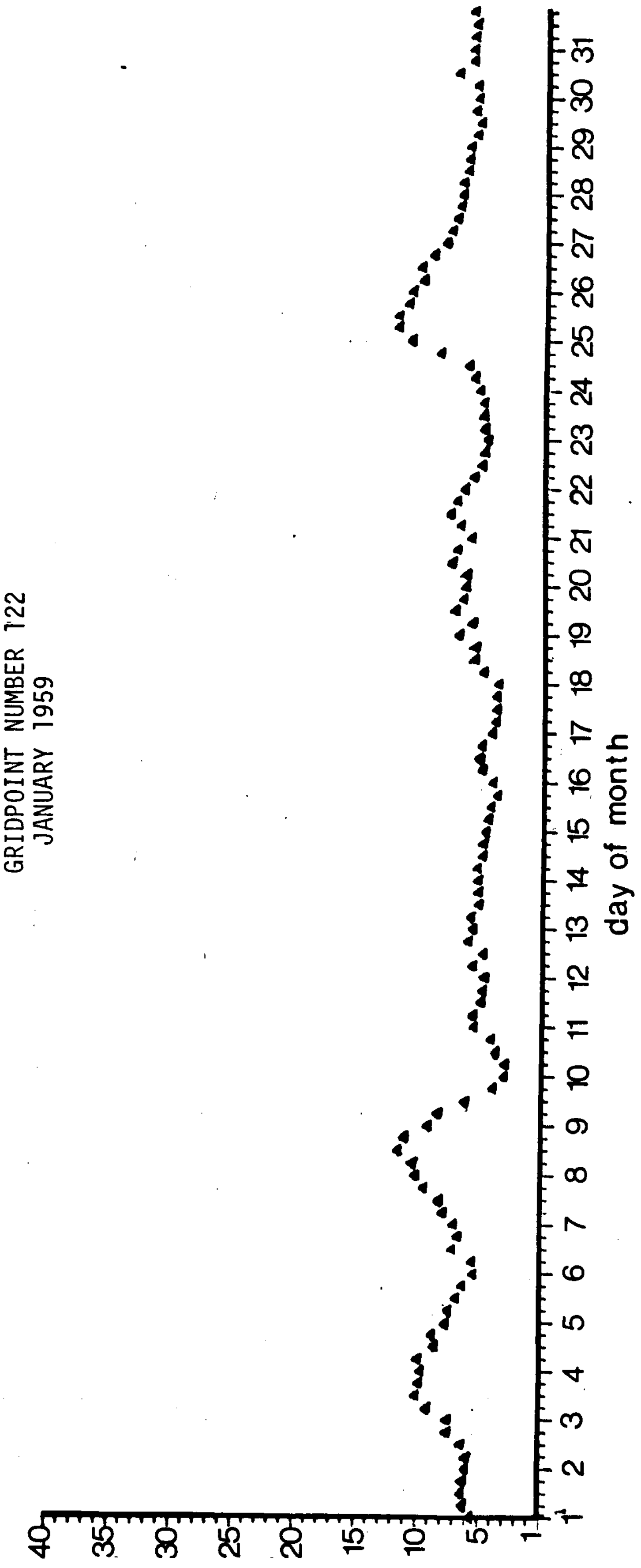


OCTOBER, NOVEMBER, DECEMBER



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-170b	Persistence of Favorable and Unfavorable Seas Ambrose Channel Lightship, New York



GRIDPOINT NUMBER 122
JANUARY 1959

TRIGOM PARC

FIGURE 3-171 The Cross Section of Significant Wave Height

3.2.9B WINDS, SEAS, AND SWELLS

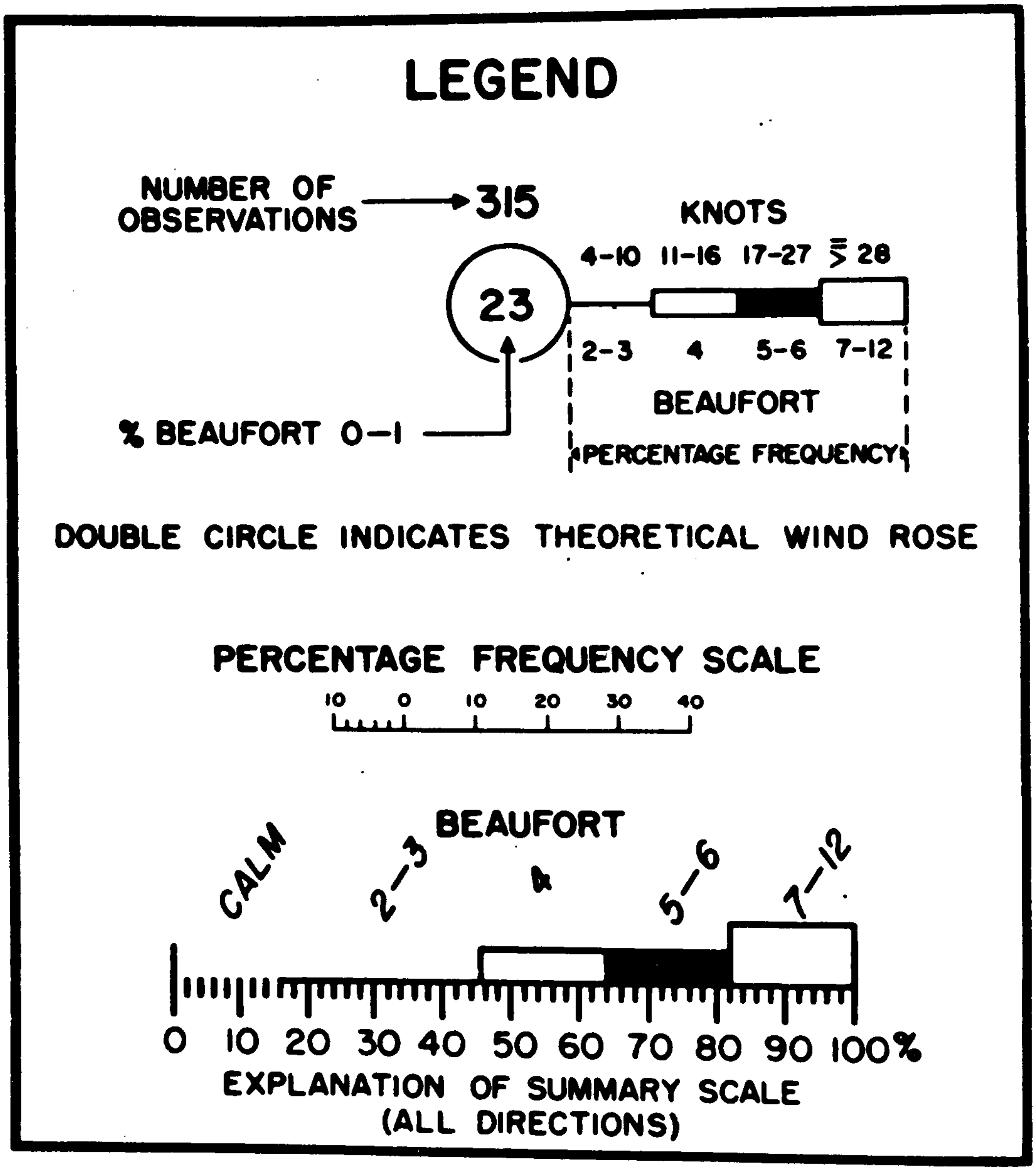
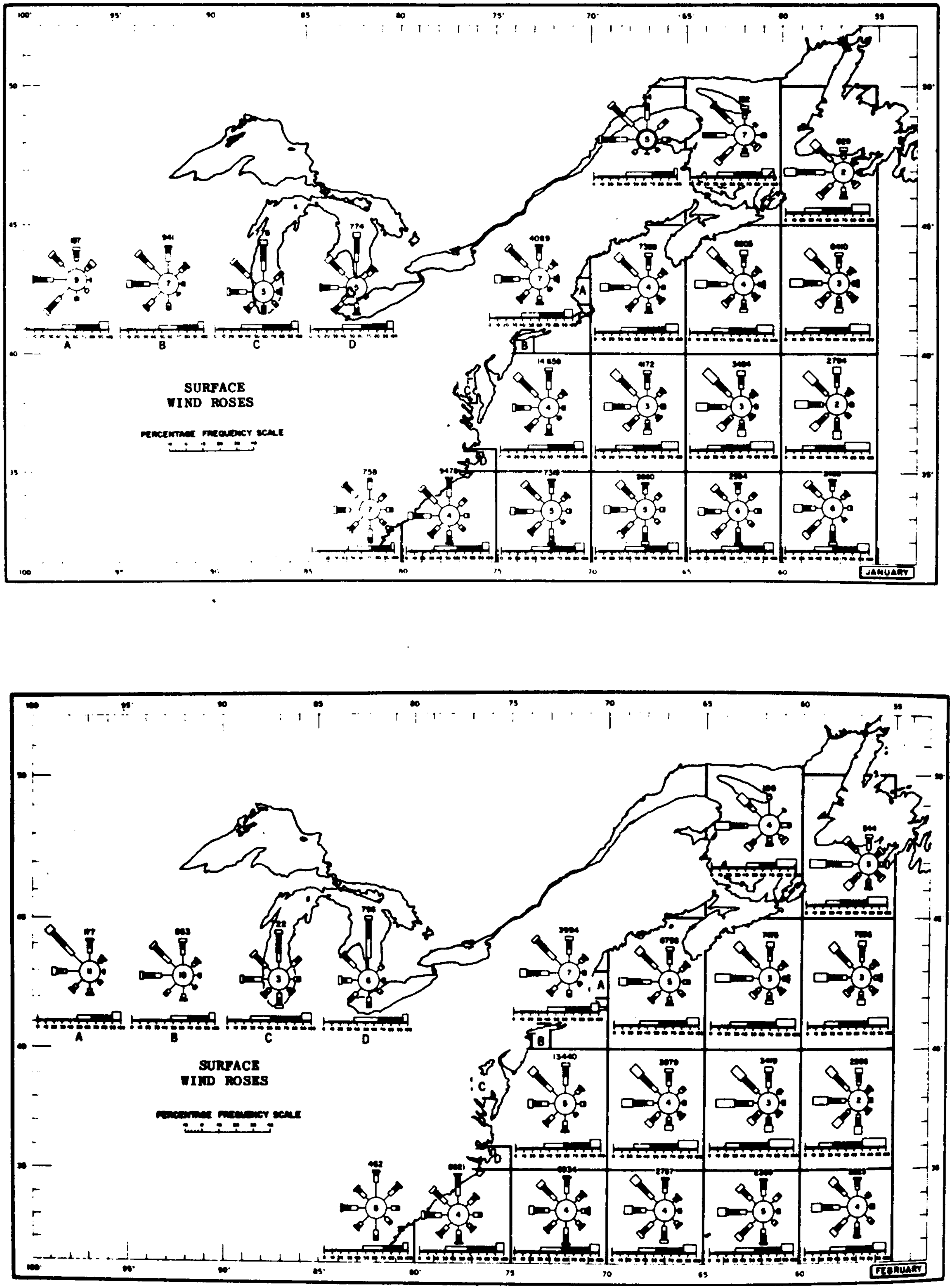


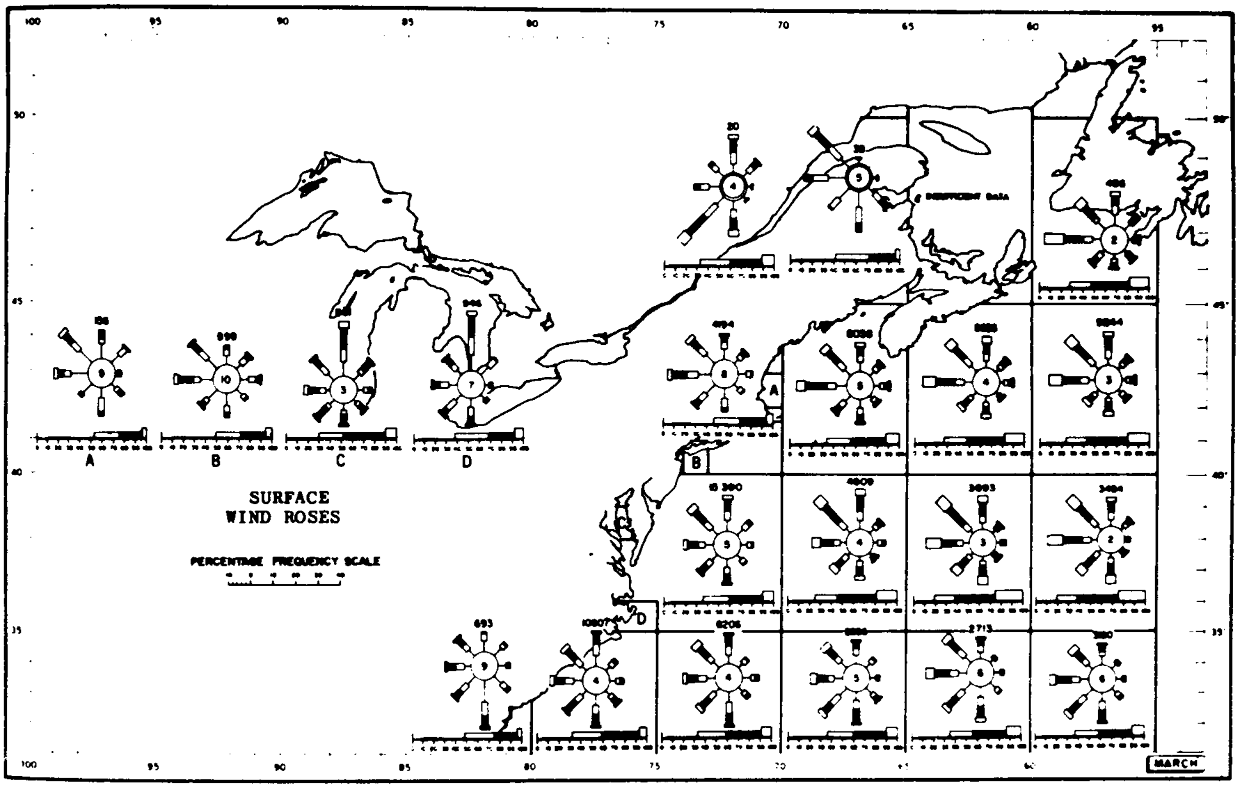
FIGURE 3-172 Legend for Western North Atlantic Surface Wind Roses



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-173 Surface Wind Roses January-February



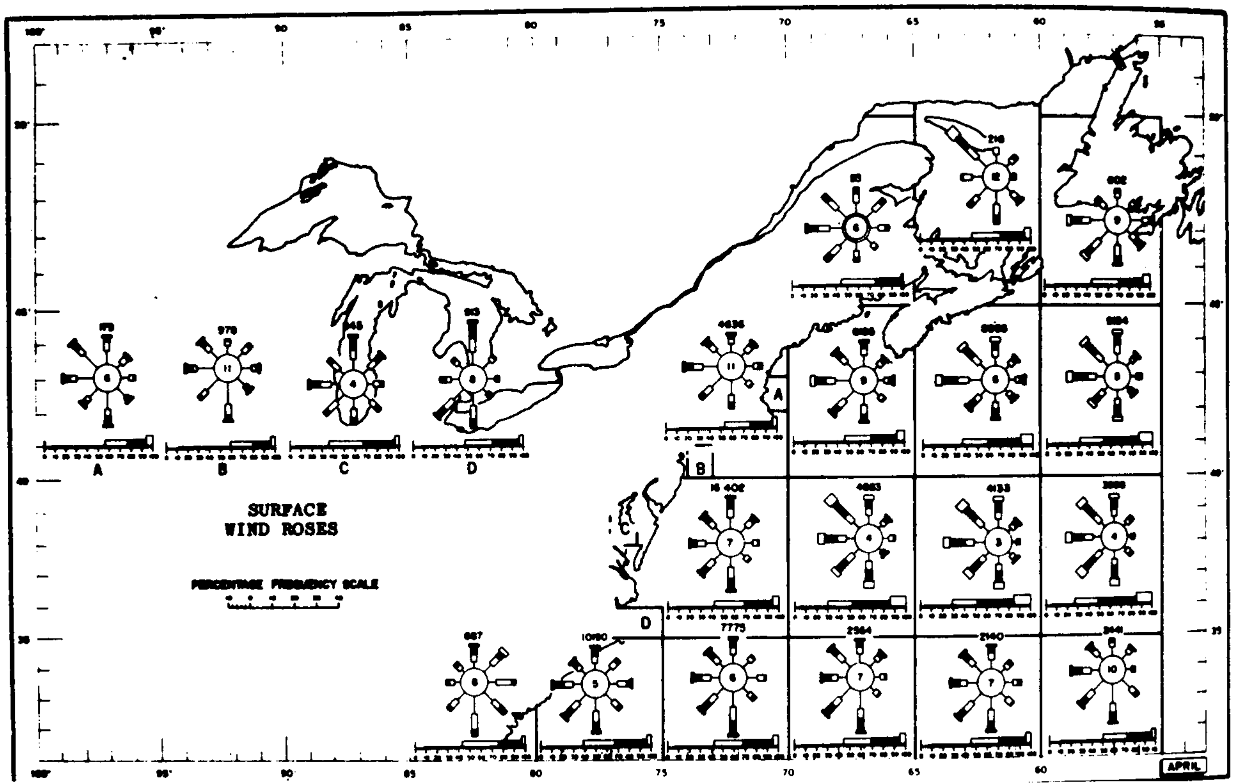
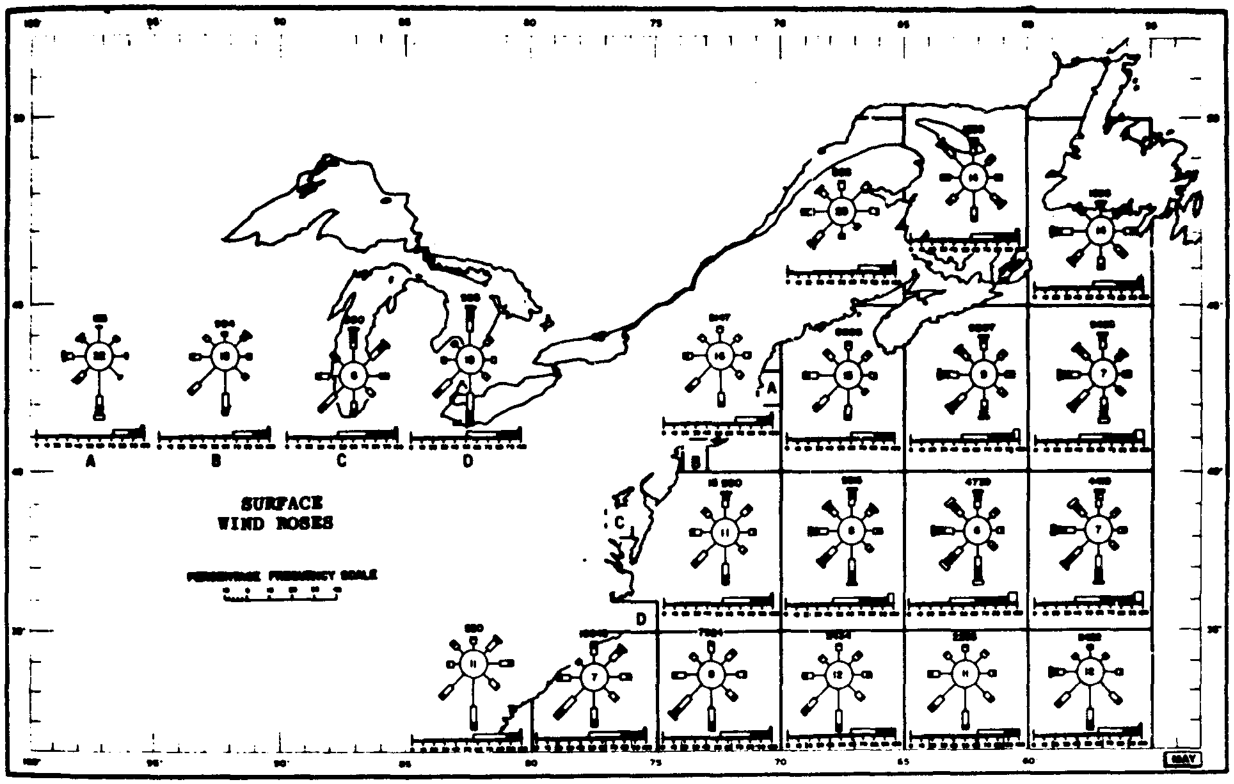
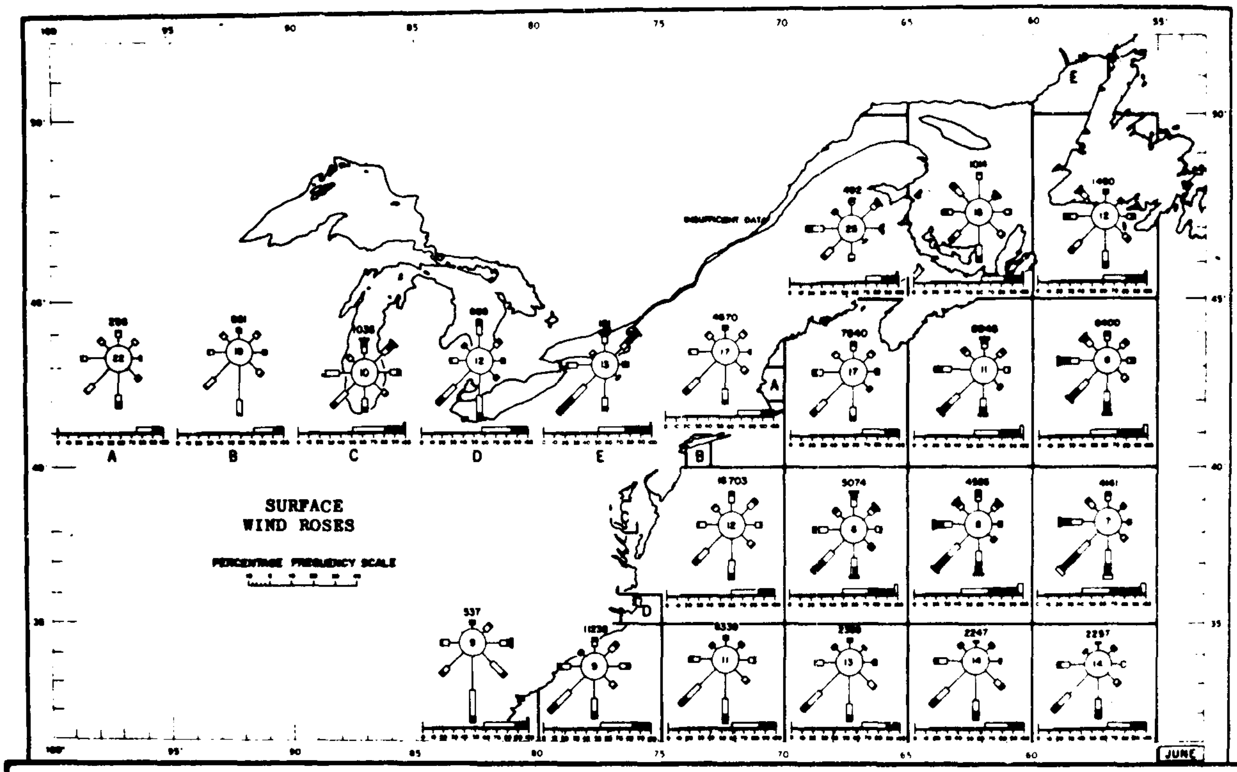


FIGURE 3-174 Surface Wind Roses March-April

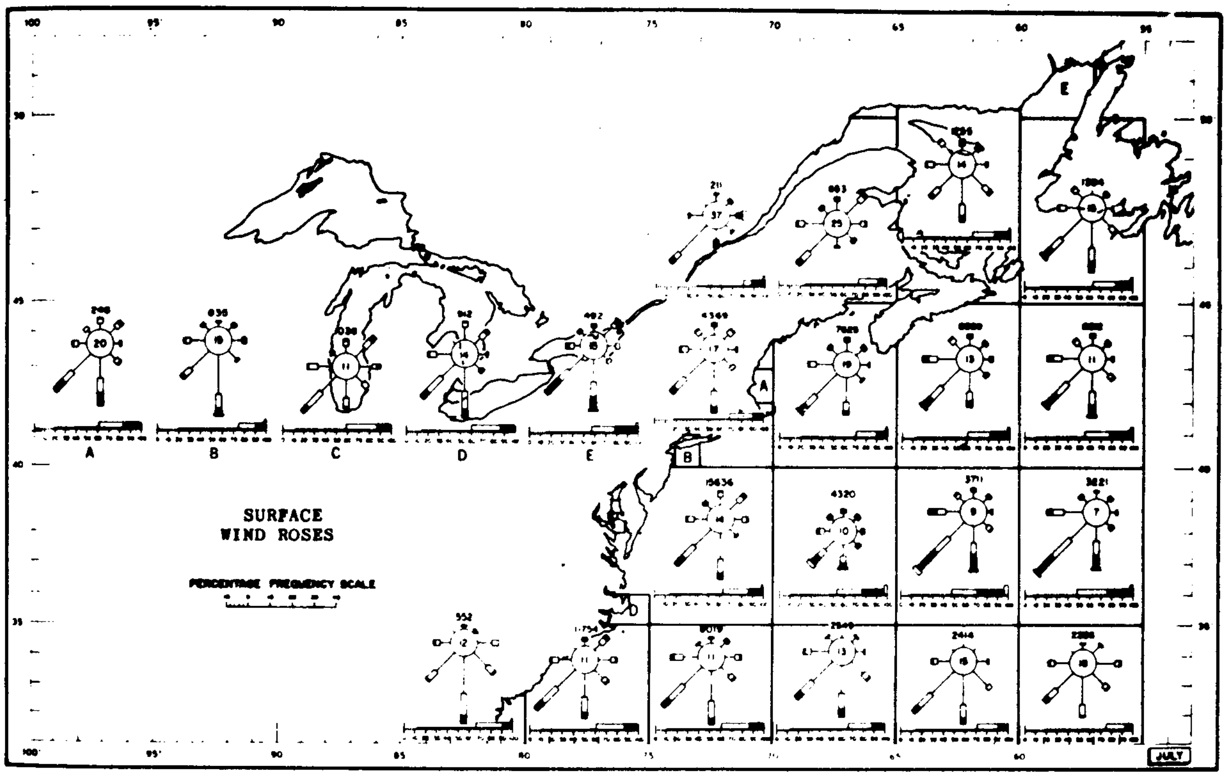




A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-175 Surface Wind Roses May-June



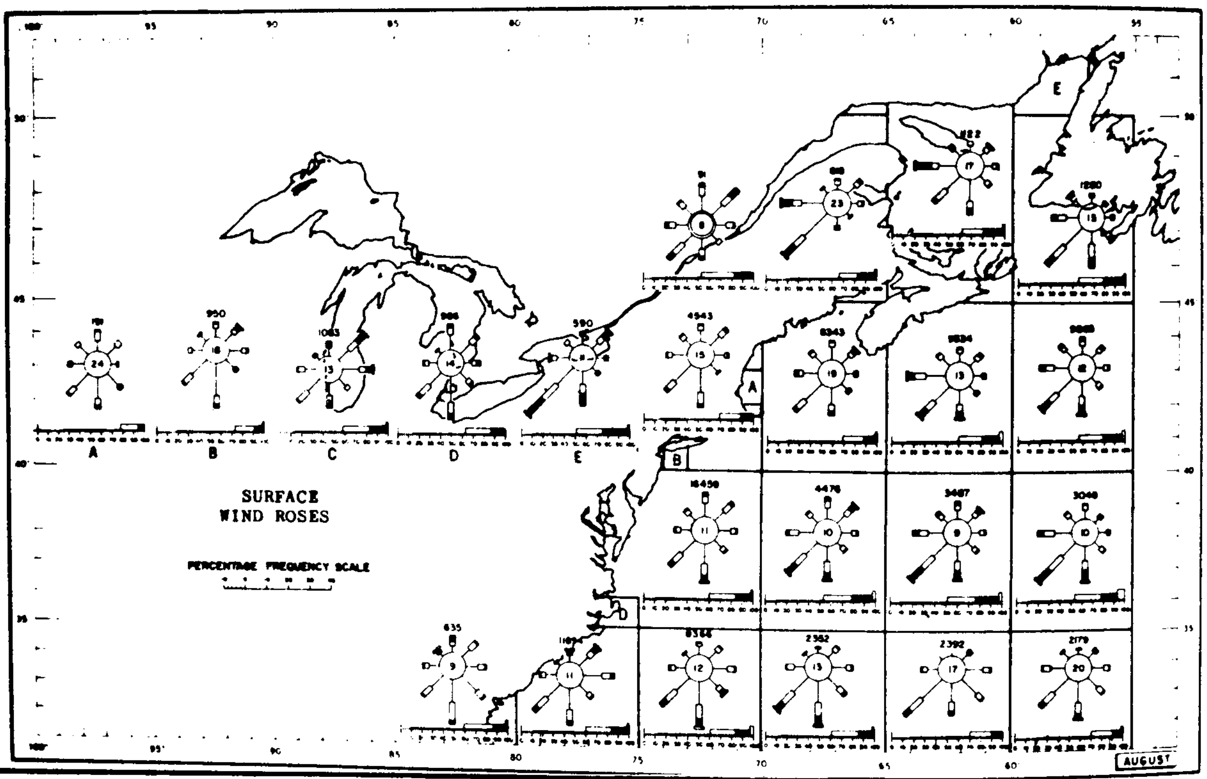
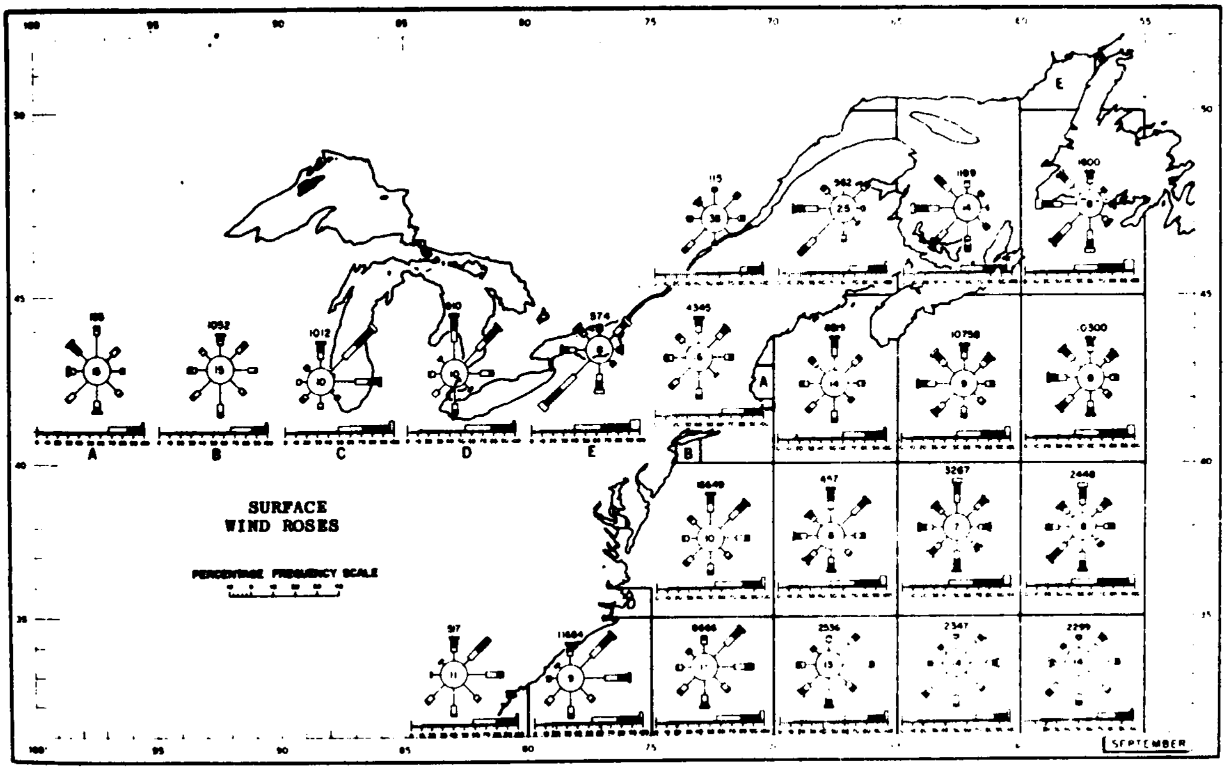


FIGURE 3-176 Surface Wind Roses July-August



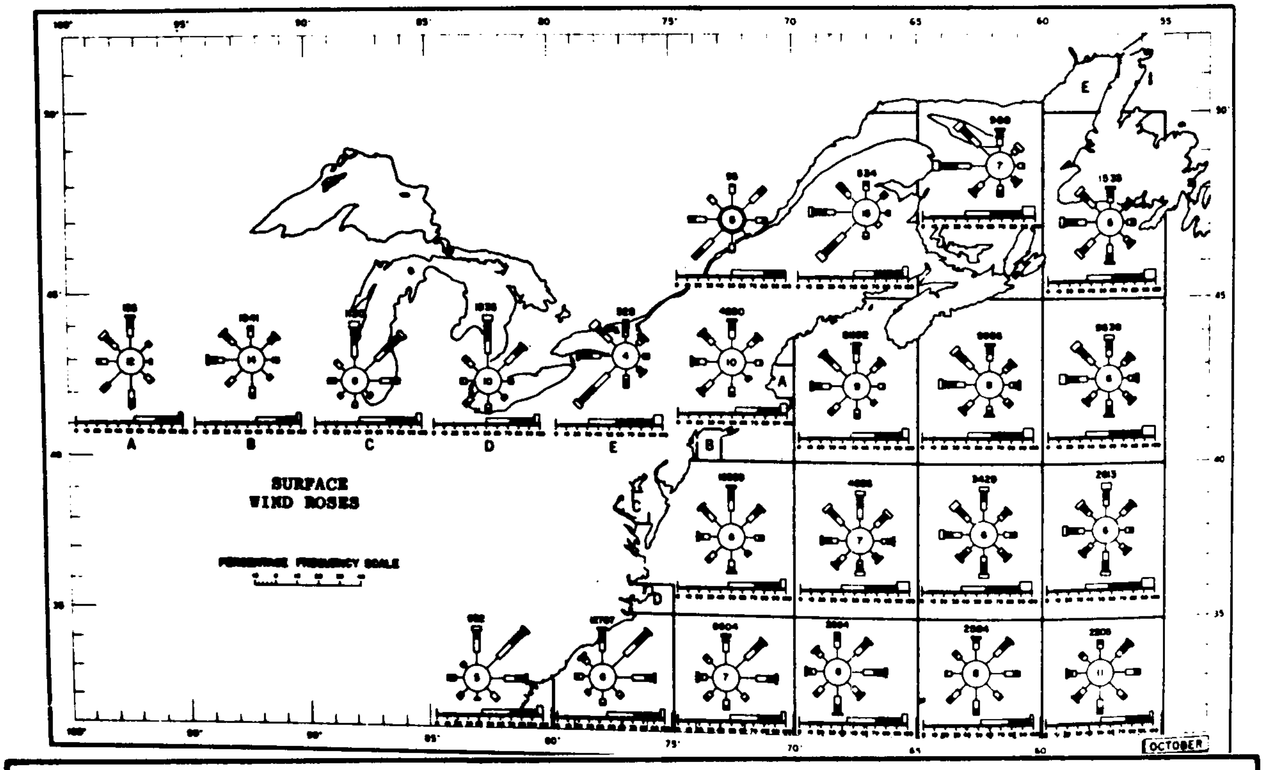
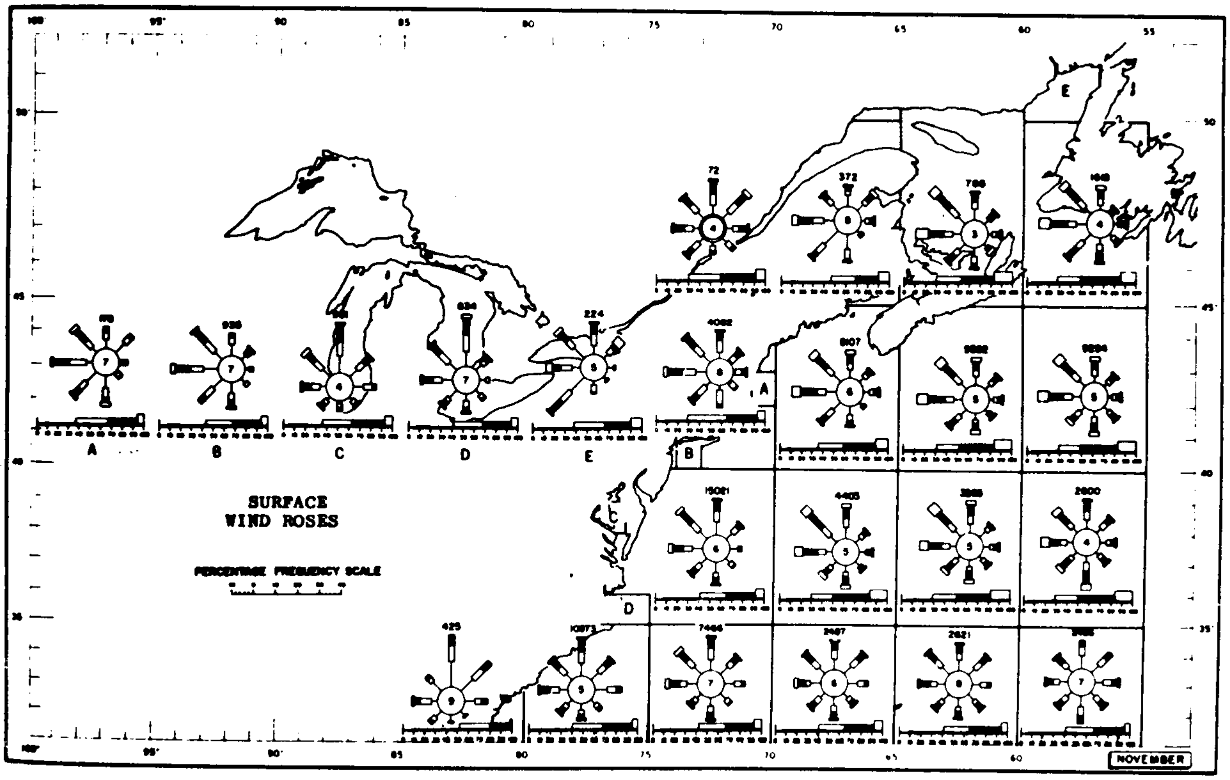


FIGURE 3-177 Surface Wind Roses September-October



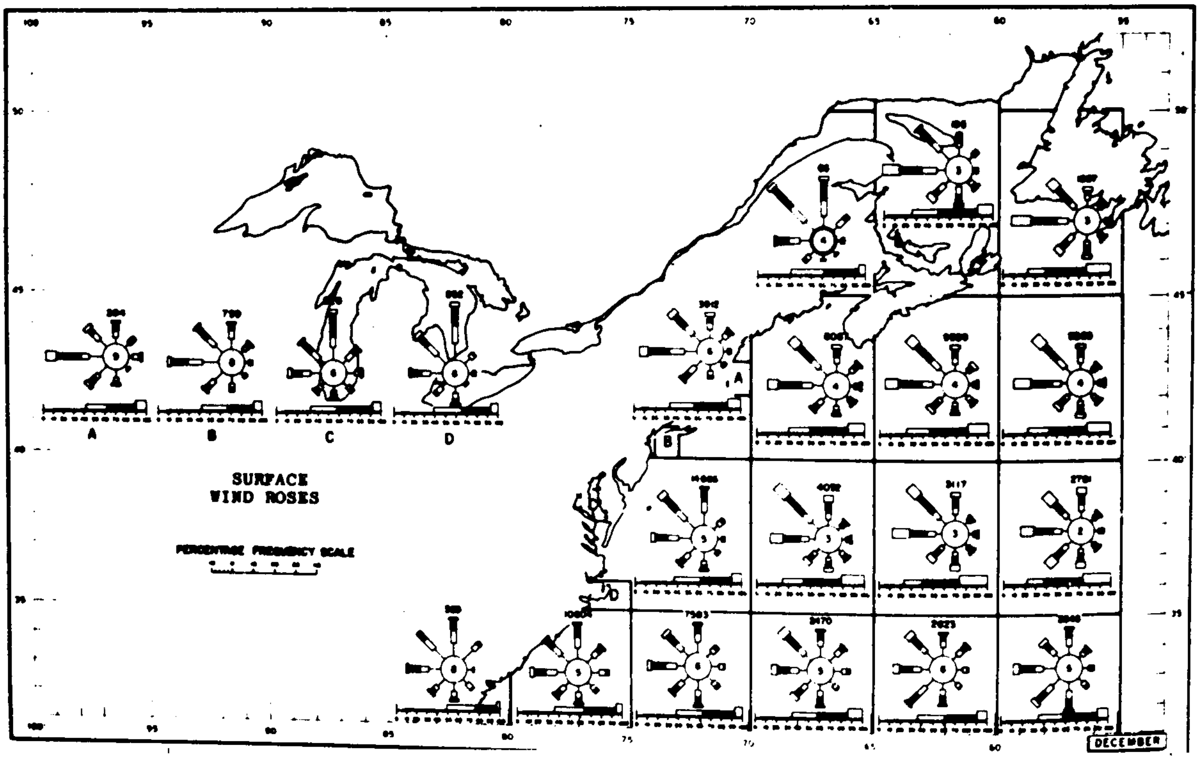


FIGURE 3-178 Surface Wind Roses November-December

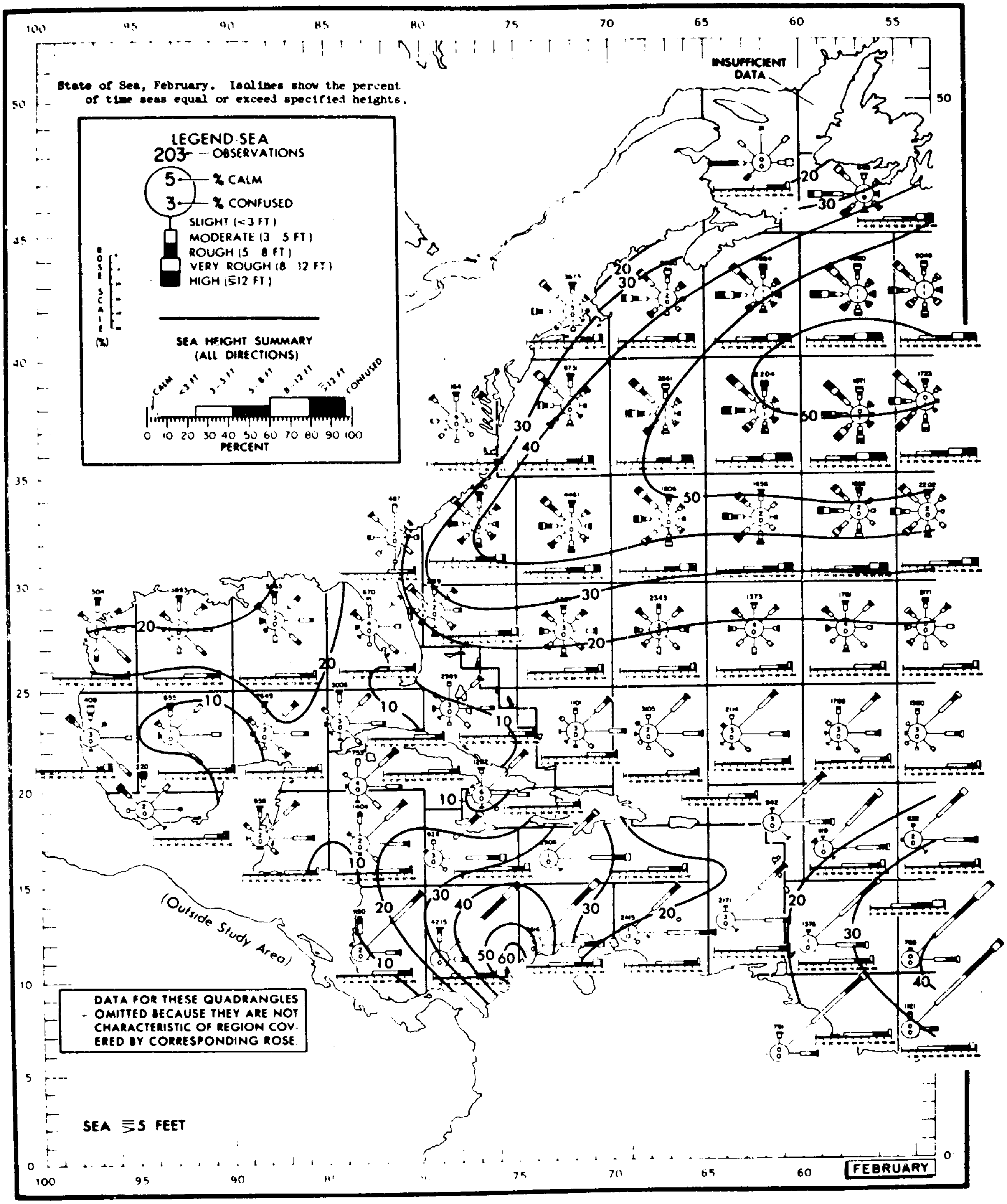
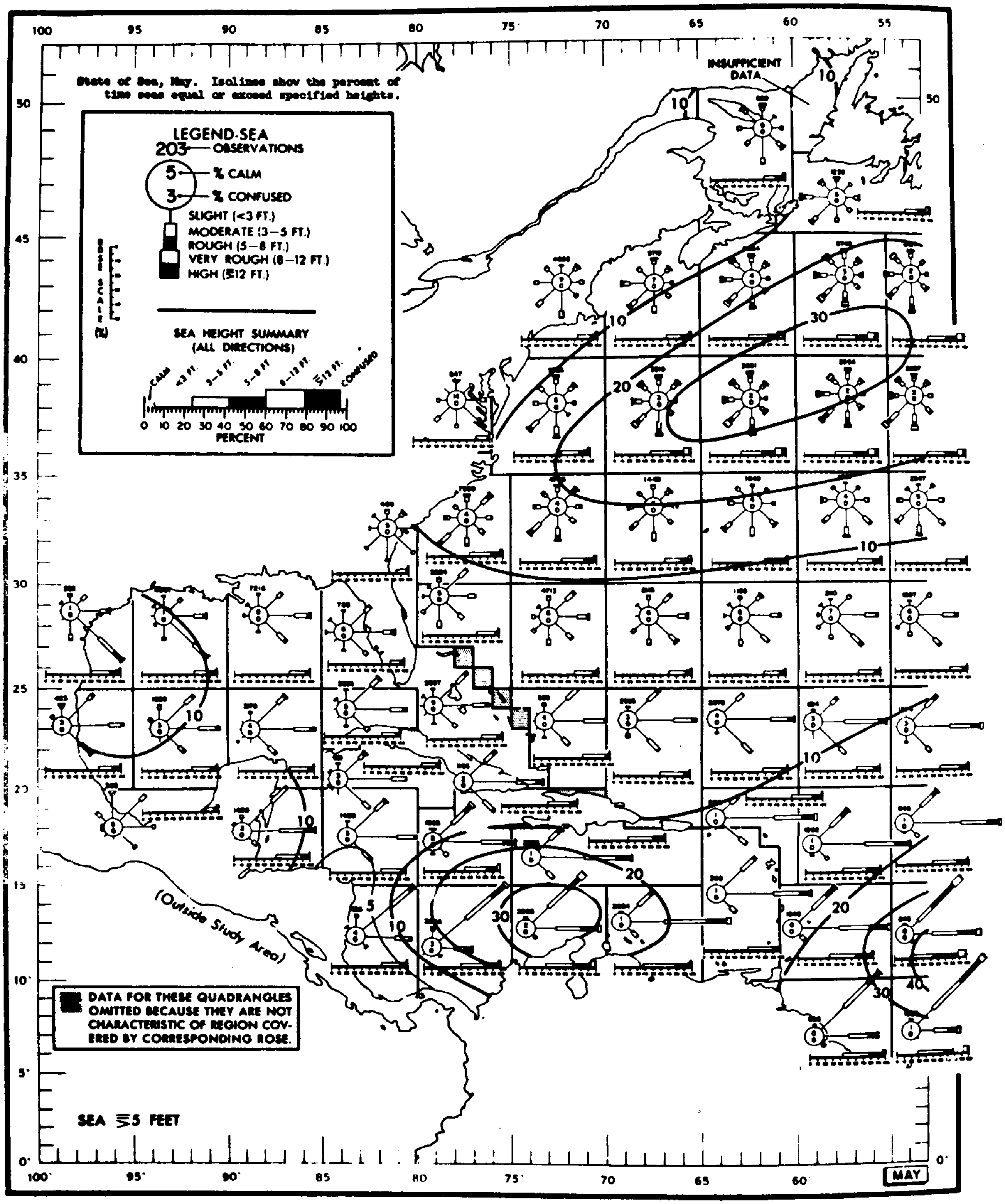


