Prepared for the
Bureau of Land Management
Under Contract Number AA 550-CT7-39

1979-14

VOLUME I
BOOK 1

A Summary and Analysis of Environmental Information on the Continental Shelf and Blake Plateau from Cape Hatteras to Cape Canaveral (1977)

CHAPTERS
I-Introduction
II-Geology
III-Chemistry
IV-Phytoplankton
V-Zooplankton
VI-Neuston
VII-Nekton

Center for Natural Areas
South Gardiner, ME; Washington, D.C.; Los Angeles, CA

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CENTER FOR NATURAL AREAS

a non-profit corporation, formerly affiliated with
the Smithsonian Institution,
dedicated to sound environmental management
with offices in:
South Gardiner, Maine
Washington, D. C.
Los Angeles, California

ABSTRACT

A 12-month study by the Center for Natural Areas (CNA) was conducted to collect and analyze published, unpublished, and raw data as well as ongoing research programs from 1974 to present, relative to the marine environment of the outer continental shelf (OCS) and the Blake Plateau from Cape Hatteras, North Carolina to Cape Canaveral, Florida. The report is to be used to assess adequacy of the regional data base, and may be used in the design of environmental studies that the Bureau of Land Management (BLM) will direct in an attempt to assess and predict the possible effects of oil and gas development on the marine life and environment.

During the course of the project, 28 scientists contacted representatives from the federal, state and local governmental; private industry; and academic sectors and developed a list of bibliographic references including over 2500 citations. The following list shows the major topics inventoried and presented in the report:

- Marine Geology
- Chemistry
- Phytoplankton
- Zooplankton
- Neuston
- Nekton
- Benthos
- Commercial Fisheries
- Sport Fisheries
- Marine Benthic Flora
- Marine Mammals
- Marine Birds
- Marine Turtles
- Endangered or Threatened Species
- Microbiology
- OCS Uses
- Unique or Endangered Environments
- Toxicity and Health Studies

The report in three volumes is appproximately 3500 pages in length with over 600 illustrations and 375 tables. Volume I contains the text for each topic; Volume II contains the master bibliography, index and acknowledgements; and Volume III contains various appendices.

PREFACE TO THE FINAL REPORT

The material and data contained in this report have been furnished to the Bureau of Land Management under the terms of Contract AA550-CT7-39. The Center for Natural Areas, as contractor, takes full responsiblity for any errors or misstatements which may exist. This inventory was put together from a large number of sources in a 12-month period. 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 CNA.

The staff at CNA thank the many authors and contributors to this study for what we believe is an extensive review of the literature and data of the marine environment of the South Atlantic OCS region.

William C. Reed, President
South Gardiner, Maine
August 1979

A Summary and Analysis of Environmental Information on the Continental Shelf and Blake Plateau from Cape Hatteras to Cape Canaveral (1977)

VOLUME I BOOK 1 Chapters I-VII

I-Introduction
II-Geology
III-Chemistry
IV-Phytoplankton
V-Zooplankton
VI-Neuston
VII-Nekton

prepared for the
Bureau of Land Management

by the
Center for Natural Areas
S. Gardiner, ME; Washington, D.C.; Los Angeles, CA

MASTER TABLE OF CONTENTS

I. INTRODUCTION

II. GEOLOGY

Dr. Vernon J. Henry, Jr.
University of Georgia
Mr. Robert T. Giles
Skidaway Institute of Oceanography
Savannah, Georgia

III. CHEMISTRY

Dr. Herbert L. Windom
Dr. Richard F. Lee
Dr. Larry P. Atkinson

Skidaway Institute of Oceanography
Savannah, Georgia

IV. Phytoplankton

Dr. Harold G. Marshall
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

V. ZOOPLANKTON

Dr. Raymond Alden
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

VI. NEUSTON

Dr. Harold G. Marshall
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

VII. NEKTON

Dr. F. John Vernberg
Ms. Donna Z. Mirkes
Belle W. Baruch Institute for
Marine Biology and Coastal Research
Columbia, South Carolina

VIII. BENTHOS

Dr. Donald F. Boesch
Virginia Institute of Marine Science
Gloucester Point, Virginia

IX. Commercial Fisheries

Dr. F. Douglas Martin
Chesapeake Biological Laboratory
University of Maryland
Center for Environmental and Estuarine Studies

X. SPORTS FISHERIES

Dr. F. Douglas Martin
Chesapeake Biological Laboratory
University of Maryland
Center for Environmental and Estuarine Studies

XI. MARINE BENTHIC FLORA

Dr. Harold J. Humm
Department of Marine Science
University of South Florida
St. Petersburg, Florida

XII. MARINE MAMMALS

Lois K. Winn
Howard E. Winn
University of Rhode Island
Kingston, Rhode Island

David K. Caldwell
Melba C. Caldwell
Biocommunication and Marine Mammal Research Facility
University of Florida
St. Augustine, Florida

J. Lawrence Dunn
University of Rhode Island
Kingston, Rhode Island

XIII. MARINE BIRDS

Dr. Dennis M. Forsythe
The Citadel
Charleston, South Carolina

Mr. Paul R. Adamus
Center for Natural Areas
South Gardiner, Maine

XIV. MARINE TURTLES

Dr. Archie F. Carr
Dr. Dale R. Jackson
Dept. of Zoology
University of Florida
Gainesville, Florida

Dr. John B. Iverson
Dept. of Natural Science
Florida State Museum
University of Florida
Gainesville, Florida

XV. ENDANGERED OR THREATENED SPECIES

Mr. James Hynson
Center for Natural Areas

XVI. MICROBIOLOGY

Dr. Carl W. Erkenbrecher, Jr.
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

XVII. OCS USES

Stephen Tibbetts
Center for Natural Areas

XVIII. UNIQUE OR ENDANGERED ENVIRONMENTS

David W. Laist
Thomas E. Bigford
Center for Natural Areas

XIX. TOXICITY AND HEALTH STUDIES

Dr. John M. Frazier
Department of Environmental Health Sciences
Johns Hopkins University, Baltimore, Maryland

XX. SUMMARY AND SYNTHESIS

Dr. Rezneat M. Darnell
Texas A&M University
College Station, Texas

1.0 BACKGROUND AND HISTORY

In preparation for the leasing of OCS lands in the South Atlantic frontier area (OCS Lease Sale 43), the Bureau of Land Management has been assembling background data for a period of five years. This effort began in April 1973 when BLM advertised for proposals to conduct a literature review of the area from Cape Hatteras to Cape Canaveral, for socio-economic and environmental data of the continental shelf to 200m. This work was contracted to the Virginia Institute of Marine Science (VIMS) and completed in 1974. This report, entitled "A Socio-Economic Environmental Baseline Summary for the South Atlantic Region between Cape Hatteras, North Carolina and Cape Canaveral, Florida", collected data that was current through early to mid-1974. The intent of the BLM and others was to provide current background, data, cite various data banks and sources of raw data, list ongoing research, and, in general, provide the BLM staff with as much information as possible to assist them in the preparation of environmental impact statements as specified by the National Environmental Policy Act-NEPA (1969).

At the Atlanta OCS Conference/Workshop held in October 1975, one of the recommendations to BLM was that there had to be an updating of the VIMS (1974) literature review, especially in the areas of new programs, ongoing research, raw and/or unpublished data, and data gaps, since those data in the 1974 document were becoming outdated in some cases. Moreover, much of the report used published literature only, and did not inventory the other sources. It had also become apparent that certain areas of the earlier work were not specific enough. In addition, various program delays and the overall delay of the lease sale until late 1977 made it imperative to thoroughly and comprehensively conduct an updating and filling of data gaps, as a part of the environmental studies required prior to exploratory drilling. Subsequently, the BLM decided to extend the literature review beyond the original 200m boundary to the continental slope (the 1500m isobath), an area not included in the original study.

Thus, in March 1977 proposals were submitted to BLM to expand and update the previous studies, while encompassing the expanded geographical coverage.

2.0 OBJECTIVES AND PURPOSE OF THE STUDY

The basic study objectives, pertaining to the geographic area outlined in Section 3.2, are listed below.

--update the environmental survey by VIMS (1974) and provide analysis of all existing biological, chemical, and geological data.

--identify and summarize ongoing biological, chemical, and geological programs in the South Atlantic region.

--identify sources of raw data and unworked samples, and evaluate the role of this material in relation to the total existing data base.

--identify gaps in the biological, chemical, and geological data base and evaluate the extent of these gaps.

3.0 SCOPE OF THE STUDY

3.1 Authorization

The study was authorized by the U. S. Department of the Interior, Bureau of Land Management, in RFP AA550-RP7-11, January 31, 1977, and by the subsequent contract, AA550-CT7-39, issued August 25, 1977 to the Center for Natural Areas.

3.2 Geographic Area Covered

The study area is presented in Figure I-1. The geographical area covered extends from Cape Hatteras, North Carolina to Cape Canaveral, Florida, from the spring tide mark to the 1,500m isobath, encompassing four coastal states-- North Carolina, South Carolina, Georgia and Florida.

3.3 Topical Coverage

The topical areas to be reviewed in the study were established by BLM in RFP AA550-RP7-11, and further supplemented by the CNA proposal. A list of the major topics is presented in Table I-1. An index of all terms, keywords, and species names may be found in Volume II of this report.

4.0 METHODS AND APPROACH

The following section describes the methodology used by CNA to organize and conduct the literature review and data update. These methods were based on three major tasks described below.

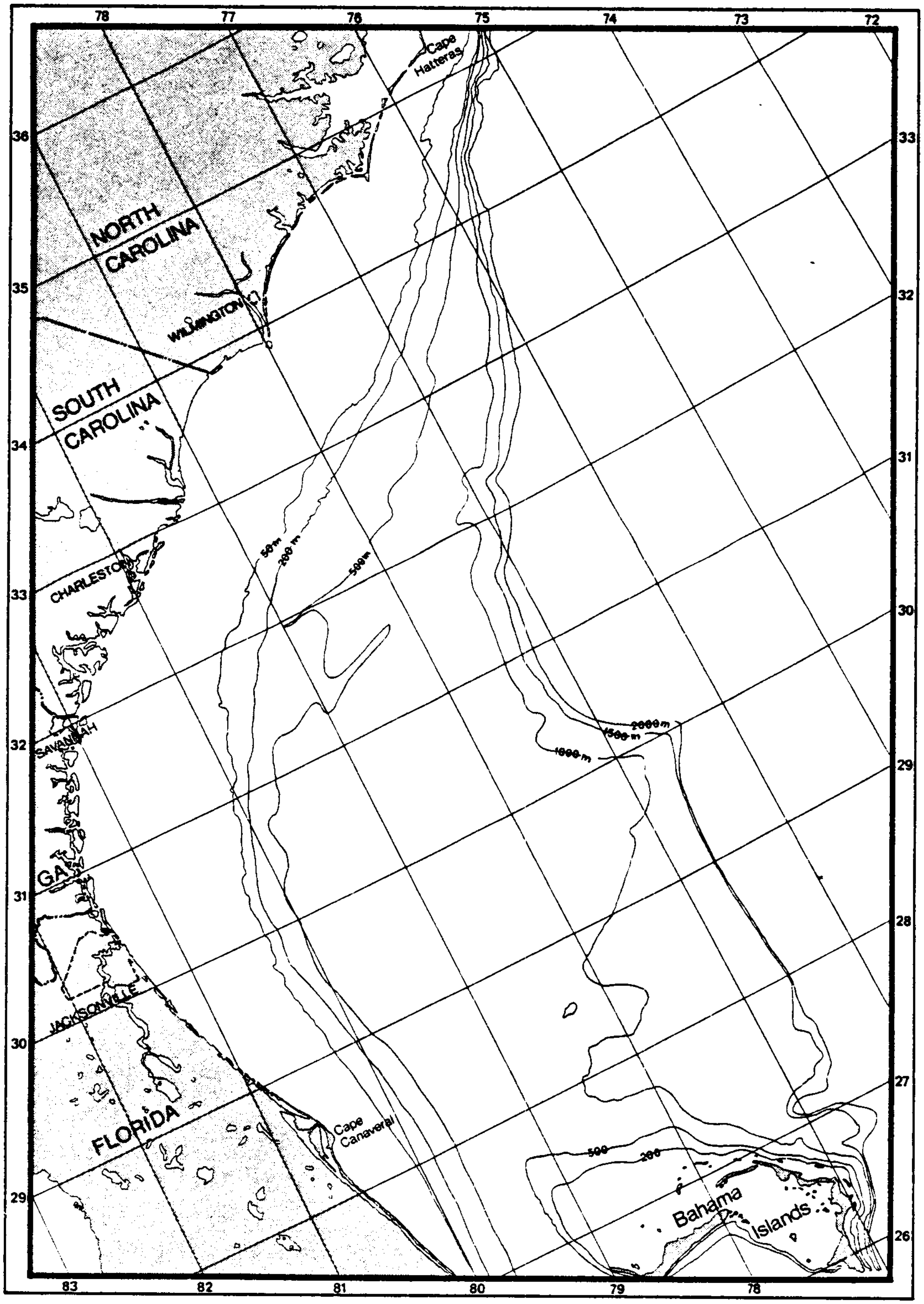

FIGURE I-1. Location of Study Boundaries and States

TABLE I-1

Major Topics Covered in Report

Marine Geology
Chemistry
Biological Oceanography
- Phytoplankton
- Zooplankton
- Neuston
- Nekton
- Benthos
- Commercial Fisheries
- Sport Fisheries
- Marine Benthic Flora
- Marine Mammals
- Marine Birds
- Marine Turtles
- Endangered or Threatened Species
- Microbiology

OCS Uses
Unique or Endangered Environments
Toxicity and Health Studies

TASK 1: Data Collection

During the initial phase of Task 1, CNA organized the entire program approach. Copies of the work statement, schedule, and program guidelines were sent to each of the principal investigators.

The major element of Task 1 involved securing a large number of professional contacts, in order to locate, describe, and obtain relevant study materials. This process yielded documents, printout materials, and citations, supplemental to data and publications collected by study investigators.

In a joint effort conducted by CNA staff and the 17 principal investigators, approximately 1,100 contacts were established. This approach consisted primarily of sending letters of request to colleagues, state and federal agencies, and marine institutions in order to obtain reprints, unpublished data, and information concerning ongoing research projects. A list of professional contacts was furnished to CNA by each principal investigator. Letters with specific requests were sent to each of the contacts. A copy of a typical letter of request and enclosures is presented in Figures I-2 and I-3. CNA found the Project Abstract (Figure I-4) to be quite useful in describing the request for information.

Depending on the type and extent of information available at various laboratories, a decision was made to send a CNA field representative to collect the materials. Alternatively, if convenient, material was sent by mail.

In response to 1,072 letters of request sent during the period of November 1977 to March 1978, CNA received 279 replies, many of which included documents. In addition, principal investigators received input from nearly 500 sources. A full list of contacts who provided materials or information appears in Volume II.

Based on previous favorable experience and the need to sample a variety of major computerized data banks and information services, CNA utilized a number of federal and private institutions to provide information concerning references to data, literature and ongoing research. The following files were searched for information.

- Oceanic Abstracts (OA)
- Environmental Data Base Directory (EDBD)
- Biological Abstracts (BA)
- Chemical Abstracts (CA)
- National Technical Information Service (NTIS)
- Reports of Observations and Samples Collected by Ongoing Oceanographic Programs (ROSCOP)
- Bibliography and Index of Geology (GEOREF)
- Smithsonian Science and Information Exchange (SSIE)

Center for Natural Areas

NORTHEAST OFFICE: Box 98, South Gardiner, Maine 04359 (207) 582-4205

March 9, 1978

Dr. Adam Zsolnay
Biostation
St. George's West
BERMUDA 7-1880

Dear Dr. Zsolnay:

The Center for Natural Areas has received a contract from the Bureau of Land Management to update all environmental literature and data for a major portion of the Atlantic east coast. I have agreed to write the chapter for them on the biology and ecology of zooplankton of the Continental Shelf from Cape Hatteras to Cape Canaveral. I'm especially interested in learning of recently published reports, compiled field data, and ongoing research project reports that you may have available. I would appreciate receiving any of these you could send along for mention or inclusion in this chapter. Although most of our effort is focused on an update of material after 1974, my topic of zooplankton also must include a review of earlier data that could be significant to BLM. The information we are collecting will be used by BLM to update subsequent oil and gas development of the OCS.

I have enclosed an abstract of the study and a brief description outline of my topic area. As you can see, BLM is interested in identifying basic ecological patterns as well as in examining laboratory and field work emphasizing the effects of hydrocarbons, trace metals, and overall OCS development of the biota. We would also like to identify raw data banks, programs in progress, and data gaps in the study of zooplankton of the Southeastern Coast and Continental Shelf.

I know you are as busy as I am but I would sincerely appreciate it if you would take a few minutes to complete the enclosed form and return it to the Center's address. If you do have reports, papers, or printed materials you can send, please forward them to me at the Department of Biological Sciences, Old Dominion University, Norfolk, Virginia 23508.

The report resulting from this rather comprehensive inventory and review will be completed by mid-1978. It is our understanding that the report will be published shortly thereafter and available to all contributors.

Thank you for your help.

Sincerely,

Dr. Raymond W. Alden III

A NON-PROFIT ENVIRONMENTAL MANAGEMENT CORPORATION FORMERLY AFFILIATED WITH THE SMITHSONIAN INSTITUTION

RWA/kp

FIGURE I-2. A Sample of Letters Sent to Obtain Literature and Data.

CNA/BLM CT7-39
November 1977

TOPIC: Zooplankton

1. Types of data and reports located at your lab

◯ published

◯ unpublished reports; theses, M.S., quarterly, progress, etc.

◯ ongoing research programs

◯ raw data, unworked samples

2. Study areas (general geographic location):

3. Availability

◯ data, reports publications will be mailed.

◯ someone from CNA should visit lab and inventory materials.

◯ I have no reports or data in the research area taken or analyzed.

◯ please call me to discuss your request.

Name ____________________

Institution/Co. ____________________

____

Phone No. ____________________

FIGURE I-3. A Sample of the Request for Literature and Data.

Center for Natural Areas

NORTHEAST OFFICE: Box 98, South Gardiner, Maine 04359 (207) 582-4205

CNA/BLM CT7-39

A SUMMARY AND ANALYSIS OF ENVIRONMENTAL INFORMATION ON THE CONTINENTAL SHELF AND BLAKE PLATEAU FROM CAPE HATTERAS TO CAPE CANAVERAL

by

Center for Natural Areas

ABSTRACT

Background

As part of its responsibility to lease and manage the outer continental shelf (OCS) seaward of state boundaries for the development of oil and gas resources, the Bureau of Land Management (BLM) has initiated a program of environmental studies that assess the effects of developing these resources. The beginning of these studies results in the extensive synthesis of existing literature and environmental data. The Virginia Institute of Marine Science conducted one survey, published in 1974, that covered this area.

Data in these compilations are now four to five years old and there are many valuable recent surveys and data bases as well as a totally new set of ongoing programs. BLM has awarded a contract to the Center for Natural Areas to conduct an updated summary and analysis from 1974 to present (1977) publication of the Virginia Institute of Marine Science effort.

Objectives

The study objectives are to collect, compile, and analyze published, unpublished, raw data, and ongoing programs of marine environmental data. The report will be used in the design of environmental studies that BLM will direct in an attempt to assess and predict the possible effects of oil and gas development on the marine life and environment. These objectives are:

—to update data from 1974 to present
—to compile and integrate lab and field data on petroleum hydrocarbons and trace metals effects on organisms
—to identify data gaps
—to identify - summarize ongoing oceanographic programs
—to identify sources of raw data and unworked samples

A NON-PROFIT ENVIRONMENTAL MANAGEMENT CORPORATION AFFILIATED WITH THE SMITHSONIAN INSTITUTION

FIGURE I-4. Project Abstract Sent In With Letters

<u>Topical Areas</u> on which we need information are:

GEOLOGY - structures, sediments, bathymetry, economic, hazards

CHEMISTRY - hydrocarbon-trace metal for water, sediment, biota, atmosphere

BIOLOGICAL - phytoplankton, zooplankton, neuston, nekton, benthos, commercial/sport fisheries, benthic flora, mammals, birds, threatened or endangered species, microbiology, marine turtles

OCS USES - transportation, dump sites, cables, mining, military

UNIQUE/ENDANGERED ENVIRONMENTS

TOXICITY AND HEALTH STUDIES - lab and field evaluations of hydrocarbon and trace metals

The CNA study is a ten-month effort being conducted through the South Gardiner, Maine office and the Washington, D. C., office. For further information, contact Mr. William C. Reed, Center for Natural Areas, Box 98, South Gardiner, Maine (207) 582-4205; or Mr. John Noble, Center for Natural Areas, 1525 New Hampshire Avenue, N. W., Washington, D.C. (202) 265-0066.

Inquiries to the Bureau of Land Management may be made to Dr. Richard Defenbaugh, U. S. Department of Interior, New Orleans Outer Continental Shelf Office, Suite 841, Hale Boggs Federal Building, 500 Camp Street, New Orleans, Louisiana 70130.

FIGURE I-4 Cont.

National Inventory of Biological Monitoring Programs (BIOMON)

Because of the project's focus on descriptive environmental information specific to the southeastern coastal and shelf area, the approach used in contacting these computer files concentrated on the use of geographic descriptors and date. Although most references obtained appeared useful, the total number of references received was disappointingly small.

The EDBD search produced 311 references to sources of data collected and archived by researchers conducting work in the study area since 1973. The ROSCOP search, which identified scientists who have collected oceanographic samples using federal funding, produced descriptions of eight cruises. Like EDBD, the ROSCOP file can be accessed by geographic coordinates and date; thus, all references applicable to the project area and time period should have been received.

Two searches were run through The National Inventory of Biological Monitoring Programs. The main data base provided 35 project summaries relevant to the study area, while the mini-BIOMON produced 281 project summaries.

The SSIE search produced 300 notices of research projects relevant to the study.

The published literature files searched produced the following overall results: BA-37 citations; CA-9 citations; OA-95 citations; NTIS-108 citations; and GEOREF-129 citations.

Varying amounts and types of materials were received from the National Oceanographic Data Center (NODC), Environmental Protection Agency, National Oceanic and Atmospheric Administration, Bureau of Land Management, National Marine Fisheries Service, U. S. Army Corps of Engineers, U. S. Fish and Wildlife Service, and the U. S. Geological Survey.

TASK 2: Data Evaluation

Task 2 essentially began as the information started to flow from the various data banks to CNA. As a result of new information obtained from the data banks, a second round of letters was sent by many of the investigators in order to gather specific materials for their respective chapters. In many cases, principal investigators also made site visits to key data repositories in an effort to supplement project files and fill specific data gaps.

Concurrently, CNA began to formulate the precise guidelines for chapter subjects, including the written and graphic formats. All authors were asked to furnish a final outline of their respective chapters in order for CNA to insure that the necessary topics were being covered.

TASK 3: Synthesis of Data - Final Report

Following submission of the individual chapter outlines and subsequent approval, all investigators/authors submitted their first drafts for CNA editing and review. The drafts were reviewed to insure that each chapter complied with BLM specifications as stated in contract AA550-CT7-39 and assumed as uniform a format as possible.

5.0 ORGANIZATION OF THE REPORT

The report is essentially organized as set forth in RFP AA550-RP7-11, using the chapter breakdown by disciplines. The basic arrangement of the final report is into three volumes. These are (1) the basic subject chapters (I through XIX), (2) Master Bibliography, Index, and Acknowledgements, and (3) Appendices, including Ongoing Research and Programs, Data Gaps, and Raw Data.

6.0 ACKNOWLEDGEMENTS

The staff at CNA 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 providing information and their affiliations is presented in Volume II.

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.

Marine Geology
Dr. Vernon J. Henry
Skidaway Institute of Oceanography

Chemistry
Dr. Herbert L. Windom
Dr. Richard F. Lee
Dr. Larry P. Atkinson
Skidaway Institute of Oceanography

Phytoplankton and Neuston
Dr. Harold G. Marshall
Old Dominion University

Zooplankton

Dr. Raymond Alden III
Old Dominion University

Nekton

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Ms. Donna Z. Mirkes
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Benthos

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Mr. Thomas E. Bigford
Center for Natural Areas

Toxicity and Health Studies

Dr. John M. Frazier
Johns Hopkins University

Project Synthesis

Dr. Rezneat M. Darnell
TerEco Corporation

Dr. Donald F. Boesch
Virginia Institute of Marine Science

Center for Natural Areas Staff

William C. Reed, President and Project Manager
Patricia E. Ryan, Project Coordinator

Thomas E. Bigford, Data Collection
Judith A. Crossman, Word Processing
Terrence DeWan, Graphics Coordination and Production
Glenn C. Hazelton, Graphics Coordination and Production
David W. Laist, Data Coordination and Collection
Kathleen S. Palmer, Word Processing
Priscilla J. Slack, Word Processing

II. GEOLOGY

Dr. Vernon J. Henry, Jr.
University of Georgia
Mr. Robert T. Giles
Skidaway Institute of Oceanography
Savannah, Georgia

1.0 INTRODUCTION

1.1 Objectives

The primary objectives of this chapter are

- to update the report on geological oceanography presented in the Virginia Institute of Marine Science (VIMS,1974) literature study of the South Atlantic outer continental shelf area
- to identify data gaps
- to identify and summarize unpublished and/or ongoing geological studies
- to identify sources of raw data and unworked samples

In addition to being a survey of pertinent geological literature, this study has attempted to evaluate, analyze and interpret the material as it relates to the overall study objectives described in Chapter I. Special effort has been made to complement, but not unnecessarily duplicate, the VIMS study. As a result, emphasis has been placed on literature dating from 1974 and it is suggested that in some instances the reader may want to refer to the VIMS report for a more detailed reference to earlier material.

In order to avoid redundance, a regional discussion of each topic is given in Section 1.4 General Description that serves as background information for each of the four Subzones of the study. The discussion of each Subzone will be based whenever possible only on material published after 1973, or that was not described in the VIMS study.

1.2 Evaluation of Source Materials

1.2.1 Published Reports

In the four years since the VIMS report (1974) most of the geological publications have been generated by regional surveys carried out by or through the sponsorship of Government agencies -- principally the Department of the Interior and the Department of Commerce -- and provide the bulk of the source materials for this report.

Most of the background and general information and much of the specific data concerning the geology of the South Atlantic continental margin and Blake Plateau is presented in Volume IV: Geological Oceanography in the Virginia Institute of Marine Science environmental baseline summary (Zeigler and Patton, 1974); the U. S. Geological Survey Open-File Report 75-411 (Dillon, Girard, Weed, Sheridan, Dolton, Sable, Krivoy, Grim, Robbins, Rhodehamel, Amato and Foley, 1975) and the Bureau of Land Management final environmental impact statement for the proposed South Atlantic Outer Continental Shelf Sale No. 43 (U. S. Department of the Interior, Bureau of Land Management, 1977).

Reflecting their level of activity in the South Atlantic region since 1974, the U. S. Geological Survey has collected the preponderance of definitive geological data publically available for that region both from in-house operations as well as through contracts or cooperative efforts with state agencies, academic institutions and private industry (Figure II-1).

Through a memorandum of understanding with the Bureau of Land Management, the Survey's investigations have centered around resource assessment, geologic hazards, and structural/stratigraphic studies of the coastal plain, continental margin and Blake Plateau (Figure II-2). A summary of these operations and a list of publications during FY75 and FY76 is given by Behrendt (1977). Several of the publications cited are program abstracts of papers presented at annual meetings of the principal earth science societies and several more are in press.

In addition to the Department of the Interior's activities, other federal agencies such as the Department of Commerce (NOAA, NOS, NMFS, and CZM), the Department of the Army (CERC), the National Science Foundation, and the Energy Research and Development Administration have been, or are presently involved, or sponsor studies that directly or indirectly relate to the geology of the South Atlantic region. Relevant publications that have resulted from such studies are discussed in appropriate Subzone sections.

1.2.2 Unpublished Reports

Response to questionnaires indicates that relatively few reports of this nature exist. Most of the unpublished material is in the form of status or progress reports relating to investigations by the U. S. Geological Survey and cooperating agencies. Pertinent information is cited in the appropriate Subzone discussion.

1.2.3 Ongoing Research Programs

Again, most of the studies in progress relate to Bureau of Land Management/U. S. Geological Survey programs on the South Atlantic outer continental shelf. Ongoing programs of the Survey are listed and described by Behrendt (1977). Regarding the South Atlantic region, five projects are relevant and concern resource assessment, petroleum geology and potential, environmental studies

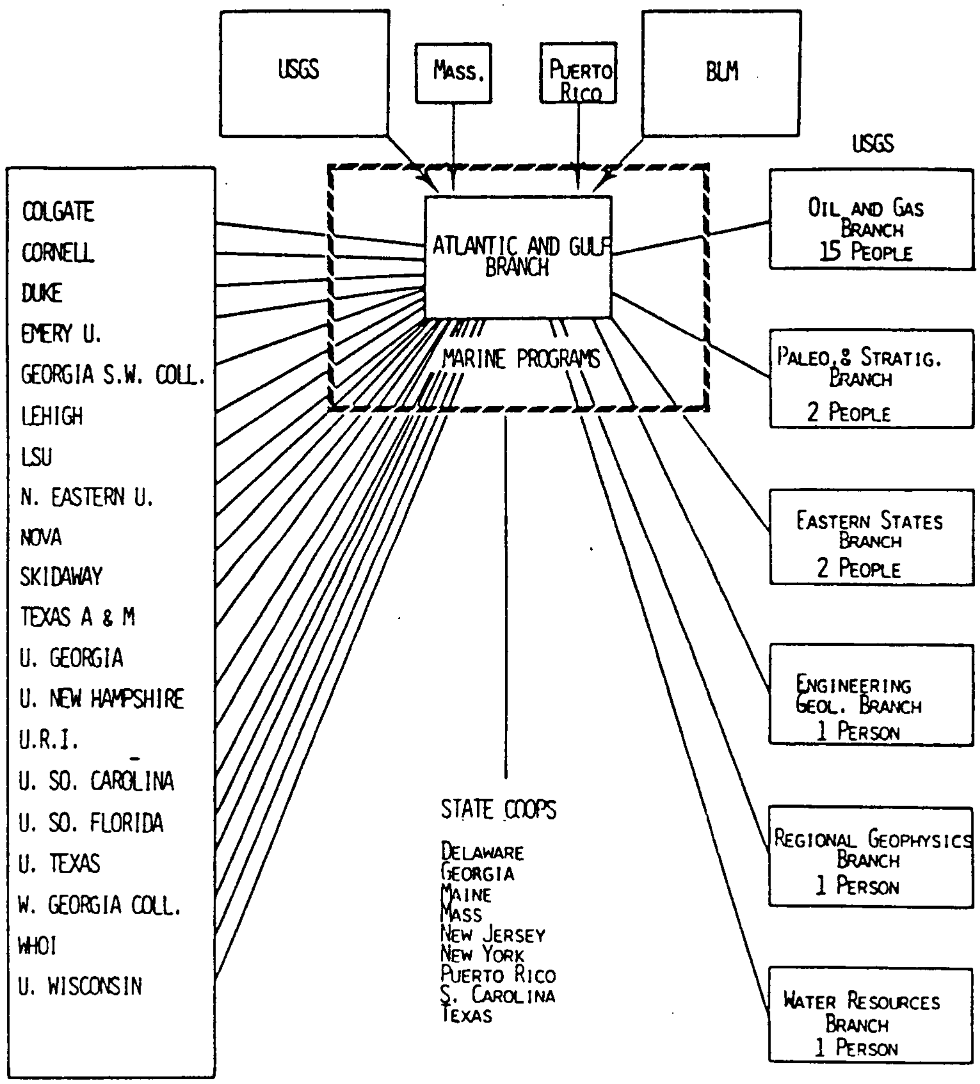


FIGURE II-1. 1977 Funds and program, U.S. Geological Survey, Office of Marine Geology, Woods Hole, MA (From Behrendt, 1977).

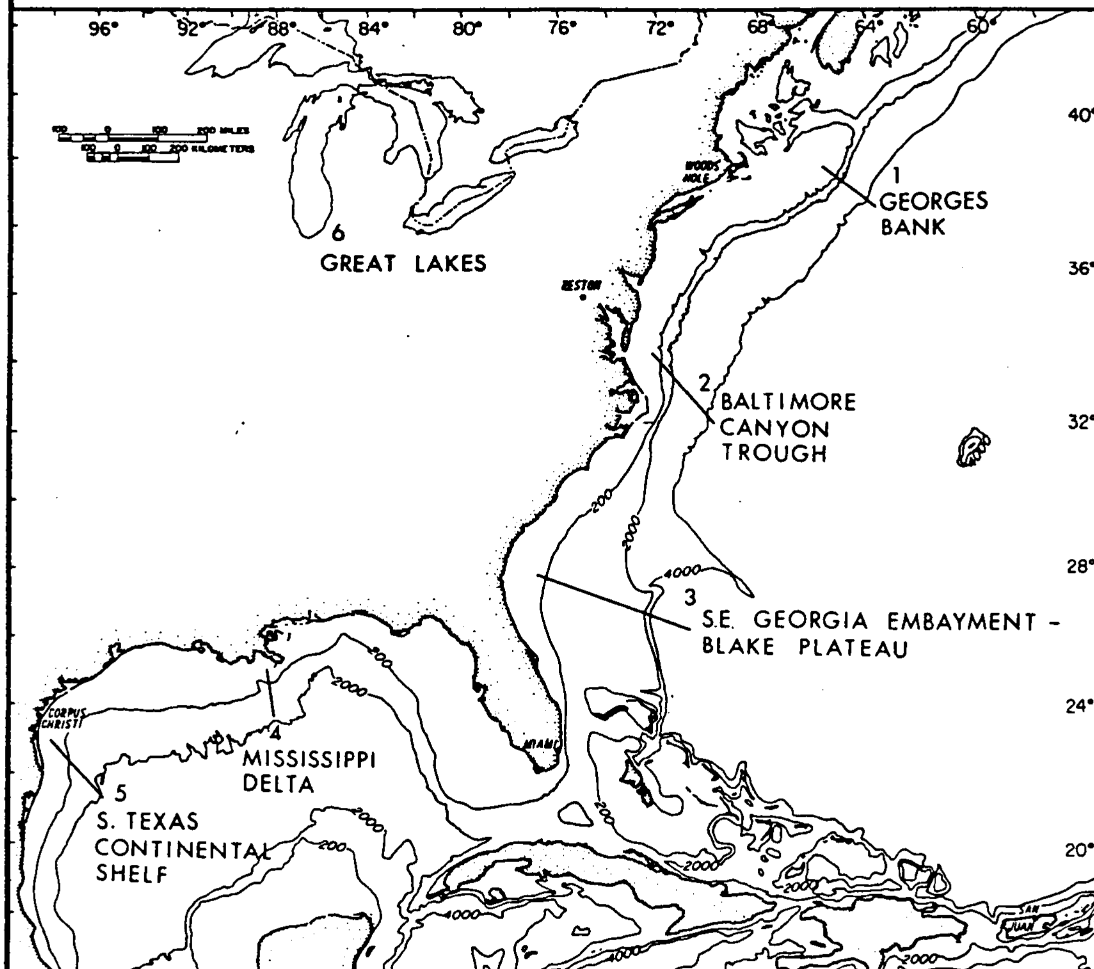


FIGURE II-2. Primary operating area of Branch of Atlantic-Gulf of Mexico Geology. U.S. Geological Survey, Office of Marine Geology, Woods Hole, MA. (After Behrendt, 1977).

and assessments related to oil spills, and pollution associated with oil exploration and development.

A benchmark environmental study of the South Atlantic Bight was carried out by Texas Instruments, Inc. under contract to the Bureau of Land Management (Figure II-3). This project, initiated in late 1976, was primarily biological and chemical in nature but also collected suspended and bottom sediment data for the U. S. Geological Survey (Texas Instruments, 1977).

Bathymetric mapping of the shelf and continental margin at a scale of 1:250,000 is in progress by the National Ocean Survey (NOS) (Figure II-4). To date 13 sheets have been completed in the project area: Beaufort, North Carolina; Cape Fear, North Carolina; Georgetown, South Carolina; Savannah, Georgia; Brunswick, Georgia; Jacksonville, Florida; Blake Spur; Harrington Hill; Hoyt Hills; McAlinden Spur; Richardson Hills; and Stetson Mesa.

Pertinent ongoing research programs are cited in the appropriate Subzone discussion.

1.2.4 Raw Data, Unworked Samples

Most of the raw data, including unworked samples, relate to ongoing programs. Pertinent information in this category is discussed in the appropriate Subzone section.

1.2.5 Other

Other source materials relevant to this study include annual summaries of marine activities in progress in the Carolinas, Georgia and the northern part of Florida by academic institutions and state and federal agencies (Coastal Plains Center for Marine Development Services, 1977); the Conference/Workshop Proceedings of the Bureau of Land Management's Environmental Studies Program for the South Atlantic Outer Continental Shelf Area held in Atlanta, Georgia in 1975 (Massoglia, 1976); list of publications for the U. S. Geological Survey (U. S. Department of the Interior, Geological Survey, 1974-76) and the final SCOPE products report (Norris, 1976).

1.3 Information Gaps

Relative to the South Atlantic region in general, the need for additional information beyond that expected to be provided by ongoing or just completed programs includes additional shallow and deep core drilling to ground-truth existing seismic data; detailed mapping of the sea bottom; seasonal process response and time

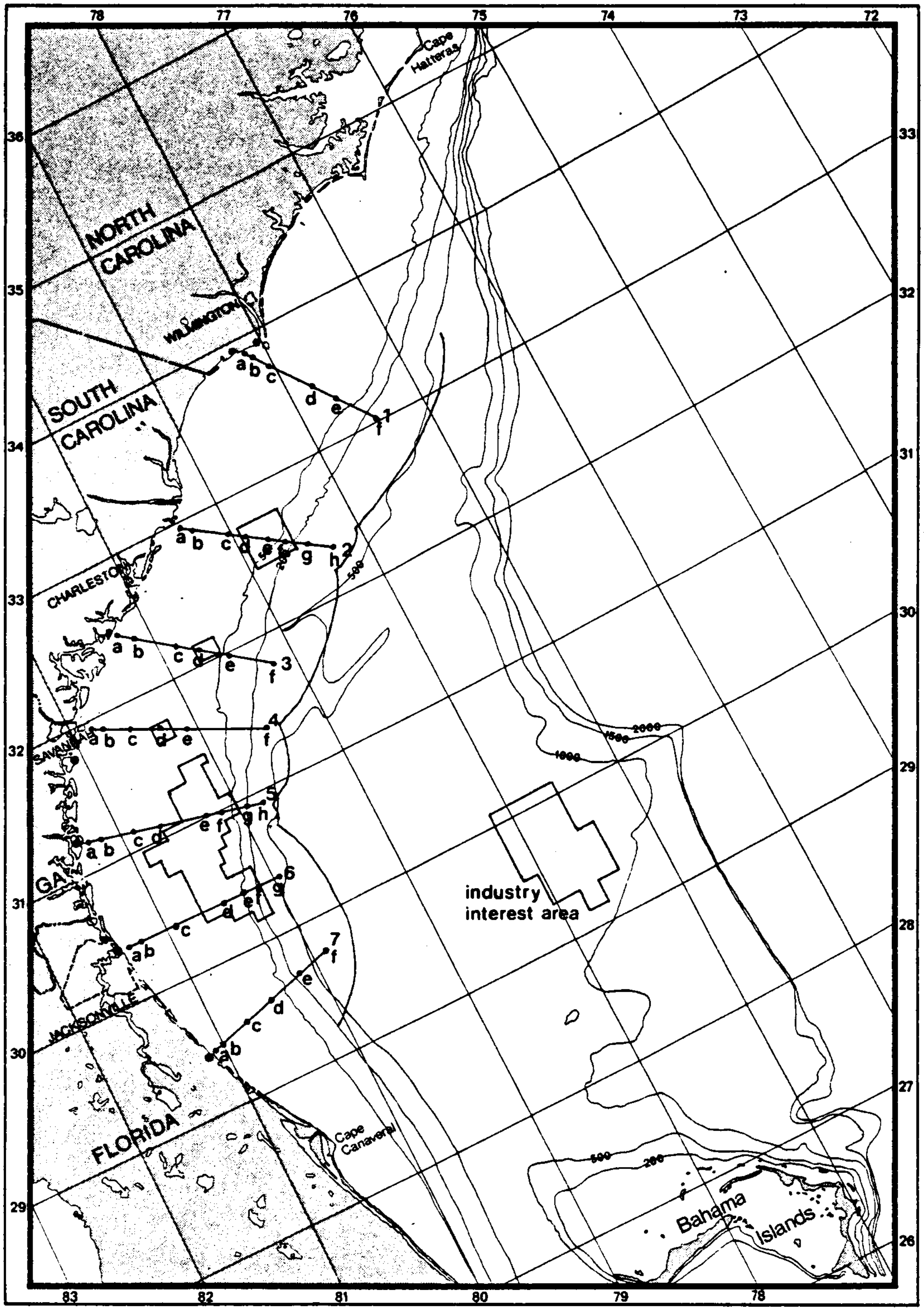


FIGURE II-3. Location of South Atlantic Benchmark Program Sampling Transects. (From Texas Instruments, Inc., 1977).

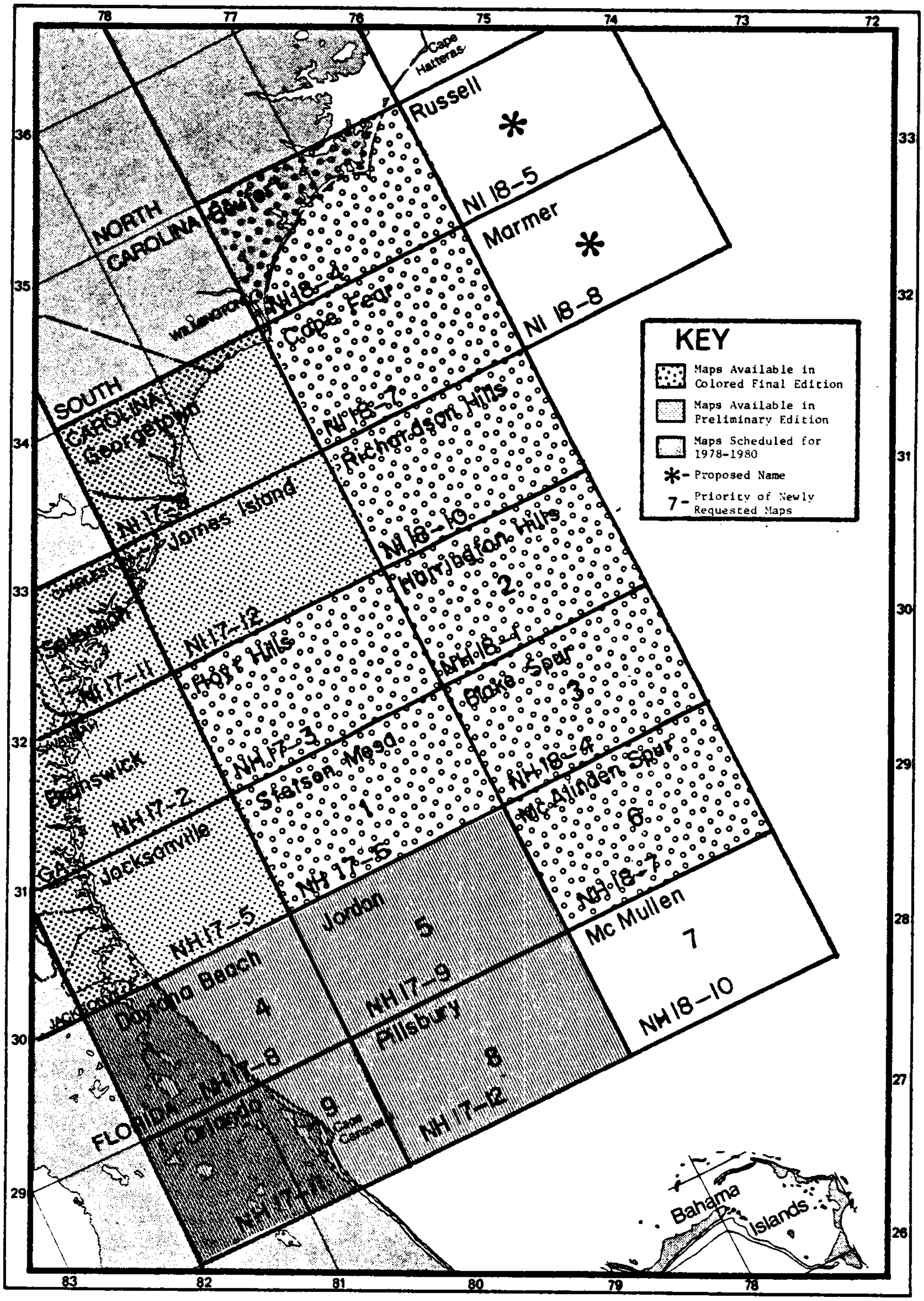


FIGURE II-4. U. S. South Atlantic Region status of bathymetric maps and proposed names. From U. S. Department of the Interior 1977 Bureau of Land Management Final Environmental Impact Statement for Proposed 1978 Outer Continental Shelf Oil and Gas Lease Sale No. 43. Updated through 1978.

series studies of representative bottom types, particularly during medium and high energy conditions; studies of geotechnical properties of bottom and subbottom sediments, particularly relating to slope stability; topical studies relating to onshore effects of oil and gas exploration and production; investigations concerning the presence of aquifers under the shelf and the effects of drilling or mining on water quality; evaluation of the relationship between geothermal gradients and seismic activity; studies defining the occurrence, value and accessibility of mineral deposits and environmental implications of mining them; and detailed examination of the topography and shallow sediments of the Blake Plateau.

The concepts and rationale for process studies and environmental management have been very well described by Stanley (1969), Stanley and Swift (1976), and Gorsline and Swift (1977).

Data gaps of a more site-specific nature are described in appropriate sub-sections.

1.4 General Description

1.4.1 Location

The geographical area covered by this study extends from Cape Hatteras, North Carolina to Cape Canaveral, Florida, and from the spring tide line to the 1,500m isobath. Relative to the 1974 VIMS study, this work does not include the coastal plains (emergent shelf) of the respective states. Based on contrasting developmental history and processes, the study area is divided into four Subzones: Subzone I, extending from Cape Hatteras, North Carolina to Winyah Bay, South Carolina; Subzone II, extending from Winyah Bay to St. Johns River, Florida; Subzone III, extending from St. Johns River to Cape Canaveral, Florida; and Subzone IV, which approximately covers the Blake Plateau (Figure II-5).

1.4.2 Geologic History

Little is known about the pre-Paleozoic geologic history of the South Atlantic outer continental shelf and Blake Plateau. A continuous magnetic high on or near the continental slope, shown in detail on maps compiled by Klitgord and Behrendt (1977b) has been reported by Taylor, Zietz and Dennis (1968) to possibly result from an igneous intrusive that parallels the edge of the pre-Paleozoic continental landmass. They interpret the magnetic data as suggesting that Florida and part of Georgia were added to the paleo-continent in pre-Paleozoic time.

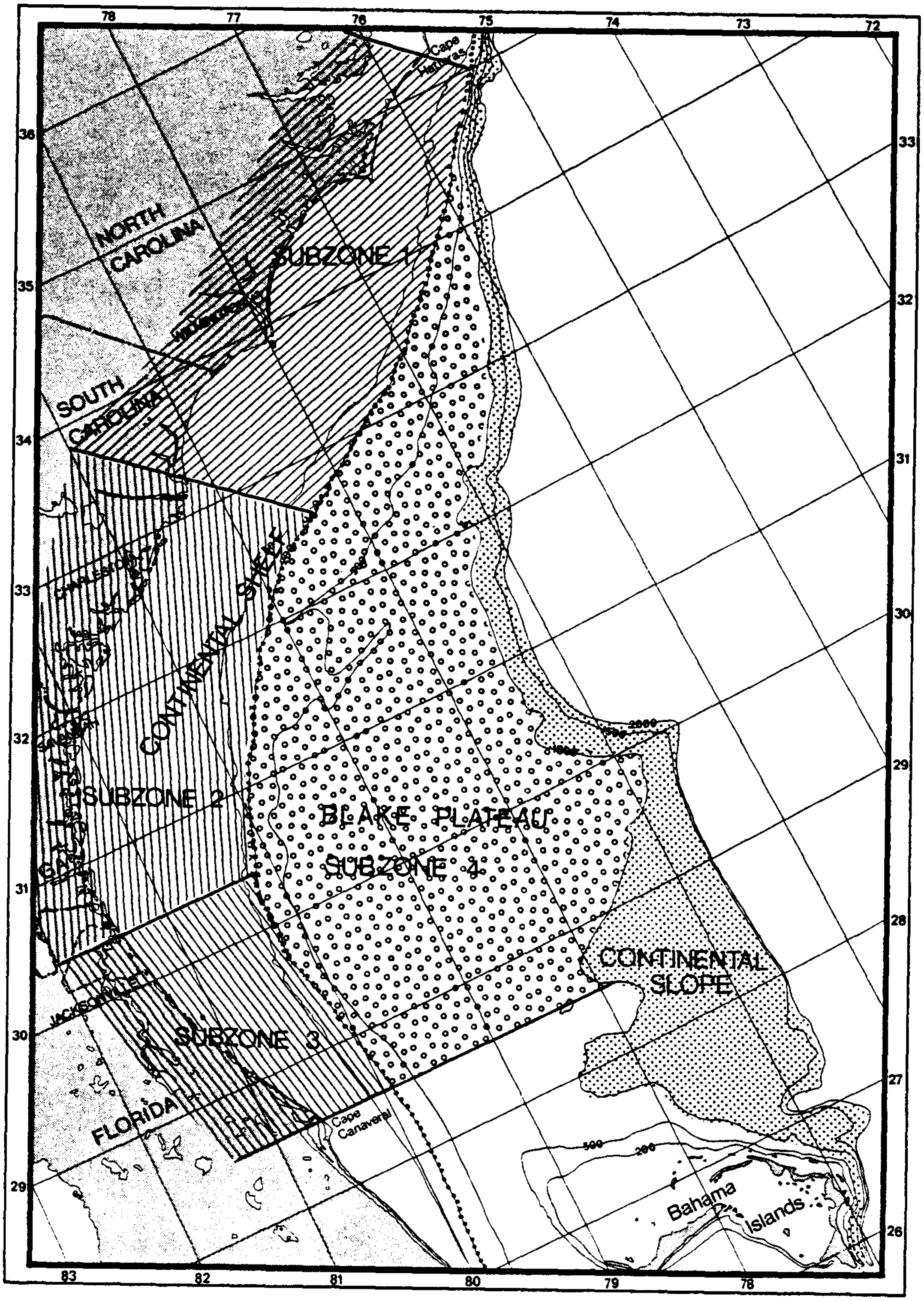


FIGURE II-5. Index map showing study area subzone divisions. (From Zeigler and Patton, 1974).

The following summary of the Late Paleozoic through Quaternary geologic history is from Dillon et al. (1975).

According to Pitman and Talwani (1972) and Mattick, Foote, Weaver and Grim (1974), collision of the North American and African continental plates during the Late Paleozoic followed by plate separation during the Late Triassic resulted in the basic structural and sedimentary configuration of the present continental margin and led to the formation of the Atlantic Ocean as it now exists (Figure II-6). Regional uplifting with associated block faulting occurred during the Late Triassic along Paleozoic fault patterns and resulted in a major rift system which later formed the Mid-Atlantic Ridge (Talwani, LePichon and Ewing, 1965; Mayhew, 1974; Olson, 1974). During Late Triassic-Early Jurassic time, extensive evaporite deposits were formed in the rift valleys along the margins of the narrow ocean that may now exist seaward of Cape Hatteras and underlie the Bahamiam Platform and the Blake Plateau (Sheridan, 1974; Olson, 1974).

The Atlantic Ocean widened during the Late Jurassic, and evaporite deposition was followed by carbonate sedimentation along the subsiding continental margin, possibly facilitated by a ridge beneath the present outer Blake Plateau behind which terrigenous sediment accumulated and on which extensive reef development occurred. On the relatively stable and shallow continental margin south of Cape Hatteras, carbonate deposition continued throughout the Cretaceous, although by mid-Cretaceous time the trough behind the marginal ridge was filled and sediments began to flow over it to form the continental slope (Figure II-7). By Late Cretaceous or early Cenozoic time, the Blake Plateau had subsided to bathyal depths and the Atlantic Ocean had widened to approximately two-thirds of the present distance between Africa and North America (Emery and Uchupi, 1972; Olson, 1974).

During most of Tertiary time the continental shelf continued to subside, in some areas as much as 10-12km, but deposition generally kept pace with subsidence creating shallow marine environments (Sheridan, 1974). Major regression may have occurred during the Oligocene and Pliocene, during which time sediments prograded across the shelf (Emery and Uchupi, 1972). Such oscillations were repeated several times during the Quaternary as a result of fluctuation in the volume of continental ice sheets.

1.4.3 Regional Physiography

The major physiographic elements of the South Atlantic continental margin of the United States are the continental shelf, the Florida-Hatteras Slope and the Blake Plateau (Figure II-8).

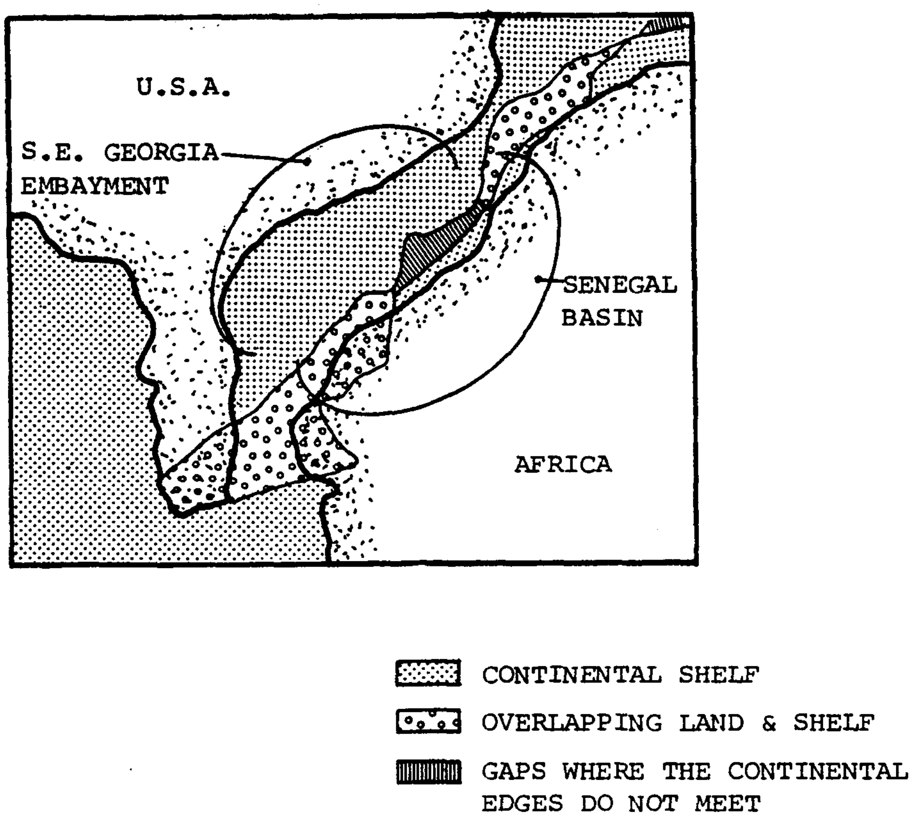


FIGURE II-6. Position of continents during Jurassic Time. 170 million years before present. (Briden, Drewry and Smith, 1974)

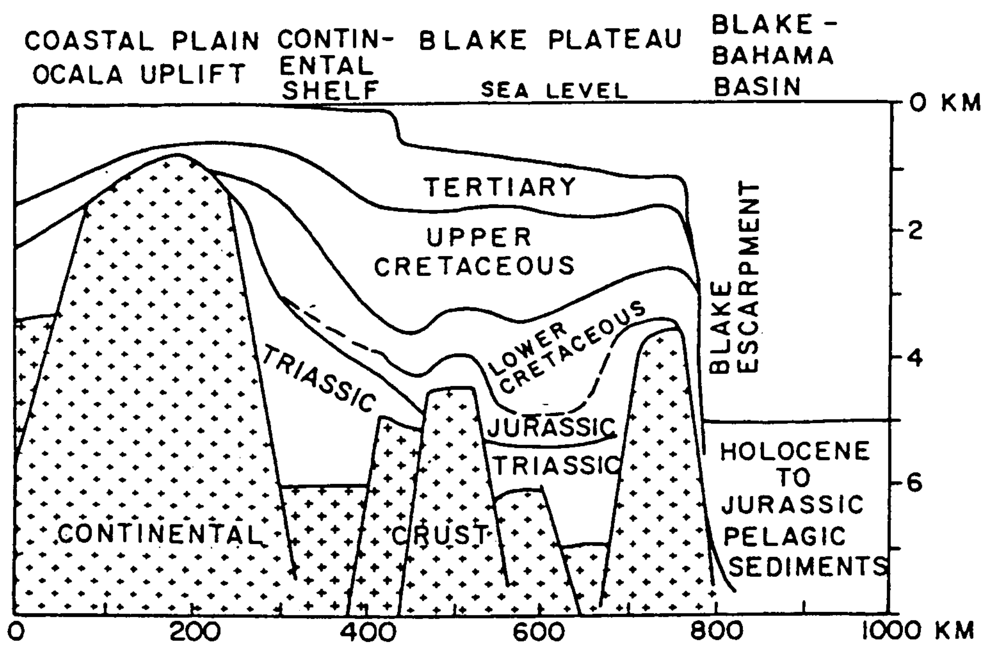


FIGURE II-7. Schematic east-west section across Florida coastal plain and Blake Plateau in latitude of Jacksonville showing hypothetical deep structures. (Olson, 1974).

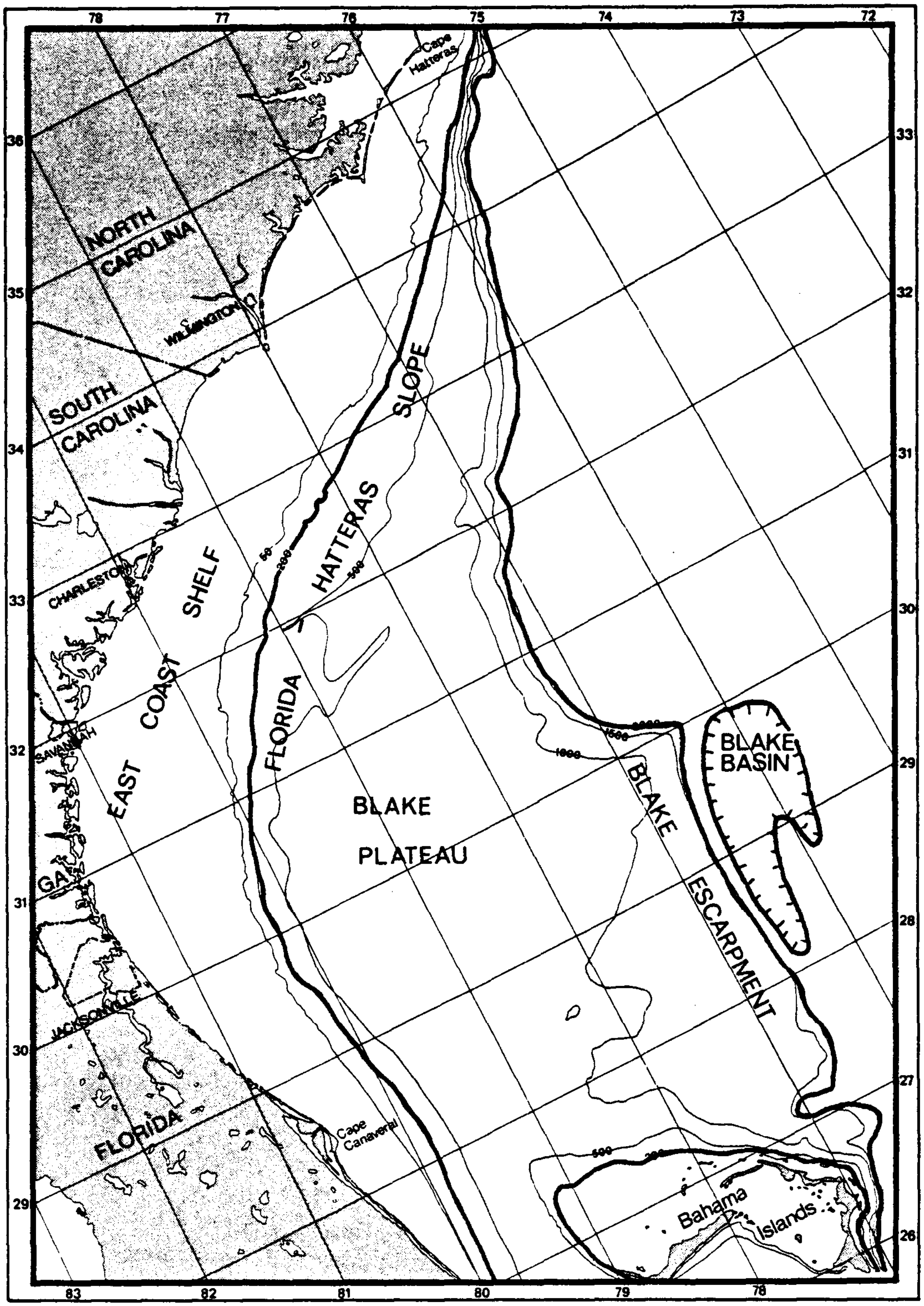


FIGURE II-8. Physiographic provinces of the continental margin off the east coast of the United States (Uchupi, 1970).

The continental shelf ranges in width from approximately 33km off Cape Hatteras to a maximum width of 135km off the Georgia coast. Shelf width off Cape Canaveral is approximately 50km. Large shelf topography consists of sand ridges, trending at low angles to the coast (Figure II-9); seven or more terraces subparallel to the present shoreline and thought to be old strandlines; and numerous algal banks (along the Carolina coast) and other hard or "live" bottoms that occur on scattered outcrops across the shelf and as an intermittent ridge along the shelf edge (Dillon et al., 1975). The shelf gradient is generally less than $0^{o}10'$ and the depth along the shelf break varies from 50m to 70m.

The Florida-Hatteras slope is intermediate between the shelf and the Blake Plateau. Although slope gradients rarely exceed 1^{o} (7m/km), irregular topography is present that could be relict and/or related to slumping, canyon formation, and erosion by the Gulf Stream. Such topography is particularly well displayed on the northern segment of the slope. Off the Carolinas the Florida-Hatteras Slope merges with the Blake Plateau and Escarpment.