FIGURE 3-179 Seasonal Sea Roses - February



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-180	Seasonal Sea Roses - May

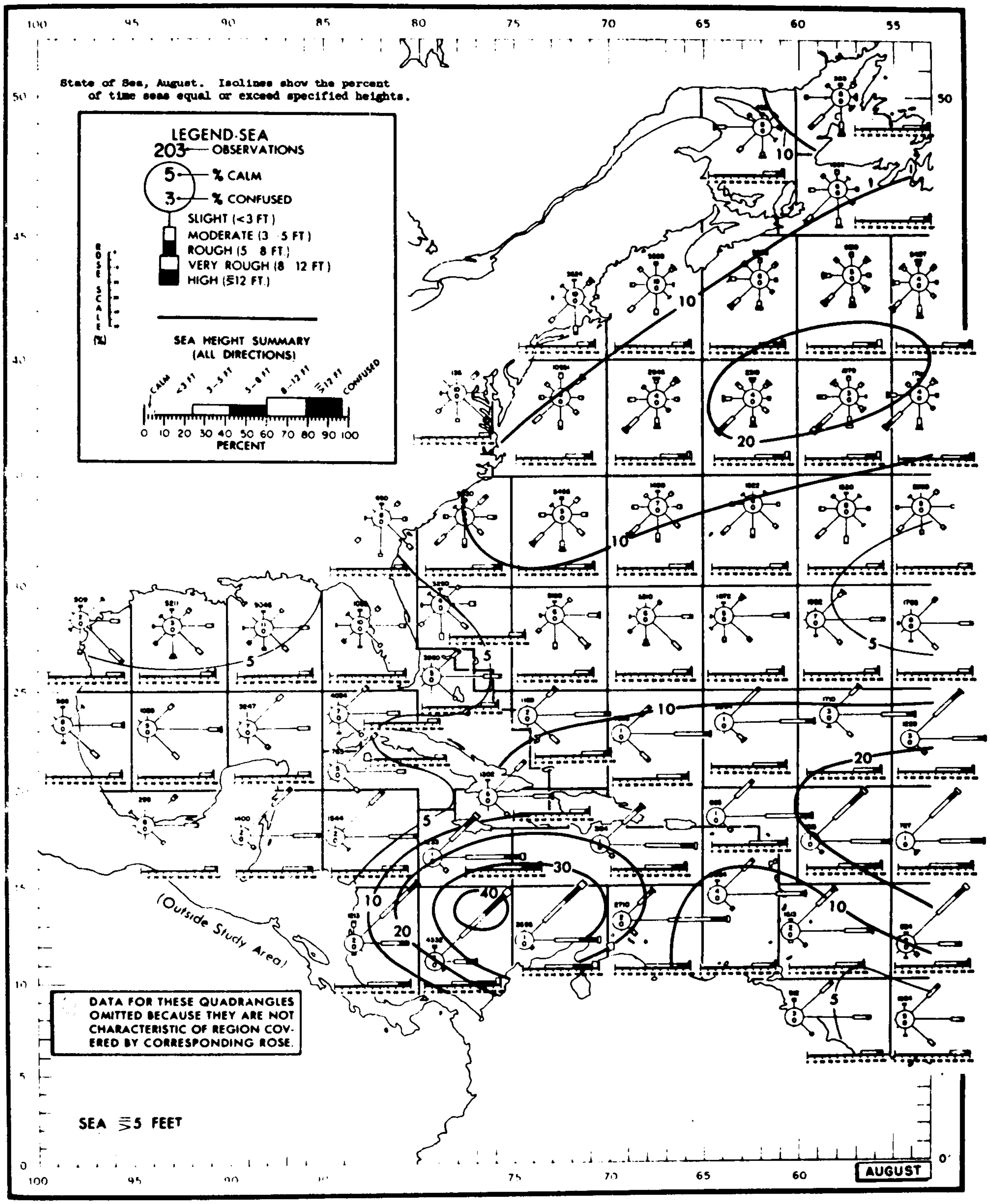
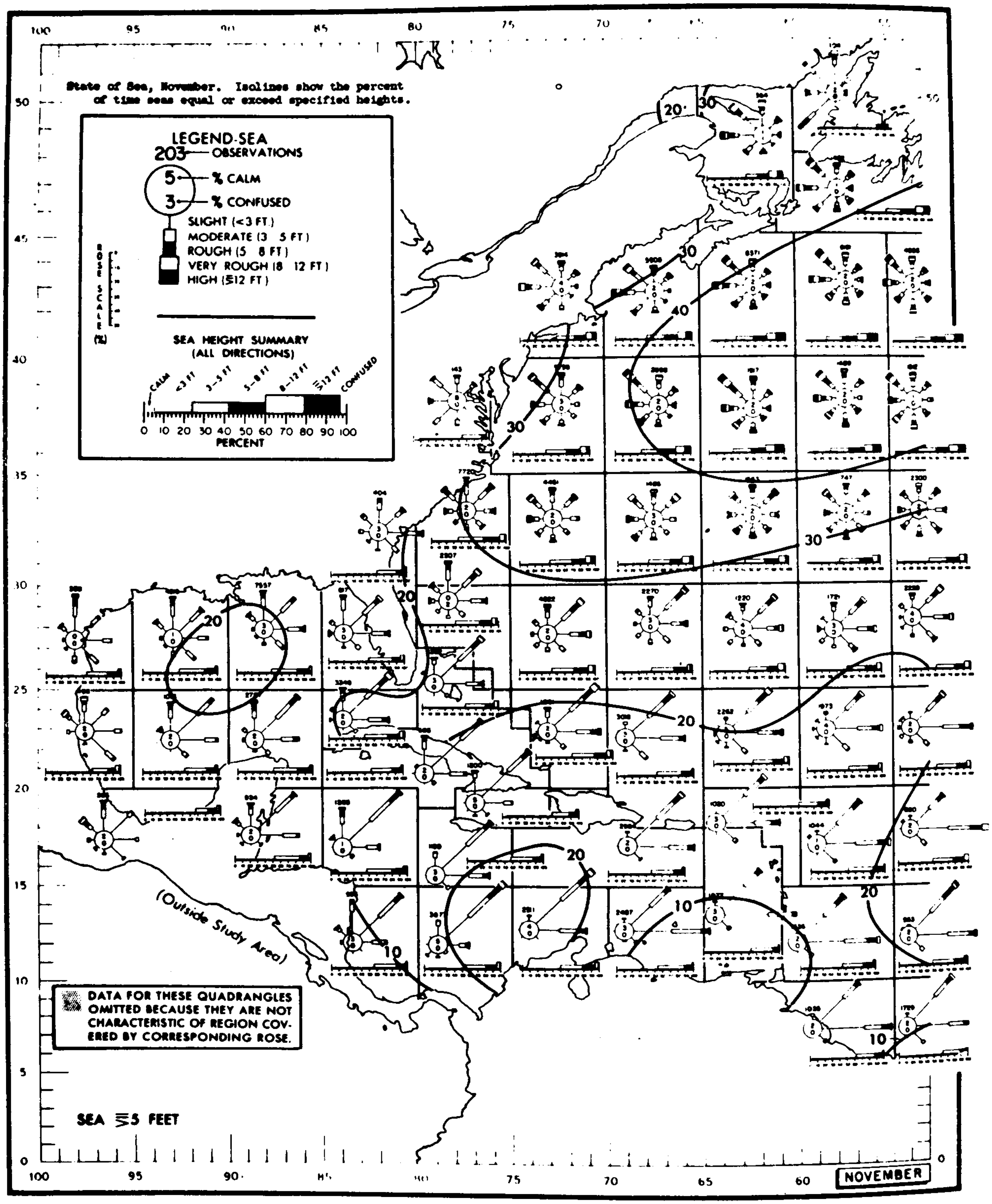


FIGURE 3-181 Seasonal Sea Roses - August



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-182

Seasonal Sea Roses - November

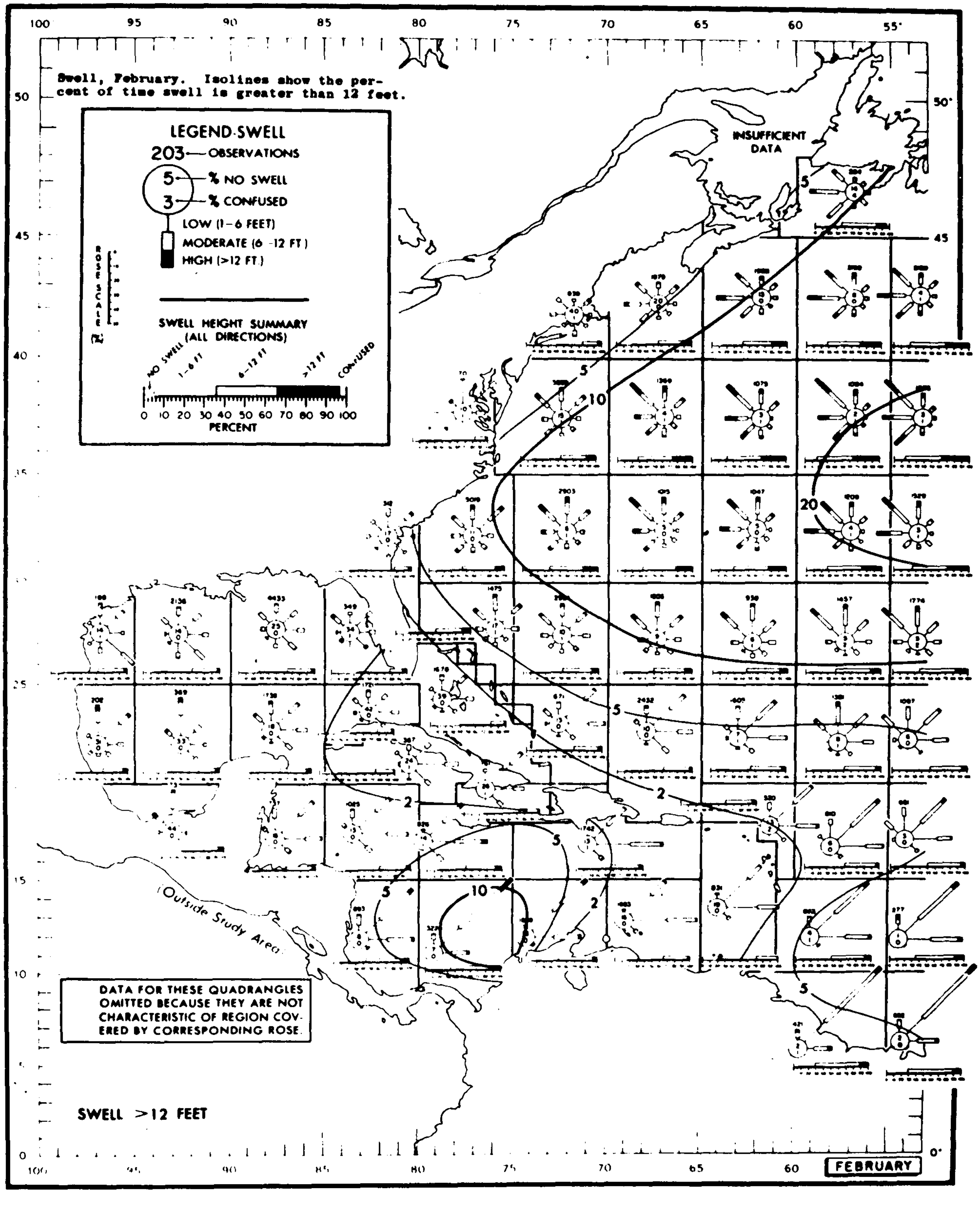

Swell, February. Isolines show the percent of time swell is greater than 12 feet.

FIGURE 3-183 Swell Roses - February

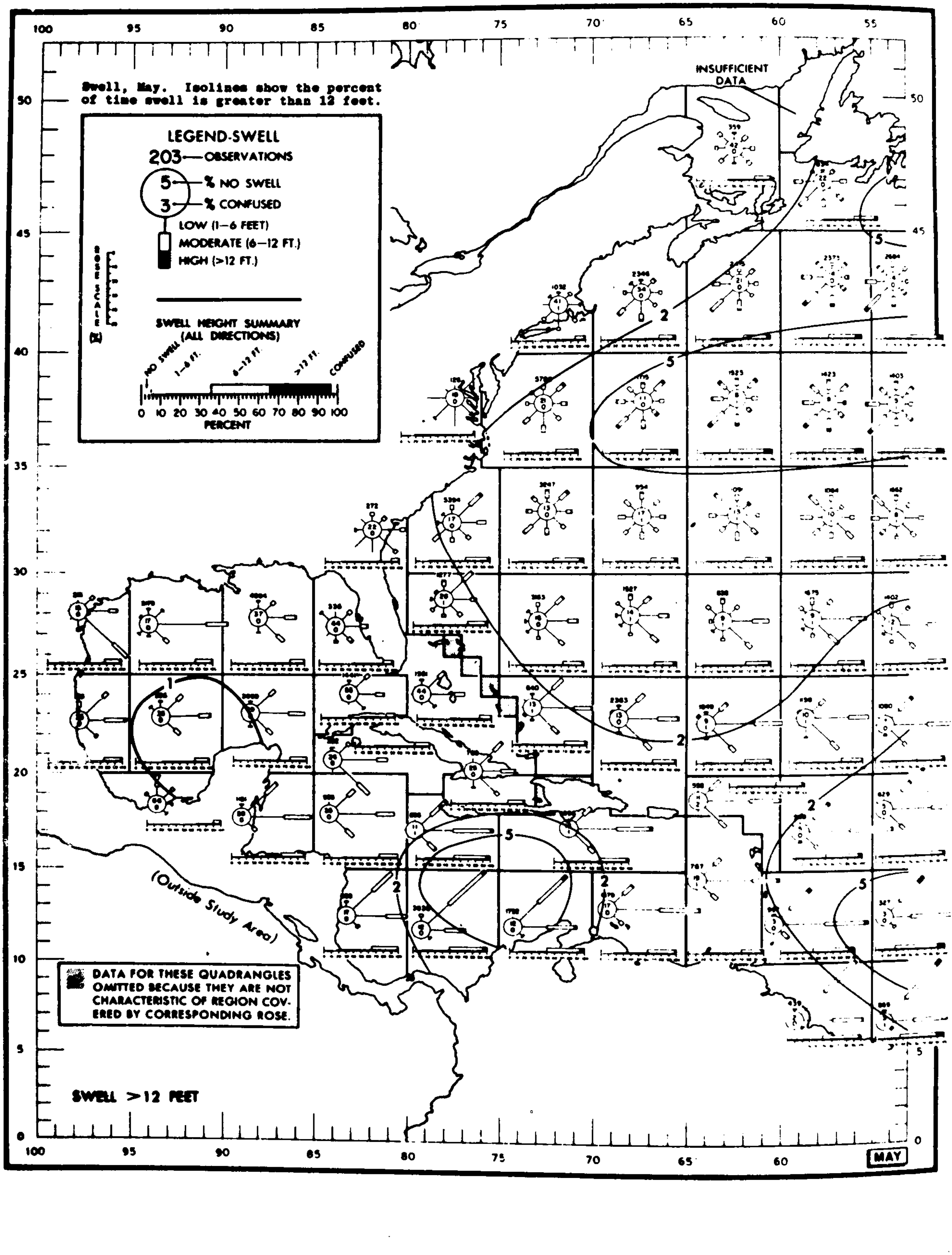
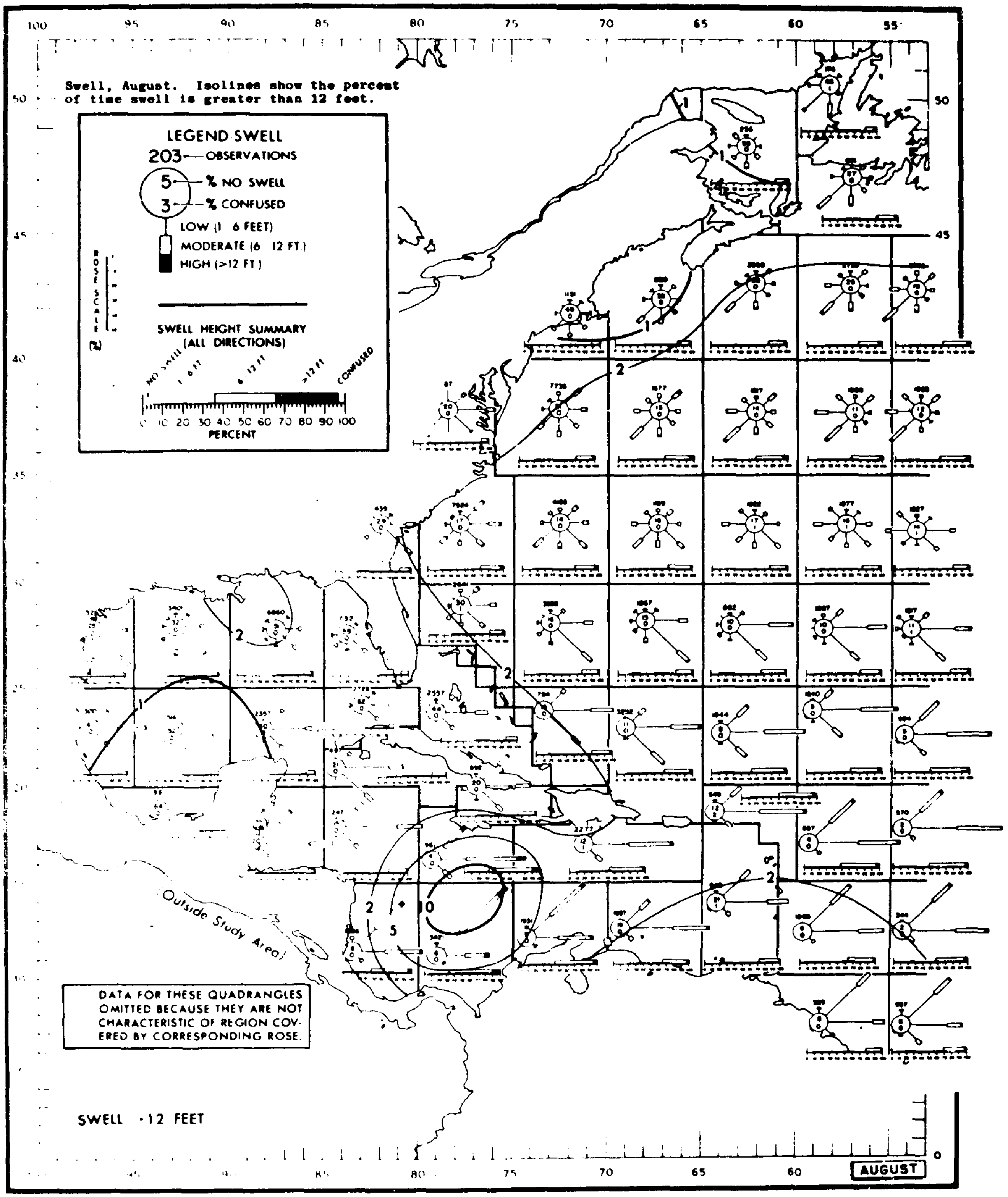


FIGURE 3-184 Swell Roses - May



Swell, August. Isolines show the percent of time swell is greater than 12 feet.

DATA FOR THESE QUADRANGLES OMITTED BECAUSE THEY ARE NOT CHARACTERISTIC OF REGION COVERED BY CORRESPONDING ROSE.

FIGURE 3-185 Swell Roses - August

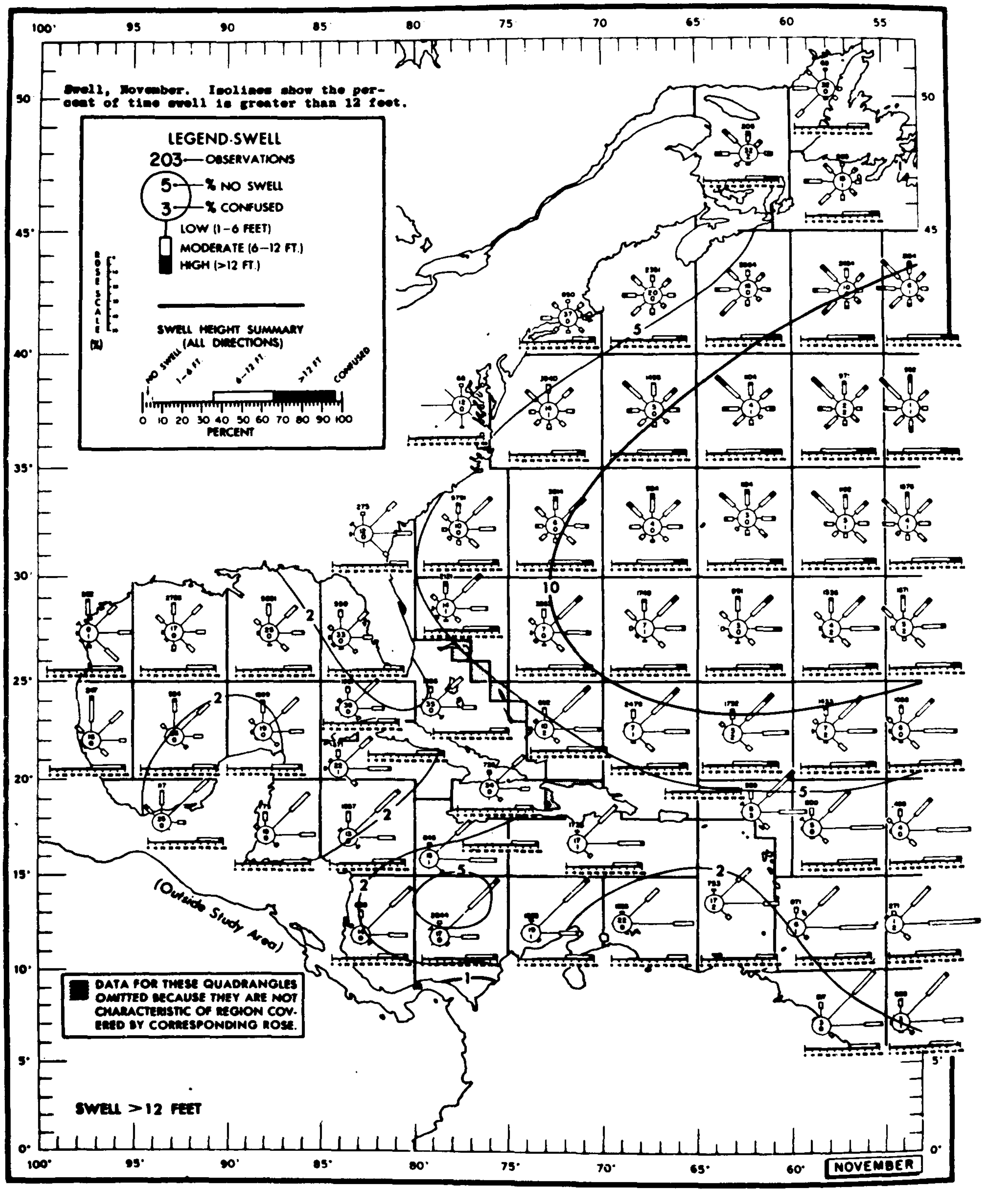


FIGURE 3-186 Swell Roses - November

Table 3-10 Meteorological Tables

METEOROLOGICAL TABLE FOR COASTAL AREA OFF NEW YORK

Boundaries: From 40°N., and 72°W., north and westward to coast

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	3.4	3.7	2.6	1.3	0.6	*	0.2	0.2	0.6	1.8	2.3	3.3	1.6	16253
Wind ≧ 41 knots (1)	1.0	1.1	0.7	0.4	0.2	*	*	0.1	0.3	0.5	0.7	0.5	0.4	16253
Wave height ≧ 12 feet (1)	5.6	3.7	1.8	0.8	1.8	*	*	*	3.5	1.2	2.9	1.4	1.7	1601
Wave height ≧ 20 feet (1)	*	*	*	0.4	*	*	*	*	*	*	0.7	*	0.1	1601
Visibility < 2 naut. mi. (1)	5.9	3.8	4.8	8.9	12.3	8.1	7.8	4.4	3.2	2.7	4.0	3.0	6.0	7099
Visibility < 0.5 naut. mi. (1)	1.5	1.0	2.3	5.7	9.2	5.1	4.0	1.8	1.8	1.8	1.3	1.4	3.3	7099
Precipitation (1)	12.2	10.8	12.7	12.2	7.2	4.7	8.1	6.2	9.4	9.7	10.2	10.4	9.4	9190
Temperature ≧ 85°F (1)	*	*	*	*	*	*	1.3	0.5	*	*	*	*	0.2	7716
Temperature ≦ 32°F (1)	22.7	31.9	10.4	*	*	*	*	*	*	*	1.0	14.8	5.7	7716
Sky overcast or obscured (1)	36.1	36.0	35.4	36.8	34.2	25.5	30.9	28.8	27.9	26.1	34.7	33.9	32.2	7015
Thunder and lightning (1)	*	*	*	0.1	0.6	1.4	1.1	1.5	0.8	0.2	0.4	*	0.5	9190
Mean wind speed (knots)	15.1	15.3	13.7	12.5	10.2	9.8	9.3	9.2	10.9	12.1	14.5	15.4	12.2	16253
Prevailing wind direction	NW	NW	NW	W	SW	S	S	S	S	NW	W	WNW	W	16253
Mean temperature (°F)	37.9	35.9	41.1	47.4	55.5	65.0	72.0	72.2	67.1	58.8	50.7	41.2	54.5	16011
Mean sea-surface temperature (°F)	43.0	40.0	40.6	44.4	52.1	62.2	69.5	71.1	67.9	60.9	54.2	47.8	55.1	14690
Mean relative humidity (%)	77	74	76	78	82	84	80	79	75	74	73	76	77	7540
Mean cloud cover (eighths)	4.8	4.5	4.4	4.7	4.6	4.2	4.5	4.3	4.0	3.9	4.7	4.7	4.4	7015
Mean sea-level pressure (2)	1018	1018	1016	1014	1016	1015	1015	1016	1017	1018	1019	1020	1016	9274
Extreme max. sea-level pressure (2)	1042	1042	1041	1035	1032	1035	1031	1032	1037	1040	1041	1041	1042	9274
Extreme min. sea-level pressure (2)	978	971	983	985	995	992	994	977	992	995	989	983	971	9274

METEOROLOGICAL TABLE FOR COASTAL AREA OFF GULF OF MAINE

Boundaries: From 42°N., and 66°W., north and westward to coast

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	7.4	7.7	4.3	1.5	0.6	0.2	0.1	0.4	0.9	2.3	4.3	7.3	3.0	29579
Wind ≧ 41 knots (1)	1.8	2.7	0.7	0.4	*	*	*	0.1	0.2	0.7	1.6	2.3	0.8	29579
Wave height ≧ 12 feet (1)	8.0	9.1	2.4	1.0	0.1	0.2	*	0.1	0.5	3.1	4.2	8.2	2.9	7610
Wave height ≧ 20 feet (1)	0.7	0.4	*	0.5	*	*	*	*	*	*	*	1.1	0.2	7610
Visibility < 2 naut. mi. (1)	8.3	8.5	12.1	8.6	12.1	16.8	22.7	17.4	10.0	6.1	5.2	7.1	10.8	21849
Visibility < 0.5 naut. mi. (1)	3.2	3.1	1.9	4.2	8.1	10.4	15.5	11.9	6.0	4.0	2.0	3.6	6.3	21849
Precipitation (1)	21.7	23.7	15.3	11.7	9.8	8.0	4.7	6.9	7.2	7.0	13.2	22.1	12.3	26487
Temperature ≧ 85°F (1)	*	*	*	*	*	*	*	*	*	*	*	*	*	23161
Temperature ≦ 32°F (1)	40.9	45.8	22.3	2.9	*	*	*	*	*	0.1	1.7	26.7	10.7	23161
Sky overcast or obscured (1)	49.6	44.3	35.0	34.5	34.1	31.1	31.1	30.8	28.9	28.8	40.8	47.0	36.2	21780
Thunder and lightning (1)	*	0.1	*	0.1	0.1	0.4	0.5	0.5	0.3	0.1	*	*	0.2	26487
Mean wind speed (knots)	18.8	18.3	16.9	13.5	12.0	11.4	9.9	10.9	12.0	14.1	16.8	18.3	14.2	29579
Prevailing wind direction	NW	NW	WNW	W	SW	SSW	SW	SW	SW	SW	NW	W	SW	29579
Mean temperature (°F)	34.1	32.7	36.4	41.5	47.3	54.8	61.2	62.0	58.8	53.1	45.7	37.9	47.7	29546
Mean sea-surface temperature (°F)	40.4	37.9	37.6	39.5	44.0	50.1	56.7	58.6	57.1	53.4	48.6	44.1	47.8	26452
Mean relative humidity (%)	79	79	78	80	85	86	88	88	84	81	78	80	82	20134
Mean cloud cover (eighths)	6.0	5.6	4.7	4.5	4.7	4.6	4.7	4.4	4.0	4.2	5.3	5.9	4.9	21780
Mean sea-level pressure (2)	1014	1013	1013	1015	1015	1014	1015	1015	1018	1017	1016	1016	1015	27274
Extreme max. sea-level pressure (2)	1052	1042	1040	1042	1038	1033	1030	1037	1041	1039	1041	1045	1052	27274
Extreme min. sea-level pressure (2)	976	970	977	980	990	994	994	992	988	973	980	971	970	27274

METEOROLOGICAL TABLE FOR COASTAL AREA OFF NANTUCKET

Boundaries: Between 40°N., and 42°N., and 69°W., and 72°W.

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	4.9	5.9	4.5	1.9	0.6	0.2	0.1	0.3	1.3	2.5	3.5	5.0	2.4	43058
Wind ≧ 41 knots (1)	1.2	1.2	1.3	0.6	0.2	0.1	*	0.1	0.5	0.5	0.8	1.8	0.7	43058
Wave height ≧ 12 feet (1)	13.4	7.4	4.5	2.2	1.6	0.4	0.2	0.4	3.7	1.1	7.8	6.0	3.8	6149
Wave height ≧ 20 feet (1)	1.9	1.0	0.6	*	*	*	*	*	0.4	0.3	0.7	0.4	0.4	6149
Visibility < 2 naut. mi. (1)	4.6	4.7	5.2	10.4	15.4	17.7	16.1	9.9	6.3	3.5	3.3	4.0	8.5	27287
Visibility < 0.5 naut. mi. (1)	1.4	1.9	3.0	6.6	11.6	12.8	11.0	6.1	4.0	2.1	1.6	1.5	5.4	27287
Precipitation (1)	12.0	12.7	10.2	9.8	6.7	4.8	5.5	6.4	7.2	7.0	9.3	12.7	8.5	32071
Temperature ≧ 85°F (1)	*	*	*	*	*	0.1	0.4	0.2	0.1	*	*	*	0.1	28281
Temperature ≦ 32°F (1)	22.9	25.4	8.0	0.3	*	*	*	*	*	*	0.1	11.3	5.0	28281
Sky overcast or obscured (1)	44.3	39.7	36.2	41.1	37.3	31.7	35.1	29.0	29.9	26.9	37.4	42.9	35.8	26977
Thunder and lightning (1)	0.1	*	0.1	0.2	0.3	0.6	1.2	1.0	0.4	0.4	0.4	0.1	0.4	32071
Mean wind speed (knots)	16.9	17.0	15.7	13.3	10.8	10.1	9.4	10.3	11.6	13.7	15.5	17.1	13.2	43058
Prevailing wind direction	WNW	NW	W	W	SW	SW	SW	SW	SW	W	W	NW	W	43058
Mean temperature (°F)	38.5	37.3	40.3	45.7	52.2	61.1	68.2	69.5	65.1	58.3	51.0	42.6	53.2	42824
Mean sea-surface temperature (°F)	44.5	41.6	41.1	43.5	48.9	57.9	65.5	68.7	65.4	59.9	54.4	49.0	53.9	39367
Mean relative humidity (%)	80	79	79	82	83	85	86	84	82	78	79	77	81	25252
Mean cloud cover (eighths)	5.5	5.2	4.6	4.8	4.7	4.4	4.7	4.4	4.3	4.2	5.1	5.6	4.8	26977
Mean sea-level pressure (2)	1015	1015	1014	1015	1015	1015	1016	1016	1018	1017	1016	1017	1016	32762
Extreme max. sea-level pressure (2)	1042	1042	1040	1040	1035	1036	1035	1037	1037	1040	1041	1043	1043	32762
Extreme min. sea-level pressure (2)	976	976	967	977	977	995	996	968	973	978	974	983	967	32762

(1) Percentage frequency.

(2) Millibars.

*0.0-0.5%

These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

(3) Data from Coast Pilot #2 NOAA 1973.

3.2.10 REFERENCES

Anonymous (annual). Tidal Current Tables. Atlantic Coast of North America. U.S. Department of Commerce, NOAA, National Oceanographic Survey. U.S. Govt. Printing Office.

Bibliography of the New York Bight, Parts 1 & 2. Marine Ecosystems Analysis Program, U.S. Department of Commerce. NOAA. U.S. Govt. Printing Office, Washington, DC 1974.

Bigelow, H. B. 1924. Physical oceanography of the Gulf of Maine. Bull. Bur. Fish., 40:511-1027.

Bigelow, H. B. 1927. Physical oceanography of the Gulf of Maine. U. S. Dept. of Fish. and Wildlife, Fish. Bull. 40: 511-1027.

Bohlen, W. F. and J. M. Tramontano. 1974. Oceanographic factors relating to the disposal of dredged materials in Long Island Sound. Physical and chemical characteristics of the waters adjacent to the New Haven dredge spoils disposal site. Data Rept. U.S. Army C.O.E.

Bumpus, D. F. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Bd. Canada, 17:181-197.

__________. 1965a. Residual drift along the bottom on the continental shelf in the Middle Atlantic Bight area. Limnology and Ocean. Suppl. to vol. 10:R50-R53.

__________. 1965b. Serial atlas of the marine environment. Folio 7. Surface circulation on the continental shelf off Eastern North America between Newfoundland and Florida. Amer. Geographical Soc.

__________. 1969. Reversal in the surface drift in the Middle Atlantic Bight area. Deep Sea Research, 16:17-23 supplement.

__________. 1974. Review of the physical oceanography of Massachusetts Bay. W.H.O.I. publication (in press).

Bumpus, D. F. and L. M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Am. Geogr. Soc., Serial Atlas of the Marine Environment 7:4 pp. 8 pl. Appendix.

Bumpus, D. F., R. E. Lynde, and D. M. Shaw. 1973. Physical Oceanography. In Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals. Mar. Publ. Series No. 2. Univ. of Rhode Island.

Bumpus, D. F., J. H. Ryther, Richards, R. F. Vaccaro. 1964. Report on a survey of the hydrography of Great South Bay and Moriches Bay made June 1954 for the towns of Islep and Brookhaven, New York. W.H.O.I. Ref. 54-85.

Colton, John B., Jr., Robert R. Marak, Samuel Nickerson, and Ruth F. Stoddard. 1968. Physical, chemical, and biological observations on the continental shelf, Nova Scotia to Long Island, 1964-66. U.S. Fish. and Wildlf. Serv. Data Rept. 23. Microfische, 1 p.

Colton, John B. Jr. and Ruth R. Stoddard. 1972. Average monthly seawater temperatures, Nova Scotia to Long Island. 1940-1959. Amer. Geog. Soc., Folio 21, 2 p. Appendix, 10 Plates.

________. 1973. Bottom water temperatures on the continental shelf, Nova Scotia to New Jersey. U.S. Dept. Comm., NOAA Techn. Rep. NMFS, 376:55 p.

Day, C. G. 1958. Gulf of Maine circulation as deduced from drift bottles. Fish Bull., U.S., 58:443-472.

________. 1963. Oceanographic observations, east coast of the U.S. Fish Wildl. Serv. spec. sci. rept. fish. #406.

Deevey, G. 1952. Zooplankton of Block Island Sound, 1943-1946. Bull. Bing. Oceanogr. Coll. 13:65-119.

Emery, K. O. and Elazar Uchupi. 1972. Western North Atlantic Ocean: topography, rock structure, water life and sediments. Amer. Assoc. Petr. Geol., Memoir 17:532 p.

Gordon, R. B. and C. Pilbeam. 1973. Tides and circulation in central Long Island Sound. EOS Trans., Am. Geophysical Union, 54(4) p. 301.

Gross, M. G., J. A. Black, R. J. Kalin, J. R. Schramel and R. W. Smith. 1971. Survey of marine waste deposits, New York Metropolitan Region. Marine Sciences Res. Center. SUNY, Stonybrook.

Gross, M. G. and D. R. Bumpus. 1972. Residual drift of near-bottom waters in Long Island Sound, 1969. Limnol. and Oceanogr. 17:636-638.

Hollman, R. 1973. Some features of the circulation in the New York Bight. EOS, Trans., Am. Geophysical Union. 54(4) p. 302.

Huff, Lloyd C. 1969. CW phase measurements in Block Island Sound. US. TM No. 2213-279-69.

Hughes, D. A. 1969. Responses to salinity change as a tidal transport mechanism of pink shrimp, Penaeus duorarum. Biol. Bull. 136:43-53.

International Commission on North Atlantic Fisheries (ICNAF). 1927. Unpublished research documents 67-2 and 67-3.

Kangas, R. E. 1973. Light Vessel/Light Station oceanographic observations east coast of the United States, January-December 1971. Oceanographic Report No. CG 373-59.

Ketchum, B. H. and H. Corwin. 1964. The persistence of "winter" water on the continental shelf south of Long Island, New York. Limnol. and Oceanogr. 9:467-475.

McMaster, R. L. 1960. Sediments of Narragansett Bay system and Rhode Island Sound, Rhode Island, Jour. Sed. Petrology, v. 30:249-274.

National Ocean Survey. 1972. Tide tables, high and low water predictions, 1973. East Coast of North and South America. U.S. Dept. of Comm. NOAA. 288 p.

National Oceanic and Atmospheric Administration, National Ocean Survey. 1974. United States coast pilot 2, Atlantic Coast, Cape Cod to Sandy Hook. U. S. Dep. of Commerce, NOAA, NOS, Washington, D. C.

Oceanographic Atlas of the N. Atlantic Ocean. 1965. Section I. Tides and Currents. Pub. #700. U.S. Naval Oceangr. Office, Washington, DC.

Powers, C., J. Ayers. 1951. Drift bottle studies in the Newport Bight and New York Bight Areas. Cruise Stirni I, July-September 1951. Cornell Univ. Status Report No. 11, ONR.

Powers, C. F. and R. H. Backus. 1951. The distribution of temperature in New York Harbor and its approaches. Cornell Univ. Status Report #10, ONR.

Redfield, A. C. 1941. The effect of circulation of water on the distribution of the calanoid community of the Gulf of Maine. Biol. Bull. Woods Hole 80:86-110.

Redfield, A. C. 1952. Report to the towns of Brookhaven and Islip, New York of the hydrography of Great South Bay and Moriches Bay. W.H.O.I., Ref. 52-26.

Riley, G. A. 1948. Hydrography of Western Atlantic; Long Island Sound, and Block Island Sound. W.H.O.I. Tech. Rept. 11.

Ryther, J. H., R. F. Vaccaro, C. S. Yentsch, E. M. Hulbert. 1957. Report on a survey of the chemistry and hydrography of Great South Bay and Moriches Bay, June 1957 for the town of Islip, New York. W.H.O.I. Ref. 57-59.

Ryther, J. H., R. F. Vaccaro, E. M. Hulbert, C. S. Yentsch, and Guilford. 1958. Report on the chemistry, biology, and hydrography of Great South Bay and Moriches Bay for the towns of Islip and Brookhaven, New York. W.H.O.I., Ref. 58-57.

Shepard, F. P. 1963. Submarine geology. Harper & Row, New York.

Shonting, D. H. and G. S. Cook. 1970. On the seasonal distribution of temperature and salinity in Rhode Island Sound. Limnol. and Oceanogr. 15:100-112.

Soderberg, E. F. and A. B. Bruno. 1971. Salinity distribution in the Thames River; New London to Norwich, Conn. NUSC Rept. No. 4005.

Stockton, W. D. and R. H. Backus. 1951. Distribution of salinity in New York Harbor and its approaches. Cornell Univ. Status Report No. 12. ONR.

Sverdrup, H. U., M. W. Johnson, and R. A. Fleming. 1942. The oceans: their physics, chemistry, and general biology. Prentice-Hall, Inc., New York, New York. 1087 p.

Swanson, R. L. 1971. Some aspects of circulation in Long Island Sound. Ph.D. Thesis, Oregon State University.

United States Coast Pilot #2. 1973. Atlantic Coast Cape Cod to Sandy Hook. U.S. Dept. of Comm., NOAA, 276 p.

U.S. Department of Commerce. 1968. Tidal bench marks. Coast and Geodetic Survey.

__________. 1974. Environmental conditions within specified geographical regions. Offshore East and West Coasts of the United States and in the Gulf of Mexico. Final report. National Oceanographic Data Center, Environmental Data Center, National Oceanic and Atmospheric Administration.

Verwey, J. 1966. The role of some external factors in the vertical migration of marine animals. Neth J. Sea Res. 3:245-266.

Whitcomb, V. L. 1970. Oceanography of the Mid-Atlantic Bight in support of ICNAF. U.S.C.G. Oceanographic Report No. 35.

White, R. E. 1974. Eldridge Tide and Pilot Book. R. E. White, Publ. Boston, Mass.

Williams, J. 1962. Oceanography. Little, Brown & Co., Boston.

Chapter

3 Offshore Region

Page

Chapter 3.3 Chemical Oceanography

3.3 CHEMICAL OCEANOGRAPHY

3.3.1 GULF OF MAINE

The Gulf of Maine has been the location of nutrient-cycling research by scientists from Woods Hole Oceanographic Institution and other laboratories for a number of years. Studies on nitrate, nitrite, phosphate,and dissolved oxygen were first carried on by Rakestraw (1933). More detailed work on the nutrients, including ammonia and silicate, was continued by Gran and Braarud (1935), Redfield, Smith and Ketchum (1937), Redfield and Keys (1938), Ketchum and Corwin (1965), Ketchum (1967, 1968), Colton, Marak, Nickerson,and Stoddard (1968), Apollonio and Applin (1972), Gran (1933), and others.

The distribution of dissolved oxygen in the Gulf of Maine area follows a pattern similar to most east-coast areas in temperate latitudes. During April, Ketchum and Corwin (1965) ran a series of stations in the Wilkinson Basin. They followed a plankton bloom and found supersaturation of dissolved oxygen (123 to 132 percent) down to nearly 50 m depth.

Because of the phytoplankton bloom during early summer the surface waters were generally supersaturated with oxygen to an average depth of 25 m. The deeper water was undersaturated with oxygen and contained about the same amount of oxygen as waters flowing into the Gulf of Maine along the eastern margin (Gran and Braarud, 1935). During the summer months in the deeper waters the oxygen content appears to decrease steadily. During August the surface water to a depth of 20 to 40 m was slightly supersaturated with oxygen (100 to 113 percent), at 9 stations located in the Gulf of Maine and on Georges Bank (Rakestraw, 1932). The maximum level was associated with the greatest abundance of diatoms. Below this supersaturated zone, which corresponded essentially to the mixed layer, the saturation of oxygen decreased to the bottom even though the actual oxygen concentration increased.

A more detailed survey of dissolved oxygen and hydrographic parameters in the Gulf of Maine and Georges Banks area was made by Colton et al (1968) in the months of March, May to June, September, and December. Figure 3-187 shows the location of all their stations. The distribution of dissolved oxygen for transects C E and G is shown in Figures 3-188 to 3-191. For each transect two years of data are shown. Differences between years should be noted even though samples were taken at nearly the same time each month.

Phosphorus cycling has been studied in detail in the Gulf of Maine by Redfield et al. (1937) and Ketchum and Corwin (1965). In both those studies the inorganic, the particulate, and the dissolved

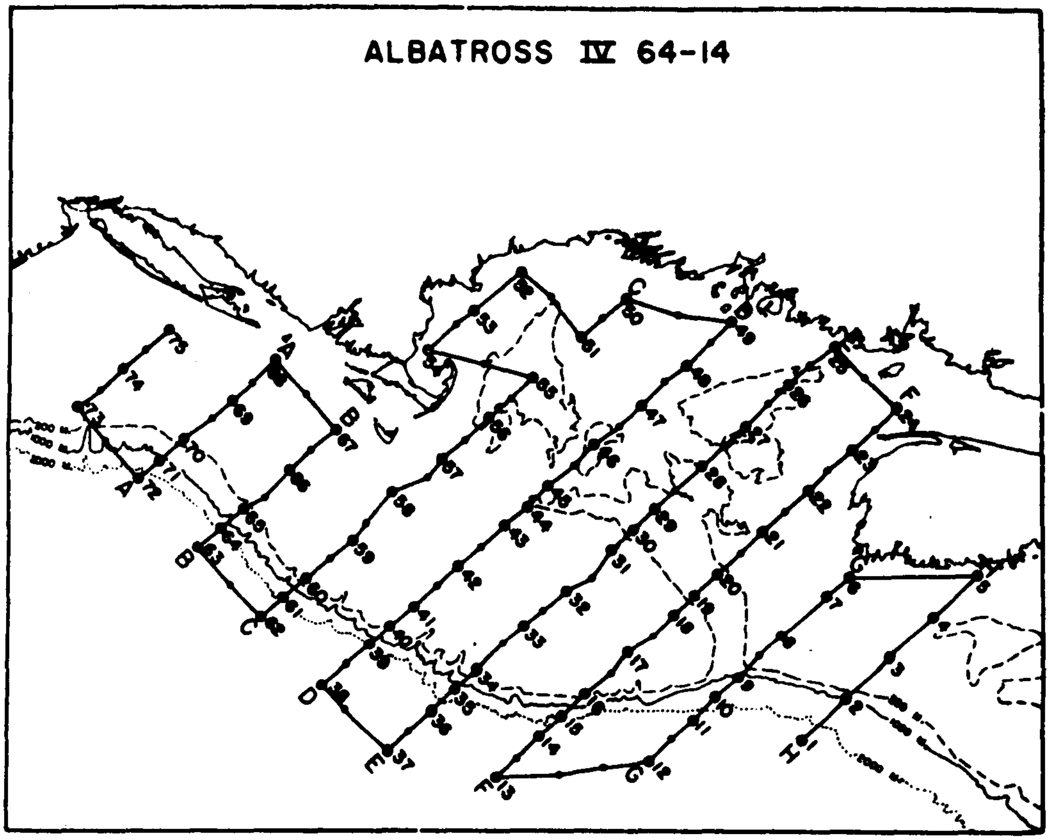
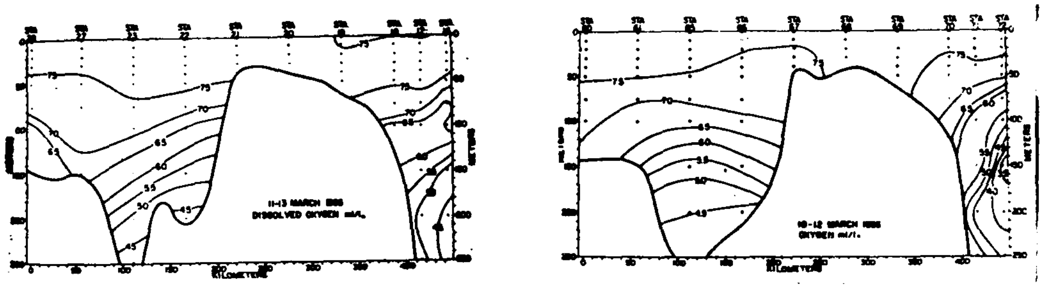
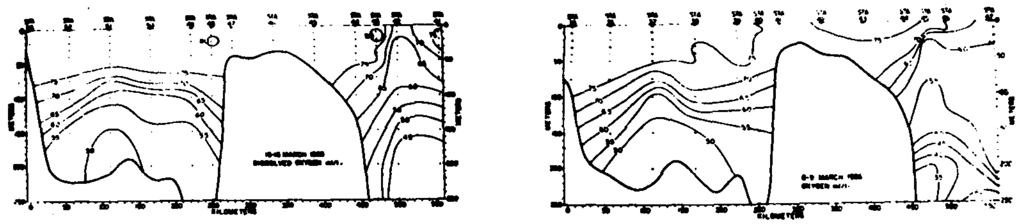


FIGURE 3-187

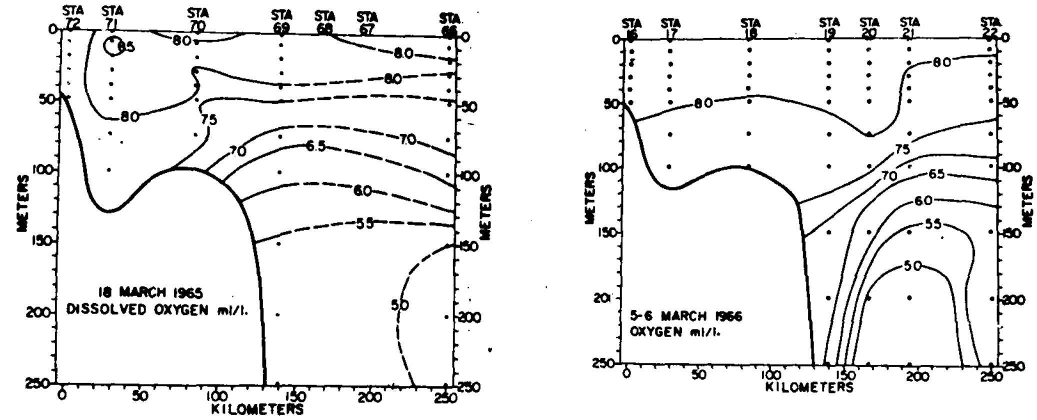
Approximate Location of Stations Used By Albatross IV (Colton et al., 1968)



Transect C



Transect E



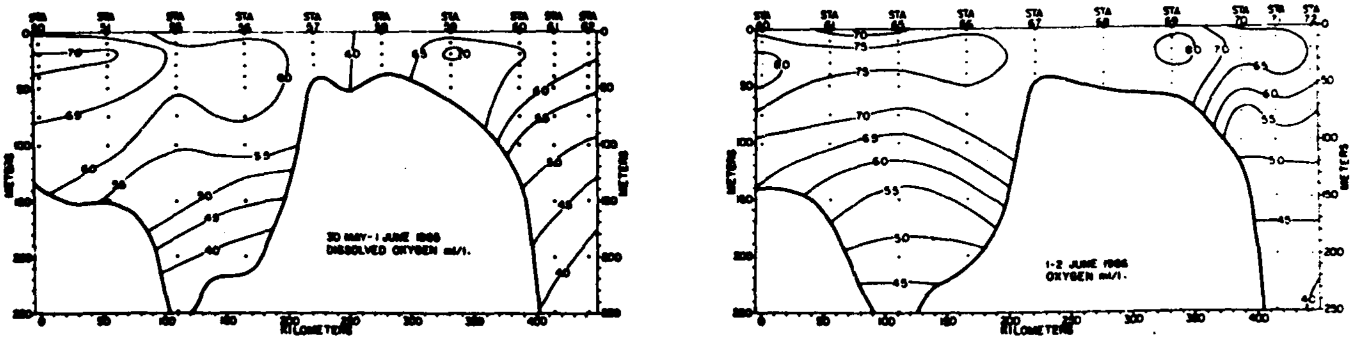
Transect G

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

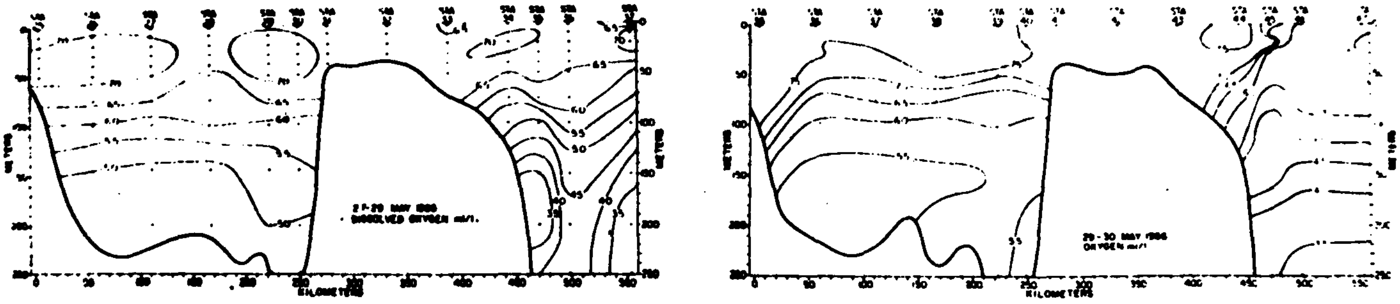
TRIGOM PARC

FIGURE 3-188

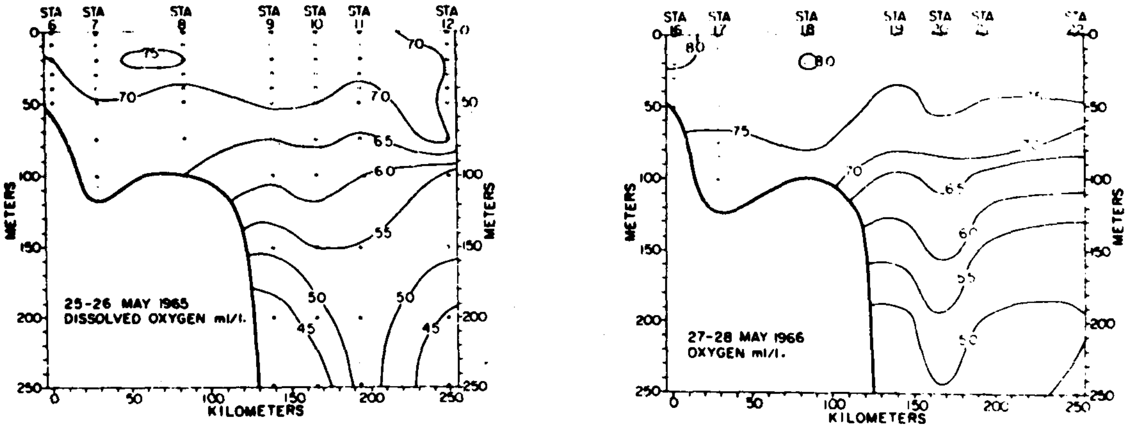
Dissolved Oxygen Concentration for Albatross IV - Transects C.E.G. March 1965-1966 (Colton et al., 1968)



Transect C



Transect E



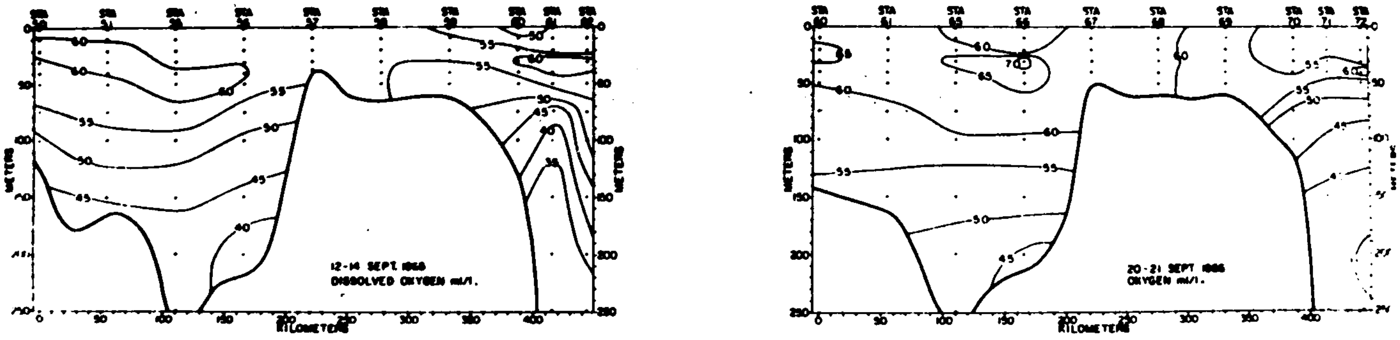
Transect G

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

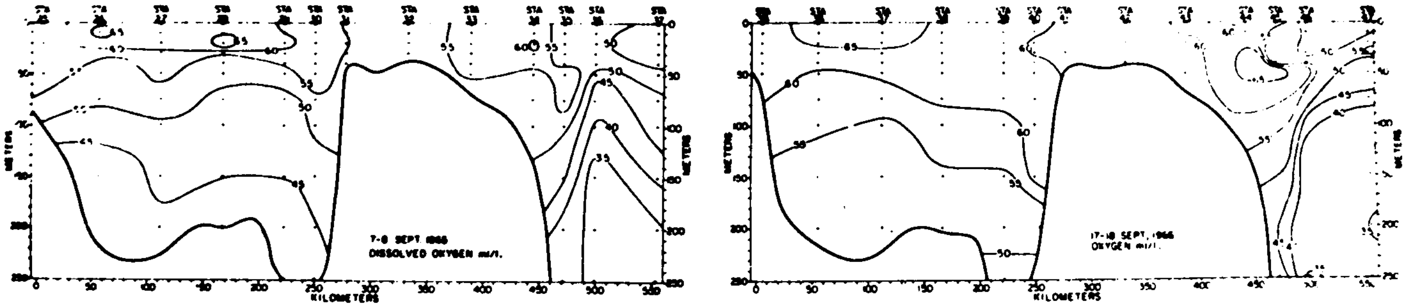
TRIGOM PARC

FIGURE 3-189

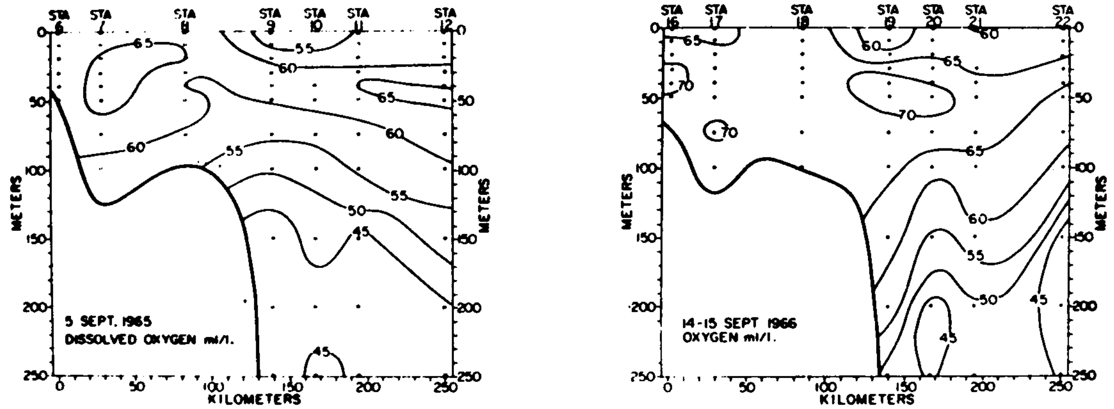
Dissolved Oxygen Concentration for Albatross IV - Transect C.E.G. May 1965-1966 (Colton et al., 1968)



Transect C



Transect E



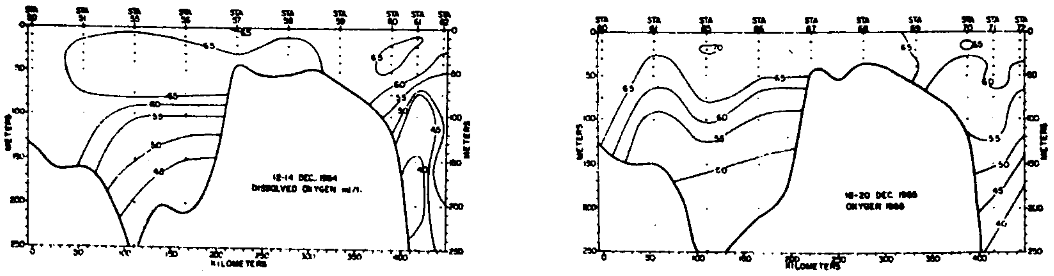
Transect G

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

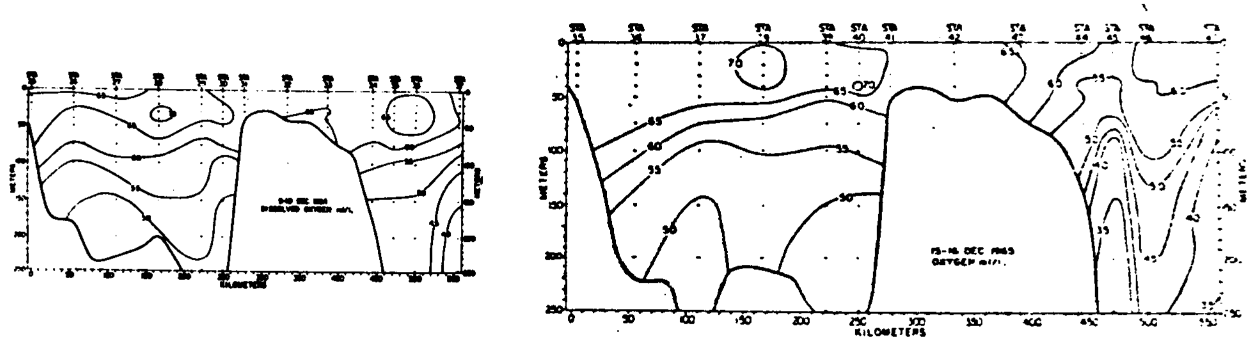
TRIGOM PARC

FIGURE 3-190

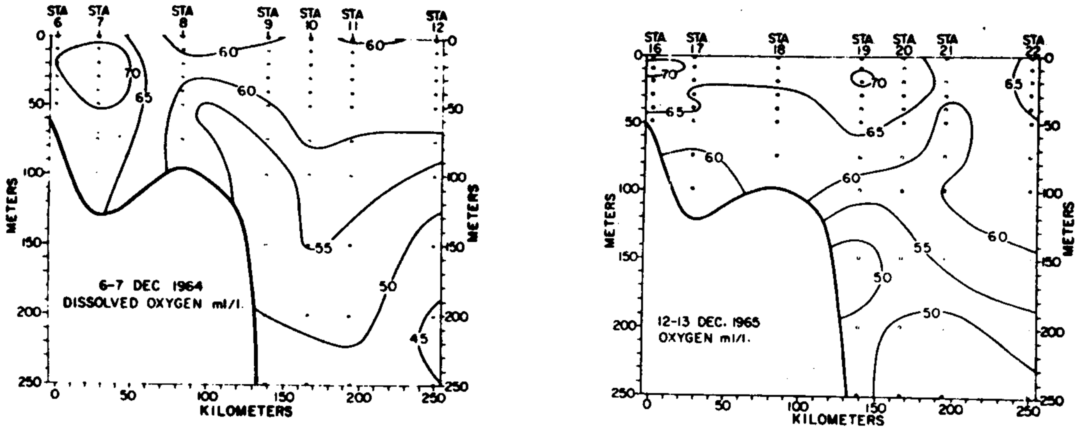
Dissolved Oxygen Concentration for Albatross IV - Transect C.E.G. September 1965-1966 (Colton et al.1968)



Transect C



Transect E



Transect G

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-191	Dissolved Oxygen Concentration for Albatross IV - Transect C.E.G. December 1964-1965 (Colton et al. 1968)

organic phosphorus were measured in order to understand changes in the various fractions during different seasons. The surface concentration of inorganic phosphate during May (1934) was considerably lower than the deeper water (Redfield et al, 1937) (Table 3-11).

Table 3-11 Average concentrations of inorganic phosphate during May (Redfield et al, 1937).

Depth	# of Samples Averaged	Average Inorganic Phosphate (μg-at PO_4-P/l)
Surface	21	0.44
60 m	21	0.91
120 m	14	1.2
180 m	11	1.3

The values at the surface were higher near the mouth of the Bay of Fundy and on Georges Bank and lowest in the western central Gulf of Maine. The reverse was true at 60 m; at 120 and 180 m the distribution was consistent.

Rakestraw analyzed phosphates during August, 1932, for five stations in the Gulf of Maine and four on Georges Bank. He found low values (several tenths of a μg-at PO_4-P/l) throughout both areas, but nowhere did phosphate reach zero.

The relative amounts of inorganic phosphorus, particulate organic phosphorus, and dissolved phosphorus have been studied in the Gulf of Maine by Redfield et al (1937), Ketchum and Corwin (1965) and Ketchum (1968) in order to better understand phosphate-uptake and cycling. All authors worked in the western Gulf of Maine about 50 to 80 km east of Cape Ann.

The data of Redfield et al (1937) are summarized in Table 3-12 and show the relative amounts of each component at different times during the year. Inorganic phosphorus reaches a maximum at the surface during February and a minimum during late summer. It remains relatively high during the year in the water column between 30 to 60 m and below

Table 3-12 Average Amounts of Inorganic Phosphorus, Particulate Organic Phosphorus, and Dissolved Organic Phosphorus for a Station located in the Gulf of Maine at about 42 20'N. 69 33'W (Redfield *et al*, 1937).

Depth (m)	Fraction	May 18 1935	Aug 21 1935	Nov 8-9 1935	Feb 26 1936	May 14 1936
1-20 (3 samples)	Inorg. P	0.34	0.27	0.39	1.1	0.14
	P. Org. P	0.19	0.15	0.13	0.05	0.18
	D. Org. P	0.15	0.47	0.30	0.07	0.16
30-60 (3 or 4 samples)	Inorg. P	0.79	0.99	0.88	1.0	1.0
	P. Org. P	0.13	0.07	0.07	0.04	0.07
	D. Org. P	0.02	0.26	0.24	0.04	0.13
80-250 (7 or 8 samples)	Inorg. P.	1.4	1.3	1.2	1.2	1.5
	P. Org. P	0.05	0.04	0.06	0.04	0.05
	D. Org. P	-0.01	0.21	0.34	0.09	0.17

80 m is essentially unchanged. Particulate organic phosphorus was highest during the spring and dropped off to a low during February for depths 0 to 60 m. No seasonal effect was noted below 80 m. Dissolved organic phosphorus reached a peak during late summer and fall at all depths.

Ketchum (1968) reported data collected during both the fall (1966) and the spring (1967) just before the bloom. At both times they found about 0.6 to 0.7 μg-at PO_4-P/l in surface waters increasing to over 1.0 μg-at PO_4-P/l below 150 m. They also related dissolved and particulate organic carbon, and chlorophyll to the phosphorus. They found that a large amount of the organic matter produced during the winter months accumulates as dissolved organic material because of a low turnover rate during the winter.

The distribution of nitrogen nutrients in the Gulf of Maine has been described by Rakestraw (1933, 1936), Redfield and Keys (1938). Nitrate values for August were reported by Rakestraw (1933) who found that surface values were low (several μg-at NO_3-N/l) but nowhere did he report zero nitrate values. He did find zero nitrite values at five of the nine stations sampled during August. Redfield and Keys (1938) measured ammonia during both May and September and found that ammonia occurred at minimal concentrations at the surface and at depths below 60 m. In May the maximum concentration was about 3 μg-at NH_3-N/l between depths of 30 and 60 m. In September ammonia values were lower and were rather uniform at all depths.

Dissolved organic carbon was found to be high at the surface (80 to 120 μg-at/l) and then uniform from 50 m depth to the bottom (50 to 70 μg-at/l) for three different diurnal stations off Cape Ann during September and April (Ketchum, 1967). No significant differences among the three observations at different times were apparent. The ratio of dissolved organic carbon to dissolved organic phosphorus was found nearly uniform in depth (275 to almost 600 m). This indicates a more rapid release of phosphorus from dissolved organic matter than particulate organic matter. The upper 20 m had an average C/P ratio of 112. The ratio increased to a maximum of 325 at 100 m and then slightly decreased with depth (Ketchum, 1967). Chlorophyll was found to be decomposed more rapidly than either phosphorus or carbon from the particulate matter (Ketchum, 1967).

Studies of suspended matter in the Gulf of Maine and adjacent waters can be divided into three types: (1) studies of total suspended matter concentrations by weight using a filtration method or by volume using the Coulter counter; (2) studies of particulate organic matter determined from particulate organic carbon (POC) or particulate phosphorus analyses; and (3) studies of water turbidity using a Secchi disk, beam transmissometer, or a photometer.

Spencer and Sachs (1970) and Ketchum (1967, 1968) studied the suspended matter in the central portions of the Gulf of Maine and Georges Bank during three cruises in September 1966, March to April 1967, and October 1967 (Fig. 3-192). The cruises in September and October were conducted when the water column was stratified whereas the March to April cruise was during isothermal conditions. The objective of this work was to determine the composition and origin of the suspended matter.

The approximate amount (3.7×10^{10}kg) of inorganic suspended matter was computed for the Gulf of Maine (Spencer and Sachs, 1970). This amount is an order of magnitude greater than the annual contribution of the North Atlantic coastal-plain rivers (Livingstone, 1965).

The surface distribution of suspended material showed a seasonal change in composition. An increase in particulate aluminum during the winter was caused by a decrease in the phytoplankton population in addition to the mixing of near-bottom resuspended sediment to the surface (Spencer and Sachs, 1970).

In general suspended matter decreased from the surface to about 50 m (the seasonal thermocline) then increased exponentially to the bottom. The source of suspended material was primarily biological productivity in the surface water and silicates at depth (Fig. 3-193). The causes for the resuspension of bottom sediments are probably storm activity (Armstrong, 1958), bottom currents (Ewing and Thorndike, 1965; Spencer and Sachs, 1970) and/or bottom organisms which rework the bottom muds (Rhodes, 1963). Average concentrations, as well as the percent of inorganic material for the Gulf of Maine proper, are summarized in Table 3-13.

The effects of trace metals, which may be toxic to the marine communities, is difficult to forecast because of the complex interaction of these elements with the biological behavior of plants and animals (Dow, 1969).

Trace-metal distribution for the Gulf of Maine is limited. The chemical composition of suspended matter for the central Gulf of Maine has been summerized in Ketchum (1967, 1968) and discussed by Spencer and Brewer (1968) and Spencer and Sachs (1970). Dissolved trace metals in the coastal waters off New Hampshire from November, 1972 to May, 1973 were studied by Kostyla (1973). Few studies of estuarine waters for trace metals have been conducted.

Spencer and Sachs (1970) analyzed particulate samples for iron, manganese, copper, zinc, nickel, and aluminum (Table 3-14). They found that the distribution of trace metals associated with the suspended matter varied significantly between the surface particu-

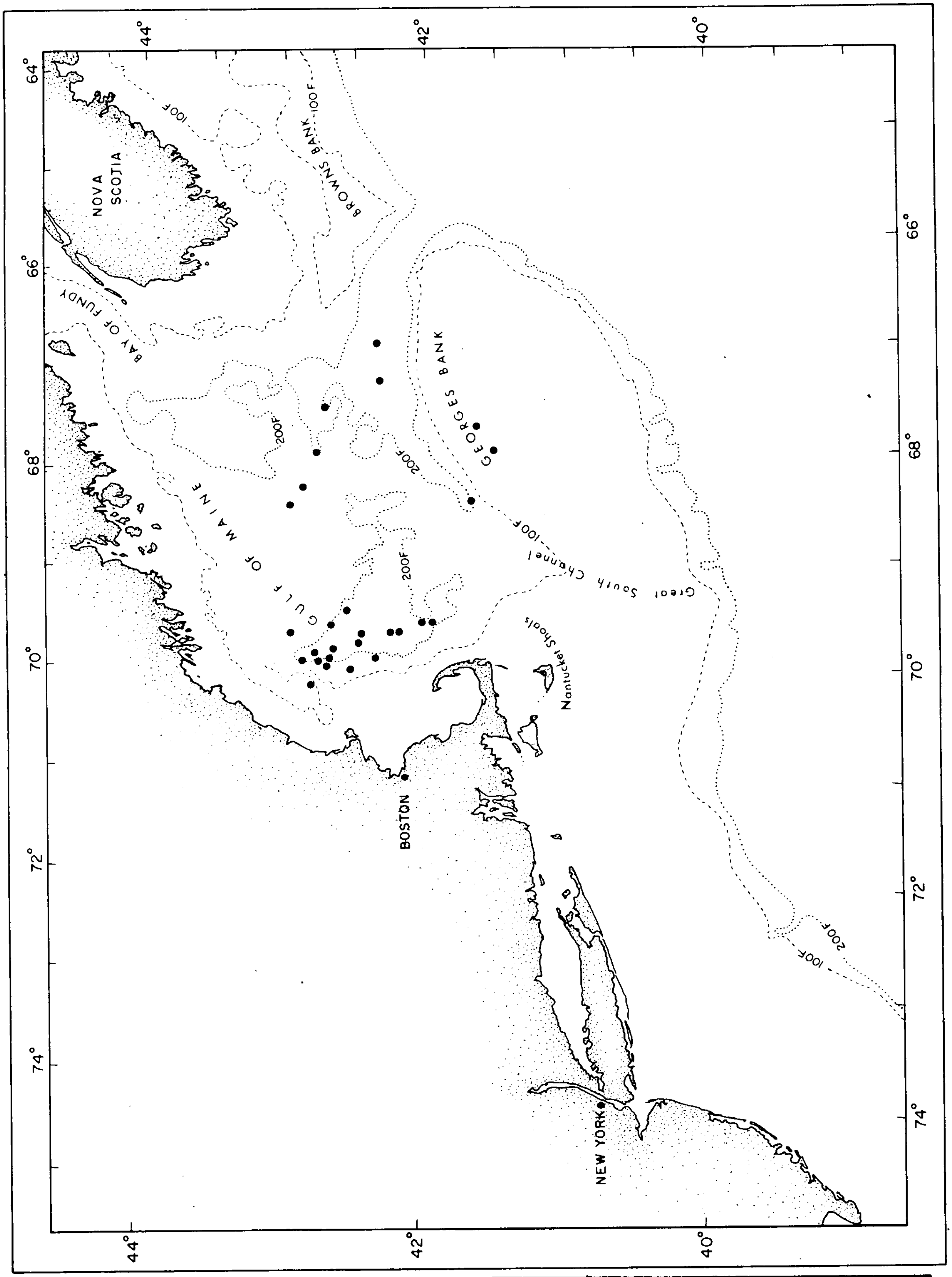
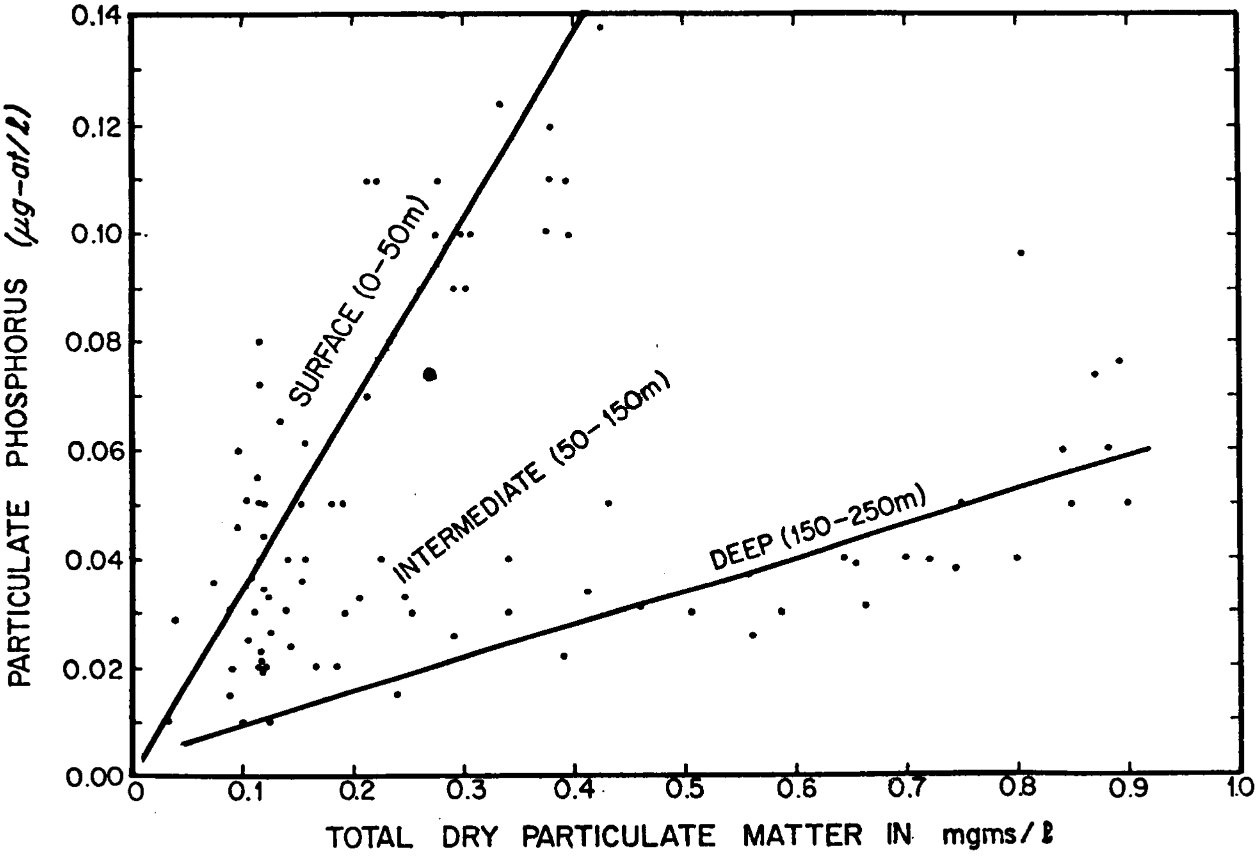


FIGURE 3-192

Station Locations for Data Used by Spencer and Sachs (1970) (Spencer and Sachs)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-193

Covariation of Particulate Phosphorus and Total Particulate Matter (Spencer and Sachs, 1970)

Table 3-13a Average Concentrations of Suspended Matter in Gulf of Maine (in mg/kg of sea water) (Spencer and Sachs, 1970).

	September 1966	March 1967	October 1967	
			(47 mm)	(142 mm)
Surface (0-25 m)	0.30	0.13	0.31	0.35
Intermediate (25-150 m)	0.14	0.17	0.17	
Deep (150 m-bottom)	0.88	0.56	0.72	1.40

Table 3-13b Average Concentrations of Filter Ash (500°C), As Percent of Total Suspended Matter (Spencer and Sachs, 1970).

	September 1966	March 1967	October 1967
Surface (0-25 m)	38	75	25
Intermediate (25-150 m)	90	90	68
Deep (150 m-bottom)	91	96	87

Table 3-14 Average Concentrations of Trace Metals in the Gulf of Maine (calculated from data in Ketchum, 1967 and Spencer and Sachs, 1970).

	Surface (5m)	Deep (163-236m)
Iron	0.8* (0.27)**	100.2 (6.04)
Manganese	0.19 (0.054)	5.3 (0.36)
Copper	0.17 (0.048)	0.15 (0.010)
Aluminum	0.77 (0.22)	166. (9.63)
Zinc	0.14 (0.036)	0.27 (0.017)
Nickel	n.d.	0.073(0.0041)

n.d. - not detectable
*Concentration (ppb)
**Percent of PM by wgt.

lates and the intermediate and deep particulates. Particulate phosphorus, copper, and zinc are generally concentrated by growing phytoplankton and are therefore higher in the surface waters. The suspended matter in the deep waters near the bottom is primarily resuspended bottom sediments. This is reflected in the distributions of particulate aluminum and iron which are controlled by the suspended silicates (Spencer and Sachs, 1970). From their data they find little evidence that the particulate phosphorus, copper and zinc concentrated by organisms are reaching the bottom in an organic-particulate form, and most appear to be regenerated in the water column (Spencer and Sachs, 1970).

Trace metals in either particulate or dissolved states are also introduced to the Gulf of Maine from terrestial runoff. Spencer and Brewer (1968) found an increase in dissolved copper and zinc during the summer months at nearshore stations. They attributed this increase to lack of vertical mixing because of a stable water column and the influence of runoff. They observed that the concentrations in the surface water were too high to be accounted for through concentration by phytoplankton. Surface concentrations of copper and zinc are about 10 times higher than those reported by Thompson, Bowen, Curl, and Nicholls (1967) who analyzed phytoplankton from various Atlantic Ocean locations.

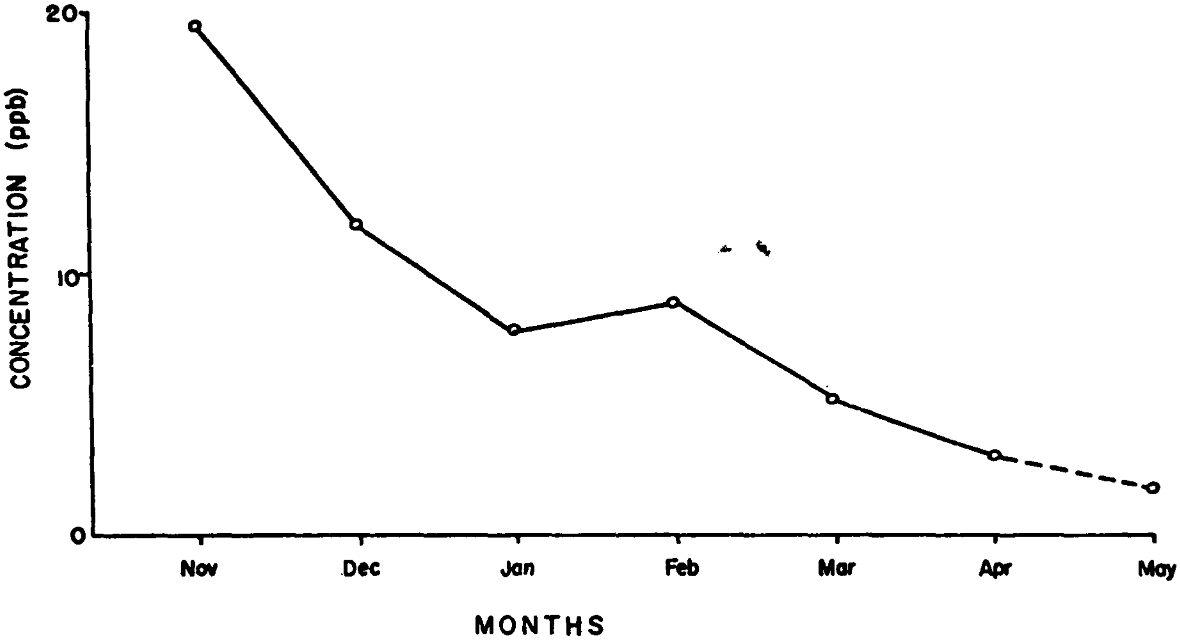
Kostyla (1973) studied the monthly variation in dissolved concentrations of copper, cadmium, zinc, and lead off the New Hampshire coast at the surface, 20 m depth and 5 m off the bottom (Fig. 3-194). Maximum concentrations were observed in November, 1972 with a secondary mode in February 1973. The monthly variations observed in these dissolved trace metals are probably due to (1) the utilization by phytoplankton; (2) absorption on clay particles; (3) input from runoff and (4) distribution of water masses. Of interest is that cadmium tends to follow different trends than the other metals studied (Fig. 3-194). Fitzgerald, Hunt, Lyons and Szechtman (1973) and Preston, Jefferies, Dutton, Harvey and Steele (1972) feel that the trends for cadmium may differ from those of zinc, copper and lead as it does not readily absorb on fine-grained sediment.

3.3.2. GEORGES BANK

Georges Bank lies on the eastern edge of the Gulf of Maine roughly within Lat. 40^o and $42^o10'$ N and Long. 66^o and 69^o W. It has a length of about 260 km and a breadth of about 150 km from north to south between the 90 m contours (Riley, 1941b). Its area is approximately 3.4×10^4 sq. km. Average depths in the southern and eastern parts are about 55 to 73 m; many parts of the northwestern third are shallower than 37 m with several shoal areas 4.5 to 18 m deep. Most of the following data on oxygen and nutrients come from papers by Riley (1941b and 1946) who reported data on nitrate, nitrite, phosphate, and oxygen for several samples taken on Georges Bank in August.

Currents on the Bank take the general form of clockwise eddies with one around the shallowest part of the bank and another around the outside edge (Bumpus and Lauzier, 1965). As a result of these clockwise eddies, water may stay one to several months on the bank and be relatively isolated during that time from surrounding bodies of water. Occasionally water flows across the bank from northwest to southeast during the winter or spring (Bigelow, 1927; Walford, 1938).

Dissolved oxygen concentrations follow the expected seasonal trends. Actual concentrations were measured by Colton et al (1968) and some data are reported herein (Figs. 3-188 to 3-191). The percent saturation of oxygen is greater than 100 percent for surface waters to a depth of 30 to 50 m in late spring and summer as a result of phytoplankton activity. There are some horizontal variations in oxygen distributions with the largest supersaturation occurring between the 55 and 90 m contours and the smallest in shallower water. The highest oxygen saturation values were found during April. The production of oxygen was related to solar radiation, plant pigments, and other biological substances; all showed a distinct gradient between shallow and deep water (Riley, 1941b). During the rest of the year, depending on the location and season, the surface waters have oxygen saturation values of 90 to 100 percent whereas deeper water (100 to 200 m) had values of 56 to 94 percent.