The third principal physiographic feature of the U. S. South Atlantic continental margin is the Blake Plateau. This feature is 270km wide along its southern margin where it is bounded by the Great Abaco Canyon and Little Bahama Bank, and wedges out to the north along the continental slope off the Carolinas. The Florida-Hatteras Slope and the Blake Escarpment form the western and eastern boundaries, respectively. The Plateau ranges in depth from 600-1200m, the deeper portion being to the southeast in the vicinity of Great Abaco Canyon. Greatest relief and surface irregularity on the Plateau occurs along the base of the Florida-Hatteras Slope, particularly in the northern portion and essentially lies beneath the axis of the Gulf Stream (Figure II-10). The rough topography is thought to primarily result from erosion by the Gulf Stream rather than tectonic activity (Zeigler and Patton, 1974). However, Holocene slumping and deltaic outbuilding during the last low stand of sea level probably are significant contributors to present topographic expression. The origin of the prominent Blake Nose or Spur which extends northeastward from the Blake Escarpment is not certain, although slumping or depositional processes have been suggested as possible factors in its formation (Pratt, 1971). The Blake Outer Ridge, trending southeastward from the north end of the Plateau, appears to be aligned with the axis of the Cape Fear Arch and may be genetically related to that structure (Hersey, Bunce, Wyrick and Dietz, 1959), although origin as a depositional ridge associated with an earlier, lower sea level position of the Gulf Stream also has been suggested (Ewing, Ewing and Leyden, 1966).

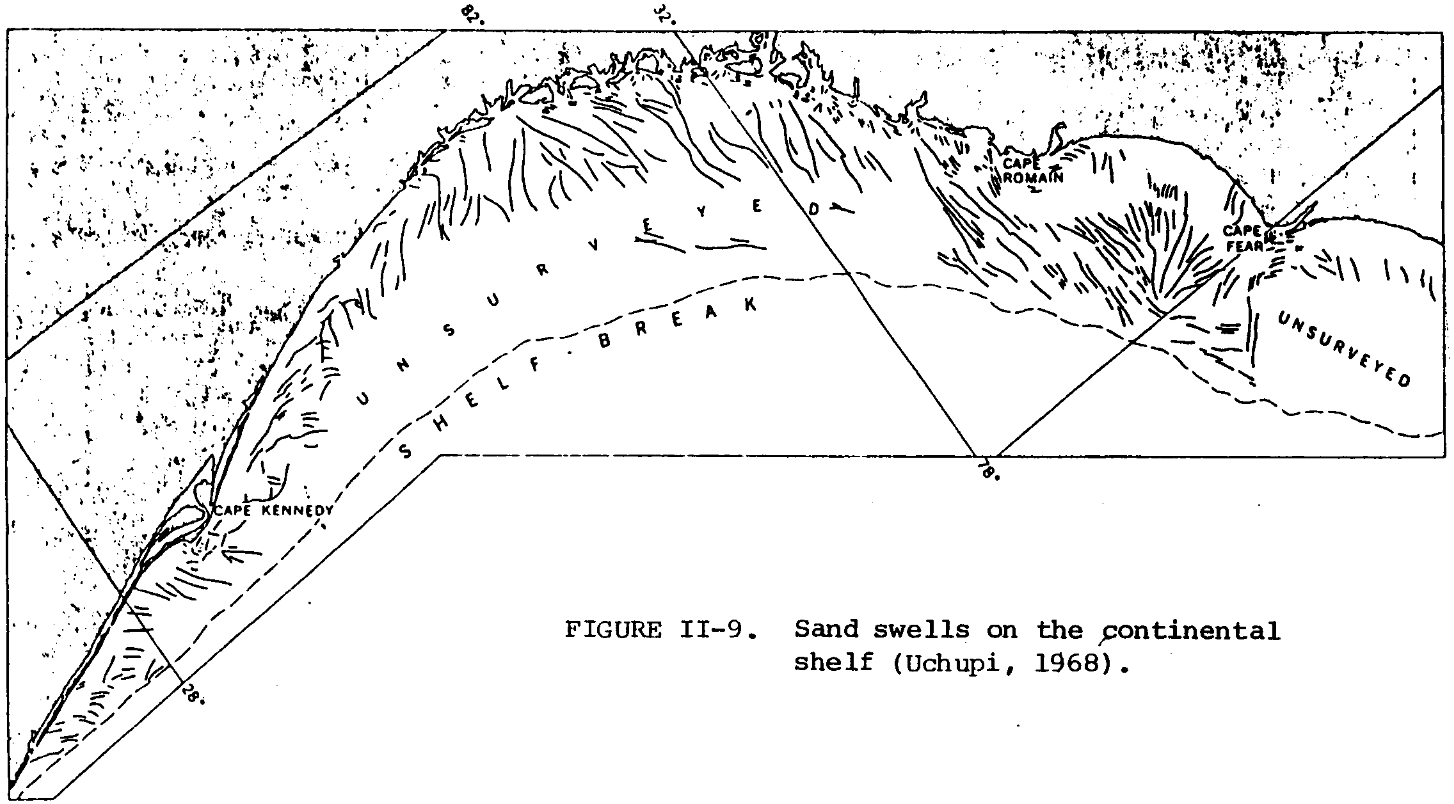


FIGURE II-9. Sand swells on the continental shelf (Uchupi, 1968).

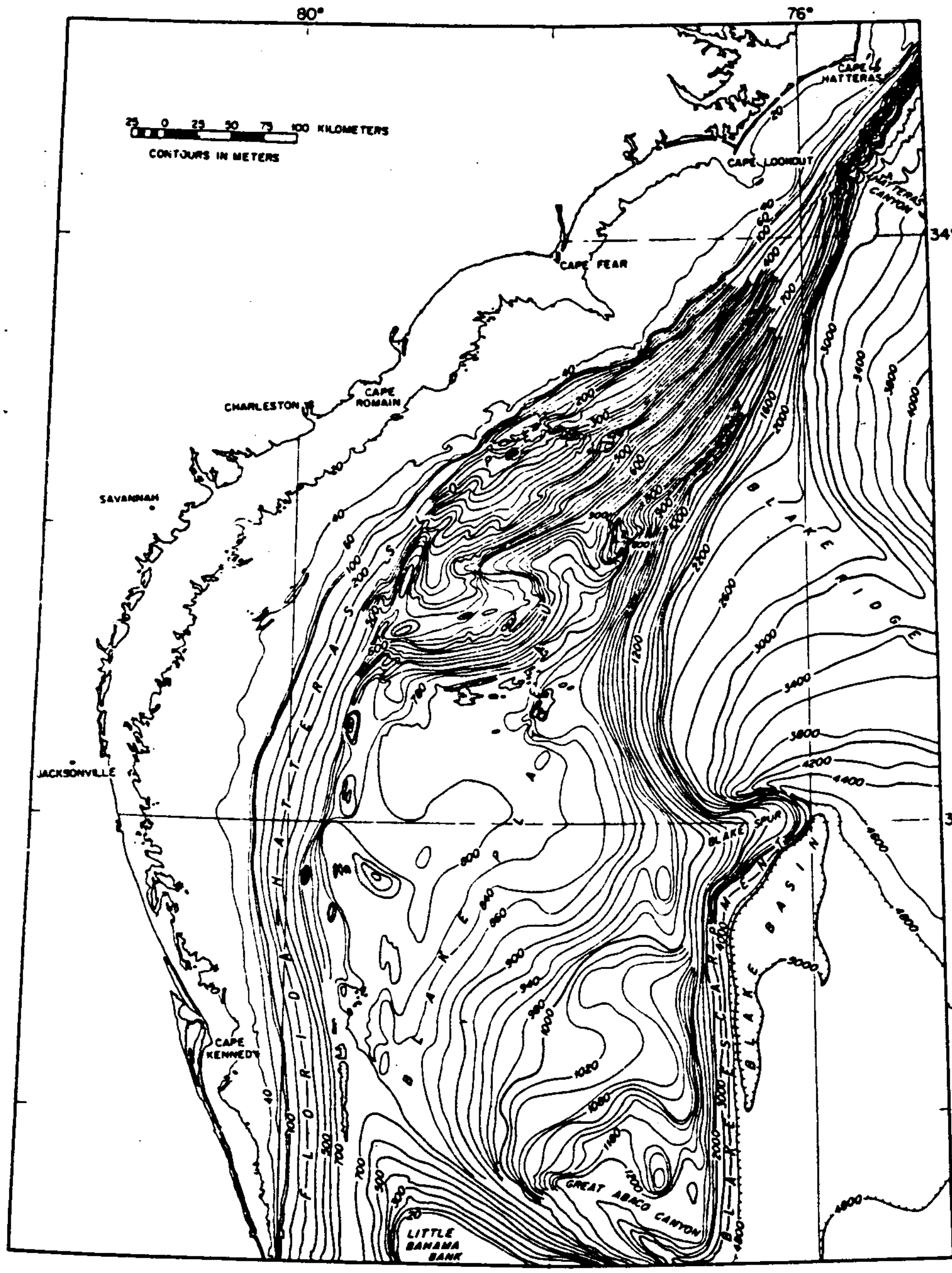


FIGURE II-10. Bathymetry of the continental margin between Cape Hatteras, North Carolina and Cape Kennedy, Florida. Based on soundings from the U.S. Coast and Geodetic Survey hydrographic surveys, and from a chart by Pratt and Heezen (1964, Fig. 1). From Uchupi (1967).

The surface sediments on the South Atlantic continental margin have been described by Milliman (1972) and Hollister (1973). No regional studies newer than 1973 have been published, although several detailed investigations have been carried out in the past several years that concern more restricted areas of the shelf. The results of these studies are discussed in appropriate Subzone sections.

A summary of regional sediment distribution by Dillon et al. (1975) states that the shelf and slope are veneered in large part by sand with silt comprising 20-40 percent of the sediment, the latter amount principally being present on the slope. Gravel forms less than 10 percent of the surface sediment and is limited to a few areas of the Blake Plateau beneath the Gulf Stream, probably as lag material (Figure II-11).

Carbonate content increases southward and offshore while high feldspar content inshore indicates influence of rivers. Glauconitic sands and montmorillonitic and kaolinitic clays characterize the shelf and slope (Figure II-12).

1.4.4 Regional Structure

The major structural elements of the South Atlantic Region are the Cape Fear Arch, the Southeast Georgia Embayment and the Peninsular Arch (Figure II-13). A very good description of these features together with a summary of pertinent literature prior to 1975 is given by Dillon et al. (1975).

The principal structure relative to petroleum potential in the South Atlantic region is the Southeast Georgia Embayment, an eastward plunging depression between the Cape Fear Arch and the Peninsular Arch. As indicated in Figure II-14, the deepest part of the Embayment exceeds 5km on the outer shelf just south of 30° N (Schlee, Martin, Mattick, Dillon and Ball, 1977). The Cape Fear Arch is a southeast plunging basement nose extending under the continental shelf and Blake Plateau. There is an inferred relationship to the Blake Outer Ridge. Dillon et al. (1975) also described the Burton High, the Stono Arch and the Yamacraw Uplift (or Ridge), structural features associated with the south flank of the Cape Fear Arch.

Since 1975, cooperative Common Depth Point (CDP) multichannel seismic surveys have been carried out by the U. S. Geological Survey, the University of Texas Marine Science Institute and the Institute Francais du Petrole (Dillon, Fail and Cassand, 1976; Dillon, Paull and Buffler, 1977; Krivoy and Eppert, 1977; Dillon, Paull, Buffler and Fail, 1978; and Shipley, Buffler and Watkins,

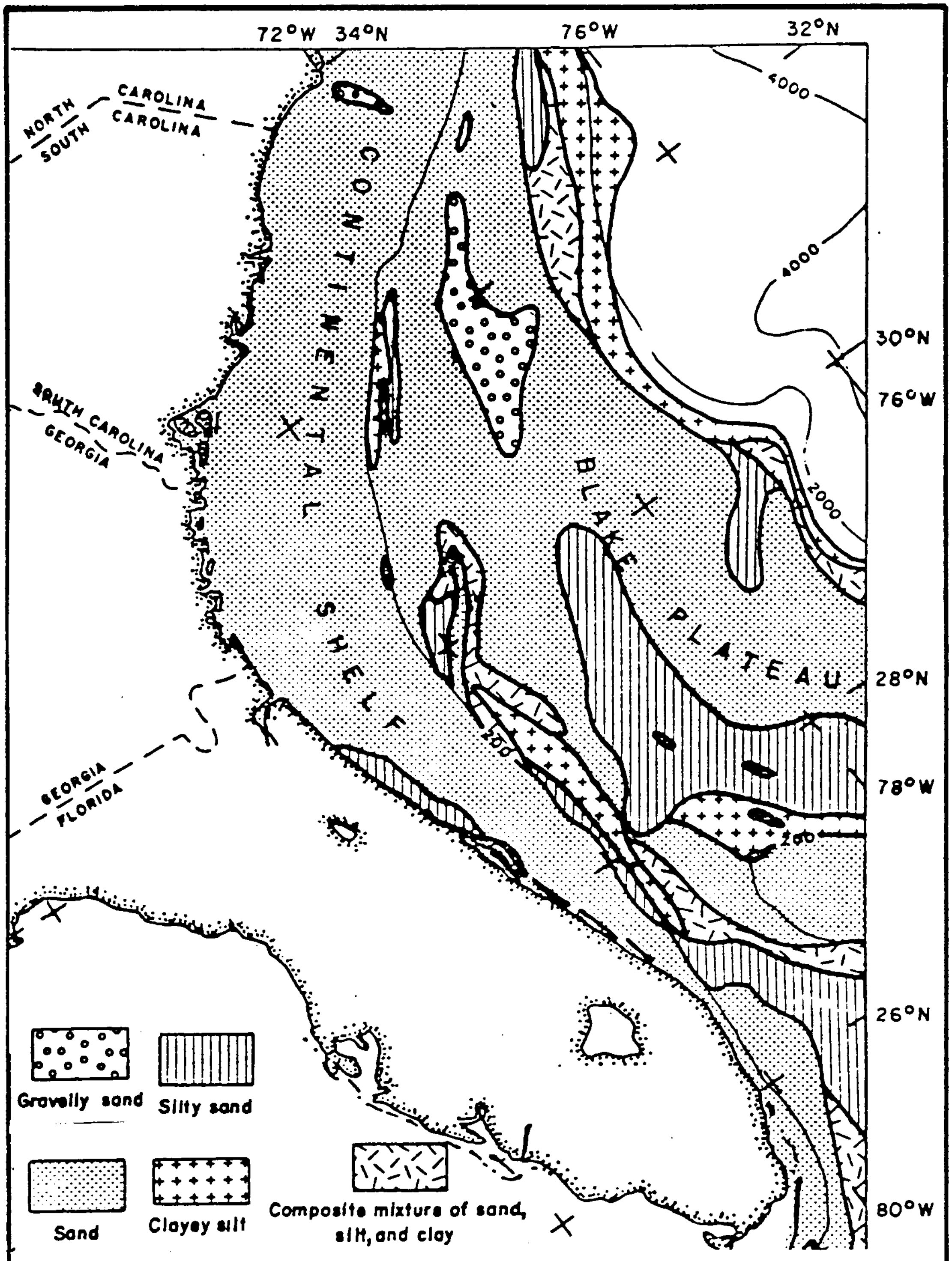


FIGURE II-11. General sediment texture of the South Atlantic Continental Margin. (From Hollister, 1973).

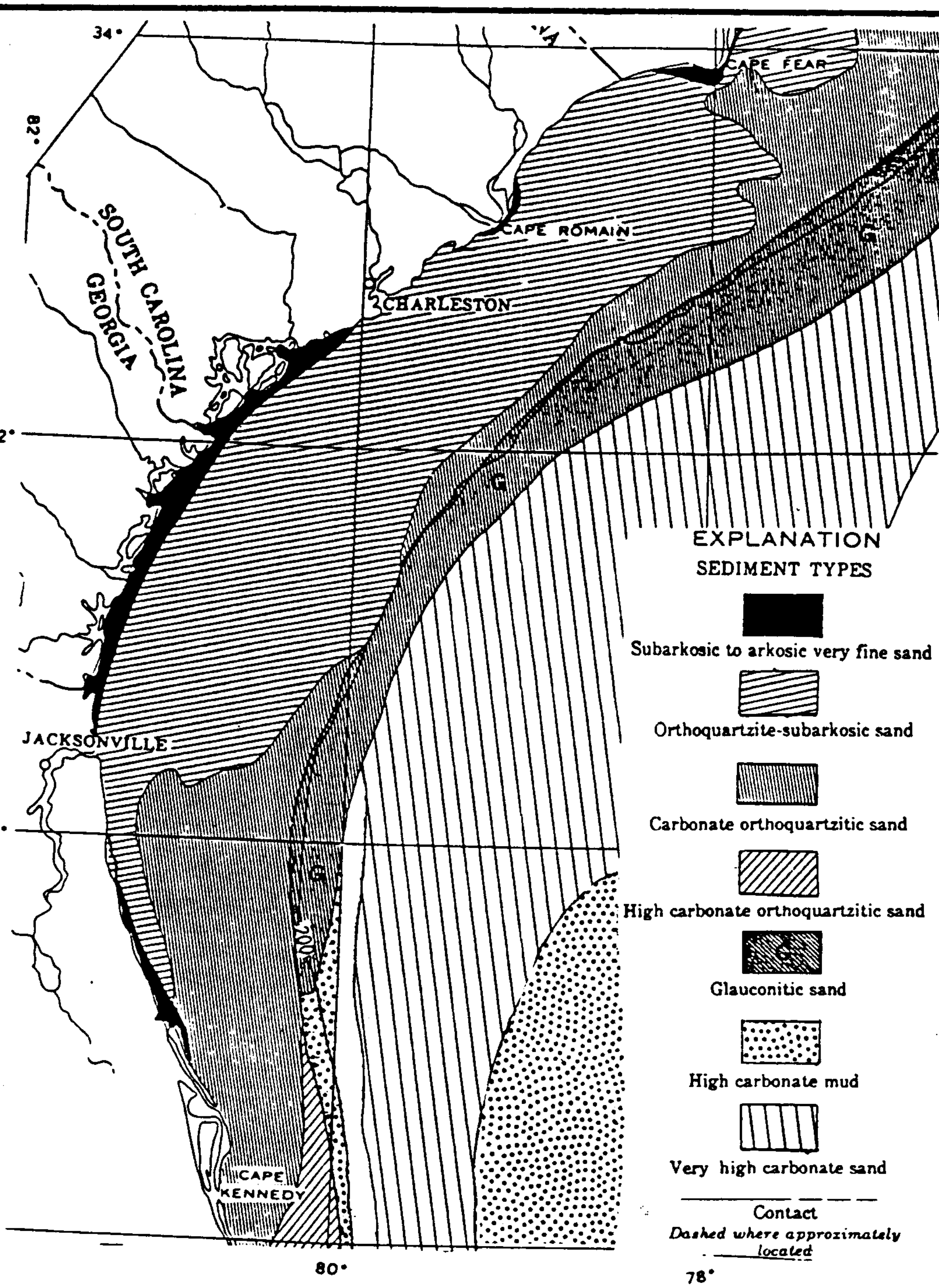


FIGURE II-12. Sediment composition types between Cape Fear and Cape Kennedy. (From Milliman, 1972).

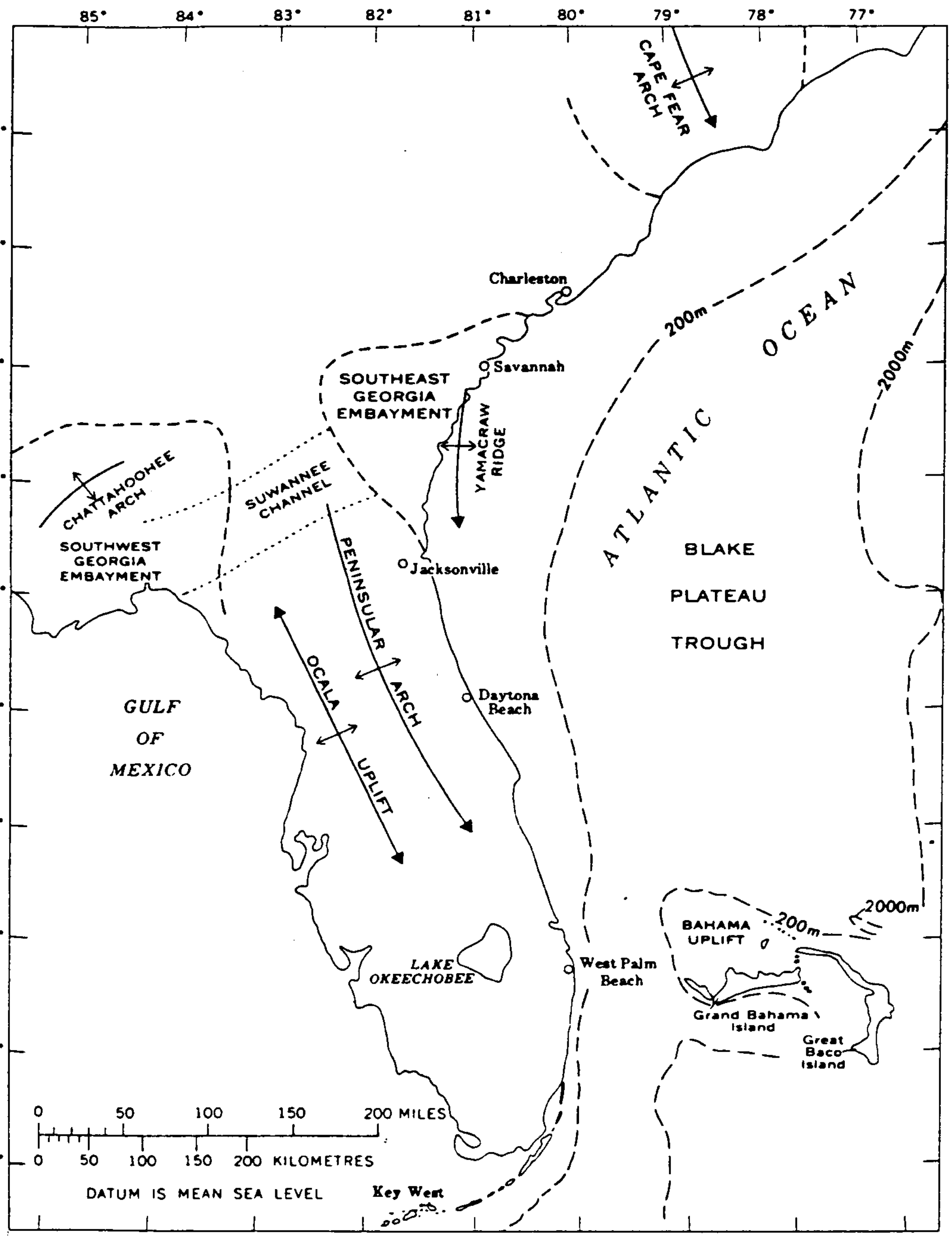


FIGURE II-13. Map showing main tectonic features of the southern United States and bordering continental margin. (From Schlee, 1977).

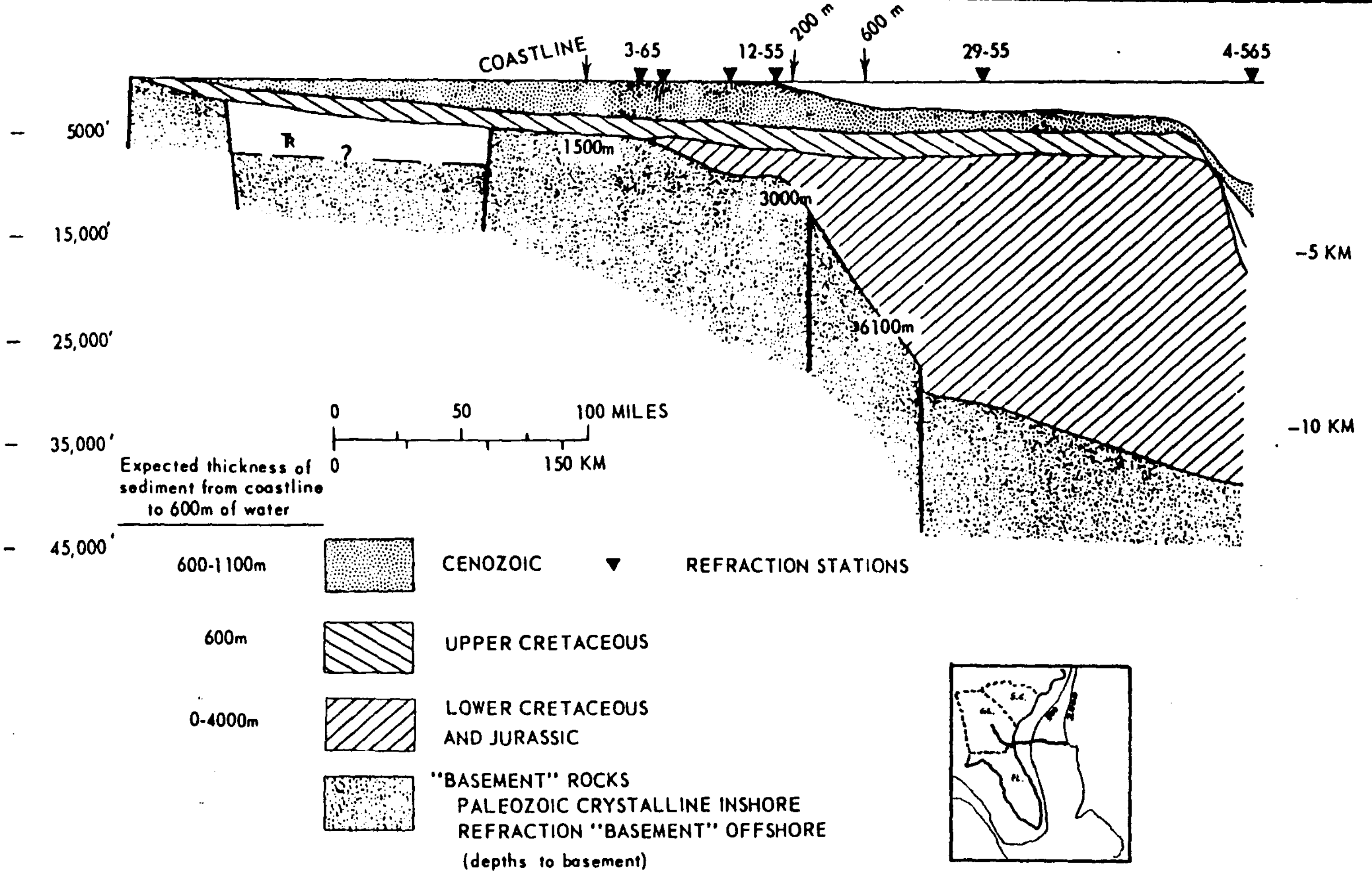


FIGURE II-14. Section from Fall line in Georgia to Blake Escarpment showing approximately thickness of sediments. (From Scott and Cole, 1975).

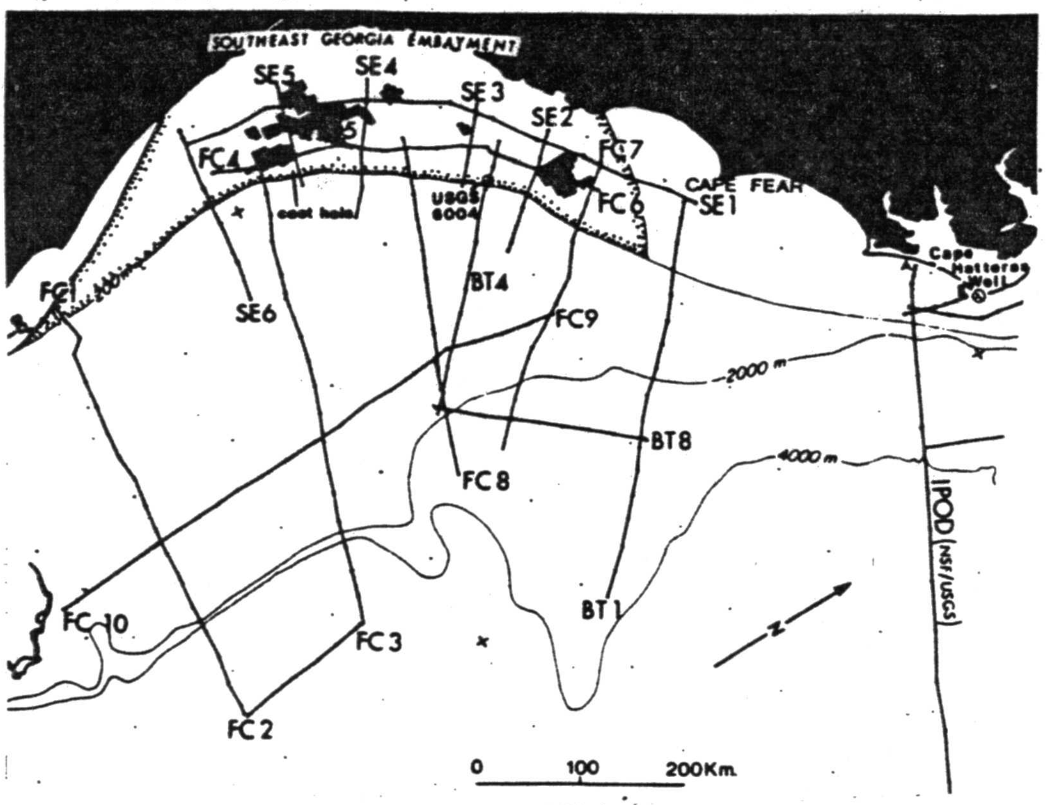
1978) (Figure II-15). Also, the Lamont-Doherty Geophysical Observatory has recently completed a multichannel seismic survey of the Blake Outer Ridge, the southern Blake Plateau-Bahama Platform and the Florida Shelf-Bahama Platform (Bryan, 1978, personal communication). The results of integrating the multichannel data with U. S. Geological Survey aeromagnetic data have been reported by Behrendt (1975) and Klitgord and Behrendt (1977a). A geologic interpretation of the structure of the Southeast Georgia Embayment is being prepared by Buffler, Watkins and Dillon (Buffler, 1978, personal communication).

1.4.5 Regional Stratigraphy

The Southeast Georgia Embayment is a transitional zone between a non-carbonate depositional province north of Cape Hatteras and the Florida-Bahamas carbonate province. Olson and Glowacz (1977) summarized the stratigraphy of the coastal plain portion of the South Atlantic region (Figure II-16) and showed the generalized geology and basement rock surface of South Carolina and vicinity (Figure II-17). Hathaway, Schlee, Poag, Valentine, Weed, Bothner, Kohout, Manheim, Schoen, Miller and Schultz (1976) discussed the stratigraphic data obtained by the U. S. Geological Survey Atlantic Margin Coring Project which included four drill holes on the continental shelf off the Carolinas and Georgia (Figure II-18). Schlee (1977) described the stratigraphy and Tertiary development of the continental margin east of Florida based on six holes drilled during the 1965 Joint Oceanographic Institutions' Deep Earth Sampling Program (JOIDES) (Bunce, Emery, Gerard, Knott, Lidz, Saito and Schlee, 1965), and Edsall and Dillon (1977) reported the results of a detailed high resolution seismic survey conducted on the continental shelf, Florida-Hatteras Slope and western Blake Plateau between 29^{o} 30'W and 33^{o} 30'N.

1.4.6 Economic Geology

A summary of the petroleum and mineral resources potential of the South Atlantic continental margin is given by Dillon et al.(1975). The geologic setting of the Southeast Georgia Embayment is discussed with particular reference to the factors that control the occurrence of oil and gas such as the timely development of effective traps and the occurrence of depositional environments that provide source rocks and petroleum reservoirs. The methods used in appraising the petroleum potential also are described. A more recent discussion of the petroleum potential of the South Atlantic region is given in Schlee et al. (1977) where it was stated that the chance of finding commercial quantities of recoverable oil and gas is four in ten. The lack of deep drill hole information on structures is cited as the major obstacle to



U. S. GEOLOGICAL SURVEY

Multichannel Seismic Reflection Data 1973-75

LINE NO	YEAR	CHANNELS	ACQUISITION	PROCESSING
FCI-8	1975	24	IFP	IFP
SEI-6	1975	24	U Texas	U Texas
BTI.4.8	1975	48	GSI	GSI(proprietary)

FIGURE II-15. Location of Atlantic multichannel reflection profiles, offshore deep drill holes, lease areas and basins. (From Schlee, Martin, Mattick, Dillon and Ball, 1977)

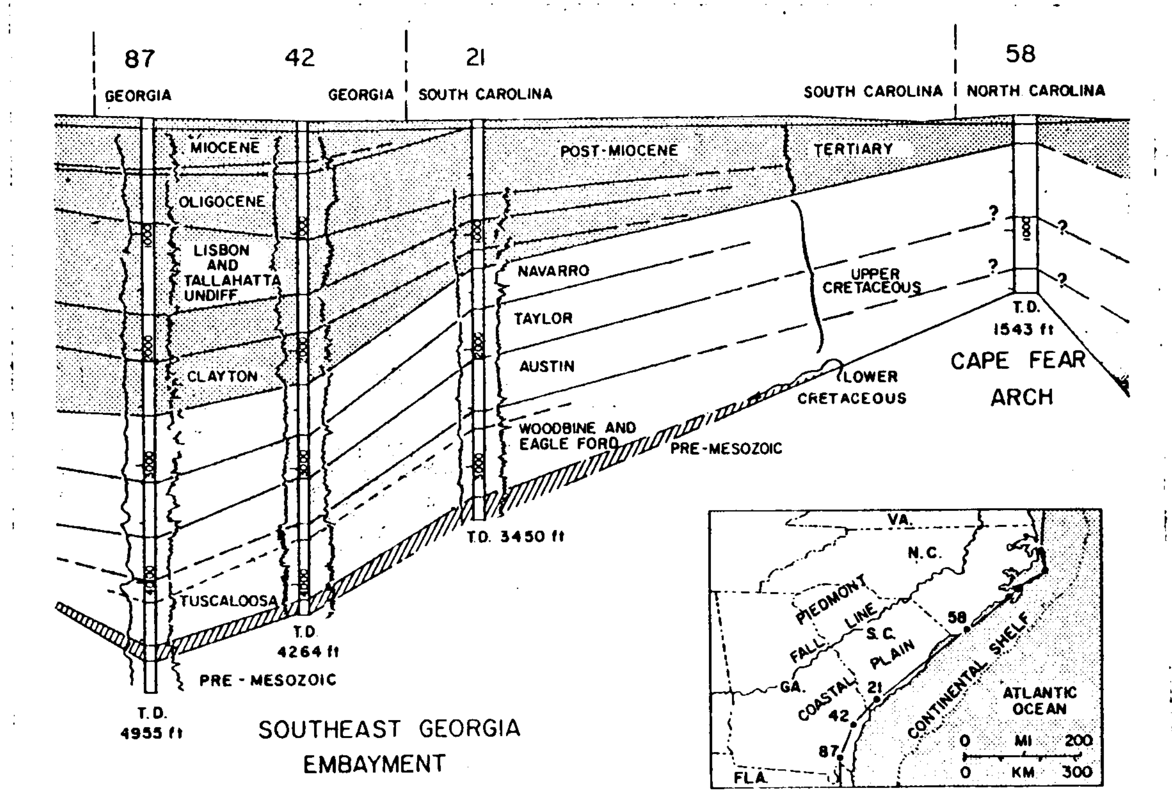


FIGURE II-16. Geologic cross section through South Carolina coastal zone and adjoining states. (From Maher and Applin, 1971).

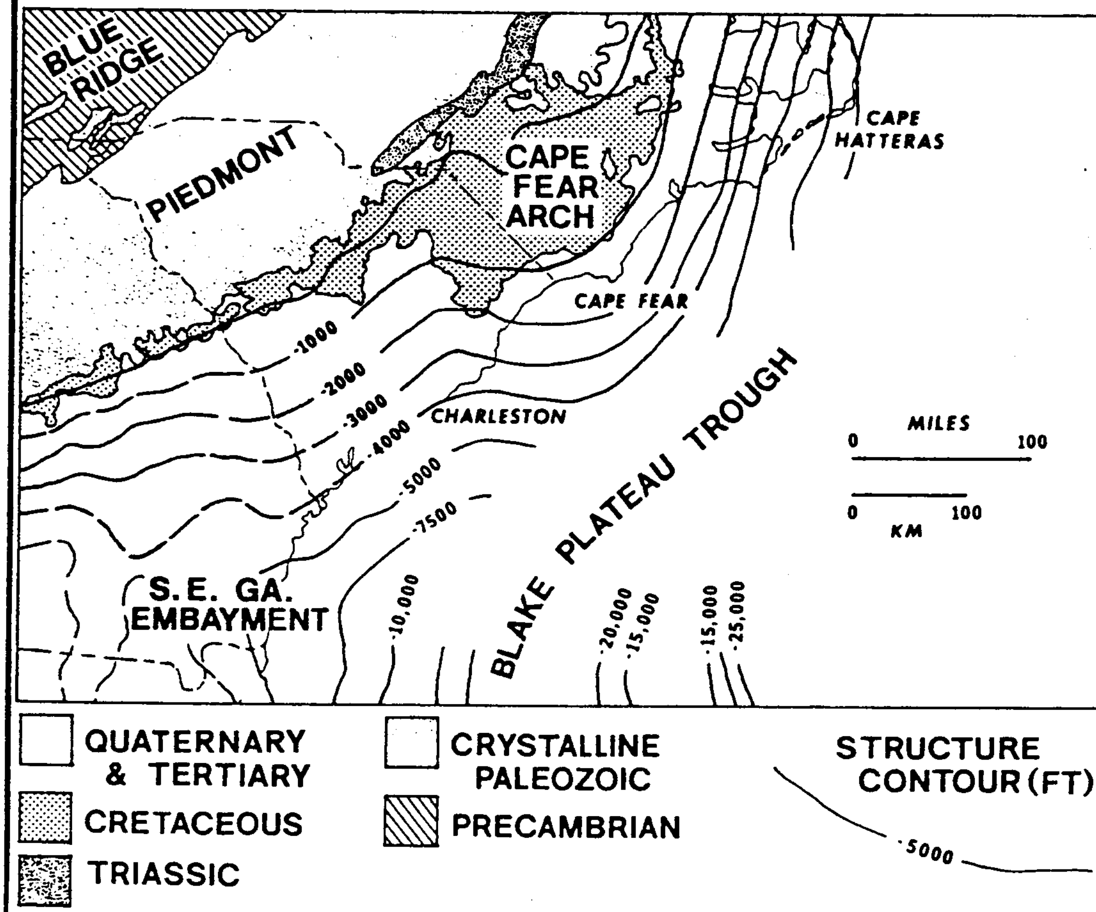


FIGURE II-17. General geology and basement rock surface (feet below MSL) of South Carolina and vicinity. (From Maher and Applin, 1971)

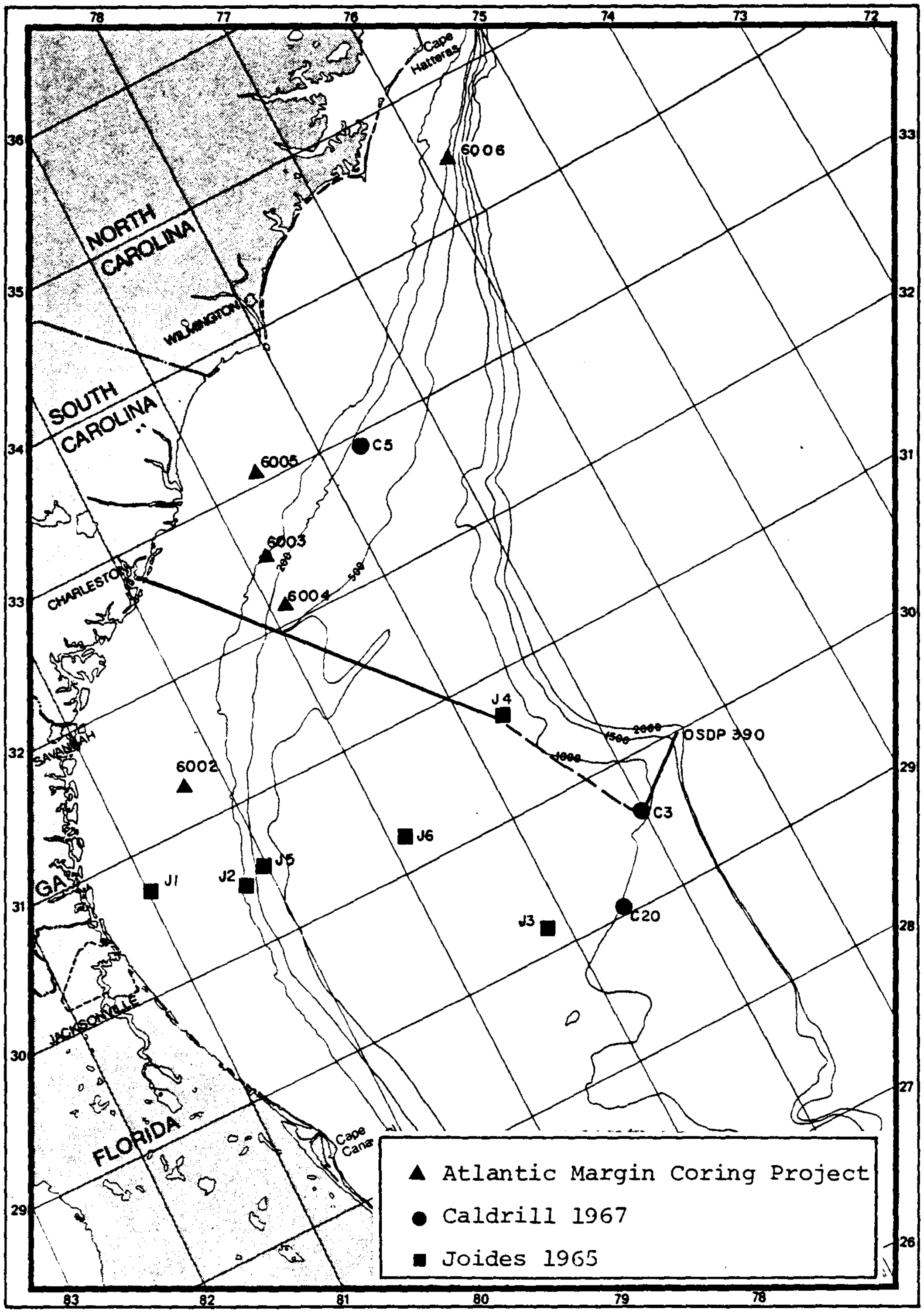


FIGURE II-18. Map showing location of Atlantic margin boreholes. (From Dillon et al., 1975) obtaining detailed information concerning petroleum potential.

Resources other than petroleum also have been discussed by Dillon et al. (1975). These include hard minerals (placer-type deposits), sand and gravel, and minerals dissolved in or precipitated from seawater. By far the largest portion of the total resources of the continental shelf, including petroleum, are considered to be undiscovered resources. Although sampling density on the shelf has been high and indicates a general paucity of hard mineral reserves, the lack of detailed sampling in areas known to contain subeconomic deposits places most of the minerals shown in Table II-1, except for sand and gravel, in the category of "identified subeconomic resources."

Sand and gravel, and possibly ceramic muds have intensively, but not fully, been investigated. Nevertheless, these deposits appear to be sufficiently abundant to be considered as "economic reserves."

Details of mineral occurrence in each Subzone are discussed in the following sections.

2.0 CONTINENTAL SHELF-SUBZONE I--CAPE HATTERAS TO WINYAH BAY

2.1 Description

2.1.1 Structures

2.1.1.1 Bottom

Organic

Two categories of organic structures that occur throughout Subzone I, those located on the shelf and those near the shelf edge, are discussed by several authors: Pearse and Williams (1951); Menzies, Pilkey, Blackwelder, Dexter, Huling and McCloskey (1966); Zarudzki and Uchupi (1968); Macintyre and Pilkey (1969); Newton and Pilkey (1969); Macintyre and Milliman (1970); Huntsman and Macintyre (1971); Newton, Pilkey and Blanton (1971); Pilkey, Macintyre and Uchupi (1971); Uchupi (1974); and Dillon et al. (1975). Terms commonly used in the literature to refer to a variety of bottom structures reflect the interest of investigators such as commercial and sports fishermen, biologists and geologists. Among the more common terms are: live bottom, hard bottom, coral patches, fishing banks, snapper banks, black rocks, limestone reefs and lithothamnion reefs.

Numerous patch reefs occur on the shelf and are particularly

TABLE II-1. Data sources for resources other than oil and gas for the Atlantic OCS. (From Dillion et al., 1975)

Material	Selected Data Sources
	Stanley, Swift and Richards (1967); McKelvey and Wang (1969), p. 10, pls. 1 and 4; Manheim (1972b), p. 11-13; Milliman (1972); McKelvey, Wang, Schweinfurth and Overstreet (1969), p. 5A53-5A57.
Anhydrite	McKelvey and Wang (1969), pl. 4.
Manganese nodules - including trace elements: Ni, Cu, Co, Sn, Fe, Zn, Ag, Ba, Al, B, Ti, V, Ar and many others	McKelvey and Wang (1969), p. 11, pl. 1; Horn, Horn and Delach (1973); Mero (1965), p. 180; Horn (1972), p. 10; Manheim (1972b), p. 11.
Ilmenite, monazite, zircon, rutile, staurolite, kyanite, sillimanite, and garnet	Trumball, Lyman, Pepper and Thomasson (1958), p. 52-53; McKelvey and Wang (1969); Emery and Noakes (1968); Hathaway (1971); Manheim (1972b), p. 7-11; Ross (1970); McKelvey, et al., (1969), p. 5A1-5A117; Manheim (1972b), p. 2, 11.
Copper and zinc (chalcopyrite and sphalerite minerals)	Manheim (1972b), p. 2, 11.
Sand, gravel and mud	Manheim (1972b), p. 13-18, 22; Schlee (1964, 1968); Schlee and Pratt (1970); Emery (1965); Duane (1968); Davenport (1971); Taney (1971); Economic Associates, Inc. (1968); Milliman (1972); Ross (1970); McKelvey and Wang (1969), p. 10; McKelvey et al. (1969), p. 5A64; Nossaman, Waters, Scott, Krueger and Riordan, Consultants (1969); Doumani (1973); Rexworthy (1968).
Glauconite	McKelvey et al. (1969), p. 5A91.
Carbonate	Hulsemann (1967); Milliman (1972).

abundant in Onslow Bay (Figure II-19) (Macintyre and Pilkey, 1969; Huntsman and Macintyre, 1971). Biological assemblages which consist of sessile invertebrates such as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, and hard corals are attached to substrates which are hard or rocky formations with rough, broken or smooth topography. Underwater TV observations indicate that live bottoms are patchy or localized, which makes areal description impossible based on existing data. Little is known about either occurrence or distribution of these areas (U. S. Department of the Interior, Bureau of Land Management, 1977).

A series of closely spaced algal reefs less than 10m high dated about 19,000-24,000 years b.p. discontinuously border the shelf break (Menzies et al., 1966; Zarudzki and Uchupi, 1968; Uchupi, 1974). They consist of algal rocks which contain small amounts of lithothamnion balls, worm tubes, and bryozoans and may be inactive at present. Reefs of this type are found near, at, or slightly below the shelf break.

Inorganic Macro/Micro-Topography

Macro-topography is made up of those features with greater than 10m relief while micro-topography is relief less than 10m based on the definition by Uchupi and Tagg (1966).

Since the report by Zeigler and Patton (1974), a study by Mixon and Pilkey (1976) discusses sand ridges on the shelf off Onslow and Raleigh Bays. The trend of the ridges suggests that they are constructional features formed subadqueously on the shelf floor by storm-generated waves and currents during the latter part of the Holocene transgression. They are almost certainly being modified today. In a more detailed study within this same area, Hunt, Swift and Palmer (1977) report that coast-parallel ridges 10m high and 5km apart near Cape Hatteras (Figure II-20) have fields of transverse sand waves up to 7m high on their ridges and troughs. Three sizes of transverse structures are found, ripples with 10 to 60cm spacing, megaripples with 3 to 6m spacing and dunes with 100m to 300m spacing.

More detailed bathymetric work needs to be carried out with sufficient spacing and precision so that a detailed macro/micro-bottom-topographic map can be prepared for Subzone I.

Brauer (1978, personal communication) has been studying the feasibility of using wet submersibles for detailed mapping of bottom topography. This is part of a larger program concerned with demonstrating the usefulness of wet submersibles in conti-

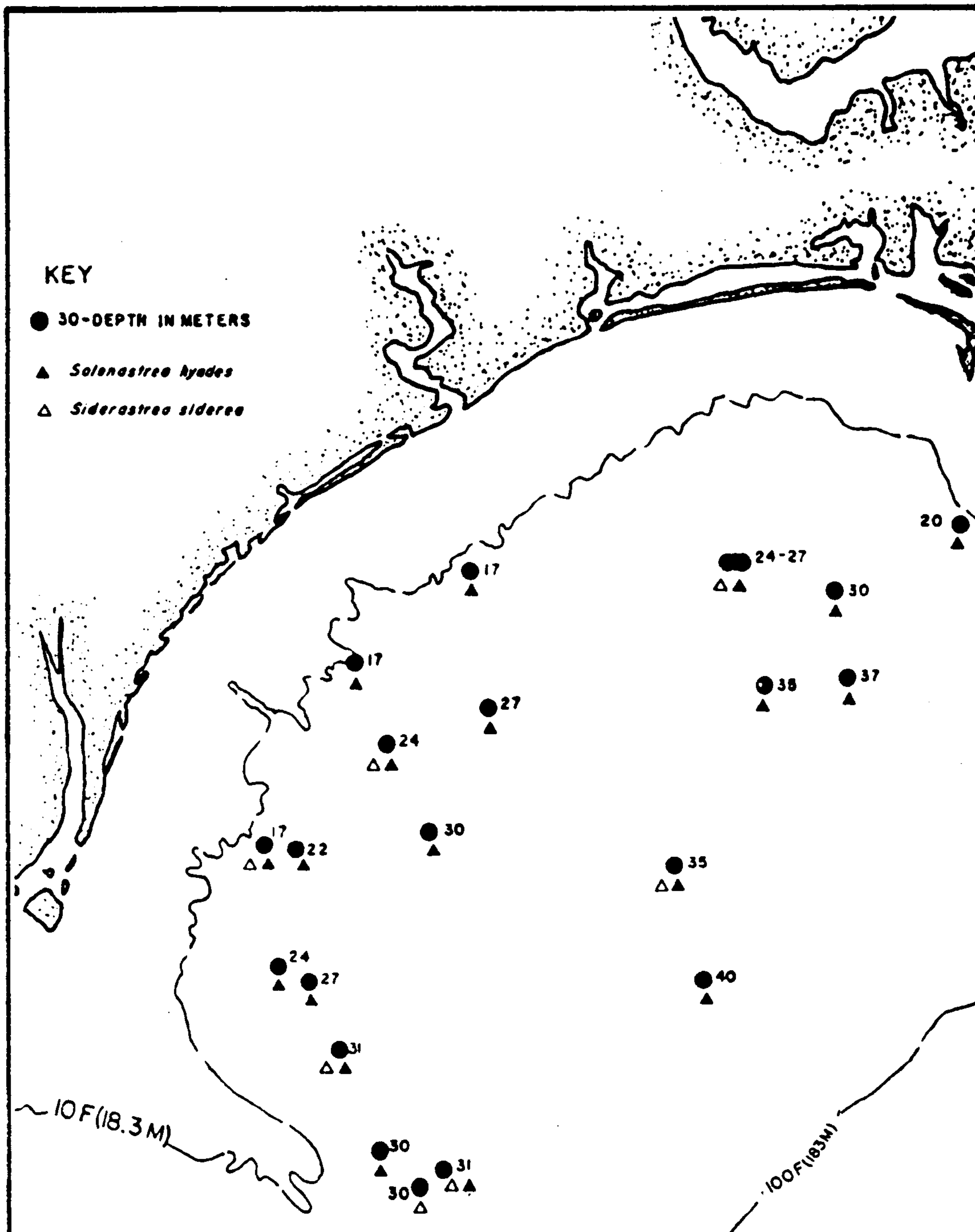


FIGURE II-19. Areas of tropical reef corals in Onslow Bay, North Carolina. U.S. Department of the Interior, Bureau of Land Management, 1977.

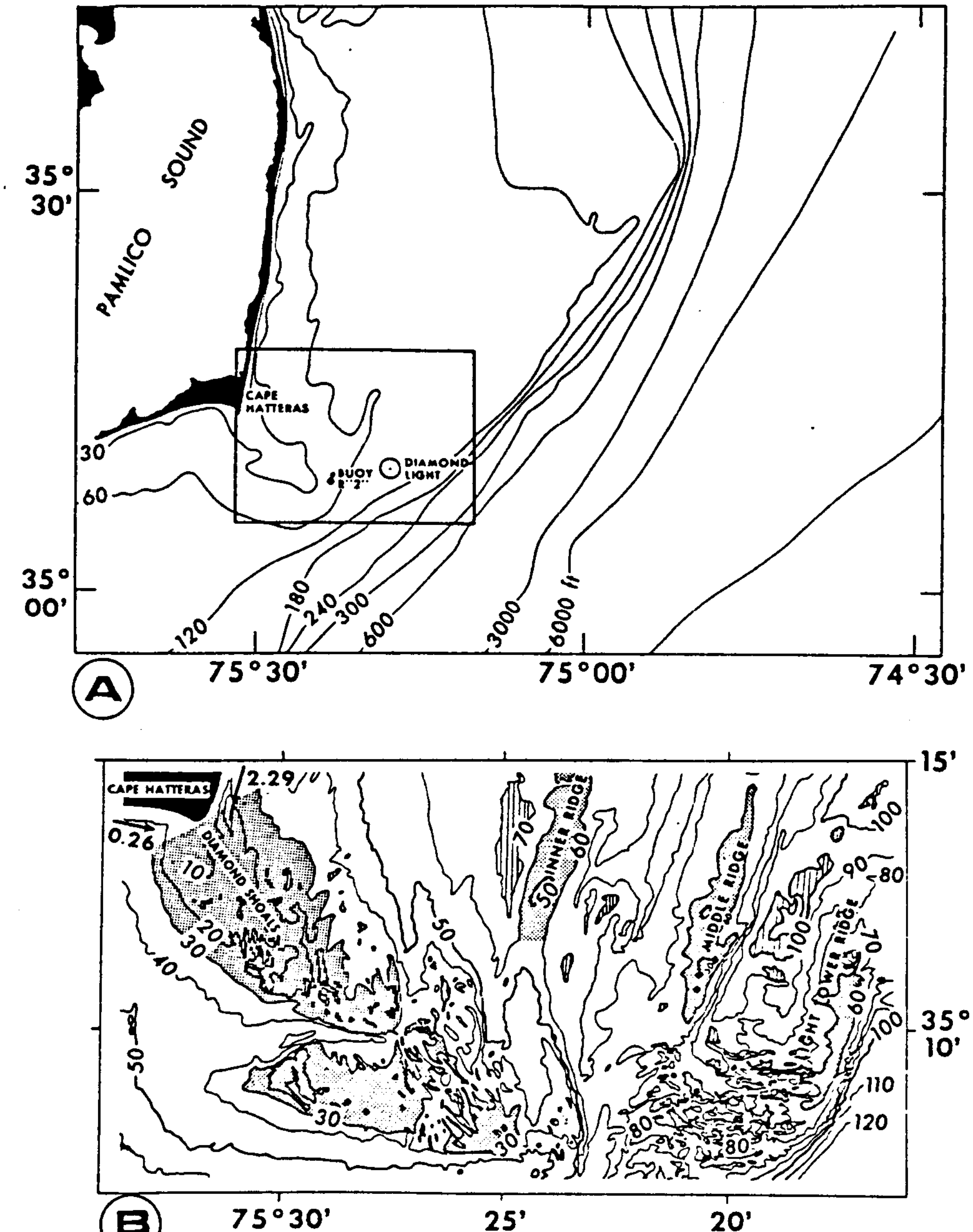


FIGURE II-20. A. Regional bathymetry of Cape Hatteras-Diamond Shoals, North Carolina. Contours in feet. B. Relationship of outer ridge topography to Diamond Shoals. Arrows indicate mean annual littoral drift in millions of cubic yards per year. Ridges are stippled; lows are ruled. Contours in feet. (From Hunt, Swift and Palmer, 1977).

nental shelf research programs.

2.1.1.2 Subbottom

Organic

The presence of buried organic structures (such as reefs) in this Subzone have not been reported.

Inorganic

Few papers published since the report of Zeigler and Patton (1974) mention the presence of subbottom structures. According to Uchupi (1974), seismic data indicate that reflecting horizons off Cape Hatteras generally parallel the present surface of the shelf and slope, although erosion has modified the surfaces to some extent (Figure II-21). Off the center of Raleigh Bay, reflectors are truncated midway down the slope, and near the top of the slope a buried canyon occurs with relief in excess of 400m. From this area to south of Cape Lookout, the deeper reflectors continue to be truncated by the continental slope. These reflectors from near Cape Fear to Cape Romain have been buried by shallower layers which have prograded from 20km to more than 100km across the Blake Plateau.

Dillon et al. (1976) report that Cretaceous sediments are faulted near Cape Fear.

Talwani, Ressetar, McAleer, Holmes, Grothaus, Findlay, Cable and Amick (1975) hypothesized, on the basis of gravity and magnetic profiles, that a Triassic basin capped with basalt flows, or a diabase sill about 100m thick, is centered near Georgetown, South Carolina (Figure II-22). The basin, which extends for a few kilometers east of the shoreline, has an areal extent of about 2500 square km and contains nearly 6km of sediment.

On a smaller scale, several papers have been published which are concerned with nearshore shallow subbottom structures. The sedimentary framework of the Cape Fear region has been studied by Meisburger (1977). Moslow and Heron (1977, 1978) and Hall (in preparation) report the presence of buried channels between Cape Lookout and Drum Inlet and in the Bogue Banks area.

2.1.1.3 Previous/Ongoing Research

In addition to the U. S. Geological Survey activities cited in Section 1.2.3, site-specific studies are in progress.

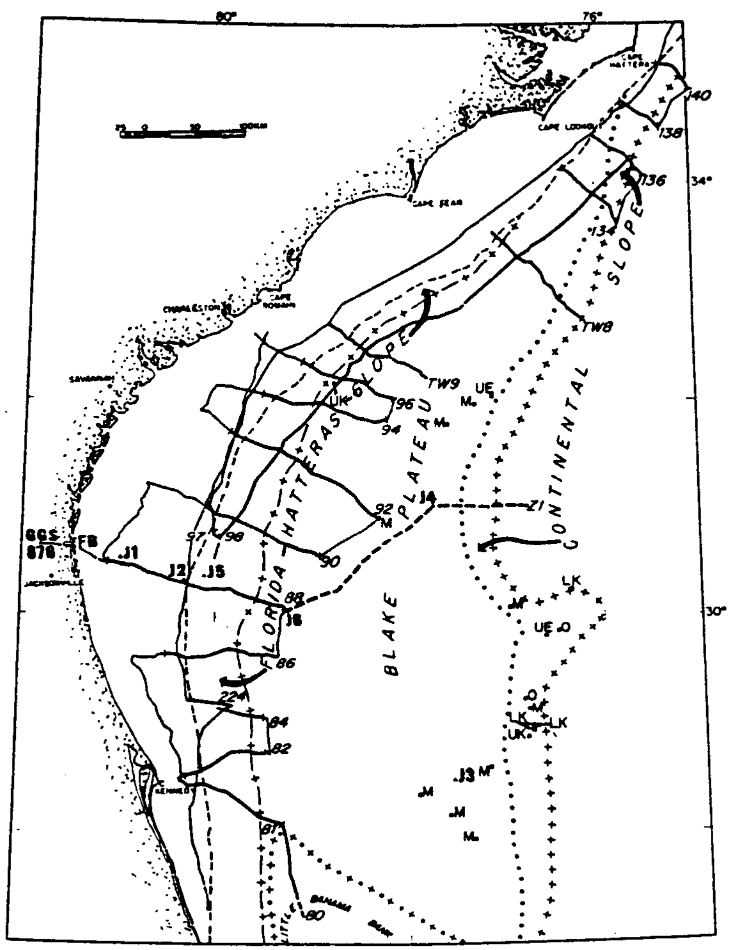


FIGURE II-21. Location of seismic profiles and positions of rock samples and holes drilled by JOIDES. (From Bunce et al., 1965)

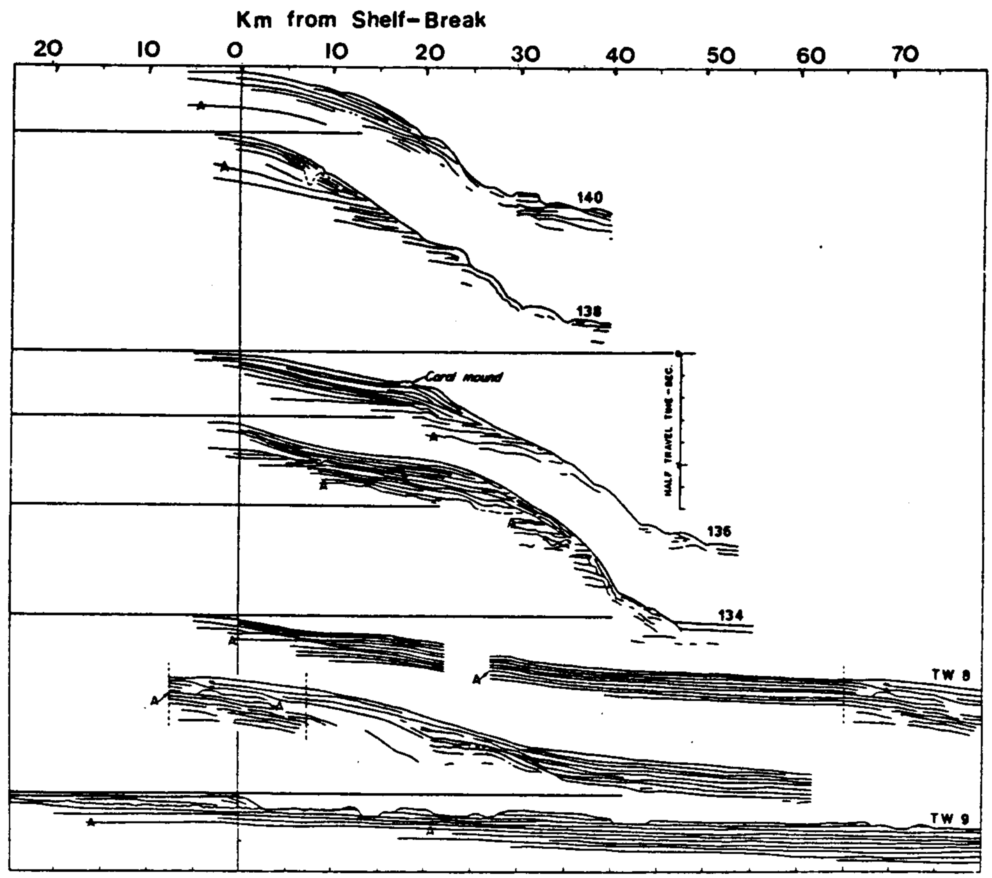


FIGURE II-21a. Continuous seismic profiles of the continental margin between Cape Hatteras and Latitude 32°. (From Uchupi, 1974). Reflector A marks top of Cretaceous.