AVERAGE TOTAL METAL CONCENTRATIONS

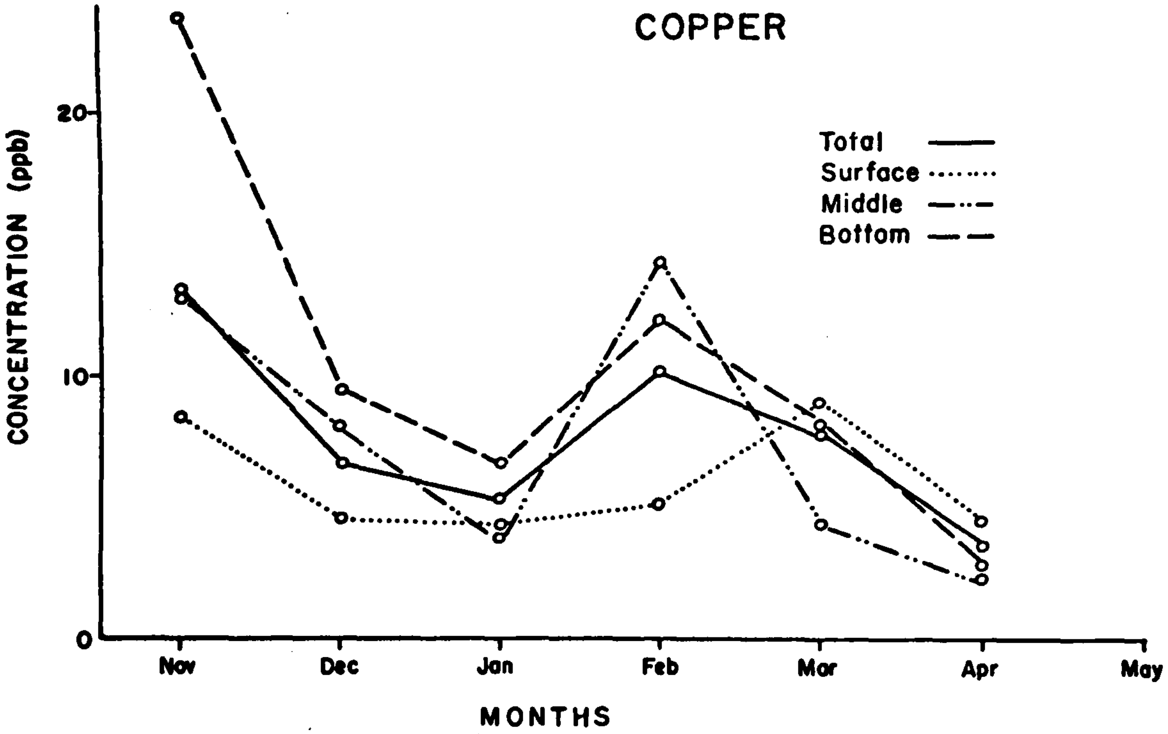
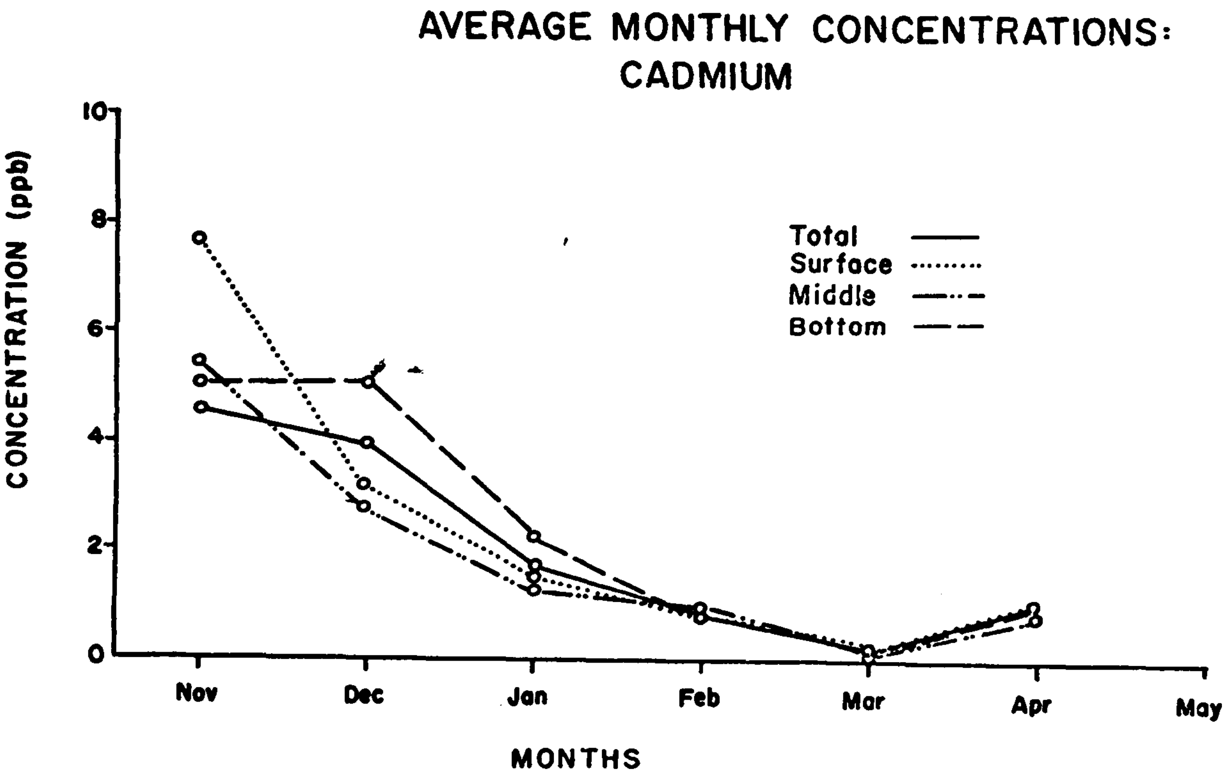
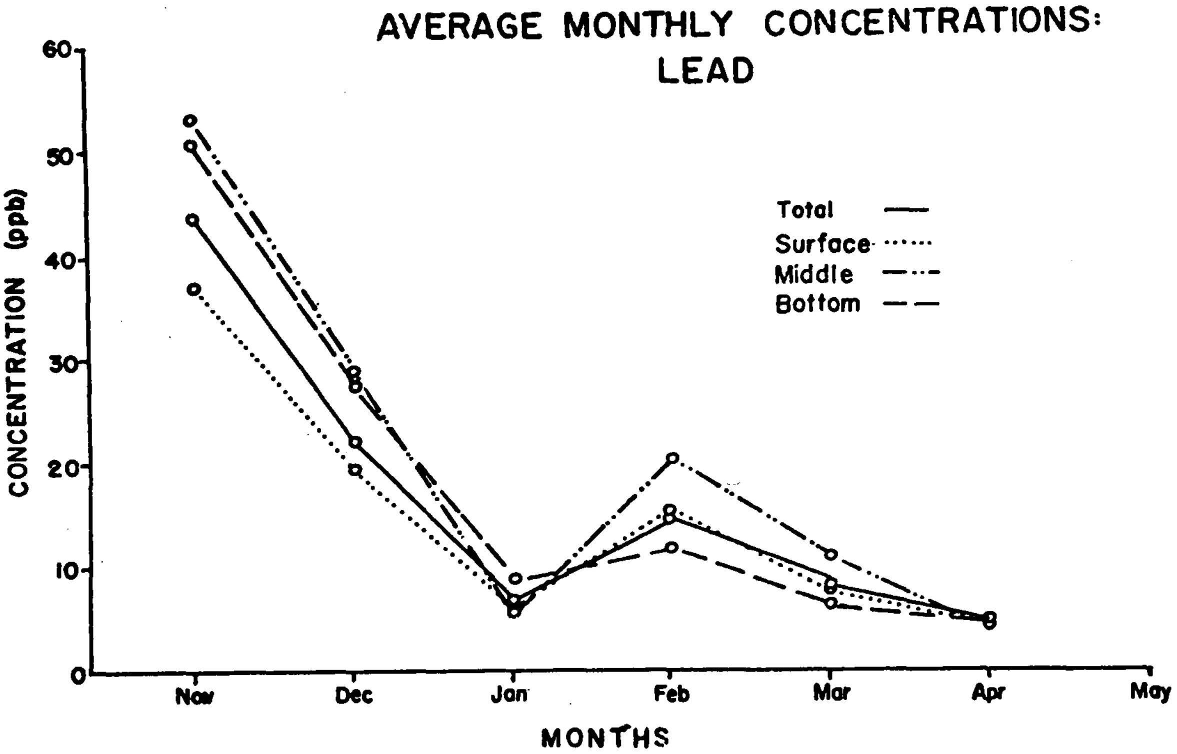

AVERAGE MONTHLY CONCENTRATIONS: COPPER

FIGURE 3-194a Averaqe Monthly Concentrations - Dissolved Metals (Kostyla, 1973)





A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-194b

Average Monthly Concentrations - Dissolved Metals (Kostyla, 1973)

Riley (1941b) found the total range of surface phosphate concentrations were 0.03 to 1.04 µg-at PO_4-P/l and nitrate was 0.7 to 9.7 µg-at NO_3-N/l. Redfield and Keys (1938) reported ammonia data for the Gulf of Maine and 2 stations on Georges Bank during September 1933 and May and June, 1934. They found between near-zero values up to a little over 1 µg-at NH_3-N/l and no definite differences in the seasonal picture. Higher concentrations were found in the North Channel all the way to the bottom.

The highest concentrations of the nitrate and phosphate nutrients were found in the shallow water (Riley, 1941b). An important finding was that no sample analyzed showed complete removal of either nitrate or phosphate, unlike some areas in the Gulf of Maine where one nutrient often becomes limiting to phytoplankton growth.

The N/P ratio was found to be substantially lower than typical oceanic waters (where values of about 15:1 are reported). Riley (1941b) found much lower ratios in the surface waters of Georges Bank, ranging from 4:1 in April to 11:1 in September. These low N/P ratios are characteristic of shallow regions where there is a rapid return to the water column of nutrients regenerated on the bottom. Phosphate is more rapidly regenerated and thus lowers the ratio (Riley, 1941a). Rakestraw (1932) reported very high nitrate values in water associated with bottom sediments and concluded the sediments on the Bank were the site of active nitrification. He did not report phosphate values in the sediments. This regeneration of nutrients coupled with periodic water movements across the Bank during all seasons allows for adequate nutrient supply to support the large plankton population, which in turn makes the Bank such a productive fishing area.

Data on suspended matter in water over Georges Bank are limited. Spencer and Sachs (1970) reported an average suspended matter value of about 0.56 mg/kg of seawater for three samples (25 m depth) in mid-September. This value is about twice the average value for the Gulf of Maine samples (see Table 3-13a) taken at the same time. Riley (1941b) reported Secchi-disk depths with the greatest depths during January (ave. 12.4 m) and shallowest in April (ave. 5.1 m) during the maximum bloom period.

Although chlorinated hydrocarbon (PCB and DDT) data were not available for water on Georges Bank, Harvey, Miklas, Bowen, and Steinhauer (1973) found that the average concentration was about an order of magnitude greater for Georges Bank fish than for similar species from the Icelandic fishing grounds.

3.3.3 REFERENCES

Apollonio, S., and H.H. Applin, Jr. 1972. An atlas of the distributions of inorganic nutrients in coastal waters of the western Gulf of Maine. Dept. of Sea and Shore Fisheries, Fisheries Research Station, West Boothbay Harbor, Maine. 130 p.

Armstrong, F.A.J. 1958. Inorganic suspended matter in sea water. Jour. Mar. Res. 17:23-24.

Bigelow, H.B. 1927. Physical oceanography of the Gulf of Maine. U.S. Bur. Fish. Bull. 40:511-1027.

Bumpus, D.F., and L.M. Lauzier. 1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Serial Atlas of the Marine Environment, Folio 7, American Geographical Society, New York.

Colton, J.B. Jr., R.R. Marak, S. Nickerson, and R.E. Stoddard. 1968. Physical, chemical, and biological observations on the continental shelf, Nova Scotia to Long Island, 1964-66. Bureau of Commercial Fisheries, Woods Hole, Mass., U.S.F. and W.S. Data Report No. 23.

Dow, R.L. 1969. Toxic metals in the marine environment. First Maine Environmental Congress, March 1969. 5 p.

Ewing, M., and E.M. Thorndike. 1965. Suspended matter in deep ocean water. Science, 147:1291-1294.

Fitzgerald, W.F., D.C. Hunt, W.B. Lyons, and R.J. Szechtman. 1973. Budgets of heavy metal wastes in eastern Long Island Sound: Chemical investigations. In A determination of heavy metal wastes in Long Island Sound. First Annual Sea Grant Report, University of Connecticut.

Gran, H.H. 1933. Studies on the biology and chemistry of the Gulf of Maine, II: Distribution of phytoplankton in August 1932. Biol. Bull. 64:159-181.

Gran, H.H., and T. Braarud. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry, and turbidity). Jour. Biol. Board Canada 1:279-467.

Harvey, G.R., H.P. Miklas, V.T. Bowen, and W.G. Steinhauer. 1973 . Observations on the distribution of chlorinated hydrocarbons in Atlantic Ocean organisms (Georges Bank). Jour. Mar. Res. (in press).

Ketchum, B.H. 1967. Biological, chemical and radiochemical studies of marine plankton. WHOI Tech. Rept. 67-27. 119 p.

____________. 1968. The phosphorus cycle and productivity of marine phytoplankton. WHOI Contr. No. 2146.

Ketchum, B.H., and N. Corwin. 1965. The cycle of phosphorus in a plankton bloom in the Gulf of Maine. Limnol. Oceanogr. 10 (Supplement): R148-R161.

Kostyla, R.J. 1973. Seasonal variations of several trace metals in the Gulf of Maine as determined by atomic absorption spectrophotometry (Bachelors thesis). University of New Hampshire.

Livingstone, R. 1965. Preliminary bibliography with KWIC index on the ecology of estuaries and coastal areas of eastern U.S. Spec. Sci. Rept., Fisheries No. 507, U.S. Fish and Wildlife Service.

Preston, A., D.F. Jefferies, J.W.R. Dutton, B.R. Harvey, and A.K. Steele. 1972. British Isles coastal waters: The concentrations of selected heavy metals in sea water, suspended matter and biological indicators. A pilot study, IDOE Baseline Study, Brookhauer National Laboratory, Brookhauer, N.Y., May 1972.

Rakestraw, N.W. 1932. Phosphorus and nitrogen in the neritic waters of the Gulf of Maine. Int. Rev. Hydrobiol. 27(1):151-160.

____________. 1933. Studies of the biology and chemistry of the Gulf of Maine. <u>In</u> Chemistry of the waters of the Gulf of Maine in August, 1932. Biol. Bull. 64:149-158.

____________. 1936. The occurrence and significance of NO_3 in the sea. Biol. Bull. 71:133-167.

Redfield, A.C., and A.B. Keys. 1938. The distribution of ammonia in the waters of the Gulf of Maine. Biol. Bull. 74(1):83-92.

Redfield, A.C., H.P. Smith, and B.H. Ketchum. 1937. The cycle of organic phosphorus in the Gulf of Maine. Biol. Bull. 73:421-441.

Rhodes, D.C. 1963. Rates of sediment reworking by Yoldia limatula in Buzzards Bay, Mass., and Long Island Sound. Jour. Sedim. Petrol. 33:723-727.

Riley, G.A. 1941a. Plankton studies III, Long Island Sound. Bull. Bingham Oceanogr. Coll. 7(4):1-93.

__________________. Plankton studies IV, Georges Bank. Bull. Bingham Oceanogr. Coll. 7(4):1-73.

__________________. Factors controlling phytoplankton populations on Georges Bank. Jour. Mar. Res. 6:5473.

Spencer, D.W., and P.L. Sachs. 1970. Some aspects of the distribution, chemistry, and mineralogy of suspended matter in the Gulf of Maine. Mar. Geol. 9:117-136.

Spencer, D.W., and P.G. Brewer. 1968. The distribution of copper, zinc, and nickel in sea water of the Gulf of Maine and the Sargasso Sea. Geochem. Cosmochim. Acta 33(3):325-339.

Thompson, G., V.T. Bowen, H. Curl, and G.D. Nicholls. 1967. Elemental composition of marine phytoplankton species. WHOI NYO-2174-60, 24 p.

Walford, L.A. 1938. Effect of currents on distribution and survival of the eggs and larvae of the haddock (Melanogramunus aeglefinis) on Georges Bank. Bull. Bur. Fish. 49(29):1-73.

Chapter
3 Offshore Region

3.4 THE OFFSHORE WEATHER AND CLIMATE

Table 3-15 provides general climatic data for the three sea areas delineated in Figure 3-195. Data for these sea areas have been summarized by the U.S. Naval Weather Service Command (1970). Also summaries by NOAA appear on Table 3-16. These compilations contain data accumulated over about one hundred years, but about 80 percent of these observations were taken during the years 1950 through 1968. The U.S. Naval Weather Service Command has emphasized that these observations were made by ships-in-passage, which tend to avoid bad weather, thus a bias is introduced into the data. In view of the large number of observations available, however, random errors undetected by the limited quality control program used by the compiler should generally be minimal. The comments made in this section, based on these data, should, nevertheless, be read with a "favorable weather bias" in mind.

The regional analyses presented here as Figures 3-196 through 3-198 are intended to give the reader a general view of some of the main elements of the offshore climate. A brief discussion of these analyses is given below. Detailed examination of these diagrams will provide additional information, as will perusal of the published summaries. The oceanic climatological analyses prepared by the U. S. Navy (1955 - currently being updated by U. S. Naval Weather Service Command) and the U. S. Department of Commerce (1959) should also be consulted for further elaboration. The italicized numbers in Figures 3-196 through 3-198 indicate the number of observations (sample size) contained in the particular element that is graphed.

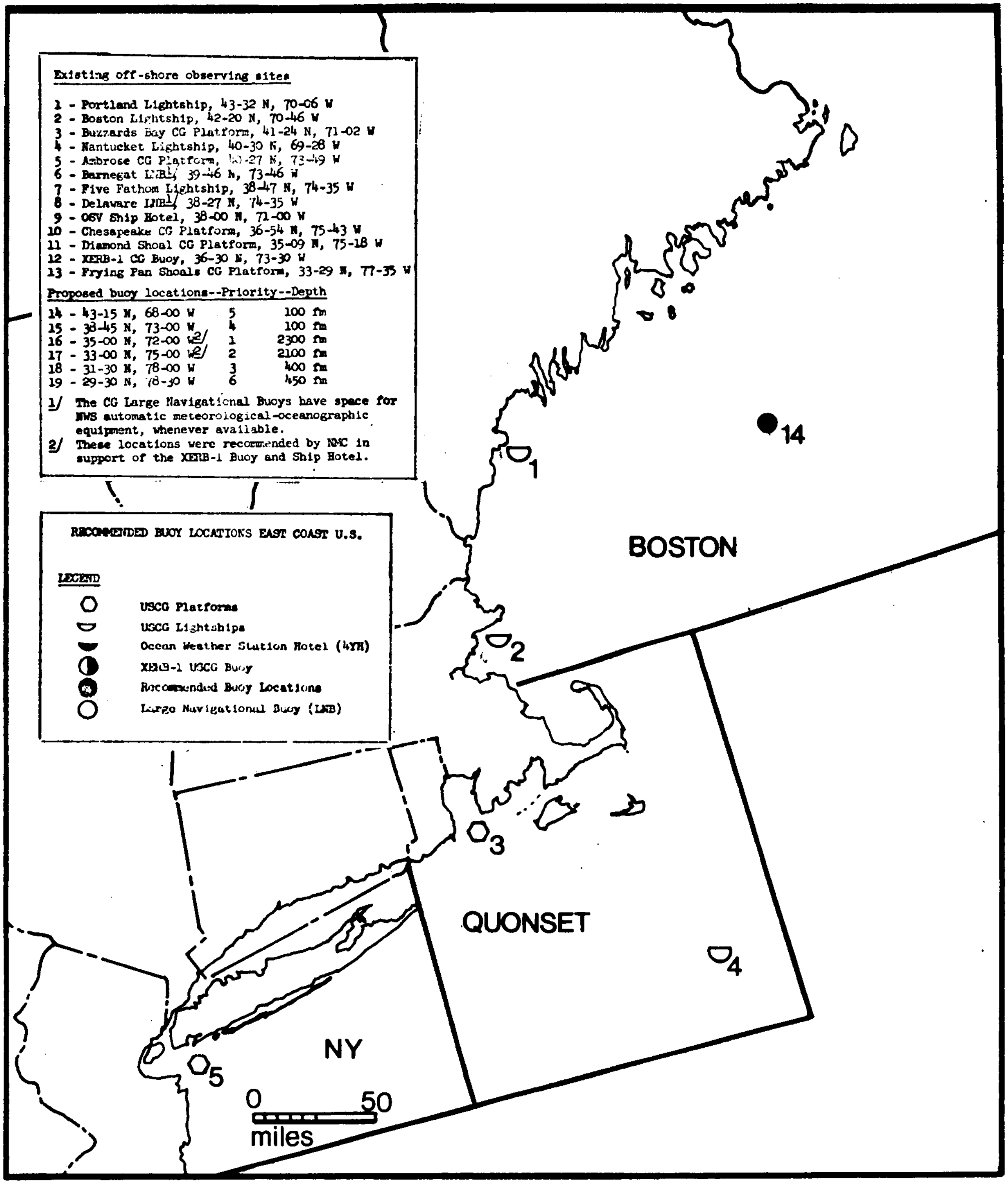
3.4.1 SOLAR CLIMATE

This element shows little variation across the region because of the restricted latitudinal spread represented. However, marked annual variation is observed. The horizontal bar graphs indicate schematically the relative length of daylight, which varies from approximately 9 hours at midwinter to more than 15 hours at midsummer.

The solar diagrams indicate the azimuth of the rising and setting sun, as well as the altitude of the sun at noon on an approximately mid-month basis. The solar azimuth of the rising/setting sun shifts from southeast/southwest during winter to northeast/northwest during the summer months. Noon solar altitude is as low as 23° in the Boston sea area during mid-December, increasing to about 72° in mid-June in the more southerly sea areas of Quonset and New York.

3.4.2 SKY COVER

Cloudiness shows an annual variation in all the sea areas, especially in Boston where it is a minimum during the autumn (4.0 eighths, Sept.)



Existing off-shore observing sites

1 - Portland Lightship, 43-32 N, 70-06 W
2 - Boston Lightship, 42-20 N, 70-46 W
3 - Buzzards Bay CG Platform, 41-24 N, 71-02 W
4 - Nantucket Lightship, 40-30 N, 69-28 W
5 - Ambrose CG Platform, 40-27 N, 73-49 W
6 - Barnegat LNB1/ 39-46 N, 73-46 W
7 - Five Fathom Lightship, 38-47 N, 74-35 W
8 - Delaware LNB1/ 38-27 N, 74-35 W
9 - OSV Ship Hotel, 38-00 N, 71-00 W
10 - Chesapeake CG Platform, 36-54 N, 75-43 W
11 - Diamond Shoal CG Platform, 35-09 N, 75-18 W
12 - XERB-1 CG Buoy, 36-30 N, 73-30 W
13 - Frying Pan Shoals CG Platform, 33-29 N, 77-35 W

Proposed buoy locations--Priority--Depth

14 - 43-15 N, 68-00 W	5	100 fm
15 - 38-45 N, 73-00 W	4	100 fm
16 - 35-00 N, 72-00 W2/	1	2300 fm
17 - 33-00 N, 75-00 W2/	2	2100 fm
18 - 31-30 N, 78-00 W	3	400 fm
19 - 29-30 N, 78-30 W	6	450 fm

1/ The CG Large Navigational Buoys have space for NWS automatic meteorological-oceanographic equipment, whenever available.
2/ These locations were recommended by NMC in support of the XERB-1 Buoy and Ship Hotel.

RECOMMENDED BUOY LOCATIONS EAST COAST U.S.

LEGEND

⬡	USCG Platforms
◡	USCG Lightships
◒	Ocean Weather Station Hotel (4YH)
◑	XERB-1 USCG Buoy
●	Recommended Buoy Locations
○	Large Navigational Buoy (LNB)

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-195

Location Map (Giraytys and Harrell, 1973)

Table 3-15 Climatological data summaries for off-shore areas.

Sea Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sky Cover (eighths)													
Boston	6.0	5.6	4.7	4.5	4.7	4.6	4.7	4.4	4.0	4.2	5.3	5.9	4.9
Quonset	5.5	5.2	4.6	4.8	4.7	4.4	4.7	4.4	4.3	4.2	5.1	5.6	4.8
New York	4.8	4.5	4.4	4.7	4.6	4.2	4.5	4.3	4.0	3.9	4.7	4.7	4.4
Air Temperature (^{o}F)													
Boston	34.1	32.7	36.4	41.5	47.3	54.8	61.2	62.0	58.8	53.1	45.7	37.9	47.7
Quonset	38.5	37.3	40.3	45.7	52.2	61.1	68.2	69.5	65.1	58.3	51.0	42.6	53.2
New York	37.9	35.9	41.1	47.4	55.5	65.0	72.0	72.2	67.1	58.8	50.7	41.2	54.5
Relative Humidity (%)													
Boston	79	79	78	80	85	86	88	88	84	81	78	80	82
Quonset	80	79	79	82	83	85	86	84	82	78	79	77	81
New York	77	74	76	78	82	84	80	79	75	74	73	76	77
Wind Speed (kts)													
Boston	18.7	18.3	16.9	13.5	12.0	11.4	9.9	10.9	12.0	14.1	16.8	18.3	14.2
Quonset	16.9	17.0	15.7	13.3	10.7	10.1	9.4	10.3	11.6	13.7	15.4	17.1	13.2
New York	15.1	15.3	13.7	12.5	10.2	9.8	9.3	9.2	10.9	12.1	14.5	15.4	12.2

Table 3-16 Meteorological Tables

METEOROLOGICAL TABLE FOR COASTAL AREA OFF NEW YORK

Boundaries: From 40°N., and 72°W., north and westward to coast

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	3.4	3.7	2.6	1.3	0.6	*	0.2	0.2	0.6	1.8	2.3	3.3	1.6	16253
Wind ≧ 41 knots (1)	1.0	1.1	0.7	0.4	0.2	*	*	0.1	0.3	0.5	0.7	0.5	0.4	16253
Wave height ≧ 12 feet (1)	5.6	3.7	1.8	0.8	1.8	*	*	*	3.5	1.2	2.9	1.4	1.7	1601
Wave height ≧ 20 feet (1)	*	*	*	0.4	*	*	*	*	*	*	0.7	*	0.1	1601
Visibility < 2 naut. mi. (1)	5.9	3.8	4.8	8.9	12.3	8.1	7.3	4.4	3.2	2.7	4.0	3.0	6.0	7099
Visibility < 0.5 naut. mi. (1)	1.5	1.0	2.3	5.7	9.2	5.1	4.0	1.8	1.8	1.8	1.3	1.4	3.3	7099
Precipitation (1)	12.2	10.8	12.7	12.2	7.2	4.7	8.1	6.2	9.4	9.7	10.2	10.4	9.4	9190
Temperature ≧ 85°F (1)	*	*	*	*	*	*	1.3	0.5	*	*	*	*	0.2	7716
Temperature ≦ 32°F (1)	22.7	31.9	10.4	*	*	*	*	*	*	*	1.0	14.8	5.7	7716
Sky overcast or obscured (1)	36.1	36.0	35.4	36.8	34.2	25.5	30.9	28.8	27.9	26.1	34.7	33.9	32.2	7015
Thunder and lightning (1)	*	*	*	0.1	0.6	1.4	1.1	1.5	0.8	0.2	0.4	*	0.5	9190
Mean wind speed (knots)	15.1	15.3	13.7	12.5	10.2	9.8	9.3	9.2	10.9	12.1	14.5	15.4	12.2	16253
Prevailing wind direction	NW	NW	NW	W	SW	S	S	S	S	NW	W	WNW	W	16253
Mean temperature (°F)	37.9	35.9	41.1	47.4	55.5	65.0	72.0	72.2	67.1	58.8	50.7	41.2	54.5	16011
Mean sea-surface temperature (°F)	43.0	40.0	40.6	44.4	52.1	62.2	69.5	71.1	67.9	60.9	54.2	47.8	55.1	14690
Mean relative humidity (%)	77	74	76	78	82	84	80	79	75	74	73	76	77	7540
Mean cloud cover (eighths)	4.8	4.5	4.4	4.7	4.6	4.2	4.5	4.3	4.0	3.9	4.7	4.7	4.4	7015
Mean sea-level pressure (2)	1018	1018	1016	1014	1016	1015	1015	1016	1017	1018	1019	1020	1016	9274
Extreme max. sea-level pressure(2)	1042	1042	1041	1035	1032	1035	1031	1032	1037	1040	1041	1041	1042	9274
Extreme min. sea-level pressure (2)	978	971	983	985	995	992	994	977	992	995	989	983	971	9274

METEOROLOGICAL TABLE FOR COASTAL AREA OFF GULF OF MAINE

Boundaries: From 42°N., and 66°W., north and westward to coast

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	7.4	7.7	4.3	1.5	0.6	0.2	0.1	0.4	0.9	2.3	4.3	7.3	3.0	29579
Wind ≧ 41 knots (1)	1.8	2.7	0.7	0.4	*	*	*	0.1	0.2	0.7	1.6	2.3	0.8	29579
Wave height ≧ 12 feet (1)	8.0	9.1	2.4	1.0	0.1	0.2	*	0.1	0.5	3.1	4.2	8.2	2.9	7610
Wave height ≧ 20 feet (1)	0.7	0.4	*	0.5	*	*	*	*	*	*	*	1.1	0.2	7610
Visibility < 2 naut. mi. (1)	8.3	8.5	12.1	8.6	12.1	16.8	22.7	17.4	10.0	6.1	5.2	7.1	10.8	21849
Visibility < 0.5 naut. mi. (1)	3.2	3.1	1.9	4.2	8.1	10.4	15.5	11.9	6.0	4.0	2.0	3.6	6.3	21849
Precipitation (1)	21.7	23.7	15.3	11.7	9.8	8.0	4.7	6.9	7.2	7.0	13.2	22.1	12.3	26487
Temperature ≧ 85°F (1)	*	*	*	*	*	*	*	*	*	*	*	*	*	23161
Temperature ≦ 32°F (1)	40.9	45.8	22.3	2.9	*	*	*	*	*	0.1	1.7	26.7	10.7	23161
Sky overcast or obscured (1)	49.6	44.3	35.0	34.5	34.1	31.1	31.1	30.8	28.9	28.8	40.8	47.0	36.2	21780
Thunder and lightning (1)	*	0.1	*	0.1	0.1	0.4	0.5	0.5	0.3	0.1	*	*	0.2	26487
Mean wind speed (knots)	18.8	18.3	16.9	13.5	12.0	11.4	9.9	10.9	12.0	14.1	16.8	18.3	14.2	29579
Prevailing wind direction	NW	NW	WNW	W	SW	SSW	SW	SW	SW	SW	NW	W	SW	29579
Mean temperature (°F)	34.1	32.7	36.4	41.5	47.3	54.8	61.2	62.0	58.8	53.1	45.7	37.9	47.7	29546
Mean sea-surface temperature (°F)	40.4	37.9	37.6	39.5	44.0	50.1	56.7	58.6	57.1	53.4	48.6	44.1	47.8	26452
Mean relative humidity (%)	79	79	78	80	85	86	88	88	84	81	78	80	82	20134
Mean cloud cover (eighths)	6.0	5.6	4.7	4.5	4.7	4.6	4.7	4.4	4.0	4.2	5.3	5.9	4.9	21780
Mean sea-level pressure (2)	1014	1013	1013	1015	1015	1014	1015	1015	1018	1017	1016	1016	1015	27274
Extreme max. sea-level pressure(2)	1052	1042	1040	1042	1038	1033	1030	1037	1041	1039	1041	1045	1052	27274
Extreme min. sea-level pressure (2)	976	970	977	980	990	994	994	992	988	973	980	971	970	27274

METEOROLOGICAL TABLE FOR COASTAL AREA OFF NANTUCKET

Boundaries: Between 40°N., and 42°N., and 69°W., and 72°W.

Weather Elements	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	No. of observations
Wind ≧ 34 knots (1)	4.9	5.9	4.5	1.9	0.6	0.2	0.1	0.3	1.3	2.5	3.5	5.0	2.4	43058
Wind ≧ 41 knots (1)	1.2	1.2	1.3	0.6	0.2	0.1	*	0.1	0.5	0.5	0.8	1.8	0.7	43058
Wave height ≧ 12 feet (1)	13.4	7.4	4.5	2.2	1.6	0.4	0.2	0.4	3.7	1.1	7.8	6.0	3.8	6149
Wave height ≧ 20 feet (1)	1.9	1.0	0.6	*	*	*	*	*	0.4	0.3	0.7	0.4	0.4	6149
Visibility < 2 naut. mi. (1)	4.6	4.7	5.2	10.4	15.4	17.7	16.1	9.9	6.3	3.5	3.3	4.0	8.5	27287
Visibility < 0.5 naut. mi. (1)	1.4	1.9	3.0	6.6	11.6	12.8	11.0	6.1	4.0	2.1	1.6	1.5	5.4	27287
Precipitation (1)	12.0	12.7	10.2	9.8	6.7	4.8	5.5	6.4	7.2	7.0	9.3	12.7	8.5	32071
Temperature ≧ 85°F(1)	*	*	*	*	*	0.1	0.4	0.2	0.1	*	*	*	0.1	28281
Temperature ≦ 32°F (1)	22.9	25.4	8.0	0.3	*	*	*	*	*	*	0.1	11.3	5.0	28281
Sky overcast or obscured (1)	44.3	39.7	36.2	41.1	37.3	31.7	35.1	29.0	29.9	26.9	37.4	42.9	35.8	26977
Thunder and lightning (1)	0.1	*	0.1	0.2	0.3	0.6	1.2	1.0	0.4	0.4	0.4	0.1	0.4	32071
Mean wind speed (knots)	16.9	17.0	15.7	13.3	10.8	10.1	9.4	10.3	11.6	13.7	15.5	17.1	13.2	43058
Prevailing wind direction	WNW	NW	W	W	SW	SW	SW	SW	SW	W	W	NW	W	43058
Mean temperature (°F)	38.5	37.3	40.3	45.7	52.2	61.1	68.2	69.5	65.1	58.3	51.0	42.6	53.2	42824
Mean sea-surface temperature (°F)	44.5	41.6	41.1	43.5	48.9	57.9	63.5	68.7	65.4	59.9	54.4	49.0	53.9	39367
Mean relative humidity (%)	80	79	79	82	83	85	86	84	82	78	79	77	81	25252
Mean cloud cover (eighths)	5.5	5.2	4.6	4.8	4.7	4.4	4.7	4.4	4.3	4.2	5.1	5.6	4.8	26977
Mean sea-level pressure (2)	1015	1015	1014	1015	1015	1015	1016	1016	1018	1017	1016	1017	1016	32762
Extreme max. sea-level pressure(2)	1042	1042	1040	1040	1035	1036	1035	1037	1037	1040	1041	1043	1043	32762
Extreme min. sea-level pressure (2)	976	976	967	977	977	995	996	968	973	978	974	983	967	32762

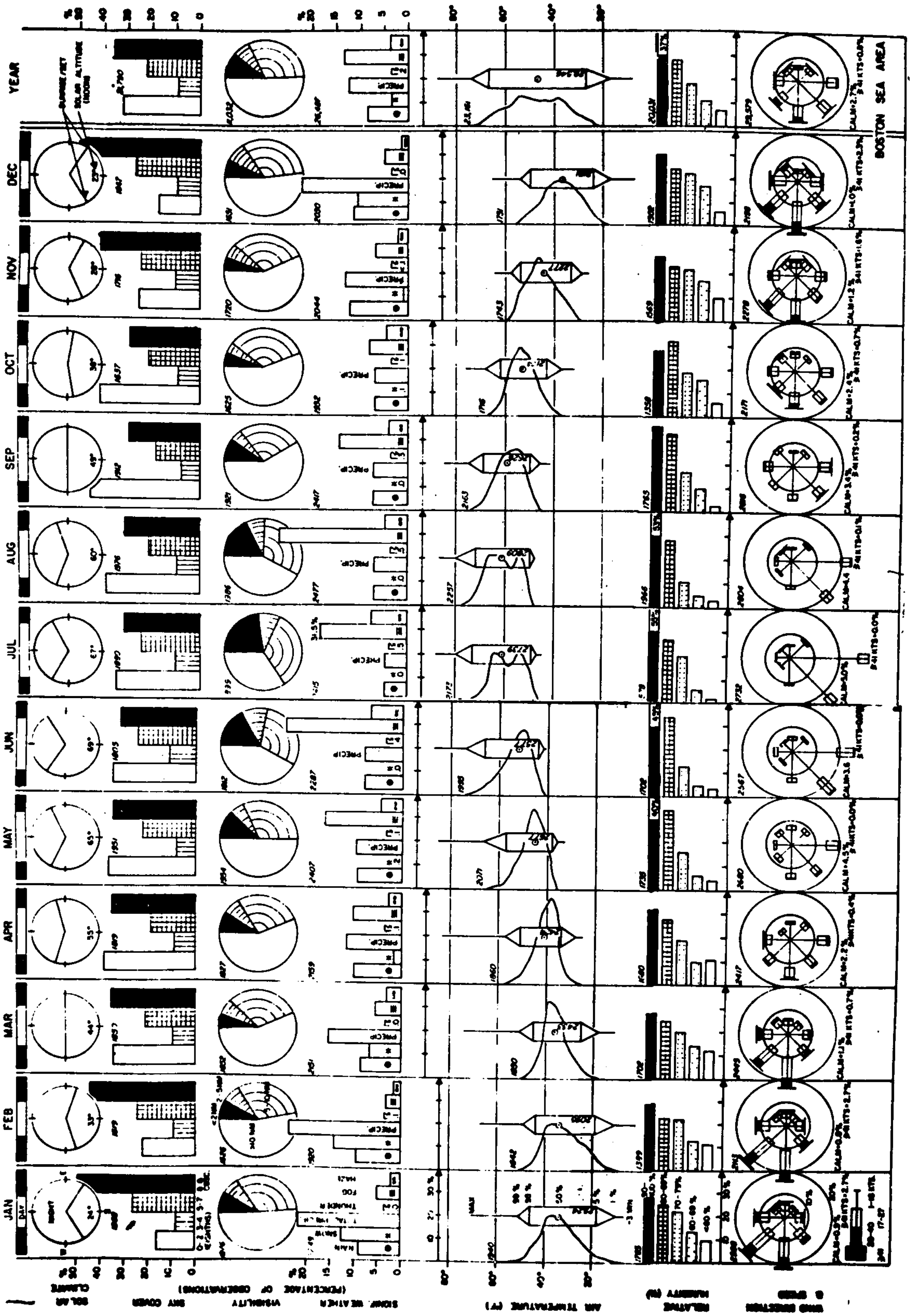
(1) Percentage frequency.

(2) Millibars.

* 0.0-0.5%

These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

(3) Data from Coast Pilot #2 NOAA 1973.

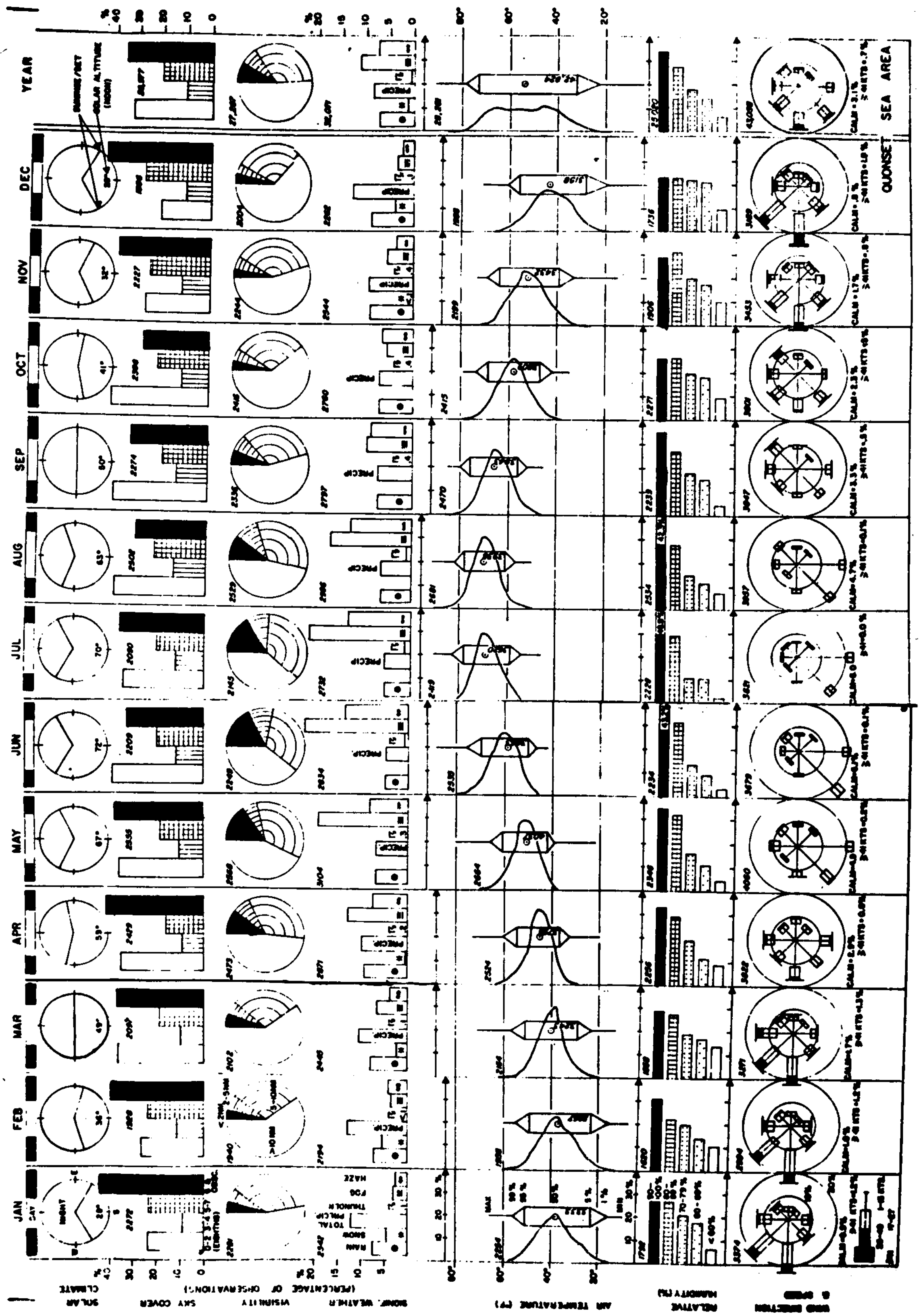


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

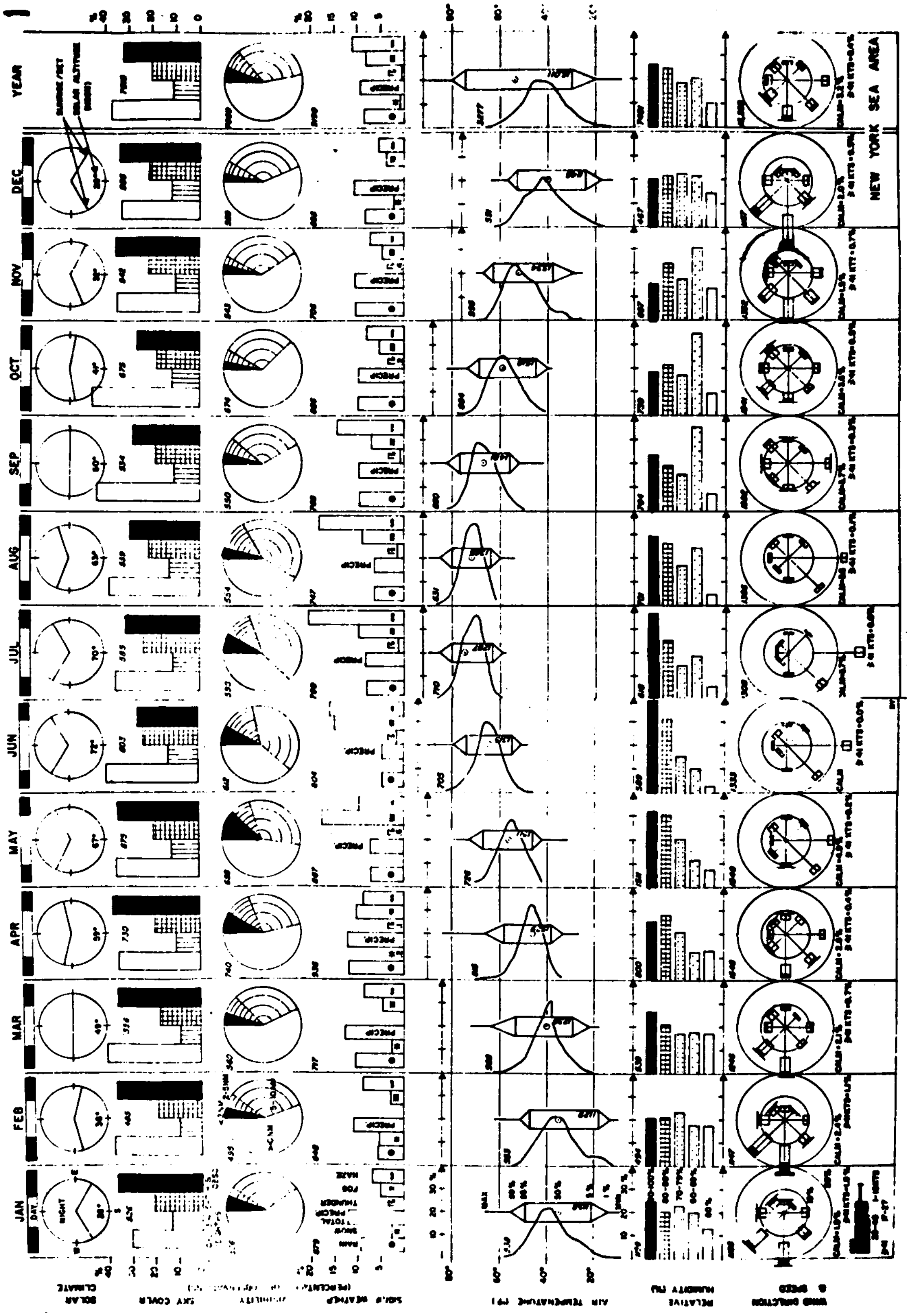
FIGURE 3-196

Meteorological Data for Boston Sea Area



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 3-197	Meteorological Data for Quonset Sea Area



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-198 Meteorological data for New York Sea Area and a maximum during winter (6.0 eighths. Jan.). The cloudiness during the winter months is emphasized by the distortion displayed by the histograms. They deviate from their usual U-shape profiles during the winter months. Cloudiness increases from north to south during the winter months but the summer months show little variation across the region.

3.4.3 VISIBILITY

Of the three sea areas Boston experiences the greatest incidence of reduced visibility (visibility less than 2 nm). This element also shows annual variations with the greatest frequency of reduced visibility evident during late spring and summer, when a high incidence of fog and haze is the main causal factor. In the Boston area during July visibility is less than 1/2 nm 15 percent of the time.

3.4.4 SIGNIFICANT WEATHER

Fog and haze mentioned above constitute the most frequently observed "significant weather," an expression that includes rain, snow, and thunder. Fog is especially frequent during the summer months in the Boston area where 31.5 percent of the observations reported it during July. It is less frequently observed in the Quonset and New York sea areas but its frequency is still high -- close to 20 percent of the observations during the summer months. Interestingly the incidence of haze is considerably less in the Boston sea area than in either the Quonset or New York areas. The latter sea areas do not extend as far seaward as does the Boston area. This could account for this difference, especially if the haze is industrial in origin.

The difficulties encountered in attempting to measure precipitation at sea are well known. Therefore, this element is usually reported in terms of frequency of occurrence. Frequencies are significantly higher during the winter months than during the summer months and markedly higher during the winter months in the Boston sea area than in Quonset and New York. Almost 24 percent of all observations taken in the Boston area during February have indicated precipitation (9.6 percent rain, 14 percent snow).

As should be expected the occurrence of snow constitutes a greater proportion of the precipitation in the northern sea area than in the southern areas.

Thunderstorm activity is not particularly common in any of the three sea areas, but it is most frequently recorded in the Quonset and New York areas during the summer months when it constitutes about 1 percent of the observations. In the Boston sea area thunderstorms can be considered to be quite rare.

3.4.5 AIR TEMPERATURE

Monthly mean temperatures show the expected increase from north to south across the region. The sea area most confined to the coast, New York, displays the greatest degree of continentality as represented by its annual mean temperature range, 23.7 C. In the Boston sea area the annual range is 1.5 C. Although the frequency curves of air temperature are quite symmetrical in sea areas Quonset and New York, the Boston curves are positively skewed during late spring and early summer. Interestingly the Boston curves show marked bimodal characteristics during July and August.

3.4.6 RELATIVE HUMIDITY

Values of this element are, of course, relatively high in all the sea areas, but the proximity of land appears to reduce the mean values slightly in the New York area. Relative humidities are highest, although by only a slight amount, in the Boston sea area during the summer months (86-88 percent), a reflection of the high frequency of fog there at this time of year.

3.4.7 WIND DIRECTION AND SPEED

The compound wind roses displayed in the regional analyses show the seasonal shift in wind direction over the entire region, from west and northwest during the winter months to south and southwest during the summer months. The annual variation in wind speed is also evident from these diagrams at a glance. Boston is the windiest area (annual mean 25.6 km/hr.); New York least (annual mean 23.2 km/hr.). Winds with speeds greater than 76 km/hr. occur 2.7 percent of the time during January and February in the Boston area. The other two areas report wind speeds of this strength only about half as frequently during these months.

A summary of wind direction and speed for the Gulf of Maine is presented on Table 3-17.

TABLE 3-17a

PERCENT FREQUENCY OF WIND DIRECTION BY SPEED AND BY HOUR FOR THE GULF OF MAINE

	Wind Velocities (knots)					Number of	Percentage of	Mean
Wind Direction	0-6	7-16	17-27	28-40	41+	Observations	Frequency	Speed
N	1.7	4.8	2.8	0.8	0.1	3024	10.2	15.1
NE	1.4	3.6	1.8	0.5	0.1	2169	7.3	14.4
E	1.6	3.2	1.3	0.5	0.1	1974	6.7	13.5
SE	1.6	4.2	1.7	0.3	0.1	2375	8.0	13.0
S	2.8	9.0	4.1	0.6	*	4915	16.6	13.4
SW	2.7	9.9	4.4	0.8	0.1	5269	17.8	13.8
W	2.4	7.9	4.9	1.7	0.2	5070	17.1	15.9
NW	1.6	5.8	4.4	1.5	0.2	3990	13.5	16.8
Variable	*	*	0.0	0.0	0.0	9	*	2.9
Calm	2.7					784	2.7	0.0
Number of Observations	5469	14348	7500	2020	242	29579		14.2
Percentage	18.5	48.5	25.4	6.8	0.88	100.0	100.0	(Mean Total)

* Frequencies between 0.0% and 0.05%　　　　Data from 1864 - 1968

SOURCE: Normandeau, Seabrook Station ER (1972)

TABLE 3-17b

PERCENT FREQUENCY OF WIND SPEED AND DIRECTION VS. SEA HEIGHTS FOR THE GULF OF MAINE

N

HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL
<1	.2	1.1	.1	*	.0	.0	104
1-2	.1	1.3	1.5	*	.0	.0	211
3-4	.0	.5	1.9	.5	.0	.0	205
5-6	.0	.2	.7	.5	*	.0	103
7	.0	*	.3	.4	.2	*	65
8-9	.0	*	*	.2	.1	.0	25
10-11	.0	.0	.1	.1	.1	.0	20
12	.0	.0	.0	.1	*	*	7
13-16	.0	.0	.0	*	.1	*	10
17-19	.0	.0	.0	.0	*	.0	2
20-22	.0	.0	.0	.0	*	*	2
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	22	228	333	135	30	6	754
PCT	.3	3.2	4.6	1.9	.4	.1	10.4

NE

HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL
<1	*	.7	.1	.0	.0	.0	56
1-2	.1	1.0	.6	*	*	*	128
3-4	*	.3	.9	.2	.0	.0	103
5-6	*	.1	.3	.3	*	.0	51
7	.0	*	.1	.2	*	.0	25
8-9	.0	*	.1	.1	*	.0	18
10-11	.0	.0	*	.1	*	*	9
12	.0	.0	.0	*	.0	*	3
13-16	.0	.0	.0	*	.0	*	2
17-19	.0	.0	.0	.0	*	.0	2
20-22	.0	.0	.0	*	*	.0	2
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	12	156	152	64	11	4	399
PCT	.2	2.2	2.1	.9	.2	.1	5.5

E

HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL
<1	.2	1.0	.1	.0	.0	.0	87
1-2	.1	1.0	.6	*	.0	.0	118
3-4	*	.4	.8	.2	*	*	112
5-6	.0	.1	.3	.3	*	.0	45
7	.0	.0	.2	.2	.1	.0	31
8-9	.0	.0	.0	.1	.1	*	15
10-11	.0	.0	*	.1	.1	.0	10
12	.0	.0	.0	.1	*	.0	7
13-16	.0	.0	*	.1	*	*	12
17-19	.0	.0	.0	.0	*	.0	1
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	*	.0	1
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	17	174	143	76	25	4	439
PCT	.2	2.4	2.0	1.1	.3	.1	6.1

SE

HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL
<1	.2	1.7	.3	.0	.0	.0	162
1-2	.1	1.4	1.7	*	.0	.0	231
3-4	.0	.6	1.5	.4	.0	.0	176
5-6	.0	.1	.3	.5	.1	.0	68
7	.0	.0	*	.2	*	*	23
8-9	.0	.0	*	.1	*	.0	7
10-11	.0	.0	.0	*	*	.0	4
12	.0	.0	*	.0	*	.0	2
13-16	.0	.0	.0	.0	.0	.0	0
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	*	.0	1
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	24	267	279	89	14	1	674
PCT	.3	3.7	3.9	1.2	.2	*	9.3

---

*Indicate mean frequencies between 0.00% and 0.05%.
Speed in knots, height in feet.

TABLE 3-17c

PERCENT FREQUENCY OF WIND SPEED AND DIRECTION VS. SEA HEIGHTS FOR THE GULF OF MAINE

			S								SW			
HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL	1-3	4-10	11-21	22-33	34-37	48+	TOTAL
<1	.3	3.0	.4	*	.0	.0	267	.1	2.6	.5	.0	.0	.0	233
1-2	.1	2.8	2.9	.1	.0	.0	420	.1	2.5	2.5	.1	.0	.0	375
3-4	*	.9	3.7	.5	.0	.0	370	*	.8	3.4	.4	.0	.0	338
5-6	.0	.1	1.0	.5	.0	*	121	.0	.1	.9	.6	.0	.0	117
7	.0	*	.3	.4	.1	.0	59	.0	*	.5	.5	*	.0	71
8-9	.0	.0	.1	.2	*	.0	18	.0	.0	.2	.2	.1	.0	33
10-11	.0	.0	.1	.1	*	.0	16	.0	.0	*	.2	.0	.0	15
12	.0	.0	*	*	*	.0	5	.0	.0	.0	.1	*	.0	12
13-16	.0	.0	.0	*	.0	.0	2	.0	.0	.0	.1	*	.0	9
17-19	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	*	.0	1
20-22	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0
TOTAL	26	491	611	139	9	2	1278	18	443	572	159	12	0	1204
PCT	.4	6.8	8.5	1.9	.1	*	17.7	.2	6.1	7.9	2.2	.2	.0	16.7

			W								NW				
HGT	1-3	4-10	11-21	22-33	34-37	48+	TOTAL	1-3	4-10	11-21	22-33	34-37	48+	TOTAL	GRAND TOTAL
<1	.2	2.4	.3	.0	.0	.0	212	.1	1.7	.2	*	.0	.0	146	1267
1-2	*	2.7	2.5	.1	*	.0	384	*	1.7	1.4	*	.0	.0	228	2095
3-4	*	.9	3.0	.2	.0	*	304	.0	.7	2.4	.4	*	.0	251	1859
5-6	.0	.1	1.5	.9	.1	.0	189	.0	.1	1.1	1.0	.1	.0	164	858
7	.0	*	.6	1.0	.3	.0	136	.0	.0	.5	1.0	.3	*	128	538
8-9	.0	.0	.2	1.0	.2	.0	93	.0	.0	.2	.7	.1	*	67	276
10-11	.0	.0	.1	.4	.2	.0	43	.0	.0	*	.2	.1	*	25	142
12	.0	.0	*	.1	.1	.0	21	.0	.0	.1	.1	.1	.0	24	81
13-16	.0	.0	*	.1	.2	*	22	.0	.0	*	.1	.2	.1	23	80
17-19	.0	.0	.0	*	*	*	3	.0	.0	.0	.0	*	.0	3	12
20-22	.0	.0	.0	.0	.0	*	1	.0	.0	.0	.0	.0	.0	0	5
23-25	.0	.0	.0	.0	*	*	3	.0	.0	.0	.0	*	*	2	6
26-32	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	1
33-40	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
41-48	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
49-60	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
61-70	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
71-86	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
87+	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	0	0
TOTAL	22	443	594	272	74	6	1411	10	300	425	252	64	10	1061	7220
PCT	.3	6.1	8.2	3.8	1.0	.1	19.5	.1	4.2	5.9	3.5	.9	.1	14.7	100.0

---

*Indicate mean frequencies between 0.00% and 0.05%.
Speed in knots, height in feet.

3.4.8 REFERENCES

Giraytys, J. and J. Harrell, 1973. Which systems meet the challenge for near coastal waters (10-300 mn offshore), W.M.O. Report No. 346, 1-34.

Normandeau Associates, 1972. Seabrook Station environmental report, for Public Service Company of New Hampshire, 3 v.

U.S. Department of Commerce, 1959. Climatological and Oceanographic Atlas for Mariners, Vol. 1: North Atlantic Ocean, 7 pp + charts.

U.S. Department of Commerce, NOAA, National Ocean Survey, 1973. United States coast pilot 2 (8th ed.), Atlantic coast - Cape Cod to Sandy Hook, Washington, D.C., 249 pp.

U.S. Navy, 1955. Marine Climatic Atlas of the World, Vol. 1: North Atlantic Ocean, 17 pp _ charts.

U.S. Naval Weather Service Command, 1970. Summary of synoptic meteorological observations, North American coastal marine areas, Vol. 2, 632 pp.

Chapter

3 Offshore Region

3.5 BIOLOGICAL OCEANOGRAPHY

3.5.1 PLANKTON-BASED PELAGIC, OFFSHORE

This section treats the biology of the plankton-based pelagic community of the offshore areas. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed and its areal distribution shown. The major biological components of the habitat are the phytoplankton, zooplankton, fishes, birds and mammals. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to the Plant and Animal Profiles, Chapters 8.0 Phytoplankton, 9.0 Zooplankton, 12.0 Fishes, 13.0 Birds, and 14.0 Marine Mammals, respectively.

HABITAT DEFINITION/DESCRIPTION

This habitat includes the saline water column from the shore to the edge of the continental shelf. Included are two distinctly different environments: 1) the offshore, open waters which are usually fairly deep (20-300 m) and of high salinity (>31 $^{o}/oo$); and 2) waters extending inland between headlands to the 0.5 $^{o}/oo$ isopleth, usually termed estuarine waters, which are of highly variable but usually shallow (<20 m) depth, and of variable salinity. The biota of both environments consist of 1) the plankton or small plants and animals unable to move against currents and 2) the nekton or animals capable of swimming against currents. The plankton is usually subdivided into phytoplankton (unicellular plants), holoplankton (animal species spending their entire life cycle in the pelagic habitat), meroplankton (pelagic larvae that will spend their adult life in another habitat (e.g. the benthos), and tychoplankton (normally benthonic forms temporarily swept into suspension by currents).

Because of the very different nature of the two pelagic environments, they will be considered separately.

HABITAT DYNAMICS

Environmental Conditions

Offshore waters are fairly homogeneous in temperature, salinity (>31 $^{o}/oo$), and dissolved oxygen over wide areas (Graham, 1973). Local concentrations of nutrients, however, are revealed by the very patchy distribution of plankton. Nutrients, especially nitrate and phosphate, may be limiting factors in phytoplankton blooms (Bigelow, Lillick and Sears, 1940). Currents are the dominant force in the distribution of both nutrients and biota.

The water column is divided into two important layers. Uppermost is the euphotic zone, a zone of effective penetration of sunlight, extending to 20-50 m depth in the gulf. Beneath this is the profundal zone (Odum, 1971). During most of the year, with the exception of the winter, the water column is also thermally stratified. The warm, uppermost layer (epilimnion) extending to 20-40 m depth in the Gulf (Graham, 1973) is separated from the cold, bottom waters (hypolimnion) by the termocline, a layer of rapidly changing temperature and density.

Microenvironments

The epilimnion and hypolimnion represent very different environments. The warm, well-lighted, epilimnion contains optimal conditions for growth of phytoplankton and the maximum volume of zooplankton is found in this zone (above 50 m). Primary productivity is nonexistent in the hypolimnion and thus organisms here depend on dead or dying organisms orginating in the epilimnion.

The coastal zone eastward from Mt. Desert Island including the Bay of Fundy constitutes an area of uniquely low primary and zooplankton productivity within the gulf. The main causative factor appears to be the unusual turbulence of the area, preventing the establishment of thermal stratification of primary importance in phytoplankton productivity (Bigelow, Lillick and Sears, 1940). The water column therefore remains too cold for zooplankton reproduction (Fish and Johnson, 1937). However, meroplankton is often very abundant here in season.

Nutrient Cycles, Seasonal Cycles and Relative Productivity

Due to an annual cycling of nutrients, both phyto- and zooplankton show annual cycles of abundance. As surface waters cool during the fall, thermal stratification breaks down. The hypo- and epilimnious thus disappear and nutrients, especially phosphates and nitrates, become mixed throughout the water column. Even though abundant nutrients and sufficient light are present throughout the winter, the phytoplankton remains very sparse. Only with the reestablishment of thermal stratification in the spring can the diatom population proceed to grow. This may be because circulation within the epilimnion and the density barrier of the thermocline help prevent sinking of phytoplankton out of optimal conditions (Bigelow, et al, 1940).

This vernal outburst starts on the western coastal belt in the vicinity of Cape Elizabeth and western Georges bank in late March followed by blooms in the northern coastal belt and the rest of the bowl of the Gulf in April or May. Thalassiosira sp. occurs as dominant first, followed by Chaetharus sp. The vernal climax is reached after a brief (days-weeks) rapid increase in rate of production and thereafter the rate abruptly declines. This occurs in early April in Massachusetts Bay and the eastern Gulf; in late April over the southwestern basin; early May over the northwestern basin and May - June in the Bay of Fundy. Along the north coastal belt, the Bay of Fundy and over Georges

Bank, rich flora persists through June and flowers in the late summer. The rest of the Gulf experiences an "abrupt impoverishment" after the vernal climax followed by a gradual and modest increase in density during July and August. In the fall, the flora becomes progressively sparser until the winter minimum is reached (Bigelow, et al, 1940). Bigelow, et al (1940) postulate that the abrupt decline in rate of increase following the vernal climax is a result of a lack of nitrate, this nutrient now being fully incorporated in the phytoplankton population and the thermocline preventing renewal from reserves in the hypolimnion. This is supported by the fact that a rich flora, although often low in density in comparison with the rest of the Gulf, does persist in those areas where turbulence would ensure a constant supply of nutrients. The progressive impoverishment in the phytoplankton is probably due to gradual sinking of the population through the thermocline in combination with the intense grazing of zooplankton.

The zooplankton show a similar cycle. In late March, reproduction starts. The calcinoid copepod, Calnaus finmarchicus is the dominant species and its abundance is the major determinant of the total volume of zooplankton. (Except where noted, following information from Fish and Johnson, 1937). However, other copepod species play an important role: C. finmarchicus reaches a peak in May, and then declines. Pseudocalanus minutus follows in June and Oithona similis in August. Centropages typicus often is important in the fall over Georges Bank.

There is a progressive delay in the onset and the peak of zooplankton productivity from west to east, probably due to the delay in vernal warming. The outer gulf shows the earliest zooplankton production (early March), followed by the western area (early April) and finally the eastern basin and Bay of Fundy (May or later). Redfield (1941; quoted in Graham, 1973) postulated that the outer gulf is the center from which the calanoid copepods are transported, via currents, to coastal waters and bays. The herring larvae show a similar pattern of distribution (Graham, Chenoweth and Davis, 1972). Calanoid copepods usually overwinter in the late copepodite stages. At the onset of spring, these mature, spawn,and die. Three to four generations follow (each 6-10 weeks) until September when development is again arrested in the late copepodite stages.

Food Webs

The phytoplankton are the fundamental source of energy for the pelagic habitat. Secondary sources of energy, however, do exist and are becoming recognized as important. Dissolved organic compounds are present in oceanic waters and phytoplankton contribute to this supply. In fact, by neglecting to measure the contribution of dissolved organics, measurements of primary productivity in open waters may be too low by as much as 50 percent (Thomas, 1971). Soft-bodied invertebrates may derive a significant portion of their energetic requirements from

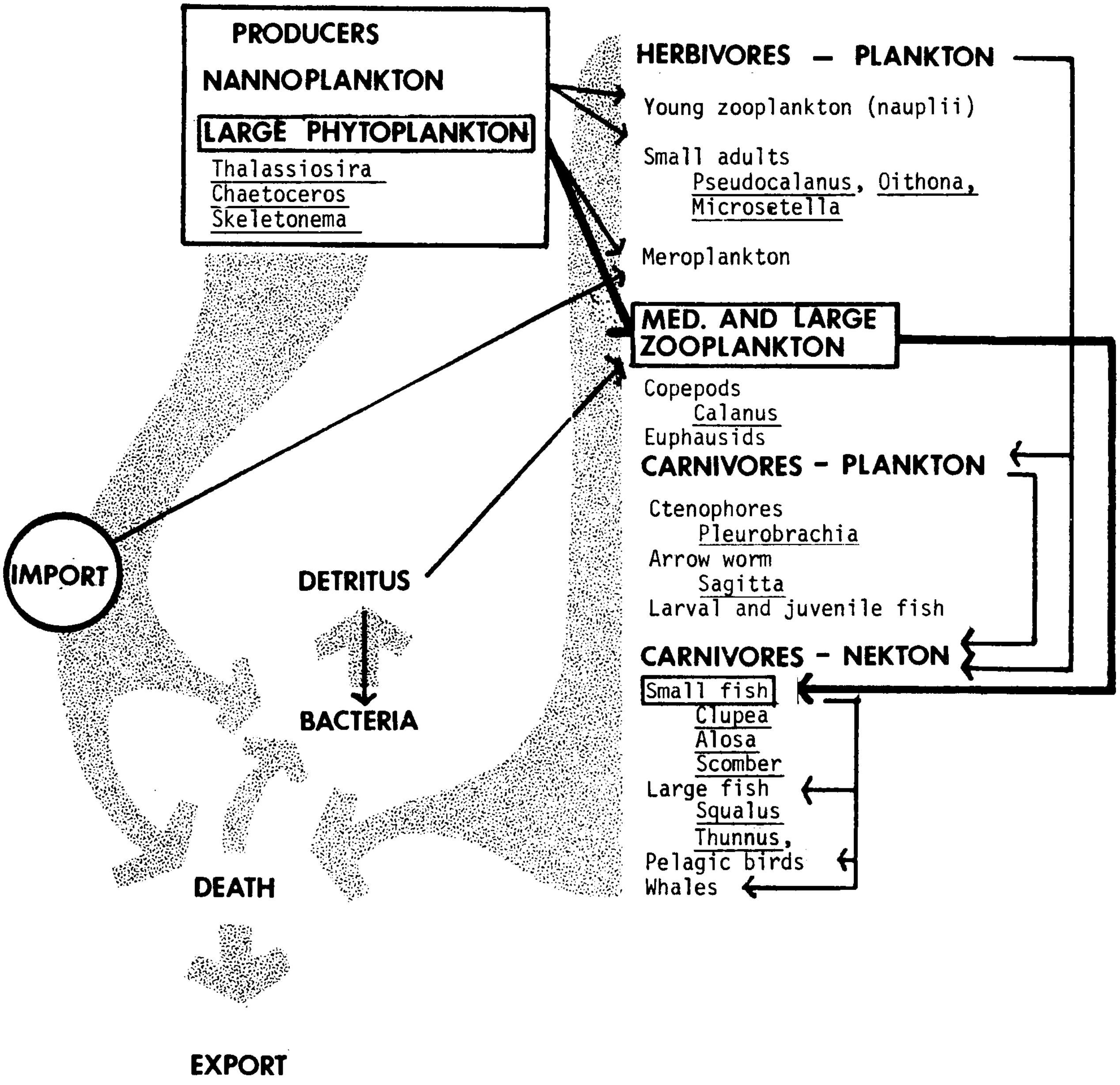


FIGURE 3-199 Food Web of Plankton based Pelagic Community

these compounds (Stephens, 1967).

Another source of energy may be derived from detritus and its associated bacteria which exists in marine waters in very large quantities (Krey, 1967). Kharlov and Finenko (1970) showed that in tropical seas, the carbon requirement of zooplankton is 1.5 x the carbon produced by primary production and concluded that detritus and bacteria are the source of the extra carbon. Sorokin (1971) showed that all filter feeders in fact do assimilate C_{14} labeled bacteria. "Coarse" filter feeders (calanoid copepods, tunicates, veliger larvae) utilized aggregated clumps (>4μ) of bacteria, while "fine" filter feeders removed the individual items.

Energy flow in the pelagic habitat was previously hypothesized to proceed through a simple pyramidal food chain. Further work is beginning to show that the food web is far more unstructured. Petypa, Pavlova and Mironov (1970) discovered that, in plankton above the thermocline, the main energy source is the phytoplankton and the main flow is through small forms. However, below the thermocline, detritus is as important as phytoplankton and the main energy flow is through the large, migratory copepodites and copepods to Oithona sp., Sagitta sp. and Pleurobranchia sp. More detailed work is sure to establish further complexities.

Natural Stress

Natural stresses in the pelagic habitat include the periodic lack of nutrients, turbidity and turbulence of surface waters, annual decline in light intensity, and temperature cycles (see above for discussion of how biota react to these stresses).

EFFECT OF MAN-INDUCED STRESS

The major man-induced stresses in the open ocean include such waterborne pollutants as oil and pesticides. Work in Chedabucto Bay, Nova Scotia after the wreck of the tanker "Arrow" shows that zooplankton ingest droplets of oil, but seem to be unaffected by it. The oil is not assimilated and passes out in the fecal pellets which then drop to the bottom. Consequently the zooplankton may be a very important natural aid in oil spill clean-up (Conover, 1971).

Isaacs (1972) demonstrated that pollutants will be concentrated in the higher levels of simple food chains, but in unstructured food webs, all levels show similar concentrations. Thus the pelagic habitat with its complicated food web may escape excessively high levels of concentration of harmful pollutants.

Man-induced stresses that would disrupt the pelagic habitat are those that would increase turbulence (large structures anchored to the sea floor), turbidity (large oil spills) and disrupt temperature cycles (hot water effluents).

BIOLOGICAL COMPONENTS

General Distribution

In the open ocean, the outstanding characteristic of the biota is the "remarkable uniformity of the population...at all times, consisting largely of boreal, endemic species" (Fish and Johnson, 1937, p. 305). The crustacea are the overwhelming dominant organisms (87-98 percent numerically). There is local, temporary dominance of other phyla but this is unimportant in the main energy flow.

In more coastal waters, however, the volume of copepods may drop to as little as 34-45 percent of the total during the spring and summer (Sherman, 1966, 1968). The major groups making up the rest of the volume include the appendicularia, fish and crustacean eggs, and decapod and cirriped larvae. There is a gradual reduction in the total volume of zooplankton proceeding from west to east along the coast.

Species Checklist

The following is a checklist of the zooplankton, fishes and mammals considered to be regular inhabitants of the plankton-based pelagic habitat.

Table 3-18 Key to Symbols

Distribution

Region

a = arctic
b = boreal
t = temperate
st = south temperate
nt = north temperate
c = cosmopolitan
tr = tropical

Zone

l = littoral
n = neritic
o = oceanic
tp = tycopelagic
f = freshwater
p = pelagic
br = brackish
e = estuarine

Area in the Gulf of Maine

B.F. = Bay of Fundy
N.S. = Nova Scotia
M.B. = Massachusetts Bay
M.S. = Montsweag Bay - Sheepscot River, Maine
P.B. = Penobscot Bay

/a = Gran and Braarud, 1935
/b = Lillick, 1940
/c = Bigelow, 1926
/d = Mulligan, in prep.
/e = McAlice, 1972

Typical example of occurrence:

(8) 16,000
B.F./a

(8) = month
16,000 = number of organisms present
B. F. = area in the Gulf of Maine
/a = reference

Table 3-19

CHECKLIST OF MARINE PHYTOPLANKTON - GULF OF MAINE

	Distribution		Occurrence and Ecological Requirements of Most Important Organisms
	Ecological	Monthly	
Bacillariophyceae:			
Achnanthes longipes Ag.	1 *	1,3-5,11-12	
A. taeniata Grun.	a;n,1	4	800-B.F./a dom.-E.Gulf 1934/b opt.T = 1.0°C.
Actinocyclus ehrenbergii Ralfs (=A.octonarius Ehr.)	n	5-9	40-B.F./a
Actinopytchus undulatus (Bail.) Ralfs (=A. senarius Ehr.)	n,tp	1-12	(4) 500-B.F./a (3-1920) dom. West N.S./c
Amphiprora alata (Ehr.) Kutz.	1	9	
Amphora ovalis Kutz.	f		
A. robusta Greg.	f		
A. turgida Greg.	f		
A. veneta Kutz.	f		
Asterionella bleakleyi W. Smith	n,1	1-7,10-12	
A. formosa var. gracillima (Hartz.) Grun. (=A. gracillima (Hartz.) Heib.)	f	5	
* A. japonica Cleve	s t ;n	3-11	(8)/a 45,000 B.F. B.B.-1912 100% tow/c
A. kariana Grun.	a;n	4-9	(5)-500-B.F./a
Asteromphalus sp. (Ehr.)	o		
Bacillaria paxillifer (Mull.) Hendey (=Nitzschia paradoxa Grun.)	n,1	1-12	
Bacteriastrum sp.			
Bacteriosira fragilis Gran	a;n	4	4,000-B.F./a indicator of polar currents opt.T = 1.4°C.

* (See key to symbols - page 19)

Table 3-19 (cont.)

Biddulphia alternans (Bail.) Van Heurck	l	9			
* B. aurita (Lyngb.) Breb.and God.	a,b;n,l	1-12	Spring		
B. mobiliensis (Bail.) Grun. ex Van Heurck	n	3-4			
B. regia (Schultze) Ost.	n	8-9	80-B.F./a		
Campylodiscus echeneis Ehr.					
Cerataulina pelagica (Cleve) Hendey (= C. bergonii (H.Perag.) Schutt)	st;n	1,5-9	(7) 16,000 B.F./a		
Chaetoceros affinis Laud.	n	4-9	(6) 16,000 B.F./a	opt.T = 14.9°C. opt.S = 21.2 ‰	
C. atlanticus Cleve	a,b;o	2-8	(4) 100- B.F./a	hi.sal.,cold	(4-1920)dom. West.N.S/c
C. borealis Bail.	b;o	1-12	(8)1,000- B.F./a	opt.T = 6.5°C. opt.S = 22.9 ‰	
C. brevis Schutt	t;n	7-8,10	B.F.	opt.T = 5.4°C. opt.S = 19 ‰	
C. ceratosporus Ost.		5			
C. cinctus Gran	st;n	7-9	(8)-abun- B.F./a		
* C. compressus Laud. (=C. contortus Schutt)	c;n	4-9	(6) 214,000 B.F./a	(4)265,000 B.B./c	opt.T = 8.5°C. opt.S = 23.4 ‰
C. concavicornis Mang.	a,b;o	4-5	G.M.,B.F.		
C. constrictus Gran.	nt;n	3-9	(8) 75,000 B.F./a	(5) dom. South of N.S./c	opt.T = 7.4°C. opt.S=21.2 ‰
C. convolutus Castr.	a,b;o	2-9	(4) 10,000 B.F./a	(4) dom. central Gulf/c	
C. costatum Pav.					
C. crinitus Schutt	nt;n	7-9			
C. curvisetus Cleve	n	3-6			
C. danicus Cleve	nt;n,tp	7-9		opt.T = 11.6°C. opt.S = 12.8 ‰	
* C. debilis Cleve	b,nt;n	3-9	(5)80,000 B.F./a	(6)910,000 M.B./d	opt.T = 6.9°C. opt.S = 26.1 ‰

Table 3-19 (cont.)

* C. decipiens Cleve	a,b;o	1-12	(8) 3,600 B.F./a	(4) 196,000 M.B./d	opt.T = 5.7°C. opt.S = 23.2 ‰
C. densus Cleve	t;o	3-9	(8) 700 B.F./a	(5-1917)dom. W. Basin/c	
* C. diadema (Ehr.) Gran (=C. subsecundus (Grun.) Hust.)	c;n	3-9	(4) 40,000 B.F./a	(3-4) 50,000 M.B./d	opt.T = 1.9°C. opt.S = 23.1 ‰
C. didymus Ehr.	st;n	3-10	(4) 4,000 B.F./a	(10) 32,000 M.B./d	(6) 49,700 B.B./d
C. difficilis Cleve	n				
C. eibenii (Grun.) Meun. ex Van Heurck	r.				
C. furcellatus Bail.	a;n	4-6	(4) 70,000	Mean T of occurrence 3.5°C	(4)abun- M.B./c
C. gracilis Schutt	n	7	B.F./a		
C. holsaticus Schutt	n				
C. laciniosus Schutt	t;n	3-10	(4) 14,000 B.F./a	(4-1920) dom. German B./c	opt.T = 8.6°C. opt.S = 24.5 ‰
C. lauderi Ralfs	st;n				
C. lorenzianus Grun.	st;n	4	B.F.		
C. mitra (Bail.) Cleve	n		Fish (1925)	Cold temp.	
C. pelagicus Cleve	nt;n				
C. pendulus Karst.					
C. perpusillus Cleve	nt;n	3-10	(6-7) dom. M.B./e		
C. perivianus Brightw.	st;o				
C. pseudocrinitus Ost.		6	rare-B.F.		
C. radicans Schutt (=C. scolopendra Cleve)	st;n	4-9	(6) 15,000 B.F./a	opt.T = 5.8°C. opt.S = 25.6 ‰	(8-1914) dom. Mt. Desert/c
C. seiracanthus Gran	n	4			
C. similis Cleve	b,nt;n	6	rare-B.F.	opt.T = .3°C opt.S = 21.2 ‰	

Table 3-19 (cont.)

C. simplex		6-9	800-B.F./a		
* C. socialis Laud.	nt;n	2-6	(4)-M.B./d 3,400,000	euryhaline stenothermal(1.9°C.)	
C. subtilis Cleve	n	9	rare-B.F.	low salinity cold temp.	
C. teres Cleve	b,nt;n,o	3-8	(8) 900 B.F./a	opt.T = 3.7°C. opt.S = 25 ‰	
C. wighami Brightw.	n	spring			
C. willei Gran	o	4		opt.T = 11°C. opt.S = 31.3 ‰	
Cocconeis placentula	n	1-12			
C. scutellum Ehr.	n	3,7-8			
Corethron criophilum Castr. (=C. hystrix Hensen)	nt;o	4-9	(8) 300 B.F./a		
Coscinodiscus argus Ehr.		2			
C. asteromphalus Ehr.	p	3-10	(3-1920)/c	(3-1920) dom. dom. West,N,S. Brown's B./c	
C. centralis Ehr.	b;o	1-12	rare-B.F./a	dom. winter central Gulf /b	
C. cinctus Kutz.		3,9	rare-B.F./a		
C. concinnus W. Smith	n	3-8	rare-B.F./a	hi. sal.	(9-1915)dom. Mt. Desert I./c
C. curvatulus Grun.	b;n	3-5	100-B.F./a		
* C. eccentricus Ehr. (=Thalassiosira eccentrica	t;n,o	1-12	160-B.F./a	dom. winter form/b	
C. lineatus Ehr.	n	4,7-8	(5)1920-abund. German B./c		
C. marginatus Ehr.	o				
C. oculus-iridis Ehr.	o,p	3-4,8-10			
C. radiatus Ehr.	t;n,o	3-9	rare-B.F./a		
C. stellaris Roper.	o	7	rare-B.F./a		

Table 3-19 (cont.)

C. sub-bulliens Jorg.	b;o	3		(3-1920)dom. N.Channel /c
Coscinosira oestrupi Ost.	o	4-9	(4) 18,000 B.F./a	
C. polychorda (Gran) Gran	n	4-9	(8) 19,000 B.F./a	opt.T = 3°C. opt.S = 26.7 ‰
Cyclotella striata (Kutz.) Grun.		1		
Cylindrotheca closterium (Ehr.) Reimann & Lewin (= Nitzschia closterium (Ehr.) W. Smith)	c;l	1-10	(7) 2,000 B.F./a	(9) 206,000 M.B./d
C. gracilis (Breb.) Grun. ex H.Perag.				
Cymbella sp. Ag.	f			
Dactyliosolen mediterraneus H. Perag.		8	rare-B.F.	
* Detonula confervacea (Cleve) Gran	n,p	1-7	13,000 B.F./a	opt.T = -0.1°C. (3) M.B. opt.S = 29.4 ‰ 2,900,000/d
Diatoma sp.	f			
Diploneis stroemi Hust.				
Ditylium brightweli (T. West) Grun.	st;n	2-10	(9) 1,420 B.F./a	
Endictya oceanic Ehr.	o	4-6	rare-B.F./a	
Epithemia turgida (Ehr.) Kutz.				
Eucampia recta Gran & Braarud		6,8	2,720 B.F./a	
E. zoodiacus Ehr.	st;n	2,4-8	(5) 2,000 B.F./a	dom. West (7) G.B./c
Eunotia arcus Ehr.		4		
Fragilaria crotonensis Kitt.	b,t;n	3-11	dom. summer	brackish
F. cylindrus Grun.	a;n	4,7-8		
F. oceanic Cleve	a;n	4	97,000 B.F./a	mean T. of occurrence = 2.2 °C.
F. striatula Lyngb.				

Table 3-19 (cont.)

F. virescens Ralfs					
Gomphonema constrictum					
G. olivaceum (Lyngb.) Kutz.					
Grammatophora angulosa Ehr.	t;l				
G. marina (Lyngb.) Kutz.	n	7-9,12			
* *Guinardia flaccida* (Castr.) Perag.	st;n	1-2,6-9	(9)460 B.F./a	(9) 23,3000 G.B./b	(12) 50,000 M.B./d
Gyrosigma attenuatum (Kutz.) Rab.					
G. balticum (Ehr.) Cleve	br	1,4-6,9-11			
G. fasciola (Ehr.) Cleve		1-12			
G. macrum (W.Smith) Griff & Henfr.	f	3,8,11			
Hantzschia amphioxys Grun.	f				
Hemiaulus hauckii Grun. ex Van Heurck	tr,t;o	7			
Isthmia nervosa Kutz.	nt;l				
* *Leptocylindrus danicus* Cleve	c;n	1,4-10	(7) 5,000 B.F./a	(9) 4,900,000 M.B./d	opt.T = 8.6°C. opt.S = 31.8 ‰
* *L. minimus* Gran	n	2-12	(6) 8,000 B.F./a	(10) 39,000 M.B./d	(10) 140,000 B.B./d
Licomorpha abbreviata					
L. flabellata (Grev.) Ag.					
L. jurgensii Ag.		8			
L. lyngbyei (Kutz.) Grun. ex Van Heurck					
L. tincta (Ag.) Grun.					
Melosira crenulata (Ehr.) Kutz.					
M. granulata (Ehr.) Ralfs	f				

Table 3-19 (cont.)

M. italica (Ehr.) Kutz.		7-8	
M. juergensii Ag.			(11) dom. M.S./e
M. moniliformis (Mull.) Ag.	1,p	1-12	dom. in summer/c
M. nummuloides Ag.	n	3-12	abun in late summer/e
Meridion sp.	f		
Navicula arenaria Donkin			
N. digito-radiata (Greg.) Ralfs (= *Pinnularia cyprinus*)			
N. distans (W.Smith) Schmidt	1	1-10	100-B.F./a
N. elegans W. Smith			
N. humerosa (Breb.) W.Smith			
N. menaiana Hendey			
N. palpebralis (Breb.) W. Smith			
N. pygmaea Kutz.			
N. vanhoffeni Gran	a;n	3-4	4,600-G.B./b
Nitzschia bilobata W. Smith			
N. delicatissima Cleve	o,n	2-9	(9) 10,000 B.F./a (10) 280,000 M.B./d
N. frigida Grun.	a;n	1-4	(1- 1971)dom. Great Bay/d
N. linearis			
N. littoralis Grun.		3	
N. longissima (Breb.) Ralfs	1	1,6-8	
N. obtusa W. Smith			
N. seriata Cleve	b,nt;n	1-12	(8-9) 8,000 B.F./a

Table 3-19 (cont.)

N. sigma (Kutz.) W.Smith		1-12			
Opephora sp.					
Paralia sulcata (Ehr.) Cleve (= *Melosira sulcata* (Ehr.) Kutz.)	b;n,tp	1-12	(4) 4,000 B.F./a	(10) 1,550 N.S/b	opt.T = 2.9°C. opt.S = 28.0 ‰
Pinnularia ambigua Cleve					
P. brebissoni (Kutz.) Rabh.	f	3-6			
Pinnularia sp.		6,9			
Pleurosigma aestuarii (Breb. ex Kutz.) W.Smith					
P. angulatum (Quek.) W.Smith		1-3,5-12			
P. balticum (Ehr,) W.Smith		7-8			
P. decorum W.Smith		7-8			
P. elongatum W.Smith		1,3-11			
P. fasciola (Ehr.)W. Smith		7-8			
P. formosum W.Smith		2-3,6-12			
P. normani Ralfs	tp	1-12	100-B.F./a		
P. strigosum W.Smith					
Porosira glacialis (Grun.) Jorg.	a;n	3-8	(4) 29,000 B.F./a	(3) 140,000 M.B./d	opt.T = 1.6°C. opt.S = 25.9 ‰
Raphoneis amphiceros (Ehr.) Ehr.		7			
R. surirella (Ehr.) Grun. ex Van Heurck		3,6			
Rhabdonema adriaticum Kutz.	st;l	7-8			
R. arcuatum (Lyngb.) Kutz.	br	6-12			

Table 3-19 (cont.)

*	*Rhizosolenia alata* Brightw.	t;o	1-12	(8) 50,000 B.F./a	dom. M.B./c (7)-1925	
	R. bergoni Perag.	o	4			
	R. calcar-avis M. Schul.	tr;n,o	8			
*	*R. delicatula* Cleve	n	10-12	(10) 1,200,000 M.B./d		(10) 99,400 M.B./d
	R. faercense (Ost.)	nt;n	3-4	(3-4) 33,000 M.B./d		
*	*R. fragillissima* Berg.	b,t;n	4-10	(6) 8,000 B.F./a	(7) 970,000 M.B./d	opt.T = 14.8°C. opt.S = 23.2 ‰
*	*R. hebetata f. semispina* Bail.	a,b;o	2-10	(4-6) 300 B.F./a	(4) dom. B.B./d	opt.T = 5.1°C. opt.S = 22.9 ‰
	R. imbricata Brightw.	o	2-10	1,500-B.F./a		
	R. setigera Brightw.	nt;n	3-10	100-B.F./a		opt.T = 3.5°C. opt.S = 17.2 ‰
	R. shrubsolei Cleve	n,o	7-12	(7) dom. east G.B./b		
	R. stolterfolii Perag.	n				
*	*R. styliformis* Brightw.	o	3-8	rare-B.F./a	(7-1916) dom. W.Georges B./c	
	Rhoicosphenia curvata (Kutz.) Grun.					
	Skeletonema costatum (Grev.) Cleve (= *Stephanopyxis costata*(Grev.) Ralfs)	c;n	1-12	(7) 780,000 B.F./a	(10)3,300,000 M.B./d	eurythermal euryhaline
	Stauroneis salina W.Smith					
	Stephanodiscus astrea		3			
	S. rotula (Kutz.)					
	Streptotheca thamesis Shrubs.	nt;n	6-9	rare-B.F./a		
	Striatella unipunctata (Lyngb.) Ag.	1				
	Surirella gemma (Ehr.) Kutz.					
	Synedra gailloni (Bory) Ehr.		7-8			

Table 3-19 (cont.)

S. pulchella Kutz.					
S. ulna (Nitzsh.) Ehr.					
Tabellaria fenestrata (Lyngb.) Kutz.	f	7-8			
T. flocculosa (Roth) Kutz.					
* *Thalassionema nitzschioides* Grun.	c;n	1-12	(9) 100,000 B,F./a	(11) 242,000 B.B./d	eurythermal euryhaline
Thalassiosira baltica (Grun.) Ost.	n	3			
T. bioculata (Grun.) Ost.	a;n	3-6,9	spring 400-B.F./a	mean T. of occurrence = 2.8°C.	
T. condensata Cleve	n				
* *T. decipiens* (Grun. ex Van Heurck) Jorg.	b;n	1-12	(4-8)14,000 B.F./a	(2) 38,000 M.B./d	(3) - E. Basin abun./c
* *T. gravida* Cleve	nt;n	3-9	(4) 100,000 B.F./a	(3)426,000 M.B./d	opt.T = 4.2°C. opt.S = 31.8 ‰
T. hyalina (Grun.) Gran	a;o	3-5,9-10	spring 55,000/B.F./a	stenothermal stenohaline	opt.T = 2.3°C. opt.S = 33.8 ‰
* *T. nordenskioeldii* Cleve	a,b;n	1-12	(4) 700,000 B.F./a	(4) 700,000 M.B./d	opt.T = 2.3°C. opt.S = 27.9 ‰
T. rotula Meunier	t;n	3-4			
T. subtilis (Osten.) Gran	t;o	3			
Thalassiothrix frauenfeldii Grun.	t;o	6-8	dom. 1915 W.Basin/c	abund.-M.B. 1925/c	
T. longissima Cleve & Grun.	a,b;o	3-10	rare-B.F./a	abund.-M.B./c 1925	
Trachyneis aspera (Ehr.) Cleve					
Trigonium arcticum (Brightw.) Cleve					
Triceratium alterans		1-9			

Table 3-19 (cont.)

Dinophyceae:

	Amphidinium crassum Lohm.	n	5-7	(5) 170,000 M.B./d	
	A. oceanicum Lohm.		9		
	Amphidinium sp.				
	Ceratium arcticum (Ehr.) Cleve	a;n	1-8	< 10°C.	B.F. 420/a
	C. bucephelum (Cleve.) Cleve	nt	3-9	(8) 2,080 B.F./a	
	C. furca Ehr.	nt;n		opt.T = 15°C. opt.S = 25.0 ‰	
	C. fusus (Ehr.) Duj.	t;o,n	1-12	B.F. 760/a	opt.T = 20°C. eurythermal
	C. lineatum Ehr.	nt	1,4-12	(9) 200 B.F./a	
*	C. longipes (Bail.) Gran	a,b;o	1-12	(6)4,260 B.F./a	
	C. macroceros (Ehr.) Cleve	nt	8-10		
*	C. tripos (Mull.) Nitzsch	t;o	1-12	(8) 580 B.F/a	abund.- winter,summer/b
	Dinophysis accuminata Clap. & Lach.		4-9	(6) 1,100 B.F./a	
	D. acuta Ehr.	o	3-10	rare-B.F./a	widely distrib. G.M./b
	D. arctica Mer.	a;o	4-5,11	< 10°C.	
	D. longi-alata Gran & Braarud		4-5	rare-B.F./a	
	D. norvegica Clap. & Lach.	n	1,4-11	(8) 1,560 B.F./a	
	D. ovum Schutt	o	4-10	B.F./a 200	
	D. parvula Schutt				
	D. recurva Kof. & Skogs.				

Table 3-19 (cont.)