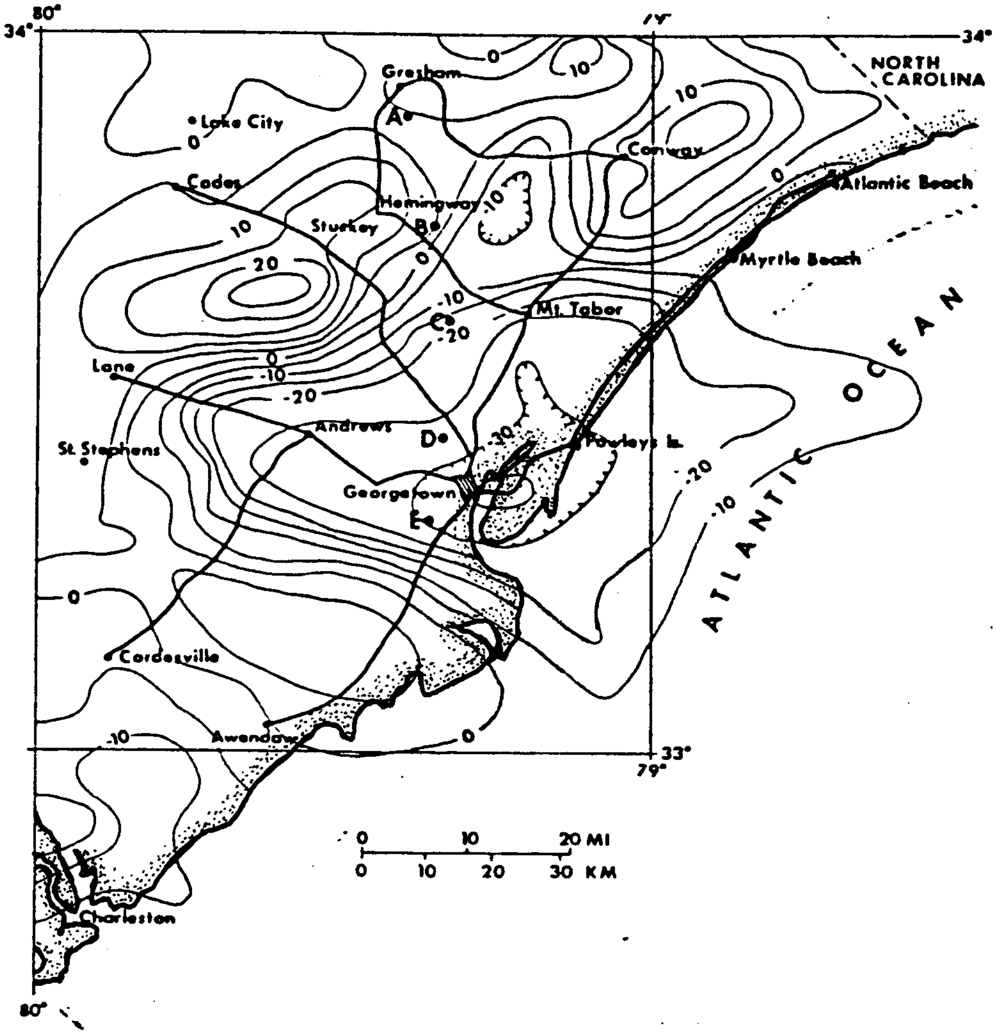


FIGURE II-22. The Georgetown Gravity Low (GGL) with profiles superimposed. Points A, B, C, D, and E locate the seismic refraction lines of Bonini and Woollard (1960). (From Talwani et al., 1975).

Neumann, Hine and Clark (Neumann, 1978, personal communication) conducted an extensive subbottom profiling program as an initial phase to identify the sequence of lagoon-marsh infilling behind the barriers and the extent of tidal-inlet channels in front of the barriers on the shallow continental shelf. Also, Hine (1978, personal communication) is collecting high resolution seismic data off Bogue and Shackleford Banks; and Riggs (1978, personal communication) is carrying out studies on subbottom estuarine and shelf structures in the Pamlico Sound area.

2.1.2 Stratigraphy

With regard to published information concerning deep stratigraphic data in Subzone I, Hathaway et al. (1976) reported on the results of the Atlantic Margin Coring Program during the course of which three boreholes (6006, 6005 and 6003) were drilled off Raleigh Bay, Long Bay and Cape Romain, respectively. The main objectives of the borings were to determine stratigraphic sequences and the presence of freshwater aquifers. Core recovery from 6006 was 20m from a bottom penetration of 89m; from 6005, 11m from a bottom penetration of 48m; and 6003, no recovery because the hole was abandoned. Boring 6006 bottomed in Pleistocene limestone and Boring 6005 bottomed in Paleocene calcareous sands and clays. No other information on deep stratigraphy has been published since this report. However, Grow, Dillon and Sheridan (1977) report seven diapiric structures in deep water along the base of the continental slope southeast of Cape Hatteras. These new data suggest the possibility of at least a few isolated salt horizons within the deepest sedimentary units beneath the outer continental shelf and slope in this area.

Pilkey (1977) reported on shallow stratigraphy determined from 10 vibrocores collected on a transect off Cape Fear. He reports that the sediment cover is typically less than 5m thick and contains a late Pleistocene or Holocene molluscan assemblage. Underlying Tertiary sediments are generally well consolidated. Most of the sediment cover apparently formed under open shelf conditions although lagoonal sediments are present in some cores.

Susman (1975) completed a M. S. thesis on the post-Miocene stratigraphy of Shackleford Banks, and Goff and Ingram (1977), working in the Pamlico Sound region, determined the presence of a tidal inlet buried in the shallow subsurface.

2.1.2.1 Geologic History

On the basis of a high resolution seismic study, Welby (1974) reports that prior to the Holocene much of the coastal area in this Subzone must have been open shelf. Extensive channeling indicates that the area was shoal or exposed subaerially for brief intervals. Barrier islands, which developed during the Holocene, trapped much fine sediment behind them.

According to Field and Duane (1976), present barrier islands probably originated far out on the shelf and retreated landward with rising sea level. Rate of sea level advance and sediment supply influenced their development.

Work by Macintyre, Blackwelder, Land and Stuckenrath (1975) indicate that a sea level curve recently constructed for this area (Milliman and Emery, 1968) may contain anomalously deep data points. Sandstone which occurs on the North Carolina shelf edge, considered intertidal beach rock, is probably the result of subtidal submarine lithification. Dillon and Oldale (1977) have found errors in the sea level rise curve due to subsidence after formation of samples. No published radiocarbon-dated samples can demonstrate a Wisconsin sea level lowering of more than 95m (Dillon et al., 1977).

2.1.2.2 Previous/Ongoing Research

Riggs (1978, personal communication) is conducting research on the stratigraphy of North Carolina estuaries and nearshore shelf, and Woolen (1978, personal communication) has collected data concerning the geologic history of the Santee Delta.

2.1.3 Sediments and Sedimentary Processes

2.1.3.1 Sediment Distribution

Literature discussing sediment distribution in Subzone I prior to 1974 was discussed by Zeigler and Patton (1974) and Dillon et al. (1975). Since that time little information on this subject has been reported except by Pilkey (1977) who, in a program abstract, observed that in Subzone I the surficial sediments are a two component system made up of reworked non-carbonate and modern unreworked carbonate fractions.

2.1.3.2 Sedimentary Processes

Research on sedimentary processes are divided into two major categories, those occurring on the open shelf and those occurring nearshore.

Pilkey (1977) determined that the non-carbonate sand fraction on the shelf has been repeatedly reworked by transgressions and regressions. The carbonate fraction is subaerially removed during each regression and recharged within the sand body during each transgression.

An analysis of sediment samples from Pamlico Sound and associated estuaries by Custer (1974) and Custer and Ingram (1974) indicated that grain size distribution reflects the proportion of sediment transported by suspension, traction and saltation, grain size limits for each population, and waves or currents as the energy source.

Welby (1974, 1975) and Miller and Berg (1976) report on using ERTS-1 imagery to study the Cape Fear River plume. Suspended sediment in the plume acts as a tracer to show how fines are transported seaward and to what extent this transportation takes place. Attempts are being made to determine the amount of sediment moving through the inlets, by studying ERTS-1 imagery.

Several studies have been completed at North Inlet, South Carolina by Finley (1975a, 1975b, 1976). He found that beach erosion is a result primarily of northeast storms and that the shoreline is transgressive. Only the beach immediately south of North Inlet, protected by an ebb tidal delta from northeast storm wave approach, is not being severely eroded. Other authors concerned with shoreline erosion are Stirewalt and Ingram (1974); Bellis, O'Connor, and Riggs (1975); O'Connor and Riggs (1977); and Riggs, O'Connor and Bellis (1977).

Surficial sediments in inlets and estuaries are discussed by Cleneay (1974) and Swift and Sears (1974) and in modern lagoonal environments by Katuna (1974) and Katuna and Ingram (1974). Other studies by Brauer (1974); Crowsen and Riggs (1976); Graeser, Muehlberger and Heron (1976); Nummedal, FitzGerald and Humphries (1976); and Cleary and Hosier (1977) relate to coastal processes within Subzone I.

2.1.3.3 Previous/Ongoing Research

Work in progress in Subzone I relates to the distribution of organic material in various marine environments in the vicinity of Pamlico Sound (Landis, 1978, personal communication); the role of microboring organisms in the alteration and destruction of marine sediments in the North Carolina offshore zone (Perkins, 1978, personal communication); the effects of winter storms on beaches and inlets (Conger, 1978, personal communication); the measurement of beach altitudes at Myrtle Beach, South Carolina (Nelson, 1978, personal communication); and the definition of major shore zone types and associated processes, problems and corrective measures

(O'Connor and Riggs, 1978, personal commuication).

2.1.4 Bathymetry

Detailed bathymetric maps at a scale of 1:250,000 are being prepared by the National Ocean Survey (NOAA/NOS) under contract to the Bureau of Land Management (see Section 1.2.3). Also, results of the SCOPE program of the National Ocean Survey are described by Norris (1976) (see Section 3.1.4).

2.1.4.1 Physiography

No pertinent papers have been published on the physiography of the continental shelf and slope in Subzone I since 1974.

2.1.4.2 Previous/Ongoing Research

No bathymetric work was reported in progress. Huntsman (1978, personal communication) has proposed a bathymetric survey from Cape Hatteras to Cape Canaveral using a remote, underwater fisheries assessment system (RUFAS).

2.2 Economic

2.2.1 Petroleum

About 50 deep wells have been drilled along North Carolina's coastal zone (Richards, 1967) and 11 in South Carolina (Olson and Glowacz, 1977). Although there were a few shows of petroleum, none were of economic value (Olson, 1974). The lack of production in coastal North Carolina has been attributed to a mostly non-marine sedimentary section, while in South Carolina the basement rock is at a relatively shallow depth (U. S. Department of the Interior, Bureau of Land Management, 1977).

The need for deep test wells on the shelf represents a serious data gap in this Subzone.

2.2.2 Sand and Gravel

Zeigler and Patton (1974) stated that sand and gravel may prove to be the most important commercially exploitable resource on this portion of the continental shelf. However, no papers have been published on this subject since 1974.

2.2.3 Aquifers

No information exists concerning offshore aquifers and this lack of information represents a significant data gap.

2.2.4 Geothermal

No papers on geothermal aspects have been published for this area, constituting another data gap. However, deep wells near Wilmington show a rise of 7.3°C per 100 meter geothermal gradient (Stewart, Dunn and Heron, 1975) which is approximately three times above normal geothermal gradient values.

2.2.5 Heavy Minerals

No papers have been published on the offshore occurrence of economic heavy mineral deposits in Subzone I.

2.2.6 Phosphate

No offshore phosphate deposits have been described since the paper of Luternauer and Pilkey (1967) as cited by Zeigler and Patton (1974).

2.2.7 Other

No other geological resources of economic value are reported for this Subzone.

2.2.8 Previous/Ongoing Research

No information has been obtained concerning active or post-1974 research relating to economic petroleum and mineral resources in Subzone I.

2.3 Potential Hazards

2.3.1 Seismicity/Earthquakes

For more than 10 years seismic disturbances have been reported in the Cape Fear area, ranging from booming noises and rattled objects in homes, to small seiches in Southport Harbor (Stewart et al. 1975; Stewart and Taylor, 1976; Taylor, 1977). The disturbances appear to originate 15-70km offshore, and south and southwest of Cape Fear.

Inconclusive data based upon anomalous elevation changes, groundwater anomalies, and earthquake history in the Wilmington-Southport area suggest a real possibility of a major earthquake in the next few years or decades (Stewart et al., 1975). Southport is on the Cape Fear Arch, a region active in the geologic past (Fairbridge, 1974).

If the Arch is an active horst with associated normal faulting, the anomalous conditions may be of no consequence; however, if a deep thrust or strike slip fault is involved, a destructive earthquake could follow (Scholz, Sykes and Aggarwal, 1973; and Kisslinger, 1974).

Earthquake activity on the east coast of the United States is shown in Figure II-23. Figure II-24 compares Charleston prior to the 1886 earthquake with Wilmington in 1975.

Detailed site-specific, deep seismic studies need to be carried out in the Wilmington-Southport vicinity.

2.3.2 Sediment Movement/Properties

Sediment movement will generally occur in this area by either scour or mass movement. The Bureau of Land Management (1977) states that the dynamic sedimentary environment of this portion of shelf indicates that scour could be a problem around the supports of any structures constructed on the shelf.

Layers of clay or patches of lagoonal muds or peats would result in areas of poor support capabilities.

Slumping occurs on the slope (Dillon et al., 1975) since, as a result of no subaerial exposure and lacking desiccation, sediments retain their mobile plasticity.

2.3.2.1 General

Little is known about sediment movement on the continental shelf and slope in Subzone I and no relevant information on this topic has been published since 1974 (Zeigler and Patton, 1974).

2.3.2.2 Storm-Related Conditions

At present nothing has been published with respect to scour or mass movement in response to storms. The lack of such information represents a significant data gap.

2.3.3 Drilling Hazards

2.3.3.1 Geopressures

At present it is not known whether geopressures will be encountered by drilling operations on the South Atlantic continental margin

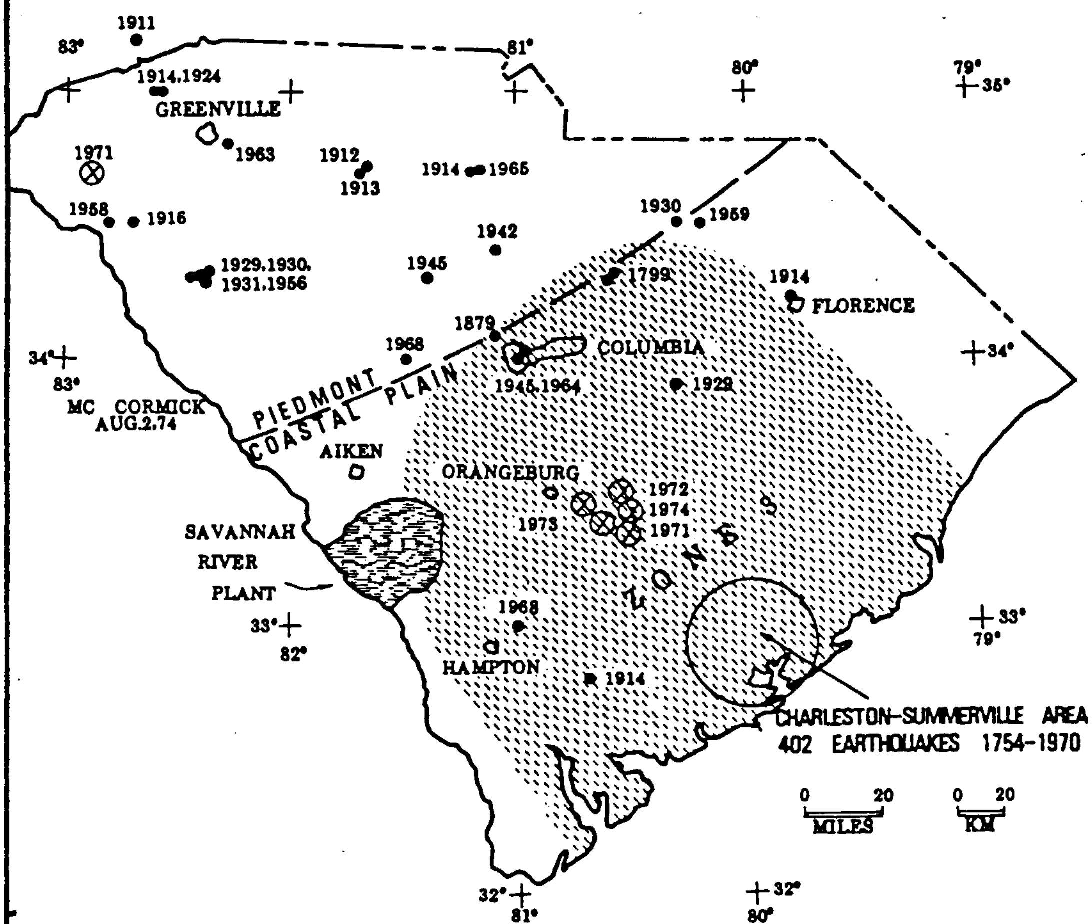


FIGURE II-23. Seismicity map for South Carolina. Year is given by each epicenter (from Bollinger, 1972; 1973). Map is updated to include 1972 and 1973 earthquakes. Map also includes seismic risk zone 3 (Algermissen, 1969), and the McCormick earthquake. U.S. Department of the Interior, Bureau of Land Management, 1977.

	CASE A Charleston, 1886	CASE B Wilmington, 1957
YEARS OF LOCAL NEWSPAPER COVERAGE	154	201
POPULATION AT END OF TIMES CONSIDERED	∿ 60,000	∿ 60,000
YEARS BETWEEN FIRST KNOWN LOCAL TREMOR AND ABOVE DATES	132	103
TOTAL NUMBER OF LOCAL TREMORS REPORTED	6	5*
LOCAL TREMOR FREQUENCY (EVENTS/YEAR)	1/22	1/21
LONGEST PERIOD OF QUIET BETWEEN TREMORS (YEARS)	45	43
LOCALLY CAUSED DAMAGE**	None	None
MAXIMUM LOCALLY GENERATED INTENSITIES (MM)	III-IV	III-IV
POSTULATED LOCAL FAULTS (GEOPHYSICAL AND OTHER DATA)	One or more	One or more
DOCUMENTED LOCAL FAULTS (MAPPED IN OUTCROP)	None	None
GEOLOGIC CAUSES OF LOCAL SEISMICITY	Not known	Not known

* One of these 5 events was actually a swarm of 5 shocks in one day but is here counted as one event.
**Charleston had some damage in 1811-12 due to a quake originating near New Madrid, Missouri—nearly 900 miles away. Also, Wilmington sustained damages in 1886 due to the large quake originating from the Charleston Area—145 miles away. These damages are not considered in this table because they were not due to local causes.

NOTE: In the column containing the Charleston data, 4 tremors in the two months preceeding the 1886 major event are not included because they are considered foreshocks of the main event and are to be grouped with it. The main Charleston event was on August 31, 1886. The foreshocks occurred in late June, and one each on August 27, 28, and 29. They were very small tremors and were not observed by most of the residents. Many who did notice them did not even realize that they were quakes but thought them to be atmospheric conditions or activities of the nearby military post. The local Charleston newspaper considered them with levity, not realizing the destruction to which they were prelude.

FUTHER NOTE: It has been stated in some reports that "Charleston has experienced over 400 local tremors in the past 200 years." It must also be added that over 400 of these tremors occurred in the 20 years following the large quake in 1886 and must be considered aftershocks of this event. If Wilmington had such a large quake, it too might have "400 or more local tremors", but until the occurrence of such an event, on cannot know. In any case, the increased seismicity of Charleston since 1886 cannot be cited as evidence that Wilmington is distinctly different from Charleston from a seismic point of view. The only valid comparison of the two areas is to compare Charleston prior to 1886 to Wilmington today.

FIGURE II-24. Two Seismic Histories: Charleston, S. C. in 1886, and Wilmington, N. C. in 1975. (Modified from Stewart, Dunn and Heron, 1975).

(U. S. Department of Interior, Bureau of Land Management, 1977). Register and Peek (1975) state that wells over 180m deep in the Wilmington-Southport area have piezometric pressures up to 36.5m above sea level. If this results from active tectonism along the Cape Fear Arch, geopressures may extend into the offshore region.

2.3.3.2 Aquifer Contamination/Drawdown

Trenching or drilling into aquifers can release artesian flow and/or cause saltwater intrusion as a result of loss of hydraulic head (U. S. Department of the Interior, Bureau of Land Management, 1977). Also, the lack of information concerning the location, depth and distribution of offshore freshwater bearing aquifers constitutes a serious data gap.

2.3.3.3 Previous/Ongoing Research

The U. S. Geological Survey (Butman, 1978, personal communication) has deployed instruments for monitoring both bottom sediment movement and associated physical parameters on the continental shelf south of Subzone I. No other information has been obtained concerning drilling hazards in Subzone I.

3.0 CONTINENTAL SHELF-SUBZONE II--WINYAH BAY TO ST. JOHNS RIVER

3.1 Description

3.1.1 Structures

3.1.1.1 Bottom

Organic

Algal limestone ledges crop out along the outer shelf and upper slope (6 to 10m relief) of the Carolinas and Georgia and support dense epifaunal communities (Macintyre and Milliman, 1970). Small patch reefs also occur on the central and inner shelf of Subzone II (U. S. Department of the Interior, Bureau of Land Management, 1977); however, only one such feature, Gray's Reef, has been described in detail (Hunt, 1974). This live bottom is located 33km off Sapelo Island, Georgia at a depth of approximately 20m (relief 6m) and consists of a strongly dolomitized, sandy biomicrite substrate heavily encrusted with sessile benthos. The reef crops out on an otherwise sandy bottom and is of suggested Pliocene age (Figure II-25). A similar feature, Rufus Reef, has been located 127km due east of Savannah Beach, Georgia in 55m of water and with relief of up to 12m (U. S. Department of Commerce, National Marine Fisheries Service, 1971). At this time a data gap

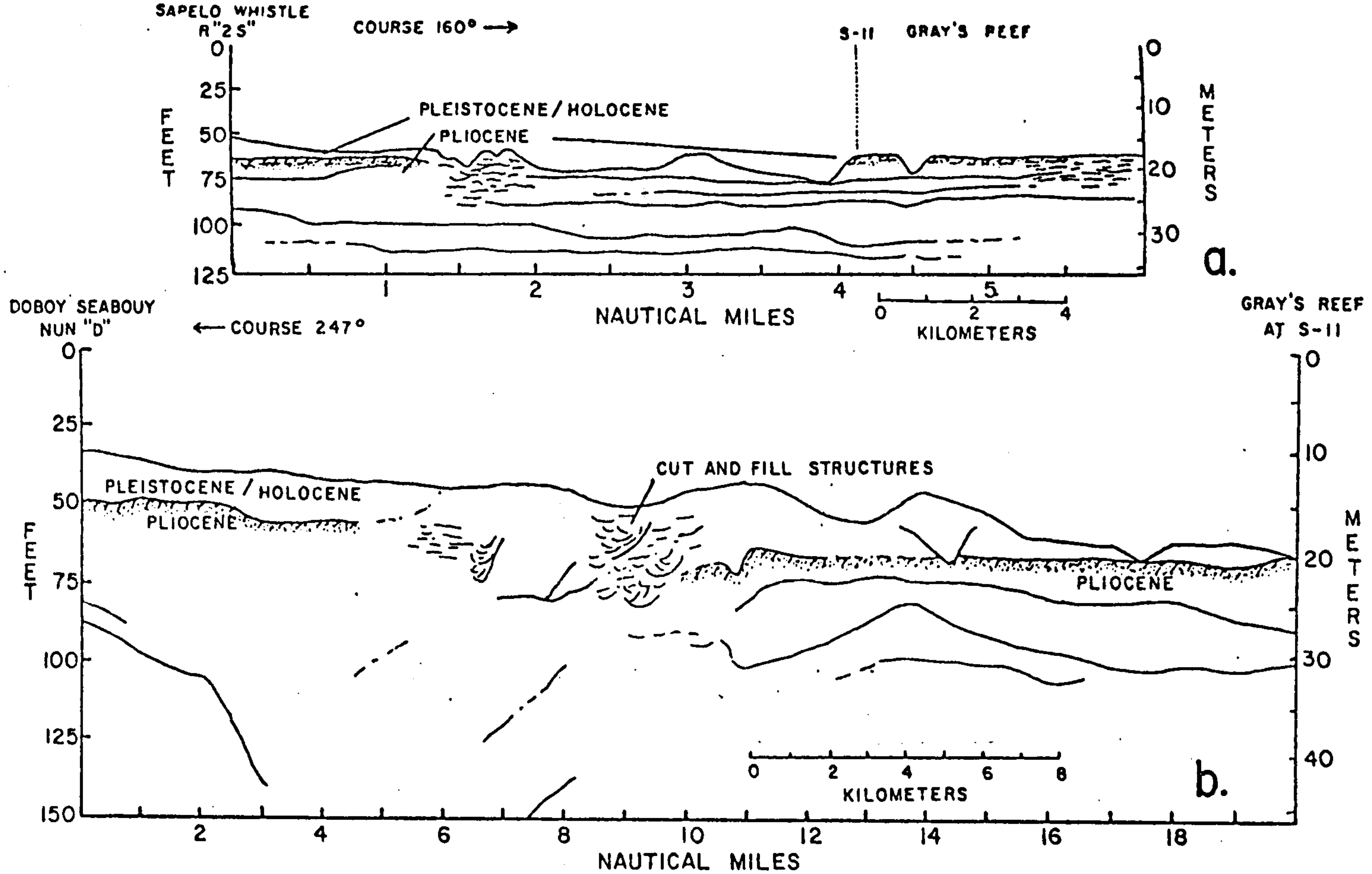


FIGURE II-25. Stratigraphic cross-sections from Gray's Reef area to the coast as interpreted from UNIBOOM profiles. Vertical exaggeration in upper is x72, for lower is x312. (From Hunt, 1974).

exists concerning the occurrence and distribution of live bottom areas on the continental shelf.

Inorganic

A limited amount of data have been collected on continental shelf bottom features since the report by Zeigler and Patton (1974).

Henry and Harding (1978) and Henry, Giles and Harding (1979) in a geological evaluation of potential pipeline corridors along the Georgia coast used side scan sonar, UNIBOOM high resolution subbottom profiler, and fathometer instrumentation to map estuarine areas and seaward to 5km offshore (Figure II-26). Significant bottom hazards to pipeline siting consisted of large mobile bedforms and areas of scour which were generally associated with ebb tidal deltas. Low amplitude sand waves (wave length > 10m) and low, irregular sand sheets were usually associated with shoal areas in offshore portions of the survey.

3.1.1.2 Subbottom

Organic

A review of all seismic and coring data published since 1974 indicates no buried organic features in the inner portion of the continental shelf of Subzone II. However, seismic profiles show buried, irregular topography along the Upper Cretaceous-Cenozoic contact near the present shelf break that is thought to represent reefs or carbonate banks (Buffler, 1978, personal communication).

Inorganic

Since Zeigler and Patton's (1974) data summary, few papers have been published concerning the presence of inorganic structures such as faults and slumps in the continental shelf and slope deposits of Subzone II.

Two arches in this area are discussed. Woolsey (1977) reports an extension of the Beaufort Arch along the Georgia coast at least as far south as St. Simons Sound. Colquhoun and Comer (1973) (Figure II-27) reported on the Stono Arch, an asymmetric structure interpreted to be a low angle reverse fault trending 297° and dipping southward. An offshore extension of the structure is indicated, and since no other deformation is known in the region, an association may exist with earthquake activity in the Charleston area.

Dillon (1974) reported possible faults off the coast of South Carolina in Tertiary strata, located on the trend of seismic

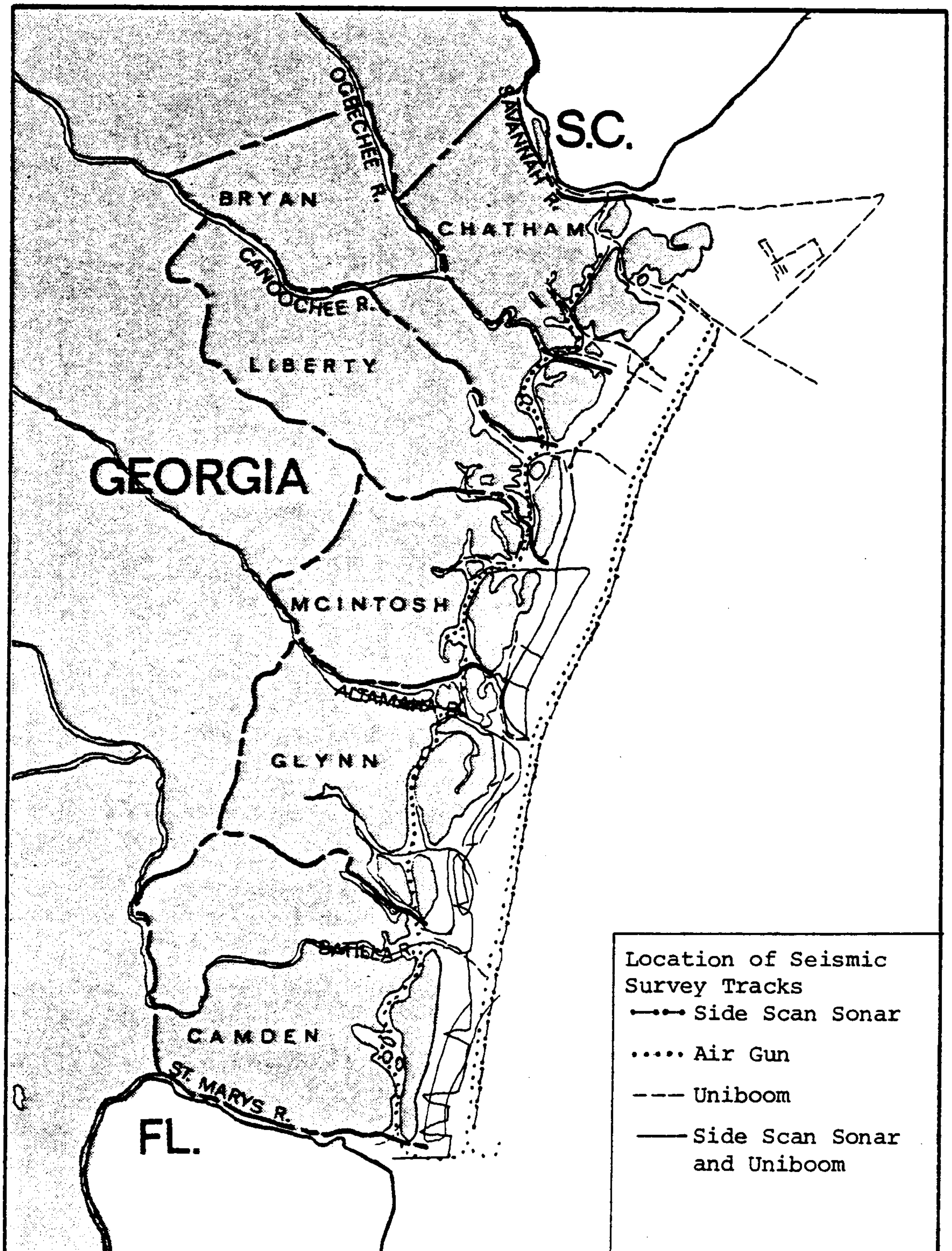


FIGURE II-26. Location of seismic survey tracks on the Georgia inner continental shelf from a study by Henry and Harding (1978).

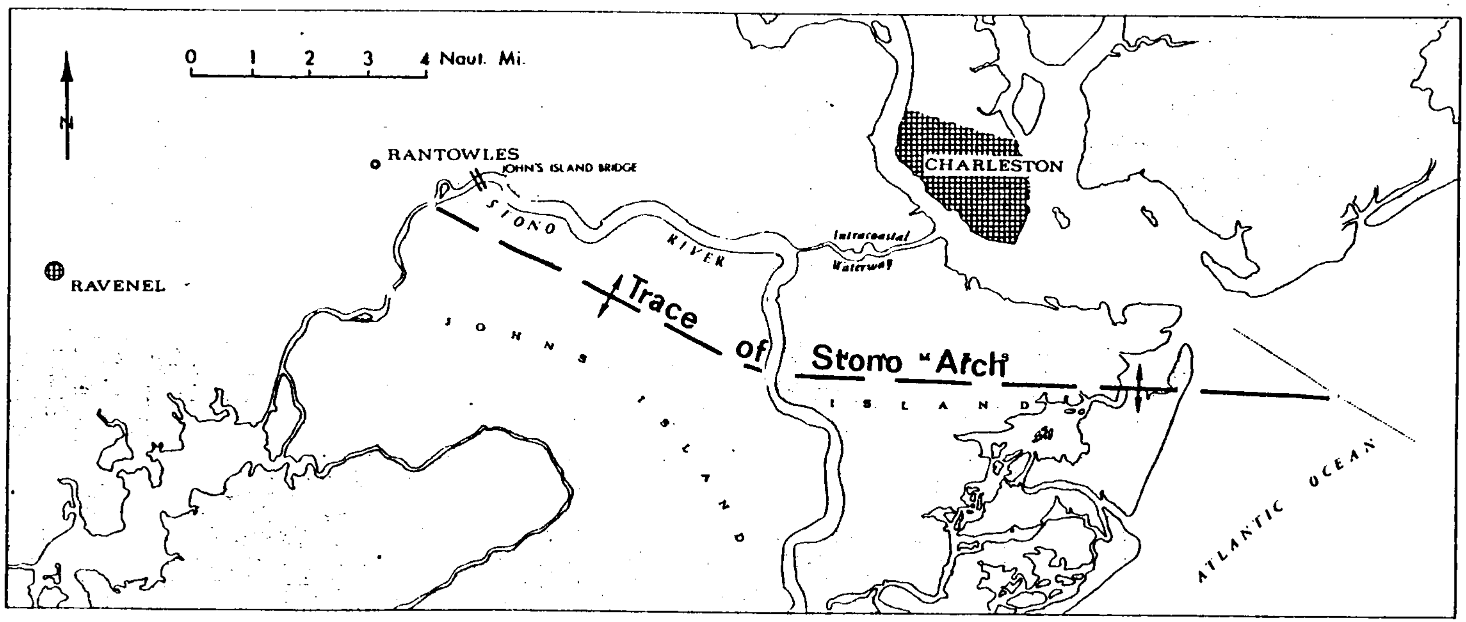


FIGURE II-27. Location map and trace of the Stono Arch. (From Colquhoun and Comer, 1973) activity which passes through the state.

Recently, Zoback, Healy, Roller, Gohn and Higgins (1978) reported that normal faults in the coastal plain sediments are currently active and the associated stress field is tectonic in origin.

3.1.1.3 Previous/Ongoing Research

A recently begun program of the U. S. Geological Survey collected high resolution seismic, side scan sonar, and underwater closed circuit television (UCCTV) data in industry interest areas (see Figure II-3) on the central and outer continental shelf off Georgia and Florida during the summer of 1978 (Henry, unpublished data). Although no published data are presently available, Harding (1978, personal communication) is conducting a side scan sonar survey of the Georgia continental shelf. Side scan sonar data obtained by the U. S. Geological Survey in industry interest sites from mid-shelf to the continental slope off Charleston, South Carolina and mid-shelf to near the shelf-edge off Brunswick, Georgia are presently being evaluated (Henry and Giles, 1979). Also, detailed high resolution seismic and side scan sonar surveys were carried out in each of the industry interest areas shown in Figure II-3 by the U. S. Geological Survey Conservation Division in late 1976 and early 1977. These data are currently being analyzed (Ball, 1978, personal communication).

3.1.2 Stratigraphy

A discussion of stratigraphy relating to Subzone II is given in Dillon et al. (1975). Stratigraphy in Subzone II is documented by core data from several drill holes (McCollum and Herrick, 1964; Bunce et al., 1965; Hathaway et al., 1976) and vibrocores (Pilkey, 1977). Shallow seismic stratigraphy of the continental shelf has been correlated with onshore and shallow offshore drill holes from South Carolina, Georgia and Florida (Henry, Giles and Woolsey, 1973; Hunt, 1974; Woolsey and Henry, 1974; Meisburger and Field, 1975 and 1976; Zupan and Abbott, 1976; Dillon, Paull and Buffler, 1977; Woolsey, 1977; Henry and Harding, 1978; and Henry et al., 1979).

Uchupi (1974) included six seismic profiles from this Subzone in his report on the continental margin south of Cape Hatteras (Figure II-28a and b). He reported that the depth below sea level to the top of the Cretaceous increases from less than 200 meters at Winyah Bay to nearly 800 meters at the St. Johns River (Figure II-29). An isopach map (Figure II-30) indicates the thickness of Tertiary sediments in this area.

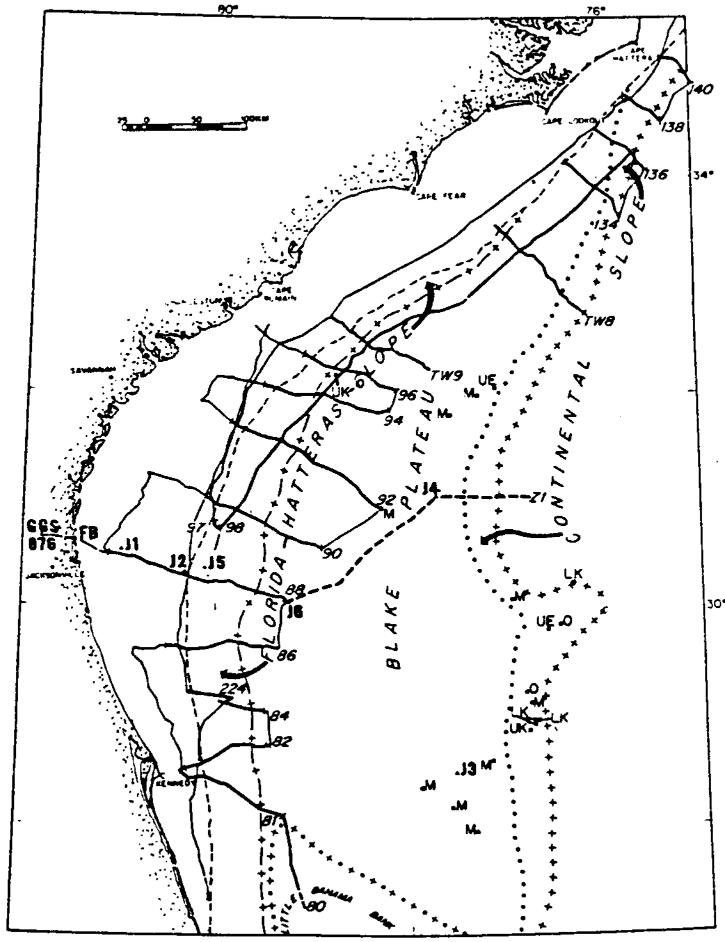


FIGURE 28a. Location of seismic profiles and positions of rock samples and holes drilled by JOIDES. (From Bunce et al., 1965)

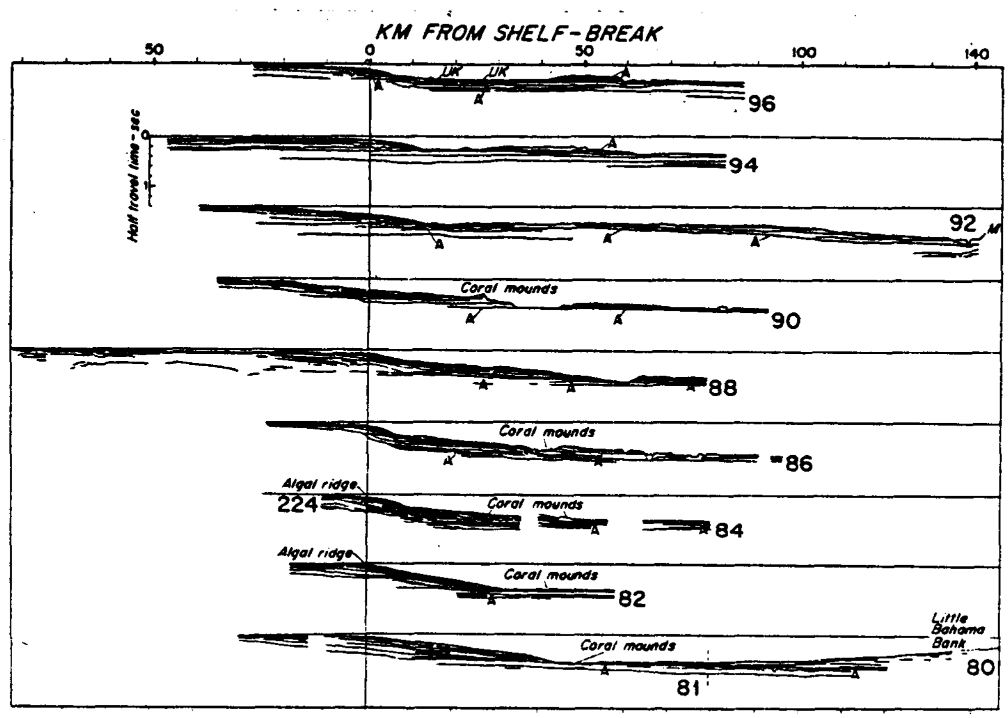


FIGURE 28b. Continous seismic profiles of the continental margin between Latitude 32° and Cape Kennedy. (From Uchupi, 1974)

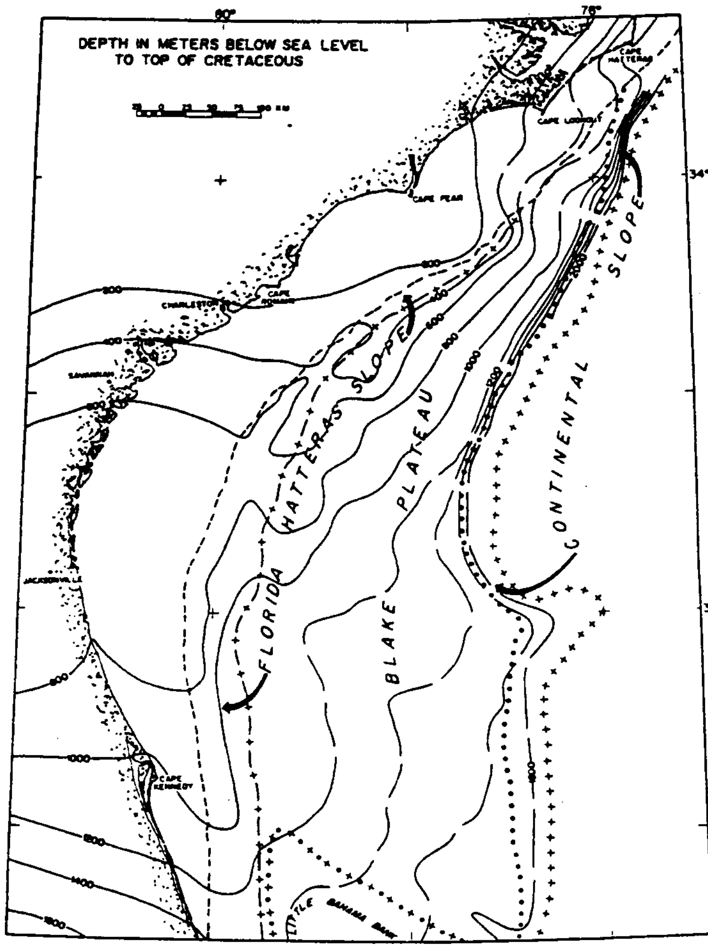


FIGURE II-29. Depth below sea level to top of Cretaceous strata in meters. (From Uchupi, 1974)

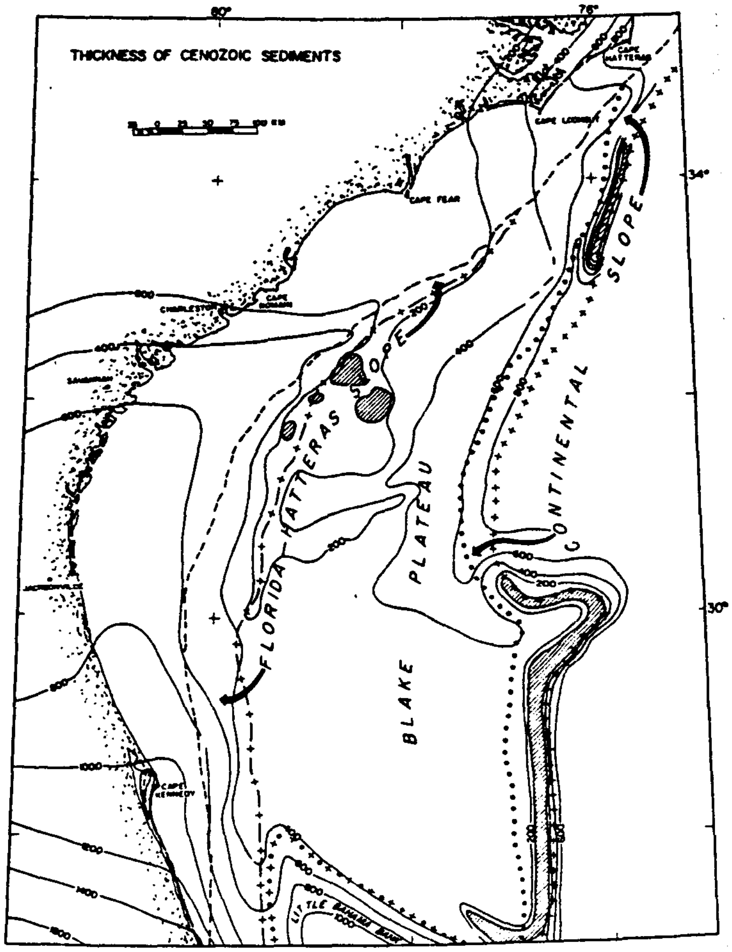


FIGURE II-30. Isopach map of the Tertiary on the coastal plain and continental margin south of Cape Hatteras. (From Uchupi, 1974)

Dillon and Paull (1978) compiled a map showing the stratigraphy and structure along the four seismic reflection profiles run between Cape Romain, South Carolina and Savannah, Georgia.

A veneer of Holocene/Pleistocene sediments generally less than 5m thick covers most of the Tertiary strata on the central and outer shelf (Pilkey, 1977). According to Meisburger and Field (1976) and Pilkey (1977) this sediment cover was probably derived from substrate erosion during the Holocene transgression.

3.1.2.1 Geologic History

Edsall (1977) reports that periods of non-deposition during the Tertiary coupled with subaerial exposure of a large portion of the shelf and subsequent erosion during the Pleistocene has resulted in numerous unconformities in the outer shelf stratigraphic record.

In the coastal zone and on the inner continental shelf, transgressions and regressions during early and middle Miocene resulted in a complex depositional history with sediments being deposited in a generally shallow, then restricted and later open, marine environment (Woolsey, 1977). A rapid drop in sea level during the late Miocene resulted in the formation of an erosional surface which was reworked during the early Pliocene transgression. Extensive deltaic deposition occurred during the middle Pliocene (Woolsey and Henry, 1974; Edsall, 1977). Seismic refraction data (Dillon et al., 1975) indicate that up to 4,000m of Lower Cretaceous and Jurassic and up to 600m of Upper Cretaceous sediments occur above the seismic basement. In Hole 6004, located 102km south of Charleston, South Carolina, Upper Cretaceous silty clay was encountered in the lower 17m of the hole which penetrated to 308m below the bottom (Hathaway et al., 1976). Drill holes on the inner continental shelf off Savannah Beach, Georgia and Jacksonville, Florida (McCollum et al., 1964; Edsall, 1977) showed a continuity between onshore and offshore stratigraphic units, and that most of the Tertiary units continue beneath the shelf, dipping seaward from the coastal plain.

Woolsey and Henry (1974); Meisburger and Field (1976); Abbott (1978); Henry and Harding (1978); and Henry et al. (1979) have studied the Cenozoic stratigraphic record of the coastal zone and inner continental shelf in considerable detail. Plio-Pleistocene marginal marine to non-marine sands and gravels cover the erosional Miocene surface on the inner shelf, resulting in shallow structures such as delta foreset beds, incised and buried river channels, and cut and fill structures (Meisburger and Field, 1976; Henry and Harding, 1978; and Henry et al., 1979) (Figure II-31).

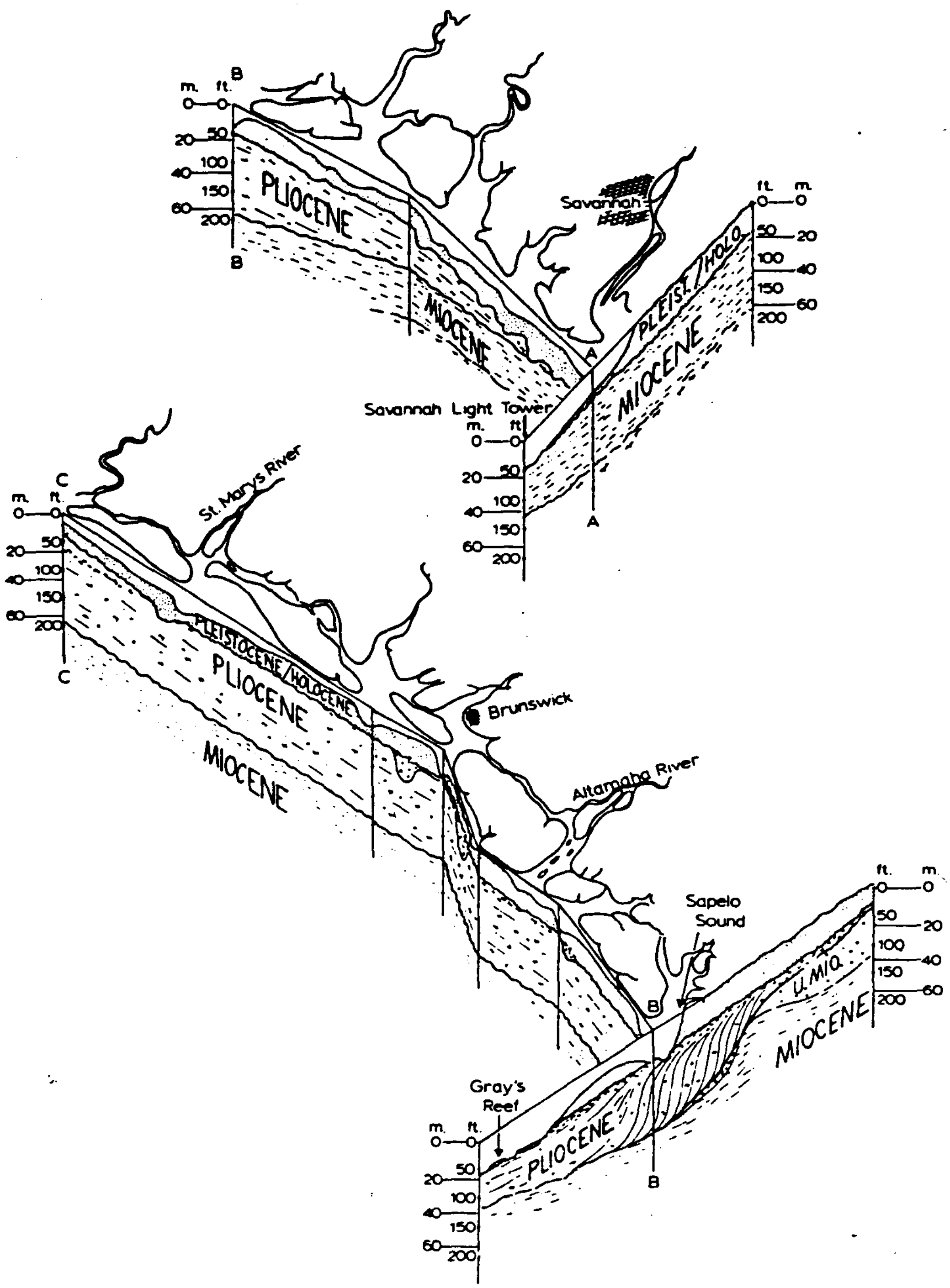


FIGURE II-31. The Neogene stratigraphy of the inner continental shelf of Georgia. (From Woolsey and Henry, 1974).

3.1.2.2 Previous/Ongoing Research

The University of Georgia, Georgia Geological Survey, and the South Carolina Division of Geology have a cooperating ongoing program investigating the shallow ($< 500m$) structures and stratigraphy of the lower coastal plain and inner continental shelf of the respective states (Henry, unpublished data).

3.1.3 Sediments and Sedimentary Processes

3.1.3.1 Sediment Distribution

Regional and local studies of the petrology and chemistry of surficial shelf sediments in Subzone II are summarized in the report by Zeigler and Patton (1974) and Dillon et al. (1975). A recent investigation of sediments on the Georgia shelf (Kingery, 1973) described the Recent-relict sediment boundary as that of two definite lobes of fine sand extending beyond the 11m depth contour (Figure II-32). Previous literature describes the Recent-relict boundary as a nearly linear feature generally following the 11m depth contour with fine sand and medium/coarse sand occurring landward and seaward of this boundary, respectively. The relict sediments have been described as palimpsest or autochthonous by Kingery (1973) and Swift (1976). From a coring investigation on the continental shelf off the Carolinas, the surficial sediments have been interpreted as a noncarbonate-palimpsest and carbonate-Holocene system (Pilkey, 1977) (Figure II-33). Percentages of silt and clay increase on the slope and carbonate percentages increase to the south and seaward (Dillon et al., 1975). Local variations in texture and composition occur and are related to surface morphology and surface exposure of underlying Pleistocene and Tertiary strata (Howard, Frey and Reineck, 1973; Meisburger and Field, 1976).

3.1.3.2 Sedimentary Processes

Surficial sediments on the continental shelf were derived from rivers, carbonate precipitation, authigenic deposition and the winnowing of Tertiary and Pleistocene outcrops (Dillon et al., 1975). Holocene paralic deposits form a 30 to 50km wide lens which straddles the present shoreline with maximum thickness of 30m occurring at the shoreline associated with inlet processes (Henry and Hoyt, 1968). Much of this sediment is believed to have been derived from erosion of shelf substrates during the Holocene transgression (Swift, 1976). Fine-grained surficial sands of the inner shelf are believed to have been derived from Holocene transgressive deposits through winnowing and landward transport of the fine fraction (Meisburger and Field, 1976). There is no

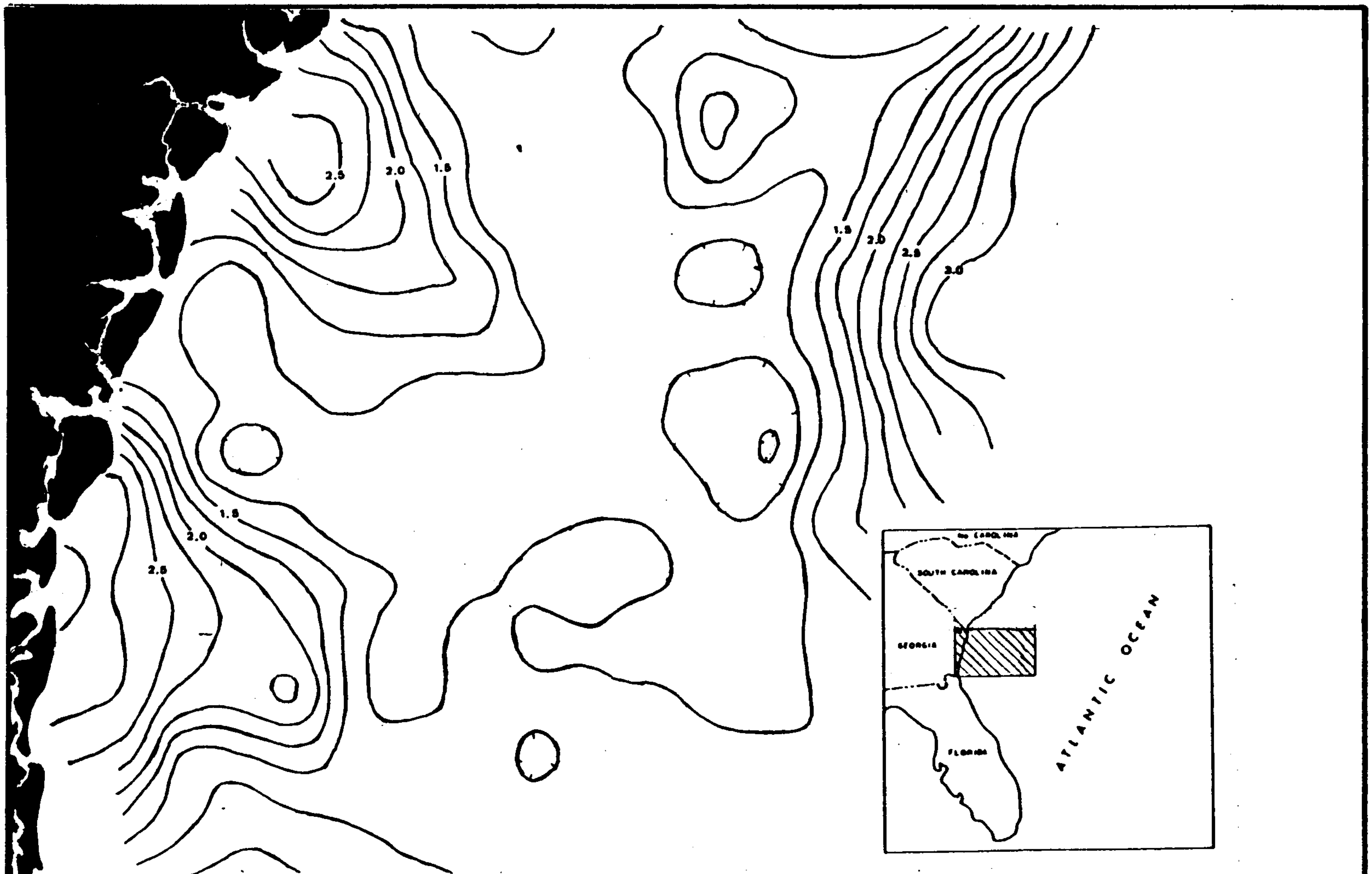


FIGURE II-32. The distribution of the mean grain size in phi units of the Georgia shelf sediments. (From Kingery, 1973).

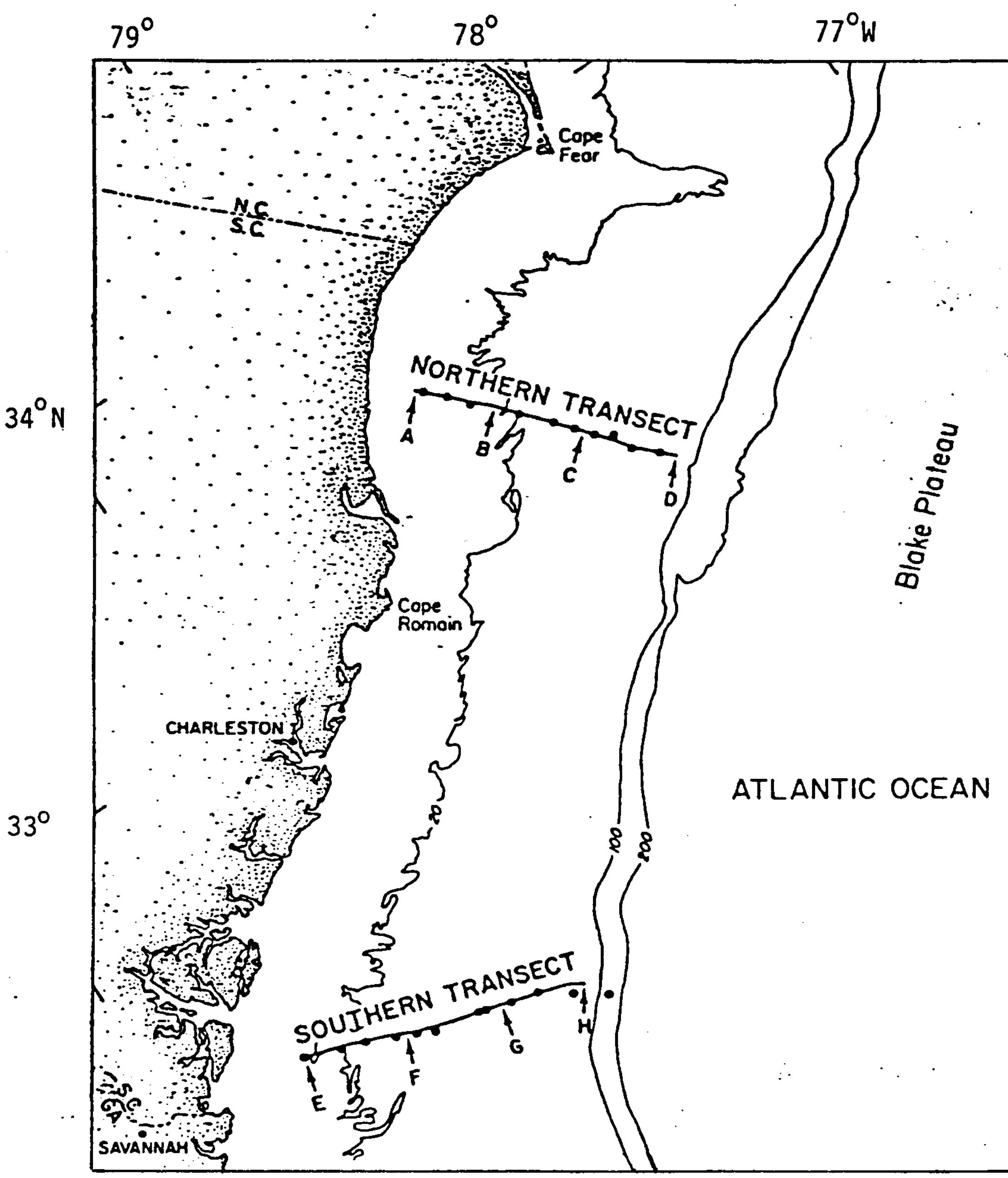


FIGURE II-33. Location of vibrocore transects conducted by Pilkey (1977) on the South Carolina continental shelf.

evidence that the major rivers of the coastal plain are delivering sediment to the present day shelf (Meade, 1969, 1972 and 1976). However, the lobate patterns of fine-grained sands on the inner continental shelf of Georgia (Kingery, 1973) suggest that the Savannah and Altamaha Rivers may have contributed significant amounts of fine-grained material to the shelf since the last transgression when sea level approached its present position.

Cross-shelf boundaries are present in carbonate and phosphorite abundance, iron staining and feldspar anomalies. Milliman, Pilkey and Ross (1972) suggest this indicates that cross-shelf sediment transport is more important than lateral transport. However, the two major lobate patterns of fine-grained sediment are offset to the south of the Savannah and Altamaha Rivers, respectively (Kingery, 1973), which also indicates the probability of a southward component of sediment transport which might be expected from the northeast approach of dominant long period waves (U. S. Naval Weather Service Command, 1970). In the area of shelf sediment transport an important data gap still exists. Although waves are generally believed to be an important agent of sediment transport on continental shelves, the state of the art is still highly theoretical and subject to continuing debate. Several papers in Stanley and Swift (1976) address the physics and mechanics of shelf sediment transport although actual measurements of wave-induced bottom currents are scarce and qualitative or quantitative measurements of transport are lacking.