D. robusta Gran & Braarud		4-5,8-9		
D. rotundata Clap. & Lach.				
D. sphaerica Stein	st;o	5,10		
Diplosalis lenticula Bergh.		8	rare-B.F./a	
Exuviella baltica Lohm.	c	1-12	(6) 6,600 P.B./a	opt.S = 10 ‰
E. marina Cienkowski	n	1-10	(8)B.F./a	
E. perforata Gran	n	8		
Glenodinium danicum Paul.		7-8		
G. lenticula (Bergh.) Schiller		4-5,7-9		
Glenodinium sp.	f,br			
Gonyaulax digitale (Pouchet) Kof.	n	7-8		
G. longispina Lebour	n	8-9	rare	
G. orientalis Lind.		8		
G. spinifera (Clap & Lach.) Diesing	n	8-9		
* *G. tamarensis* Lebour	n	3-12	dom.sp. B.F./a	(9) 1973 B.B./d
G. triacantha Jorg.	n	5-9	rare-B.F./a	
Gymnodinium lohmanni Paul.		4-8	(5) 800 B.F./a	
Mesoporos asymmetricus (Schiller) Lillick		10		
M. perforatus (Gran) Lillick		12		
Minuscula bipes (Paul .) Lebour	n			
Noctiluca milaris Sur.		5,8,12		

Table 3-19 (cont.)

Oxytoxum gracile Schiller		8		
O. reticulatum (Stein) Butschli		8		
Peridiniopsis rotunda Lebour			(7) 39,400 B.F./a	
Peridinium achromaticum Levander	n,br	8-9		
P. americanum Gran & Braarud		4-5,9-10		
P. breve Paulsen	a;n	3,5,9-10	present B.F./a	
P. brevipes Paulsen	b;n	4-9	common B.F./a	
P. cerasus Paulsen	n	4-9	(5) 400 B.F./a	
P. conicoides Paulsen	a;n	4-12	present B.F./a	
P. conicum (Gran) Ost. & Schmidt	n,o	4-9	eurythermal coastal B.F./a	
P. crassipes Kof.	o	8	central Gulf/b	eurythermal
P. curvipes Ost.	n	4-6	(5) B.F./a	
P. denticulatum Gran & Braarud		3-5,9-10	(4-5) B.F./a	
P. depressum Bail.	b;o,n	3-12	entire Gulf	
P. divergens Ehr.	n	3-9	scattered B.F./a	
P. excentricum Paulsen		8		
P. faeroense Paulsen	n			
P. fimbriatum (Meun.)				
P. gracile Gran & Braarud				
P. granii Ost.	b;n	1,3,5-10		
P. globulus Stein	st	4-9		

Table 3-19 (cont.)

P. hangoei Schiller		3-6		
P. minisculum Paul. (= Miniscula bipes Paul.)		1,7-8,12		
P. monacanthum Broch	a	4-5	present B.F./a	
P. novascotiense Gran & Braarud		4		
P. obtusum Karsten		7-8		
P.oceanicum Vanhoffeni	o			
P. ovatum (Pouchet) Schutt	o	4-5,8-9	(5) B.F./a	eurythermal euryhaline
P. pallidum Ost.	o,n	8-10	rare sp.	
P.pellucidum (Bergh) Schutt	n	3-9	(5) B.F./a	eurythermal euryhaline
P. pentagonum Gran	n	5,9	present B.F./a	
P. pyriforme Paulsen	o	4-5,8-9	(5) B.F./a	
P. roseum Paulsen	b;n			
P. rotundatum (Lebour) Schiller		7-8		
P. simplex Gran & Braarud		1-6,9-10	present entire area/b	
P. steinii Jorg.	o,n	6,8-9	rare-B.F./a	
P. sub-curvipes Lebour	o			
P. subinerme Paulsen	a,b;n	7-6	present B.F./a	
P. thorianum Paulsen		4-5	scattered B.F./a	
P. triquetrum (Ehr.) Lebour (= Heterocapsa triqueta Paulsen)	n,e	3-10	(8)120,000 B.F./a	(8) 103,000 M.B./d
P. trochoideum (Stein) Lemm.	n	3-9	(8) 6,900 B.F./a	
P. variegatum Peters		5		

Table 3-19 (cont.)

Phalacroma irregulare Leb.		1,3	
P. parvulum			
Prorocentrum micans Ehr.	c;n,e	1,5,8-12	abundant in winter/b
P, minimum Schiller		12	
P. scutellum Schroder	o	4-8	
P. triangulatum Martin			
Protoceratium reticulatum (Clap & Lach.) But.	nt;n	8	opt.T = 25°C.
Pyrophacus horologium Stein		8	
Chrysophyceae :			
Chrysosphaerella longispina Laut.			
Cyclonexis annularis Stokes			
Dictyocha fibula Ehr.		1,3,6-10	scattered B.F./ a
Dinobryon sertularia Ehr.			
Distephanus speculum (Ehr.) Haek.	o	1-10	(10) 35,200 B.F./a
Ebria antiqua Schulz		12	
E. tripartita (Schum.) Lemm.		4,7-9	(9) 740 B.F./a
Skadovskeilla sp.			
Synura uvella Ehr.			
Uroglena soniaca			
Cryptomonadaceae :			
Chroomonas sp.			

Table 3-19 (cont.)

Haptophyceae :

Acanthoica acanthifera Lohm.	o	6,9	(9)280-B.F./a
A. acanthos Schiller		1-3,6,9-12	
A. coronata Lohm.		3	
A. monospina Schiller		3,9	
Calyptrosphaera oblonga Lohm.		9	rare-B.F./a
Calyptrosphaera sp.			
C. uvella Schiller		3	
Coccolithus pelagicus (Wall.) Schiller		1,3-9	< 200-B.F./a
Discosphaera tubifer (Murr. & Black.) Lohm.		3	
Lohmannosphaera adriatica Schiller		3,8-9	(8) 60 B.F./a
L. subclausa Gran & Braarud			
Phaeocystis pouchetii (Harriot) Lagerh.		2-5	(4) 1,160,000 M.B./d
POntosphaera bigelowi	o	8-9	680-G.M./b
P. huxleyi Lohm.	o	1,3-9	(7) 308,000 E.Gulf/b
P. ovalis Schiller		1	
Rhabdosphaera stylifera Lohm.		1,3,9-10	(9) 1,420 B.F./a
R. tubulosa Schiller		1	
Scyphosphaera apsteini Lohm.		3	
Syracosphaera mediterranea Lohm.		3,10-11	(10) 41,000 M.B./d
S. pulchra Lohm.		9-10	rare-B.F./a

Table 3-19 (cont.)

Prasinophyceae :				
Halosphaera viridis Schmitz	o,n	5-10	eurythermal euryhaline	
Chlorophyceae :				
Ankistrodesmus convolutus	f			
Bipedimonas sp.	f			
Carteria sp.			(6) 135,000 B.B./d	
Chlamydomonas bullosa				
C. uva maris				
Chlamydomonas sp.		1-12	(6) 900,000 M.B./d	(12) 1,551,000 M.B./d
Closterium danae	f			
Cosmarium sp.	f			
Crucigenia sp.	f			
Dictyosphaerium pulchellum Wood.	f			
Dunaliella parva	br			
D. tertiolecta	br			
Kirchneriella obesa (West) Schmidle	f			
Pediastrum sp.	f			
Pyramimonas grossi	f			
P. plurioculata	f			
Scenedesmus dimorphus (Turp.) Keut.	f			

Table 3-19 (cont.)

S. quadricauda (Turp.) de Bréb	f		
Thalassomonas sp.	f		
Xanthidium antilopaeum (Breb.) Kutz.	f		
Cyanophyceae:			
Anabaena sp.	f		
Gloeocapsa sp.	f	1,9	
Lyngbya sp.	f		
Merismopedia elegans Braun	f	1	
M. punctata Meyen	f		
Nostoc sp.	f		
Oscillatoria sp.	f		
Spirulina major	f		
Euglenophyceae:			
Etripea sp.	n		(7) 169,000 M.B./d
Euglena sp.	n	3-9	(6) 48,000 M.B./d
E. viridis			
Eutreptia lanowii Steuer	n	4-9	(6) 20,680 B,F./d
Eutreptiella sp.			
Phacus sp.			
Trachelomonas sp.			

Zooplankton

The following checklist includes both species that remain pelagic throughout their lives (holoplankton) and the species of benthic invertebrates that have a pelagic stage during some part of their lives (meroplankton). The list does not include larval fishes, although they are considered as a component of the zooplankton. The species of larval fish found in the study area are listed in Chapter 12.0, Fishes.

Table 3-20 Zooplankton checklist

PHYLUM CTENOPHORA

CLASS TENTACULATA

Bolinopsis infundibulum
Mertensia ovum
Mnemiopsis leidyi
Pleurobrachia pileus

CLASS NUDA

Beroe cucumis

PHYLUM CNIDARIA

CLASS HYDROZOA

Aeginura grimaldii
Aequorea albida
A. tenuis
Agalma elegans
Aglantha digitale
Aglaura hemistoma
Bougainvillia carolinensis
B. superciliaris
Catablema vesicarium
Dimophyes arctica
Euphysa aurita
E. flammea
Halicreas minimum
Halopsis ocellata
Hybocodon pendulus
H. prolifer
Laodicea undulata
Lensia conoidea
Leuckartia octona
Liriope tetraphylla
Melicertum octocostatum
Mitrocomella polydiademata
Nanomia cara
Nemopsis bachei
Obelia spp.
Phialidium bicophorum
P. languidum
Physalia physalia
Physophora hydrostatica

Table 3- 20 Zooplankton checklist

Podocoryne borealis
P. carnea
Ptychogena lactea
Rathkea ocopunctata
Rhacostoma atlanticum
Rhopalonema funerarium
R. velatum
Sarsia tubulosa
Staurophora mertensi
Stomotoca pterophylla
Tiaropsis multicirrata
Tima formosa
Toxochis kellneri

CLASS SCYPHOZOA

Aurelia aurita
A. limbata
Cyanea capillata
Dactulometra quinquecirrha
Haliclystus auricula
H. salpinx
Halimocyathus lagena
Lucernaria quadricornis
Pelagia noctiluca
Periphylla perphylla
Phacellophora camtschatica

PHYLUM ROTIFERA

CLASS MONOGONANTA

Kellicottia longispina
Keratella cochlearis
Notholca foliacea
Synchaeta balthica
S. johanseni
S. triophthalma
S. littoralis
Trichocera stylata

PHYLUM MOLLUSCA

CLASS GASTROPODA

Clione limacina

Table 3-20 Zooplankton checklist

Diacria trispinosa
Limacina helicina
L. inflata
L. retroversa
Littorina littoria (larvae)
Paedoclione doliiformis
Pneumodermopsis paucidens

CLASS PELECYPODA

Amonia aculeata (larvae)
A. simplex (larvae)
Ensis directus (larvae)
Macoma balthica (larvae)
Modiolus demissus (larvae)
Mytilus edulis (larvae)
Placopecten magellanicus (larvae)

CLASS SCAPHOPODA

Dentalium entale stimpsoni

CLASS CEPHALAPODA

Rossia palpebrosa

PHYLUM ANNELIDA

CLASS POLYCHAETA (all larvae)

Autolytus alexandri
A. cornutus
A. emertoni
A. prismaticus
A. prolifer
Lepidonotus squamatus
Nereis virens
Ophioglycera gigantea
Pectinaria granulata
Phyllodoce sp.
Polydora commensalis
P. concharum
P. ligni
P. quadrilobata
P. socialis
P. websteri

Table 3-20 Zooplankton checklist

Scolecolepides viridis
Sternaspis scutata
Tomopteris helgolandia
T. septentrionalis

PHYLUM ARTHROPODA

CLASS CRUSTACEA

SUBCLASS BRANCHIOPODA

Bosmina longirostris
Evadne nordmanni
E. spinifera
Penilia avirostris
Podon intermedius
P. leuckarti
P. polyphemoides

SUBCLASS COPEPODA

ORDER CALANOIDA

Acartia bifilosa
A. clausi
A. longiremis
A. tonsa
Aetidius armatus
Anomalocera ornata
A. patersoni
Bradyidus similis
Calanus finmarchicus
C. glacialis
C. hyperboreus
Candacia armata
Centropages bradyi
C. hamatus
C. typicus
Dioptomus minutus
Eucalanus attenuatus
E. elongatus
Euchaeta media
E. norvegica
Euchirella rastrata
Eurytemora affinis

Table 3-20 Zooplankton checklist

E. americana
E. herdmani
E. hirundoides
Gaidius tenuispinis
Heterorhabdus spinifrons
Labidocera acutifrons
L. aestiva
L. detruncata
Mecynocera clausi
Metridia longa
M. lucens
Microcalanus pusillus
Nannocalanus minor
Paracalanus crassirostris
P. parvua
Phyllopus bidentatus
Pleuromomma abdominalis
P. gracilis
P. robusta
P. xiphias
Pontella atlantica
P. meadii
P. mimocerami
P. securifer
Pontellopsis regalis
P. villosa
Pseudocalanus minutus
Pseudodiaptomus coronatus
Rhincalanus cornutus
R. nasutus
Scolecithricella minor
Scolecithrix danae
Temora longicornis
T. stylifera
T. turbinata
Tortanus discaudatus
Tortanus setacaudatus

ORDER HARPACTICOIDA

Alteutha oblonga
Canuella canadensis
Dactylopodia tisboides
D. vulgaris
Diosaccus tenuicornis
Ectinosoma neglectum

Table 3-20 Zooplankton checklist

Harpacticus chelifer
H. gracilis
H. littoralis
H. uniremis
Macrosetella gracilis
Metis ignea
Microsetella norvegica
M. rosea
Parathalestris croni
P. jacksoni
Thalestris gibba
T. longimana
Tisbe furcata
Zaus abbreviatus
Z. goodsiri
Z. spinatus
Tachidius brevicornis
Tachidius littoralis

ORDER CYCLOPOIDA

Ergasilus sp.
Oncea conifera
Oithona brevicornis
Oithona plumifera
O. similis
O. spinirosris
Sapphirina gemma

ORDER MONSTRILLOIDA

Monstrilla canadensis
M. dubia
M. helgolandica
Thaumaleus rigidum

ORDER CALIGOIDA

Caligus rapax

SUBCLASS CIRRIPEDIA (all larvae)

Balanus balanoides
B. crenatus
B. improvisus
Dendrogaster sp.

Table 3- 20 Zooplankton checklist

SUBCLASS MALACOSTRACA

ORDER MYSIDACEA

Erythrops erythrophthalma
Heteromysis formosa
Mysis mixta
M. stenolepis
Neomysis americana
Praunus flexuosus

ORDER CUMACEA

Campylaspis rubicunda
Diastylis abbreviata
D. polita
D. quadrispinosa
D. sculpta
Eudorella emarginata
E. hispida
E. truncata
Lamprops fuscata
Leptostylis longimana
Leucon americanus
L. nasicoides
Oxyurostylis smithi
Petalosarsia declivis

ORDER ISOPODA

Aegathoa oculata
Calathura branchiata
Chiridotea tuftsi
Cyathura polita
Edotea montosa
Idotea balthica
I. metallica
I. phosphorea
Limnoria lignorum
Munna kroyeri
Munnopsis typica

ORDER AMPHIPODA (most as larvae)

Aeginina longicornis
Ampelisca abdita

Table 3-20 Zooplankton checklist

A. agassizi
A. vadorum
Ampithoea rubricata
Anonyx lilljeborgi
A. nugax
Calliopius laevisusculaus
Caprella linearis
Corophium insidiosum
C. volulator
Dexamine thea
Dulichia curticauda
D. fulcata
D. monocantha
D. porrecta
Gammarus duebeni
G. lawrencianus
G. micronatus
G. oceanicus
Hyperia galba
H. medusarum
Jassa falcata
J. marmorata
Leptocheirus pinguis
Maera danae
Melita nitida
Metopa alderi
M. borealis
M. spectabilis
Metopella angusta
Monoculodes edwardsi
M. intermeius
Orchomenella minuta
O. pinguis
Parametopella cypris
Parathemisto gaudichaudii
P. gracilipes
Phoxocephalus holbolli
Phronima sedentaria
Pleusymtes glaber
Podocerus falcatus
Pontocrates sp.
Pontogeneia inermis
Pontoporeia femorata
Proboloides holmesi
Stegocephalus inflatus
Stenopleustes gracilis

Table 3-20 Zooplankton checklist

Stenothoe minuta
Synchelidium americanum
Syrrhoe crenulata
Tiron acanthurus
Unicola dissimilis
U. inermis
U. irrorata

ORDER EUPHAUSIACEA

Euphausia krohni
Meganyctiphanes norvegica
Nematoscelis megalops
Thysamoessa gregaria
T. inermis
T. longicaudata
T. raschii
Thysanopoda acutifrons

ORDER DECAPODA (all larvae)

Cancer irroratus
Carcinus maenas
Crangon septemspinosus
Homarus americanus
Hyas araneus
H. coarctatus
Callinectes sapidus
Hippolyte sp.
Libinia sp.
Neopanope texana
Pagurus sp.
Palaemonetes vulgaris
Pandalus borealis
P. montagui
Pasiphea multidentata
Pinnixia sp.
Pinnotheres maculatus
Polyonyx macrocheles
Spirontocaris sp.
Uca sp.
Upogebia sp.

ORDER STOMATOPODA

Squilla empusa (larvae)

Table 3-20 Zooplankton checklist

PHYLUM BRYOZOA

Electra sp. (larvae)

PHYLUM PHORONIDA

Phoronis sp.

PHYLUM CHAETOGNATHA

Eukrohnia hamata
Sagitta elegans
S. enflata
S. hexaptera
S. lyra
S. maxima
S. serratodentata

PHYLUM ECHINODERMATA (all larvae)

CLASS ASTEROIDEA

Asterias vulgaris

CLASS ECHINOIDEA

Amphipholis squamata
Strongylocentrotus dröbachiensis

CLASS HOLOTHUROIDEA

Cucumaria frondosa
Psolus sp.

PHYLUM CHORDATA

CLASS THALIACEA

Iasis zonaria
Salpa fusiformis
Thalia democratica
Thetys vagina

CLASS COPELATA

Doliolum sp.

Table 3-20 Zooplankton checklist

Fritillaria borealis
Oikopleura dioica
O. labradorensis
O. vanhoeffeni

Fishes

The following is a list of fishes normally found in the plankton-based pelagic habitat within the continental shelf area between Sandy Hook, New Jersey and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, i.e. if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance

A. The geographical distribution includes three categories

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west to that line.

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e. north, south, or throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh water
Brackish water
Nearshore - coastline to 18 m
Coastal - out to 91 m
Offshore - 91 m to the continental slope
Basin - deep basin of the Gulf of Maine
Banks - shallow, offshore banks areas, i.e. Georges Bank
Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species or a rare or endangered species. The life history of these species will be treated in Chapter 12.0, Fishes.

Table 3- 21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Sharks			
Mackeral shark Lamma nasus	common north	coastal to offshore	food - small fish
Mako Isurus oxyrhynchus	occasional south	coastal to oceanic	food - small fish
White shark Carcharodon cavcharias	occasional south	coastal to oceanic	food - large fish, invertebrates
Basking shark Cetorhinus maximus	occasional south	oceanic	food - zooplankton
Thresher shark Alopius vulpinus	common south	coastal to oceanic	food - schooling fish
Tiger shark Galeocerdo cuvieri	occasional south	coastal	food - fish invertebrates
Blue shark Priorace glauca	occasional south	offshore	food - small fish
Sandbar shark Carcharhinus milberti	common south	offshore	food - bottom fish, invertebrates
Dusky shark Carcharhinus obscurus	common south	offshore	food - fish, large invertebrates
Hammerhead shark Syphyrna zygaena	occasional south	coastal to nearshore	food - fish, large invertebrates
Spiny dogfish *** Squalus acanthias	abundant throughout	nearshore to offshore	food - fish, invertebrates
Black dogfish Centrocyllium fabricci	occasional throughout	offshore over 275 m	food - pelagic invertebrates

Table 3- 21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Herrings and tarpons			
Atlantic tarpon Megalops atlantica	rare south	coastal	
Round herring Etrumeus teres	occasional south	coastal	
Atlantic herring *** Clupea harengus	abundant north	coastal, banks	food - zooplankton, esp. copepods
Hickory shad Alosa mediocris	common south	fresh water to coastal	food - zooplankton, small fish anadromous
Alewife Alosa pseudoharengus	abundant throughout	fresh water to coastal	food - zooplankton anadromous
Blueback herring Alosa aestivalis	common south	brackish to coastal	food - zooplankton anadromous
American shad Alosa sapidissima	common throughout	brackish to coastal	food - zooplankton anadromous
Spanish sardine Sardinella anchovia	rare south	coastal	food - zooplankton, esp. copepods
Menhaden *** Brevoortia tyrannus	abundant south	coastal	food - phytoplankton
Anchovies			
Anchovy Anchoa mitchelli	common south	nearshore to coastal	principally mouths of rivers food - copepods
Striped anchovy Anchoa hepsetus	rare south	coastal	food - copepods, univalve molluscs

Table 3- 21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
Salmons			
Brook trout Salvelinus fontinalis	rare throughout	fresh water	rarely running to brackish of salt water
Coho salmon Onchorhynchus kisutch	rare north	fresh water to coastal	introduced species anadromous
Atlantic salmon *** Salmo salar	rare throughout	fresh water to coastal	food - small fish, crustaceans anadromous
Brown trout Salmo trutta	common north	fresh water to brackish	food - fish, invertebrates introduced species
Smelts			
Rainbow smelt *** Osmerus mordax	abundant throughout	brackish to nearshore	food - small fish, crustaceans spawns brackish
Capelin Mallotus villosus	occasional north	coastal	food - small invertebrates eastern Maine, Bay of Fundy
Argentines			
Atlantic argentine Argentina silas	common north	offshore 55 - 183 m	
Eels			
Snipe eel • Nemichthys scolopaceus	rare throughout	offshore 183-366 m	

Table 3-21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
Needlefishes			
Atlantic needlefish *Stongylura marina*	common south	brackish to coastal	swift swimmer, predaceous, food-small fish, shrimp
Sauries			
Atlantic saury *Scomberesox saurus*	common south	oceanic	food - small fish, crustaceans
Flyingfishes			
Halfbeak *Hyporhamphus unifasciatus*	occasional south	coastal	food - herbivorous, green algae
Atlantic flyingfish *Cypselurus heterurus*	occasional south	oceanic	epipelagic habit
Codfishes			
Silver hake *** *Merluccius bilinearis*	abundant throughout	coastal to offshore	food - small fish, larger invertebrates
Pollock *** *Pollachius virens*	abundant north	coastal, Banks to 183 M	food - small fish, crustaceans
Dories			
American john dory *Zenopsis ocellata*	occasional throughout	offshore 51.2-366 m	
Snipefishes			
Longspine snipefish *Macrorhamphosus scolopax*	rare throughout	coastal oceanic	
Mullets			
Striped mullet *Mugil cephalus*	common south	coastal	food - plankton, marine plants

Table 3-21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
White mullet Mugil curema	common south	brackish to coastal	food - plankton, marine plants
Liza Mugil liza	occasional south	coastal	
Barracudas			
Northern sennet Sphyraena borealis	occasional south	coastal	food - small fish
Cornet fishes			
Bluespotted cornetfish Fistularia tabacaria	occasional south	coastal to 128 m	
Mackerals			
Atlantic mackeral *** Scomber scomber	abundant throughout	coastal to offshore	food - small fish, zooplankton
Chub mackeral Scomber japonicus	common south	coastal to offshore	food - small fish, zooplankton
Skipjack tuna Euthynnus pelamis	common south	oceanic	food - large, small pelagic fish
Little tunny Euthynnus alletteratus	occasional south	coastal to oceanic	food - fish, squid
Atlantic bonito Sarda sarda	occasional south	coastal to oceanic	food - fish, squid
Albacore Thunnus alalunga	occasional south	oceanic	food - fish
Bluefin tuna *** Thunnus thynnus	common throughout	coastal to oceanic	food - fish
Spanish mackeral Scomberomorous maculatus	occasional south	oceanic	food - small fish

Table 3-21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
Cero Scomberomorous regalis	occasional south	coastal	food - small fish
Snake mackerals			
Snake mackeral Gempylus serpens	rare south	oceanic	
Cutlassfishes			
Atlantic cutlassfish Trichiurus lepturus	rare south	oceanic	
Swordfishes			
Swordfish Xiphias gladius	common throughout	oceanic	food - fish
Marlins and sailfishes			
Sailfish Istiophorus platypterus	occasional throughout	oceanic	food - fish
White marlin Tetrapterus albidus	occasional south	oceanic	food - fish
Blue marlin Makaira nigricans	occasional south	oceanic	food - fish
Dolphins			
Dolphin Coryphaena hippurus	occasional south	offshore to oceanic	food - fish swift swimmer
Butterfishes			
Man-of-war fish Nomeus gronovii	rare south	oceanic	
Butterfish *** Poronotus triacanthus	abundant south	nearshore to 210 m	food - small fish, Pelagic invertebrates

Table 3- 21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
Barrelfish Hyperoglyphe perciformes	common south	coastal to oceanic	food - small fish, invertebrates
Pampanos and jacks			
Pilotfish Naucrates ductor	occasional south	oceanic	food - fish
Banded rudderfish Seriola zonata	occasional south	coastal to oceanic	food - fish
Round scad Decapterus punctatus	rare south	oceanic	food - small fish, copepods
Mackeral scad Decapterus macarellus	occasional south	oceanic	food - fish
Crevalle jack Caranx hippos	occasional south	oceanic	
Blue runner Caranx crysos	occasional south	oceanic	food - fish, shrimp
Rough scad Trachurus lathami	rare south	oceanic	food - fish
Bigeye scad Selar crumenophthalmus	rare south	oceanic	food - fish
Atlantic moonfish Vomer setapinnis	rare south	oceanic	
Lookdown Selene vomer	rare south	oceanic	
Permit Trachinotus falcatus	rare south	oceanic	
Florida pampano Trachinotus carolinus	rare south	oceanic	

Table 3- 21 Checklist of Fishes - Pelagic Habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Bluefishes			
Bluefish *** Pomatomous saltatrix	abundant south	coastal to oceanic	food - fish, squid
Temperate basses			
Striped bass *** Morone saxatilis	abundant throughout	nearshore to coastal	food - small fish, invertebrates
Tripletails			
Tripletail Lobotes surinamensis	rare south	oceanic	
Porgies			
Pinfish Logocon rhomboides	rare south	coastal	
Sheepshead Archosargus probatocephalus	common south	coastal	
Drums			
Weakfish Cynoscion regalis	common south	brackish to coastal	food - small schooling, invertebrates sandy bottom
Silver perch Bairdiella chrysura	occasional south	coastal	sandy bottom
Remoras			
Sharksucker Echeneis naucrates	occasional south	offshore to oceanic	attached to larger vertebrates
Remora Remora remora	occasional south	offshore to oceanic	attached to larger vertebrates

Table 3-21 Checklist of Fishes - Pelagic habitat

Species	Abundance, Geographical Distribution	Depth Distribution	Habit
Spearfish remora *Remora brachyptera*	occasional south	oceanic	attached to larger vertebrates
Spadefishes			
Spadefish *Chaetodipterus faber*	occasional south	coastal to oceanic	
Sunfishes			
Ocean sunfish *Mola mola*	occasional south	oceanic	food - jellyfish, ctenophores, salps

Table 3-22a Key species of Cetaceans in the Gulf of Maine

Common Name(s)	Species Name	Western Atlantic Range and Distribution	Habitat	Abundance Gulf of Maine	Dominance in Gulf of Maine
Harbor porpoise	Phocoena phocoena	New Jersey to Baffin Bay. Center of population in approaches to Bay of Fundy and inshore Gulf of Maine	Coastal and inshore waters.	4000-10,000	Numerically dominant cetacean
Pilot whale	Globicephala melaena	New York to Greenland. Especially common in Newfoundland.	Pelagic (winter) and coastal (summer)	NDA Most common whale seen in Cape Cod Bay, schools of 500 on Georges Bank	Frequently seen
Finback whale	Balaenoptera physalus	Population centered between 41°20'N and 57°00'N and from coast to 2000 m contour	Pelagic, but enter bays and inshore waters in late summer	7200	Dominant large whale, one of the most common cetaceans.
Sei whale	Balaenoptera borealis	New England to Arctic Ocean	Pelagic, does not usually approach coasts	NDA 1570 off Nova Scotia	Much less common than finback
Minke whale	Balaenoptera acutarostrata	Chesapeake Bay to Baffin Island in Summer, eastern Gulf of Mexico, northeast Florida and Bahamas in Winter	Pelagic, but may stay nearer to shore than other rorquals (except humpback)	NDA	Less common than finback but sighting are routine
Humpback whale	Megaptera novaeangliae	Common near land, but can be found in deep ocean	Approaches land more closely and commonly than other large whales. Also found in deep ocean	1500?	Routinely seen but much recorded from past abundance

Table 3-22a Key species of Cetaceans in the Gulf of Maine (cont)

Common Name(s)	Species Name	Western Atlantic Range and Distribution	Habitat	Abundance Gulf of Maine	Dominance in Gulf of Maine
Killer whale	<u>Orcinus orca</u>	Greenland	Mainly pelagic and oceanic	NDA Apparently not seen as commonly as in more northerly areas	Uncommon
Beluga	<u>Dalphinapteras leucas</u>	St. Lawrence River and Gulf to Arctic regions.	Brefer estuaries and shallow water areas	Rare visitor from Gulf of St. Lawrence	Rare
White-sided dolphin	<u>Lagenorhynchus acutus</u>	Cape Cod to Davis Strait.	Often schools with pilot whales, but is less common than that species.	Not common	Apparently not important by numbers.
White-beaked dolphin	<u>Lagenorhynchus albirostrus</u>	Massachusetts to Davis Strait, but ranges farther north into Arctic waters than <u>L. acutus</u> Rarely seen south of Labrador and Newfoundland.	Coastal waters	Rare stray in Gulf of Maine	Apparently minimal
Bottlenosed dolphin	<u>Tursiops truncatus</u>	Argentina to Greenland, but most common from Florida, West Indies and Caribbean to New England	Usually close to shore and near islands. Enter bays, lagoons, rivers	Rare	Rare
Right whale	<u>Eubalaena glacialis</u>	New England to Gulf of St. Lawrence. Possibly found as far south as Florida	Pelagic and coastal. Not normally inshore	Very rare. 200 - 1000	Much reduced from former importance. Very rare.

Table 3-22a Key species of Cetaceans in the Gulf of Maine (cont)

Common Name(s)	Species Name	Western Atlantic Range and Distribution	Habitat	Abundance Gulf of Maine	Dominance in Gulf of Maine
Sperm whale	Physeter catadon	Equator to 50°N (females and juveniles) or Davis Strait (males)	Pelagic, deep ocean	Very rare	Uncommon visitor
Bottlenosed whale	Hyperoodon ampullatus	Rhode Island to Davis Strait	Pelagic. Cold temperate and subarctic waters.	Poorly known. Between 260 - 700 taken annually in North Atlantic Ocean.	Poorly known
Beaked whale (North Sea)	Mesoplodon bidens	Recorded from Newfoundland and Massachusetts. Main range is in eastern Atlantic	Poorly known. Apparently frequents bays and seas.	Extremely rare. Expected as a stray visitor.	Minimal
True's beaked whale	Mesoplodon mirus	Northern Florida to Nova Scotia	Nothing is known.	Extremely rare. Poorly known.	Minimal.
Blue whale	Balaenoptera musculus	Gulf of St. Lawrence to Davis Strait. Routinely sighted on banks fringing outer Gulf of Maine. Population much reduced from original number of about 1,100 in western N. Atlantic.	Pelagic, deep ocean. However some summer in St. Lawrence estuary channels.	Generally not common. Some sightings expected in offshore regions.	Much less common than finback
Grey grampus, Risso's dolphin	Grampus griseus	Ranges south from Massachusetts.	Coastal waters. Habitat poorly known.	Uncommon, but possibly not rare.	Much less common than Phocoena

Table 3-22a Key species of Cetaceans in the Gulf of Maine (cont)

Common Name(s)	Species Name	Western Atlantic Range and Distribution	Habitat	Abundance Gulf of Maine	Dominance in Gulf of Maine
Pygmy sperm whale	*Kogia breviceps*	Tropics to Nova Scotia	Pelagic in warm ocean waters.	Very rare. Only 1 record.	Minimal
Common dolphin	*Delphinis delphis*	Caribbean Sea to Newfoundland. Very wide ranging. May be most widespread and abundant delphinid in world.	Seldom found inside 100 m contour, but does frequent seamounts, escarpments and other offshore features.	Poorly known. Probably more common than available records indicate. May be more common in Massachusetts Bay.	Not known. Possibly *Phoecoena* is competitor.

Table 3-22b Pinniped species in the Gulf of Maine

Family	Common Name(s)	Species Name	Western Atlantic Range or Distribution	Habitat	Abundance in Gulf of Maine	Relative Dominance in Gulf of Maine
Phocidae	*Harbor seal or common seal	Phoca vitulina concolor (Dekay)	Labrador to Rhode Island; occasionally to Carolinas	Inshore residents of bays and estuaries. Breeding, sunning, and resting on half-tide ledges-Non-migratory	6000+ Maine waters 5000-6000 Canadian Maritime provinces	Common
Phocidae	*Gray seal or Atlantic seal "horsehead seal"	Halichoerus grypus (Fabricus)	Gulf of St. Lawrence to coast of Newfoundland; S. to Massachusetts	Remote coastal ledges and sand shoals. Dispersal outside of breeding seasons; transient in Maine waters	18,000 Maritime province waters 100± seasonally in Maine; breeding colony of 10-15 at Nantucket	Uncommon in U.S. Gulf of Maine waters
Phocidae	Harp seal	Pagophilus groenlandicus (Erxleben)	N. Atlantic and adjoining Arctic waters	Pelagic, breeding on pack ice; migratory	Occasional stray	Rare, accidental
Phocidae	Hooded seal	Crystophora cristata (Erxleben)	S. Greenland and Baffin Island to Gulf of St. Lawrence	Pelagic, breeds on drifting floe ice	Occasional stray	Rare, accidental
Odobenidae	Walrus	Odobenus rosmarus (Linnaeus)	Ellsmere Is. to Barrow Strait S. to Hudson Bay and Hudson Strait	Remains in near-shore waters of remote islands or ice	Rare visitor	Rare, accidental

*Denotes key species based on present abundance, estimated historical abundance or ecological importance

REFERENCES

Bigelow, H. D., L. C. Lillick, and M. Sears. 1940. Phytoplankton and planktonic protozoa of the offshore waters of the Gulf of Maine. Trans. Am. Phil. Soc. 31:149-237.

Conover, R. J. 1971. Some relations between zooplankton and bunker C oil in Chadabucto Bay following the wreck of the tanker "Arrow". J. Fish Res. Board Can. 28(9).

Fish, C. J. and M. W. Johnson. 1937. The biology of zooplankton population in Bay of Fundy and Gulf of Maine with special reference to production and distribution. J. Fish. Res. Board. Can. 3(3): 189-332.

Graham, J. J., S. B. Chenoweth, C. W. Davis. 1972. Abundance, distribution movements and lengths of larval herring along western coast of Gulf of Maine. Fish. Bull. 70:307-321.

Graham, J. 1973. Interrelationships of coastal plankton: production and trophic levels. pp 68-93. In "A socio-economic and environmental inventory of the outer continental shelf and adjacent waters." TRIGOM prelim. report, unpubl. manuscr.

Isaacs, John D. 1972. Unstructured marine food webs and "pollutant analogues." Fish. Bulletin 70(30):1053-1059.

Kharlov, K. M. and L. L. Finenko. 1970. Organic macromolecular compounds dissolved in sea water and their inclusion into food chains. pp 5-17 In J. H. Steele, ed. "Marine Food Chains." Berkeley: Univ. of Calif. Press, 552 pp.

Krey, J. 1967. Detritus in the ocean and adjacent sea. pp. 389-394. In G. H. Lauff, ed. "Estuaries." AAAS publ. no. 83. 757 pp.

Odum, E. P. 1971. Fundamentals of Ecology. Phila.: W. B. Saunders Co. 574 pp.

Petypa, T. S., E. V. Pavlova, and G. N. Mironov. 1970. The food web structure, utilization and transport of energy by trophic levels in the planktonic communities. pp. 142-167. In J. H. Steele, ed. "Marine Food Chains". Berkeley: Univ. of Calif. Press. 552 pp.

Redfield, A. C. 1941. The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. Biol. Bull. 80:86-110.

Sherman, K. 1966. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1964. USFWS Spec. Sci. Rep. Fish. No. 530:1-11.

Sherman, K. 1968. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1965 and 1966. USFWS Spec. Sci. Rep. Fish. No. 562:1-11.

Sorokin, M. I. 1971. Bacterial populations as components of oceanic ecosystems. Mar. Biol. 11:101-105.

Stephens, G. C. 1967. Dissolved organic material as a nutritional source for marine and estuarine invertebrates. pp. 367-373. In G. H. Lauff, ed. "Estuaries" AAAS publ. no. 83. 757 pp.

Thomas, J. P. 1971. Release of dissolved organic matter from natural populations of marine phytoplankton. Mar. Bio. 11:311-323.

3.5.2 OFFSHORE BOTTOM

This section treats the biology of the offshore bottom community. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed and its areal distribution shown. The major biological components of the habitat are the benthic invertebrates and the fishes. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to the Plant and Animal Profiles, Chapters 10.0 and 12.0.

HABITAT DEFINITION/DESCRIPTION

The offshore bottom habitat consists of all bottom types lying under more than 20 m of water to the edge of the continental shelf. For this report, it is arbitrarily divided up into banks, or those bottoms lying under 20-100 m of water, and basins, bottoms deeper than 100 m. This habitat is one of the largest in areal extent and yet the least studied in the Gulf of Maine. Studies of bottoms in Buzzards Bay (Sanders, 1960; Wieser, 1960) Cape Cod Bay (Rhoads and Young, 1971); Rhoads and Young, (1971), however, provide some clues as to how this habitat functions. Wigley (1968, 1970) has made preliminary reports on an extensive survey of the bottom macroenvironment in the Gulf of Maine.

HABITAT DYNAMICS

Environmental Conditions

The offshore bottom habitat is buffered from most stresses by the overlying waters. Thus, temperature is relatively uniform, varying at most 4-10 C annually and in deeper portions (>25m) that lie beneath the thermocline rarely rising above 4 C. Salinity is also constant (>31 $^{o}/oo$). Currents and, relatedly, sediment type are the most influential factors of this habitat which lies below the thermocline and euphotic zone. The biota are dependant on debris and detritus originating outside the habitat.

Microenvironments

The biota in the offshore bottom can be divided into three types; the infauna, i.e. animals living in tubes or burrows beneath the sediment surface; the epifauna, i.e. species living on or just above the sediment surface; and the interstitial fauna, i.e. those very small species that live between, or on, the sediment particles. The specific species found within each type at a particular location are determined to a large extent by the type of bottom.

Offshore bottoms are largely unconsolidated sediments and are loosely classified by the sediment particle size. The finest sediments are the silt-clay bottoms. Increasing in coarseness are the silt-sand (≈25 percent silt), sand, sand-shell-gravel, and gravel bottoms.

In general, deposit-feeders dominate in the finer sediments, while suspension feeders become more important as the sediment becomes coarser (Sanders, 1958). This is probably the result of several factors. First, current strength increases as the particle size increases. Thus the food supply for suspension feeders is more often renewed over coarse sediments. Secondly, a flocculent layer occurs very often over a fine sediment bottom, clogging the filtering apparatus. Finally, the food supply for deposit feeders increases as particle size decreases. Exceptions to the exclusion of suspension-feeders from fine sediments occur when the mud surface becomes stabilized by tube-dwelling organisms. Certain suspension feeders can then survive (Rhoads and Young, 1971). The Sessile epifauna become more well developed in the harder sediment types (gravel).

The diversity of the interstitial fauna is also affected by sediment type. Evidence exists that there are two niches open in the interstices of sandy sediments - sand grain scrapers and deposit eaters - and only one is finer substrates - deposit eaters (Wieser, 1960).

Nutrient and Seasonal Cycles

There has been no work dealing directly with these cycles. However, certain predictions can be made on the basis of present knowledge. Seasonal cycles in physical conditions appear to be all but nonexistent in this habitat. A seasonal cycle in food renewal may, however, be expected since the bottom is dependent for its food source on detritus originating in the overlying waters. Pelagic production has been shown to have a markedly seasonal cycle (see offshore pelagic).

The major primary energy source for the biota is probably the bacteria feeding on the detritus. Bacteria also grow on fecal pellets, enriching their nitrogen content (Newell, 1965). The deposits may be considered a closed system whereby nutrients and food contained within the sedimentary deposits are constantly reworked (Rhoads and Young, 1970;

Levinton, 1972), with bacterial augmentation occurring simultaneously. Since the bodies of organisms return to the nutrient pool at death, caloric content of the detritus originating from overlying waters need only equal the energy lost by respiration and gamete spawning for a steady state system to survive, dependent on continuous nutrient recycling within the substrate. The importance of organisms such as *Molpadia ooletica* (a sea cucumber)(Rhoads and Young, 1971) and *Yoldia limatula* (Rhoads and Young, 1970) that return buried sediment, and any nutrients trapped in it, to the surface in such a system cannot be underestimated.

Food Webs

As indicated above, each sediment type supports a particular association of species. Consequently the food webs and major energy pathways will differ from type to type. Very little work has been done elucidating these food webs, but it is possible to construct a generalized diagram from known feeding habits. The one included here (Figure 3-200) is only an indication of what the relationships might be and includes species found in all sediment types.

The most striking characteristic of the offshore bottom habitat is the exchange of material between the benthos and the water. As stated above, a constant rain of detritus augments the benthic food supply. Most of the benthos have pelagic larvae which contribute to the food supply in the pelagic habitat.

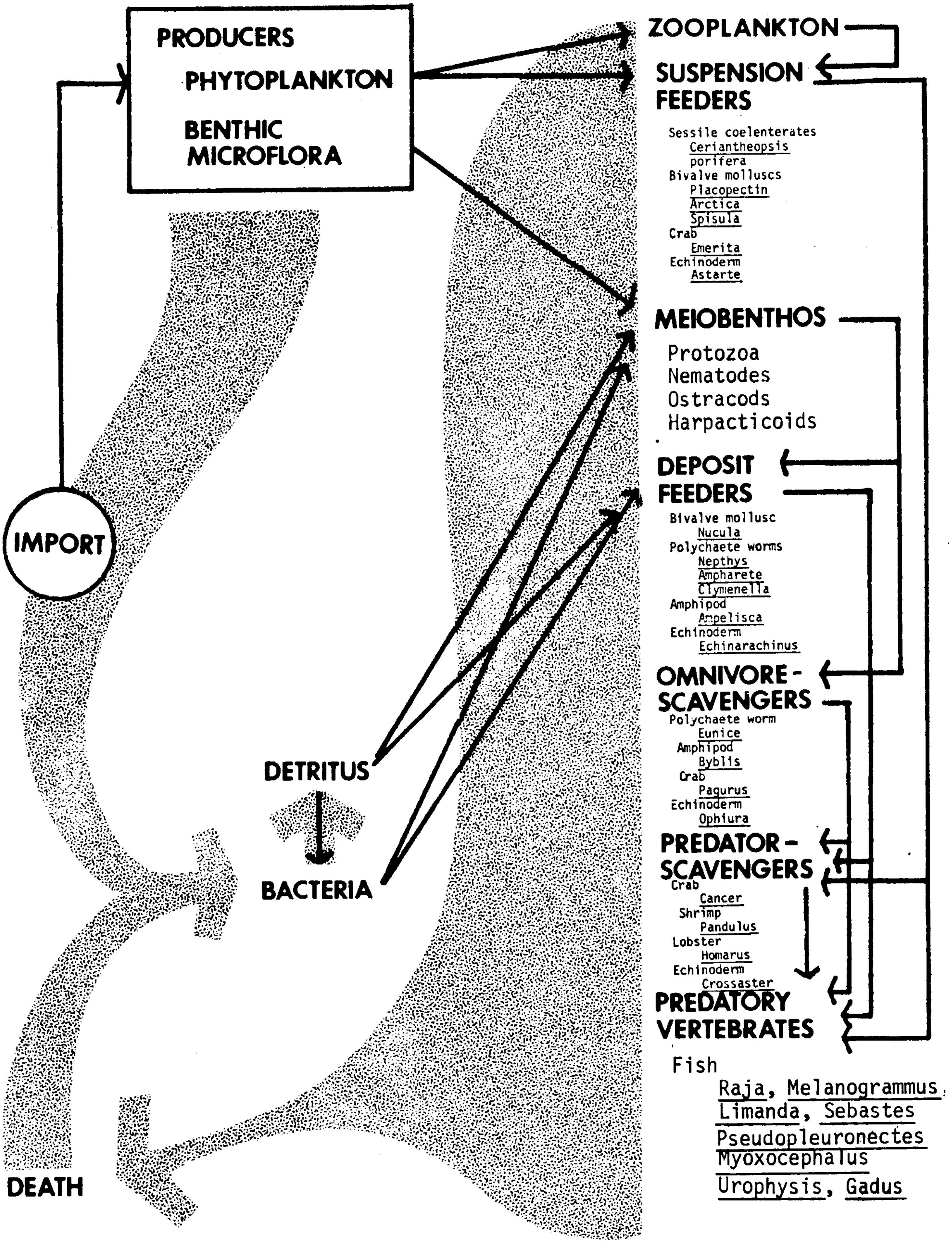
The importance of the meiofauna in the metabolism of detritus and as a food source has not been determined. Wieser (1960) found that the biomass/m^2 of the meiofauna in a silty sediment in Buzzards Bay (Station R) averaged at least 3 percent of the biomas of the macrofauna (Sanders, 1960). From this alone, it can be hypothesized that the meiofauna are of some significance in this habitat.

Relative Productivity

As shown in Table 1, available measures of productivity show that wide differences exist both between large areas of bottom and, within those areas, among different sediment types. Wigley (1970) also showed that in general, the benthos on Georges Bank are more abundant and diverse than in areas south of Martha's Vineyard. He also found that the fauna of the gravel beds in the Gulf of Maine were the richest and most complex of all (Wigley, 1968), although he did not report any measures of this. Clearly this is an area that needs intensive work.

Natural Stress

The natural stresses on the organisms of this habitat are not well



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 3-200

Food Web of Offshore Bottom Habitat

known; however, considering the stable nature of the environment the principal stresses would probably be competition for space and predation.

EFFECT OF MAN-INDUCED STRESS

Pollutants, such as heavy metal wastes, that render the sediment toxic to settling larvae would disrupt recruitment of the benthic fauna (Mileikovsky, 1970) and depress productivity. The dumping of such wastes as sewage sludge and dredging spoil increases the organic content of the sediment and lower the oxygen content of overlying waters, to a point where the normal fauna cannot survive and the bottom becomes devoid of life (Pearce, 1970). Sediments surrounding such a site show an impoverished fauna consisting of fragments of the original benthic communities. Pearce (1970) found that epifauna, such as crabs, that stray into a disposal site quickly develop exoskeletal lesions and clogged gills that lead to death.

Any increase in turbity, such as might accompany dredging, would alter the balance between suspension feeders and deposit feeders toward the latter in many communities. Since the evidence so far indicates that productivity is greater in sandy areas, probably due to the presence of suspension feeders in addition to deposit feeders, an increase in silt and turbulence would be expected to depress productivity. This would finally be reflected in a decrease of the bottom-fish catch.

Toxic substances, such as persistent pesticides would be expected to accumulate in the bottom sediments. Consequently, species feeding on the sediments could concentrate the toxins, passing them on to their predators. Evidence for persistent pesticide poisoning, for example, has been found in eider ducks (Somaterice mollessima) (Colemanand van Genderen, 1972).

The above discussion is by no means a complete survey of man-induced stresses and their consequences.

BIOLOGICAL COMPONENTS

General Distribution

As discussed above, within a specific geographic locality, separate communities are associated with each sediment type. However, from locality to locality, the particular community associated with, for example, sand, will be very different. Consequently, work to date has revealed a great diversity in the fauna of offshore bottoms. Rather than present an exhaustive review of the literature, a sample of this diversity will be given. Tables 3-24 to 3-26 list the most abundant species (usually accounting for 80-90 percent of the biomass) associated with different sediment types within three localities. For more complete lists, the reader is referred to the original source.

It should be noted that the very great differences in the faunal types listed for the Gulf of Maine versus the more southern bays may be only apparent. Wigley's data were not treated quantitatively and, in fact, many of the species he reports are also listed in Sanders and Rhoads and Young but are not important numerically.

Table 3-23 Measures of productivity using the macrobenthos

Locality	Sed. Type	no/m^2	biomass/mg^2	Source
Buzzards Bay,	silt	9,000	12	Sanders, 1960
Sta. R.	all	4,430		Sanders, 1958
Sta. P.	fine sand	12,576/m^2		
Cape Cod Bay average	all	15,410	2-26	Rhoads & Young
Sta. 1918	sand	30,150	26	

Table 3- 24 Representative species from sandy and muddy sediments in Buzzards Bay (Sanders, 1958)

Sta. No.	Sediment Type	Animal Species	Feeding Type
R	muddy (≈90 percent silt-clay)	Mecula proxima	DF
		Nephtys incisa	DF
		Nerinides sp.	?
		Cyleclina orzya	?
		Lumbrinereis tenuis	DF
		Retusa caniculata	? C
P	sandy (≈5 percent silt-clay)	Byblis serrata	?
		Ampelisca macrocephala	
		A. spinipes	SF
		Ninoe nigripes	DF
		Unicola irroiata	DF
		Nephtys bucera	? DF

Table 3- 25 Representative species from sandy and muddy sediments in Cape Cod Bay (Rhoads and Young, 1971)

Sta. No.	Sediment Type	Animal Species	Feeding Type
1118	muddy (93 percent silt-clay)	Euchone incolor	SF
		Spio limicola	DF
		Capitella capitata	DF
		Ninoe negripes	DF
		Tharyx sp.	DF
		Paraonis graciles	DF
1918	sand (≈14 percent silt-clay)	Capitella capitata	DF
		Euchone incolor	DF
		Spio limicola	DF
		Asabellides oculata	DF
		Tharyx sp.	DF
		Aeginina longicanis	SF

Table 3-26

Representative species from several sediment types in the Gulf of Maine (Wigley, 1968).

Locality	Sediment type	Animal Species
Nantucket Shoals, Stellwagen Bank Central Georges Bank, Central and eastern Browns Bank	Sand	*Echinarachnius parma*
		Crangon septemspinosis
		Lunatia heros
		Nassarius trivitattus
		Spisula solidissima
		Astarte castanea
		Lystocuma sp.
		Chiridota sp.
		Ophelia sp.
		Clymenella sp.
So. Georges Bank deeper Nantucket Shoals	Silty Sand	*Arctica islandica*
		Thyone scabra
		Ampelisca vadorum
		A. compressa
		Amphioplus sp.
		Amphilimna sp.
		Nucula sp.
		Nephtys sp.
		Cerianthus sp.
Cashes Ledge, northeastern Georges Bank Jeffreys Ledge, western Browns Bank	gravel	*Polymastia* sp.
		Cliona sp.
		Balanus crenatus
		Tubularia sp.
		Sertularia
		Terebratulina sp.
		Paragorgia sp.
		Boltenia sp.
		Placopecten magellanicus
		Spirorbis sp.
		Solaster sp.
		Hyas sp.
		Ophiopholis sp.
deepwater basins	mud	*Briaster fragilis*
		Ophiura sarsi
		O. robusta
		Modiolaria discors
		Dentalium sp.
		Haploops tubicola
		Pandalus sp.
		Amphitrite sp.
		Onuphis sp.
		Geryon sp.

Table 3-27 Benthic invertebrates

ECOLOGY CODE: 1 2 3 4 5

First number, Geographic Range

1. South of Cape Cod
2. North of Cape Cod
3. Recorded from both sides of the Cape

Second number, Depth Range

1. Infralittoral and deep water only
2. May also be found intertidally or in very shallow water close to shore

Third number, Bottom Type or Substrate

1. Sand
2. Silty-sand
3. Silt, clay or mud
4. Gravel, shell or rubble
5. Firm, hard surfaces: rocks, timers, kelp fronds, shells
6. Irregular and rocky, with crevices to hide in or under

Fourth number, Living Style

1. Sessile
2. Tubicolous or permanent burrow
3. Active burrower
4. Motile (usually exposed, able to move about to some degree)
5. Commensal

Fifth number, Feeding habit

1. Filter feeder
2. Tentacular suspension feeder
3. Tentacular deposit feeder or selective deposit feeder
4. Non-selective deposit feeder
5. Predator
6. Omnivore
7. Scavenger
8. Herbivore

Table 3-27

Phylum Porifera	Sponges				
Family Homocoelidae					
Leucosólenia botryoides	3	1	5	1	1
L. cancellata	2	1	5	1	1
Clathrina coriacea	2	2	5	1	1
Ascortis fragilis	3	-	5	1	1
Family Heterocoelidae					
Scypha (=Grantia) ciliata	3	2	5	1	1
Family Desmacidonidae					
Isodictya palmata	3	1	5	1	1
I. lobata	2	-	5	1	1
I. infundibuliformis	2	-	5	1	1
Family Haliclonidae					
Haliclona oculata	3	1	5	1	1
H. urceola	2	1	5	1	1
Family Tedaniidae					
Tedania suctoria	2	1	5	1	1
Family Microcionidae					
Microciona prolifera	3	2	5	1	1
Family Myxillidae					
Myxilla incrustans	2	2	5	1	1
M. fimbriata	2	1	5	1	1
Iophon chelifer	2	-	5	1	1
Family Mycalidae					
Mycale lingua	2	1	5	1	1
M. ovulum	2	1	5	1	1
Family Halichondriadae					
Halichondria panicea	3	2	5	1	1
H. caduca	1	-	5	1	1
H. fibrosa	2	-	5	1	1
H. bowerbanki	1	2	5	1	1
Pellina sitiens	2	1	5	1	1
Family Axinellidae					
Cladocroce ventrilabrum	2	1	5	1	1
Stylotella simplissima	2	-	5	1	1
S. heliophila	3	1	5	1	1
Family Suberitidae					
Suberites ficus	3	1	5	1	1
S. hispida	2	1	5	1	1

Table 3-27 (cont.)

Family Suberitidae (Continued)						
Polymastia robusta	3	1	5	1	1	
Tentorium semisuberites	2	1	5	1	1	
Family Clionidae						
Cliona celata	3	2	5	1	1	Bores in mollusc shells
C. vastifica	3	2	5	1	1	
Family Jaspidae						
Topsentia genetrix	2	1	5	1	1	
Phylum Cnidaria						
Class Hydrozoa			Hydroids			
Family Clavicae						
Corynitis agassizii	1	-	5	1	5	
Syncoryne mirabilis	3	2	5	1	5	
Zanclea gemmosa	1	-	5	1	5	
Family Atractylidae						
Bimeria brevis	2	2	5	1	5	
Bougainvillia superciliaris	3	2	5	1	5	
Dicoryne flexuosa	2	1	5	1	5	
Garveia groenlandica	1	1	5	1	5	
Perigonimus jonesi	1	1	5	1	5	Commensal on Libinia
P. repens	1	1	5	1	5	
Family Eudendridae						
Eudendrium album	3	2	5	1	5	
E. capillare	3	2	5	1	5	
E. carneum	1	2	5	1	5	
E. dispar	3	2	5	1	5	
E. insigne	2	1	5	1	5	
E. ramosum	3	2	5	1	5	
E. tenellum	3	1	5	1	5	
E. tenue	3	1	5	1	5	
E. vaginatum	3	1	5	1	5	
Family Hydractinidae						
Hydractinia echinata	3	2	5	5	5	Commensal on hermit crabs
H. valens	2	1	5	-	5	
Podocoryne carnea	3	2	5	5	5	Commensal on hermit crabs
Stylactis hooperi	1	2	5	5	5	Commensal on *Nassarius*
Family Pennaridae						
Pennaria tiarella	1	2	5	1	5	

Table 3-27 (cont.)

Class Hydrozoa (Continued)					
Family Acaulidae					
Acaulis primarius	2	1	5	1	5
Blastothela rosea	2	1	5	1	5
Family Myriothelidae					
Myriothela phrygia	2	-	5	1	5
Family Corymorphidae					
Corymorpha pendula	3	1	5	1	5
Family Tubularidae					
Ectopleura dumartier;	1	1	5	1	5
E. prolifica	1	1	5	1	5
Tubularia couthouyi	3	-	5	1	5
T. crassa	3	1	5	1	5
T. crocea	3	2	5	1	5
T. indivisa	3	1	5	1	5
T. larynx	3	1	5	1	5
T. spectabilis	3	2	5	1	5
T. tenella	3	2	5	1	5
Family Hypolytidae					
Dahlgrenella farcta	2	1	3	2	5
Family Hybocodonidae					
Hybobodon prolifer	3	-	5	1	5
Family Campanularidae					
Campanularia abyssa	1	1	5	1	5
C. amphora	3	2	5	1	5
C. angulata	3	1	5	1	5
C. fasciculata	1	1	5	1	5
C. flexuosa	3	2	5	1	5
C. gelatinosa	3	2	5	1	5
C. gigantea	3	1	5	1	5
C. groenlandica	2	1	5	1	5
C. hincksi	3	1	5	1	5
C. integra	3	1	5	1	5
C. neglecta	2	2	5	1	5
C. verticellata	3	1	5	1	5
C. volubilis	3	1	5	1	5
Clytia cylindrica	3	2	5	1	5
C. edwardsi	3	2	5	1	5
C. johnstoni	3	2	5	1	5
C. longicyatha	1	1	5	1	5
C. minuta	1	2	5	1	5
C. noliformis	1	1	5	1	5
C. raridentata	3	1	5	1	5

Table 3-27 (cont.)

Family Campanularidae (Continued)					
Eucopella caliculata	3	1	5	1	5
Gonothyrea gracilis	3	2	5	1	5
G. loveni	3	2	5	1	5
Obelia articulata	3	2	5	1	5
O. bicuspidata	1	2	5	1	5
O. commissuralis	3	2	5	1	5
O. dichotoma	3	2	5	1	5
Obelia flabella	3	2	5	1	5
Ol geniculata	3	2	5	1	5
O. longissima	3	2	5	1	5
Family Campanulinidae					
Calycella syringa	3	1	5	1	5
Cuspidella costata	1	1	5	1	5
C. humilis	1	1	5	1	5
Egmundella fasciculata	1	1	5	1	5
Lovenella gracilis	1	1	5	1	5
L. grandis	1	1	5	1	5
L. producta	2	1	5	1	5
Opercularella lacerata	3	2	5	1	5
Stegopoma fastigiata	1	1	5	1	5
S. plicatile	3	1	5	1	5
Family Halicidae					
Halecium articulosum	3	1	5	1	5
H. beani	3	1	5	1	5
H. curvicaule	2	1	5	1	5
H. diminutivum	1	1	5	1	5
H. gracile	3	2	5	1	5
H. halecinum	3	2	5	1	5
H. minutum	2	1	5	1	5
H. muricatum	3	1	5	1	5
H. robustum	2	1	5	1	5
H. sessile	2	1	5	1	5
H. tenellum	3	1	5	1	5
Family Hebellidae					
Hebella calcarata	1	2	5	1	5
H. pocillum	3	1	5	1	5
Family Lafoeidae					
Filellum serpens	3	1	5	1	5
Grammaria abietina	3	1	5	1	5
G. gracilis	3	1	5	1	5
Lafoea dumosa	3	1	5	1	5
L. fruticosa	3	1	5	1	5
L. gracillima	3	1	5	1	5
L. symmetrica	3	1	5	1	5
Lictorella crassitheca	2	1	5	1	5

Table 3-27 (cont.)

Class Hydrozoa (Continued)					
Family Sertularidae					
Abietinaria abietina	3	1	5	1	5
A. filicula	2	1	5	1	5
Diphasia fallax	3	1	5	1	5
D. robusta	1	1	5	1	5
D. rosacea	3	1	5	1	5
D. tamarisca	2	-	5	1	5
Hydrallmania falcata	3	1	5	1	5
Selaginopsis mirabilis	3	1	5	1	5
Sertularella gayi	1	1	5	1	5
S. geniculata	2	1	5	1	5
S. gigantea	3	1	5	1	5
S. polyzonias	3	2	5	1	5
S. rugosa	3	2	5	1	5
S. tricuspidata	3	1	5	1	5
Sertularia gracilis	1	1	5	1	5
S. pumila	3	2	5	1	5
Thuiaria argentea	3	2	5	1	5
T. cupressina	3	2	5	1	5
T. cupressina	3	2	5	1	5
T. fabricii	3	2	5	1	5
T. immersa	2	1	5	1	5
T. latiuscula	3	1	5	1	5
T. lonchitis	3	1	5	1	5
T. plumulifera	1	1	5	1	5
Thuiara ramosissima	3	1	5	1	5
T. tenera	3	-	5	1	5
T. thuja	3	1	5	1	5
Family Plumularidae					
Antennularia americana	1	1	5	1	5
A. antennina	3	1	5	1	5
A. pinnata	1	1	5	1	5
A. rugosa	1	1	5	1	5
Plumularia polynema	1	1	5	1	5
P. setacea	1	1	5	1	5
Schizotricha gracillima	2	-	5	1	5
S. tenella	1	2	5	1	5
Aglaophenopsis cornuta	2	1	5	1	5
Cladocarpus flexilis	1	1	5	1	5
Thecocarpus myriophyllum	2	1	5	1	5

All of the above species of hydroids have been designated as predators since, although sessile, they catch and kill living organisms with the stinging cells in their tentacles.

Table 3-27 (cont.)

Class Hydrozoa (Continued)

Since the prey is necessarily small, generally planktonic, the hydroids could possibly be classed as tentacular suspension feeders as well.

Most of the above species are colonial. The individual organisms are very small, but the colonies may be quite large and conspicuous.

Class Scyphozoa						
Family Eleutherocarpidae						
Lucernaria quadricornis	2	2	5	1	-	
Haliclystus salpinx	2	2	5	1	-	
H. auricula	2	2	5	1	-	
Family Cleistocarpidae						
Craterolophus convolvulus	2	2	5	1	-	
Thaumatoscyphus atlanticus	2	2	5	1	-	
Halmocyathus lagena	2	2	5	1	-	
H. platypus	2	2	5	1	-	
Class Anthozoa						Sea plumes, sea anenomes and corals
Family Clavulariidae						
Clavularia modesta	2	1	5	1	5	
Family Alcyoniidae						
Alcyonium digitatum	3	1	5	1	5	
Family Nephteidae						
Gersemia rubiformis	2	1	5	1	5	
Family Anthotheidae						
Paragorgia arborea	2	1	5	1	5	
Family Primnoidae						
Primnoa resedaeformis	2	1	5	1	5	
Family Pennatulaceae						Sea plumes
Pennatula aculeata	3	1	3	1	5	
P. borealis	2	1	3	1	5	
Family Edwardsiidae						
Edwardsia elegans	3	2	2	2	5	Sea anemone
E. sipunculoides	2	1	-	2	5	Sea anemone
Fagesia lineata	1	1	1	2	5	Sea anemone

Table. 3-27 (cont.)

Class Anthozoa (Continued)						
Family Halcampidae						
Halcampa duodecemcirrata	2	1	6	4	5	Sea anemone
Family Actinidae						Sea anemones
Bolocera tuediac	2	1	-	1	5	
Liponema multicornis	2	1	-	1	5	
Tealia felina	3	2	5	1	5	
Bunodactis stella	2	2	5	1	5	
Family Actinostolidac						Sea anemones
Actinostola callosa	3	1	5	1	5	
Stomphia coccinea	2	2	5	1	5	
Family Hormathiidae						Sea anemones
Hormathia nodosa	2	1	-	1	5	
Actinauge verrilli	3	1	4	1	5	
Stephanauge nexilis	2	1	5	1	5	
Family Sagartiidae						Sea anemones
Actinothoe modesta	1	2	2	2	5	
Family Metridiidae						Sea anemones
Metridium senile	3	2	5	1	5	
Family Aiptasiomorphidae						Sea anemones
Haliplanella luciae	3	2	-	1	5	
Family Diadumenidae						Sea anemones
Diadumene leucolena	1	2	6	1	5	
Family Cerianthiadac						Sea anemones
Cerianthus borealis	2	1	2	2	5	
Ceriantheopsis americanus	1	1	2	2	5	
Order Madreporaria						
Astrangia danae	1	2	5	1	5	Star coral

The preceding species of Anthozoa have been designated as predators. Although they do not hunt prey, being for the most part sedentary, they catch and kill living organisms with stinging cells on their tentacles. Some of the prey may be planktonic and to some extent they are also tentacular suspension feeders.

Table 3-27 (cont.)

Phylum						
Platyhelminthes						
Class Turbellaria						
Family Plehniidae						
Discocelides ellipsoides	2	2	4	4	5	
Family Stylochidae						
Stylochus ellipticus	3	2	4	4	5	
S. zebra	1	2	4	4	5	
S. oculiferus	1	2	1	4	5	
Family Leptoplanidae						
Euplana gracilis	3	2	4	4	5	
Notoplana atomata	3	2	4	4	5	
Trigonoporus folium	3	2	-	4	5	
T. dendriticus	1	-	-	4	5	
Family Hoploplanidae						
Hoploplana iniquiliana	3	2	-	5	-	Commensal on Busycon
Family Bdellouridae						
Bdelloura candida	3	2	-	5	-	Commensal on <u>Limulus</u>
Syncoelidum pellucidum	3	2	-	5	-	Commensal on <u>Limulus</u>
Plylum Rhynchocoela (Nemertinea)						
Family Cephalothricidae						
Procephalothrix spiralis	3	2	4	3	5	
Family Carinomidae						
Carinoma tremaphoros	1	2	1	3	5	
Family Lineidae						
Zygeupolia rubens	3	2	1	3	5	
Lineus pallidus	2	1	-	3	5	
L. bicolor	1	1	4	4	5	
Micrura affinis	3	1	4	4	5	
M. rubra	2	1	-	-	5	
M. albida	2	1	-	-	5	
Cerebratulus lacteus	3	2	2	3	5	
C. luridus	3	1	3	3	5	
C. marginatus	2	2	-	3	5	
Family Emplectonematidae						
Emplectonema giganteum	2	1	-	3	5	

Table 3-27 (cont.)

Phylum Rhynchocoela (Nemertinea) (Continued)					
Family Prosorhochmidae					
Oerstedia dorsalis	3	2	4	4	5
Family Amphiporidae					
Amphiporus angulatus	2	2	-	4	5
A. rosens	2	-	-	4	5
A. agilis	2	-	-	4	5
A. caecus	3	1	-	4	5
A. ochraceus	1	2	4	4	5
A. tetrasorus	2	1	-	4	5
A. bioculatus	1	2	-	-	5
A. cruentatus	1	2	-	-	5
A. multisorus	2	-	-	-	5
A. pulcher	2	2	-	-	5
A. lactifloreus	2	1	-	-	5
Zygonemertes virescens	3	2	4	4	5
Family Tetrastemmidae					
Tetrastemma candidum	3	2	5	4	5
T. elegans	1	2	5	4	5
T. vittatum	3	2	3	4	5
T. dorsale	3	2	5	4	5
Family Malacobdellidae					
Malacobdella grossa	3	2	-	5	-
Phylum Mollusca					
Class Polyplacophora	Chitons				
Family Hanleyidae					
Hanleya mendicaria	2	1	5	1	8
Family Ischnochitonidae					
Ischnochiton ruber	3	2	5	1	8
I. alba	2	2	5	1	8
Tonicella marmorea	2	2	5	1	8
Family Chaetopleuridae					
Chaetopleura apiculata	1	1	5	1	8
Family Molpaliidae					
Amicula vestita	2	1	5	1	8
Class Scaphopoda	Tusk Shells				
Family Dentaliidae					
Dentalium entale	3	1	3	2	3
D. meridionale	1	1	-	2	3
D. occidentale	3	1	3	2	3

Table 3-27 (cont.)

Class Scaphopoda (Continued)						
Family Siphonodentaliidae						
Cadulus spp.	1	1	2	2	3	
Siphonodetalium spp.	1	1	2	2	3	
Class Aplacophora						
Crystallophrisson nitidulum	2	1	3	2	3	
Class Pelecypoda						Clams, Mussels, etc.
Family Solemyacidae						
Solemya borealis	2	2	2	2	-	
S. velum	3	2	2	2	-	
Family Nuculidae						
Nucula proxima	3	1	3	2	3	
N. delphihodonta	3	1	3	2	3	
N. tenuis	2	1	3	2	3	
N. annulata	1	1	3	2	3	
Family Nuculanidae						
Yoldia sapotilla	3	1	3	2	3	
Y. limatula	3	1	3	2	3	
Y. myalis	2	1	3	2	3	
Y. thraciacformis	2	1	3	2	3	
Nuculana tenuisulcata	2	1	3	2	3	
N. acuta	1	1	3	2	3	
Family Arcidae						
Anadera transversa	1	2	3	2	1	
A. ovalis	1	1	2	2	1	
Family Mytilidae						
Musculus corrugatus	3	1	-	2	1	
M. discors	3	1	4	2	1	
M. niger	3	1	1	2	1	
Modiolus modiolus	3	1	4	1	1	Horse mussel
Crenella decussata	3	1	3	2	1	
C. glandula	3	1	3	2	1	
Family Ostreidae						
Crassostrea virginica	3	2	4	1	1	American oyster
Ostrea edulis	2	2	4	1	1	European oyster
Family Pectinidae						
Aequipecten irradians	1	2	2+	4	1	Bay Scallop
Placopecten magellanicus	3	1	2	4	1	Sea Scallop
Chlamys islandica	3	1	1	4	1	

Table 3-27 (cont.)

Class Pelecypoda (Continued)						
Family Anomiidae	Jingle Shells					
Anomia simplex	3	2	4	1	1	
A. aculeata	3	2	4	1	1	
Family Astartidae						
Astarte undata	3	1	2+	2	1	
A. borealis	3	1	2+	2	1	
A. castanea	3	1	2+	2	1	
A. subaequilatera	3	1	2+	2	1	
Family Crassatellidae						
Crassinella mactracea	1	1	1	2	1	
Family Carditidae						
Cardita borealis	3	1	4	2	1	
Family Arcticidae						
Arctica islandica	3	1	3	2	1	Ocean quahog
Family Leptonidae						
Kellia planulata	2	1	-	2	-	
Family Turtoniidae						
Turtonia minuta	2	2	6	2	1	
Family Lucinidae						
Lucinoma filosa	3	1	-	2	-	
Divaricella quadrisulcata	1	1	1	2	1	
Family Thyasiridae						
Thyasira gouldii	3	1	2+	2	1	
T. plana	2	1	2+	2	1	
T. trisinuata	3	1	1	2	1	
Family Cardiidac						Cockles
Cerastoderma pinnulatum	3	1	2+	2	1	
Clinocardium ciliatum	3	1	2+	2	1	
Laevicardium mortoni	1	2	3	2	1	
Serripes groenlandicus	2	1	3	2	1	
Family Veneridae						
Mercenaria mercenaria	3	2	2	2	1	Quahog
Gemma gemma	3	2	1	2	1	
Pitar morrhuana	3	1	3	2	1	
Family Petricolidae						
Petricola pholadiformis	3	2	5	2	1	Burrow in hard clay or peat

Table 3-27 (cont.)

Class Pelecypoda (Continued)						
Family Mactridae						
Spisula Solidissima	3	2	1	2	1	Surf Clam
S. polynyma	2	1	-	2	1	
Mulinia lateralis	3	2	2	2	1	
Family Mesodesmatidae						
Mesodesma arctata	2	2	2	2	1	
Family Tellinidae						
Tellina agilis	3	2	2	2	3	
Macoma balthica	3	2	2+	2	3	
M. tenta	1	1	3	2	3	
M. calcarea	2	1	-	2	3	
Family Semelidae						
Cumingia tellinoides	1	2	3	2	3	
Family Solecurtidae						
Tagelus plebius	1	2	2	2	3	
Family Solenidae						
Ensis directus	3	2	2	2	1	Razor clam
Siliqua costata	3	2	2	2	1	
S. squama	2	1	2	2	1	
Solen viridis	1	2	-	2	1	
Family Myidae						
Mya arenaria	3	2	2+	2	1	Soft-shell clam subtidal usually under estuarine conditions
M. truncata	2	1	-	2	1	
Family Corbulidae						
Corbula contracta	1	1	1	2	1	
Family Hiatellidae						
Hiatella arctica	3	2	6	2	1	
H. striata	1	-	-	-	-	
Cyrtodaria siliqua	2	1	-	2	1	
Panomya arctica	2	1	3	2	1	
Family Pholadidae						
Zirfaea crispata	3	2	5	2	1	Burrows in hard clay, etc.
Cyrtopleura truncata	3	1	-	-	-	
Family Lyonsiidae						
Lyonsia hyalina	3	2	2	2	1	
L. arenosa	2	1	2	2	1	

Table 3-27 (cont.)

Class Pelecypoda (Continued)					
Family Periplomatidae					
Periploma papyratium	3	1	3	2	1
P. leana	3	1	2	2	1
Family Thraciidi					
Thracia conradi	3	1	2	2	1
T. myopsis	2	1	3+	2	1
T. truncata	2	1	-	2	1
Family Cuspidariidae					
Cuspidaria pellucida	2	1	-	2	1
Family Montacutidae					
Montacuta elevata	1	1	2	2	-
M. percompressa	1	2	2	2	-
Class Gastropoda, Prosobranchia			Snails		
Family Fissurellidae					
Puncturella noachina	2	2	5	4	8
Family Lapetidae					
Lapeta caeca	2	1	5	4	8
Family Trochidae					
Margarites gruenlandica	2	2	5	4	-
M. costulata	2	1	-	4	-
M. cinerea	2	1	4	4	-
M. argentata	2	1	-	4	-
M. obscura	3	1	-	4	-
M. helecina	2	2	5	4	-
Family Lacunidae					
Lacuna vincta	2	2	5	4	-
Family Hydrobiidae					
Hydrobia minuta	3	2	3	4	6
Family Rissoidae					
Cingula aculeus	2	2	6	4	-
Alvania (=Cingula) castanea	3	1	3	4	-
A. (") areolata	2	1	3	4	-
A. (") carinata	2	1	3	4	-
Family Turritellidae					
Turritellopsis acicula	2	1	3	4	-
Turritella erosa	2	1	4	4	-

Table 3-27 (cont.)

Class Gastropoda, Prosobranchia (Cont.)						
Family Cerithiidae						
Bittium alternatum	1	2	5	4	6	
Cerithiopsis subulata	1	1	5	4	6	
Seila adamsii	1	2	5	4	6	
Family Epitoniidae						
Epitonium groenlandicum	2	1	-	4	-	
E. rupicolum	1	2	-	4	5	
E. humphreysi	1	2	-	4	-	
E. multishiatum	1	1	-	4	-	
Family Trichotropiolae						
Trichotropis borcalis	2	1	1	4	-	
Family Calyptracidae	(Slipper shells)					
Crucibulum striatum	3	1	6	1	1	
Crepidula fornicata	3	2	4	1*	1	
C. convexa	3	2	4	1*	1	
C. plana	3	2	4	1*	1	
C. glauca	3	2	4	1*	1	
*Juveniles may move about, adults remain stationary although not permanently attached.						
Family Aporrhaidae						
Aporrhais occidentalis	3	1	3	2	-	
Family Naticidae	(Moon snails, sand collar snails)					
Polynices heros	3	2	1	4	5	
P. duplicata	3	2	1	4	5	
P. triseriata	3	1	3^+	4	5	
P. groenlandica	2	-	-	4	5	
P. immaculata	3	1	-	4	5	
Natica clausa	3	1	4	4	5	
N. pusilla	3	1	2	4	5	
Amauropsis islandica	2	1	3	4	5	
Bulbus smithi	2	1	-	-	-	
Family Lamellariidae						
Velutina undata	2	1	4	-	-	
V. laevigata	2	1	-	-	-	
Marsenina glabra	2	1	-	-	-	
Family Muricidae						
Urosalpinx cinerea	1	2	4	4	5	Oyster drill
Eupleura caudata	1	2	4	4	5	
Boreotrophon clathratus	2	1	-	4	5	
B. truneatus	2	1	4	4	5	

Table 3-27 (cont.)

Family Columbellidae						
Anachis haliaecti	3	1	-	4	5	
A. avara	3	1	2	4	5	
A. translirata	1	1	2	4	5	
Mitrella lunata	3	2	2	4	5	
M. rosacea	2	1	3	4	5	
Family Buccinidae						
Buccinum undatum	3	2	2^{+}	4	5	Whelk
Neptunea decemcostata	2	1	-	4	5	
N. despecta	2	1	-	4	5	
Colus stimpsoni	3	1	4	4	5	Distaff shell
C. pygmaeus	3	1	3	4	5	
Family Melongenidae						
Busycon canaliculatum	1	2	2	4	5	Channeled whelk
B. carica	1	2	2	4	5	
Family Nassariidae	Mud snails					
Nassarius obsoletus	3	2	3^{+}	4	3	
N. trivittatus	3	2	3	4	3	
Family Cancellariidae						
Admete couthouyi	2	1	4	-	-	
Family Turridae						
Lora bicarinata	3	1	3	-	-	
L. nobilis	2	1	3	-	-	
L. incisula	2	1	3	-	-	
L. harpularia	3	1	3	-	-	
L. rugulata	2	1	3	-	-	
L. exarata	2	1	3	-	-	
L. decussata	2	1	3	-	-	
L. scalaris	2	1	3	-	-	
L. cancellata	2	1	3	-	-	
L. pleurotomaria	2	1	3	-	-	
Family Pyramidellidae						
Odostomia modesta	3	2	3	4	5	
O. seminuda	3	2	4	4	5	
O. bisuturalis	3	2	4	4	5	
O. producta	3	2	-	4	5	
O. fusca	3	2	-	4	5	
Turbonilla spp. (14 species of this genus recorded by name and others unidentified to species recorded by Sumner, Osburn and Cole (1913).						
Couthouyella striatula	3	1	4	4	-	
Family Caecidae						
Caecum pulchellum	1	1	1	-	-	
C. johnsoni	1	1	4	-	-	
C. cooperi	1	1	1	-	-	

Table 3-27 (cont.)

Family Vermetidae						
Vermicularia spirata	1	1	4	-	-	
Family Skencidae						
Separatista cingulata	1	1	-	-	-	
Gastropoda, Opisthobranchia	Shelled and Shell-less snails					
Family Acteonidae						
Acteon punctostriatus	1	2	-	-	-	
Family Retusidae						
Retusa obtusa	1	1	3^+	4	5	
R. obesiuscula	3	1	3^+	4	5	
R. canaliculata	3	2	3^+	4	5	
R. pertenuis	2	1	3	4	5	
R. gouldii	2	1	3	4	5	
Family Scaphandridae						
Cylichna alba	3	1	3	4	-	
C. oryza	3	1	3	4	-	
Scaphander punctostriatus	3	1	3	4	-	
Family Philinidae						
Philine spp.	2	1	3	-	-	Very small, frequently overlooked
P. lima	3	2	-	-	-	
Family Lamellidoridae						Sea slugs
Onchidoris fusca	2	2	5	4	5	
O. aspersa	2	2	5	4	5	
O. diademata	2	1	5	4	5	
Lamellidoris grisea	2	-	5	4	5	
L. bilamellata	2	-	5	4	5	
Acanthodoris pilosa	3	2	5	4	5	
Family Polyceridae						Sea slugs
Polycera emertoni	3	2	5	4	5	
P. lessonii	2	2	5	4	5	
Family Dendronotidae						Sea slugs
Dendronotus frondosus	2	2	5	4	5	
D. robustus	3	2	5	4	5	
Family Tethyidae						Sea hare
Tethys fimbria	1	2	-	4	-	
Family Dotonidae						Sea Slugs
Doto coronata	3	2	5	4	5	
D. formosa	3	2	5	4	5	

Table 3-27 (cont.)

Family Coryphellidae						Sea Slugs
Coryphella rufibranchialis	2	2	5	4	5	
C. salmonacea	3	2	5	4	5	
C. stellata	2	2	5	4	5	
C. diversa	2	2	5	4	5	
Family Cuthonidae						Sea Slugs
Tergipes despectus	2	1	5	4	5	
Family Facelinidae						Sea Slugs
Facelina bostoniensis	3	2	5	4	5	
Family Cratenidae						Sea Slugs
Cratena gymnota	3	2	5	4	5	
C. pilata	3	2	5	4	5	
Family Aeolidiidae						Sea Slugs
Aeolidia papillosa	3	2	5	4	5	
Phylum Annelida						
Class Polychaeta	Bristle worms					
Order Archiamelida						
Polygordius appendiculatus	1	2	2	-	-	
Family Phyllodocidae						
Phyllodoce mucosa	3	2	4	4	-	
P. maculata	3	2	4	4	-	
P. arenae	3	2	4	4	-	
P. groenlandica	3	2	4	4	-	
Paranaitis speciosa	3	2	4	4	-	
P. Kosteriensis	1	-	-	-	-	
Mystides borealis	2	1	4	4	-	
Eteone lactea	3	1	4	4	-	
E. trilineata	2	2	3	4	-	
E. heteropoda	3	2	3	4	-	
E. longa	3	2	4	4	-	
E. flava	3	2	4	4	-	
Eumida sanguinea	3	2	4	4	-	
Eulalia vinidis	3	2	4	4	-	
E. bilineata	3	2	4	4	-	
Family Aphroditidae						
Aphrodite hastata	3	1	3	4	-	Sea mouse
Laetmonice filicornis	3	1	3	4	-	
Family Polynoidae						Scale worms
Austrolaenilla mollis	2	1	2^+	4	-	
Antinoella sarsi	2	1	3	4	-	
A. angusta	2	1	3	4	-	
Eucranta villosa	3	1	2^+	4	-	
Lepidametria commensalis	3	2	3^+	5	-	Commensal with Amphitrite

Table 3-27 (cont.)

Lepidonotus squamatus	3	2	4	4	5	
L. subevis	1	2	4	4	5	
Gattyana cirrosa	3	2	4^+	5	-	Commensal in worm tubes
G. amondseni	3	2	4^+	4	-	
G. nutti	2	1	4^+	4	-	
Arcteobia anticosteinsis	2	1	2^+	4	-	
Hartmania moorei	2	2	2^+	5	-	Commensal with Nercis
Enipo gracilis	3	1	2^+	5	-	Commensal with Nicomache
Harmathoe acanellac	3	1	4	4	-	Commensal on corals
H. imbricata	3	2	4	4	5	
H. spinulosa	2	1	-	-	-	
H. extenuata	3	2	4	4	5	
H. nodosa	3	1	4	4	5	
H. oerstedi	3	2	4	4	5	
Harmathoe fragilis	2	1	4^+	4	5	
Alentiana aurantiaca	1	1	-	5	-	Commensal on sea anemone
Family Sigalionidae						
Sigalion arenicola	1	2	1	4	-	
Pholoe minuta	3	2	4	4	-	
Sthenelais boa	1	2	2	4	-	
S. limicola	3	2	2	4	-	
Leanira tetragona	3	1	3^+	4	-	
L. hystricis	1	1	3	4	-	
Family Chrysopetalidae						
Dysponetus pygmaeus	2	2	1			
Family Glyceridae						
Glycera capitata	2	2	2^+	3	5	
G. americana	1	2	2^+	3	5	
G. dibranchiata	3	2	2^+	3	5	Bloodworm
G. robusta	3	2	3	3	5	
Family Goniadidae						
Goniada norvegica	3	1	3^+	3	-	
G. maculata	3	2	3	3	-	
G. brunnea	3	1	3	3	-	
Goniadella gracilis	1	2	1	3	-	
Ophioglycere gigantea	3	2	3	3	-	
Family Sphaerodoridae						
Sphaerodorum gracilis	3	2	3^+	4	-	
Ephesiella minuta	2	2	4^+	4	-	
Family Nephtyidae						
Nephtys incisa	3	2	3	3	4	
N. picta	1	2	2	3	-	
N. caeca	1	2	1	3	5	
N. bucera	3	2	1	3	5	
N. squamosa	1	1	2	3	5	
N. ciliata	2	2	2^+	3	5	
N. paradoxa	2	1	2^+	3	5	
N. discors	2	2	4^+	3	5	
Aglaophamis circinata	3	1	2^+	3		

Table 3-27 (cont.)

Family Syllidae						
Autolytus cornutus	3	2	4	4	-	
A. prismaticus	3	2	4	4	-	
A. prolifer	3	2	4	4	-	
A. alexandrae	3	2	4	4	-	
A. fasciatus	1	2	4	4	-	
A. villosa	3	-	-	-	-	
Sphaerosyllis erinaceus	3	2	4	4	-	
Brania clavata	3	2	4	4	-	
B. vellfleetensis	1	2	3	4	-	
Exogone dispar	3	2	4	4	-	
E. verugera	2	2	4	4	-	
E. hebes	3	2	4	4	-	
Amblyosyllis finmarchica	2	2	4	4	-	
Syllides longocirrata	3	2	4	4	-	
Odontosyllis fulgurans	1	2	4	4	-	
Eusyllis blomstrandi	2	1	4	4	-	
E. lamelligera	1	1	4	4	-	
Syllis spongiphila	1	1	4	4	-	
S. cornuta	3	2	4	4	-	
S. gracilis	1	2	4	4	-	
Family Hesionidae						
Nereimyra punctata	1	2	2^+	4	-	
Gyptis vittata	2	2	4	4	-	
Podarke obscura	1	2	4	4	-	
Microphthalmus aberrans	2	2	1	4	-	
M. sczelkowskii	2	2	3	4	-	
Family Pilargiidae						
Ancistrosyllis groenlandica	3	1	3	4	-	
Family Nercidae						
Platynereis dumerilii	1	2	4	3	-	
Ceratocephale loveni	3	1	3	3	-	
Nereis arenaceodonta	3	2	2^+	3	-	
N. succinea	3	2	4^+	3	-	
N. virens	3	2	2^+	3	6	Sand worm
N. diversicolor	2	2	3^+	3	-	
N. pelagica	3	2	4	3	-	
N. grayi	1	2	3	3	-	
N. Zonata	2	2	4	3	-	
Family Capitellidae						
Capitella capitata	3	2	-	-	-	
Heteromastus filiformis	3	2	3^+	-	4	
Notomastus luridus	3	2	4	-	4	
N. latericeus	1	2	3	-	-	
Medeomastus ambiseta	1	-	3	-	-	
Family Scalibregmidae						
Scalibregma inflatum	-	2	-	-	-	

Table 3-27 (cont.)

Family Maldanidae						
Nicomache lumbricalis	3	1	3	2	4	
Praxillella praetermissa	2	1	3	2	4	
P. ornata	2	1	3	2	4	
P. tricirrata	3	1	3	2	4	
Rhodine loveni	3	1	3	2	4	
Clymenella torquata	3	2	3	2	4	Bamboo worm
C. zonalis	2	1	3	2	4	
Maldana sarsi	3	1	3	2	4	
Maldanopsis elongata	3	2	3	2	4	
Axiothella catenata	1	-	-	2	4	
Family Opheliidae						
Ophelia denticulata	3	-	4	-	-	
O. bicornis	1	1	1	-	-	
Travisia carnea	3	2	-	-	-	
Ammotrypane aulogaster	3	1	3	-	-	
Family Amphinomichlae						
Paramphinome pulchella	3	1	3	-	-	
Pareurythoe borealis	1	1	1	-	-	
Family Euphrosinidae						
Euphrosine cirrata	3	1	4	-	-	
E. borealis	2	1	4	-	-	
E. armadillo	1	1	2	-	-	
Family Spintheridae						
Spinther citrinus	2	1	4	5	-	Commensal on sponges
Family Magelonidae						
Magelona rosca	1	2	3	-	-	
Family Orbiniidae						
Orbinia ornata	3	2	2	2	-	
O. swani	3	2	1	-	-	
O. norvegica	1	1	2	-	-	
O. michaelseni	3	1	3	-	-	
O. kupferi	1	1	3	-	-	
Nainereis quadricuspida	3	2	4	-	-	
Scoloplos rebustus	3	2	2	3	-	
S. fragilis	3	2	2	3	-	
S. armiger	2	2	2	3	-	
S. acutus	3	2	2	3	-	
Family Cirratulidae						
Cirratulus cirratus	2	2	4^+	-	-	
C. grandis	1	2	3^+	-	-	
Tharyx actus	3	2	3	-	-	
T. marioni	1	1	-	-	-	
T. annulosus	1	1	-	-	-	
Dodecaceria concharum	2	1	4	-	-	
Cossura longocirrata	2	1	-	-	4	

Table 3-27 (cont.)

Family Oweniidae						
Owenia fusiformis	3	1	-	-	-	
Myriochele heeri	2	1	3	-	-	
Family Sabellariidae						
Sabellaria vulgaris	1	2	-	-	-	
Family Onuphidae						
Onuphis opalina	3	1	3	2	-	
O. conchylega	3	1	4	2	-	
O. eremita	1	1	2	2	-	
O. quadricuspis	3	1	3^+	2	-	
Diopatra cupraea	3	2	2^+	2	5	
Hyalinoecia tubicola	3	1	2^+	2	-	
Family Eunicidae						
Eunice bennata	3	1	4	2	-	
E. norvegica	1	2	4	2	-	
Marphysa sanguinea	1	2	4	2	5	
M. belli	1	2	4	2	-	
Family Lumbrinercidae						
Lumbrinercis tenuis	3	2	2^+	-	-	
L. fragilis	3	2	3^+	-	-	
L. latreilli	3	1	2	-	-	
L. acuta	3	2	3^+	-	-	
L. coccinea	1	1	4	-	-	
L. brevipes	1	1	3^+	-	-	
L. impatiens	3	1	3	-	-	
Ninoe nigripes	3	2	3	2	-	
Family Arabellidae						
Arabella iricolor	1	2	2^+	3	-	
Drilonereis longa	1	2	3	3	-	
D. filum	3	1	-	-	-	
D. magna	3	2	4	-	-	
D. caulleryi	1	1	3	5	-	Commensal in worm tubes
Notocirrus spiniferus	1	2	2^+	5	-	
Family Dorvilleidae						
Stauronereis rudolphi	1	2	2	4	-	
S. caecus	3	2	3	-	-	
Protodoryillia gracilis	1	-	-	-	-	
Family Spiunidae						
Spio filicornis	1	2	2	2	3	
S. limicola	3	-	-	2	3	
S. Jetosa	3	2	2	2	3	
Scolicolepides viridis	3	2	2	2	3	
Scolilepis squamata	1	2	-	2	3	
S. acutus	1	1	-	2	3	
Nerinides gracilis	1	-	-	-	3	
Prionospio malmgreni	3	1	-	2	3	

Table 3-27 (cont.)