Considerably more attention has been given the movement of sediment on the shallow shoreface (Dean, 1973, 1976; Oertel,1974; Komar, 1976; and others). Much of this interest has resulted from the geometric growth of coastal development and the ensuing erosional problems. Many coastal areas in Subzone II have severe localized erosional problems and numerous related studies appear in the literature. A gradual rise in sea level along the southeast Atlantic coast (Hicks, 1973) is commonly cited as a primary cause of erosional problems. However, a significant data gap still exists because the processes of shallow shoreface sediment transport also are mostly theoretical. Sediment tracer and current measurement studies have been very local and limited to "fair weather" conditions. Major sediment transport is likely to occur during periods of severe storms and hurricanes.

3.1.3.3 Previous/Ongoing Research

Analyses of surface and suspended sediment samples collected during the South Atlantic Benchmark Program (Texas Instruments, 1977) together with a heavy mineral analysis by Giles (1978, personal communication) of the samples collected earlier by Howard

(Kingery, 1973) will provide a better understanding of sediment distribution and shelf processes.

3.1.4 Bathymetry

Since the summary by Zeigler and Patton (1974) the only publication concerning bathymetric studies in Subzone II is that by Norris (1976) describing the results of the Southern Coastal Plains Expedition (SCOPE) of the National Ocean Survey. The project operations included hydrographic surveys and sampling of estuarine and continental shelf bottom sediment; aerial photography of the entire coast; tidal, current, temperature, salinity and suspended sediment observations in selected inshore areas; physical oceanographic study of tidal characteristics in the deep sea and on the shelf; and synoptic weather observation.

Detailed bathymetric charts of the South Atlantic region at a scale of 1:250,000 are being prepared by National Ocean Survey for the Bureau of Land Management (see Section 1.2.3).

3.1.4.1 Physiography

See Section 3.1.1.1, Inorganic, and Section 3.1.1.3.

3.1.4.2 Previous/Ongoing Research

See Section 3.1.1.1, Inorganic, and Section 3.1.1.3.

3.2 Economic

3.2.1 Petroleum

An evaluation of petroleum potential in the Southeast Georgia Embayment is presented in Dillon et al. (1975) and Schlee et al. (1977). Pre-continental drift suggests an analogy between the Senegal Basin on the northwest coast of Africa and the Southeast Georgia Embayment which would offer low potential for hydrocarbon production. However, the authors believe the South Florida Embayment to be a more realistic analogy to the hydrocarbon potential of the Southeast Georgia Embayment. Eight small fields have been discovered in this structure with low yields (Dillon et al., 1975). The Lower Cretaceous section is believed to offer the best hydrocarbon potential in the Southeast Georgia Embayment.

Additional data from South Carolina coastal plain drill holes (Olson and Glowacz, 1977) have been utilized to demonstrate the concept of a starved-basin topography within the Southeast Georgia Embayment with strata progressively thinning offshore. Salinity gradients in the embayment also indicate an incomplete flushing of connate water within rock units (Olson and Glowacz, 1977). Both of these factors are negative evidence for petroleum potential off the South Carolina coast. Negative evidence for the occurrence of gas accumulations was derived from "bright-spot" seismic processing (Olson and Glowacz, 1977). Schlee et al. (1977) consider the primary structural traps to be drape structures above basement which have been identified from multichannel seismic profiles.

3.2.2 Sand and Gravel

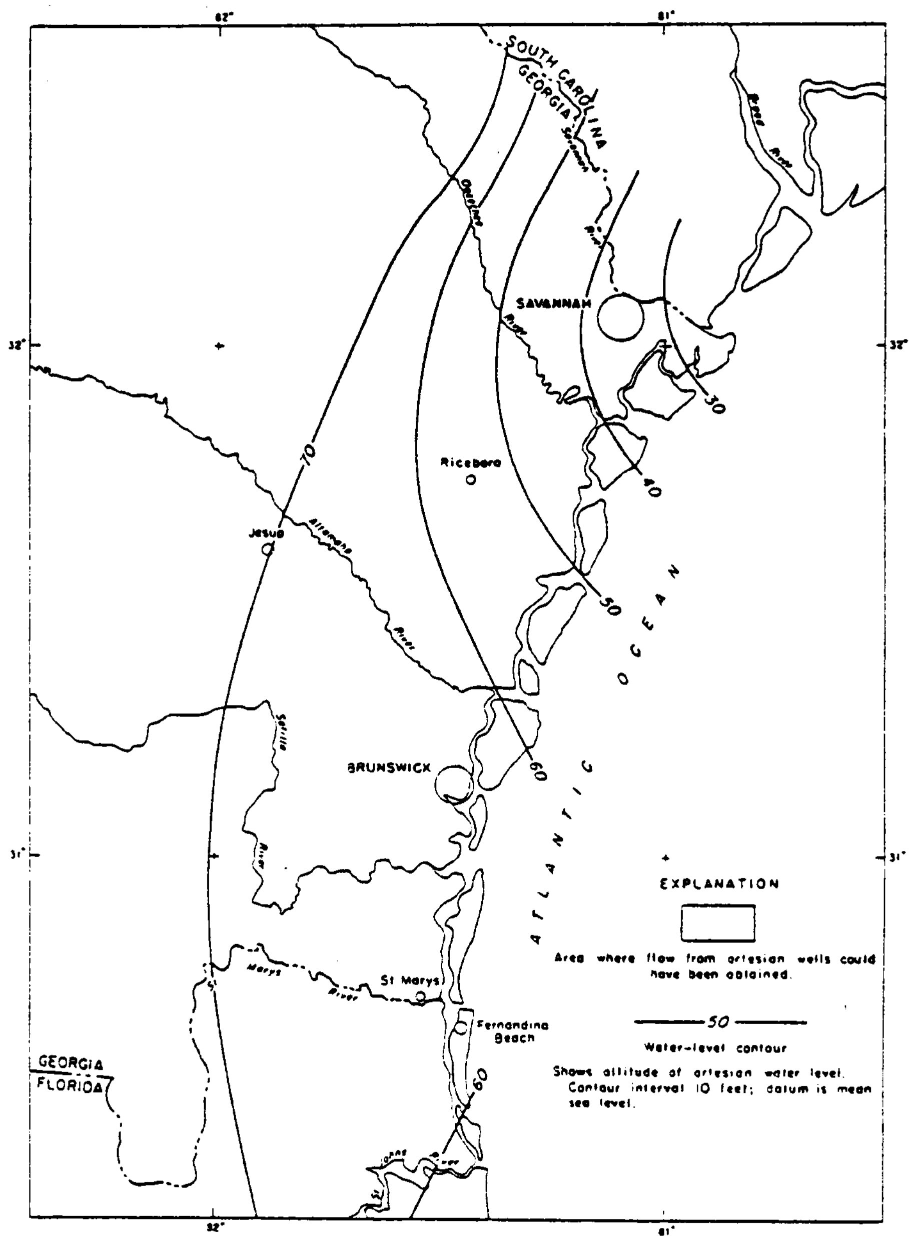
Harding and Woolsey (1975) conducted a reconnaissance survey for aggregate resources along the northern part of the Georgia coast including portions of the continental shelf. Potentially economic sources of sand and gravel were found which consisted of Quaternary alluvial deposits and relict gravels of the inner continental shelf. The existence of similar deposits can be extrapolated to the south Georgia coast based on intensive shallow seismic work (Henry and Harding, 1978; Henry et al., 1979) and to the north Florida coast (Meisburger and Field, 1975). The latter report located several deposits of well-sorted sand suitable for beach restoration.

3.2.3 Aquifers

The principal artesian aquifer (called the Floridan aquifer) has been discussed in detail (Dillon et al., 1975). The aquifer consists of Eocene, Oligocene and Miocene limestone and extends offshore beneath the continental shelf. Chloride content from 1966 data was generally low ($<$ 100 ppm) in the Subzone II region, although higher chloride contents may be expected locally in the lower parts of the aquifer. Water levels in the principal aquifer have declined significantly with the growth of industry in the past decade. Intense industrial usage in the areas of Savannah and Brunswick, Georgia has resulted in the upward leakage of contaminating brackish water in these areas (Wait and Gregg, 1973) (Figures II-34a,b and II-35). Although there was no evidence of the lateral encroachment of sea water in the vicinity of Brunswick, Georgia, saltwater enters the aquifer in areas of offshore exposure and in the sounds of coastal South Carolina and migrates down the hydraulic gradient toward the cone of depression in the area of Savannah, Georgia.

3.2.4 Geothermal

There is no known geothermal information for this Subzone.



1880

FIGURE II-34a. Altitude of artesian water level in 1880 in coastal Georgia. (From Krause and Gregg, 1972)

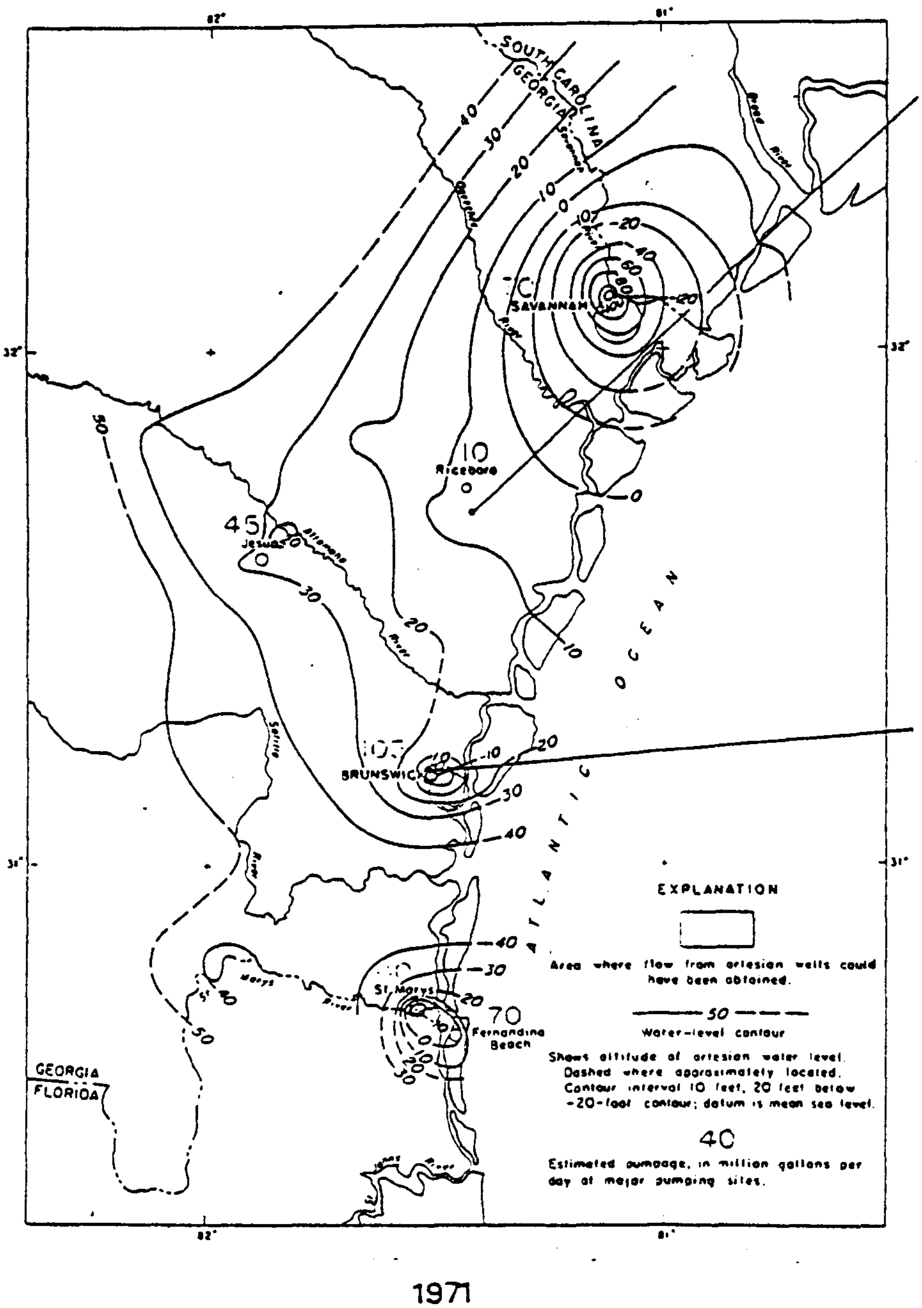


FIGURE II-34b. Altitude of artesian water level in 1971 in coastal Georgia. (From Krause and Gregg, 1972]

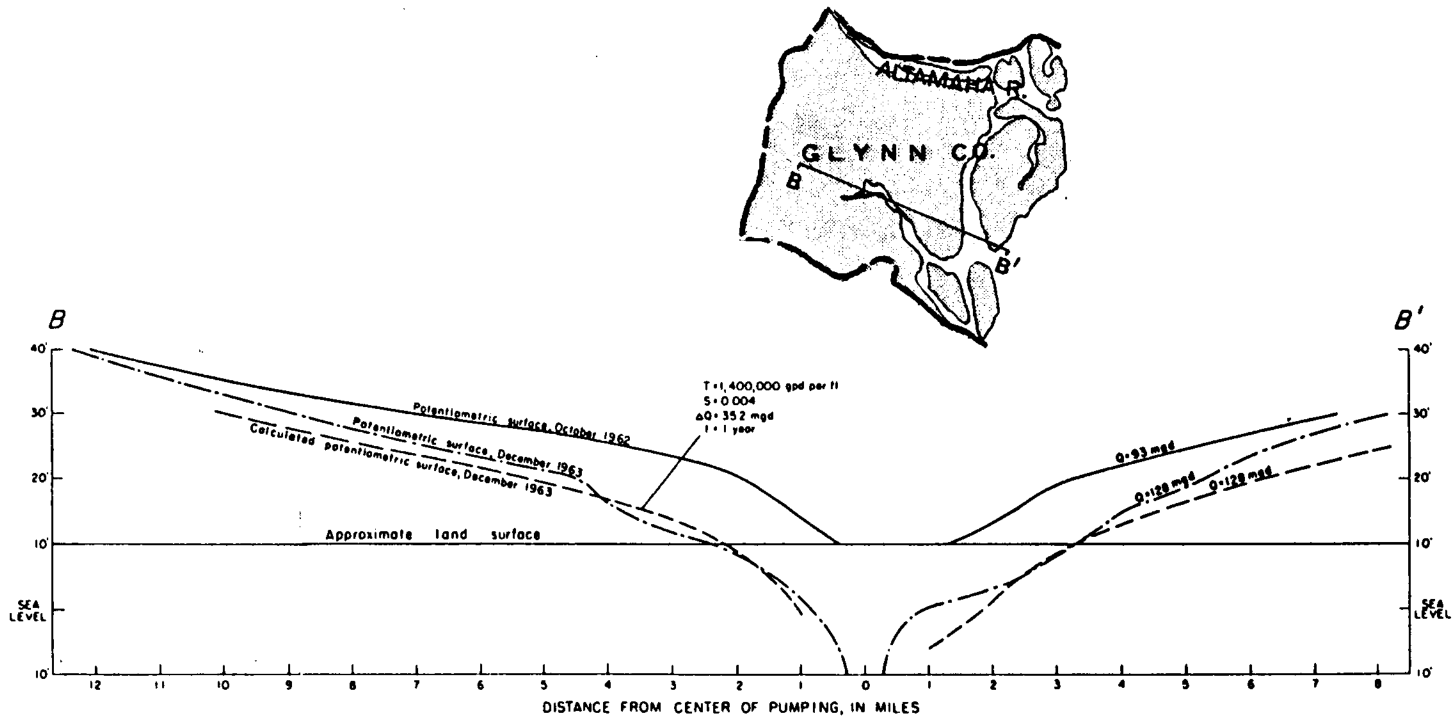


FIGURE II-35. Profiles of potentiometric surfaces for October 1962, December 1963 and a calculated profile for December 1963 in the vicinity of Brunswick, Georgia. (From Wait and Gregg, 1973)

3.2.5 Heavy Minerals

No economic deposits of heavy minerals are known to occur in the offshore areas of Subzone II although good possibility exists for such occurrences in barrier island deposits (Woolsey, Henry and Hunt, 1975).

3.2.6 Phosphate

A large phosphate ore body is known to exist in onshore and offshore areas of Chatham County, Georgia. The ore zone may be over 20m thick in places and consists primarily of Upper Miocene sediments (Furlow, 1969; Woolsey, 1977). Overburden decreases in offshore areas where economic phosphate deposits may exist where the Miocene erosional surface approaches the seafloor.

3.2.7 Other

No information was found concerning any other potentially important mineral resources in Subzone II.

3.2.8 Previous/Ongoing Research

Research is presently being conducted on the continental shelf of Subzone II by Noakes and Harding that concerns the in situ determination, by neutron activation analysis, of the percentage occurrence of heavy mineral deposits (Harding, 1978, personal communication).

3.3 Potential Hazards

3.3.1 Seismicity/Earthquakes

More than 400 earthquakes have occurred in the vicinity of Charleston since 1954 (Bollinger, 1972) (Figure II-23). Colquhoun and Comer (1973) discovered a reverse fault in the area, trending along the axis of the Stono Arch (Figure II-27) which may be associated with this earthquake activity. Dillon (1974) reports possible faulting on the South Carolina shelf along the trend of seismic activity. This may be an extension of the offshore portion of the Stono Arch.

Several other papers are in press which consider various aspects of seismicity in the vicinity of Charleston (Bollinger, 1977; Gohn, Higgins, Smith and Owens, 1977; Kane, 1977; Popenoe and Zietz, 1977).

3.3.2 Sediment Movement/Properties

3.3.2.1 General

Visual observations by Hunt (1974) on Gray's Reef off central Georgia indicate that sediment transport zones extend well onto the continental shelf. Surficial sediments being at least in partial equilibrium with present environmental conditions indicate that sediment transport has occurred (Pilkey, 1977). Studies of wave physics (Stanley and Swift, 1976) indicate that wave-generated sediment transport may occur in depths of water as great as those of the outer continental shelf. As previously mentioned in Section 3.1.3 there exists a significant data gap in the area of deep water, wave-generated sediment transport because most predictions are based on mathematically derived equations rather than actual field observation. This topic needs further study because of the potential movement of sediments supporting platform foundations. Furthermore, patches of lagoonal muds and peats which occur on the shelf may represent areas of poor support capability, and slope sediments may be subject to slumping (U. S. Department of the Interior, Bureau of Land Management, 1977). Engineering studies should be conducted in these areas.

3.3.2.2 Storm-Related Conditions

An important data gap exists in the area of storm-related sediment transport. No physical data are available for Subzone II offshore areas during the passage of severe storms or hurricanes; however, the expected intensification of wind, wave and current vectors would probably increase sediment transport significantly. Several post-hurricane studies in other areas, particularly by Rodolfo, Buss and Pilkey (1971) off Cape Lookout, North Carolina suggest that hurricanes may well account for much of the sediment distribution pattern observed in the geologic record. A record of tracks of hurricanes affecting the Southeastern Atlantic of the U. S. is shown in Figure II-36. Extratropical storms such as "Northeasters" may be potentially more hazardous than hurricanes due to their frequency, longer duration and greater over-water fetch (Nash, 1978).

3.3.3 Drilling Hazards

3.3.3.1 Geopressures

No publications are available concerning geopressures in Subzone II. Because faulting is active in the vicinity of the Stono Arch (Zoback et al., 1978), significant geopressures may be encountered along its seaward extension. The lack of information on the presence, extent and magnitude of geopressures under the South Carolina, Georgia and North Florida shelf constitutes a significant data gap.

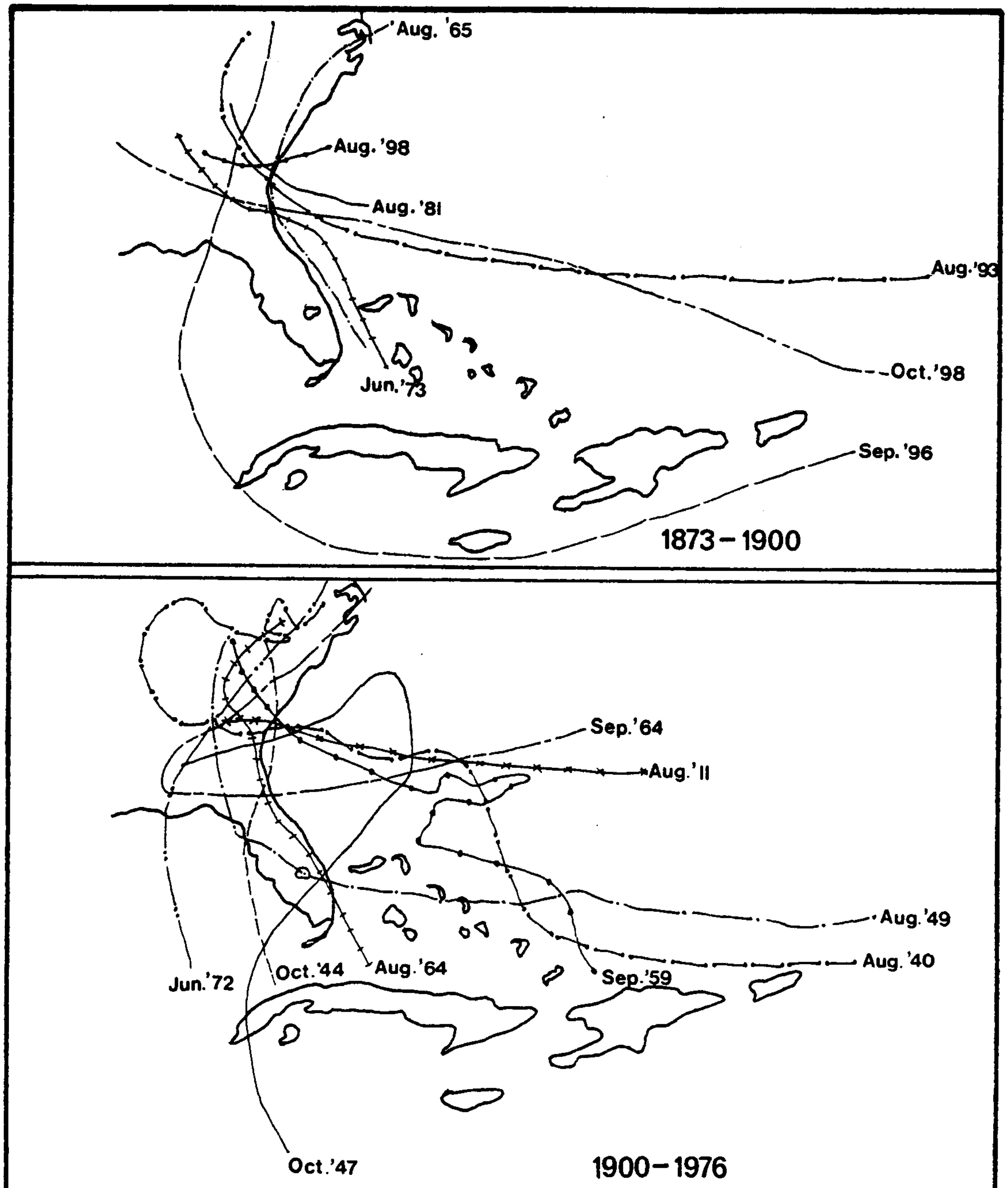


FIGURE II-36. Tracks of hurricanes affecting the Southeastern Atlantic Coast of the United States between 1873 and 1976. (From: Field and Duane, 1974).

3.3.3.2 Aquifer Contamination/Drawdown

The high chloride content of interstitial water from drill holes near the shelf edge off Georgia and South Carolina indicated the absence of a freshwater aquifer (Hathaway et al., 1976). Although the Floridan aquifer clearly extends onto the outer shelf off Jacksonville, Florida, the seaward extension to the north in Subzone II is probably greatly reduced (Dillon et al., 1975). A dàta gap does exist, however, in the present knowledge of the hydrogeologic framework beneath the continental shelf. Studies should be conducted to determine the presence of a significant aquifer as well as possible impacts of petroleum production.

3.3.4 Previous/Ongoing Research

A study has just been completed (Henry and Harding, 1978; Henry et al., 1979) concerned with geologic hazards of the Georgia coastal zone and inner continental shelf. A seismic/acoustic survey mapped potential surface and subsurface hazards on the inner continental shelf to 5km seaward. Scour, mobile bedforms, high-angle bedding, buried river channels, cut and fill structures and two possible faults were delineated.

4.0 CONTINENTAL SHELF-SUBZONE III--ST. JOHNS RIVER TO CAPE CANAVERAL

4.1 Description

4.1.1 Structures

4.1.1.1 Bottom

Organic

Rock outcrops supporting epifaunal communities of soft corals, sponges, sea fans and associated fauna have been observed between the 15-30 meter isobaths off Cape Canaveral (U. S. Department of Commerce, National Marine Fisheries Service, 1971). Dense epifaunal communities are also found on algal ledges along the outer shelf and upper slope (Macintyre and Milliman, 1970).

Inorganic Macro/Micro Topography

Few papers on inorganic bottom structures have been published since the summary by Zeigler and Patton (1974).

Field (1974), Field and Duane (1974), Meisburger and Field (1975), and Field and Duane (1976) have studied linear shoals and contrasting terraces or benches which extend 8km seaward of Cape Canaveral. These structures, thought to be Holocene marine transgressive features, resulted from erosion. The occurrence of sinkholes and numerous other karst features which are believed to occur on the continental shelf off Florida, only a few of which have been either charted or investigated , are the result of cavernous Tertiary limestones (Dillon et al., 1975). Kohout, Dill, Royal, Benjamin and Hill (1972) and Wilcove (1975) report a sinkhole believed to have a maximum depth of 142m located 42km off Crescent Beach, Florida in 27m of water.

4.1.1.2 Subbottom

Organic

Schlee (1977) and Buffler (1978, personal communication) infer the presence of buried reef structures located approximately beneath the shelf break off the Georgia and North Florida coast.

Inorganic

According to Meisburger and Field (1975) and Schlee (1977) some folding is present in this Subzone. A wide, shallow upwarp of Cretaceous strata with reefs built on tectonic highs underlies the middle of the continental shelf seaward off Jacksonville, Florida (Dillon et al., 1975; Schlee, 1977). Meisburger and Field (1976) report a wide truncated anticline of Miocene age off Daytona Beach, Florida, cores from which show dip reversal in rocks as old as late Eocene (Field, 1974). Buried strandline deposits, thought to be submerged Pleistocene shorelines, have been found in this Subzone (Field, 1974; Field and Duane, 1976).

4.1.1.3 Previous/Ongoing Research

No research has been reported in progress for the purpose of locating or describing bottom or subbottom structures in Subzone III.

4.1.2 Stratigraphy

Field and Duane (1974), Dillon et al. (1975), and Schlee (1977) have discussed in detail the generally carbonate stratigraphic section from cores collected from the three JOIDES holes drilled seaward off Jacksonville, Florida. Vertical variations in lithology in which carbonates are overlain by fine-grain terrigenous clastics suggest changes in paleogeography which allowed deposition of volcanic ash and terrigenous detritus. Lateral changes from well-sorted grainstone on the inner shelf to carbonate muckstone and wackystone on the outer continental shelf suggest a change in the site of deposition from a platform or shallow shelf to outer shelf or upper slope (Schlee, 1977).

4.1.2.1 Geologic History

Schlee (1977) covers the Tertiary history in great detail. Sedimentation rates in the Cretaceous and Tertiary equalled regional subsidence. During the Tertiary the carbonate platform of the continental shelf was periodically exposed while carbonate ooze accumulated on the Florida-Hatteras Slope (Schlee, 1977). The Pleistocene history of Subzone III was discussed by Field (1974), Dillon et al. (1975), Meisburger and Field (1975), Field and Duane (1976), and Schlee (1977). The Pleistocene was a period of regressive deposition and evidence exists that much of the Pleistocene morphology was removed by the truncating or beveling action of the Holocene regression.

4.1.2.2 Previous/Ongoing Research

No current research was reported concerning either geologic history or stratigraphy for Subzone III.

4.1.3 Sediments and Sedimentary Processes

4.1.3.1 Sediment Distribution

Sediment distribution in Subzone III was discussed by Zeigler and Patton (1974) and Dillon et al. (1975). No papers concerned with sediment distribution in this area have been subsequently published.

4.1.3.2 Sedimentary Processes

The sand which mantles the shelf is actively being resorted and redistributed (Meisburger and Field, 1975). Most of the surficial sediment is believed to have been derived from erosion of Tertiary strata and Pleistocene deposits during the Holocene transgression. Fine-grain sand on the inner continental shelf is believed to be derived from the winnowing and landward transport of the fine fraction of Holocene transgressive sands. Field and Duane (1974) found that sediments are being reworked on the shoals and that shoals are moving toward the southeast.

4.1.3.3 Previous/Ongoing Research

No research was reported which was concerned with either sediment distribution or sedimentary processes in Subzone III.

4.1.4 Bathymetry

Meisburger and Field (1975) show continuous shelf profiles and the generalized bathymetry of the shelf off North Florida and together with the SCOPE report (see Sections 1.2.3 and 3.1.4) constitute the published information since 1974 concerning Subzone III bathymetry.

4.1.4.1 Physiography

Other than the report of Field and Duane (1974) and Meisburger and Field (1975) no papers have been published concerning the physiography of Subzone III since 1974.

4.2 Economics

4.2.1 Petroleum

According to Dillon et al. (1975), the Jurassic beds off the Florida coast are potential reservoir rocks and together with the Lower Cretaceous carbonates described earlier offer the best chance of hydrocarbon discovery in this Subzone. Controversy regarding the petroleum potential of the buried reefs beneath the lower slope off Florida's coast indicate the need for more investigation in this area (Dillon et al., 1975; U. S. Department of Interior, Bureau of Land Management, 1977). JOIDES drilling data show no prospect of oil or gas in Tertiary deposits (Dillon et al., 1975; Schlee, 1977).

4.2.2 Sand and Gravel

Meisburger and Field (1975) carried out an extensive study of sediments off the coast of Florida. They conclude that there are excellent sources of beach fill in Holocene shelf sands.

4.2.3 Aquifers

The Floridan aquifer extends beneath the continental shelf and is of major economic importance to the area (Pearman and Stafford, 1975). Kohout (1965,1966) and Henry and Kohout (1972) suggest that the lower parts of the aquifer may be open to slow movement of seawater circulated by geothermal heating. This potential energy source has not been investigated.

4.2.4 Geothermal

There is no known geothermal information for this Subzone.

4.2.5 Heavy Minerals

No papers concerned with economic heavy mineral deposits on the continental shelf in Subzone III have been published since the compilation by Zeigler and Patton (1974).

4.2.6 Phosphate

Dillon et al. (1975) and Schlee (1977) have reported the occurrence of Tertiary phosphate deposits on the continental shelf. No research has been done on their economic potential.

4.2.7 Other

No other geologically related products of economic importance have been reported in Subzone III.

4.2.8 Previous/Ongoing Research

No unpublished or ongoing research was reported with respect to economic geology in Subzone III.

4.3 Potential Hazards

4.3.1 Seismicity/Earthquakes

No data exist with respect to earthquake activity in Subzone III.

4.3.2 Sediment Movement/Properties

4.3.2.1 General

Sediment movement is a possible problem for platforms constructed on the shelf (Field and Duane, 1974; U. S. Department of Interior, Bureau of Land Management, 1977). As mentioned earlier, there is substantial evidence for shoal movement (Field and Duane, 1974; Field, 1974; U. S. Department of Interior, Bureau of Land Management, 1977).

4.3.2.2 Storm-Related Conditions

No data exist for Subzone III with respect to sediment movement under storm-related conditions. This constitutes a significant data gap.

4.3.3 Drilling Hazards

4.3.3.1 Geopressures

Nothing is known with regard to geopressures on the continental shelf of Subzone III.

4.3.3.2 Aquifer Contamination/Drawdown

The Ocala limestone, the principal aquifer in Florida, is cavernous throughout this Subzone (Dillon et al., 1975). While near surface karst features are detectable, deep caves are not and could cause serious problems with regard to both rig safety and aquifer contamination.

4.3.3.3 Previous/Ongoing Research

No research has been reported with respect to potential hazards.

5.0 BLAKE PLATEAU

5.1 Description

5.1.1 Structures

5.1.1.1 Bottom

Organic

Subsequent to the literature cited by Zeigler and Patton (1974) no papers which discuss organic bottom structures have been published. Prior to that report, Stetson, Squires and Pratt (1962) reported coral mounds and ridges with more than 100 meters relief. Organic ridges and mounds, according to Milliman, Manheim, Pratt and Zarudzki (1967) are numerous beneath the present axis of the Gulf Stream. Deep water coral mounds are active at present (Stetson et al., 1962).

A data gap exists with respect to occurrence and distribution of organic bottom structures on the Blake Plateau.

Inorganic Macro/Micro Topography

Pratt and Heezen (1964), Ewing et al. (1966), and Stetson, Uchupi and Milliman (1969) reported portions of the Plateau as very rough as a result of erosion. Pratt (1971) describes Eastward Canyon, about 65km long with a maximum depth of 500m, along the north side of Blake Nose (Figure II-37).

At present the microtopography of this area is poorly known. More detailed studies are needed such as that carried out by Lonsdale and Spiess (1977) on the Blake Outer Ridge using a deep towed

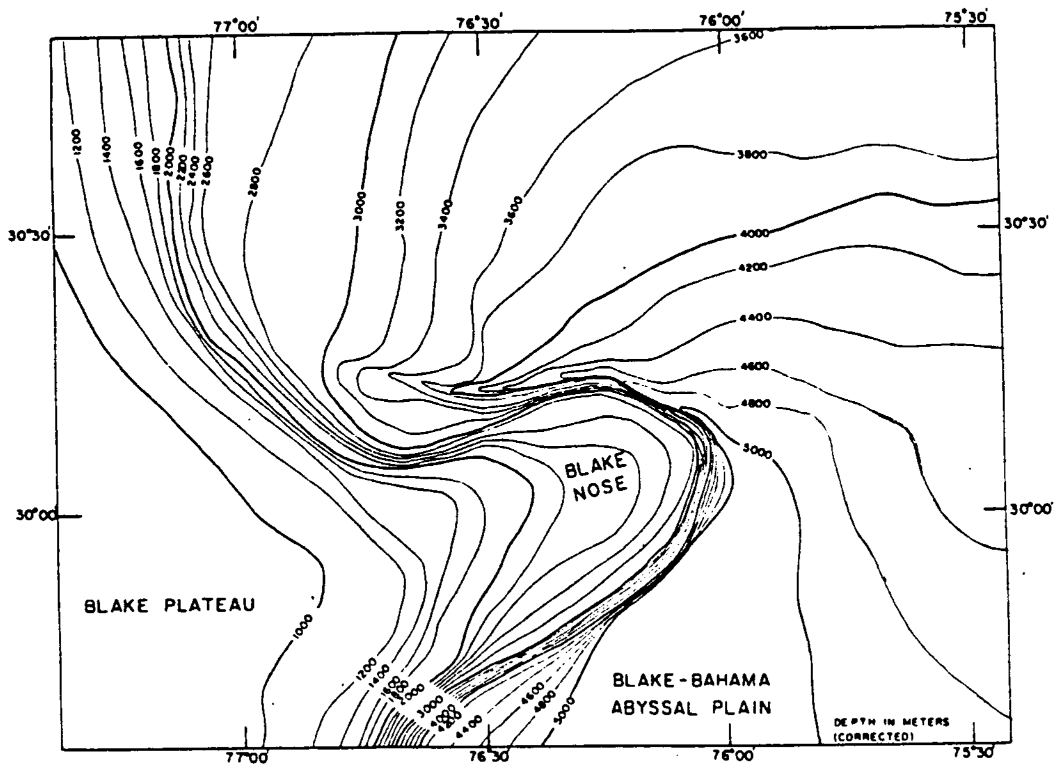


FIGURE II-37. Detailed bathymetry in the Blake Nose-Eastward Canyon area. (From Pratt, 1971) instrument package.

5.1.1.2 Subbottom

Organic

Most information on buried organic structures predate the compilation by Zeigler and Patton (1974). Zarudzki and Uchupi (1968) report a carbonate ridge system on the western side of the Plateau buried by up to 100m of sediment. Buffler, Watkins and Dillon (1978) discuss an irregular reflecting surface which may represent a buried reef on a carbonate bank or buried karst topography.

Inorganic

High resolution and multichannel seismic reflection profiles have been recently collected (Edsall, 1977; Buffler, Watkins and Dillon, 1978 and McGregor, 1978). Edsall (1977) reports up to 375m acoustic penetration, but no buried structures other than stream channels were detected. Sylwester and Dillon (1977) discovered a major growth fault, the largest known to offset Tertiary sediments on the Atlantic coast, on the eastern edge of the Blake Plateau about 175km southeast of Cape Fear. Minor folding, faulting, slumping and differential compaction occurs in the upper 350m of sediment. McGregor (1978) reported many unconformities with one in late Tertiary truncating an extensive sequence of foreset beds on the north end of the Blake Plateau.

5.1.1.3 Previous/Ongoing Research

Articles recently published or in press concerning the structure of the Blake Plateau have been reported by Dillon et al. (1978), Buffler et al. (1978), Buffler, Shipley and Watkins (in press), and Shipley et al. (1978).

Bryan (1978, personal communication) reports multichannel seismic records now being processed, which tie together wells drilled near the southern boundary of the Plateau (Figure II-38), as well as ongoing research.

Neumann (1978, personal communication) has raw data, unpublished reports and ongoing research programs in the Little Bahama Bank/Blake Plateau transition zone. Also, he reports work in progress by Mullins (Ph.D. dissertation) which will contain seismic profiles and core descriptions of the north margin of Little Bahama Bank.

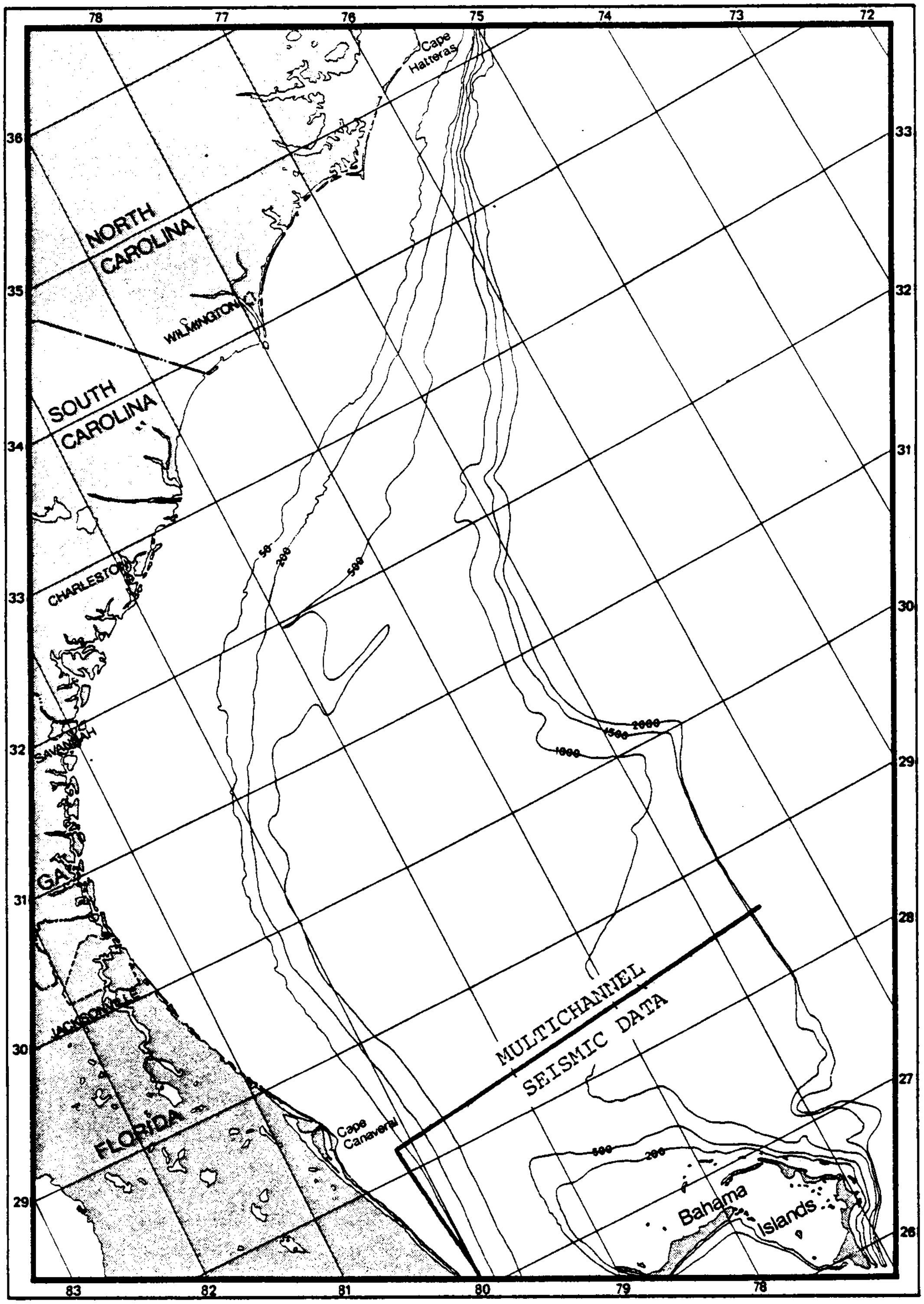


FIGURE II-38. Lines along which multichannel seismic profiles were run which tie together wells drilled near the southern boundary of the Blake Plateau. (From Lamont-Doherty Geological Observatory of Columbia University, Cruise Report No. 21-02, R/V ROBERT D. CONRAD, personal communication from Bryan, 1978)

5.1.2 Stratigraphy

Edsall (1977) reports that the surface of the Plateau is Miocene, perhaps buried under a thin surficial cover of Holocene sediment. Shipley, Buffler and Worzel (1976) and Buffler, Watkins and Dillon (1976) discuss the seismic stratigraphy of the area. They subdivide it into Lower to Upper Cretaceous, Upper Cretaceous and Cenozoic intervals. The first interval, thought to be Early through middle Lower Cretaceous, is probably a carbonate facies along the inner platform and may consist in part of interbedded dolomite and evaporite. The Upper Cretaceous interval, thought to be of a Late Cretaceous age, is probably mostly carbonate, but may also contain progressively more terrigenous clastic components to the northwest. Several depositional sequences are found in the Cenozoic interval, lower Tertiary to Miocene in age, but no attempt was made to map them in the preliminary study. The rocks are mostly carbonates, although terrigenous clastics increase in the younger sediments, and toward the north. Schlee (1977) summarized the data from three holes drilled on the Blake Plateau (Figure II-39). He reports that a sequence of deep water calcareous oozes gives way at depth to siliceous limestone and chert.

Abbott (1978) proposed six Atlantic Miocene siliceous microfossil zones which range from Early to Middle Miocene. As these zones have been correlated with Deep Sea Drilling Project (DSDP) core 391A in the Blake-Bahama Basin, they may be applicable to the Miocene sediments on the Plateau.

5.1.2.1 Geologic History

Shipley et al. (1976) discussed the geologic history of the Blake Plateau. A summary by Buffler et al. (1978) indicates that in Early to middle Late Cretaceous, 135-80 million years ago, a broad carbonate platform became established across the Plateau. During Late Cretaceous, 80-65 million years ago, a continued rise in sealevel displacement of Gulf Stream-like currents caused the shelf margin to shift from the Blake Escarpment to approximately its present location. Uniform, fine-grained, mostly carbonate, sediments from the shelf prograded onto the inner Plateau. During the Cenozoic, 65 million years ago to present, the continental slope continued to prograde over the Plateau. Deposition of sediments, mostly fine-grained and carbonates, continued with numerous periods of erosion or nondeposition resulting from changes in sealevel and bottom currents.

According to Schlee (1977) Tertiary bottom currents apparently fluctuated widely. At times they were weak enough to permit thin ash beds to be deposited and at times strong enough to winnow and sort fine detritus and erode previously deposited carbonate mud.

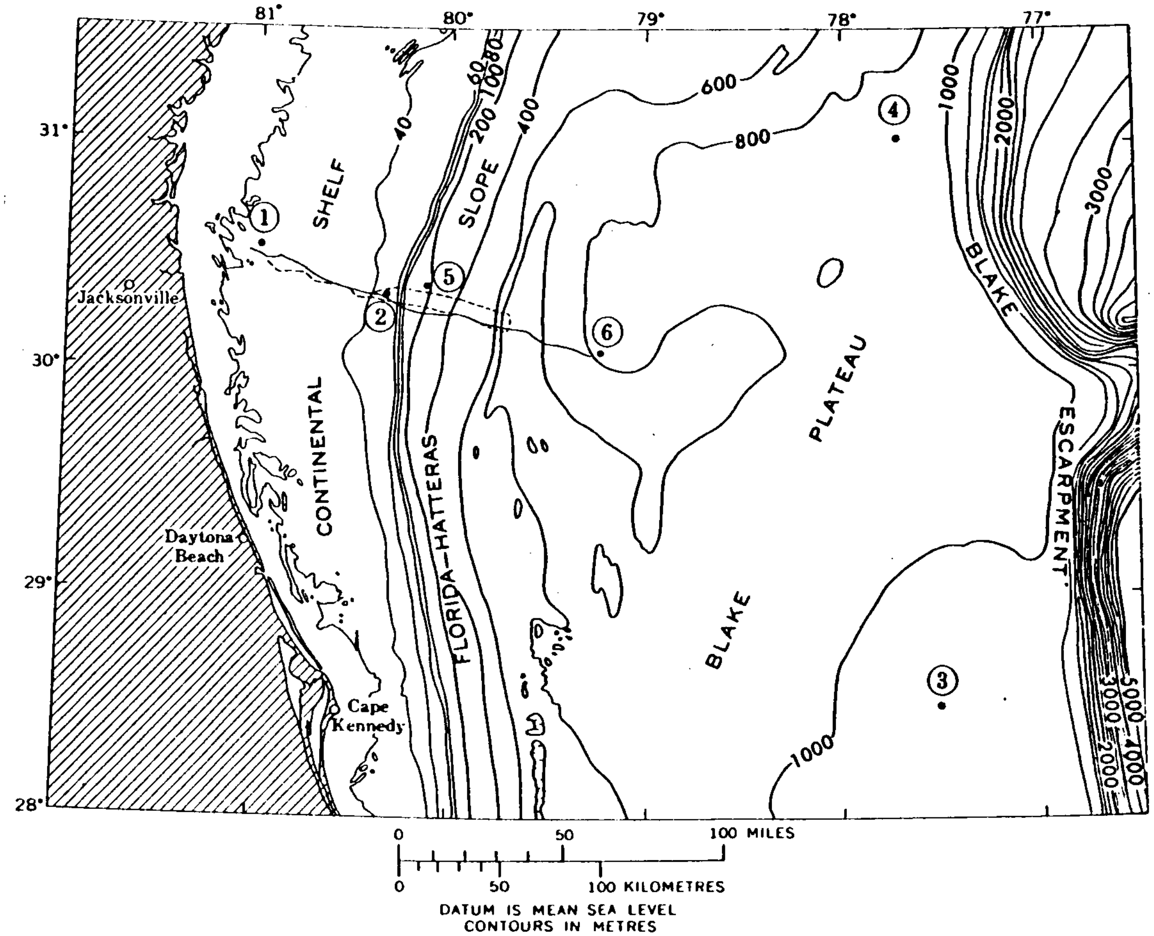


FIGURE II-39. Index map of continental margin off eastern Florida. Numbers 1-6 show the position of Joint Oceanographic Institutions' Deep Earth Sampling Program (JOIDES) drill sites. (From Schlee, 1977).

5.1.2.2 Previous/Ongoing Research

Several papers are in press at present which will discuss various aspects of stratigraphy and geologic history of the Blake Plateau (see Section 5.1.1.3).

5.1.3 Sediments and Sedimentary Processes

5.1.3.1 Sediment Distribution

Little is known about sedimentation on the Blake Plateau. Emiliani, Gartner and Lidz (1972) discussed sedimentation based on piston core P6603-49, a 9.6m core from the eastern edge of the Plateau. A characteristic Globigerina-ooze texture is found in the bottom 1.76m, lacking, however, the typical clayey constituents. From - 7.50m to the top of the core it appears that sediment starvation and sorting increased, with a notable decrease in the finer than sand fraction. Hathaway, McFarlin and Ross (1970) found the same lack of fine sediment in the post-Miocene upper section in the JOIDES cores from this area.

Over most of the Plateau, the lack of information concerning the surface sediment distribution with respect to size and composition is a significant data gap.

5.1.3.2 Sedimentary Processes

The lack of data concerning sedimentary processes on the Blake Plateau since the book by Heezen and Hollister (1971) represent a significant data gap. However, McGregor (1978) reports that the shelf width and the pattern of erosion and deposition on the Blake Plateau is controlled by the Gulf Stream.

5.1.3.3 Previous/Ongoing Research

No work has been reported since 1973 concerning either sediment distribution or sedimentary processes on the Blake Plateau.

5.1.4 Bathymetry

No reports have been published on Blake Plateau bathymetry since that compiled by Zeigler and Patton (1974).

5.1.4.1 Physiography

Regional physiography of the Plateau was discussed in Section 1.4.3. No papers have appeard since those compiled by Zeigler and Patton (1974).

5.1.4.2 Previous/Ongoing Research

No report of bathymetric or physiographic studies are reported in progress on the Blake Plateau.

5.2 Economic

5.2.1 Petroleum

Based on seismic data Sheridan (1977) reports 7 to 14km of carbonate rocks on the Blake Plateau. Ridgelike reflectors along the Blake Escarpment have been shown by drilling data to be Cretaceous reef-rim complexes. Thickness and composition of the sediments seem favorable to petroleum production.

Structurally, the Blake Plateau also may be favorable to petroleum accumulation. Ewing et al. (1966) report an arch trending north-south in the northern end of the Plateau. Other subsurface arches (Olson, 1974), possibly basement horsts related to block faulting, are indicated. The Blake Plateau trough (Figure II-40) offers promise of petroleum because of a thick sedimentary section with excellent source beds and trapping possibilities (Olson and Glowacz, 1977). Olson (1974) compares this area to similar oil producing areas. He concludes that the main obstacle is the 1000m water depth.

5.2.2 Geothermal

A literature search revealed no papers on this subject.

5.2.3 Phosphate

Pratt and McFarlin (1966) report a zone of phosphate on the western margin of the Plateau (Figure II-41). Hawkins (1968, 1969) mentions phosphate but does not discuss the economic potential of the deposit.

5.2.4 Manganese

Pratt and McFarlin (1966), Hawkins (1968, 1969), Brundage (1972), Manheim (1972a), and Fewkes (1976) report the presence of a pavement of manganese nodules on portions of the Blake Plateau (Figures II-41 and II-42). Manganese is reported as abundant at the surface over very large areas; however, its potential economic value is not discussed.

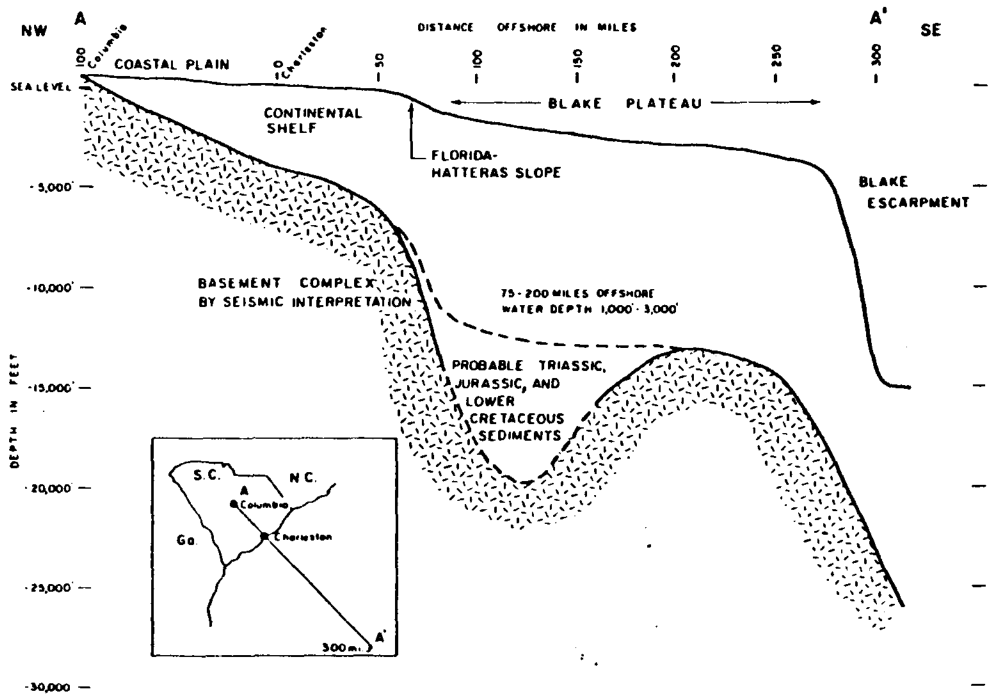


FIGURE II-40. Idealized cross section through Columbia and Charleston toward Blake Escarpment. (From Olson and Glowacz, 1977)

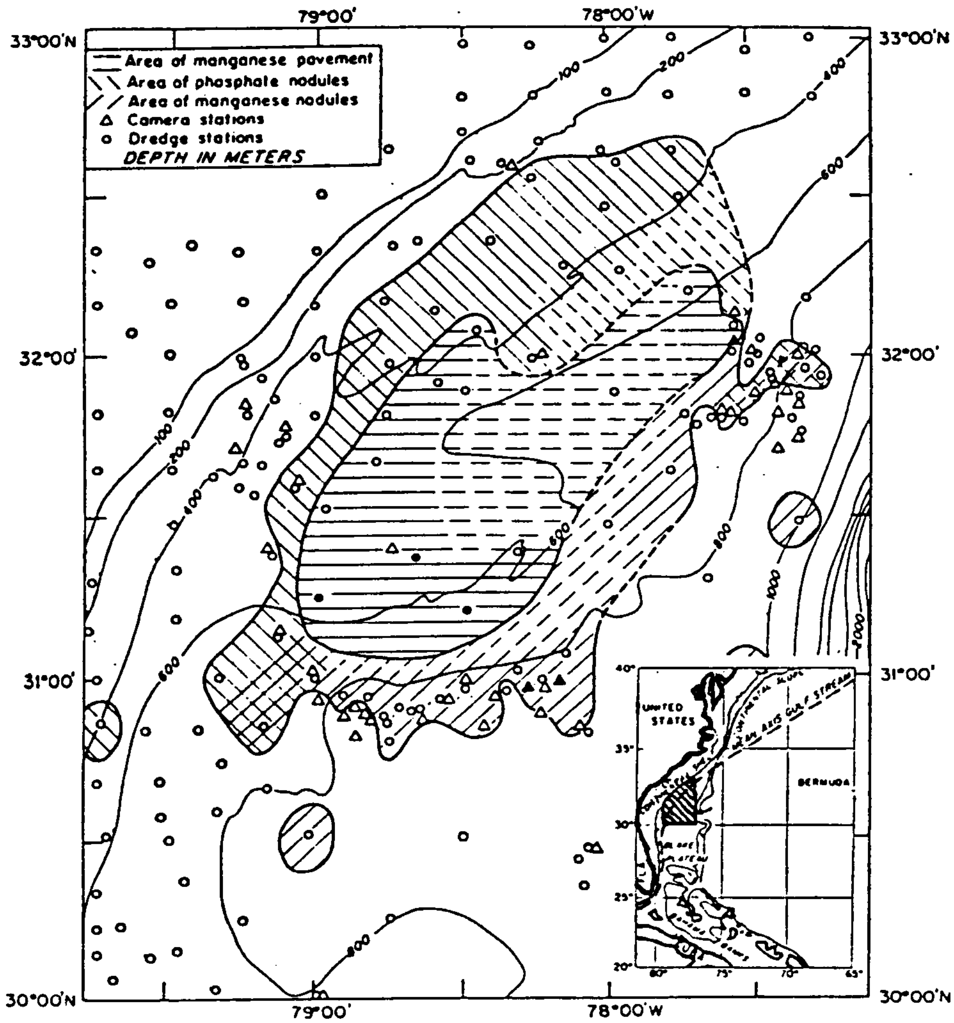


FIGURE II-41. Location of manganese pavement on the Blake Plateau. (From Pratt and McFarlin, 1966)

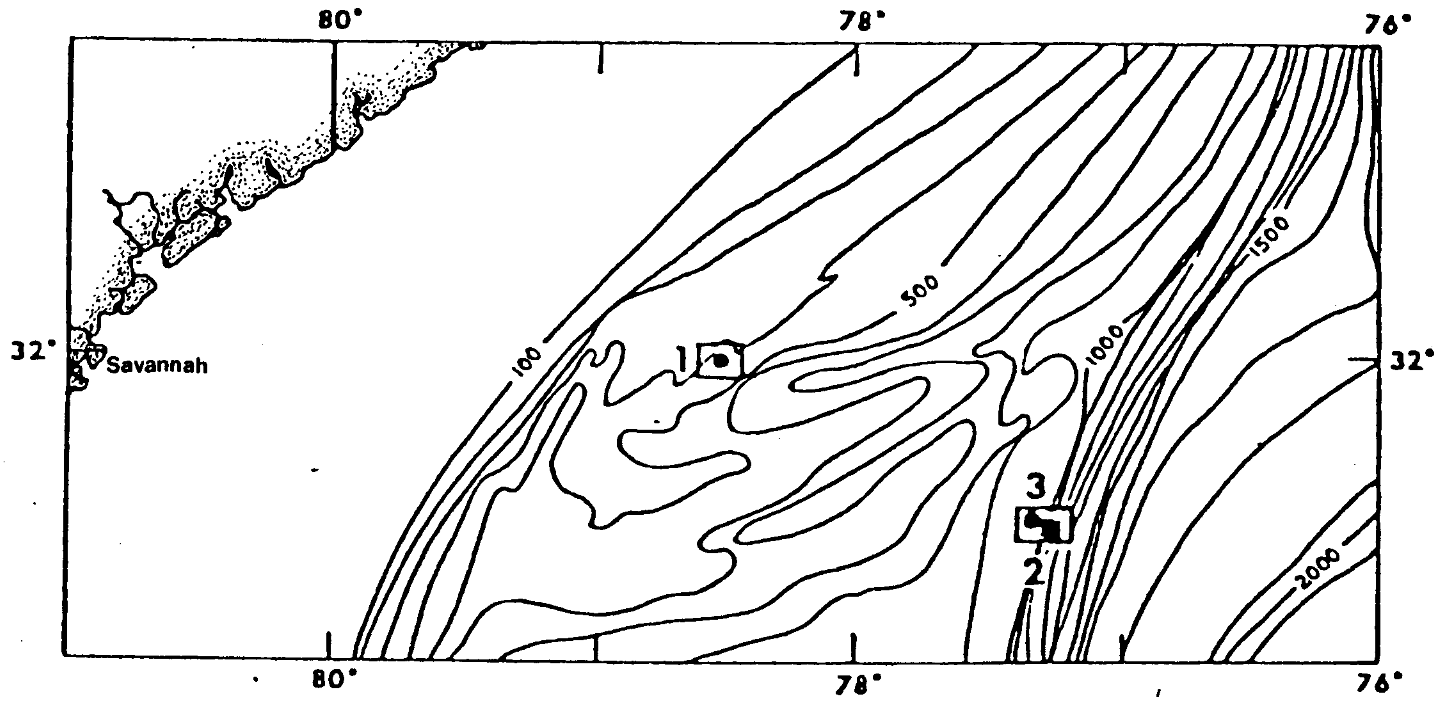


FIGURE II-42. Location of manned submersible dives on the Blake Plateau. (From Hawkins, 1969).

5.2.5 Other

No other sources of possible economic value on the Blake Plateau have been reported.

5.2.6 Previous/Ongoing Research

No previous or ongoing research with respect to any resource other than petroleum was reported.

5.3 Potential Hazards

5.3.1 Seismicity/Earthquakes

Earthquake activity in the Blake Plateau area has not been reported in the literature.

5.3.2 Sediment Movement/Properties

5.3.2.1 General

Vigorous erosion by the Gulf Stream on the inner margin of the Blake Plateau can affect the support characteristics of structures directly as well as through movement of bottom sediments (Edsall, 1977).

5.3.2.2 Storm-Related Conditions

Slumping along the Florida-Hatteras slope under storm-related conditions could affect the upper portion of the Blake Plateau; however, little information is available in this regard.

5.3.3 Drilling Hazards

5.3.3.1 Geopressures

Nothing is known with respect to geopressures on the Blake Plateau, as there is no previous drilling history (U. S. Department of Interior, Bureau of Land Management, 1977).

5.3.3.2 Aquifer Contamination/Drawdown

A literature search found no information with respect to aquifers in this area.

5.3.3.3 Previous/Ongoing Research

No studies were reported which were concerned with either previous or ongoing hazards research.

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III. CHEMISTRY

Dr. Herbert L. Windom
Dr. Richard F. Lee
Dr. Larry P. Atkinson

Skidaway Institute of Oceanography
Savannah, Georgia

1.0 INTRODUCTION

1.1 Organization of the Chapter

This chapter is separated into sections which address the chemistry of the water column, sediments, biota and atmosphere. Each of these are in turn divided into subsections which treat hydrocarbons, trace elements, nutrients, chlorinated hydrocarbons and radionuclides. In each of the subsections a review of the research conducted between Cape Hatteras, North Carolina and Cape Canaveral, Florida since about 1973 is presented. This generally summarizes work accomplished since the review of Roberts (1974); in some cases, work conducted prior to that review, but not included in it, is included here. If applicable, the last paragraph of each subsection describes ongoing programs and locations of raw data or unworked samples relating to the particular subject.

Dr. Richard F. Lee wrote subsections dealing with hydrocarbons and chlorinated hydrocarbons, and Dr. Larry P. Atkinson wrote subsections dealing with nutrients. Dr. Herbert L. Windom was responsible for the remainder of this report.

1.2 Introduction to Subsections

1.2.1 Hydrocarbons

Hydrocarbons in the environment are derived from a variety of sources, both anthropogenic and natural. The thousands of hydrocarbons found in fossil fuels and their products makes it difficult to completely analyze environmental samples for anthropogenic hydrocarbons. In addition, a variety of hydrocarbons are biosynthesized by marine plants and animals. Before detailed analysis, the hydrocarbon fraction can be separated into aliphatics and aromatics with a focus on aromatics because of their toxicity and association with fossil fuels or their products. The various methods for hydrocarbon analysis, using gas-liquid chromatography, infrared spectroscopy, ultra-violet spectroscopy and liquid chromatography, measure different classes of hydrocarbons. This results in making it difficult to compare results from various areas where different methods have been used. Special note should be made of "oil and grease" measurements which involve solvent extraction of an environmental sample. This method measures a variety of lipids in addition to hydrocarbons and is probably of little use for hydrocarbon determinations, except in an area polluted only with petroleum.

1.2.2 Trace Metals

Prior to the review of Roberts (1974) most of the published trace metal research conducted in the area between Cape Hatteras, North Carolina and Cape Canaveral, Florida was of a descriptive nature. Since that time a considerable amount of additional work has been carried out. Much of this has also been descriptive, consisting of trace metal analyses of various compartments of the estuarine and coastal marine ecosystem. Recent studies have also addressed the transfer of trace metals through these compartments and have included laboratory experiments as well as field investigations. This review attempts to summarize not only the data resulting from these studies but also the conclusions as to processes and pathways influencing trace metal variations.

1.2.3 Nutrients

The following sources were searched for relevant information on the nutrient chemistry of the waters of the South Atlantic Bight.

- Limnology and Oceanography (1973-present)
- Deep-Sea Research and Oceanographic Abstracts (1973-present)
- Journal of Geophysical Research (1973-present)
- Geophysical Research Letters (1975-present)
- Southeast Geology (1973-present)
- U. S. Government Research and Development Reports (1973-present)
- Oceanic Abstracts (1973-present)
- Personal files of L. Atkinson

Some obscure technical reports may have been missed in our search, but it is doubtful if they detract much from the report. As expected, much of the data are in technical report form or abstracts.

The notable advances in the last few years are in three areas: 1) nutrient flux experiments in South Carolina salt marshes by Gardner and associates at the University of South Carolina; 2) wide area quasi-synoptic, hydrographic sampling by Mathews and co-workers (South Carolina Wildlife and Marine Resources Department); and 3) the studies by Atkinson and associates (Skidaway Institute) in Onslow Bay, North Carolina and the Georgia Bight. Other studies have tended to be of limited scope and hence not useful for the purpose of this report. There has been a large study by the Coast Guard (Search and Rescue cruises) which is in raw data form and will not be discussed. Also, Texas Instruments, Inc., under BLM contract, has made seasonal sampling cruises in the Bight. These data are not available at this time.

1.2.4 Chlorinated Hydrocarbons (Pesticides)

With the exception of chlorinated hydrocarbons all of the chemical species considered in this review are natural substances. Their distributions and concentrations in the environment may be influenced by man, but unlike the pesticides, they are not produced by man.

The chlorinated hydrocarbons discussed in this review include the insecticide DDT and its degradation products DDD and DDE, PCBs (polychlorinated biphenyls) and other less well known compounds.

Although DDT and PCB uses have been severely restricted in the U. S. since 1972, they and their by-products still are present in the environment. Most of the attention has been paid to DDT and PCBs, but other chlorinated hydrocarbons have been shown to be equally dangerous to the environment.

1.2.5 Radionuclides

The Savannah River watershed currently contains three operating production reactors, two chemical nuclear fuel reprocessing plants, and the nuclear fuel fabrication facilities of the Department of Energy's Savannah River Plant site. Duke Power Company operates three power reactors at Oconee, South Carolina. The Georgia Power Company is planning two reactors at its Vogtle site across the river from the Savannah River Plant, and a commercial nuclear fuel reprocessing plant is located on the east side of the Savannah River Plant. Releases of radionuclides from currently operating facilities are well below any applicable standards, but, nevertheless, some nuclides are detectable in the Savannah River estuarine area. Charleston, South Carolina is the home of a nuclear submarine base and a Trident base is being planned for Kings Bay, Georgia.

As will be evident from this review, the amount of information on radionuclide distributions in the southeastern Atlantic coastal environment is not extensive when compared to the increasing potential sources of these substances. The lag is due to the lack of scientists with appropriate expertise to conduct the required studies in this region.

2.0 SUMMARY OF RESEARCH SINCE 1973

2.1 Water Column

2.2.1 Hydrocarbons in the Water Column

2.1.1.1 Rivers and Estuaries

Only a few determinations have been made on hydrocarbons in inshore waters of the southeastern United States. In the Skidaway River, an estuarine river near Savannah, Georgia, total hydrocarbon concentrations varied from 10 to 60 μg/liter (Lee and Ryan, 1976). Naphthalene, 1-methylnaphthalene and 2-methylnaphthalene were not detected (less than 0.5 μg/liter). Hexadecane varied from 0.5 to 3 μg/ liter. Benzene and toluene varied from nondetectable to 3 μg/liter. Large concentrations of hydrocarbons would not be expected since there are few highly populated or industralized areas along this coast. No natural oil seeps have been reported for this area (Wilson, Managhan, Osanik, Price and Rogers, 1974). The largest coastal cities are Brunswick (20,000 population), Charleston (100,000), Jacksonville (600,000), Savannah (100,000), and Wilmington (50,000). A number of oil storage tanks are along the Cooper River in Charleston. Oil slicks are often seen on this river and surface water samples near oil tanks had hydrocarbon concentrations from 400 to 1100 μg/liter with a mean of 900 μg/liter (Lee, 1977). Gas-liquid chromatograms of extracts from this water were similar to those of fuel oil with a series of paraffin peaks superimposed on an unresolved envelope. Nearby sites showed no visible slicks and had concentrations of non-volatile hydrocarbons ranging from 40 to 100 μg/liter with a mean of 70 μg/liter.

A series of measurements giving the concentration of "oil" in coastal waters of South Carolina have been carried out by the U. S. Geological Survey of South Carolina (Harris, 1978, personal communication).

2.1.1.2 Continental Shelf

Few studies have been conducted on hydrocarbons in marine waters between Cape Hatteras and Cape Canaveral. Data on hydrocarbons in the water column presented in the report of the National Academy of Sciences (NAS, 1975) show no collections from this region.

Swinnerton and Lamontagne (1974) have reported concentrations of low-molecular weight hydrocarbons in ocean surface waters off the southeastern United States. Average concentrations in nanoliters per liter for these hydrocarbons were: methane, 45; ethane, 1.0;

ethlene, 4.7; propane, 0.1; propylene, 0.5. The vertical distribution of ethane and ethylene at 30°N is shown in Figure III-1.

Brown and Huffman (1976) and Brown, Searl, Elliott, Brandon and Monaghan (1973) reported hydrocarbon concentrations in surface waters of this region to range from 5 to 17 μg/liter (Figure III-2) and near-surface samples ranged from 1 to 3 μg/liter (Figure III-3). The paraffinic hydrocarbons comprised most of the hydrocarbon fraction with less than 10 percent aromatics (Figures III-4,5).

Levy (1977) has reported on tar distribution in the North Atlantic (Figures III-6,7). In the southeastern waters of the U. S., tar concentrations were between 0.1 to 0.01 mg/m^2. He proposed that the source of this tar was from tanker traffic going from Venezuela and the Middle East to North America and Europe. Losses during transportation of this oil found their way into the Gulf Stream system and thus were carried along the waters of the continental shelf.

Warner (1978) has analyzed hydrocarbons in this OCS region under contract to the Bureau of Land Management. Concentrations of dissolved hydrocarbons were between 0.005 to 0.1 μg/liter.

2.1.2 Trace Metals in the Water Column

In the review by Roberts (1974) very few studies of trace metals in coastal and estuarine waters were referenced. Since that time several research efforts have resulted in a considerable increase in the available data. The following sections review the research since about 1973 which was not treated in the earlier review.

2.1.2.1 Rivers and Estuaries

The concentration of iron, manganese, cadmium, copper, and mercury in solution and in particulate phases in rivers was determined by Windom (1975b). He used these values along with the discharge rates for the nine rivers studied to estimate transport to the estuarine zone. Due to chemical processes in the estuaries some metals such as iron are apparently not transported through the estuarine zone. This is reflected in their concentration variation with salinity (Figure III-8).

Recently the concentration of mercury in southeastern rivers was reevaluated. Studying the ten major rivers emptying into the coastal area between Cape Hatteras, North Carolina and Cape Canaveral, Florida (Figure III-9), Windom and Taylor (1978) found

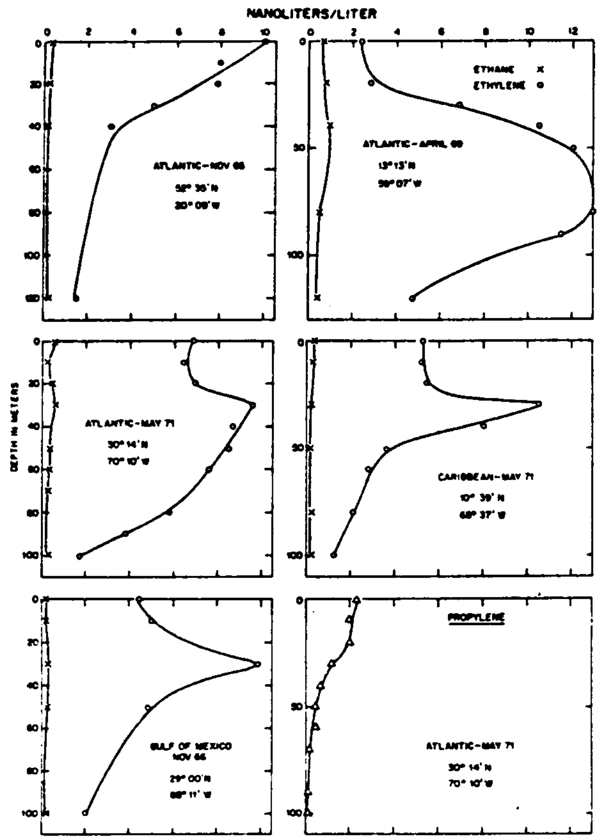


FIGURE III-1. Vertical distribution of ethane (X), ethylene (O), and propylene (Δ) in the North Atlantic, Gulf of Mexico, and Caribbean Sea. From Swinnerton and Lamontagne (1974).

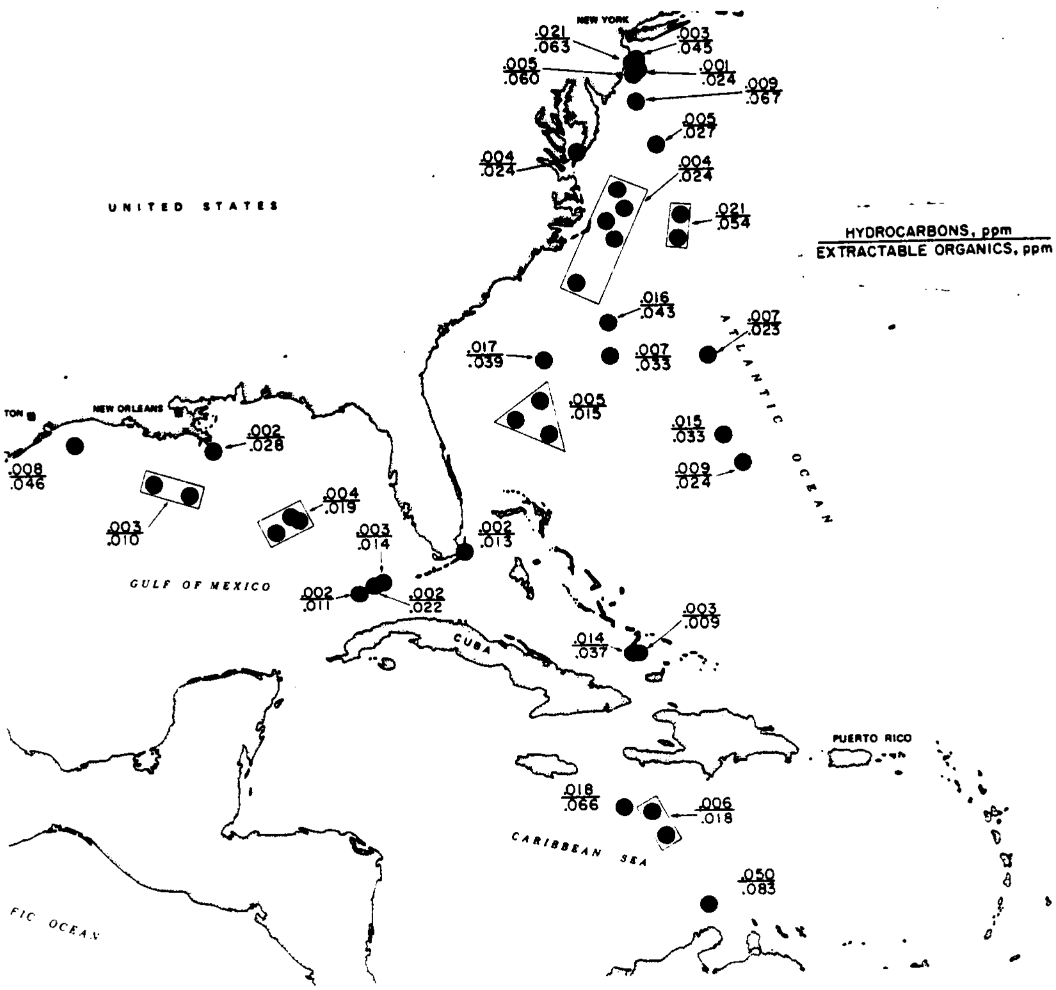


FIGURE III-2. Total hydrocarbons in surface water samples. From Brown et al. (1973).

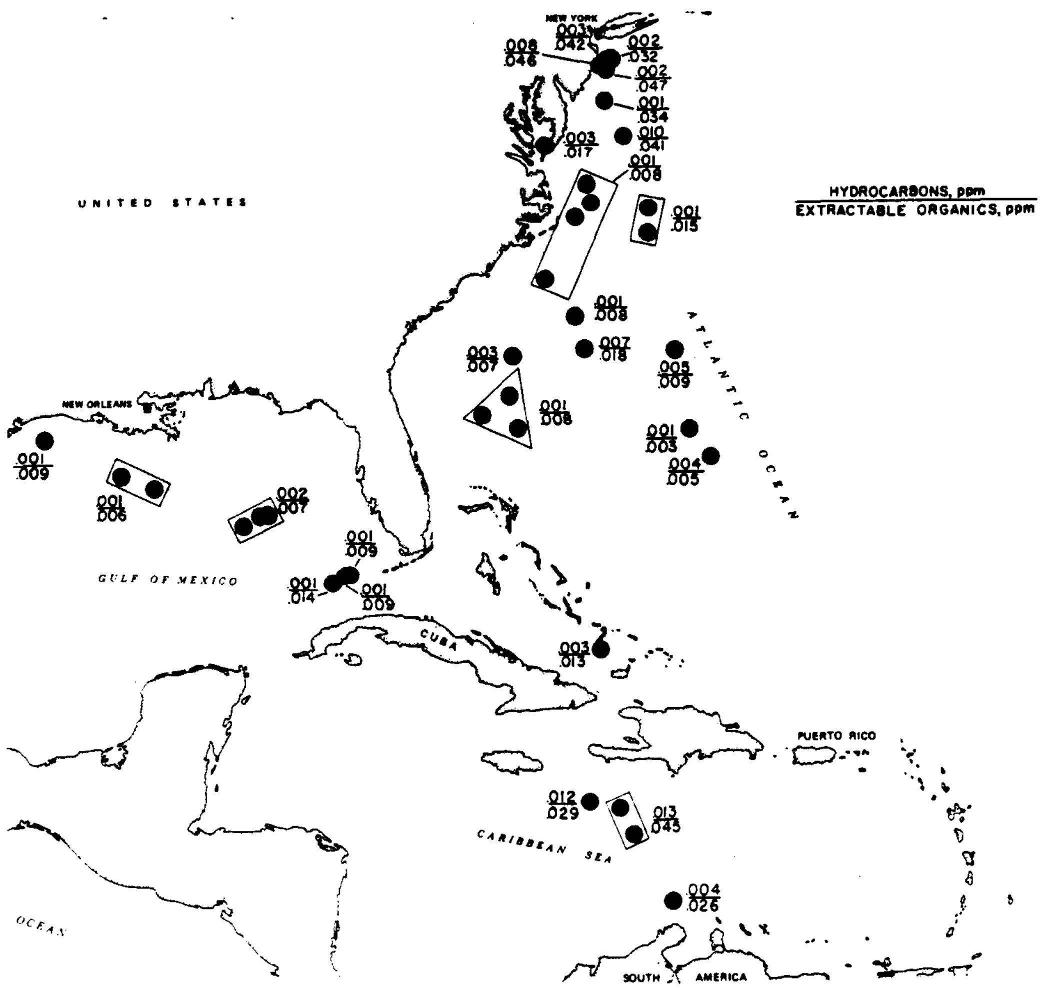


FIGURE III-3. Total hydrocarbons in near-surface water samples. From Brown et al. (1973).

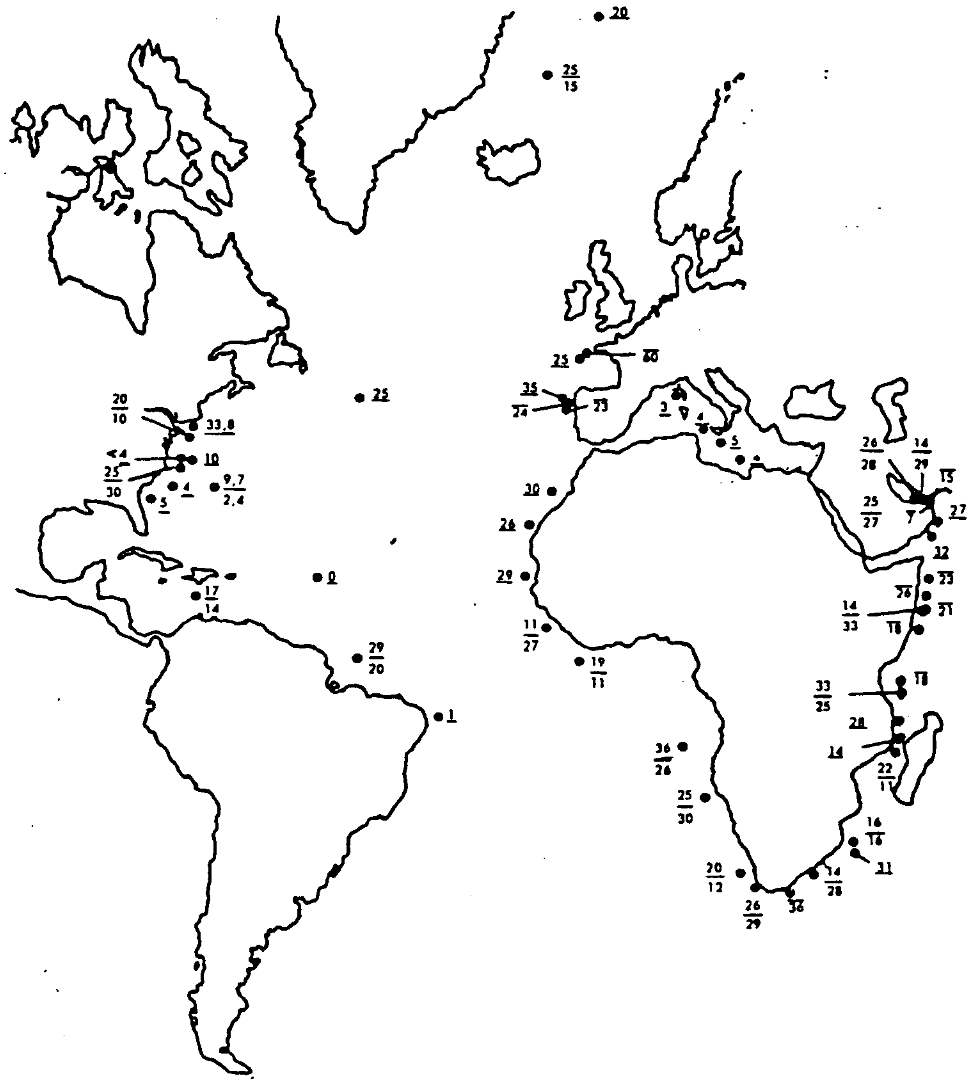


FIGURE III-4. Relative concentrations of aromatics in hydrocarbons extracted from ocean water. The numerator of each "fraction" represents the relative percentage of aromatics in surface water, and the denominator represents the relative percentage of aromatics in surface water at a depth of 10m. From Brown and Huffman (1976)

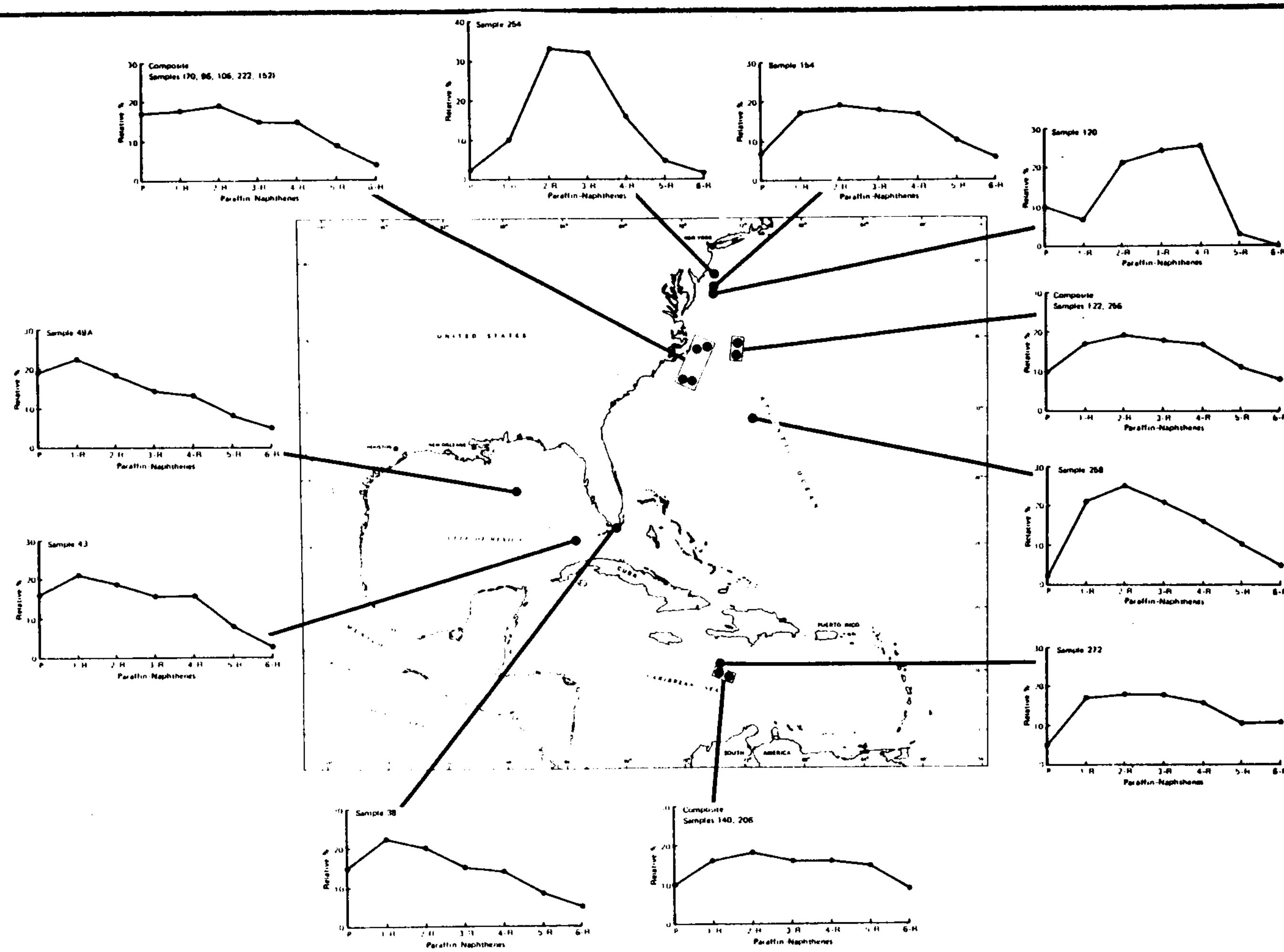


FIGURE III-5. Composition of saturate hydrocarbons extracted from sea waters. From Brown et al. (1973).

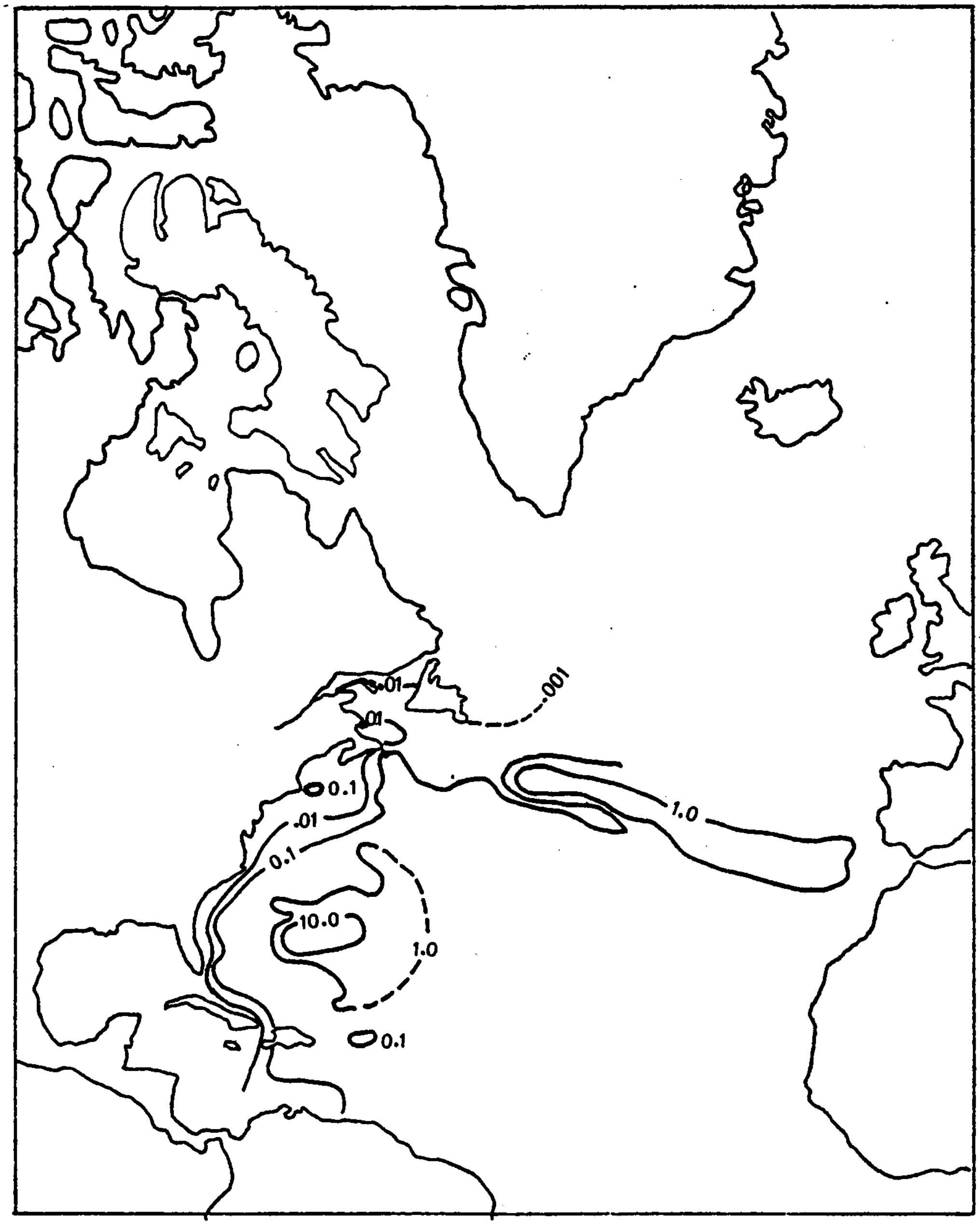


FIGURE III-6. Isopleths of tar distribution 1972. Concentration in mg/m^2. From Levy (1977).

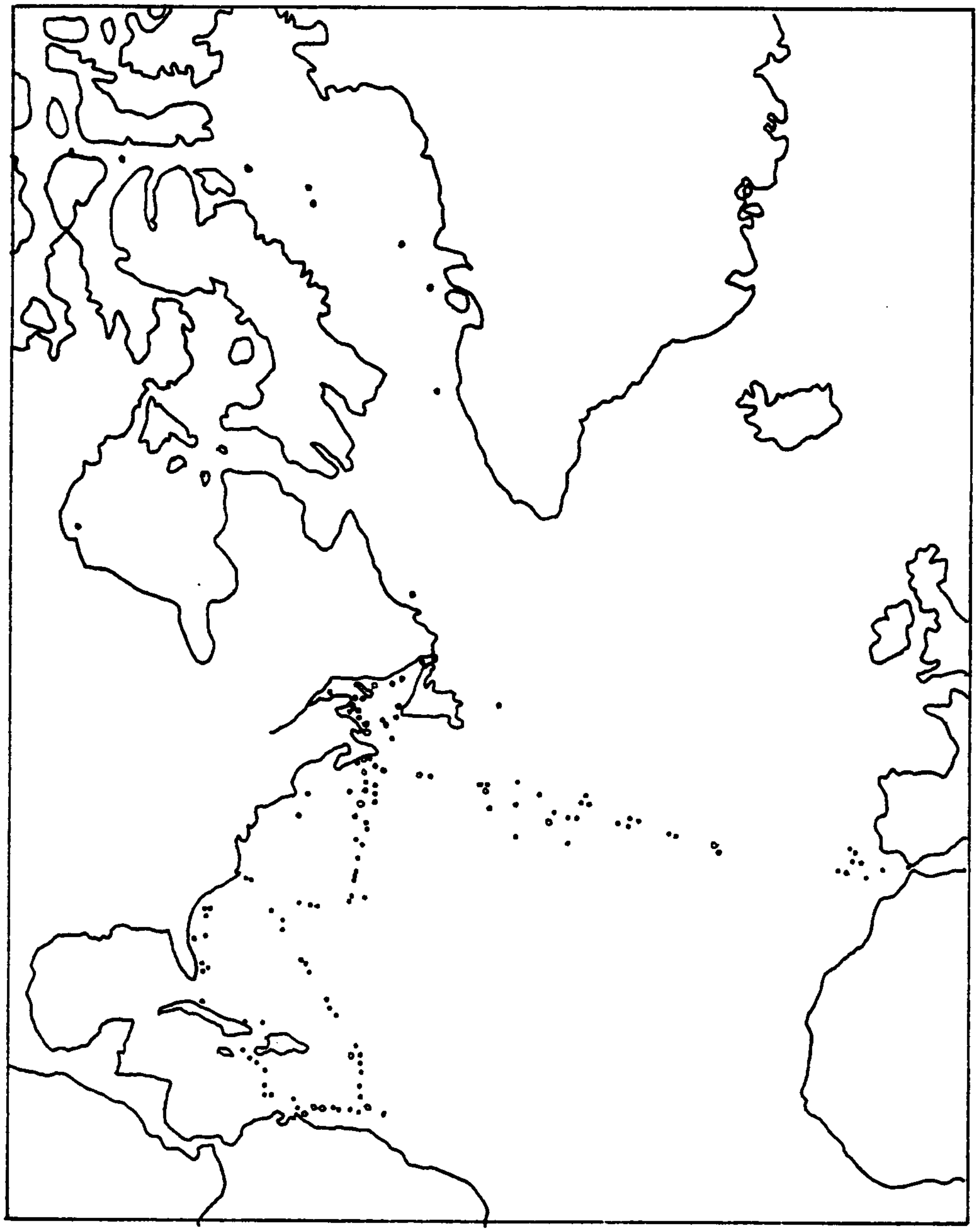


FIGURE III-7. Distribution of sampling stations for 1972 study of tar in North Atlantic Ocean waters. Open circles indicate presence of tar; darkened circles indicate absence of tar. From Levy, 1977.

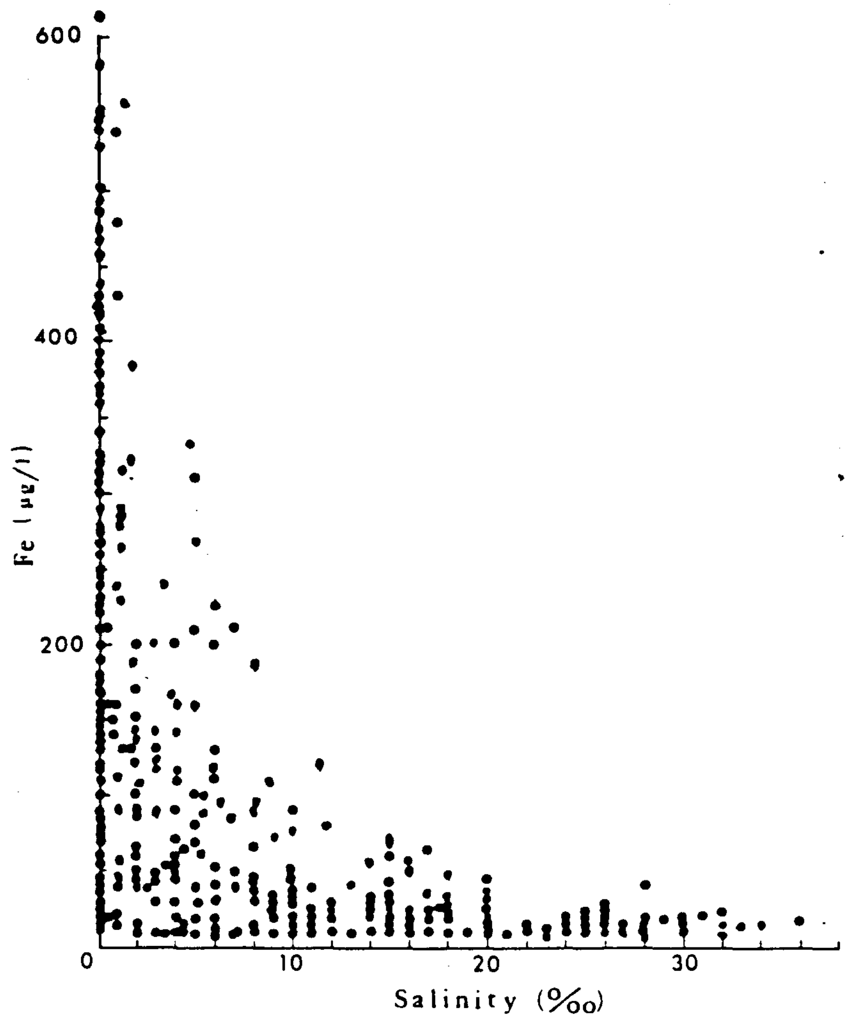


FIGURE III-8. Dissolved iron concentrations as a function of salinity in southeastern estuaries. From Windom, 1975b.

that the average concentration of mercury was between 16 and 37 ng/liter (Table III-1). They calculated the transport of this metal by the rivers to be about one-third of that previously calculated by Windom (1975b). They also found that on the average about 27 percent of the mercury is associated with organic matter.

The concentrations of copper, nickel, and zinc in the same ten major rivers have been determined by Windom and Smith (1978b). These authors found that the rivers are generally similar in metal concentration and used the average metal concentrations to estimate their riverine flux to the South Atlantic Bight (Table III-2). The small variation in the mean copper concentration between rivers appears to be correlated to dissolved organic carbon (Figure III-10).

The concentrations of iron, aluminum, and manganese were determined in Coastal Plain rivers by Beck, Reuter and Perdue (1974). These authors found a correlation of iron and aluminum with dissolved organic matter (Figure III-11). They postulate that this relationship is due to the formation of metal-fulvic acid associations. As a part of this work the authors characterized the dissolved organic matter in rivers and determined concentrations of the major cations and anions.

Waslenchuk (1977) determined the seasonal variations in arsenate, the predominant form of dissolved arsenic, in the major rivers of the southeast (Figure III-12). He observed that higher concentrations of arsenate are generally associated with higher river discharges. Waslenchuk and Windom (1978) have investigated the behavior of arsenic in estuaries and concluded that it is transported conservatively through estuaries since its concentration is a linear function of salinity (Figure III-13).

The cycling of manganese in the Newport River estuary was studied by Evans, Cutshall, Cross and Wolfe (1977). These authors found that highest manganese concentrations were at intermediate salinities (Figure III-14). They suggested that the additional amount above what is expected due to conservative mixing was released from bottom sediments.

The transport of metals by rivers in particulates was evaluated by Windom (1975b). Nance (1974) investigated the nature of the particulate phases in which the metals were contained (Table III-3). In studies of the Ogeechee and Savannah River estuaries he found considerable differences in the partitioning of iron, manganese, zinc, cadmium, lead, and copper (Table III-4).

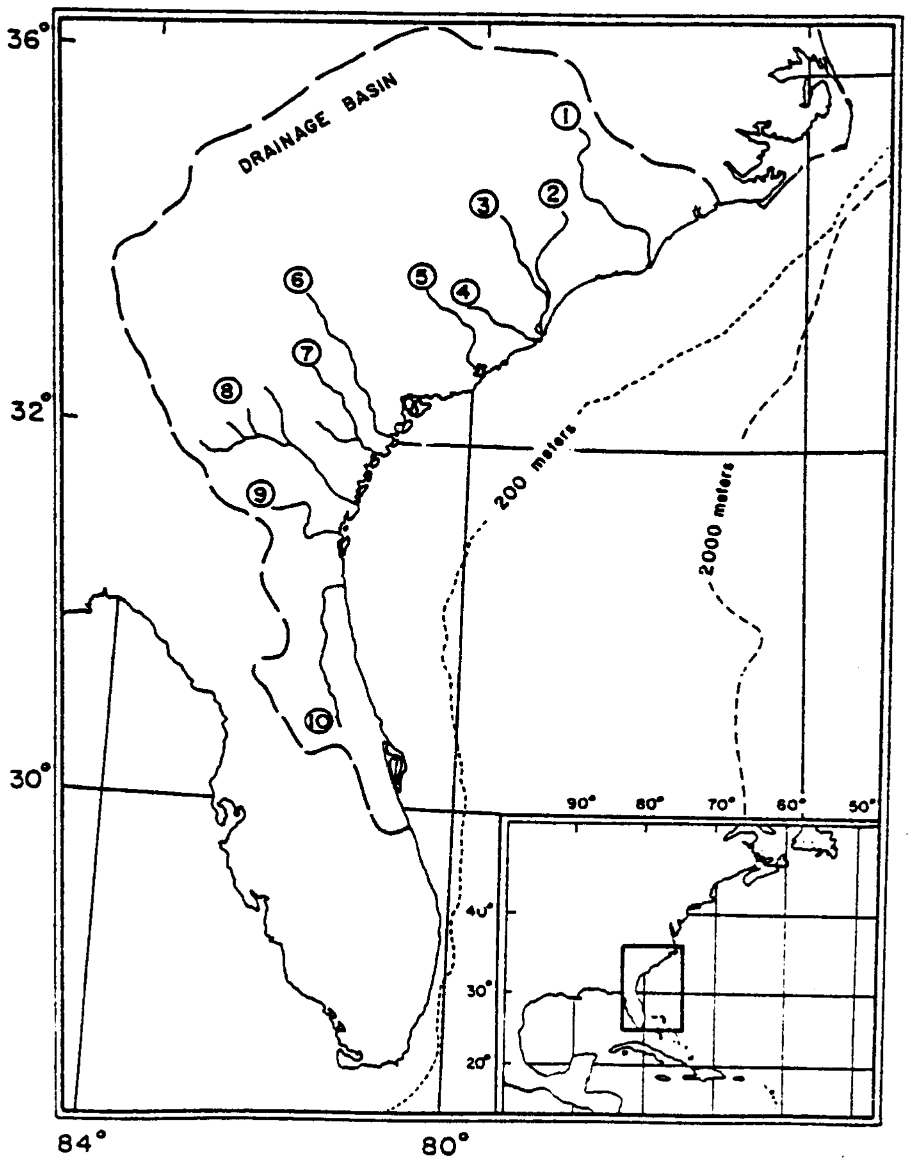


FIGURE III-9. Location and drainage basin of the ten major rivers emptying into the South Atlantic Bight. Numbers in circles refer to rivers listed in Tables III-1 and III-2. (From Windom and Taylor, 1978).

TABLE III-1

Dissolved mercury in southeastern rivers (in ng/l)
(From Windom and Taylor, 1978)

	1976 Apr	May	Jun	Jul	Sep	Oct	Dec	1977 Jan	Feb	Apr	Jun	River Mean ± 1σ	Av. Annual Discharge (10^{12} l)	Mean Annual Hg Transport (kg)
1. Cape Fear	26	36	21	21	15	14	35	23	10	37	12	23 ± 10	7.1	161
2. Pee Dee	22	35	18	20	10	15	20	16	9	34	12	18 ± 9	12.4	236
3. Black	25	38	18	24	13	10	10	17	7	43	14	20 ± 12	0.8	16
4. Santee	27	38	19	19	10	13	8	17	9	37	9	18 ± 11	1.9	34
5. Cooper	23	28	17	22	18	10	8	14	7	25	7	16 ± 7	13.3	213
6. Savannah	22	38	25	24	13	15	12	20	9	52	12	22 ± 13	10.8	237
7. Ogeechee	19	36	21	23	13	14	10	15	7	46	9	19 ± 12	2.1	40
8. Altamaha	20	34	17	19	13	14	10	23	5	34	12	18 ± 9	12.3	221
9. Satilla	26	33	18	26	13	15	10	24	7	40	9	20 ± 11	2.0	40
10. St. Johns	41	52	31	50	16	61	23	48	32	40	12	37 ± 16	2.8	103
Monthly Mean	25	37	21	25	13	18	15	22	10	37	11	Total Hg transport 1.3×10^{3} kg		
1σ	6	6	4	9	2	15	9	10	.8	7	2			

*Averaged over 7-47 water data years, depending on the river, at downstream-most gaging station.

TABLE III-2. Concentration and transport of copper, nickel, and zinc in southeastern U. S. rivers. (From Windom and Smith, 1978b)

	Mean Annual Discharge (km^3)	DOC[1] (mg/l)	Mean Concentrations and Variations[5] Cu[2] (µg/l)	Ni[3] (µg/l)	Zn[4] (µg/l)	Annual Transport Cu (10^3 kg)	Ni	Zn
1. Cape Fear	5.6	8 ± 3	2.1 ± 0.7	3.7 ± 1.8	7.0 ± 2.7	12	21	39
2. Pee Dee	16.1	8 ± 3	1.6 ± 0.5	2.3 ± 1.7	3.9 ± 1.3	26	37	63
3. Black	0.9	10 ± 5	1.1 ± 0.6	1.8 ± 1.1	4.2 ± 2.3	1	2	4
4. Santee	0.6	6 ± 2	1.7 ± 1.1	3.1 ± 2.5	3.1 ± 2.0	1	2	2
5. Cooper	13.2	6 ± 4	1.5 ± 0.7	3.7 ± 3.4	4.2 ± 3.9	20	49	55
6. Savannah	13.0	8 ± 4	1.6 ± 1.0	3.9 ± 4.4	5.1 ± 3.9	21	51	66
7. Ogeechee	2.1	12 ± 8	1.0 ± 0.6	2.9 ± 2.8	2.7 ± 1.5	2	6	6
8. Altamaha	12.0	9 ± 5	1.6 ± 0.8	2.9 ± 1.1	3.0 ± 1.5	19	35	36
9. Santilla	2.2	18 ± 11	1.0 ± 0.6	2.9 ± 1.9	5.9 ± 3.4	2	6	13
10. St. Johns	6.5	11 ± 4	1.6 ± 0.6	2.0 ± 0.8	4.4 ± 2.5	10	13	28
				Total Annual Transport		114	222	312

[1]Based on 14 samples collected between January 1976 to April 1977
[2]Based on 14 samples collected between January 1976 to April 1977
[3]Based on 8 samples collected between July 1976 to April 1977
[4]Based on 8 samples collected between July 1976 to April 1977
[5]Variation is one standard deviation for the mean.

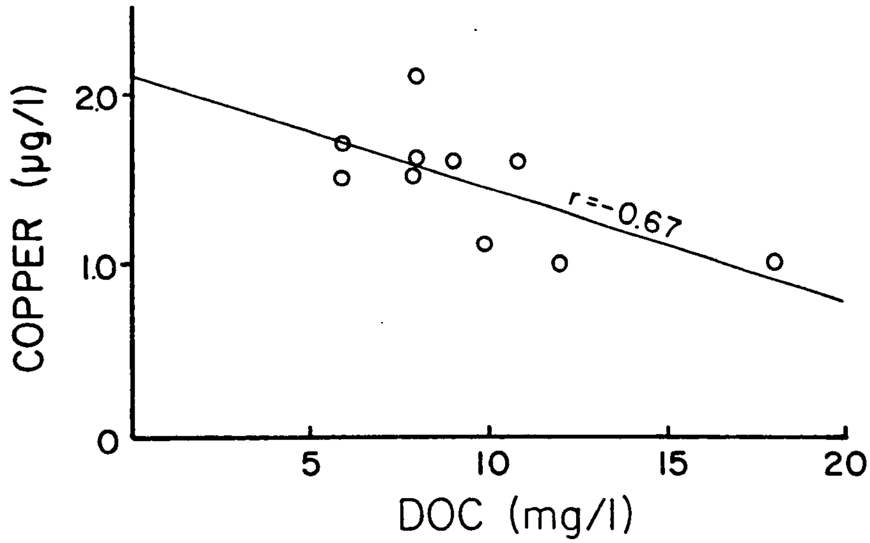


FIGURE III-10. Mean copper concentrations in southeastern rivers as a function of mean dissolved organic carbon. (From data of Windom and Smith, 1978b).

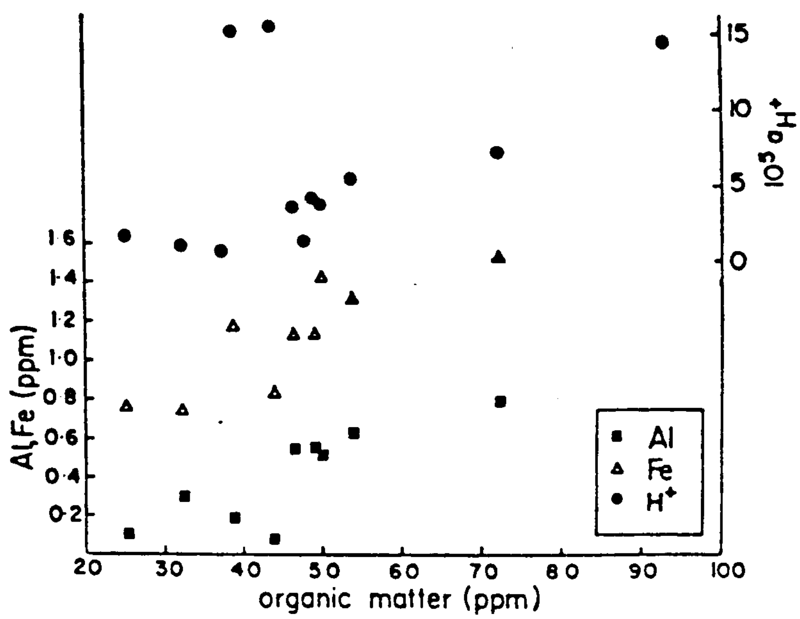


FIGURE III-11. Correlation of Al, Fe, and H^+ with dissolved organic matter. (From Beck et al., 1974).

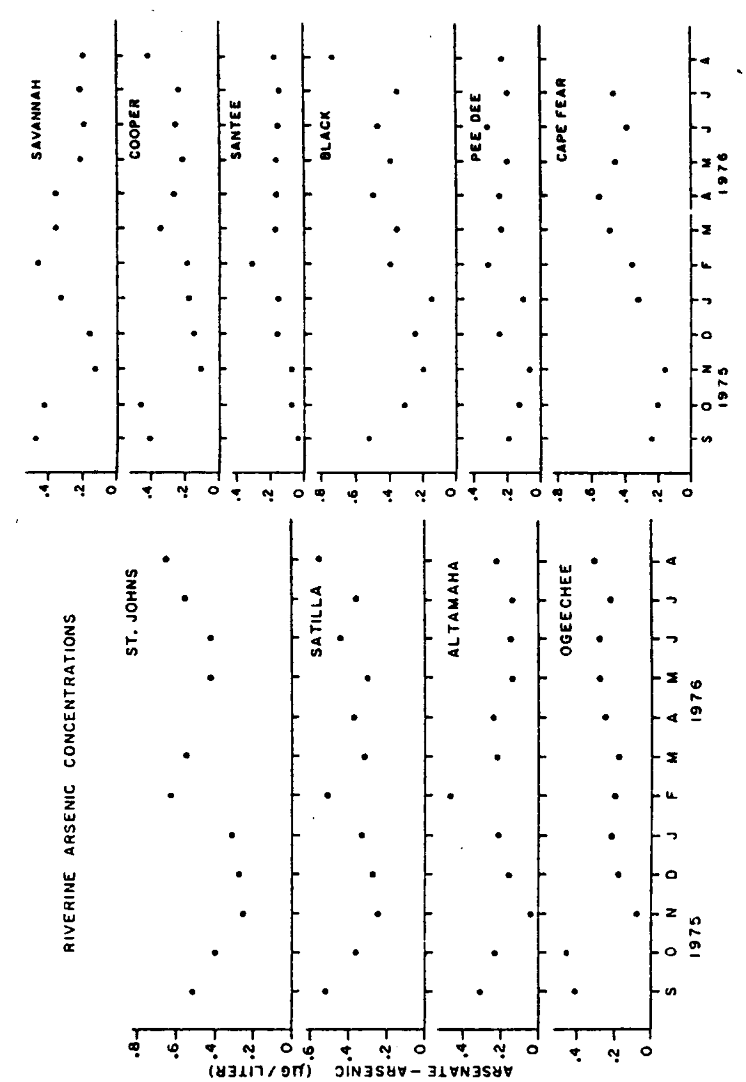


FIGURE III-12. Variation in arsenic concentration in southeastern rivers (From Waslenchuk, 1977).

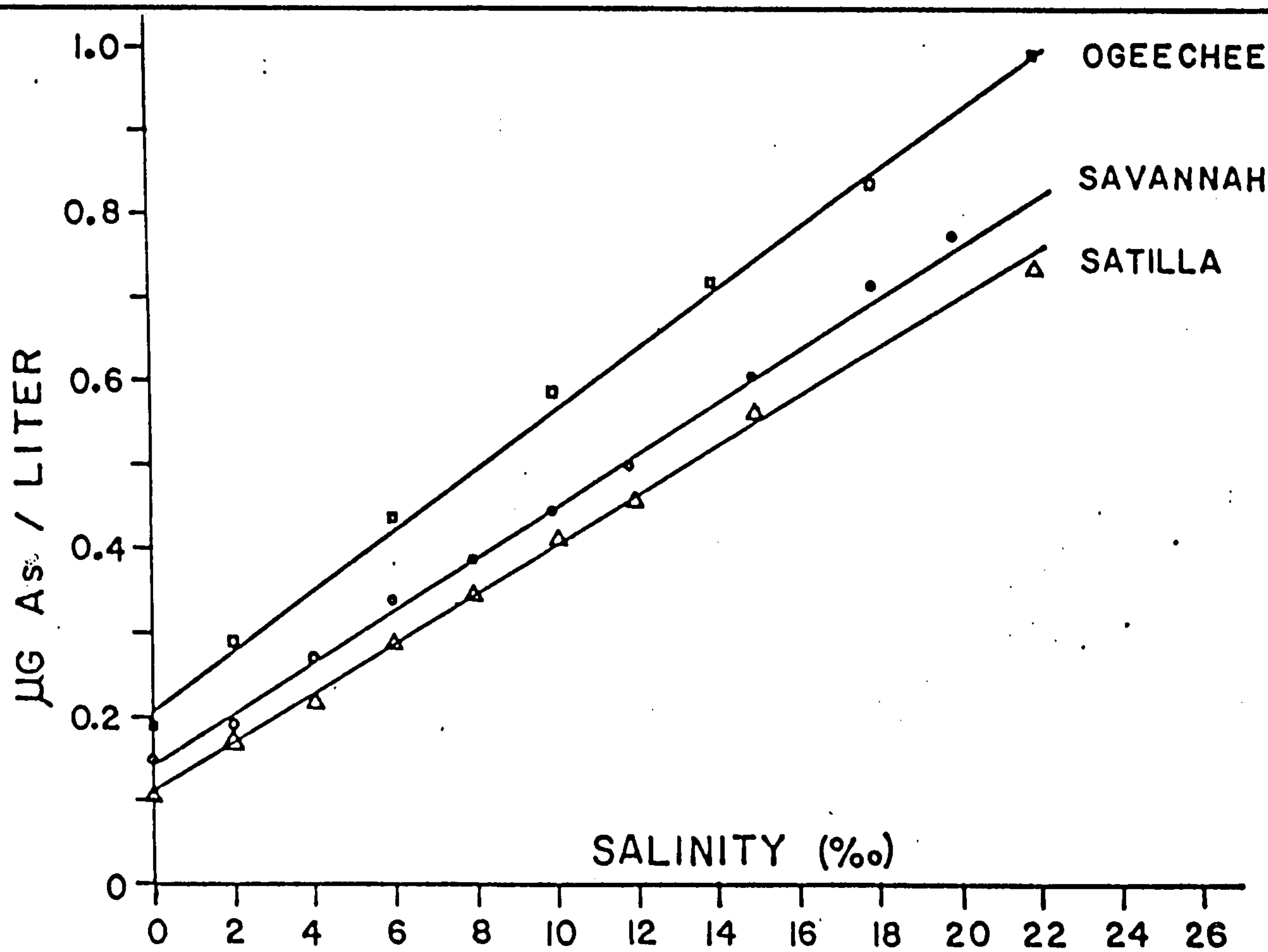


FIGURE III-13. Arsenic concentration in estuarine waters. (From Waslenchuk and Windom, 1978).

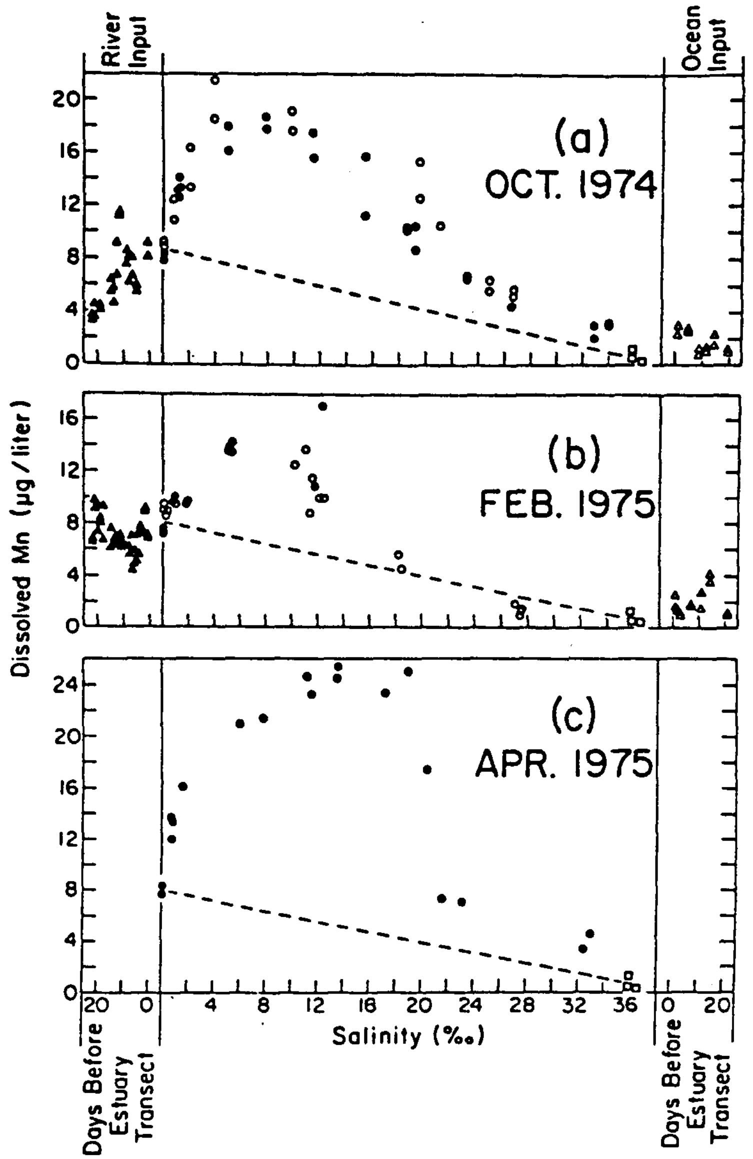


FIGURE III-14. Variation in dissolved manganese in the Newport River estuary as a function of salinity (From Evans et al., 1977)

TABLE III-3

Percentages of the total metal transported by solution and the leached fractions. (From Nance, 1974).

Mechanism	Fe	Mn	Zn	Pb	Cu	Cd
Savannah Estuary						
1. solution	27	41	55	32	77	94
2. adsorbed	0	18	1	0	3	0
3. reduced	4	30	25	34	5	2
4. oxidized	0	2	2	26	5	0
5. residual	68	7	18	7	11	5
Ogeechee Estuary						
1. solution	11	39	34	36	73	79
2. adsorbed	0	13	3	0	8	0
3. reduced	2	32	29	40	2	1
4. oxidized	2	8	7	7	4	0
5. residual	85	9	28	17	12	19

Evans (1977) studied the exchange of trace metals between dissolved and particulate phases in the Newport River estuary, North Carolina. He found that iron, copper, and zinc were lost from solution in the estuary.

Smith (1976) made an initial study of the complexation capacity of samples collected from the Ogeechee River estuary, Georgia. He found that the dissolved organic carbon in all molecular weight fractions decreased with increasing salinity while complexation capacity increased in the lighter fractions.

Baier (1977), using anodic stripping voltammetry and atomic absorption spectrophotometry, studied the distribution of dissolved lead in the Cape Fear river plume. His results are presented in Figure III-15.

The above studies generally employed flameless atomic absorption to analyze preconcentrated samples. This is the most generally accepted technique presently available to the marine chemist.

In addition to that from the above studies, several ongoing programs are producing trace metal data in the water column. Mathews and co-workers at the Marine Resources Research Institute, Charleston, South Carolina, have conducted surveys of copper,

TABLE III-4. Partitioning of trace metals between phases of particulates equilibrated at different salinities. (From Nance, 1974)

SAVANNAH RIVER

Metal	Salinity	Total (ppm)	Adsorbed	Reduced	Oxidized	Residual
Fe	0°/oo	42500	0	3	0	96
	20°/oo	33400	0	3	1	95
Mn	0°/oo	2102	21	63	4	13
	20°/oo	879	15	64	6	16
Zn	0°/oo	276	10	41	10	39
	20°/oo	227	3	59	7	32
Cd	0°/oo	2.03	8	27	5	59
	20°/oo	1.63	4	28	4	64
Pb	0°/oo	141	0	78	4	17
	20°/oo	133	0	75	8	16
Cu	0°/oo	79.8	11	24	24	40
	20°/oo	45.2	18	12	17	53

OGEECHEE RIVER

Metal	Salinity	Total (ppm)	Adsorbed	Reduced	Oxidized	Residual
Fe	0°/oo	33800	0	4	3	93
	20°/oo	50400	0	1	1	98
Mn	0°/oo	1194	30	44	15	11
	20°/oo	893	9	64	9	19
Zn	0°/oo	153	8	41	13	38
	20°/oo	162	1	46	8	45
Cd	0°/oo	0.53	1	34	14	51
	20°/oo	10.83	1	3	1	95
Pb	0°/oo	70	0	60	13	26
	20°/oo	65	0	63	8	28
Cu	0°/oo	32.1	21	9	23	48
	20°/oo	40.0	39	6	11	44

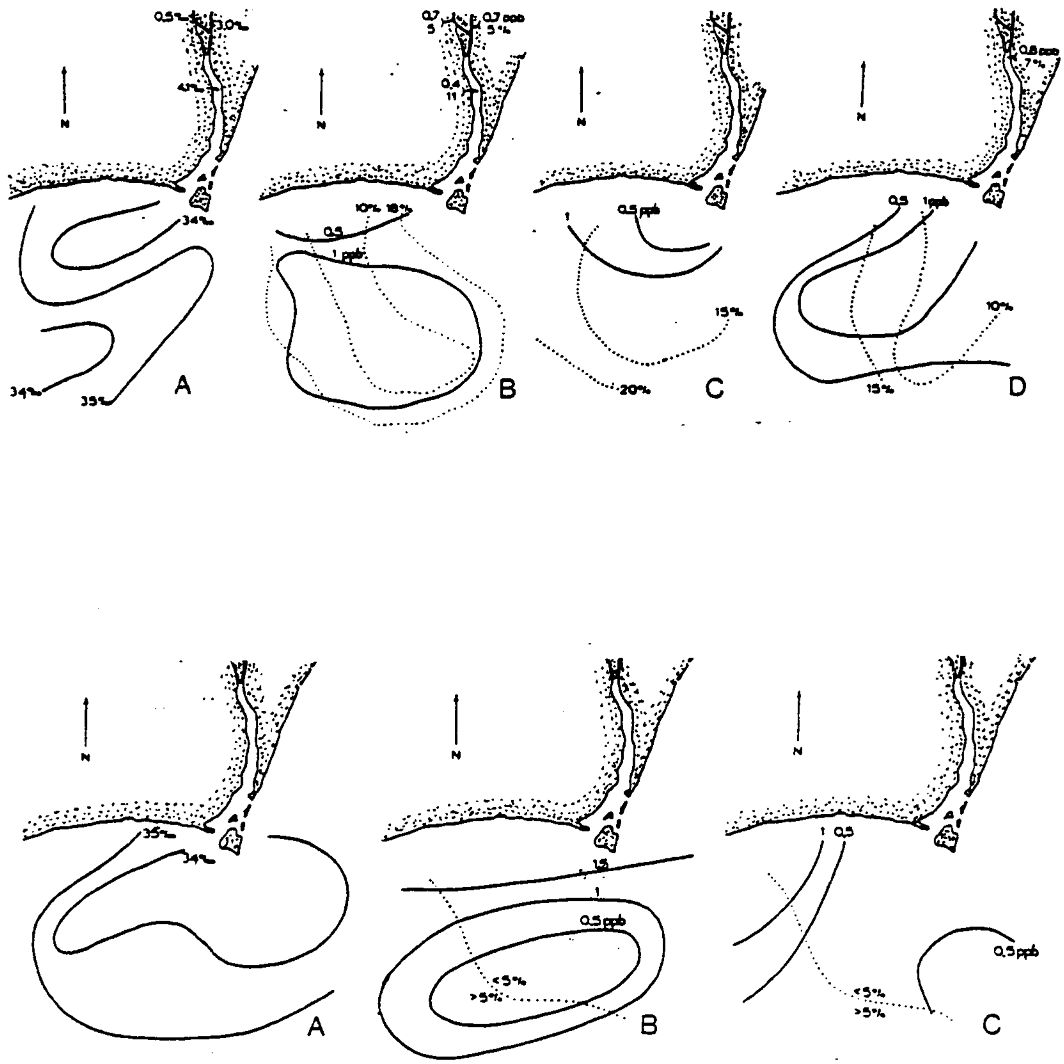


FIGURE III-15. Dissolved lead variations in the Cape Fear River plume. (From Baier, 1977) iron, and zinc in South Carolina estuarine waters (Mathews, 1978, personal communication). Barber (1978, personal communication) and co-workers at Duke University have an ongoing study of trace metals in Calico Creek, North Carolina, and Baier (1978, personal communication) has unpublished data from the Cape Fear River. Ongoing programs at the NOAA Marine Fisheries Laboratory in Beaufort, North Carolina, are also producing new trace metal data (Cross, 1978, personal communication). Windom and co-workers at the Skidaway Institute, Savannah, Georgia, have unpublished trace metal data on several southeastern rivers. Other surveys of coastal waters include those conducted in South Carolina by the USGS (Harris, 1978, personal communication) and by Smythe at the College of Charleston, South Carolina (Smythe, 1978, personal communication).