P. steenstrupi	2	1	-	2	3	
Polydora ligni	3	2	2	2	3	
P. websteri	3	2	2	2	3	
P. gracilis	2	1	3	2	3	
P. ciliata	3	2	-	2	3	
P. concharum	3	2	4	5	3	
Spiophanes bombyx	3	2	-	2	3	
S. verrilli	2	-	-	2	3	
S. wigleyi	3	1	-	2	3	
Dispio uncinata	1	1	-	2	3	
Streblospio benedicti	3	2	2	2	3	
Family Sternaspidae						
Sternaspis scutata	3	1	3	-	-	
Family Trochochaetidae						
Trochochaeta multisetosa	3	1	3	2	-	
Family Paraonidae						
Paraonis gracilis	3	1	3	-	-	
P. fulgens	3	2	3	-	-	
P. lyra	3	1	2	-	-	
Aricidea albatrossac	1	1	3	-	-	
A. jeffreysi	3	1	2	-	-	
A. suecica	3	1	3	-	-	
A. quadrilobata	2	1	3	-	-	
Family Apistobranchidae						
Apistobranchus tullbergi	2	1	2^+	2	-	
Family Chaetopteridae						
Chaetopterus variopedatus	1	2	2	2	1	
Spiochaetopterus oculatus	1	2	2	2	1	
Family Pectinariidae						Trumpet worms
Pectinaria gouldii	3	2	2	2	4	
P. hyperborea	2	2	2	2	4	
P. granulata	2	1	-	2	4	
Family Ampharetidae						
Ampharete acutifrons	3	2	3	2	3	
Asabellides oculata	3	1	2	2	3	
Melinna cristata	3	2	3	2	3	
Anobothrus gracilis	2	1	3	2	3	
Amage auricula	2	1	4	2	3	
A. busilla	2	1	4	2	3	
Samythella elongata	2	1	-	2	3	
Family Terebellidae						
Amphitrite ornata	3	2	3	2	2	
A. brunnea	3	2	3^+	2	2	
Enoplobranchus sanguineus	3	2	2^+	2	2	
Trichobranchus roseus	2	1	-	2	2	

Table 3-27 (cont.)

T. glacialis	3	2	-	2	2
Terebellides stroemi	2	1	3^+	2	2
Lysilla alba	1	2	3	2	2
Nicolea venustula	3	2	1^+	2	2
Pista palmata	3	2	1^+	2	2
P. intermedia	3	-	3^+	2	2
Polycirrus eximius	3	2	-	2	2
P. phosphoreus	3	2	4	2	2
P. medusa	2	1	-	2	2
Thelepus cincinnatus	3	2	3	2	2
Family Flabelligeridae					
Flabelligera affinis	3	2	3	-	-
Pherusa plumosa	2	1	-	-	-
P. affinis	3	2	3	-	3
P. arenosa	3	1	-	-	-
Brada granosa	2	2	-	-	-
B. villosa	2	-	3	-	3
B. setosa	3	1	3	-	-
Diplocirrus hirsutus	2	1	-	-	-
Family Sabellidae					
Fabricia sabella	3	2	3	2	2
Euchone rubrocineta	3	-	-	2	2
E. elegans	1	1	3	2	2
Sabella microphthalama	1	2		2	2
S. crassicornis	3	2	-	2	2
Potamilla neglecta	1	1	-	2	2
P. reniformis	3	2	4^+	2	2
Myxicola infundibulum	3	2	4^+	2	2
Family serpulidae					
Hydroides dianthus	3	2	5	2	2
Filograna implexa	3	1	5	2	2
Spirorbis borealis	3	2	5	2	2
S. spirillum	3	2	5	2	2
Phylum Gephyrea					
Order Echiuroidea					
Family Echiuridae					
Echiurus echiurus (=pallasii)	2	1	2	2	3
Family Thalessemidae					
Thalessema viridis	2	1	3	2	3
Order Sipuncula					
Golfingia (=Phascolosoma) eremita	2	1	2	2	3
G. verrilli	1	1	2	2	3
G. improvisa	1	1	-	2	3
G. sabellariae	3	1	-	2	3

Table 3-27 (cont.)

Phascolopsis (=Phascolosoma) gouldii	3	2	2	2	3
Phascolion strombi	3	2	2	2	3
Order Priapulida					
Priapulus caudata	2	1	3	2	5
Phylum Arthropoda					
Class Crustacea					
Sub-class Cephalocarida					
Hutchinsoniella macracantha	1	1	3	-	-
Order Cumacea					
Sub-class Malacostraca					
Family Bodotriidae					
Leptocuma minor	3	1	2	4	3
Family Lauconidae					
Leucon nasicoides	2	1	-	4	3
Eudorella truncatula	3	1	2^+	4	3
E. hispida	3	1	2^+	4	3
Eudorellopsis deformis	3	1	2^+	4	3
Family Nannastacidae					
Campylaspis rubicunda	2	1	3	4	3
C. affinis	2	1	3	4	3
Family Lampropidae					
Lamprops quadriplicata	3	1	2^+	4	3
Family Diastylidae					
Diastylis sculpta	3	1	2^+	4	3
D. quadrispinosa	3	1	2^+	4	3
D. polita	3	1	2^+	4	3
D. abbreviata	2	1	3	4	3
D. lucifera	2	1	3	4	3
Leptostylis longimana	2	-	-	4	3
L. ampullacea	2	1	3	4	3
Oxyurostylis smithi	1	1	3	4	3
Family Pseudocumidae					
Petalosarsia declivis	2	1	3	4	3

Table 3-27 (cont.)

Order Caprellidea

Family Caprellidae						
Aeginella spinosa	3	2	5*	4	5	
Aeginina longicornis	3	2	5*	4	5	
Caprella linearis	3	2	5*	4	5	
C. penantis	3	2	5*	4	5	
C. unica	2	2	5*	5	5	Commensal on starfish
C. septentrionalis	2	2	5*	4	5	
C. equilibra	3	2	5*	4	5	
Paracaprella tenuis	1	2	5*	4	5	
Mayerella limicola	2	2	5*	4	5	

*Usually on hydroid colonies, bryozoan colonies or seaweed fronds.

Order Amphipoda (Beach fleas, scud, etc.)

Family Acanthonotozomatidae					
Acanthonotozoma serratum	2	1	-	-	-
Family Ampeliscidae					
Ampelisca abdita	1+	2	3	2	1
A. vadorum	3	2	2	2	1
A. macrocephala	3	1	1	2	1
A. verrilli	1	2	1	2	1
A. agassizi	3	1	2	2	3
Byblis serrata	3	2	1	2	1
B. gaimardi	2	1	-	-	-
Family Aoridae					
Microdeutopus anomolus	1	2	4	2	1
M. gryllotalpa	1				
Family Bateidae					
Batea catharinensis	1	2	4	4	-
Family Curophiidae					
Corophium crassicorne	3	2	2	2	1
C. tuberculatum	3	2	3	2	1
C. acherusicum	1	2	-	-	-
C. simile	1	2	3	2	1
C. tuberculatum	1	2	-	-	-
C. bonelli	2	2	-	-	-
Cerabus tubularis	1	2	1	4	1
Siphonoecetes smithianus	1	1	-	-	-
Erichthonius rubricornis	3	2	4	2	1
E. brasiliensis	1	2	2	-	-
Unciola irrorata	1	2	2	2	3
U. inermis	3	2	2	2	1
U. laticornis	2	1	-	-	-
U. dissimilis	3	2	2	2	1
U. obliqua	3	2	1	2	1
U. serrata	1	2	3	2	1

Table 3-27 (cont.)

Family Dexaminiidae					
Dexamine thea	3	2	4	2	1
Family Calliopidae					
Calliopius laeviusculus	3	2	-	-	-
Family Gammaridae					
Gammarus oceanicus	2	2	4	4	-
G. setosus	2	2	-	-	-
G. lawrencianus	1	2	4	4	6
G. annulatus	1	2	1	4	6
Gammarellus amgulosus	2	2	-	-	-
Casco bigelowi	3	2	4	4	6
Melita nitida	3	2	4	4	6
M. dentata	2	2	-	-	-
Maera danae	3	2	5	4	6
Elasmopus laevis	1	2	-	-	-
Family Eusiridae					
Rachotropis aculeata	2	1	-	-	-
Family Haustoriidae					
Amphipureia lawrenciana	2	2	-	-	-
A. gigantea	1	1	1	4	3
Acanthohaustorius millsi	3	2	1	4	3
A. intermedius	1	2	1	4	3
A. spinasus	3	1	1	4	3
A. shoemakeri	1	1	1	4	3
Bathyporeia quoddyensis	3	2	1	4	3
B. parkeri	1	2	1	4	3
Parahaustorius attenuatus	1	2	1	4	3
P. holmesi	1	1	1	4	3
P. longimerus	1	2	1	4	3
Protohaustorius wigleyi	3	2	1	4	3
P. deichmanni	1	2	2	4	3
Pseudohaustorius caroliniensis	1	2	1	4	3
P. borealis	1	1	1	4	3
Pontoporeia femorata	2	1	-	-	-
Family Ischyroceridae					
Ischyrocerus anguipes	3	1	-	-	-
Jassa falcata	3	2	4	2	5
Family Leucothoidae					
Leucothoe spinicarpa	2	1	-	-	-

Table 3-27 (cont.)

Family Lysianassidae					
Anonyx sarsi	1	1	1	4	7
A. lilljeborgi	2	2	-	-	-
Lysianopsis alba	1	2	1	4	7
Orchomenella pinguis	3	2	1	4	7
O. minuta	3	2	2	4	7
Tmetonyx nobilis	3	2	4	3	7
T. cicada	2	1	-	-	-
Hippomedon serratus	1	1	2	4	7
Family Oedicerotidae					
Monoculodes edwardsi	1	2	2	4	3
M. tesselatus	2	2	-	-	-
Paroediceros lynceus	2	1	-	-	-
Family Paramphithoidae					
Paramphithoe hystrix	2	1	-	-	-
Family Photidae					
Leptocheirus pinguis	3	2	2	2	1
Podoceropsis nitida	3	2	-	-	-
Photis macrocoxa	3	2	3	2	1
P. rheinhardi	3	1	3	2	1
P. dentata	2	1	-	-	-
Microprotopus ranei	1	2	1	2	1
Family Phoxocephalidae					
Phoxocephalus holbolli	3	2	3	4	3
Paraphoxus epistomus	3	2	1	4	3
P. spinosus	1	2	1	4	3
Harpinia propinqua	2	1	-	-	-
Family Pleustidae					
Pleustes panopla	2	1	-	-	-
Neopleustes pulchellus	2	1	-	-	-
Sympleustes glaber	2	2	-	-	-
Stenopleustes gracilis	1	1	1	4	6
Family Podoceridae					
Dulichia porrecta	2	1	-	-	-
D. spinosissima	3	1	3	2	1
D. monacantna	1	-	-	-	-
Family Pontugeniidae					
Pontogenia inermis	2	2	-	-	-
Family Stegocephalidae					
Stegocephalus inflatus	2	2	-	-	-

Table 3-27 (cont.)

Family Stenothoidae						
Stenothoe gallensis	2	2	-	-	-	
S. minuta	1	2	4	4	6	
S. peltata	2	1	-	-	-	
Metopella angusta	3	1	3	4	6	
Parametopella cypris	1	2	3	4	6	
Metopa bruzeli	2	2	-	-	-	
Family Tironidae						
Syrrhoe crenulata	2	1	-	-	-	
Family Amphithoidae						
Amphithoe rubricata	1	2	-	-	-	
Order Tanaidaceae						
Family Paratanaidae						
Leptognatha caeca	2	1	-	-	-	
Heterotanais limicola	2	1	-	-	-	
Leptochelia rapax	3	2	4	2	-	
L. filum	2	1	-	-	-	
L. savignyi	1	2	4	-	-	
Family Tanaidae						
Tanais cavolini	3	2	4	-	-	
Order Isopoda						
Family Anthuridae						
Cyathura polita	3	2	3	2	3	
Calathura branchiata	3	1	-	-	-	
Ptilanthura tenuis	3	2	2	4	6	
Family Gnathiidae						
Grathia cerina	3	1	-	-	-	
Family Cirolanidae						
Cirolana concharum	3	2	1	4	7	
C. borealis	3	1	-	4	7	
C. polita	2	2	-	4	7	
Family Limnoriidae						
Limnoria lignorum	3	2	5	3	8	Wood borer
Family Idoteidae						
Chiridotea arenicola	3	1	1	4	6	
C. tuftsi	3	2	2	4	6	
Idotea metallica	3	2	3^+	4	6	
I. balthiea	3	2	3^+	4	6	
I. phosphorea	3	2	3^+	4	6	
Edotea montosa	3	2	3	4	6	

Table 3-27 (cont.)

E. triloba	3	2	3	4	6	
Erichsonella filiformis	3	2	4	4	6	
E. attenuata	1	2	4	4	6	
Family Janiridae						
Janira alta	2	2	-	-	-	
Family Munnidae						
Munna fabricii	2	1	-	-	-	
Munnopsis typica	3	1	3	-	-	
Order Decapoda						
Family Penaeidae						
Penaeus setiferus	(1)	2	3	4	5	White Shrimp
P. aztecus	(1)	2	3	4	5	Brown Shrimp
Parapenaeus longivostris	1	1	3	4	5	Shrimp
Lucifer faxoni	3	2	-	4	-	Shrimp
Family Pasiphaeidae						
Pasiphaea tarda	2	1	-	4	-	Shrimp
P. multidentata	2	1	-	4	-	Shrimp
Family Hippolytidae						
Caridion gordoni	2	1	-	4	-	Shrimp
Eualus fabricii	2	2	-	4	-	Shrimp
E. gaimardi	2	1	-	4	-	Shrimp
E. fusiolus	2	2	-	4	-	Shrimp
Spriontocaris spinus	2	1	-	4	-	Shrimp
S. lilljeborgii	2	1	-	4	-	Shrimp
S. phippsi	2	1	-	4	-	Shrimp
S. microceros	2	-	-	-	-	Shrimp
Lebbeus polaris	2	2	-	4	-	Shrimp
L. groenlandica	2	1	-	4	-	Shrimp
L. zebra	2	2	-	4	-	Shrimp
Family Pandalidae						
Pandalus borealis	2	1	3	4	5	Northern Shrimp
P. montagui	2	1	3	4	5	Montague's Shrimp
P. propinquus	3	1	-	4	5	Shrimp
Dichelopandalus leptocerus	3	1	-	4	5	Shrimp
Family Crangonidae						
Crangon septemspinosus	3	2	3^+	4	5	Mud or sand shrimp
Sabinea septemcarihata	2	1	-	4	-	Shrimp
S. sarsii	2	1	-	4	-	Shrimp
Sclerocrangon boreas	2	1	-	4	-	Shrimp
Family Nephropsidae						
Homarus americanus	3	2	6^+	4	5	Lobster

Table 3-27 (cont.)

Family Axiidae						
Axius serratus	3	1	3	2	7	
Calocaris templemani	2	1	3	2	-	
Family Upogebiidae						
Upogebia affinis	1	2	3	2	7	
Family Laomediidae						
Naushonia crangonides	1	2	2	2	7	
Family Callianassidae						
Callianassa atlantica	3	2	2	2	7	
Family Galatheidae						
Munidopsis curvivostra	2	1	-	-	-	
Family Paguridae						
Pagurus longicarpus	3	2	1^+	4	7	Hermit crab
P. pollicaris	1	2	1	4	7	Hermit crab
P. annulipes	1	2	2	4	7	Hermit crab
P. acadianus	2	1	-	4	7	Hermit crab
P. pubescens	2	1	-	4	7	Hermit crab
P. politus	3	1	-	4	7	Hermit crab
P. arcuatus	2	1	-	4	7	Hermit crab
P. kroyeri	3	-	-	-	-	Hermit crab
Family Lithodidae						
Lithodes maia	2	1	-	4	7	Spider crab
Family Porcellanidae						
Porcellana sigsbeiana	(1)	1	4	4	-	Porcelain crab
Polyonyx gibbesi	1	2	2	5	-	
Family Homolidae						
Homola barbata	1	1	-	-	-	
Family Maiidae						
Chionocetes opilio	2	1	-	4	5	Spider crab
Hyas araneus	2	1	-	4	-	Spider crab
H. coarctatus	3	1	-	4	-	Spider crab
Libinia emarginata	3	2	-	4	-	Spider crab
L. dubia	1	2	-	4	-	Spider crab
Pelia mutica	1	2	-	4	-	
Family Portunidae						
Carcinides moenas	3	2	6	4	5	Green crab
Ovalipes ocellatus	3	2	1	4	5	
Portunus gibbesii	(1)	1	-	4	5	
P. ordwayi	(1)	1	-	4	5	
Callinectes sapidus	1	2	2^+	4	5	Blue crab
Araneus cribrarius	(1)	2	-	4	5	

Table 3-27(cont.)

Family Cancridae						
Cancer borealis	3	1	6	4	5	Jonah crab
C. irroratus	3	2	2	4	5	Rock crab
Family Parthenopidae						
Heterocrypta granulata	1	1	4	4	5	
Family Xanthidae						
Panopeus herbstii	1	2	4	4	5	Mud crab
Neopanope texana sayi	3	2	4	4	5	Mud crab
Hexapanopeus angustifrons	1	1	4	4	5	Mud crab
Eurypanopeus depressus	1	2	4	4	5	Mud crab
Rhithropanopeus harrisii	3	2	4	4	5	Mud crab
Family Geryonidae						
Geryon quinquidens	3	1	-	4	5	Red crab
Family Pinnotheridae						
Pinnotheres ostreum	3	2	-	5	-	Commensal in oysters
P. maculatus	1	2	-	5	-	Commensal in mussels
Pinnixa chactopterana	1	2	-	5	-	Commensal in worm tubes
P. sayana	1	2	-	5	-	Commensal in worm tubes
Dissodactylus mellitae	1	1	-	5	-	Commensal in sand dollars
Cirripedia						
Family Balanidae						Barnacles
Balanus balanus	3	2	5	1	1	
B. crenatus	2	2	5	1	1	
B. hameri	2	1	5	1	1	
B. eburneus	1	2	5	1	1	
B. improvisus	3	2	5	1	1	
Stomatopoda						
Family Squillidae						Mantis shrimps
Squilla empusa	1	2	3	2	5	
Family Lysiosquillidae						
Nannosquilla grayi	3	2	3	2	5	
Mysidacea						
Family Mysidae						
Neomysis americana	3	2	-	4	5	
Heteromysis formosa	1	2	-	4	5	
Mysidopsis bigelowi	1	2	-	4	5	
Mysis stenolepis	3	2	-	4	5	

Table 3-27 (cont.)

Class Pantopoda					
Family Nymphonidae					
Nymphon stromi	3	1	-	4	-
N. macrum	2	1	3	4	-
N. grossipes	3	1	-	4	-
N. longitarse	2	1	3	4	-
Family Ammotheidae					
Achelia spinosa	3	2	4	4	-
Family Tanystylidae					
Tanystylum orbiculare	1	2	4	4	-
Family Phoxichilidiidae					
Anoplodactylus lentus	1	2	4	4	-
Family Pycnogonidae					
Pynogonum littorale	3	2	4	4	-
Family Pallenidae					
Callipallene brevirostris	3	2	4	4	-
Class Merostomata					
Family Limulidae					
Limulus polyphemus	3	2	1	4	5
Phylum Echinodermata					
Class Asteroidea					
Family Astropectinidae					
Leptychaster arcticus	2	1	-	4	-
Psilaster florae	3	1	3	4	5
Family Goniopectinidae					
Ctenodiscus crispatus	2	1	3	4	4
Family Benthopectinidae					
Pontaster tenuispina	3	1	-	4	-
Family Odontasteridae					
Odontaster hispidus	1	1	-	4	-
O. setosus	1	1	-	4	-
Family Goniasteridae					
Pseudarchaster intermedius	3	1	-	4	-
Pentagonaster eximius	2	1	-	4	-
Ceramaster granularis	3	1	-	4	-
Hippasteria phrygiana	3	1	-	4	5
Peltaster planus	1	1	-	4	-

Table 3-27 (cont.)

Family Solasteridae					
Solaster endeca	2	2	-	4	5
S. papposus	3	2	-	4	5
Lophaster furcifer	3	1	-	4	-
Family Pterasteridae					
Pteraster militaris	3	1	-	4	-
Diplopteraster multipes	3	1	-	4	-
Family Poraniidae					
Poraniamorpha hispida	3	1	-	4	-
Family Echinasteridae					
Henricia sanguinolenta	3	2	4	4	-
Family Asteriidae					
Asterias vulgaris	3	2	4	4	5
A. forbesii	3	2	4	4	5
Leptasterias tenera	3	1		4	5
L. littoralis	2	2		4	5
Stephanasterias albula	3	1		4	5
Family Pedicellasteridae					
Pedicellaster typicus	3	1		4	5
Class Ophiuroidea	Brittle stars				
Family Ophiomyxidae					
Ophioseolex glacialis	3	1	3	-	-
O. purpureus	2	1	3	-	-
Family Gorganocephalidae					
Gorganocephalus areticus	3	1	3^+	4	5
G. eucnemis	2	1	-	4	5
Family Asteronychidae					
Asteronyx loveni	3	1	-	4	5
Family Ophiuridae					
Ophiura robusta	2	1	3	4	5
O. sarsi	2	1	3	4	5
O. signata	2	1	-	4	5
Ophiocten sericeum	2	1	-	4	5
Ophiomusium lymani	3	1	-	4	5
Family Ophiodermatidae					
Ophioderma brevispinum	1	2	1	4	5
Family Ophiacanthidae					
Ophiacantha bidenta	3	1	4	4	5
O. spectabilis	2	1	4	4	5
Ophiomitrella clavigera	3	1	-	-	-
Amphilimna olivacea	1	1	2	4	-

Table 3-27 (cont.)

Family Ophiactidae						
Ophiopholis aculeata	3	2	-	4	5	
Family Amphiuridae						
Amphipholis squamata	3	2	4	4	5	
Amphioplus abdita	3	1	2	4	5	
Amphiura otteri	3	1	3	-	-	
Class Echinoidea	Sea worms					
Family Arbaciidae						
Arbacia punctulata	1	2	4	4	8	
Family Strongylocentrotidae						
Strongylocentrotus droehbachiensis	2	2	5	4	8	
Family Echinarachnidae						
Echinarachnius parma	3	2	1	4	3	Sand dollar
Family Mellitidae						
Mellita quinquesperforata	1	2	-	-	-	
Family Schizasteridae						
Brisaster fragilis	3	1	3	2	-	
Class Holothuroidea	Sea cucumbers					
Family Psolidae						
Psolus phantapus	2	1	4	4	2	
P. fabricii	2	1	4	4	2	
Family Phyllophoridae						
Pentamera pulcherrima	1	2	3	2	3	
P. calcigera	2	1	-	-	3	
Havelockia scabra	3	1	2	-	3	
Family Sclerodactylidae						
Sclerodactyla briareus	1	2	3	2	3	
Family Cucumariidae						
Cucumaria frondosa	2	2	6	4	2	
Stereoderma unisemita	3	2	1	-	3	
Family Synaptidae						
Leptosynapta inhaerens	3	2	1	2	3	
L. roseola	1	2	1	2	3	
Family Chiridotidae						
Chiridota laevis	2	2	-	2	3	
Family Molpadiidae						
Molpadia oolitica	3	1	3	2	3	

Table 3-27 (cont.)

Family Caudinidae					
Caudina arenata	3	1	3	2	3
Class Crinoidea					
Family Antedonidae					
Hathrometra tenella	3	1	-	4	2
H. sarsi	3	1	-	-	2
Heliometra glacialis	2	1	-	-	2
Family Bathycrinidae					
Rhizocrinus lafotensis	3	1	5	5	2
Phylum Ectoprocta					
Family Alcyonidiidae					
Alcyonidium verrilli	1	2*	5	1	2
A. mammillatum	2	2	5	1	2
A. polyoum	3	2	5	1	2
A. gelatinosum	3	2	5	1	2
A. parasiticum	3	2*	5	1	2
A. hirsutum	3	2	5	1	2
A. mytili	1	2	5	1	2
Family Flustrellidridae					
Flustrellidra hispida	3	2	5	1	2
Family Vesiculariidae					
Bowerbankia gracilis	3	2	5	1	2
Amathia dichotoma	1	2	5	1	2
Family Nolellidae					
Anguinella palmata	1	2	5	1	2
Family Walkeriidae					
Walkeria uva	3	2	5	1	2
Aeverrillia armata	3	2*	5	1	2
Family Triticellidae					
Triticella elongata	1	2	5	1	2
T. pedicillata	3	1	5	1	2
Family Crisiidae					
Crisea eburnea	3	2*	5	1	2
C. cribraria	3	2	5	1	2
C. denticulata	3	1	5	1	2
Family Tubuliporidae					
Tubulipora liliacea	3	2	5	1	2
T. flabellata	3	1	5	1	2
Idmonea atlantica	2	1	5	1	2

Table 3-27 (cont.)

Family Microporellidae					
Microporella ciliata	3	2*	5	1	2
Family Hippoporinidae					
Hippoporina americana	3	1	5	1	2
H. reticulopunctata	2	2	5	1	2
H. smitti	2	1	5	1	2
H. porosa	3	1	5	1	2
Family Celleporidae					
Turbicellepora canaliculata	2	1	5	1	2
Family Escharellidae					
Escharella immersa	2	2	5	1	2
E. ventricosa	2	2	5	1	2
E. abyssicola	2	1	5	1	2
Family Hincksiporidae					
Hincksipora spinulifera	2	1	5	1	2
Family Smittinidae					
Porella concinna	3	2	5	1	2
P. acutirostris	3	2	5	1	2
P. proboscidea	3	-	5	1	2
Rhamphostomella scabra	2	2	5	1	2
R. bilaminata	3	2	5	1	2
R. costata	3	2	5	1	2
R. ovata	3	1	5	1	2
R. radiatula	2	1	5	1	2
Smittina trispinosa	2	-	5	1	2
Family Cheiloporinidae					
Cryptosula pallasiana	3	2	5	1	2
Family Bugulidae					
Bugula turrita	3	2*	5	1	2
B. flabellata	3	2	5	1	2
B. stolonifera	3	-	5	1	2
Dendrobeania murrayana	3	2	5	1	2
Family Bicellariellidae					
Bicellariella ciliata	3	2	5	1	2
Family Scruposellariidae					
Scrupocellaria scabra	3	2	5	1	2
Tricellaria peachii	3	1	5	1	2
T. ternata	3	2	5	1	2
Caberia ellisii	3	1	5	1	2
Family Cribrilinidae					
Cribrilina annulata	2	1	5	1	2
C. punctata	2	2	5	1	2

Table 3-27 (cont.)

Family Umbonulidae					
Umbonula arctica	2	1	5	1	2
Family Hippothoidae					
Hippothoa hyalina	3	2	5	1	2
H. divaricata	3	1	5	1	2
Family Gigantoporidae					
Cylindroporella tubulosa	2	2	5	1	2
Family Stomachetosellidae					
Stomachetosella sinuosa	3	2	5	1	2
S. producta	2	-	5	1	2
Posterula sarsi	2	1	5	1	2
Family Schizoporellidae					
Schizoporella unicornis	3	2*	5	1	2
Stephanosella biaperta	3	1	5	1	2
Schizomavella auriculata	3	2	5	1	2
Family Oncousoeciidae					
Oncousoecia diastoporides	2	1	5	1	2
Family Diaperoeciidae					
Diaperoecia harmeri	2	1	5	1	2
Diplosolen obelium	2	1	5	1	2
Family Lichenoporidae					
Lichenopora hispida	3	2	5	1	2
L. verrucaria	3	2	5	1	2
Family Aetiidae					
Aetia anguina	3	1*	5	1	2
Family Scrupariidae					
Scruparia chelata	1	2	5	1	2
Haplota clavata	3	1	5	1	2
Eucratia (=Gemellaria) loricata	3	2	5	1	2
Family Membraniporidae					
Membranipora tenuis	1	2*	5	1	2
Family Hinksinidae					
Cauloramphus eymbaeformis	3	1	5	1	2
Family Calloporidae					
Callopora aurita	3	2	5	1	2
C. craticula	3	2	5	1	2
C. lineata	3	2	5	1	2
C. dumerilii	2	1	5	1	2
Amphiblestrum flemingii	3	1	5	1	2
Tegella arctica	3	2	5	1	2
T. armifera	3	2	5	1	2
T. unicornis	3	1	5	1	2

Table 3-27 (cont.)

Family Electridae					
Electra bilosa	3	2*	5	1	2
E. monostachys	3	2	5	1	2
Family Myrioporidae					
Myriozoella plana	2	1	5	1	2
Phylum Endoprocta					
Family Pedicellinidae					
Barentsia major	3	2	5	1	2
B. gracilis	3	2	5	1	2
B. discreta	1	2	5	1	2
Pedicellina cernua	1	2	5	1	2
Family Loxosomatidae					
Loxosomella minuta	3	2	-	5	2
L. davenporti	3	2	-	2	2
Phylum Brachiopoda					
Family Cancellothyrididae					
Terebratulina septentrionalis	3	2	5	1	2
Phylum Hemichordata					
Family Harrimaniidae					
Saccoglossus kowalevskii	3	2	2	2	4
Stereobalanus canadensis	2	-	-	2	4
Phylum Chordata					
Class Ascidiacea					
Family Clavelinidae					
Distaplia clavata	2	1	5	1	1
Family Polyclinidae					
Amaroucium glabrum	2	2	5	1	1
A. pallidum	3	2	5	1	1
A. stellatum	1	1	5	1	1
A. pellucidum	1	1	5	1	1
A. constellatum	1	2	5	1	1
A. spitzbergense	2	1	5	1	1
Synoicum pulmonaria	2	1	5	1	1
Family Didemnidae					
Didemnum albidum	2	2	5	1	1
D. candidum	1	2	5	1	1
Trididemnum tenerum	2	1	5	1	1
Leptoclinides faeroensis	3	1	5	1	1
Lissoclinem aurem	2	2	5	1	1

Table 3-27 (cont.)

Family Cionidae						
Ciona intestinalis	3	2	5	1	1	
Family Perophoridae						
Perophora viridis	1	2	5	1	1	
Family Corellidae						
Chelyosoma macleayanum	2	1	5	1	1	
Family Ascidiidae						
Ascidia prunum	2	1	5	1	1	
A. callosa	2	2	5	1	1	
A. obliqua	2	1	5	1	1	
Family Styelidae						
Polycarpa fibrosa	2	1	5	1	1	
Dendrodoa carnea	3	2	5	1	1	
Styela coriacea	2	1	5	1	1	
S. partita	3	2	5	1	1	
Cnemidocarpa mollis	3	2	5	1	1	
C. mortenseni	2	1	5	1	1	
Botryllus schlosseri	3	2	5	1	1	
Botrylloides aureum	2	1	5	1	1	
Family Pyuridae						
Boltenia ovifera	3	1	5	1	1	
B. echinata	3	2	5	1	1	
Halocynthia pyriformis	2	2	5	1	1	Sea peach
Craterostigma singulave	2	1	5	1	1	
Family Molgulidae						Sea grapes
Molgula siphonalis	2	2	5	1	1	
M. citrina	3	2	5	1	1	
M. complanata	3	2	5	1	1	
M. retortiformis	3	2	5	1	1	
M. manhattensis	3	2	5	1	1	
M. arenata	1	1	5	1	1	
M. robusta	3	1	5	1	1	
M. provisionalis	2	2	5	1	1	
M. lutulenta	1	1	5	1	1	
Bostrichobranchus pilularis	3	2	5	1	1	

Species Checklist

The following is a checklist of the fishes that are considered to be regular inhabitants of the offshore bottom habitat.

The following species list is not exhaustive. Although all of those listed have been reported from waters of the study area, others may be missing from the list, even though there is a good possibility that they might occur in this area. Species from the arctic or boreal waters to the north, the warm temperate waters to the south or the deep waters beyond the continental shelf could well be found in the limits of the study area.

Names with doubtful specific validity have been omitted. Various authors differ on whether a species previously considered one is actually two or more, or whether several previously distinct species are actually only one.

Strictly intertidal and brackish organisms are not included, although those intertidal or brackish species which have been collected on subtidal bottoms as well are listed.

Parasitic species are not included, nor are the meiobenthic organisms such as protozoans, rotifers, nematodes, gastrotrichs, tardigrades, cyprids, harpacticoids, etc.

Ecological notations are frequently broad generalizations. So little is know about the ecology of most of the species that exceptions should be expected.

The list should provide a useful working guide. In all cases of doubt or for critical purposes, it is recommended that the monographs of specialists in the various taxonomic groups be consulted.

Fishes

The following is a list of fishes normally found in the offshore bottom habitat within the continental shelf area between Sandy Hook, New Jersey and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, i.e. if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notation in the checklist are defined as follows:

I. Geographical distribution and relative abundance.

A. The geographical distribution includes three categories.

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west to that line

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area primary distribution, i.e. north, south, or throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh water
Brackish water
Nearshore - coastline to 18 m
Coastal - out to 91 m
Offshore - 91 m to the continental slope
Basin - deep basin of the Gulf of Maine
Banks - shallow, offshore bank areas, i.e. Georges Bank
Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species or a rare or endangered species. The life history of these species will be treated in Chapter 12.0.

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance Geographical Distribution	Depth Distribution	Habitat
Cyclostomes			
Atlantic hagfish Myxine glutinosa	common throughout	coast, basin, offshore 27-959 m	Scavenger, mud bottom
Sea lamprey Petromyzon marinus	occasional throughout	fresh to coastal 73 m	parasitic on fishes anadromous
Sharks			
Chain dogfish Scyliorhinus retifer	rare south	offshore 73-229 m	
Smooth dogfish Mustelus canis	common south	coastal to 165 m	food - large crustacea
Sand shark Odontaspis taurus	common south	nearshore to coastal 1.8-18 m	food - small fish shallow sand bars
Skates and rays			
Atlantic torpedo Torpedo nobliana	common south	nearshore to coastal	food - large fish uses electric shock
Barndoor skate Raja laevis	common throughout	nearshore to 183m	food - fish and bottom invertebrates
Winter skate Raja ocellata	common throughout	nearshore to 91 m	food - fish, small invertebrates
Clearnose skate Raja eglanteria	occasional south	coastal, banks	
Little skate *** Raja erinacea	abundant throughout	nearshore to 137 m	food - small fish, invertebrates sandy-pebbly bottom
Rosetted skate Raja garmani	common south	coastal to offshore 55-549 m	
Smooth skate Raja senta	occasional offshore	banks, basin 73-875 m	

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Thorny skate *Raja radiata*	common north	banks, basin offshore 18-604 m	food - fish, bottom invertebrates
Stingray *Dasyatis centroura*	common	coastal	
Butterfly ray *Pteroplatea micrura*	occasional south		food - bottom invertebrates, esp. crabs
Bullnose ray *Myliohatus freminvilli*	occasional south	coastal	food - lobster, crabs, large molluscs
Cownose ray *Rhinoptera bonasus*	occasional south		food - bottom crustaceans, molluscs
Sturgeons			
Atlantic sturgeon *Acipenser oxyrhinchus*	occasional throughout	fresh to 45.7 m	food - bottom invertebrates, anadromous, soft bottom
Shortnosed sturgeon *** *Acipenser brevirostrum*	rare throughout	fresh to coastal	anadromous endangered species
Eels			
Conger eel *Conger oceanicus*	common south	coastal to offshore	food - fish, polychaete worms
Slime eel *Simenchelys parasiticus*	occasional south	banks to offshore 366-1,647 m	partly parasitic on large fish
Snake eel *Omechelys crientifer*	occasional south	banks, offshore	possibly parasitic
Hake and codfishes			
Atlantic cod *** *Gadus morhua*	abundant north	coastal, banks to 457 m	food - molluscs and other bottom invertebrates, fish

Table 3- 28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Haddock *** *Melanogrammus aeglefinis*	abundant north	coastal, banks 18-146.4 m	food - bottom invertebrates, fish
White hake *Urophysis tenuis*	abundant north	nearshore to 366 m	food - bottom crustaceans
Red hake *** *Urophysis chuss*	abundant throughout	nearshore to 915 m	food - bottom crustaceans
Spotted hake *Urophysis regius*	common south	nearshore to 366 m	food - bottom crustaceans
Longfin hake *Phycis chesteri*	common throughout	banks, off-shore greater than 183 m	deep water
Blue hake *Antimora rostrata*	common throughout	offshore 366-1,830 m	deep water
Fourbeard rockling *Enchelyopus cimbrius*	common throughout	nearshore to offshore, 1,281 m	food - small crustaceans
Cusk *Brosme brosme*	common north	coastal, banks off-shore 18-366 m	food - bottom invertebrates
Grenadiers			
Marlin-spike *Nezumia bairdi*	common throughout	basin, off-shore 91-1,830 m	food - crustaceans deep mud bottom
Flounders and Soles			
Halibut *Hippoglossoides hippoglossus*	common north	coast, banks 9.1-183 m	food - larger fish sand, mud bottom
American plaice *Hippoglossoides platessoides*	common north	coast, banks, basin 9.1-549 m	food - bottom invertebrates
Summer flounder *** *Paralichthys dentatus*	abundant south	nearshore to 183 m	food - small fish, bottom invertebrates

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Fourspot flounder Paralichthys oblongus	common south	coast, banks, offshore 9.1-275 m	food - small fish, bottom invertebrates
Yellowtail flounder *** Limanda ferruginea	abundant throughout	coast, banks 9.1-109.8 m	food - bottom invertebrates sandy mud bottom
Winter flounder *** Pseudopleuronectes americanus	abundant throughout	brackish to banks, to 128 m	food - small bottom invertebrates
Smooth flounder Liopsetta putnami	abundant north	brackish to coastal to 27.4 m	food - small bottom invertebrates soft bottom
Gray sole Glyptocephalus cynoglossus	common throughout	coastal, banks, basin, 18.9-1,464 m	food - bottom invertebrates; sand, mud bottom
Windowpane Scophthalmus aquosus	common south	nearshore to coastal 73 m	food - small invertebrates
Gulfstream flounder Citharichthys arctifrons	common south	offshore 73-366 m	
Hogchoker Trinectes maculatus	occasional south	fresh to nearshore	food - small crustaceans, worms
Sea bass			
Black sea bass Centropristis striata	common south	coastal to 128 m	food - bottom invertebrates, fish
Porgies			
Scup *** Stenotomus chrysops	abundant south	coastal to 165 m	food - bottom invertebrates, plant debris
Drums			
Channel bass Sciaenops ocellatus	occasional south	nearshore to coastal	food - molluscs, crustaceans, sand bottom

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Spot Leiostomus xanthurus	common south	nearshore to coastal	
Atlantic croaker Micropodon undulatus	occasional south	nearshore to coastal	
Northern kingfish Menticirrhus saxatilis	common south	nearshore to coastal	food - invertebrates, young fish; hard or sandy bottom
Black drum Pogonias cromis	occasional south	coastal	
Tilefishes			
Tilefish Lopholatilus chamaeleoticeps	common south	offshore 82-366 m	food - bottom invertebrates
Scorpionfishes			
Redfish *** Sebastes marinus	abundant north	nearshore to banks, basins to 732 m	food - crustaceans, other invertebrates
Blackbellied rosefish Helicolenus dactylopterus	occasional south	offshore 124.4-677 m	
Sculpins			
Arctic hookear sculpin Artediellus uncinatus	occasional north	banks, basin, 36.5-366 m	food - scavenger, fish, invertebrates
Mailed sculpin Triglops nybelini	occasional north	coastal	food - scavenger, fish, invertebrates
Grubby Myoxocephalus aeneus	common throughout	nearshore to coastal	food - scavenger, fish, invertebrates
Shorthorn sculpin Myoxocephalus scorpius	common north	nearshore to coastal	food - scavenger, fish, invertebrates

Table 3 -28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Longhorn sculpin Myoxocephalus octodecemspinosus	abundant throughout	brackish to coastal, Banks to 183 m	food - scavenger, fish, invertebrates
Artic sculpin Myoxocephalus scorpioides	occasional throughout	basin, offshore 219.6-732 m	food - scavenger, fish, invertebrates
Sea raven Hemitripterus americanus	common throughout	nearshore to 91 m	food - scavenger, fish, invertebrates
Alligator fishes			
Alligator fish Aspidophoroides monopterygius	occasional north	coastal, banks, basin 18-183 m	
Lumpfishes			
Lumpfish Cyclopterus lumpus	common north	nearshore to coastal	food - crustaceans hard bottom
Seasnail Liparis atlanticus	common north	coastal, banks to 91 m	food - crustaceans molluscs; hard bottom
Stripped seasnail Liparis inquilinus	common throughout	coastal, banks 9.1 - 183 m	food - crustaceans molluscs; hard bottom
Sea robins			
Northern sea robin Prionotus carolinus	common south	nearshore to offshore to 732 m	food - scavenger, fish, bottom invertebrates
Striped sea robin Prionotus evolans	occasional south	nearshore to coastal	food - scavenger, fish, bottom invertebrates
Armored sea robin Peristidion miniatum	occasional south	offshore 91-366 m	food - small bottom crustaceans

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Cunners			
Cunner *** Tautogolabrus adspersus	abundant throughout	nearshore to coastal banks to 128 m	food - omnivorous scavenger
Tautog *** Tautoga onitus	abundant south	brackish to coastal to 36.5 m	food - molluscs, other invertebrates
Gunnels			
Rock gunnel Pholis gunellus	common north	nearshore to coastal, banks to 183 m	food - molluscs, crustaceans; hard bottom
Pricklebacks			
Snake blenny Lumpenus lumpretaeformis	common north	nearshore to coastal 91 m	food - small crustaceans
Daubed shanny Lumpenus maculatus	occasional north	offshore, basin	deep water, arctic fish
Artic shanny Stichaeus punctatus	rare north	coastal	arctic fish, eastern extreme
Radiated shanny Ulvaria subbifurcata	common north	nearshore to basin to 82.3m	hard bottom
Wrymouths			
Wrymouth Cryptocanthodes maculatus	common north	nearshore to basin to 183 m	food - fish, bottom invertebrates
Wolffishes			
Wolffish Anarhichus lupus	common north	coast, banks to 165 m	food - molluscs, echinoderms, crustaceans; hard bottom

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Eel pouts			
Ocean pout *** _Macrozoarces americanus_	abundant throughout	nearshore to coastal banks basin 3.66-192m	food - molluscs, crustaceans, echinoderms
Wolf eelpout _Lycenchelys verrilli_	rare throughout	offshore 45.7-1,098m	food - fish, bottom invertebrates
Toadfishes			
Oyster toadfish _Opsanus tau_	common south	nearshore to coastal	food - fish, invertebrates; sand, mud bottom
Triggerfishes			
Gray triggerfish _Balistes capriscus_	occasional south	coastal to offshore	food - copepod, amphipod, seaweed
Planehead filefish _Monacanthus hispidus_	occasional south	coastal to offshore	
Fringed filefish _Monacanthus ciliatus_	occasional south	coastal to offshore	
Orange filefish _Aluterus schoepfi_	occasional south	coastal to offshore	
Puffers			
Northern puffer _Sphaeroides maculatus_	common south	brackish to nearshore	food - small crustaceans
Goosefish			
Goosefish _Lophius americanus_	common throughout	nearshore to offshore to 589 m	food - fish of all kinds

Table 3-28 Checklist of Fishes - Offshore Bottom

Species	Abundance, Geographical Distribution	Depth Distribution	Habitat
Flounders			
Smallmouth flounder *Etropus microstomus*	occasional south	nearshore	
Goatfishes			
Red Goatfish *Mullus auritus*	occasional south	coastal	
Sand lances			
Sand lance *** *Ammodytes sp.*	abundant throughout	coastal, banks	food - small crustaceans, molluscs
Boxfishes			
Spiny boxfish *Ostracion diaphanum*	rare south	coastal	food - small crustaceans, molluscs
Gobies			
Naked goby *Gobiosoma bosci*	occasional south	brackish to nearshore	

REFERENCES

Bailey, R. M., J. E. Fitch, E. S. Harold, E. A. Lachner, C. C. Lindsey, C. R. Robbins, W. B. Scott. 1970. A list of common and scientific names of fishes from the United States and Canada. Third edition. Amer. Fish. Soc. Spec. Publ. No. 6.

Coleman, J. H. and H. van Genderen. 1972. Tissue levels in animals and effects caused by chlorinated hydrocarbon insecticides, chlorencited biphenyls and mercury in the marine environment along The Netherlands coast. pp. 428-435. *In* M. Ruivo, ed. "Marine Pollution and Sea Life." London: Fishing News (Books) Ltd. 624 pp.

Levinton, J. 1972. Stability and trophic structure in deposit-feeding and suspension-feeding communities. Amer. Natural. 106: 472-486.

Mileikovsky, S. A. 1970. The influence of pollution on pelagic larvae of bottom invertebrates in marine nearshore and estuarine waters. 6(4):350-356.

Newell, R. 1965. The role of detritus in the nutrition of two marine deposit feeders, the prosobranch *Hydrobia ulvae* and the bivalve *Macoma balthica*. Proc. Zool. Soc. Lond. 144:25-45.

Pearce, J. B. 1970. The effects of solid waste disposal on benthic communities in the New York Bight. pp. 404-411. *In* M. Ruivo, ed. "Marine Pollution and Sea Life." London: Fishing News (Books) Ltd. 624 pp.

Rhoads, D. C. and D. K. Young. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. J. Mar. Res. 28:150-178.

______________. 1971. Animal-sediment relations in Cape Cod Bay, Massachusetts. II Reworking by *molpadia oolitica* (Holothuroedea) Mar. Biol. 11:255-261.

Sanders, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limin. Oceanogr. 3:245-258.

______________. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. Limin. Oceanogr. 5:138-153.

Wieser, W. 1960. Benthic studies in Buzzards Bay. II. The meifauna. Liniol. and Oceanogr. 5:121-137.

Wigley, R. 1968. Benthic invertebrates of the New England fishing banks. Underwater Natural. 5:8-13.

Wigley, R. L. and R. B. Theroux. 1970. Sea-bottom photographs and macrobenthos collections from the continental shelf off Massachusetts. USFWS Spec. Sc. Rep. Fish No. 613:1-12.