2.1.2.2 Offshore

The only detailed studies of trace metals in offshore waters have been conducted by Windom and co-workers at the Skidaway Institute. The initial work of this group (Windom and Smith, 1972; Windom, 1972c) was reviewed by Roberts (1974). Since then additional studies of offshore waters have addressed input mechanisms to shelf waters and regional variations in trace metal concentrations.

Windom, Taylor and Waiters (1975) investigated seasonal variations in surface water mercury concentrations in the Georgia Embayment. Mean values for different seasons varied significantly and these authors suggested that atmospheric input was responsible. More recently, Windom and Taylor (1978) reevaluated this possibility but could not unequivocally confirm this conclusion. They did point out, however, that atmospheric input of mercury is probably as important as river input. They proposed that intrusion of Gulf Stream waters was the major mecahnism that controlled mercury concentrations in continental shelf water. Mercury concentrations in water samples collected at several stations along the shelf varied between 4 and 46 ng/liter (Table III-5). In many samples a large portion of the mercury was associated with organic matter.

The concentration of the major forms of arsenic in continental shelf, Sargasso Sea and Gulf Stream waters was determined by Waslenchuk (1977). He found that arsenic(V) was the predominant form of arsenic and its concentration varied around 1 μg/liter (Figure III-16). Dimethylarsenic was detected in most samples but represented a small percentage of the total arsenic. Arsenic(III) was the second most abundant species and it varied with respect to arsenic(V) in a way that suggested biological mediation since surface productive waters had the highest reduced arsenic

TABLE III-5. Mercury concentrations in continental shelf waters. (From Windom and Taylor, 1978).

Station Number	Location	Depth (meter)	PO_4 (μmole/l)	SIL (μmole/l)	NO_3 (μmole/l)	Hg concentrations Reactive (ng/l)	Hg concentrations Total (ng/l)	% Organically Associated
BLUE FIN - January 1977								
1	31°52'N 80°52'W	1	0.25	26.1	1.02		15	
2	31°46'N 80°45'W	1	0.13	0.2	0.09		13	
4	31°40'N 80°38'W	1	0.07	0.3	0.10		13	
		20	0.07	0.3	0.19		13	
6	31°34'N 80°31'W	1	0.05	0.1	0.14		17	
		23	0.11	1.1	0.05		15	
8	31°27'N 80°24'W	1	0.05	0.8	0.21		12	
		30	0.09	0.4	0.10		11	
10	31°21'N 80°17"W	1	0.05	0.5	0.33		13	
		15	0.07	0.5	0.19		14	
		33	0.07	317	0.12		13	
12	31°21'N 80°10'W	1	0.10	0.5	0.40		12	
		18	0.20	13.3	1.05		13	
		36	0.15	2.7	1.29		13	
BLUE FIN - March 1977								
1	31°52'N 80°50'W	18	0.13	3.1	0.10	12	46	74
4	31°51'N 80°23'W	26	0.04	0.9	0.12	11	20	45
7	31°46'N 80°05'W	34	0.04	0.7	0.20	6	8	25
10	31°39'N 79°48'W	3	0.17	0.8	1.05	8	10	20
		43	0.22	1.6	1.68	6	17	65
12	31°36'N 79°36'W	3	0.07	1.0	0.30	10	17	41
BLUE FIN - May 1977								
1	31°46'N 80°42'W	3				9	15	40
		15				11	11	0
2	31°40'N 80°32'W	3				9	11	18
		21				7	11	36
3	31°35'N 80°24'W	3				7	9	22
		32				7	9	22
4	31°29'N 80°11'W	3				5	8	37
		36				9	9	0
5	31°24'N 80°04'W	3	0.05	1.0	0.02	6	8	25
		40	0.06	0.8	0.13	4	4	0
6	31°19'N 79°55'W	3	0.04	0.4	0.01	7	9	22
		55	0.09	0.9	0.13	4	7	43
COLUMBUS ISELIN - July 1977								
1	31°54'N 80°52'W	3	0.44	0.9	0.8	5	12	58
4	31°48'N 80°44'W	3	0.14	0.4	0.01	5	7	28
		25	0.20	0.7	0.01	7	9	22
7	31°43'N 80°07'W	3	0.09	1.0	0.01	7	16	56
		36	0.07	1.6	0.07	5	12	58
53	31°14'N 79°28'W	10	0.01	1.6	0.07	5	7	28
		100	0.10	1.8	1.03	5	7	28
		300	0.28	2.1	4.29	5	5	0
		500	1.27	10.9	20.3	5	5	0
		670	1.86	21.5	27.5	5	5	0

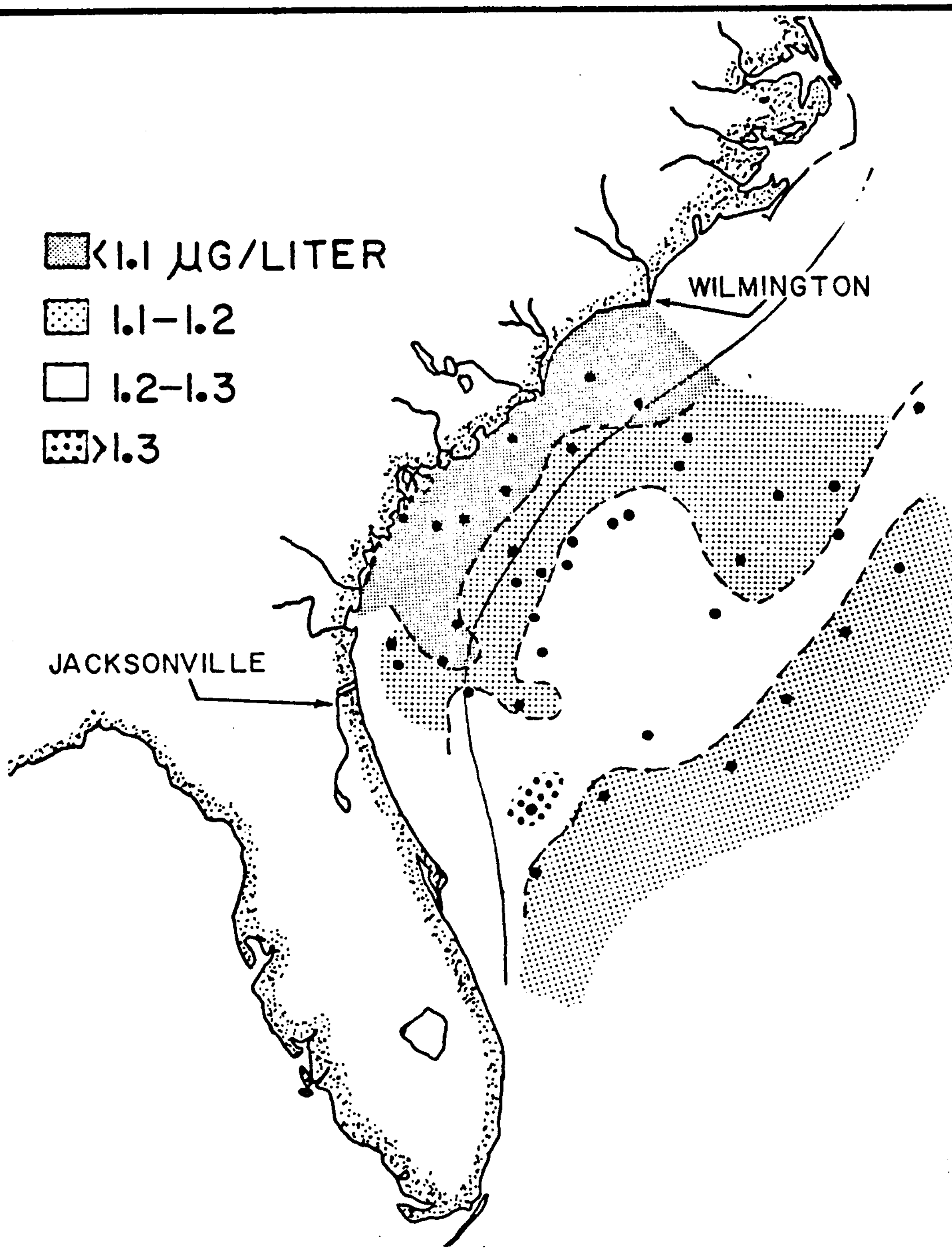


FIGURE III-16. Arsenic (V) distribution in surface waters March, 1976. (From Waslenchuk, 1977).

concentrations (Figure III-17).

The concentration of copper in surface waters (Table III-6) was found to vary regionally by Windom and Smith (1978a). Windom and Smith (1978b) determined the concentrations of copper, nickel, and zinc in shelf waters (Figure III-18) and also estimated the relative importance of various transfer pathways (Table III-7). They concluded that the most important input mechanism for these metals is intrusion.

TABLE III-6

Regional variation in surface water copper concentrations. From Windom and Smith (1978a).

Region	Mean Cu Concentration (μg/kg)	(nm/kg)
Gulf Stream	0.14 ± 0.05	2.2 ± 0.8
Georgia Embayment*	0.15 ± 0.08	2.4 ± 1.2
Onslow Bay**	0.07 ± 0.03	1.1 ± 0.5
Blake Plateau	0.20 ± 0.08	3.1 ± 1.2

* continental shelf between Cape Canaveral and Cape Fear.
** continental shelf between Cape Fear and Cape Lookout.

TABLE III-7

Relative importance of transfer pathways. From Windom and Smith (1978b).

Transfer Pathway	Percent of Total Annual Input: Cu	Ni	Zn
River input	8	5	3
Atmospheric input	15	8	8
Biological uptake	46	4	32
Gulf Stream intrusions	77	87	89

Analytical techniques used in the above studies employed heated graphite furnace flameless AA of extracted samples (copper, nickel, and zinc), cold vapor AA (mercury) or D.C.-arc induced plasma emission spectrophotometry (arsenic).

Three ongoing projects are generating data on trace metals in offshore waters. Windom and co-workers at Skidaway are conducting

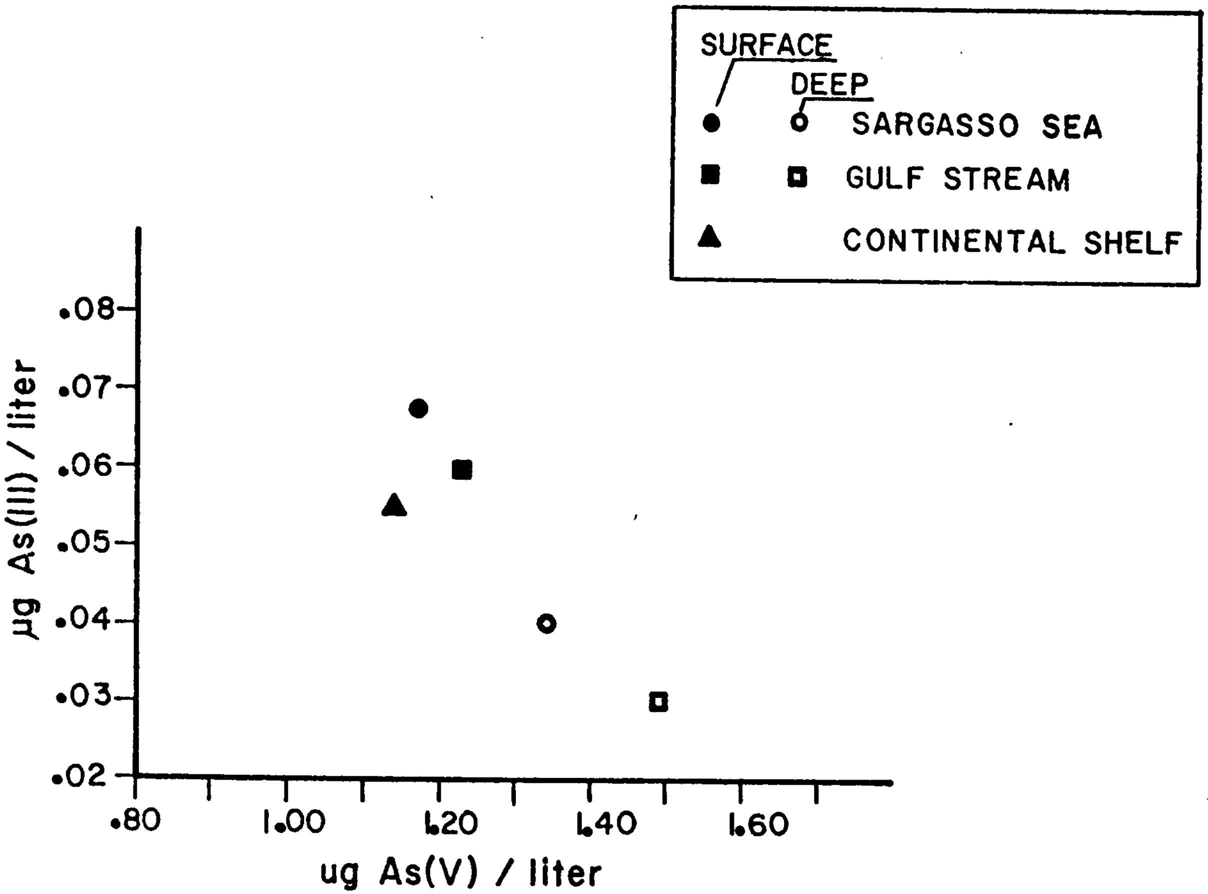


FIGURE III-17. Arsenic (V) vs arsenic (III) March, 1976. (From Waslenchuk, 1977).

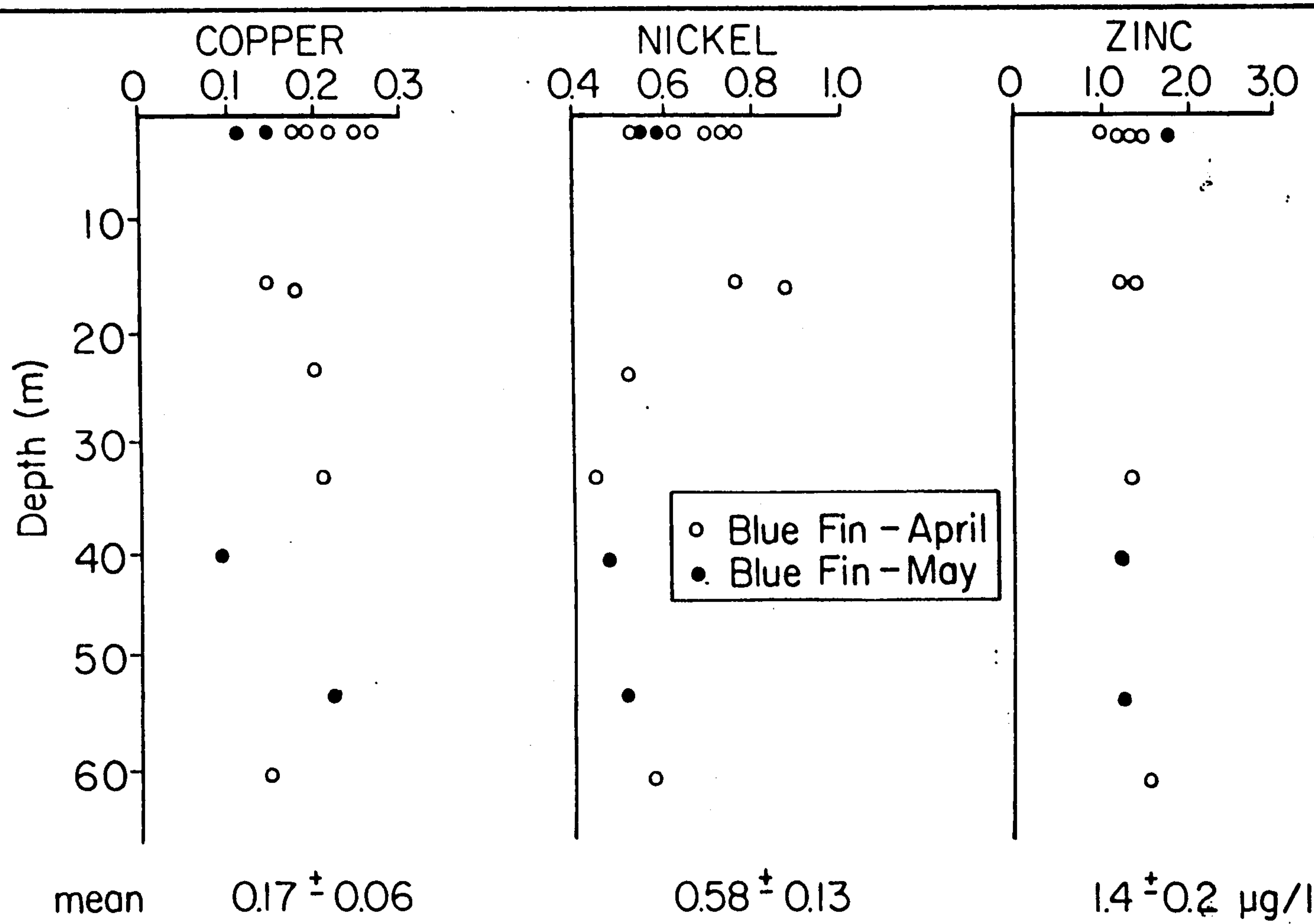


FIGURE III-18. Copper, nickel, and zinc concentrations in continental shelf waters. All values are in micrograms/liter. (From Windom and Smith, 1978b).

investigations on the geochemistry of trace metals in South Atlantic Bight waters under sponsorship of the U. S. Department of Energy. Shuman and co-workers at the University of North Carolina are evaluating the complexation capacity of marine waters for trace metals as part of a NSF grant (Shuman, 1978, personal communication). Some trace metal data is also being produced by Texas Instruments as a part of the BLM South Atlantic Benchmark Study (May, 1978, personal communication).

2.1.2.3 Effects of Dredging on Trace Metals in the Water Column

The effects of dredging and dredge spoil disposal on southeastern estuarine water quality has been discussed in four recent publications by Windom (1972b, 1973, 1975a, 1976b). The influence of dredging on trace metals was particularly emphasized in these papers. The results of this research suggest that dredging projects in southeastern estuaries do not appreciably affect metal levels in the water column. This conclusion may be due to the fact that the sediments that were dredged during these studies were not greatly contaminated with trace metals.

Windom and co-workers have recently completed a study which evaluates the use of salt marshes for overland flow treatment of effluents from dredged material disposal sites. This research was sponsored by the Waterways Experiment Station of the U. S. Army Corps of Engineers.

2.1.3 Nutrients in the Water Column

2.1.3.1 Rivers and Estuaries

Unlike the continental shelf waters and the Gulf Stream there is very little systematic work being done on the nutrient chemistry of estuaries, rivers and sounds. James Howard at the Skidaway Institute of Oceanography is attempting to assemble all of the relevant data for the Georgia coast, but the project is still incomplete (Howard, 1978, personal communication). The study by Vernberg and co-workers at the Belle Baruch Field Laboratory will be most valuable in this area when results are published (Vernberg, 1978, personal communication).

There have been few new measurements of nitrate, nitrite, ammonia, phosphate and silica in estuarine waters. Simple measurements are of very little or no use unless related to a valid hypothesis so no attempt was made to obtain every measurement that may have been made for various Environmental Impact Statements and such.

Studies that determine temporal and spatial variations, and more importantly relate to significant processes, are the key to increasing our knowledge. A publication by Gardner (1976) is perhaps the most important publication in this area since the VIMS report (Roberts, 1974). It has previously been hypothesized that salt marsh systems were "nutrient traps", thus explaining their high relative productivity. Gardner, however, made many measurements of silica and phosphate flux from salt marsh sediment into the coastal waters and concluded as follows:

> "The input of these substances to coastal waters by runoff from South Carolina marshlands is approximately equal to that supplied by freshwater runoff from the State. Thus marsh runoff may play an important role in regulating the nutrient chemistry of estuarine waters and should be considered in any attempt to model the water quality of estuaries."

It seems clear that the concept of "trap" or "source" may be too simplistic in a dynamic, possibly non-steady state, system such as a salt marsh ecosystem.

Fanning and Pilson (1973) conclusively show that silica acts as a conservation property during the mixing of Savannah River water with the shelf waters.

A recent paper by Windom, Dunstan and Gardner (1975) quantified the input of nutrients via runoff to the estuarine/sound systems. Figure III-19 shows the annual supply of phosphate from runoff could meet all the phosphorus requirements of the coastal salt marshes. Nitrate, however, could meet only 20 percent of the demand implying other sources or more likely active regeneration.

Non-natural sources of nutrients to the South Atlantic Bight are limited to the waste of the cities bordering the coast. Since the population density is relatively low, this input is considered negligible except in a few local cases.

The study of nutrient dynamics in the rivers, sounds and salt marshes of the southeast U. S. has been quite unsuccessful in elucidating specific critical pathways, determining the relative role of regeneration and advective transport, or defining the role of the salt marsh (Is it a trap or a source?). The work of Gardner at the University of South Carolina on nutrient flux in the salt marsh is probably the most applicable to the problem.

The integration of recent work with past is difficult to assess since to date there has been no large-scale study of these problems.

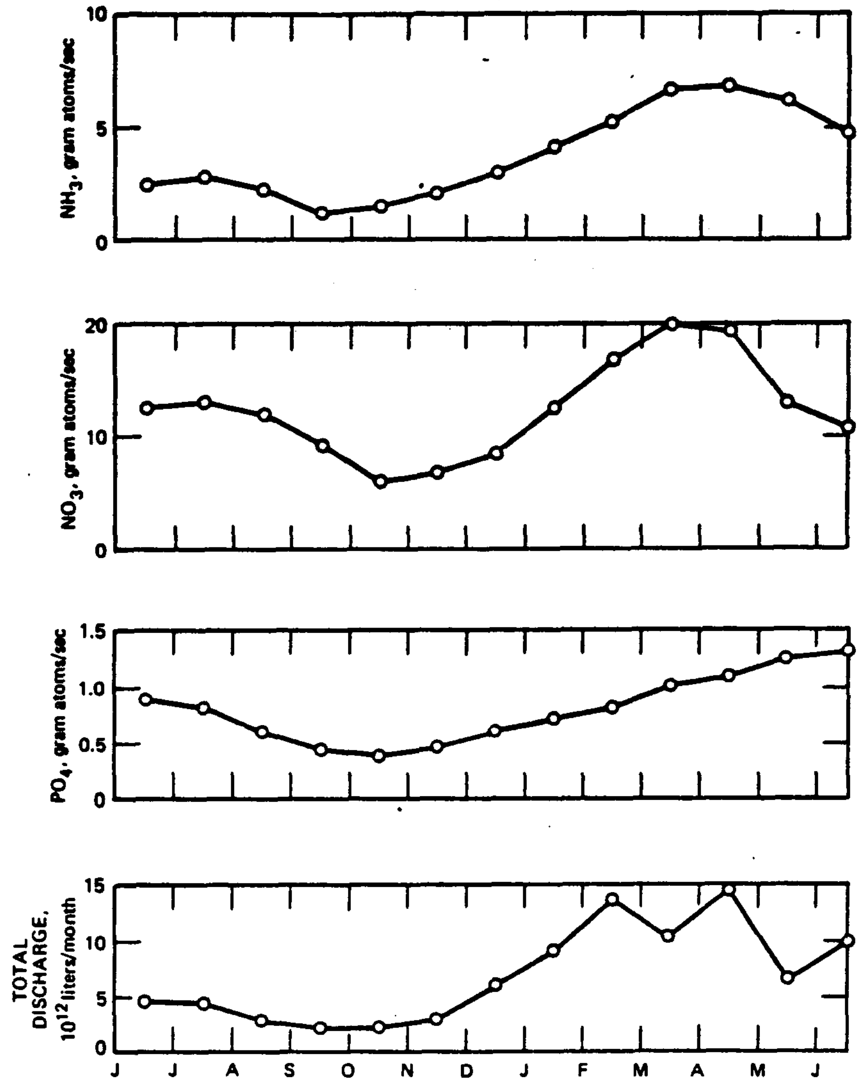


FIGURE III-19. Seasonal variations in the discharge rate of NH_3, NO_3, and PO_4 by the combined flow of the Pee Dee, Cooper, Savannah, and Altamaha rivers. Total monthly discharge of the nine major rivers is also shown. (Windom, Dunstan and Gardner, 1975)

As mentioned previously a large amount of data are being gathered under the direction of Howard (Skidaway Institute). No doubt there are other efforts along the coast. Nearshore data are particularly difficult to handle in a large data handling system because the mode of acquisition is often so sporadic and unplanned.

2.1.3.2 Continental Shelf

Since 1972 there has been a resurgence of interest in the continental shelf waters and especially the dynamic processes that influence them. The effort has been carried out mainly by two groups.

The Department of Energy initiated funding of a South Atlantic Bight program in 1975 with scientists at North Carolina State University, Skidaway Institute of Oceanography, University of Georgia, and the University of Miami participating (Atkinson, 1978, personal communication). Another project, funded by NOAA under the MARMAP program, was directed by scientists at the South Carolina Wildlife and Marine Resources Department (Burrell, 1978, personal communication). Additionally, the Coast Guard, as part of its Search and Rescue research effort, made several studies in the area in the mid-1970s. To date those data are unpublished.

As mentioned, the two efforts that have produced the most data are the South Carolina MARMAP cruises and the DOE-funded effort (Atkinson, 1978, personal communication; Burrell, 1978, personal communication). The nutrient and hydrographic part of the DOE effort is focused at the Skidaway Institute of Oceanography. Table III-8 and Table III-9 summarize the cruise efforts of the two groups.

TABLE III-8

Cruises by the South Carolina Wildlife and Marine Resources Department as part of their MARMAP Program (cruises for which technical data reports exist). Reference for all cruises is Mathews and Pashuk (1977).

Date	Cruise #	Area
13 Feb - 23 Mar 1973	D2-73	Cape Canaveral to Cape Fear
15-27 May 1973	D3-73	Jacksonville to Cape Fear
9-10 July 1973	D4-73	Savannah to Charleston
23 Oct - 16 Nov 1973	D5-73	Cape Canaveral to Cape Fear

TABLE III-9. Cruises by the Skidaway Institute of Oceanography as part of their Department of Energy funded program for which technical data reports exist or are in preparation.

DATE	CRUISE #	AREA	REFERENCE
4-11 September 1973	E-13-73	Georgia Bight	Atkinson (1975, 1977)
8-15 December 1973	E-19-73	Georgia Bight	Atkinson (1975, 1977)
23-30 April 1974	E-3-74	Georgia Bight	Atkinson (1976, 1977)
23-30 July 1974	E-12-74	Georgia Bight	Atkinson (1976, 1977)
9-14 April 1975	E-1G-75	off St. Augustine, Fla.	Atkinson, Paffenhofer, and Dunstan (1977)
6-7 August 1975	AD-75-01	Onslow Bay, N. C.	Atkinson, Singer and Pietrafesa (1976)
4-14 September 1975	E-9-75	Onslow Bay, N. C.	Atkinson, Singer, Dunstan, and Pietrafesa (1976)
13-14 October 1975	AD-75-02	Onslow Bay, N. C.	Atkinson, Singer and Pietrafesa (1976)
8-11 December 1975	AD-75-03	Onslow Bay, N. C.	Atkinson, Singer and Pietrafesa (1976)
14-18 July 1976	BF-76-ØB5	Onslow Bay, N. C.	Singer, Atkinson, Chandler and O'Malley (1977)
21-23 July 1976	BF-76-ØB6	Onslow Bay, N. C.	Singer, Atkinson, Chandler and O'Malley (1977)
28 July-6 August 1976	BF-76-ØB7	Onslow Bay, N. C.	Singer, Atkinson, Chandler and O'Malley (1977)
14-16 August 1976	BF-76-ØB8	Onslow Bay, N. C.	Singer, Atkinson, Chandler, and O'Malley (1977)
18 August 1976	BF-76-ØB9	Onslow Bay, N. C.	Singer, Atkinson, Chandler, and O'Malley (1977)
8-18 October 1976	BF-76-30,32,33,39	Georgia Coast	In preparation
9-15 December 1976	CI-76-12	Georgia Bight	In preparation
8-9 March 1977	BF-77-14	Georgia Bight	In preparation
8-16 April 1977	AD-77-4	Georgia Bight	In preparation
19 April 1977	BF-77-29	Georgia Bight	In preparation
21 April 1977	BF-77-30	Georgia Coast	In preparation
26-27 April 1977	BF-77-38	Georgia Bight	In preparation
4-10 July 1977	CI-77-03	Georgia Bight	In preparation
13-14 September 1977	BF-77-57	Georgia Bight	In preparation
5-9 November 1977	CI-77-07	Georgia Bight	In preparation
23-27 January 1978	CI-78-01	Georgia Bight	In preparation

Cruises listed in these tables are our principal new source of nutrient information. By area the MARMAP cruises covered the whole South Atlantic Bight and added new information for the area off Charleston. The DOE and pre-DOE cruises out of Skidaway Institute, North Carolina State University and the University of Miami are concentrated in Onslow Bay and the Georgia Bight.

Most of these cruises included measurements of silica, phosphorus and nitrate. Nitrite is seldom measured because experience has shown that the concentrations are typically very low. Ammonia also is seldom measured, both out of knowledge that concentrations are low and that the method is difficult and unreliable at low concentrations.

The only new published data on particulate nitrogen are from the paper by Haines (1975) and Haines and Dunstan (1975). Haines and Dunstan (1975) found highest particulate nitrogen concentrations in nearshore areas with a seasonal peak in the summer (Table III-10). No recent particulate phosphorus data have been published.

TABLE III-10

Mean particulate organic nitrogen concentrations* (µgN/L) in surface waters of the Georgia Bight (from Haines and Dunstan, 1975).

	CRUISE/DATE			
	E-13-73	E-19-73	E-3-74	E-12-74
Water Depth	Sept 1973	Dec 1973	Apr 1974	July 1974
0-20m	27.6 ± 19.8	29.8 ± 15.5	34.6 ± 9.2	37.3 ± 10.7
20-200m	20.8 ± 8.1	14.5 ± 4.8	20.6 ± 8.4	14.4 ± 8.1
over 200m	9.5	7.6	21.2 ± 0.2	7.5 ± 3.4
shelf	23.7 ± 16.1	23.4 ± 10.8	27 ± 10.7	23.4 ± 15.4

* ± one standard deviation unit.

Studies of temporal and spatial variations in nutrient concentrations are the key to understanding nutrient dynamics. Intrusions of Gulf Stream water into the South Atlantic Bight Shelf waters is one of the dominant processes affecting nutrient concentrations in the Bight. Atkinson (1977) noted that the Gulf Stream can present waters of various densities at the shelf break. Easterly motions of the Stream cause ascending movement of isotherms and cold, dense water appears at the shelf break. Conversely, westerly motions of the Stream cause descending movement of isotherms and warmer, less dense waters at the shelf break (Figure III-20). At this point whether the water intrudes across the shelf or not depends on the relative difference between shelf and intruding water densities and forcing by wind, tide or Gulf Stream. Atkinson identified three basic types of intrusions (Figure III-21): override, interleaving and bottom intrusion. Analysis of the average shelf water densities indicated that 20^{o}C Gulf Stream water could form a bottom intrusion anywhere along the southeast U. S. coast except in January when shelf water densities are relatively higher and interleaving or override would occur.

While Atkinson (1977) discussed intrusions as to cause and type, it is of essence to discuss the effect on nutrient concentrations. Intruding Gulf Stream water can transport large amounts of nutrients--especially nitrate--into the shelf waters. Figure III-22 shows a nitrate - temperature plot for South Atlantic Bight shelf waters and Gulf Stream waters. The important observation is that Gulf Stream waters of less than 20^{o}C contain large amounts of nutrients (>5μM) and represent an important nutrient source.

The horizontal and vertical extent of nutrient-rich intrusion was determined by Atkinson (1978) based on four cruises in the South Atlantic Bight in 1973 and 1974. Figure III-23 shows the zone of nutrient-rich Gulf Stream water as it moves onto the shelf from east to west. Note that in the southern sections, off the St. Johns River, high nutrient concentrations extended to the surface. Runoff is shown moving out from the coast. Figures III-24, III-25, and III-26 show similar maps for the other three cruises. The horizontal extent of the intrusions and runoff is summarized in Table III-11.

The flux of nutrients into the shelf waters is difficult to quantify. Dunstan and Atkinson (1976), using intrusion volume data, estimated the annual flux at 25 percent of the required new nitrogen.

Haines (1975) summarized some of the results of four cruises in 1971 and 1972 into a table of the standing stock of nitrogen in shelf waters (Table III-12). Based on more recent data discussed in this paper, she has probably underestimated the effect of Gulf Stream intrusions.

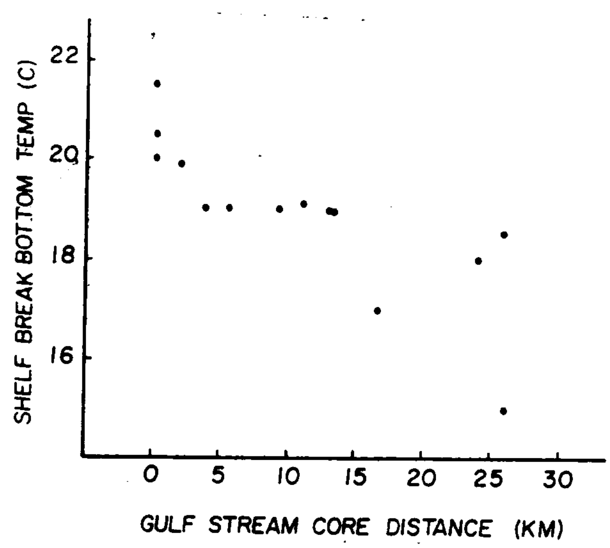


FIGURE III-20. Relation of the onshore/offshore position of the Gulf Stream to the near-bottom temperature at the shelf break (50m). The lateral position of the Gulf Stream was horizontal distance from the shelf break to the point at which the $20^{0}C$ isotherm reaches 100m depth. Data from Atkinson (1975, 1976). (From Atkinson, 1977).

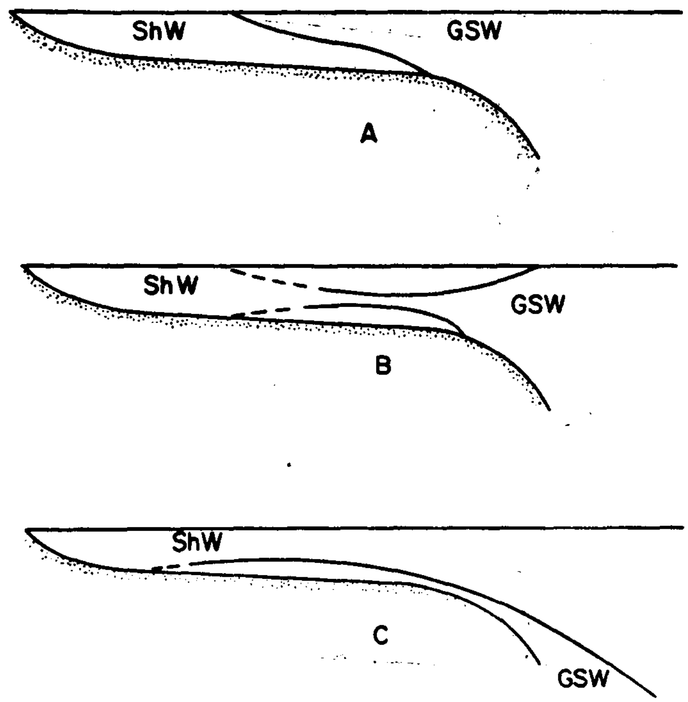


FIGURE III-21. Modes of Gulf Stream water (GSW) intrusion into shelf water (ShW): a) override; b) interleaving; c) bottom intrusion. (Atkinson, 1977).

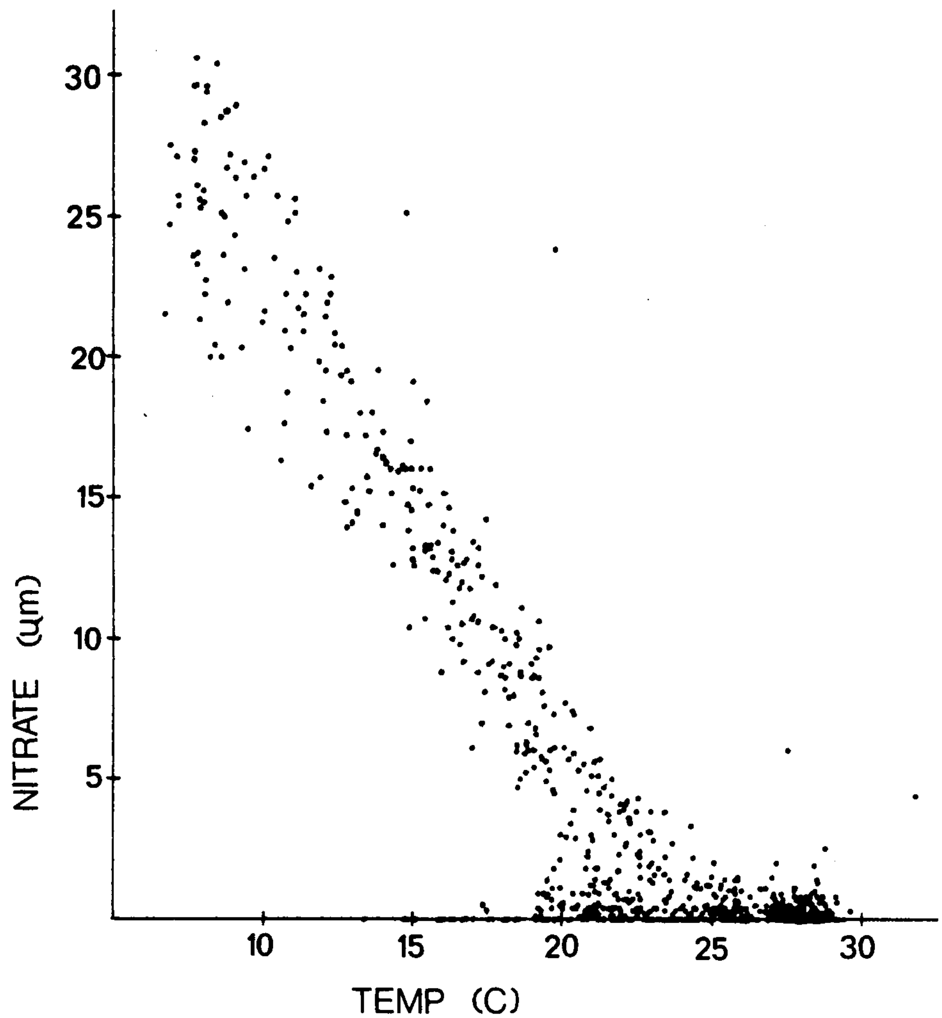


FIGURE III-22. Nitrate vs temperature for South Atlantic Bight waters (shelf and Gulf Stream). From Atkinson (1978).

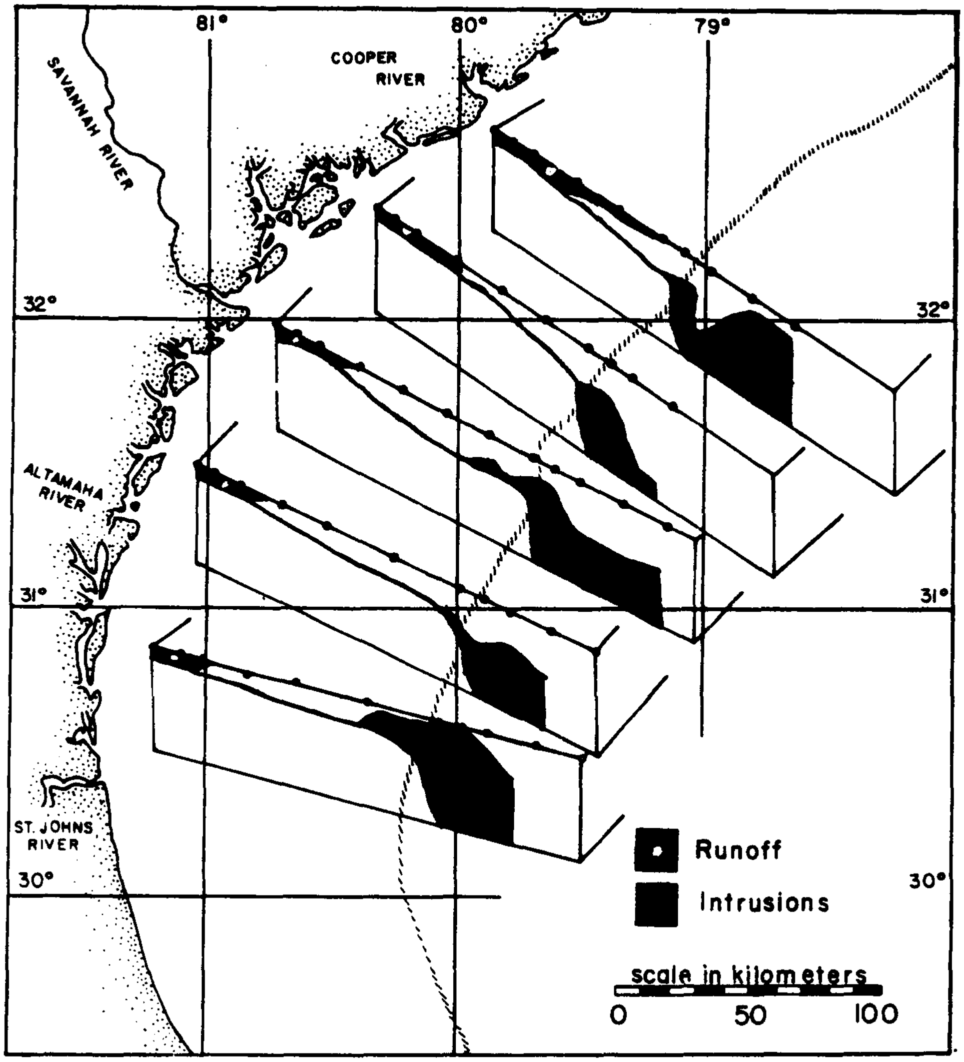


FIGURE III-23. Observed distribution of runoff (from the shore) and nutrient rich Gulf Stream intrusion water for cruise E-13-73 (Sept. 1973). From Atkinson (1978).

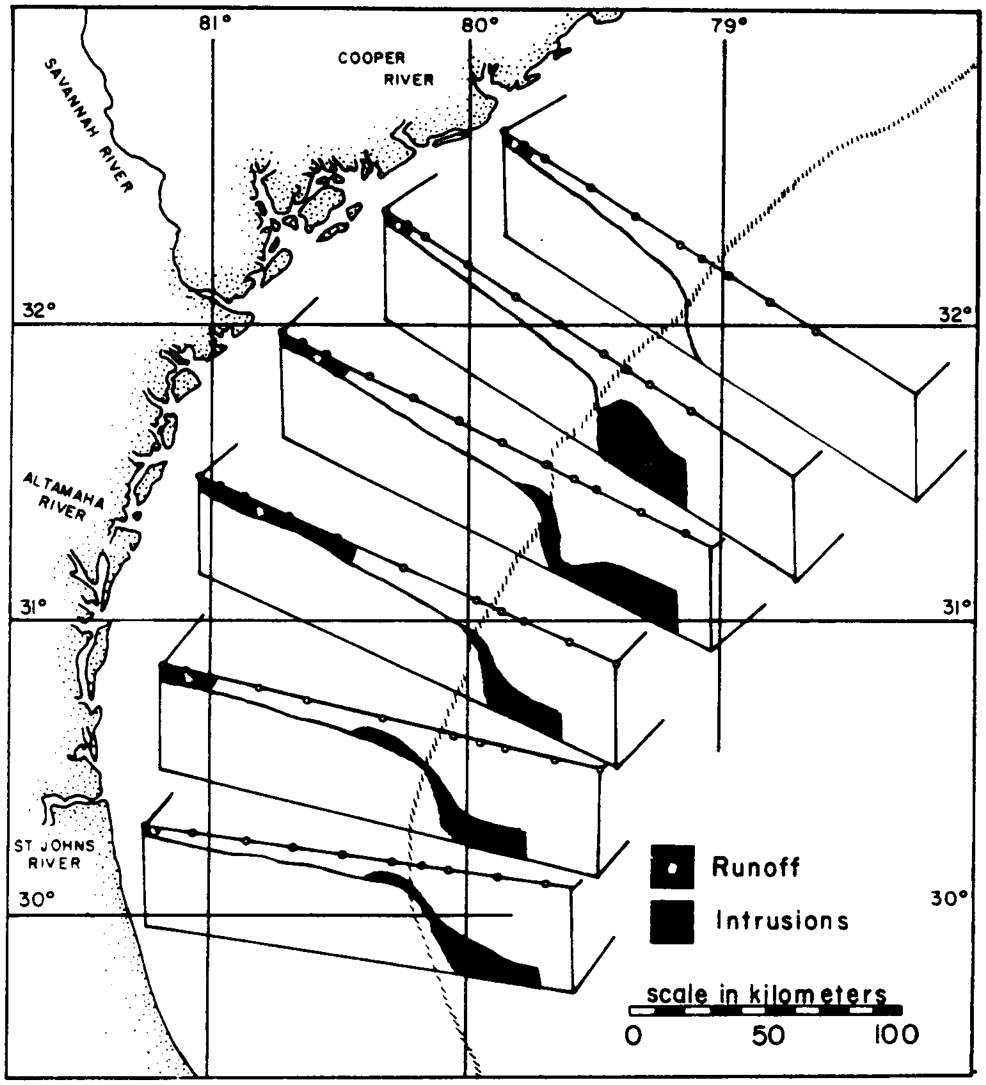


FIGURE III-24. Observed distribution of runoff (from the shore) and nutrient rich Gulf Stream water for cruise E-19-73 (Dec. 1973). From Atkinson (1978).

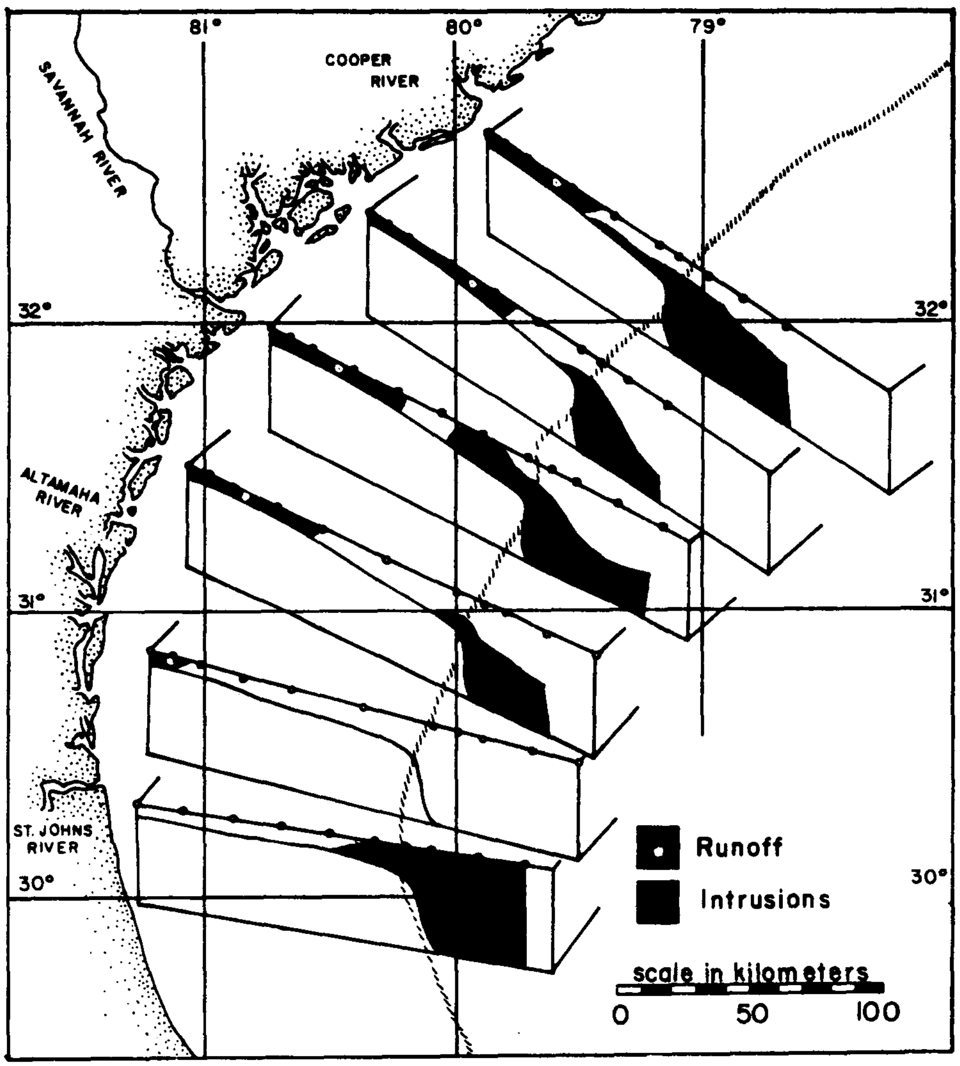


FIGURE III-25. Observed distribution of runoff (from the shore) and nutrient rich Gulf Stream water for cruise E-3-74 (April 1974). From Atkinson (1978).

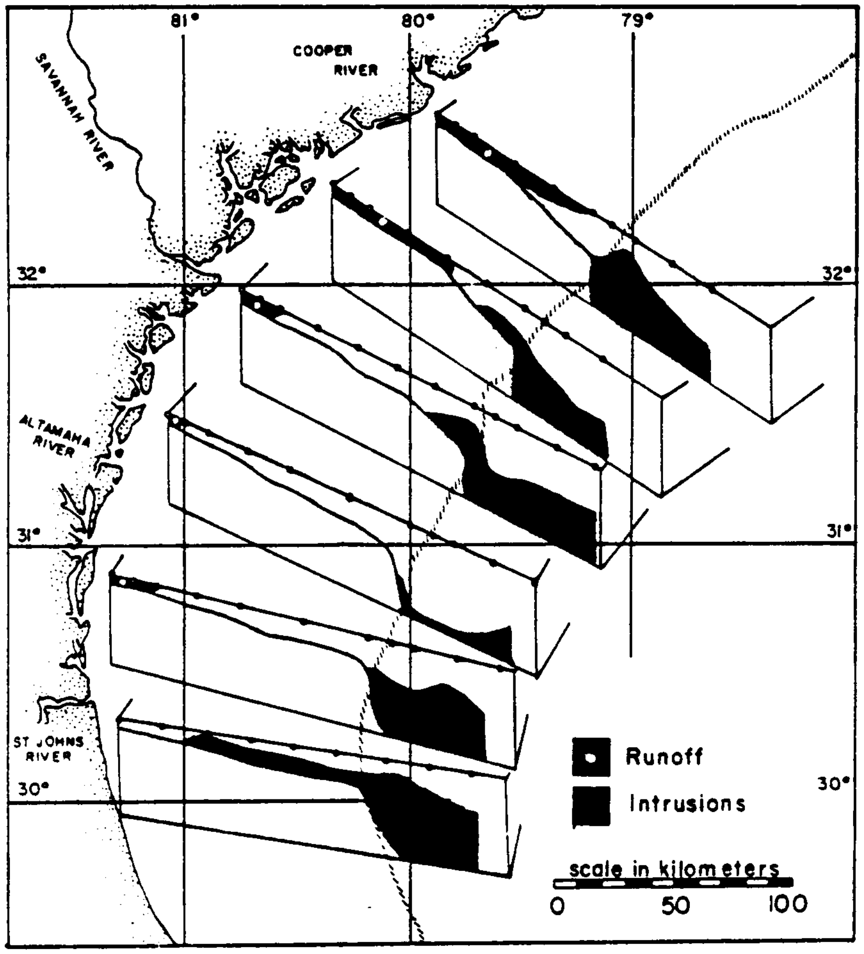


FIGURE III-26. Observed distribution of runoff (from the shore) and nutrient rich Gulf Stream water for cruise E-12-74 (July, 1974). From Atkinson (1978).

TABLE III-11. Average observed offshore extent of runoff and onshore extent of intrusions (Atkinson, 1978). Distances in km ± one standard deviation unit. n is number of observations.

AVERAGE OFFSHORE EXTENT OF RUNOFF

Section I (off Charleston)	56.5 ± 33.3	n= 4
Section II (off St. Helena Is.)	42.3 ± 23.6	n= 4
Section III (off Savannah)	33.8 ± 15.0	n= 4
Section IV (off Sapelo Is.)	37.8 ± 23.0	n= 4
Section V (off Jekyll Is.)	19.5 ± 1.3	n= 4
Section VI (off Jacksonville)	2.7 ± 4.6	n= 3
Average for all sections	33.4 ± 24.7 km	n=23

AVERAGE INSHORE EXTENT OF INTRUSIONS

Section I (off Charleston)	15.5 ± 17.2	n= 4
Section II (off Helena Is.)	12.8 ± 10.5	n= 4
Section III (off Savannah)	27.3 ± 9.5	n= 4
Section IV (off Sapelo Is.)	11.5 ± 1.3	n= 4
Section V (off Jekyll Is.)	13.5 ± 13.4	n= 4
Section VI (off Jacksonville)	40.0 ± 30.8	n= 3
Average for all sections	19.2 ± 16.6 km	n=23

TABLE III-12
Calculated nitrogen inputs, uptake, and standing stock in shelf waters between Charleston, South Carolina and Fernandina Beach, Florida (10^{10} gN). (From Haines, 1975)

	Nearshore Zone 0-20m	Total for Shelf 0-200m
Annual inputs		
Fresh-water drainage	-	0.42
Deep-water intrusions	-	0.76
Precipitation	0.29	0.75
Total		1.93
Annual uptake	46.7	93.7
Standing stock	0.48	1.88

There are only two important sources of new nutrients to the South Atlantic Bight: Gulf Stream intrusions and runoff. Runoff is not a significant nutrient source (Windom, Dunstan and Gardner, 1975). Intrusions of Gulf Stream water (Atkinson, 1977) are a significant source of "new" nutrients (Haines, 1975; Dunstan and Atkinson, 1976). Dunstan and Atkinson (1976) estimated that Gulf Stream intrusions could supply at least 25 percent of the nitrate requirements of shelf primary production.

The regeneration of nutrients, especially nitrate which is probably limiting, has not yet been measured directly in the South Atlantic Bight. It is the current feeling among area scientists that it is a very important source and may well control primary productivity during some seasons. To date no definitive experiments have been made.

While the previous discussion has focused on the Georgia Bight, there is also new information from the Onslow Bay area. Recent evidence (Singer, Atkinson, Chandler and O'Malley, 1977) confirms the previous observations made in the Bay that nutrient-rich waters do often invade the Bay in the summertime. Calculations of intrusion volumes (Atkinson, 1978, personal communication) show a range of 11 to 35 percent of the Bay volume. Although the nitrate concentrations in these intrusions were less than 1 μM, they are still an important source of nutrient since there are essentially no other sources.

2.1.3.3 Gulf Stream and Blake Plateau

The Gulf Stream and Blake Plateau (which essentially lies beneath the Gulf Stream) has not been the subject of any specific recent studies except as incidental to the South Carolina MARMAP study (Mathews and Pashuk,. 1977) and the DOE-funded studies at University of Georgia, Skidaway Institute, North Carolina State University and the University of Miami. No doubt there have been incidental measurements, especially by the EASTWARD program at Duke University.

The Gulf Stream is of course a region of steeply inclined isotherms. The concentrations of the principal nutrients (phosphate, nitrate and silicate) increase nearly linearly in proportion to decreasing temperatures (see nitrate vs. temperature plot in previous section (2.1.3) on continental shelf nutrients). The transport of this nutrient-rich water into shelf waters was already discussed in previous sections; however, there are some exciting new developments, especially with respect to the permanent Gulf Stream meander off Charleston.

The observations of Mathews and Paskuk (1977) over four cruises delineated the large Gulf Stream meander off Charleston (locally known as the "Charleston Bump"). Two figures from their study are shown. The section depicted is on the $32.5^{O}N$ parallel which runs essentially due east of Charleston. Figure III-27 is the temperature section and Figure III-28 is the phosphorus section. In the normal case the isotherms rise to the west and intersect the continental slope; however, in this case, a dome structure is present that is indicative of a large Gulf Stream eddy (Lee, 1975; Lee and Mayer, 1977). The vertical motions associated with this feature are important to the vertical flux of nutrients.

In this case, phosphate concentrations of 0.3 μm are found at 50m which is well within the euphotic zone. A phosphate concentration of 0.3 μm would correspond to a nitrate concentration of about 5 μm waters in this area. It would be expected that phytoplankton productivity would be particularly high in this area.

Little has been added to our basic concept of nutrient dynamics of the Gulf Stream (excluding shelf break/intrusion studies) since the Woods Hole studies in the 1930-1960 time span. The one new development is the awareness of the permanent meander off Charleston. This, however, is a fine tuning of our knowledge.

A large amount of data are being gathered by three groups: 1) the DOE funded researchers at Skidaway Institute, University of Miami, University of Georgia, and North Carolina State University; 2) Coast Guard Search and Rescue studies; and 3) Bureau of Land

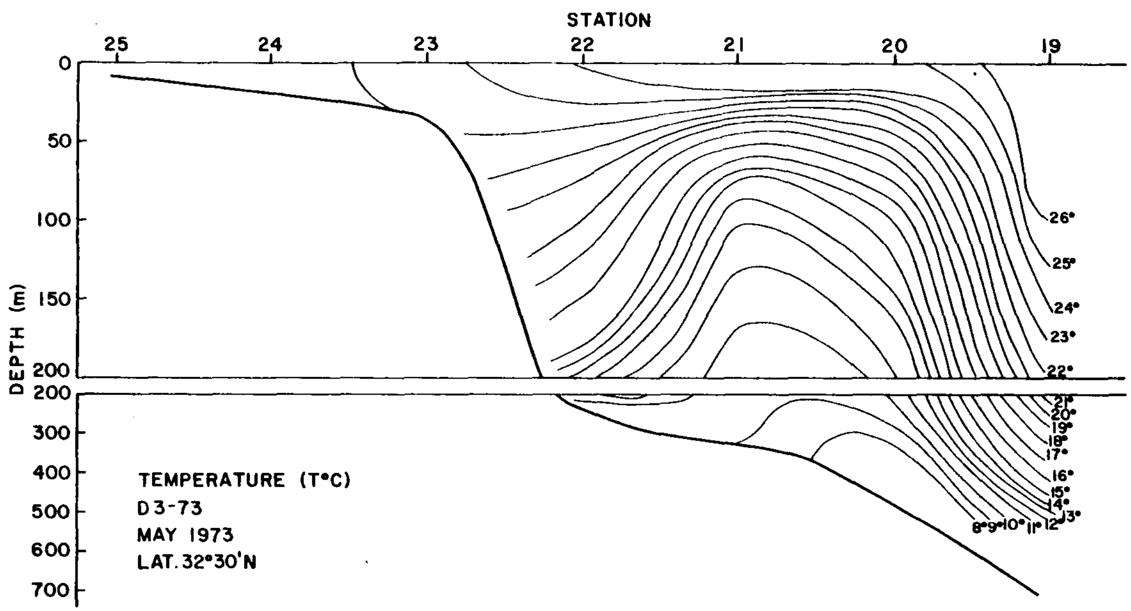


FIGURE III-27. Vertical distribution of temperature off Charleston, S. C. Note atypical "doming" of isotherms. Figure from Mathews and Pashuk (1977).

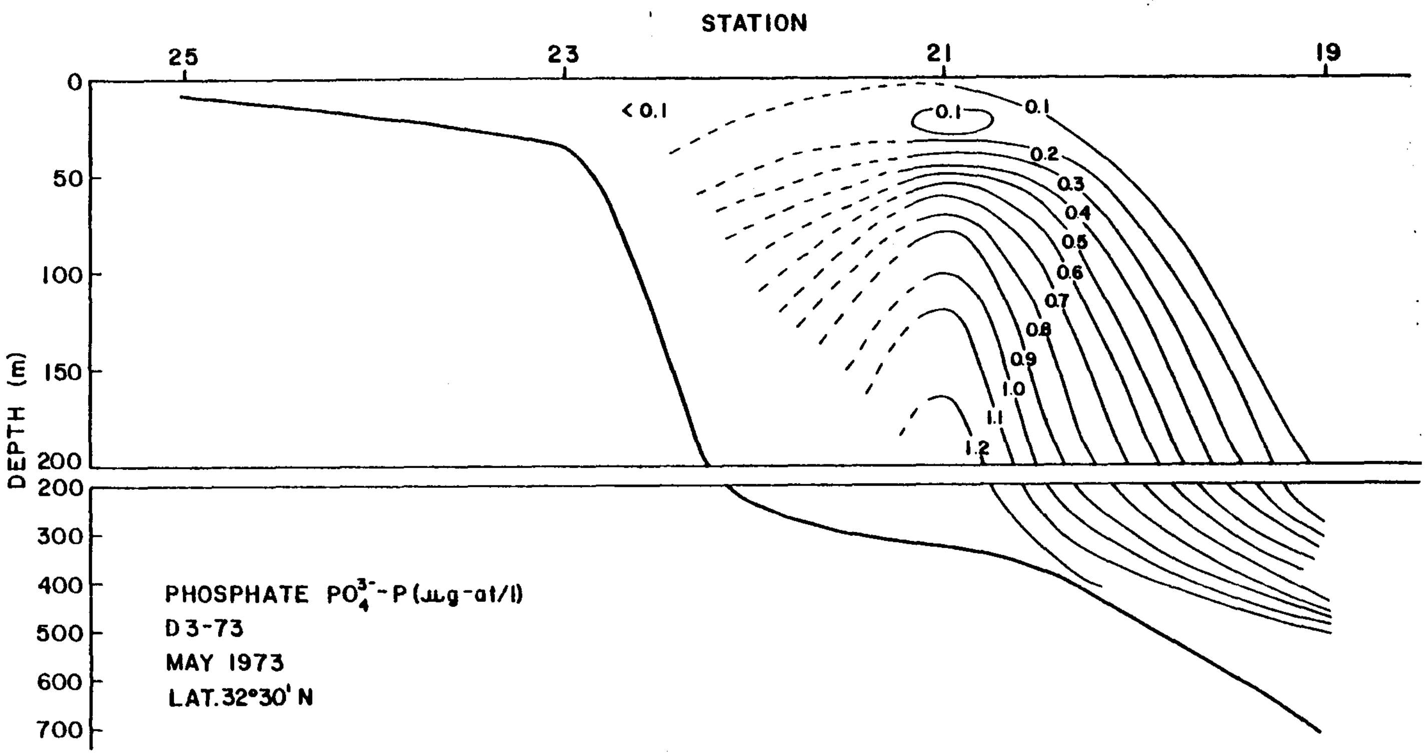


FIGURE III-28. Vertical distribution of phosphate off Charleston, S. C. Note rise of isolines to shallow depths in the "dome" structure. Data from Mathews and Pashuk (1977).

Management benchmark studies. All three data sources are regularly submitting their data to the NODC so it is available. We know of no large data sets that would be of value to the study of relevant processes that are lying in a state of permanent recluse. One exception may be data acquired by the Navy with respect to the submarine activities off Charleston, South Carolina. It could be reasonably assumed that they have a large amount of information and knowledge from the area and have it classified.

2.1.4 Chlorinated Hydrocarbons in the Water Column

2.1.4.1 Rivers and Estuaries

The Indian River Ecological Study analyzed water from this estuarine river and lagoon system located near Titusville, Florida, for heptachlor epoxide, ethion, malathion and dieldrin (Gibson, 1978, personal communication). On a weekly or monthly basis the sediments and waters of South Carolina at 350 stations have been analyzed for pesticides by the U. S. Geological Survey of South Carolina (Harris, 1978, personal communication). The pesticides included diazinon, DDA, DDD, DDE, DDT, dieldrin, aldrin, buthoion, carbaryl, chlordane, ednrin, ethion, heptachlor, heptachlor epoxide, lindane, methoxychlor, methylparathion, mirex, telodrin, toxaphene and toxaphene. DDT and DDE have been analyzed in the Santee River, South Carolina (Mathews, 1978, personal communication). Concentration of pesticides in these waters is generally very low (Table III-13).

2.1.4.2 Continental Shelf

Harvey, Steinhauer and Teal (1973) analyzed PCBs in Atlantic ocean surface waters. Between 25°N and 35°N the concentrations ranged from 1 to 88 x 10^{-3} μg/liter. At a station at 27°N, 67°W the PCB concentration at 10m, 150m and 600m was 0.7, 0.8 and 0.9 x 10^{-3} μg/liter, respectively (Harvey and Steinhauer, 1976a).

2.1.5 Radionuclides in the Water Column

No studies on radionuclides in the water column were reviewed by Roberts (1974). Very little data have been produced since then. Much of the data which has been accumulated has been by the Department of Energy's Savanah River Laboratory and is not available to the public. Most of this, however, has dealt with the upper Savannah River. The only publication that has dealt with radionuclides in southeastern waters is that of Hayes, LeRoy and Cross (1975). They measured the activity of plutonium-239 and plutonium-240 in estuarine particulates collected in the Neuse,

TABLE III-13.

Pesticide analyses from South Carolina water samples. From Law (1971).

(μg/l)

Sampling Site	Date & Time	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane	2,4-D	2,4,5,-T	Silvex
PB-1 Cooper R. at mile 5.2 Charleston	5-4-71 0900	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Trace
PB-10 W. branch Cooper R. at mile 35.4 Berkeley	5-4-71 1350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
PB-11 Winyah Bay 1 mi. below Sampit R. nr Georgetown	5-25-71 1030									Trace	Trace	0.00

Newport and Savannah River estuaries (Table III-14). Assuming that plutonium is primarily associated with particulate matter, these authors estimate that estuarine waters contain 0.24-2.4 f Ci/liter.

Hayes and co-workers at the Savannah River Laboratory of E. I. du Pont de Nemours and Company in Aiken, South Carolina, are continuing their work on the plutonium distribution in southeastern Atlantic estuaries (Hayes, 1978, personal communication). They are also conducting investigations of tritium in coastal and estuarine waters. Cross at the NOAA, NMFS Lab in Beaufort, North Carolina, is collaborating on this project (Cross, 1978, personal communication).

2.2 Sediments

2.2.1 Hydrocarbons in Sediments

2.2.1.1 Rivers and Estuaries

Fluoranthene and benzo(a)pyrene have both been identified in sediments from the Cooper River, South Carolina, in an area heavily contaminated with oil (Lee, 1978). Sediment samples from the Santee River, South Carolina, have been analyzed for "oil" quarterly during one year (Mathews, 1978, personal communication). Analysis by the Environmental Protection Agency (Linton, 1972) show high concentrations of "oil and grease" in sediments of the Charleston Harbor (Table III-15).

2.2.1.2 Continental Shelf

In continental slope and continental shelf areas, hydrocarbon concentrations in the sediment generally are in the range of 1 to 100 μg/g (Farrington and Meyer, 1975). Inshore areas generally have much higher hydrocarbon concentrations. Farrington and Tripp (1977) report on some hydrocarbon analyses of sediment from 31°N. The concentration of hydrocarbon was 1.2 μg/g with no aromatics detected. The concentration of $n\text{-}C_{17}$ was 5.1×10^{-3} μg/g and for $n\text{-}C_{29}$ was 32×10^{-3} μg/g. The preliminary results of Warner (1978) for the Bureau of Land Management's OCS study of the South Atlantic Benchmark Program shows hydrocarbon concentrations in the sediment to range from 0.2 to 2.0 μg/g. These appeared to be primarily biogenic hydrocarbons. Pyrene and fluoranthene have been isolated from manganese nodules collected on the Blake Plateau (30°N, 78°W; Thomas and Blumer, 1964).

The recently completed BLM South Atlantic OCS Benchmark Study will produce considerable new data on hydrocarbons in sediments.

TABLE III-14. Measurements of Pu-239, 240 in estuarine particulate matter. (From Hayes et al., 1975).

Sample Location (See Figs. 1 & 2)	Salinity Parts per Thousand	Activity in Particulates (5-μm + 1-μm) fCi/l water[a]	Concentration of 5-μm Particulate Matter, mg/l water	Portion of Total Particulate Activity in 5-μm Fraction, %[b]	5-μm Particulate Activity, fCi/g ash
Neuse River Estuary[b]					
Station 1	<0.1	0.42 ± 0.08	2.5	30	
2	2.8	0.28 ± 0.11	1.3	23	49
3	5.4	0.52 ± 0.20	1.9	22	60
4	8.3	0.45 ± 0.06	2.7	53	89
5	9.8	0.60 ± 0.06	2.9	47	97
Beaufort Inlet	34.1	1.20 ± 0.12	12.7	62	59
Newport River Estuary[c]					
Station 1	<0.1	0.24 ± 0.08	0.8	22	66
2	1.4	1.83 ± 0.24	8.1	29	66
3	4.8	2.13 ± 0.31	9.5	35	79
4	9.8	1.56 ± 0.21	3.9	23	92
5	13.1	2.53 ± 0.40	9.5	18	48
		1.23 ± 0.25	5.6	24	52
Savannah River Estuary[d]					
Station 1	<0.1	0.25 ± 0.07	3.0	17	14
2	1.6	0.47 ± 0.10	3.6	31	40
3	3.1	0.57 ± 0.10	3.4	24	40
4	6.8	0.35 ± 0.10	3.5	45	45
5	14.4	0.64 ± 0.13	6.7	30	28
6	27.4	0.17 ± 0.03	7.4	87	20

[a]The drinking water standard for plutonium is 5×10^3 fCi/l [15].

[b] $\frac{^{239,240}\text{Pu in the 5-μm particulates}}{^{239,240}\text{Pu in the (1-μm + 5-μm) particulates}} \times 100$

[c]See Figure 1.

[d]See Figure 2.

TABLE III-15. Concentrations of oil and grease in Charleston Harbor sediment samples (collected March 1971). From Linton (1972).

Lab No.	Sample No. 1/	Percent Dry Weight Oil and Grease
EPA LIMITS		0.15
71-306	NMF-1	0.715
71-307	NAD-1	0.903
71-308	NAD-2	0.542
71-309	NAD-3	0.698
71-310	NAD-4	0.442
71-311	CC-1	0.737
71-312	S12-1	0.717
71-313	S12-2	0.283
71-314	S12-3	0.156
71-315	S3-1	0.598
71-316	S4-1	0.518
71-317	S4-2	0.124
71-318	S5-1	0.121
71-319	S5A-1	0.069
71-320	S5A-2	0.072
71-321	S5A-3	0.260
71-322	S5A-4	0.313
71-323	SR-1	0.234
71-324	SR-2	0.285
71-325	SR-3	0.042
71-326	SR-4	0.107
71-327	S6-1	0.094
71-328	S6B-1	0.019
71-329	S6A-1	0.090
71-330	S6A-2	0.066
71-331	S6A-3	0.063
71-332	S6A-4	0.136
72-333	S6C-1	0.074
71-334	S6C-2	0.054
71-335	S6C-3	0.007
71-336	CHR-1	0.072
71-337	TWR-1	0.226
71-338	AB-1	0.012
71-339	AB-2	0.058
71-340	AB-3	0.075
71-341	AB-4	0.048
71-342	EC-1	0.030
71-343	EC-2	0.028
71-344	EC-3	0.026
71-345	EC-4	0.038
71-346	EC-5	0.008

2.2.2 Trace Metals in Sediments

2.2.2.1 Salt Marsh and Estuarine Sediments

Many publications describe various types of trace metal studies that have been conducted in southeastern Atlantic salt marsh estuaries. Some of these have been general surveys but most are addressed to the biogeochemical behavior of these substances in sediments. Studies have dealt with the interactions between the sedimentary and water columns as well as the exchange of trace metals from sediments to biota. For this reason, many of the references cited here are also cited in trace metal sections dealing with the water column or biota.

General sediment exchange processes which determine particulate matter fluxes through salt marshes have been investigated by Settlemyre and Gardner (1975b; 1977). Gardner (1976) found that salt marsh sediments are enriched in trace metals such as molybdenum, copper, and zinc as compared to river flood plain sediments. This may be related to the findings of Settlemyre and Gardner (1977) who found that salt marshes import inorganic suspended solids and export organic suspended solid, if the latter is less enriched in these elements.

Several workers have estimated trace metal budgets in salt marsh sediments. Using data on trace metal distributions in marsh sediments with depth and a sedimentation-diffusion model (Figure III-29), Bhate (1972) calculated budgets for iron, manganese, zinc, copper, nickel, and cobalt. These budgets took into account advection-diffusion, sediment accumulation and uptake by *Spartina alterniflora*. Bhate (1972) also evaluated metal distributions in relation to vertical variations in Eh, pH, and sulfide potential.

Settlemyre and Gardner (1975a) determined the concentration of iron, copper, zinc, and lead flow into and out of a salt marsh. No significant differences were observed in the concentration of copper, zinc, and lead, but observed variations in the iron concentrations suggest that marshes may export this metal at a rate of 1.0 g/m^2 per year. These authors also evaluated the various processes which may influence trace metal transfer through salt marshes.

Studying two different marsh sites, Barnes, Craft and Windom (1973) estimated budgets for iron and scandium (Table III-16). These indicate that plant uptake is an important process.

Windom (1976a) determined trace metal concentrations in salt marsh cores collected at 25 stations between Georgetown, South Carolina,

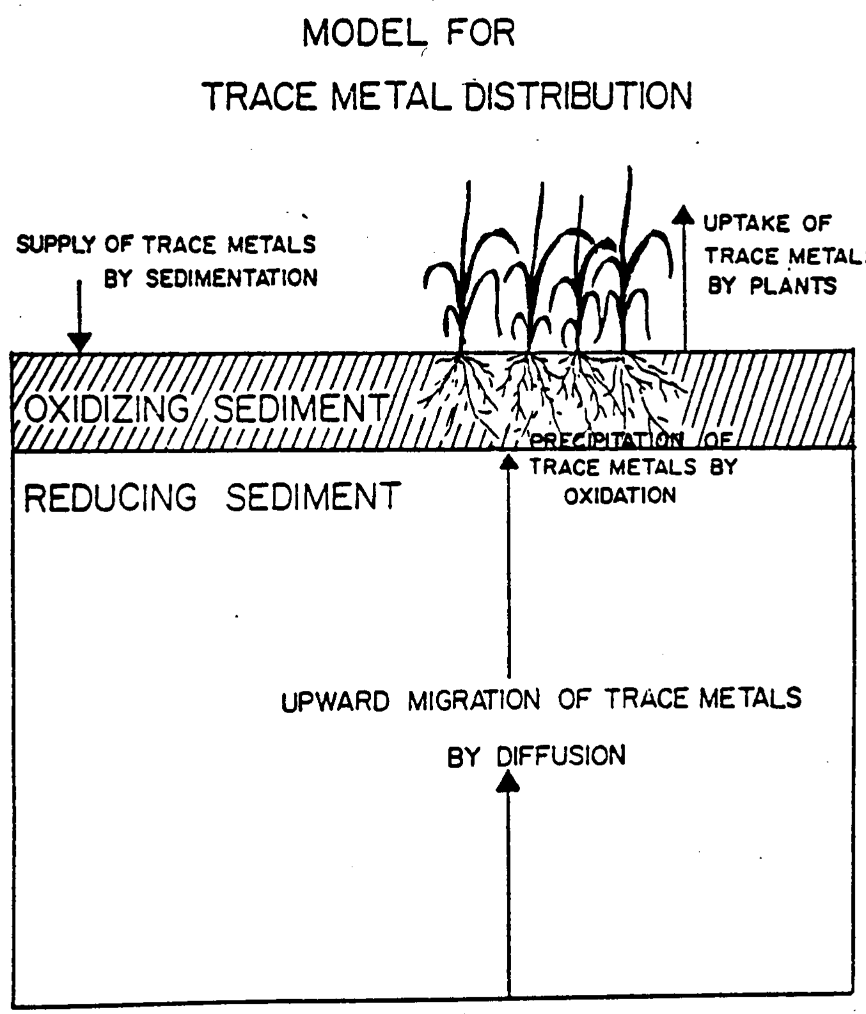


FIGURE III-29. Model for trace metal distributions in marsh sediments showing various processes involved in the supply and removal of trace metals from sediments. (From Bhate, 1972)

TABLE III-16. Budgets for iron and scandium in salt marsh sediments. From Barnes et al., 1973.

Marsh sedimentation rate = 1 mm/yr or ≅ 0.50 mm/yr (dry wt)
Sediment density = 2 g/cm³
Annual production of *Spartina alterniflora* ≅ 700 g/m²/yr (dry wt)

	Thunderbolt	Hell Gate
Av. per cent of Fe in sediment	2.9	1.8
Av. per cent of leachable Fe in sediment	0.8	0.3
Av. ppm Sc in sediment	14.4	12.7
Fe accretion rate in sediment	20-30 $g/m^2/yr$	18-20 $g/m^2/yr$
Sc accretion rate in sediment	1.4-1.5 x 10^{-2} $g/m^2/yr$	1.3 x 10^{-2} $g/m^2/yr$
Fe uptake by plants	1.5 $g/m^2/yr$	0.9 $g/m^2/yr$
Sc uptake by plants	1.9 x 10^{-4} $g/m^2/yr$	2.0 x 10^{-4} $g/m^2/yr$
Per cent Fe removed by plants	~6	~5
Per cent leachable Fe removed by plants	~20	~30
Per cent Sc removed by plants	<1	<1

and Jacksonville, Florida (Figure III-30). Samples were analyzed for iron, manganese, copper, mercury, cadmium, lead, and zinc (Table III-17). Of the total amounts of iron, manganese, cadmium, and mercury transported into the salt marsh system by rivers, Windom (1976a) estimates that 100 percent of the iron, 64 percent of the manganese, 17 percent of cadmium, and 11 percent of the mercury is lost to sediments.

Trace metal interactions between sediments and biota have been the subject of several studies conducted in the southeastern Atlantic estuarine environment. The early work of Williams and Murdoch (1969) considered the interactions between Spartina alterniflora and sediments in the cycling of zinc, manganese, and iron. Subsequently, Rahn (1973) evaluated this same interaction for mercury. Dunstan, Windom and McIntire (1975) investigated the role of Spartina alterniflora on the flow of lead, cadmium, and copper through the salt marsh ecosystem. They found little relationship between concentrations in the plant and those in the sediment (Figure III-31).

Whaling, Barber and Paul (1977) have determined the concentrations of mercury, cadmium, chromium, copper, iron, lead, manganese, and zinc in sediments of Calico Creek, North Carolina, near a municipal sewerage outfall. These investigators also determined metal levels in macrobenthic organisms from the area. For most metals, a clear relationship was found between concentrations in sediments and organisms with distance from the outfall. A study by Windom, Gardner, Stephens and Taylor (1976) of the mercury distribution in sediments in the vicinity of a chlor-alkali plant showed similar results.

In each of the four states bordering the study area of this review, many ongoing monitoring programs are conducted which result in data on sediment trace metal concentrations. The Wilmington, Charleston, Savannah, and Jacksonville Districts of the U. S. Army Corps of Engineers routinely monitor sediments in harbors and waterways as a part of their dredging program (Kutscheid, 1978, personal communication; Carothers, 1978, personal communication; DeRigo, 1978, personal communication; L. Sanders, 1978, personal communcation). As a result, they generally have extensive sediment trace metal data. Research programs conducted by Gardner and co-workers at the University of South Carolina (Gardner, 1978, personal communication), the Marine Resources Research Institute in Charleston, South Carolina (Mathews, 1978, personal communication), and Barber (1978, personal communication) and associates at Duke University have ongoing programs which relate to trace metals in sediments.

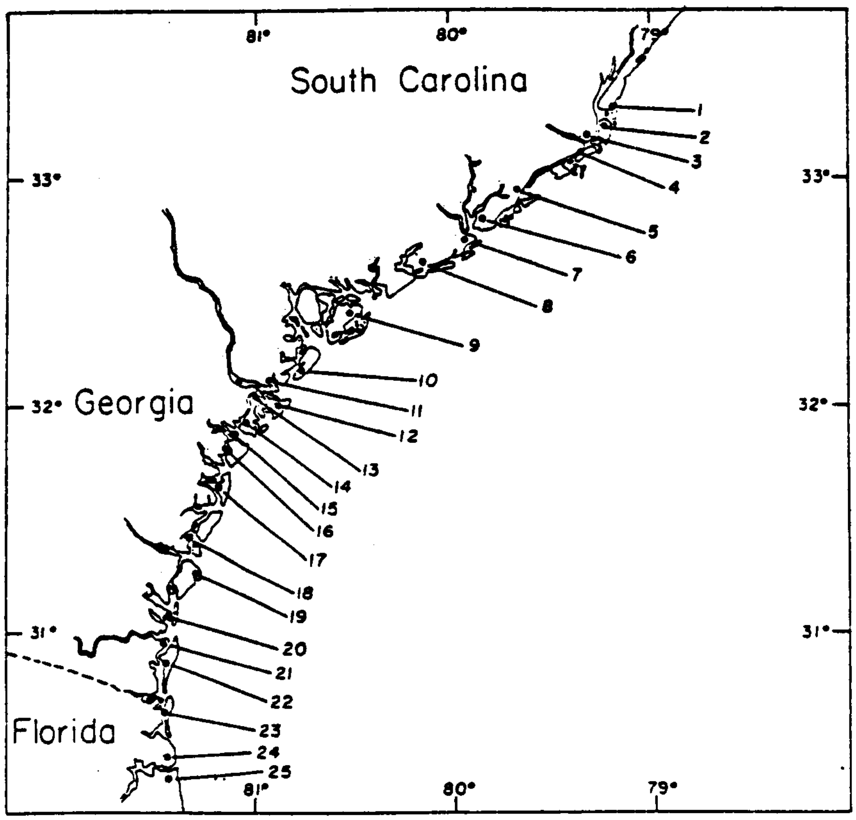


FIGURE III-30. Locations of salt marsh cores analyzed by Windom (1976a).

TABLE III-17. Average metal concentrations in marsh cores. Station numbers correspond to those shown in Figure III-30. From Windom (1976a).

Station Number	% Fe	ppm Mn	Cu	Hg	Cd	Pb	Zn
1	3.9	103	30	0.12	3.4	25	63
2		250	16	0.09	5.0	26	67
3	3.9	166	26	0.16	2.9	20	67
4	5.0	142	25	0.05	3.3	20	72
5		209	24	0.08	4.4	27	70
6		158	10	0.01	1.0	16	36
7	1.2	139	4	0.04	0.4	9	51
8	1.8	114	4	0.02	0.8	9	21
9	4.1	309	16	0.04	2.1	13	51
10	1.9	174	3	0.04	0.1	4	11
11	2.4	151	8	0.06	0.5	8	67
12	4.8	260	12	0.09	0.6	16	70
13	4.6	353	20	0.16	0.8	21	81
14	3.4	319	10	0.10	0.4	20	57
15	4.0	173	10	0.11	018	19	64
16	2.9	366	8	0.02	0.8	15	48
17	2.7	262	6	0.05	0.2	20	42
18	3.2	273	12	0.16	0.8	24	61
19	1.1	175	4	0.03	1.6	11	17
20	3.7	168	8	0.06	0.8	15	43
21	3.1	244	8	0.07	1.2	12	37
22	4.7	132	7	0.06	0.8	13	39
23	2.9	128	10	0.08	0.7	20	45
24	0.9	205	5	0.05	0.8	15	21
25	1.5	74	2	0.05	0.4	9	15
Mean	3.1	202	11	0.07	1.4	17	49
Average Accumulation Rate* ($mg/m^2 \cdot yr$)	4.5×10^4	303	16	10	2.1	25	71

*Assuming an average sedimentation rate of 1 mm/yr and an average specific gravity of marsh sediments of 1.5 g/cc.

Analytical techniques similar to those for suspended sediment.

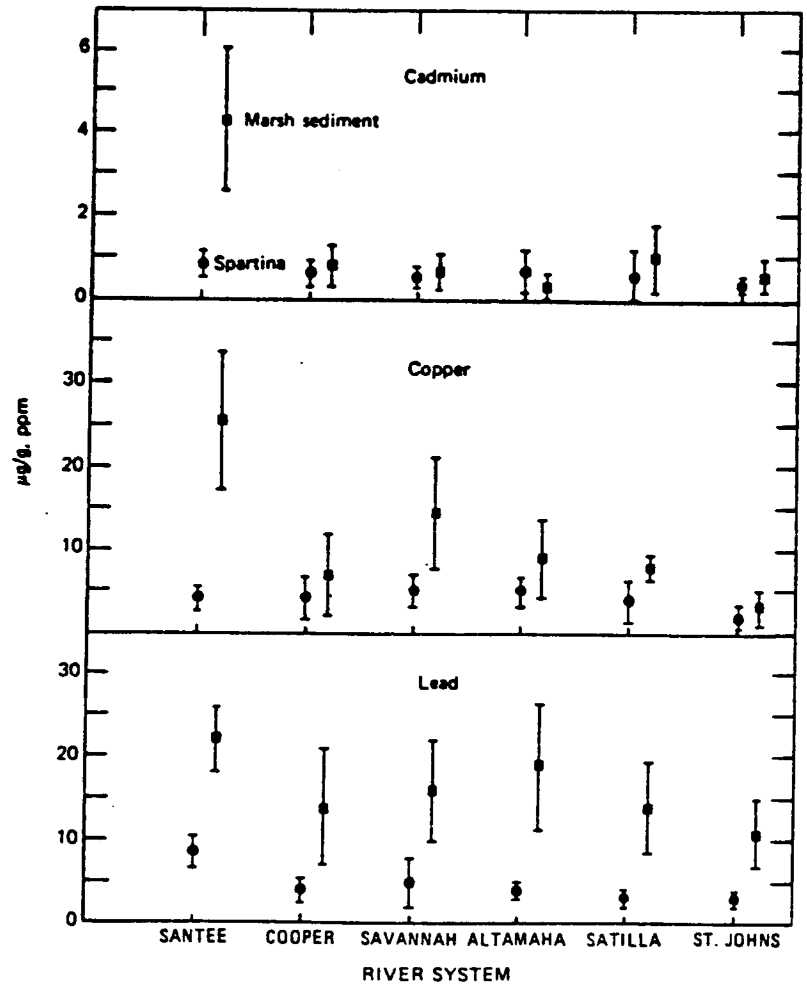


FIGURE III-31. Mean metal concentrations in *Spartina* and marsh sediment from six southeastern rivers. Each Point represents the mean of at least six measurements for *Spartina* and 10 measurements for the sediment. The standard deviation about each mean is indicated by the vertical lines. From Dunstan et al. (1975).

2.2.2.2 Continental Shelf and Blake Plateau

There have been no publications on the trace metal concentration of continental shelf sediments. Ongoing programs are, however, producing extensive data on this subject and much of this should be published soon. For example, M. Bothner of the U. S. Geological Survey has completed a study of the vertical distribution of copper, zinc, chromium, and lead-210 in cores collected from the continental shelf off Georgia (1978, personal communication). This data should be available in report form by the summer of 1978. Results of the BLM South Atlantic OCS Benchmark program conducted by Texas Instruments will contain extensive trace metal data for surficial sediments and should also be available soon.

Trace metal concentrations in sediments of the Blake Plateau are dominated by manganese nodules. A survey of the composition of manganese nodules from this areas has been made by Manheim (1974). No other data are available, although some corporations interested in these mineral deposits have conducted proprietary investigations.

2.2.3 Nutrients in Sediments

The interrelationship between nutrients and the sediment is discussed in the section on rivers and estuaries. There have been no reported studies specific to this topic relative to shelf sediments.

Studies that have been conducted indicate that the sediment is not a significant source of nutrients for the South Atlantic Bight waters. Gardner and Menzel (1974), for example, found particulate carbon in the sediment to decrease rapidly offshore, implying that nutrient release rates would also decrease rapidly in the offshore direction.

South Atlantic Bight sediments are, in general, not fine grained and areas of mud or clay that would be conducive to anoxic conditions are rare or non-existent. Therefore, the sediments are not expected to be a significant nutrient source. Reidl, Huang and Machan (1972) did make an interesting study of the "tidal pump", a mechanism by which interstitial waters are advected out of the sediment as a result of tidal action. However, since it is anticipated that nutrient concentrations in the sediments are very low, the resultant flux would be minimal.

2.2.4 Chlorinated Hydrocarbons in Sediments

2.2.4.1 Rivers and Estuaries

Estuarine sediments near Georgetown, South Carolina, had concentrations of 1.8, 1.9, and 3.0 ng/g for DDE, DDD, and PCB, respectively (Williams and Bidleman, 1977; 1978). Toxaphene was less than 3 ng/g (Table III-18). Concentrations of pesticides in sediments of the Cooper River are shown in Table III-19. The Army Corps of Engineers has data on the amounts of aldrin, DDE, DDD, DDT, and dieldrin, endrin, heptachlor, lindane, and 2,4-D in sediments in coastal waters of Florida (L. Sanders, 1978, personal communication). Estuarine sediments collected near a toxaphene plant near Brunswick, Georgia, had toxaphene concentrations of up to 180 μg/g but less than 3 μg/g after reduction of plant effluent (Reimold and Durant, 1974; Reimold, 1975; Robinson, 1978, personal communication). Dieldrin and DDE were also determined in this area.

TABLE III-18

Levels of chlorinated hydrocarbons in sediments collected at the North Inlet Estuary, South Carolina (means of 4-6 results). From Williams and Bidleman (1977).

ORGANOCHLORINES IN MARSH SEDIMENTS

	10^{-9} g/g Dry Wt.*
Aroclor 1254	3.0
p,p-DDE	1.8
p,p-DDD	1.9
Toxaphene	<3 ?

*Upper 1-5cm

2.2.4.2 Continental Shelf

In the bottom sediments of the open Atlantic Ocean between 25 and 33°N where water depths were 4000 to 6000m, the PCB concentrations ranged from 0.1 to 57 μg/kg (Harvey and Steinhauer, 1976b).

2.2.5 Radionuclides in Sediments

Hayes et al. (1975) determined the concentrations of plutonium in surface marsh sediments from the Savannah River estuary. Increased plutonium-238 alpha percentages above that expected from fallout were assumed to result from releases from the Savannah River Nuclear Plant. Total plutonium activity in surface sediments of between 4 and 11 fCi/g decreased at depths to about 0.1-1 fCi/g.

TABLE III-19.
Pesticide analyses for Cooper River, South Carolina bottom sediments.
From Law, 1971.

(μg/kg)

Sampling Site	Date & Time	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane	2,4-D	2,4,5-T
PB-1 Cooper R. at mile 5.2	5-4-71 0900					1.7	0.0				
PB-2 Cooper R. at mile 8.0	5-4-71 0930					1.1	0.0				
PB-3 Cooper R. at mile 10.3 at mouth of goose C	5-4-71 1020					0.0	0.0				
PB-4 Clouter C 1.5 mile from North Confluence with Cooper R.	5-4-71 1045	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
PB-5 Clouter C 1/4 mile from Northern Confluence with Cooper R.	5-4-71 1035					0.0	0.0				
PB-6 Cooper R. at mile 15.5	5-4-71		0.0		0.0	0.0	0.0				
PB-7 Cooper R. at mile 19.0	5-4-71 1152	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0		
PB-8 Durham C. Canal 1/4 mi. from Northern Confluence with N. Branch Cooper R.	5-4-71 1330	0.0	8.4	1.5	0.0	0.0	0.0	0.0	0.0		

Goldberg, Griffin, Hodge, Koide and Windom (1978) also investigated the distribution of plutonium in the Savannah River estuary. Using the lead-210 dating method, they determined rates of sediment accumulation and established time-stratigraphic horizon plutonium profiles. Cesium-137 was also measured in these depth profiles. Activities of these isotopes in the surface sediment were found to be similar to those of other similar estuarine environments.

Hayes and co-workers at the Savannah River Plant have an ongoing program of study of both plutonium and tritium in southeastern Atlantic estuarine sediments (Hayes, 1978, personal communication).

2.3 Biota

2.3.1 Hydrocarbons in Biota

2.3.1.1 Estuarine Organisms

We can find little reported information on hydrocarbons of the biota from the region of study. Using a liquid-chromatograph with a fluorescence detector, some preliminary work has been done on benzo(a)pyrene from oysters (*Crassostrea virginica*) collected in estuarine rivers of South Carolina and Georgia (Lee, 1978). Oysters from pilings treated with creosote had concentrations of benzo(a)pyrene from 40 to 100 μg/kg of this compound. Oysters from the mouth of the Savannah River had 3 μg/kg, while oysters collected near oil storage tanks along the Cooper River had up to 200 μg/kg. The major fluorescent hydrocarbon in oysters from the Cooper River was fluoranthene.

The uptake, metabolism, and discharge of hydrocarbons by a variety of marine invertebrates from this area has been under investigation for several years (Lee, 1976; Lee, Ryan and Neuhauser, 1976; Singer and Lee, 1977).

2.3.1.2 Continental Shelf Organisms

A few preliminary studies on the plankton of the southeast coast have been carried out (Lee, 1978). The major hydrocarbon in phytoplankton was the polyunsaturated olefin, 21:6, which has been identified in a number of phytoplankton species (Blumer, Guillard and Chase, 1971; Lee and Loeblich, 1971). The copepod, *Eucalanus* sp., which is a common zooplankter in these offshore waters, had pristane as the major hydrocarbon and only traces of the 21:6

hydrocarbon (Lee, 1978). The Bureau of Land Management's OCS studies (Warner, 1978) have collected and analyzed zooplankton and benthic fauna from offshore. In benthic fauna, the concentration of paraffins was 1 to 100 µg/g and 0.1 to 10 µg/g in the unsaturated/aromatic fraction. Pristane, C_{15}, C_{17}, and C_{19} were the dominant hydrocarbons in the paraffin fraction. Pristane and biogenic olefins predominated in zooplankton hydrocarbon fractions.

As part of a National Marine Monitoring Program supported by the Environmental Protection Agency, Scripps Institute of Oceanography and Woods Hole Oceanographic Institute are carrying out a survey of bivalves, primarily mussels, from east and west coastal areas, in order to use these animals as an early warning system for pollutants. The focus of the analysis is on PCB, DDT, and three- and four-ring polycyclic aromatic hydrocarbons (Goldberg and Farrington, 1977). In most areas, mussels are being used, but, because mussels do not occur in some areas of the southeast, oysters or clams are being analyzed.

2.3.2 Trace Metals in Biota

2.3.2.1 Plants

Macrophytes and Macroalgae

The major primary producer in the coastal zone of the southeastern United States is the salt marsh macrophyte, *Spartina alterniflora*, or smooth cordgrass. No data were reported for trace metal concentrations in this plant in the 1974 VIMS report (Roberts, 1974), although Williams and Murdoch (1969) had determined its concentration of iron, manganese, and zinc. Also, Bhate (1972), studying the distribution of trace elements in salt marshes, reported the concentrations of copper, cobalt, iron, manganese, mercury, nickel, and zinc in *Spartina alterniflora* leaves and stalks. Windom (1972a) reported average concentrations for arsenic, cadmium, copper, lead, mercury, and zinc in *S. alterniflora* based on eight analyses and, subsequently, Windom (1975b) reported mean values for iron, manganese, cadmium, copper, and mercury in this species collected from 25 stations between Cape Romain, South Carolina, and Amelia Island, Florida. Barnes et al. (1973) determined the concentration of iron and scandium in *Spartina*. Whaling et al. (1977), in a detailed study of the distribution of metals in Calico Creek, North Carolina, reported the concentrations of mercury, cadmium, chromium, copper, iron, lead, manganese, and zinc in the leaves, stems, and roots of this plant. Dunstan and Windom (1975) have also reported metal concentrations in *Spartina* as a part of their work on heavy metal influences on this plant. The results of these studies (Table III-20) show reasonably good agreement between investigators.

The ability of S. alterniflora to accumulate large concentrations of metals has led many workers to evaluate its role in the transfer of these materials. Williams and Murdoch (1969) concluded that this plant is potentially important in conveying zinc, manganese, and iron into estuarine food chains. Bhate (1972), based on budgets of metals in salt marshes, concluded that Spartina alterniflora annually removes about 2, 6, 14, 26, 47, 37, and 100 percent of the available iron, manganese, zinc, copper, nickel, cobalt, and mercury in sediments. Rahn (1973), based on laboratory experiments, has evaluated the role of Spartina in the transfer of mercury. He concluded that, in addition to uptake, this plant may also release mercury to the water column. Of the total amount of cadmium and copper delivered to salt marsh estuaries by rivers, Dunstan, Windom and McIntire (1975) estimate that about three percent is taken up in Spartina.

TABLE III-20

Trace metal concentration in Spartina alterniflora leaves and stems (ppm dry weight)

	Reference						
	1	2	3	4	5	6	7
Arsenic			<1.0				
Cadmium			0.5	0.5		0.2	0.61
Chromium						2.0	
Copper		6.5	2.3	3.7		4.0	3.9
Cobalt		12					
Iron	590	1400		750	1700	500	700
Lead			5.3			2.0	4.1
Manganese	49	85		50		25	45
Mercury		1.0	0.7	0.20		0.08	0.32
Nickel		16					
Scandium					0.27		
Zinc		16	22			19	32

References
1. Williams and Murdoch (1969)
2. Bhate (1972)
3. Windom (1972a)
4. Windom (1975b)
5. Barnes et al. (1973)
6. Whaling et al. (1977)
7. Dunstan and Windom (1975)

Upon decomposition, the trace metal content of S. alterniflora changes. Drifmeyer, Heywood, Cross and Odum (1977) found this to be true of most brackish water plants. They report that trace metals generally increase in the detritus of Spartina with age.

Drifmeyer and Odum (1975) investigated the uptake of lead, zinc, and manganese in dredge-spoil pond ecosystems. These authors found that the increased metal content of sediments in the system was reflected in increases in the plant.

The concentrations of trace metals have also been determined in other macrophytes and macroalgae. The concentrations of manganese, iron, copper, and zinc in eelgrass (Zostera marina) in relation to sediment concentrations were determined by Wolfe, Thayer and Adams (1976). They found that a significant fraction of the annual sediment accumulation of these metals was incorporated in the plant. Drifmeyer, Thayer and Cross (1977) also investigated the concentrations of trace elements in eelgrass. These authors found very little spatial variation in the concentrations of manganese, iron, copper, and zinc. Their results did, however, suggest that iron nickel, copper and zinc increase in the detritus of this plant while manganese appeared to decrease and silver and chromium remained relatively constant.

The concentrations of manganese, iron, copper, and zinc in macroalgae have been determined by Wolfe et al. (1976). These metals show a wide range in concentrations for various species (Table III-21). Windom (1972a) reported the concentration of mercury in the leaves, stalk, and float pods of Sargassum to be 0.44, 0.39, and 0.30 µg/g, respectively.

TABLE III-21

Metal content of eelgrass and macroalgae
(From Wolfe et al., 1976)

Species	No. of Samples	µg/g dry weight Mn	Fe	Cu	Zn
Zostera marina	6	154	1240	7.9	70
Ectocarpus	4	66	4360	9.4	67
Gymnogongrus	2	312	1840	5.6	102
Agardiella	3	84	1060	8.7	42
Gracilaria	2	57	619	3.2	33
Dictyota	1	194	1330	8.9	48
Dasya	2	69	1530	17	60
Ulva	2	78	2100	20	46
Enteromorpha	2	54	3040	15	48
Bryopsis	1	161	1300	5.5	120

Several research projects are underway, or in the early stages of initiation, which are addressed to trace metal uptake by macrophytes and macroalgae. Windom has recently completed a study sponsored by the U. S. Army Corps of Engineers Waterways Experiment Station of the uptake of iron, manganese, cadmium, copper, nickel, and zinc by Spartina alterniflora salt marshes adjacent to dredged material disposal areas. Work of Ecological Division staff at the Beaufort National Marine Fisheries Service Laboratory on the biogeochemistry of trace elements in eelgrass is continuing under funding by the Department of Energy (Cross, 1978, personal communication). A project at the Skidaway Institute of Oceanography that has been funded by NSF-IDOE has evaluated the concentration of arsenic in a number of marine macroalgae and is also investigating the role of at least one species of Valonia on arsenic speciation (J. Sanders, 1978, personal communication). Studies of the form and distribution of trace elements in detritus of a number of species of seaweeds and Spartina alterniflora, and their availability to benthic organisms, are also underway at Skidaway under a NSF grant directed by Windom and Tenore.

Phytoplankton

Very little information exists on the trace metal composition of estuarine and marine phytoplankton in the study area. Results of one analysis of a mixed natural phytoplankton sample collected off the Georgia coast was reported by Windom (1972a). He reported values of 8.2, 2.1, 22, 18, and 109 ppm for arsenic, cadmium, copper, lead, and zinc, respectively, but pointed out that these values may be high due to contamination from paint chips from the vessel on which the samples were collected. He also reported a mercury concentration of 0.42 ppm based on ten replicate analyses. Most of the other work related to trace metals in phytoplankton has dealt with their effect on growth, photosynthesis, and other physiological processes.

Using radioisotope tracers, Sick and Windom (1975) investigated the rate of uptake of cadmium and mercury. Their results indicate that these metals are taken up in proportion to their concentration in the water column. Windom, Gardner, Dunstan and Paffenhofer (1976) report similar results for cadmium uptake by Skeletonema costatum and mercury uptake by Carteria sp., Dunaliella tertiolecta, and Nitzchia closterium (Figure III-32). Sanders (1975) studied the effect of manganese on natural phytoplankton populations in Calico Creek. He found that additions of manganese had mixed effects on carbon uptake by phytoplankton and attributed this to the interaction of some unknown compound with the metal. Bishop (1977) conducted laboratory experiments with mixed phytoplankton cultures to

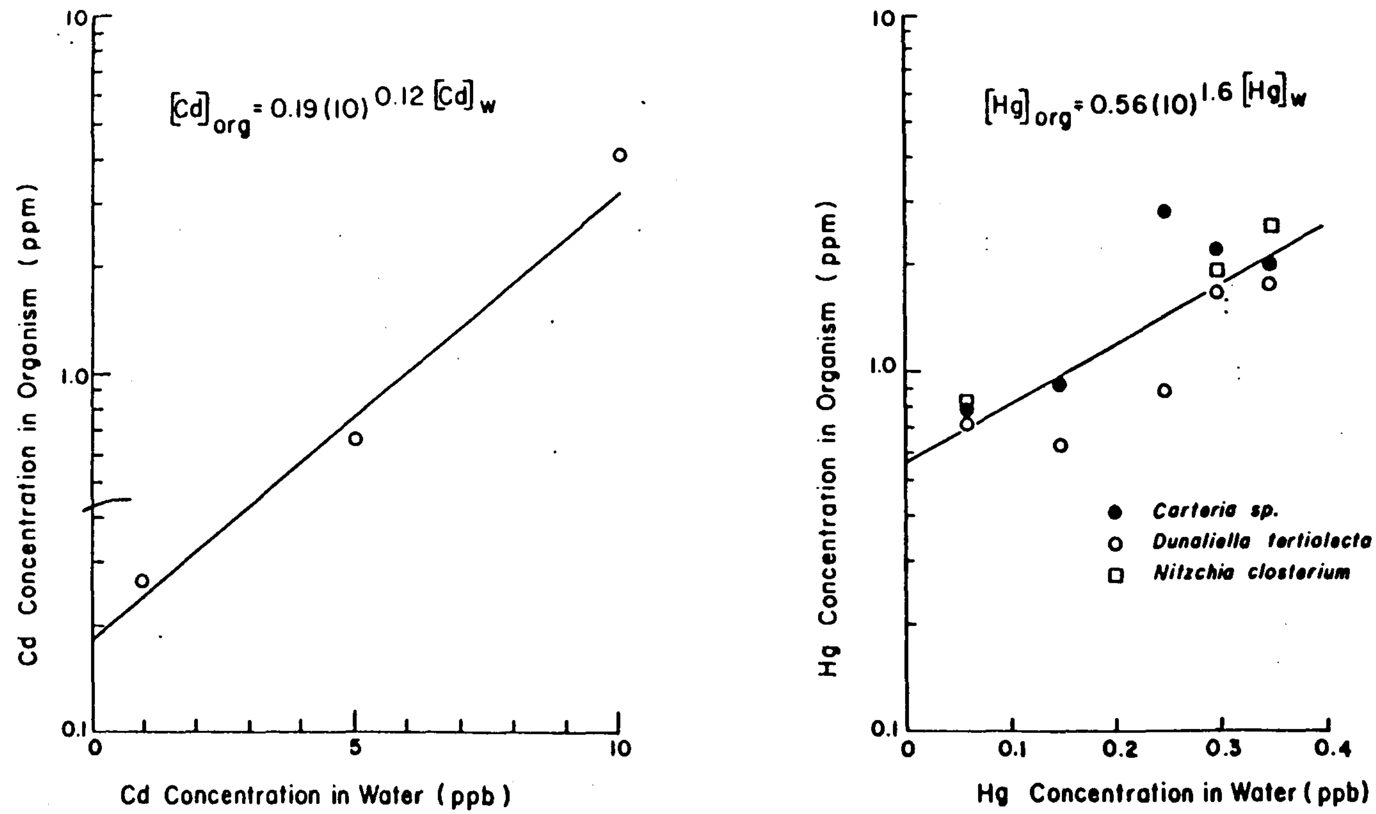


FIGURE III-32. Cadmium uptake by Skeletonema costatum. Mercury uptake by phytoplankton species. Equations are for the regression lines shown. Metals were added as soluble chlorides. (From Windom et al., 1976) determine the effect of copper on species diversity, cell concentrations and size, amount of chlorophyll and carbon, and primary production. Similar studies of the effects resulting from increased mercury levels were carried out by Zingmark and Miller (1975) who found that concentrations of 1 ppb reduced phytoplankton growth by 50 percent.

An ongoing project related to trace metals in phytoplankton is that being conducted by Windom and co-worker at Skidaway. This research is directed toward understanding the influence of marine algae on arsenic speciation in the marine environment. Work is being carried out mostly with pure cultures of marine diatoms.

2.3.2.2 Zooplankton

The review of marine chemistry up until 1973 by Roberts (1974) included only one reference to trace metals in zooplankton. This was the work of Windom, Taylor and Stickney (1973) which was concerned with mercury in zooplankton. This was part of the earlier work reported by Windom (1972a) who also reported concentrations for arsenic, cadmium, copper, lead, and zinc in zooplankton samples collected along the east coast from the New York Bight to off the Georgia coast (Figure III-33). These results may be contaminated from ship's debris.

A few trace metal analyses of individual zooplankton species have been performed. Windom (1972a) reported concentrations for arsenic, cadmium, copper, lead, mercury, and zinc in mixed copepod samples. Windom et al. (1976), in laboratory uptake studies using the copepod *Pseudodiaptomus coronatus*, found that this species accumulated cadmium in response to levels in the water in much the same way as marine algae (Figure III-34).

The only major recently completed program concerning the trace metal content of zooplankton is that being conducted by Texas Instruments under contract to the U. S. Department of Interior, Bureau of Land Management (May, 1978, personal communication).

2.3.2.3 Macrobenthos

Up until recently, data on trace metal concentrations in macrobenthic organisms has generally been limited to commercial species. The review of Roberts (1974) included only results for oysters (*Crassostrea virginica*). More recent data has been produced by Huggett, Cross and Bender (1975) for copper and zinc in oysters. These authors found that samples collected in the fresher parts of the Newport River estuary had higher concentrations of these metals. Heavy metals in oysters were also

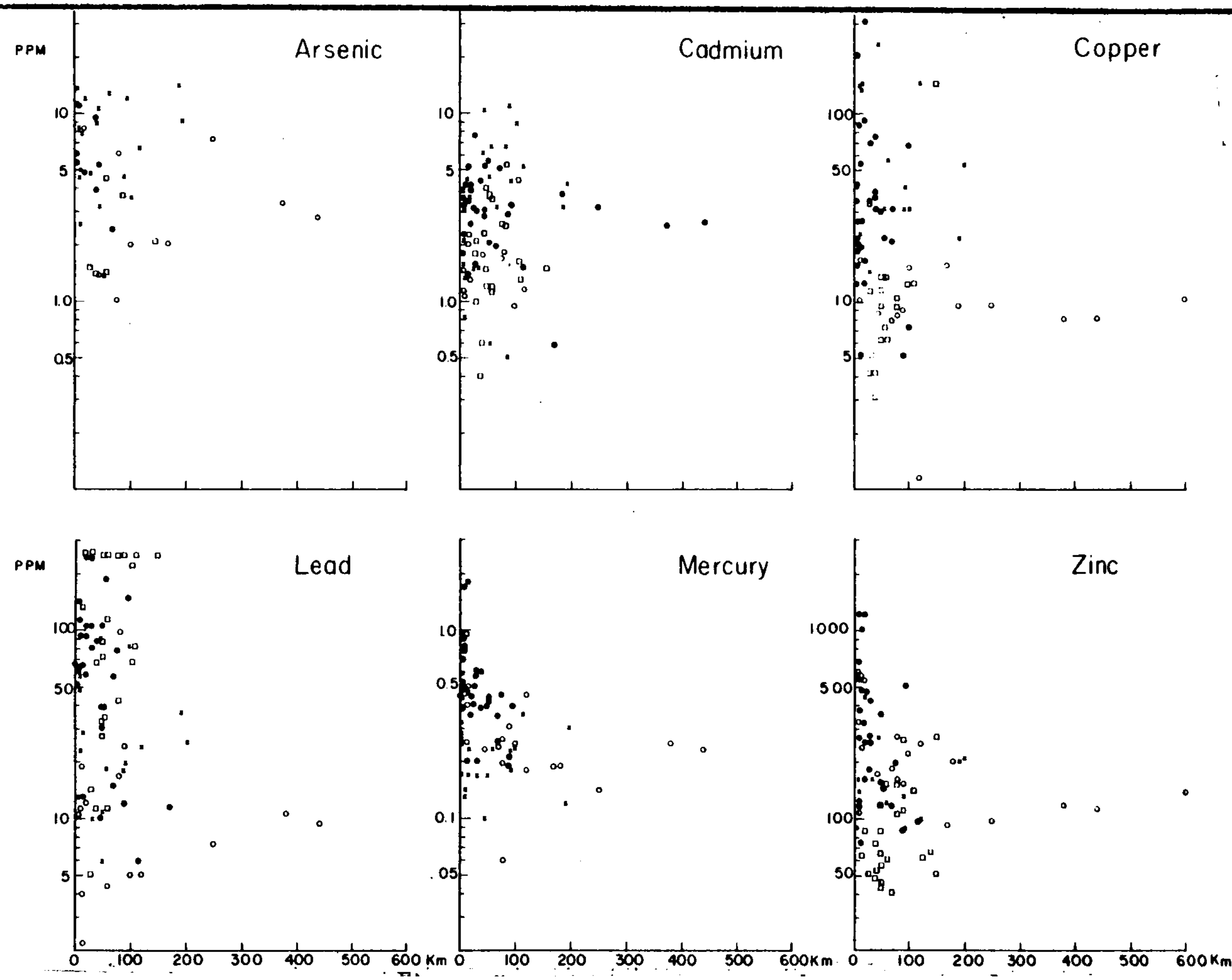


FIGURE III-33. Trace metals in zooplankton (from Windom, 1972a). Circles and dots are for samples collected off the Northeast U. S. coast, other data points represent samples collected off the coast of Georgia and South Carolina.

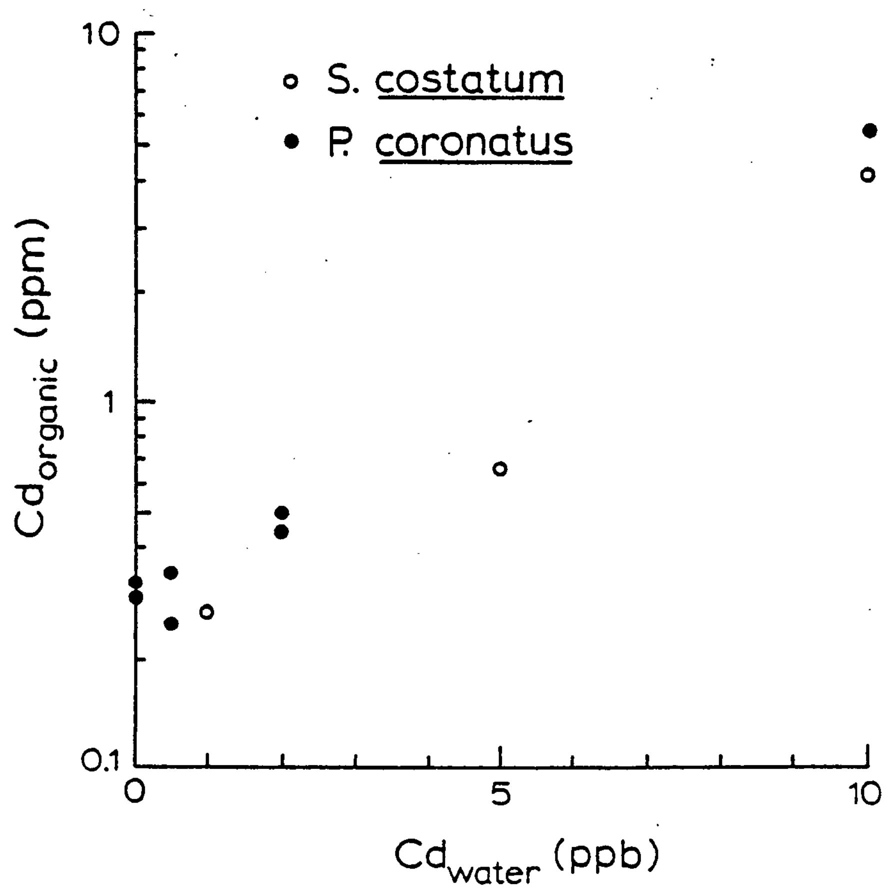


FIGURE III-34. Cadmium uptake of P. coronatus compared to Skeletonema costatum. (From Windom et al., 1976) determined by Whaling et al. (1977) for samples collected in Turner Creek. Arsenic, cadmium, copper, lead, mercury, and zinc concentrations in oysters and quahog clams (Mercenaria mercenaria) have been reported by Windom (1972a). Wolfe et al. (1976) reported values for manganese, iron, copper, and zinc in quahogs as well as seven other species of bivalve molluscs. They also analyzed these metals in gastropods, amphipods, decapods, polychaetes, echinoderms, and tunicates as a part of a comprehensive study of a North Carolina eelgrass community.

Species of epibenthic decapods and amphipods commonly ingested by southeastern estuarine finfish were analyzed by Stickney, Windom, White and Taylor (1975) for cadmium, copper, lead, mercury, and zinc. They found no clear relationship between metal levels in benthic organisms and those in fish.

Windom, Gardner, Stephens and Taylor (1976) studied the distribution of mercury in a polluted salt marsh system on the Georgia coast. They found that the primary consumers Littorina irrorata and Uca sp. represented the lowest trophic level in which significant amounts of methylmercury were found. Whaling et al. (1977) also determined mercury concentrations of this species as well.

The most comprehensive study of the trace metal distribution in macrobenthic organisms in southeastern estuarine ecosystems is that of Kendall (1978). This author investigated the role of these organisms in the cycling of mercury, cadmium, copper, and zinc. He evaluated the trace metal content of over 70 species of invertebrates in relation to size, feeding habit, season, sediment metal level and type, and their location within the estuary. He found that metal levels were highly correlated with body size and independent of season, sediment levels, and spatial differences. Uptake experiments also indicated that the polycheate Nereis succinea accumulated its body burden of metals primarily from the water column rather than sediments.

Many of the above-referenced studies include data on nektonic invertebrate organisms such as commercial species like penaeid shrimp. Generally, however, the bulk of the data is for benthic organisms.

The most important program concerning trace metals in benthic orgamisms is the recently-completed BLM Benchmark Study conducted by Texas Instruments. This study provided considerable new data on trace metal levels in benthic orgamisms of the continental shelf where little data existed before (May, 1978, personal communication).

2.3.2.4 Vertebrates

Several studies have resulted in trace metal data for finfish in coastal and estuarine waters between Cape Hatteras and Cape Canaveral. Most of these, however, have been conducted or published since the review of Roberts (1974). One of the first was that by Windom, Stickney, Smith, White and Taylor (1973). These authors analyzed 91 individuals from 35 species of Chondriethys and Osteichthys for arsenic, cadmium, copper, mercury, and zinc. They compared metal concentration in offshore species with those of inshore species and found no significant differences (Figure III-35). Stickney et al. (1975) discuss cadmium, copper, lead, mercury, and zinc concentrations in estuarine fish in relation to their feeding habits. This was done also by Windom et al. (1976) who determined the transfer efficiency of cadmium and mercury from food to several species of finfish. These authors concluded that cadmium is preferentially decreased at higher trophic levels while mercury accumulates. Gardner, Windom, Stephens, Taylor and Stickney (1975) measured total and methyl mercury in estuarine fish. They found that, generally, top carnivorous fish had the highest percentage of methylmercury in their muscle tissue.

Barber, Vijayakumar and Cross (1972) and Cross, Hardy, Jones and Barber (1973) evaluated metal concentrations in fish as a function of body size. Barber et al. (1972) found that mercury concentrations increased with fish length in Antimora rostrata. Similar observations were made by Cross et al. (1973) for mercury in muscle tissue of bluefish (Pomatomus saltatrix) as well as A. rostrata, but manganese, iron, copper, and zinc were relatively constant or decreased with increasing fish size. Cross, Wilis, Hardy, Jones and Lewis (1975) found that zinc, iron, manganese, and copper increased with total dry body weight in menhaden (Brevoortia tyrannus), spot (Leiostomus xanthurus), and pinfish (Lagodon rhomboides). Mercury levels of different tissues in this last species have also been reported by Whaling et al. (1977).

Very little information exists on the concentration of trace metals in marine mammals such as dolphins and whales. Results of mercury analyses on one individual dolphin (Tursiops truncatus) were reported, however, by Stickney, Windom, White and Taylor (1973). These authors found mercury concentrations on a dry weight basis as high as 34.7 ppm in the liver. The lowest value reported was for the skin which contained 0.12-0.51 ppm.

A major project which produced new trace metal data for vertebrates is the recently completed Texas Instrument-BLM Benchmark Study of the southeastern outer continental shelf.

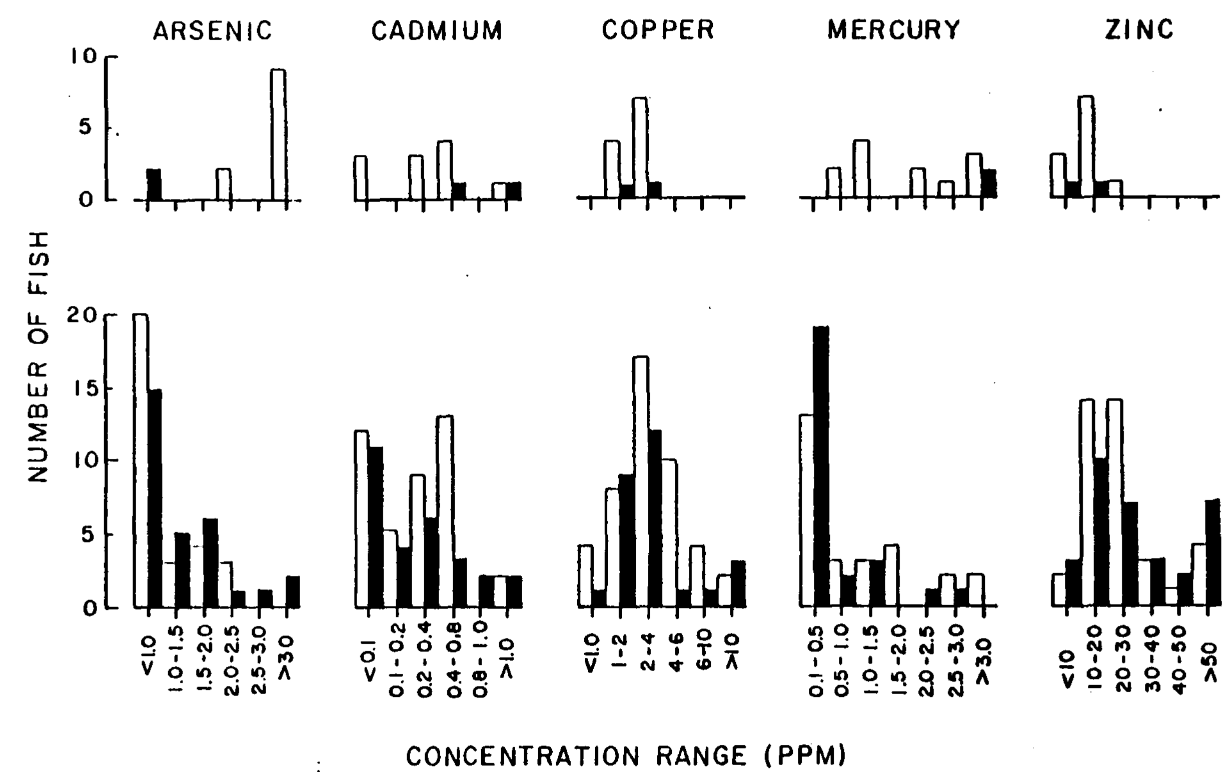


FIGURE III-35. Metal distribution in fish. (Upper and lower histograms represent distribution for Chondrichthys and Osteichthys, respectively. Black and white bars represent offshore and inshore species, respectively. Concentration is on dry weight basis. From Windom et al., 1973.

Demersal fish have been collected and are being analyzed for barium, cadmium, chromium, copper, iron, nickel, lead, vanadium, and zinc (May, 1978, personal communication). In addition, Barber and co-workers at Duke University are conducting studies of trace metals in finfish and whales (Barber, 1978, personal communication).

2.3.2.5 Trace Metal Cycling in Coastal Ecosystems

Research programs at the NOAA National Marine Fisheries Service Laboratory in Beaufort, North Carolina, and at the Skidaway Institute of Oceanography since about 1972, have been directed toward understanding metal cycling through ecosystems. These programs have resulted in several publications which have attempted to quantify trace metal transfer through biological components of the systems studied.

As a result of the program at the Skidaway Institute, Windom (1975b) estimated the relative amounts of several metals that are transferred through *Spartina* annually. More recently Windom et al. (1976) proposed models for the flux of mercury and cadmium through major biological components of the estuarine zone (Figure III-36). They also proposed a model for cadmium and mercury transfer through a pelagic food chain of the Georgia Embayment (Figure III-37). This work utilized information of feeding habits and metal levels of the prey of carnivorous fishes. The model also assumed a growth efficiency at each trophic level of 25 percent.

Wolfe (1975) at the Beaufort Marine Fisheries Service Laboratory discussed a model for the transfer of manganese, iron, and zinc through estuarine ecosystems (Figure III-38). Using this model and metal levels, standing crop, and annual production of major biological components, he estimated budgets for the cycling of zinc within the Newport River estuary in North Carolina (Wolfe, 1974). Wolfe et al. (1976) used similar procedures to determine that the largest metal fluxes in an eelgrass ecosystem were associated with sedimentation and *Zostera* production. Cross et al. (1975), also at Beaufort, have evaluated the role of juvenile fish in the cycling of trace metals in estuaries.

Studies of the cycling of trace metals in estuarine ecosystems are being continued at the Beaufort Laboratory by Cross and co-workers (1978, personal communication). The work at Skidaway Institute is being conducted by Windom, Tenore, and co-workers, and is focusing on metal transfer in experimental detritus-based food chains.

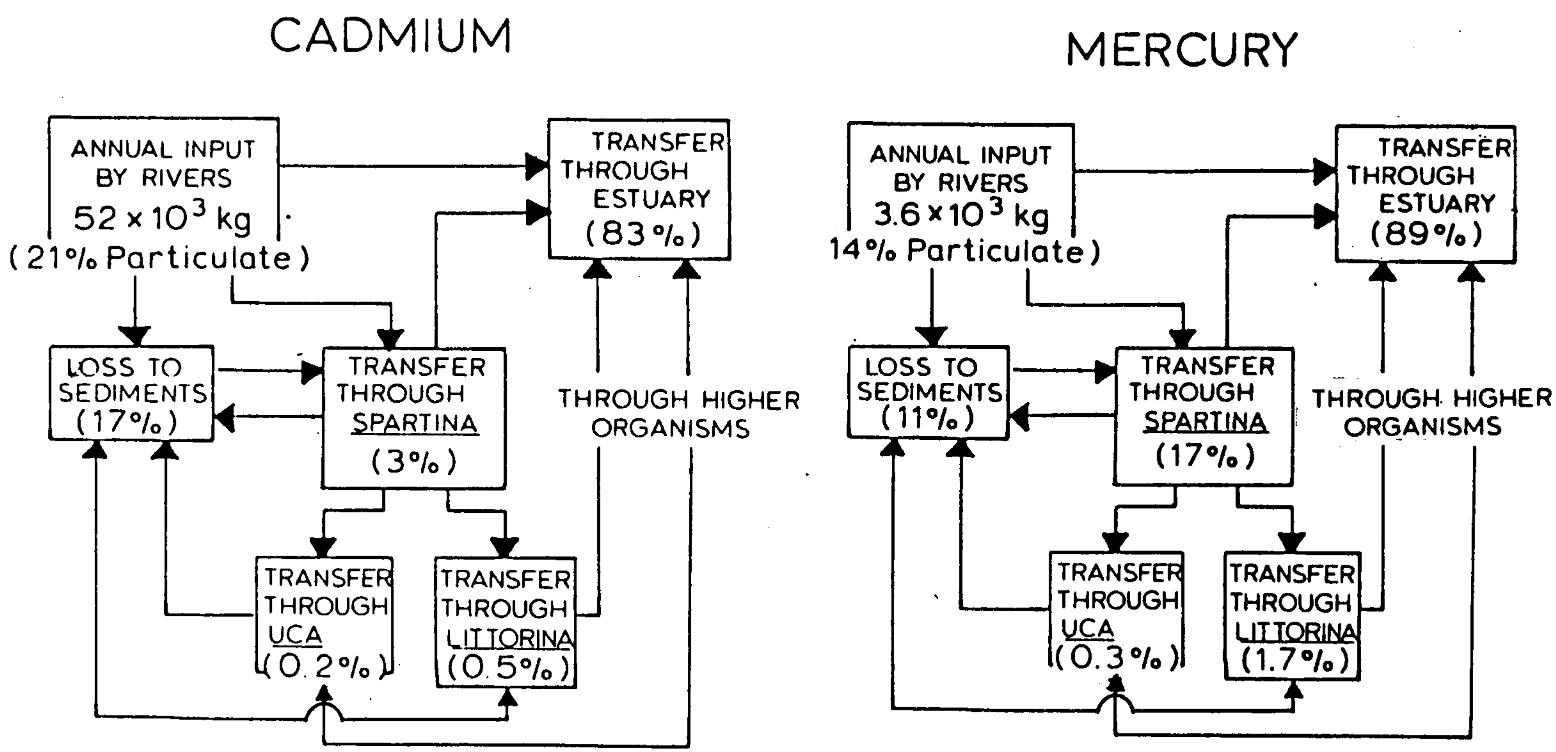
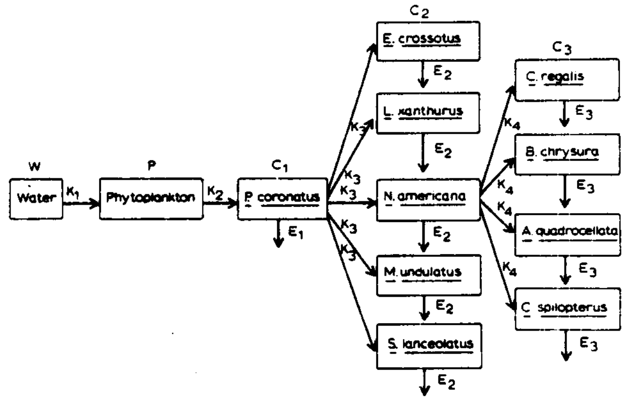
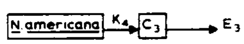


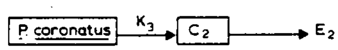
FIGURE III-36. Potential transfer pathways of cadmium and mercury through the estuarine zone. Estimated percentages of total input which passes through biological compartments are given in parentheses. From Windom et al. (1976).



	CADMIUM	MERCURY
W (µg/L)	0.10	0.06
P (µg/g dry wt.)	0.20	0.45
G_1 (growth efficiency)	0.25	0.25
K_2 (µg/g dry wt. consumer)	0.80	1.80
C_1 (µg/g)	0.15	0.15
E_1 (µg/g dry wt. consumer)	0.65	1.65



SPECIES	CADMIUM (µg/g dry wt. consumer) C_3	CADMIUM E_3	MERCURY C_3	MERCURY E_3
Bairdiella chrysura (SILVER PERCH)	0.12	1.48	1.07	(0.83)
Cynoscion regalis (WEAKFISH)	0.05	1.55	0.44	(0.20)
Ancylopsetta quadrocellata (OCELLATED FLOUNDER)	0.22	1.38	0.46	(0.22)
Citharichthys spilopterus (BAY WHIFF)	0.07	1.53	0.17	0.07



SPECIES	CADMIUM (µg/g dry wt. consumer) C_2	CADMIUM E_2	MERCURY C_2	MERCURY E_2
Neomysis americana (OPPOSSUM SHRIMP)	0.40	0.20	0.06	0.54
Leiostomus xanthurus (SPOT)	0.04	0.56	0.23	0.37
Micropogon undulatus (ATLANTIC CROAKER)	0.04	0.56	0.31	0.29
Stellifer lanceolatus (STAR DRUM)	0.04	0.56	0.50	0.10
Etropus crossotus (FRINGED FLOUNDER)	0.07	0.53	0.10	0.50

FIGURE III-37. Cadmium and mercury transfer through pelagic food chains in the Georgia embayment. (From Windom et al., 1976)

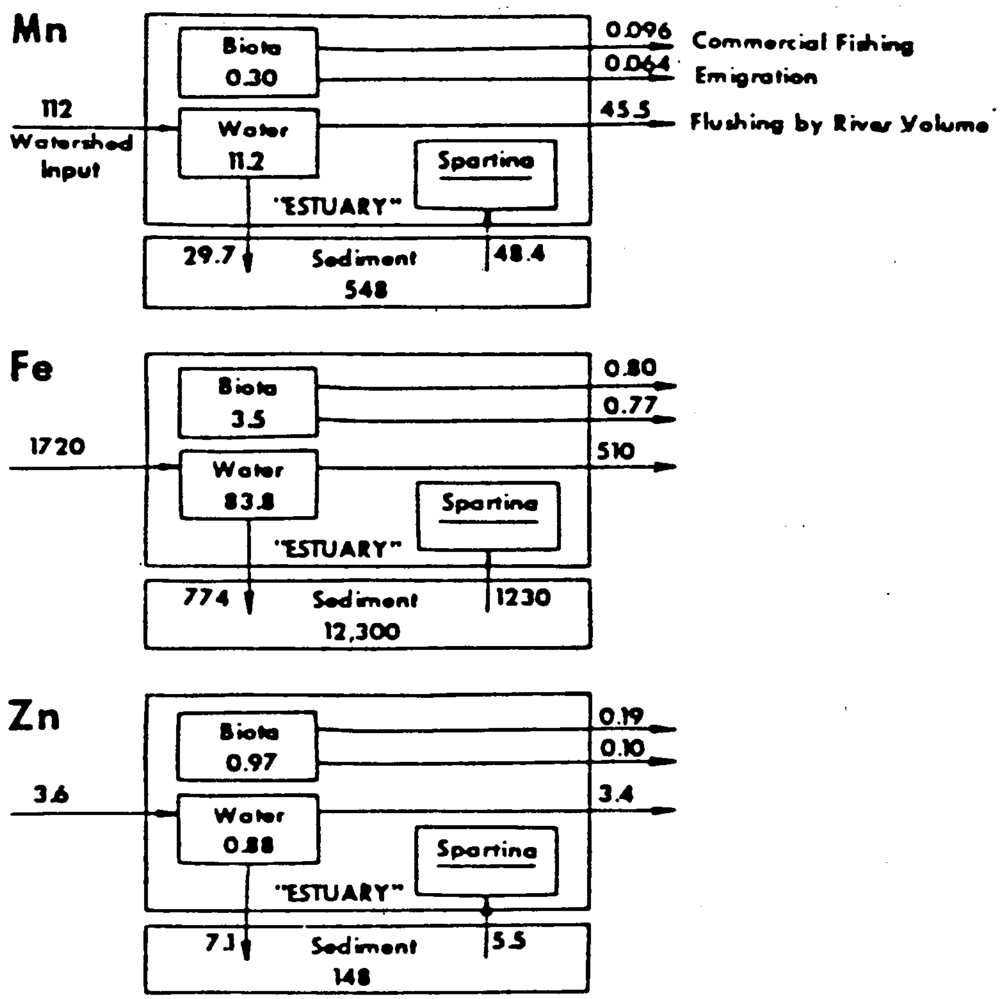


FIGURE III-38. Annual inputs and exports of Mn, Fe, and Zn for the Newport River estuary. The "estuary" is considered to have an area of $31km^2$ and a half-tide depth of 1.3m. Units in boxes are mg element/m^2 and on arrows are mg element/m^2. yr. The sediment compartment represents the acid-extractable element in the top 2cm only. (From Wolfe, 1975)

2.3.3 Chlorinated Pesticides in Biota

2.3.3.1 Estuarine Organisms

Mahood, McKenzie, Middaugh, Bollar, Davis and Spitzbergan (1970) analyzed blue crabs collected in estuaries of the southeastern United States for aldrin, dieldrin, lindane, dieldrin, DDT, DDE, DDD, endrin, heptachlor epoxide, methoxychlor, mirex, toxaphene, and chlordane (Table III-22). Up to 0.4 μg/g of Mirex was found in crabs collected in Georgia waters. Data are available on the toxaphene concentration in the plants and animals near a toxaphene plant near Brunswick, Georgia (Reimold and Durant, 1974; Reimold, 1975; Robinson, 1978, personal communication). Toxaphene has been identified in oysters collected in various estuaries of South Carolina (Hulsey, 1976). The amounts of dieldrin and 2,4-D in biological samples from coastal waters of Florida have been determined by the Army Corps of Engineers (L. Sanders, 1978, personal communication). The concentrations of PCB and DDT in mussels and oysters from coastal waters of the southeast are being determined as part of National Marine Monitoring Program (Goldberg and Farrington, 1977).

2.3.3.2 Continental Shelf Organisms

The concentration of DDT in zooplankton collected in open ocean areas between 23^{o}N and 30^{o}N was less than 0.00001 μg/g while PCBs ranged from 0.3 to 0.45 μg/g (Risebrough, Vreeland, Harvey, Miklas and Carmignani, 1972).

2.3.4 Radionuclides in Biota

Goldberg et al. (1978) have determined the activity of plutonium-239+240 and cesium-137 in living and dead *Spartina alterniflora* and in spanish moss collected in the vicinity of the Savannah River estuary (Table III-23). The plutonium-239+240/cesium-137 activity ratio in plants was generally lower than that in sediments.

Hayes et al. (1975) found that the activity of plutonium in *Spartina* varied from 0.7 to 9.3 fCi/g dry weight and that there was no significant difference between activities found in living and dead plants. This activity is similar to that found in surface sediments.

With the collaboration of Cross and the NOAA, NMFS Lab in Beaufort, North Carolina, Hayes and co-worker are measuring the plutonium and tritium content of estuarine sediments and biota (Hayes, 1978, personal communication).

TABLE III-22. Chlorinated hydrocarbons in blue crabs. (From Mahood et al., 1970).

LOCATION	PERCENT OCCURRENCES	MEAN	LOW	HIGH
North Carolina: 50 samples				
DDD	100	0.051	0.010	0.188
DDE	100	0.053	0.013	0.122
DDT	100	0.077	0.012	0.213
Mirex	16	0.023	0.005	0.045
Dieldrin	10	0.003	0.002	0.005
South Carolina: 50 samples				
DDD	100	0.076	0.009	0.160
DDE	100	0.081	0.011	0.180
DDT	100	0.092	0.012	0.247
Mirex	44	0.088	0.005	0.209
Dieldrin	28	0.009	0.002	0.019
Georgia: 50 samples				
DDD	100	0.068	0.012	0.179
DDE	100	0.077	0.015	0.231
DDT	100	0.092	0.018	0.176
Mirex	54	0.162	0.015	0.389
Dieldrin	36	0.017	0.004	0.072
Florida: 45 samples				
DDD	100	0.066	0.012	0.180
DDE	100	0.047	0.010	0.114
DDT	100	0.082	0.018	0.196
Mirex	31	0.031	0.005	0.164
Dieldrin	2	0.008	0.008	0.008

TABLE III-23. Plutonium and cesium-137 contents of plants from the Savannah River estuary system. (From Goldberg et al., 1978)

	Pu-239+240 in dpm/kg	Pu-238 / Pu-239+240 (Activity ratio)	Cs-137 dpm/kg	Pu-239+240 / Cs-137 (Activity ratio)
Spanish Moss (Living)	7.5 ± 0.5	0.17 ± 0.03	1114 ± 37	0.007
Spartina grass (Detritus)	4.6 ± 0.3	0.17 ± 0.03	201 ± 8	0.023
Spartina grass (Living)	1.7 ± 0.1	0.31 ± 0.03	102 ± 3	0.017

2.4 Atmosphere

2.4.1 Trace Metals in the Atmosphere

Prior to the review of Roberts (1974) no data on atmospheric levels of trace metals had been published. Since then only a few analyses of atmospheric samples have been made. These are briefly described below.

Waslenchuk (1977) analyzed four atmospheric samples collected over the continental shelf between Cape Canaveral, Florida, and Savannah, Georgia, for arsenic, zinc, and iron. The concentration ranges found were 0.2-1.2 $ngAs/m^3$, 4.6-10 $ngZn/m^3$, and 63-460 $ngFe/m^3$. He also reports values of 0.33 and 0.03 $\mu gAs/l$ for two rain samples. Using these data Waslenchuk estimated that the atmospheric input of arsenic to the South Atlantic Bight is 16.2 metric tons annually.

The concentration of mercury in the atmosphere over the South Atlantic Bight was estimated by Windom et al. (1975) to range from 10 to 160 ng/m^3. These values were based on a rather crude technique and were reevaluated by Windom and Taylor (1978) using an improved method. With this method they determined concentrations between 0.3 and 8.2 ng/m^3 for the atmosphere over the South Atlantic Bight (Table III-24). They also determined that about 30 percent of the total mercury was in particulate phases while the remainder was in the vapor phase.

Windom and Smith (1978b) report value for the atmospheric concentrations of copper, nickel, and zinc (Table III-25). Samples were collected by high volume filtration through Whatman #41 filters which were subsequently digested and analyzed by flameless atomic absorption. Reported values, therefore, primarily reflect concentrations in particulates.

Under funding from the U. S. Department of Energy, Windom and co-workers are conducting an ongoing study of atmospheric transport of trace metals to the South Atlantic Bight. Unpublished data include values for the atmospheric concentrations of cadmium, copper, nickel, zinc, lead, iron, aluminum, and sodium.

2.4.2 Chlorinated Hydrocarbons in the Atmosphere

There appear to be few studies monitoring pesticides in the atmosphere off the United States southeastern coast. Harder, Christensen, Matthews and Bidleman (1977) recently determined the concentration of toxaphene in 41 rain samples along the South Carolina coast and found concentrations varied from 10 to 470 ng/liter with a mean of 75 ng/liter (Table III-26). Calculations for estuarine systems where the measurements were made showed that

TABLE III-24

Atmospheric mercury concentration (in nanogram/m^3).

From Windom and Taylor (1978)

	COLUMBUS ISELIN (April 1976)	BLUE FIN (1977)					COLUMBUS ISELIN (July 1977)		
	Total	Jan Total	Feb Total	Mar Total	April Total	May Total	Part.	Vapor	Total
	2.8	1.1	7.6	2.2	2.8	5.0	3.8	2.7	6.5
	2.0	2.5	4.9	2.7	2.7	6.0	1.7	3.0	4.7
	1.6	1.8	4.7	1.4	1.8	3.9	1.0	2.4	3.4
	1.5	1.2	3.1	8.2	3.5	3.9	1.1	2.6	3.7
	2.3	2.8	2.4	4.6			0.5	2.8	3.3
	0.5	4.4	2.9	3.6			0.6	2.5	3.1
	1.0	7.6	1.5				0.7	1.7	2.4
	1.0	1.5	1.9				0.4	3.2	3.6
	1.8	0.8	1.2				0.5	5.7	6.2
	0.8	1.0	1.2				0.5	4.1	4.6
	1.1	2.1	1.3				1.0	2.7	3.7
	1.5	1.3	2.1				0.4	2.5	2.9
	0.8	1.2					0.3	2.8	3.1
	2.9						0.3	2.8	3.1
	1.4						0.4	2.1	2.5
	0.3						0.5	2.3	2.8
	1.6						0.4	2.;	2.5
							0.9	2.5	3.4
Mean	1.5	2.2	2.9	3.8	2.7	4.7	0.8	2.8	3.6
lo	0.7	1.9	1.9	2.4	0.7	1.0	0.8	0.9	0.9

TABLE III-25.

Atmospheric concentrations of copper, nickel, and zinc over the South Atlantic Bight. (From Windom and Smith, 1978b).

Sampling Platform	Date Collected	No. of Samples	Concentrations (ng/m^3)* Cu	Ni	Zn
R/V BLUE FIN	Jan 1977	2	6.2	17	28
" " "	Feb 1977	4	7.0	14	48
" " "	Mar 1977	5	1.7	2.3	17
" " "	Apr 1977	3	2.4	4.3	21
" " "	May 1977	3	2.2	5.3	19
R/V COLUMBUS ISELIN	Jul 1977	12	18.0	35	37
Mean Atmospheric Concentration			6.3	13	28
Range in Concentrations			0.4-40	1.1-105	4-96

*Means of samples collected on given cruise.

TABLE III-26.

Toxaphene concentrations in rainfall from intermittent rain collections in estuaries of South Carolina. From Harder et al. (1977).

Volume (liters)	Date (1977)	Toxaphene Rain (ng/l)	Toxaphene Atmosphere (ng/m)	Washout Ratios
2.0	7/22	235	0.40	588
2.6	7/26	50	0.47	106
3.6	7/26	203	0.47	366
3.8	7/27	168	0.47	358
2.6	7/27	127	0.47	270
1.45	8/2	*		
2.4	8/4	60	0.85	71
1.1	8/5	33	0.85	39
1.3	8/5	*	0.85	
.96	8/17	*		
1.1	8/18	470	5.40	87
1.0	8/19	179	5.40	33
3.6	9/4	*	0.80	
3.6	9/5	21	0.80	26

*Not detectable. Blank values for air and rain were 15 - 25 ng and have been subtracted in calculating the above results.

540 grams of toxaphene were being carried by rain to the estuary over a three month period.

3.0 IDENTIFICATION OF DATA GAPS

Gaps in data for the southeastern Atlantic coastal marine environment between Cape Hatteras, North Carolina, and Cape Canaveral, Florida, are summarized in Tables III-27 and III-28. The first table summarizes the existing data by compartments. The second summarizes our present understanding of source-inputs of the various chemical species to the study area. Both tables are subjective, but at least give a relative indication of our state of knowledge on the chemistry of this region.

3.1 Hydrocarbons

3.1.1 Water Column

Of all the compartments, most of the data are for the water column. Even so there are little available data for this compartment at the present time. Few seasonal data are available and spatial distribution of data is also limited. Information on sources is almost non-existent, although their location can be assumed in many instances. Inputs to coastal waters are also poorly understood.

3.1.2 Sediments

To evaluate sources, transport and fates of hydrocarbons it is important to know their concentration distributions in sediments. At the present time the sparse amount of data on sediments is very inadequate for this purpose. There are no data for the distribution of hydrocarbons in sediment surrounding suspected sources and there are no vertical profiles by which to evaluate input and degradation rates.

3.1.3 Biota

Very little hydrocarbon data is available in any of the biological components of the southeastern Atlantic coastal ecosystem. Levels of petroleum hydrocarbons in the organisms are important for background considerations but the greatest need is for studies related to effects of these substances on the biota. Since no significant petroleum "spills" have occurred in the area, and there are no present major sources, information on effects of hydrocarbons on species indigenous to the region will be gained best through laboratory experiments.

TABLE III-27.
Available data on chemical parameters of various compartments.

Compartment	Hydrocarbons	Trace Metals	Nutrients	Chlorinated Hydrocarbons	Radionuclides
Water Column					
Inshore	2	2	3	1	1
Offshore	1	2	3	1	0
Particulates	1	0	2	0	1
Sediments					
Inshore	1	3	2	1	1
Continental Shelf	1	0	0	0	0
Blake Plateau	0	1	0	0	0
Biota					
Inshore					
Plankton	0	2	NA	0	0
Nekton	0	2	NA	1	0
Benthos	1	2	NA	2	0
Offshore					
Plankton	1	2	NA	1	0
Nekton	0	2	NA	0	0
Benthos	1	1	NA	0	0
Atmosphere					
Air	0	1	0	0	0
Precipitation	0	1	0	1	0

NA-not applicable; 0-no data; 1-very limited; 2-moderate; 3-extensive

TABLE III-28.
Adequacy of knowledge.*

Inputs	Hydrocarbons	Trace Metals	Nutrients	Chlorinated Hydrocarbons	Radionuclides
River Transport	1	2	2	1	1
Atmospheric Transport	1	1	1	1	1
Offshore-Onshore Transport	1	1	2	1	1
Pollutant Sources	1	2	3	2	3

1-Poor

2-Moderate

3-Good

*as judged by the authors

3.1.4 Atmosphere

The atmospheric compartment is probably the least important compartment for understanding petroleum hydrocarbon transfer and fate. The complete lack of data for this component, therefore, does not represent a major data gap.

3.2 Trace Metals

3.2.1 Water Column

Levels of some trace metals are well understood in inshore and coastal waters. Important trace metals (or trace elements) that have not been studied in the region are cadmium, selenium, antimony, and vanadium which are enriched in fossil fuels and may be relased to the environment by energy producing activities. Levels of other trace metals are poorly understood. A notable example is lead.

Very little is known about the speciation of trace metals in the water column or their association with particles. Transport on, and exchange with, particles may be important processes governing trace metal distributions and fates.

3.2.2 Sediments

Inshore sediment levels of many trace metals are well known. Few data exist for many important ones such as selenium, antimony, and vanadium. There is also a lack of data on trace metal concentration with depth in dated cores. This information would be useful in determining source-rate functions.

Although no data presently exist on metal levels in continental shelf sediments, this probably does not represent a major data gap. These sediments are coarse grain quartz and carbonate sands and therefore contain low levels of trace metals. Those metals that are present are probably strongly bound and therefore have limited interaction with the other components.

The distribution of metals in Blake Plateau sediments is probably dominated by manganese nodule formation. More data on their concentrations in these phases would be scientifically interesting, but in terms of environmental quality are of limited value.

3.2.3 Biota

Considerable data exist on trace metal concentrations in biota.

Data gaps do exist, however, for certain important metals. Trace metal uptake by, and effects on, organisms are poorly understood as is their transfer in food chains.

3.2.4 Atmosphere

The atmosphere may be an important transfer mechanism for trace metals to continental shelf waters. A need, therefore, exists for more data on trace metal levels in the atmosphere and in precipitation.

3.3 Nutrients

There are few data gaps with respect to nutrient concentrations in the various components of the estuarine-coastal marine system. It is difficult to assess data gaps for nutrients since their dynamics are of most concern. Gaps exist, but only in terms of understanding processes.

3.4 Chlorinated Hydrocarbons

Data gaps exist for all components of the ecosystem if one is concerned about present concentrations. These are probably not serious in the southeastern Atlantic coastal environment since severe inputs of these materials have discontinued. It is probably important, however, to develop a better understanding of the distribution of the most persistent pesticides in estuarine and coastal sediments and biota since past contamination may result in present day increased levels.

3.5 Radionuclides

Only two studies have been conducted in the region that have addressed radionuclides in the environment, and these were of an extremely limited nature. Gaps exist in data for these substances in every component of the ecosystem. The increased activities in the area which may result in radionuclide releases to the environment make it imperative that these data gaps be filled.

4.0 RECOMMENDATIONS FOR FUTURE STUDIES

At present there is a shortage of marine chemists along the southeastern Atlantic coast. This means that if the recommended studies described below are to be implemented, an increase in the number of scientists with specific interests and backgrounds will be required. For example, there are very few chemists that are addressing problems related to petroleum and chlorinated hydrocarbons in the coastal marine environment between Cape

Hatteras, North Carolina, and Cape Canaveral, Florida. Although there are several laboratories in the area investigating trace metals in the environment, many do not have the capability to perform many analyses with the required precision and accuracy. Only one research group in the Southeast is presently investigating radionuclides in the estuarine and coastal marine environment.

In light of the proposed activities, primarily related to energy resource exploitation and energy production, many studies will be required to predict their impact on the environment. In anticipation of these required studies, many of which are described below, expertise in marine chemistry in the southeast should be increased.

4.1 Hydrocarbons

4.1.1 Water Column

The concentration of hydrocarbons in the water is so low, even in water under oil spills, that there seems little point to propose extensive studies on its hydrocarbon content. A better study would be to analyze filter feeding animals which bio-accumulate hydrocarbons from the water.

4.1.2 Sediment

Polycyclic aromatic hydrocarbons are ubiquitous in marine sediments. Elevated concentrations of these compounds in sediments or animals are an indication of pollution by fossil fuels. Future studies should be carried out to determine the concentrations of these compounds in coastal sediments in the area of Cape Hatteras to Daytona Beach. The present sources of polycyclic aromatic hydrocarbons, such as sewer outfalls, refineries, and air particulates from urban areas, need to be evaluated as to their relative contribution. Studies on the fate of these compounds in water, sediment, and biota would be of use in prediction models concerned with oil spill effects.

4.1.3 Biota

In addition to analysis of hydrocarbons in biota, there should be future emphasis on the uptake and removal processes of fossil fuel hydrocarbons by marine organisms from the study area.

4.2 Trace Metals

4.2.1 Water Column

Future studies should be directed toward understanding the modes of input (eg. rivers, atmosphere, intrusions) of trace metals to the water column. Emphasis should also be placed on distinguishing the different forms in which trace metals exist. Studies of the interaction of trace metals between particulate and soluble phases would help in understanding their fate in this environment. Since deep offshore waters of the Gulf Stream and over the Blake Plateau are the source of new water on the shelf, studies of metal variation with depth in these areas are extremely important. This information would allow for a better estimate of the input of trace metals to continental shelf waters in intrusions.

4.2.2 Sediments

Future studies of trace metals in sediments should include a detailed investigation of their variation with depth. These studies should be conducted in conjunction with age determinations of sediment strata so that data may be interpreted in a time framework. The lead-210 method probably has the most promise for this work.

4.2.3 Biota

Studies to be conducted in the future should address trace metal availability to, and uptake, by estuarine and marine organisms. These studies will necessarily be limited initially to laboratory experiments with representative organisms and simple food chains. Emphasis should be place on understanding fundamental transfer processes between organisms and their environment or between organisms within food chains.

4.2.4 Atmosphere

More collections and analyses of air and precipitation samples over the continental shelf are recommended to better qualify this input pathway to coastal waters. This should be coupled with air mass trajectory studies and experiments to determine deposition velocities for given metals under different wind regimes.

Studies of the concentration of trace metals in the surface microlayer are also recommended. This information is necessay to evaluate if trace metals in the atmosphere originate from the sea surface.

4.3 Nutrients

4.3.1 Water Column

The design and execution of proper experiments and the practical and economical storage of the data being gathered are recommended. Experiments are particularly needed in the following areas:

- Nitrogen dynamics of stranded Gulf Stream intrusions;
- Relative regeneration rate of nitrogen and phosphorus;
- Nitrogen/phosphorus/silica relationships in ascending Gulf Stream water in a Gulf Stream eddy;
- Nitrogen fixation rates with respect to the abundant concentrations of nitrogen fixing algae.

As mentioned above, there is a need for the useful storage of the data gathered. Skidaway Institute is acquiring all of the data submitted to the NODC from the South Atlantic Bight and developing the software and hardware to analyze and display it. This effort only applies to standardized data which often does not include data from experimental situations. Only close cooperation of investigators in the area can insure full use of these types of data.

4.3.2 Sediments

The few studies that have been conducted indicate that the sediment is not a signficant source of nutrients for South Atlantic Bight waters. Particulate carbon has been found to decrease in sediment rapidly offshore implying that nutrient release rates would also decrease rapidly in the offshore direction.

4.3.3 Biota

The topic in need of intensive work is nitrogen dynamics. A thorough study of the nitrogen dynamics of a stranded Gulf Stream intrusion is recommended. This would include various ammonia uptake and release experiments including or omitting zooplankters. Another topic to be investigated is the reason for the apparent high nearshore productivity. Here again specific experiments addressing the regeneration problem are required.

4.4 Chlorinated Hydrocarbons

4.4.1 Water Column

Concentrations of most chlorinated hydrocarbons in the water are very low and future studies should concentrate on organisms which filter these compounds from the water, such as bivalves.

4.4.2 Sediments

There is a need for a good survey of various chlorinated compounds in the sediments of the study area, both coastal and offshore. To date there are a few studies at specific estuarine sites. There appears to be almost no information on the concentration of these compounds in offshore sediments. An analytical study of sediments from offshore into an estuarine area with high concentrations of some pesticides should be carried out to determine the importance of transport of pesticides to offshore. Studies are needed to determine the fate of chlorinated hydrocarbons in both coastal and in offshore sediments.

4.4.3 Biota

More studies of chlorinated compounds in species from both coastal and offshore areas should be conducted to determine the concentrations of these compounds in biota. The relative importance of uptake of chlorinated hydrocarbons from food, water, and sediment in selected members of the biota would be of use in determining the importance of the various pollutant sources.

4.5 Radionuclides

There is such a paucity of data on radionuclides in the coastal and estuarine environment between Cape Hatteras and Cape Canaveral that any new information would be worthwhile. It is particularly recommended, however, that studies be made of the distribution of transuranic and fission product isotopes in coastal and estuarine sediments in the vicinity of potential sources.

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IV. Phytoplankton

Dr. Harold G. Marshall
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

1.0 INTRODUCTION

Phytoplankton represents the primary autotrophic entity in the marine ecosystem and is mainly composed of microscopic algal cells, destined to a life where, either a portion, or their total existence is in a floating state. The major constitutents are the diatoms, a variety of phytoflagellates (e.g. dinoflagellates, coccolithophores, silicoflagellates, etc.), the blue-green algae, and some macroscopic forms. Phytoplankton represent the initial autotroph within a wide variety of food webs and have traditionally been recognized in relation to their production of organic matter within the oceans.

Phytoplankton distribution patterns are known to be influenced by a variety of environmental conditions that may also affect their concentration and productivity. The relationship of phytoplankton populations to water quality changes within the environmental setting have also been well documented. Phytoplankton composition and density values are known to be affected by nutrient levels, patterns of nutrient replenishment, and the seasonal environmental changes of sunlight, salinity, and temperature, among others. Nearness to estuaries and the coastal area, the degree of upwelling, or variations in seasonal mixing action, all provide additional influence to the development of phytoplankton. Thus, traditional studies of the phytoplankton have included an array of investigations, many of which have emphasized laboratory approaches to better understand the metabolic aspects of growth, production, photosynthesis, etc., with others directed to these similar problems at sea, while a few have combined both approaches.

1.1 Scope of This Evaluation

The approach taken in this chapter is to concentrate on a review of phytoplankton investigations in the area between Cape Hatteras, North Carolina and Cape Canaveral, Florida that will update the Virginia Institute of Marine Science publication of 1974. Emphasis is placed on field studies within this area, and extending seaward to the 1500m isobath. Of importance is the fact that several different types of water systems are present in this area. These would include water entry from major coastal estuaries, the waters over the shelf, the Gulf Stream, sub-surface entry from beyond the shelf, and the western North Atlantic (Sargasso Sea).

1.2 Information Sources

Several major approaches were followed in obtaining information for this chapter. First, the services of several data retrieval systems were utilized to obtain information on existing publications, ongoing, and past studies. Information questionnaires were sent to agencies, universities, and private laboratories that have marine biological activities within the Atlantic coastal plain to obtain information about their programs in phytoplankton studies. In addition, letters were sent to various investigators involved in phytoplankton studies within this area to provide specific information about their recent and ongoing programs. Visits were made to several of the Atlantic coast laboratories for discussions with investigators about their programs and data base, with further phone calls made to others regarding their programs. This report is based primarily on the responses of these investigators and the representatives from the various organizations. Their assistance is greatly appreciated and the responders are recognized in the Acknowledgments section of this report.

1.3 General Review of Studies Prior to 1973

Phytoplankton studies between Cape Hatteras and Cape Canaveral were sparse prior to 1973. Of note is the study by Hustedt (1955) of littoral diatoms near Beaufort, North Carolina, the investigations in the Pamlico River by Hobbie (1971), and Carpenter's (1971) study in the Cape Fear River estuary, among others. In most of the past studies seasonal changes in composition and concentrations have been identified with relationships to specific environmental conditions noted. The work by Campbell (1973) in Gales Creek, a tributary of Bogue Sound, located south of Morehead City, North Carolina has special significance. Campbell provides taxonomic descriptions and illustrations, along with seasonal and ecological relationships for the phytoflagellates. This category of phytoplankters has often been slighted in the past studies for the region, and this work offers an extensive and illustrated coverage for this important group.

The earlier phytoplankton studies over the continental shelf between Cape Hatteras and Cape Canaveral were mainly the result of scattered cruises through this area. Hulburt (1967) reported on the differences between plankton flora found between the Gulf Stream and coastal waters off Jacksonville, Florida. He indicated differences in composition of phytoplankters found in waters classified as coastal or slope water, the Gulf Stream, and Sargasso Sea water. Hulburt and MacKenzie (1971) also reported on the shoreward increase of phytoplankton cell numbers between Virginia and Georgia, and the southward decrease between Virginia and the Turks Islands, Bahamas. This study revealed the presence of a pattern of large changes in phytoplankton across the continental shelf of the southern United States. Marshall (1971) reported on the composition of phytoplankton off the southeastern coast of the United States based on seasonal station data from 13 cruises. In this report he noted 189 species and presented the representative species for those seasonally common to shelf waters, the Gulf Stream, and the Sargasso Sea. Emphasis was placed on the diatoms, pyrrhophyceans, coccolithophores, and silicoflagellates, with comments directed to the vertical distribution and seasonal appearances of the major species. In this study, and in previous ones, Marshall (1969) noted a predominant diatomaceous flora at the coastal stations, with dinophyceans and coccolithophores becoming more predominant seaward. The vertical and seaward concentrations of coccolithophores from the North Carolina coast into the Sargasso Sea is further discussed by Marshall (1968).

2.0 SUMMARY OF RESEARCH CONDUCTED SINCE 1973

2.1 Phytoplankton Composition and Concentrations in Continental Shelf Waters

The composition of phytoplankton and the general distribution patterns of the major taxonomic groups are discussed by Marshall (1976) for the eastern shelf waters of the United States. A species list of 609 phytoplankters is given with the dominant cold and warm water forms noted. In coastal waters south of Cape Hatteras, there existed a greater species diversity of diatoms than what was noted along the northeastern United States waters. The phytoflagellates were common throughout the year with dominants such as *Ceratium fusus*, *C. masseliense*, *Exuviaella compressa*, *E. marina*, *Oxytoxum scolopax*, *O. variabile*, *Podolampas palmipes*, *P. spinifer*, and *Dictyocha fibula*. Coccolithophores also had a greater diversity in these warmer waters with typical species including *Coccolithus (Emiliania) huxleyi*, *Cycloccoccolithus leptoporus*, *Discosphaera tubifera*, and *Gephyrocapsa oceanica*. Ubiquitous species were *Skeletonema costatum*, *Thalassionema nitzschioides*, and *Coccolithus huxleyi*.

The phytoplankton composition in the continental shelf waters south of Cape Hatteras is briefly discussed by Marshall (1979). He characterizes the populations as having less seasonal fluctuations compared to phytoplankton north of Cape Hatteras with the stabilizing influence of the Gulf Stream as a major factor.

An apparent regional distinction of the phytoplankton composition may be defined in the vicinity of Cape Hatteras. South of Cape Hatteras, the typical subtropical-tropical species are found and consist of a rather diverse group of neritic and pelagic species. To the north of Cape Hatteras, the more typical temperate and boreal neritic species are common. Entry of northern and southern species past this area would occur in relation to specific current movements, ring formation, and storm action, among other factors. Table IV-1 presents phytoplankton common to the eastern coastal waters that have been found associated with warm (>18°C) and cold (<10°C) waters. Warm water associations south of Cape Hatteras generally contain an increase in the species representation of the following genera: Rhizosolenia, Coscinodiscus, Hemiaulus, Ceratium, and Podolampas.

The results of phytoplankton collections taken during a 1974 MARMAP cruise, with stations located over the shelf between Cape Hatteras and Cape Canaveral, have been presented by Marshall (1979). In this study he noted an additional 39 new species to the 609 phytoplankters reported in his earlier report. In these collections, the phytoplankton off Cape Canaveral consisted mainly of diatoms with dominant species representative by Biddulphia alternans, Cymatosira belgica, and Thalassionema nitzschioides. In addition there was a large complement of small, mostly unidentified diatoms. Coscinodiscus centralis and C. lineatus were common at nearshore stations, but in the more seaward stations their numbers declined, along with a reduction in their average size. There were also isolated pockets over the shelf of major development for several species, e.g. Synedra fulgens, S. undulata, and various Rhizosolenia species. The phytoflagellates were more abundant at the nearshore stations with Prorocentrum micans, Ceratium furca, and C. fusus most common. There were also represented various blue green algae, e.g. Agmenellum quadriduplicatum, Gomphosphaeria sp., Nordularia harveyana, and Nostoc sp. Also widely distributed was Oscillatoria erythraea which on several occasions completely dominated the samples. Future collections through the MARMAP program will be continued in these waters. A complete series of samples has been taken during the July 1978 MARMAP cruise and will be processed and studied by Marshall. These results will be included with ongoing collections north of Cape Hatteras, over the continental shelf, and eventually added to an extensive data base that now exists from previous collections for the east coast. Emphasis is placed on species composition, concentrations, seasonal distribution patterns, and identification of long term changes over the eastern shelf region.

TABLE IV-1. Phytoplankton associated with warm and cold water temperatures along the eastern coastal waters of the United States (warm waters > 18°C, cold waters < 10°C). (From Marshall, 1978).

	Warm Water Forms	Cold Water Forms
Diatoms		
	Asterolampra marylandica	*Achnanthes taeniata*
	Bacteriastrum delicatulum	*Amphiprora hyperborea*
	Coscinodiscus lineatus	*Biddulphia aurita*
	Hemiaulus hauckii	*Chaetoceros atlanticus*
	Nitzschia delicatissima	*Chaetoceros compressus*
	Planktoniella sol	*Chaetoceros convolutus*
	Rhizosolenia alata	*Chaetoceros curvisetus*
	Rhizosolenia calcar avis	*Chaetoceros debilis*
	Rhizosolenia cylindrus	*Chaetoceros socialis*
	Rhizosolenia delicatula	*Chaetoceros wighami*
	Rhizosolenia setigera	*Corethron hystrix*
	Rhizosolenia styliformis	*Fragilaria oceanica*
	Thalassionema nitzschioides	*Rhizozolenia alata*
	Thalassiothrix frauenfeldi	*Rhizosolenia stolterfothii*
		Thalassiosira nordenskioeldi
Pyrrhophyta		
	Amphisolenia bidentata	*Ceratium arcticum*
	Ceratium declinatum	*Ceratium lineatum*
	Ceratium extensum	*Ceratium longipes*
	Ceratium kofoidi	*Ceratium macroceros*
	Ceratium massiliense	*Dinophysis acuta*
	Ceratium trichoceros	*Dinophysis arctica*
	Cladopyxis caryophyllum	*Dinophysis norvegica*
	Dinophysis fortii	*Peridinium brevipes*
	Dinophysis schuetti	*Peridinium depressum*
	Exuviaella compressa	
	Exuviaella ovum	
	Ornithocercus magnificus	
	Oxytoxum milneri	
	Oxytoxum scolopax	
	Peridinium steini	
	Podclampas bipes	
	Podolampas palmipes	
	Podolampas spinifer	
Cocclithophores		
	Coccolithus huxleyi	*Coccolithus huxleyi*
	Discosphaera tubifera	*Coccolithus pelagicus*
	Rhabdosphaera stylifer	*Cyclococcolithus leptoporus*
	Syracosphaera pulchra	
	Umbellosphaera irregularis	

Phytoplankton and zooplankton species composition and production associated with the water masses intruded onto the southeastern continental shelf have been under study by G. Paffenhöfer and W. Dunstan, and centered at the Skidaway Institute of Oceanography. An extensive study (1975) in Onslow Bay included vertical series of summer collections from nearshore stations to the shelf break. The phytoplankton portion is presently being prepared by Dunstan which includes information on composition, numbers, primary productivity and chlorophyll, plus physical and chemical parameters. An expanded study has been underway by Paffenhöfer and Dunstan in the Georgia Bight off Savannah seaward (Paffenhöfer, 1978, personal communication). Approximately monthly samples are taken at seven stations. Drogues are used to follow intruded water, with diel sampling occurring at three hour intervals in surface waters and in the near bottom intrusion. Phytoplankton composition and production are determined for these samples. An additional series of monthly collections has been established since 1975 at three nearshore stations off the Savannah coast that include phytoplankton composition and nutrient data. These collections are presently in the process of being worked-up at the Skidaway Institute of Oceanography.

2.2 Phytoplankton Composition in Nearshore and Estuary Areas

Although a specific task of this report is to discuss research along the coastal extent between Cape Hatteras and Cape Canaveral, it is essential to include the work that has taken place in several of the major river and estuary systems that enter the offshore waters, as various degrees of movement exist between these water masses and the biota between the estuary and the shelf waters beyond the shoreline. Due to these associations and the ecological importance of the estuary to the region, these studies have been included in the review given below.

Pamlico River - Pamlico Sound

Located behind the barrier islands along the eastern shoreline of North Carolina, Pamlico Sound represents a large estuary system. The estuary receives flow from several rivers, which include the Pamlico River where several long-term studies of estuary biota have taken place. Eutrophication studies of the Pamlico River were begun in 1966 by the Water Resources Research Institute of North Carolina State University and the University of North Carolina. Studies in the Albemarle Sound and the Neuse River were begun in 1970.

Hobbie (1971) has described the phytoplankton of the Pamlico River estuary as completely dominated by dinoflagellates, and the diatoms becoming more important in the lower reaches of the river near where the river enters Pamlico Sound. *Peridinium triquetrum* is the dominant organism which typically is involved with other dinoflagellates in bloom from January through March. *P. triquetrum* is associated with extremely rich or polluted conditions. In the Pamlico River estuary the enrichment of the water is attributed to large amounts of nitrates that reach the river system from small city sewage outflow and from farm and swamp runoff. The effects of phosphorus on the ecology of the Pamlico River estuary were measured by Copeland and Hobbie (1972) and supported the lesser role of phosphorus in determining phytoplankton blooms for this area. They found that the estuary is rich in phosphorus due to land runoff and mining waste sources, with much of the incoming phosphorus accumulating in the bottom sediments. Release of phosphorus into the water column was noted to occur during periods of low oxygen condition. Their experiments indicated that carbon intake was not enhanced by additional phosphorus, but was increased when nitrates were added. They concluded that nitrogen was the limiting nutrient in the Pamlico River estuary. In a later study, the effects of temperature increase on the composition of brackish water phytoplankton populations were observed by Carpenter (1973). Studies were conducted in four plastic pools located near the Pamlico River estuary, where higher temperature ranges were maintained in two of the pools than in the two control pools during a February-April time period. The phytoplankton populations in the heated pools were more diverse and were composed of larger cells than in the control ponds. Carpenter indicated that the warming tended to accelerate the late winter and early spring successional patterns to a more mature successional stage. He indicated the warming of brackish water by possible heated effluents associated with electrical generating plants may subsequently alter the phytoplankton composition.

Hulburt and Horton (1973) have observed conditions affecting phytoplankton growth in Pamlico Sound. They observed a sequence of dominant species where overlap of major populations was common and the species benefited from a minimum of interference to their development from other species. They concluded that one group of species was not prevented from developing by the dominant presence of another group of species. The groups would share the same waters, showing minimum interference, with each responding to growth patterns and growing in unison. Hobbie (1974) has further investigated the phytoplankton composition, biomass, and nutrient concentrations in the Pamlico River.

Gales Creek - Bogue Sound

Campbell's (1973) study of the brackish water phytoplankton emphasized the phytoflagellates of Gales Creek, a small tributary of Bogue Sound (just south of Morehead City, North Carolina), and he noted the diatoms had a typical bimodal period of annual abundance with peaks in spring and fall. A total of 152 phytoflagellates were identified and dominated the phytoplankton throughout the year. They had maximum densities in late summer with the majority being eurythermal and euryhaline species. The low population numbers were attributed to low nitrate concentrations and a high flushing rate for the estuary.

Cape Fear

Using multispectral aerial photography techniques, Welby (1976) reports on this procedure to examine two different types of water quality. Selected sites included the Cape Fear River and the Chowan River. The report concerns results from these flights and the application of such data to management planning of North Carolina water resources. The technique may be used to trace pollutants associated with turbid water, and how water draining from the swamps might be traced to larger bodies of water. Phytoplankton monitoring to note differences in concentrations are discussed. Application of the multispectral analysis values to limited ground truth information may allow useful phytoplankton monitoring to a wide range of natural water systems. A technique was developed by which the difference between the extinction depths of a red quadrant and a white quadrant on a modified Secchi disc was used with water sampling and analysis to obtain biomass concentrations indirectly. This relationship was presented as one of the ground truth measurements used to establish relationships between the reflectance characteristics of a specific waterway to different water quality parameters.

The Cape Fear estuary and adjacent nearshore ocean were studied extensively by Copeland, Birkhead and Hodson (1974) with portions of this information mentioned earlier by Copeland and Birkhead (1973). The Cape Fear study was initiated to determine ecological effects incident to the construction and operation of the Brunswick nuclear generating plant. The biotic survey included a qualitative and quantitative study of the phytoplankton, with over 450 species found in the Cape Fear River estuary system and ocean off Oak Island. They noted that fourteen of the species were abundant and thirty-six were common, with the remaining species rare or not common in the samples. The diatoms were the most abundant group with *Stephanopyxis* the most common genus represented. It occurred in over 50 percent of the samples and averaged more than 100,000 cells per liter. This genus was found throughout the year and was widespread in the collections. Other genera that were common included Rhizosolenia, Nitzschia, and Navicula. Copeland et al. (1974) reported over fifty species that were restricted to the ocean stations, but none of these were found in any abundance. The cell counts ranged from 171,000 to 10,070,000 per liter. The total cell counts were greater at stations in the Intracoastal Waterway and the ocean, particularily during August 1971 and April 1973. During periods of large concentrations, Stephanopyxis costatum composed the majority of the cells. The lowest concentration of cells occurred during October with the highest values during the summer months. It was noted that on the incoming tide the total cell count was higher at the estuary and nursery areas stations. Thus, tidal conditions influenced, and allowed entry of phytoplankton populations into the Cape Fear estuary from the ocean area. The lowest species diversity indices also occurred in the nursery area stations, particularly during times of the outgoing tide. Incoming tidal conditions brought into the estuary additional species, with a tendency to increase species diversity at that time. Species diversity was also highest during fall and winter months, with lowest values in summer. Periods of highest diversity also were times of lowest concentrations in the Cape Fear estuary. During the period of highest concentrations, the phytoplankton were dominated by fewer species, but in greater numbers. The diversity was lowest for the Intracoastal Waterway and ocean stations, but these areas had the largest concentrations of phytoplankton. Blooms, composed chiefly of Stephanopyxis costatum, were evident in the ocean during August (of 1971, 1972), and April 1973.

Cooling water used in the Brunswick nuclear-fueled electric generating plant is eventually discharged into the nearshore ocean off Oak Island. Hodson, Schneider and Copeland (1977) have assessed the impact of once-through cooling on the ecology of the lower Cape Fear estuary. In entrainment studies they found the phytoplankton showed no apparent effect attributable to the plant dumping activities. They noted the close relationship between the type of phytoplankton in the offshore waters and in adjacent estuaries. Any withdrawal of phytoplankton from the Cape Fear estuary was replaced by incoming populations. These were mainly from the ocean, but also included forms from upstream entry. They indicated that the Cape Fear estuary phytoplankton was similar to populations in the coastal waters. Hodson et al. (1977) also refer to additional reports submitted to the Carolina Power and Light Company that pertain mainly to the Cape Fear estuary prior to 1974.

Charleston Region

An extensive project concerning an environmental baseline study of South Carolina estuaries was begun in 1973 by the Marine Resources Division of South Carolina Wildlife and Marine Resources Department, which includes phytoplankton sections, along with other biota, physical, and chemical parameters. The field survey program involves quarterly collections at 33 stations across the state's coastal zone, and 17 stations in the North and South Edisto Rivers and the Cooper River that are sampled monthly. Productivity values and monthly phytoplankton concentrations from portions of this study have been reported by Manzi, Burrell and Carson (1977) for several marsh impoundments and their associated tidal creeks. The potential primary production here was higher in the impoundments than in the tidal creeks. The highest values ranged from 32.2 to 228.6 $mgC/M^3/hr$.

An annotated checklist of South Carolina biota for the coastal zone of South Carolina is presently in press (Zingmark, 1978a) and contains listings of phytoplankton species for these waters. An additional survey of phytoplankton production in North Inlet is provided by Vennewitz (1977) who presents information on species composition, their concentrations, photosynthetic rates, and chlorophyll-a values. Hall (1978) has also reported on the seasonal succession and species diversity of phytoplankton in the North Inlet estuary.

A one year seasonal succession study was conducted by Zingmark (1978b) at Kiawah Island located along the South Carolina coast, south of Charleston. Oceanic, estuarine, and freshwater (coastal ponds) stations were established. Zingmark lists 240 taxa, with the diatoms dominant in the oceanic and estuarine stations, while chlorophyta were most abundant in the freshwater stations. He characterized the marine phytoplankton community of Kiawah Island as typical of the eastern coast of the United States, with the dominant marine diatoms being *Asterionella glacialis* (*A. japonica*), *Rhizosolenia alata*, and *Skeletonema costatum*.

Georgia estuaries

Monthly measurements of phytoplankton photosynthesis and chlorophyll-a in Doboy Sound, in the Duplin River, and in tidal water inundating a marsh adjacent to Sapelo Island are being conducted by E. Haines, L. R. Pomeroy, and D. L. Whitney (Haines, 1978, personal communication). The study is designed to analyze the magnitude and distribution of phytoplankton production in the salt marsh estuary and to determine the importance of phytoplankton photosynthesis to the carbon budget of the marsh.

Both particulate and dissolved organic production are measured by ^{14}C uptake over a vertical series from the surface to two meters. Unpublished results (Haines, 1978, personal communication) over an eleven month period indicate the highest rates of carbon fixation for the Duplin River and Doboy Sound occurred in spring and summer, with lowest in fall and winter. Photosynthesis rates appeared to be most strongly dependent on light availability. In these waters the phytoplankton composition was generally a mixture of pelagic centric diatoms (Skeletonema, Asterionella, Rhizosolenia), benthic pennate diatoms (Nitzschia, Navicula, Pleurosigma), dinoflagellates, and green flagellates. The phytoplankton production represents a negligible source of carbon for the marsh because of the infrequency of significant inundation during daylight hours, but this amount would vary in different watersheds where there would be differences in the area of euphotic zone (e.g. open water-marsh area inundation). The work by Haines (1977) is discussed later where she brings out the importance of the phytoplankton as an important source of carbon in estuary systems. Haines is also studying the fluxes of organic materials in an estuarine ecosystem using $^{13}C/^{12}C$ ratios, emphasizing the sources and fates of estuarine detritus. This work is being conducted in Altamaha, Doboy, and Sapelo Sounds, nearby marshes, and nearshore shelf waters. In this use of stable carbon isotope ratio analysis, the study will concentrate on the evaluation of carbon pathways in the salt marsh ecosystem to determine the sources of carbon for the organic matter, and further analyze estuarine food webs. The Satilla River, which enters the ocean at the southeastern coast of Georgia, has been studied by D. Gillespie, with emphasis on obtaining quantitative field data and the distribution of total annual production among the various habitats.

Jacksonville and Cape Canaveral Area

The St. John's River estuary from Lake George to Mayport was studied over a three year period by Drs. C. Demort and R. Bowman in a broad-based study which emphasized the identification of major zones of environmental stress within the river system and included the correlation of phytoplankton standing crop, community metabolism, and plankton associations, with chemical and physical parameters. Demort has indicated (1978, personal communication) that between 200 and 300 phytoplankton species have been identified during the study which included monthly collections at 15 stations over the 209km extent of the St. John's River. A report for this Sea Grant-sponsored project will be completed by late 1978. An additional nearshore shelf study has also been underway by Dr. Demort since the summer of 1977. This includes collections at approximately eight stations off the northeastern coast of Florida between Fernandina Beach (near the Florida-Georgia border) and Anastasia, Florida. This is expected to be a long-term study which would include phytoplankton composition and counts, with related environmental parameters also recorded.

A broad-based ecological study and monitoring program has been conducted in the Cape Canaveral area in relation to the Florida Power and Light Company's Hutchinson Island nuclear power plant. Applied Biology, Inc. has prepared a report "Ecological Parameter Monitoring at the Canaveral Plant". Unfortunately, this report is not available for distribution at this time. In addition, the Department of Natural Reources of the State of Florida conducted baseline studies for the Hutchinson Island area, which include reports that have recently been published and several that are in press (Walker and Steidinger, 1978; Tester and Steidinger, 1978; and Walker, 1978). These investigations include a monthly sampling program for nearby areas of the shelf over the last three years. Diel studies were also included for one year. Among the results, it was found that many of the dinoflagellates could serve as species indicators of intrusion of oceanic water into this area.

Apparently a variety of reports have been prepared for different biota and the ecology of the Indian River estuary system. Some of these may include phytoplankton as one of several segments studied. Although no additional publications or items under study were available to this author, it is apparent that this section of the southeastern coast represents an area where future concerted efforts will be continued and the various institutions of that area would be a source of this continued work. Studies of this area include the work of Dye (1978), who reports on limiting nutrient algal assays from stations in the Indian River-Banana River area near Cocoa Beach, Florida. Innoculating the samples with Dunaliella tertiolecta, nutrient studies showed significant algal growth with the addition of phosphorus, with even more growth increase with both nitrogen and phosphorus added. With sufficient amounts of phosphorus available, nitrogen was the limiting nutrient. Also, within the Indian River system between Vero Beach and Fort Pierce an extensive plankton study has been underway for several years by investigators from the Harbor Branch Foundation. Water quality and phytoplankton studies values have been determined at several stations in this area and include phytoplankton composition counts, and pigment values (Gibson, 1978, personal comunication). Additional studies of benthic epiphytic diatoms are being conducted off West Palm Beach to 91m depth.

2.3 Productivity and Nutrient Studies

The association between nitrate uptake and the development of a phytoplankton bloom was discussed by Harrison (1973) in a study in Pamlico River estuary. He found that phytoplankton nitrate reductase activity occurred during the development of a winter dinoflagellate bloom. Such activity is induced by nitrate assimilation and repressed during ammonium assimilation. His studies indicated that nitrate is the major nitrogen source during such blooms, even in the presence of ammonium. In this study, Harrison found that nitrate levels were apparently a major influence in the initiation and maintenance of phytoplankton blooms.

Sanders (1978) conducted a study on response of a natural phytoplankton population to increased concentrations of manganese. Working with samples taken from Calico Creek, a tributary to Newport River estuary (North Carolina), he indicated a high phytoplankton productivity rate, 230 $gC/M^2/yr$, with summer populations dominated by <u>Navicula arvensis</u>, <u>Nannochloris</u> sp., and <u>Nephroselmis gilva</u>. The response to the excess manganese varied with tidal amplitude, where carbon uptake was high at low periods of tidal amplitude. He suggests it is likely this stimulation was due to interactions between the added manganese and dissolved organics present in the creek, and this affected the availability of the manganese to the phytoplankton.

Phytoplankton productivity was studied by Thayer (1971) in an extensive estuary system, bordered by the barrier islands, near Cape Lookout. He measured photosynthesis, nutrients, and the standing crop of phytoplankton for one year at 32 stations. He noted minimal production in the winter and maximal in June and July. The annual range of production was from 16 gC/M^2 to 163 gC/M^2 with an average of 66.6 gC/M^2 for the 400km^2 study area. He indicated that both phosphorus and nitrogen concentrations were probably limiting factors, but N:P ratios suggest nitrogen was more limiting. Thayer noted that the diatoms predominated throughout the year with <u>Skeletonema costatum</u>, and species of <u>Nitzschia</u> and <u>Chaetoceros</u>, the most numerous forms. In a later report, Thayer (1974) discusses nutrient limitation to phytoplankton production in the same estuary. Using nutrient enrichment techniques, he identified nitrogen as a primary limiting nutrient, with phosphorus limiting at times. Thayer further mentions the presence of organic substrates, that are low in these nutrients relative to their carbon content, may be one of the factors limiting the availability of nutrients to the phytoplankton. In his study of the Cape Fear River plume for over a year with ERTS imagery, Welby (1975) cites conditions where imagery studies may be useful in monitoring coastal phytoplankton blooms.

Several R/V EASTWARD cruises have been involved with productivity measurements in shelf waters off the North Carolina coast. On cruise E-12-72, four transects, each with six stations, were established between Cape Hatteras and Cape Lookout. Collections were taken about two miles offshore and extended seaward between Core Banks and Hatteras Inlet. Chemical and physical parameters were measured along with primary productivity, chlorophyll, pheophytin and particulate carbon. A raw data report is presented for a vertical series of measurements for each of these stations (Anonymous, 1972). Smith and Barber (1974) provide raw data from an extensive series of transects over the shelf between Cape Hatteras and just south of Cape Lookout. Nutrient and productivity values were determined at each station, over a vertical range from surface to bottom. Smith and Cowles (1975) present additional data for some of the stations covered previously by Smith and Barber (1974). In all of the reports the data are presented, but not summarized or evaluated. A similar raw data report is given by Haines (1972) for a series of EASTWARD cruises occurring over the shelf between Cape Hatteras and Cape Canaveral. In this report the data are given for a vertical series of measurements which includes nutrient, chlorophyll, and productivity data.

A discussion and evaluation of the ^{14}C method in measuring productivity in the North Inlet estuary (near Georgetown, South Carolina) is presented by Sellner, Zingmark and Miller (1976). The productivity values ranged from a November low of 6-4 $mgC/M^2/hr$. to a high of 234 $mgC/M^2/hr$. in August. A comparison of primary production rates for the eastern seaboard is also given (Table IV-2) in which Sellner et al. (1976) compare these values and their results. The North Inlet estuary with a particulate production of 259 $gC/m^2/yr$. is between the North Carolina and Georgia estuarine production data. If carbon release is included, the total production is 346 gC/m^2yr. By not including the released carbon, the value is underestimated by 25 percent. They found the highest release rates were observed during the 1972 summer where up to 55 percent of fixed carbon was released, with this percentage dropping to between 3-14 percent during the following spring-summer period. The release of fixed carbon would be partly due to lysis of cells in the filtering process. The authors conclude their evaluation with the suggestion that the 14-C method should be used with caution with attention given to volume filtration errors (cell lysis) producing high released carbon percentages and incorporation of the dark bottle in primary production studies.

TABLE IV-2. A comparison of estuarine primary production rates for the eastern seaboard of the United States (Sellner, Zingmark and Miller, 1976).

Location	Method	Production Rate gC/m²/yr.	Reference
Narragansett Bay	O_2	84	Smayda, 1957
Long Island Sound	O_2 (net)	170	Riley, 1956
Patuxent River Estuary	^{14}C	193-330	Stross & Stottle-meyer, 1966
Beaufort Estuary, N. C.	^{14}C	67	Thayer, 1971
Beaufort Estuary, N. C.	O_2 (net)	53	Williams, 1966
North Inlet Estuary	^{14}C	259 (346)[1]	present study
Atlamaha River mouth	^{14}C	546	Thomas, 1966

[1]Particulate = 259; total (particulate + released) = 346.

In a report by Vernberg, Bonnel, Coull, Dame, DeCoursey, Kitchens, Kjerfve, Stevenson, Vernberg and Zingmark (1977) on the North Inlet estuary there are further studies on the phytoplankton and microbenthic algae. In the chapter by R. Zingmark, productivity values are presented. The rate of phytoplanktonic production was 273 $gC/m^2/yr$. This rate was less than the earlier study mentioned above, but considerably larger than the values reported by Thayer (1971) for a shallow estuary near Beaufort, North Carolina, which average 66.6 $gC/m^2/yr$., and similar to that noted by Sanders (1978) where 230 $gC/m^2/yr$. was noted for Calico Creek, near Morehead, North Carolina. High productivity was also recorded for the benthic microflora, in North Inlet, which had an annual rate of 685 $gC/m^2/yr$. The results indicate that in the North Inlet estuary the algae (phytoplankton, benthic microflora, benthic macroalgae), in contrast to the halophytes, are the most important primary producers. This represents a greater role normally assigned to the algae for their contributions to the productivity in an estuary system.

Haines (1977), in her discussion of origins of detritus in Georgia salt marsh estuaries, offers evidence for a source other than *Spartina alterniflora* for a significant fraction of organic seston. She also indicates that phytoplankton production is probably more important to the food webs of the estuary than is presently thought. Utilizing the stable carbon isotopic composition of organic seston, it was found that these did not match the isotopic composition of *Spartina* carbon, yet the ^{13}C and ^{12}C ratios were compatible to those of phytoplankton and terrestrial sources. Haines offers estimates of potential input of organic materials to Georgia estuaries of 770 $gC/m^2/yr$. for phytoplankton production and 600 $gC/m^2/yr$. for terrestrial plant detritus, which are comparable to estimated values (780-1660 $gC/m^2/yr$.) given for *Spartina* salt marshes. Haines and Dunstan (1975) have conducted a seasonal survey of particulate organic materials and primary production in the Georgia Bight. The area studied is part of the continental shelf between Cape Romain, South Carolina and St. John's River, Florida. Previous studies have shown this area to have one of the highest annual rates for marine phytoplankton production recorded (546 $gC/m^2/yr$. in the inner 15km of Georgia coastal waters, (Thomas, 1966). In this study they noted a general lack of seasonality in production where phytoplankton blooms in Georgia shelf waters were non-seasonal and of short duration. Their production values for mean annual rates show the following: 285 gC/m^2 for nearshore waters, 132 gC/m^2 for the outer shelf, with 171 gC/m^2 for the entire shelf. Utilizing ratios of carbon to nitrogen and carbon to chlorophyll-a, with carbon isotopic ratios, they found that the data indicated an *in situ* origin of most nearshore particulate organic material, rather than from the nearby estuaries, with the source coming from the phytoplankton production. Haines (1975) earlier studied the continental shelf area between Charleston, South Carolina to Fernandina Beach, Florida to determine to what extent nutrients from nearby estuaries were brought to the shelf waters and how this outwelling affects production in Georgia coastal waters. She established a nitrogen flux budget for the Georgia and South Carolina shelf waters. The influx of nitrogen from fresh water drainage, deep water intrusion, and precipitation was compared to uptake values by the primary producers and to the standing stock of particulate nitrogen. Her results indicated *in situ* regeneration the major process for continuing high rates of nutrient flux (and biological productivity) for these shelf waters. Lesser significance was placed on nutrient influx from estuary outwelling and from deep water across the edge of the shelf. Haines has also indicated (1978, personal communication) the importance of sub-surface Gulf Stream water as a nutrient source for the shelf phytoplankton, whose role and contributions to the productivity of coastal estuaries is probably greater than is now recognized.

Morris, Yentsch and Yentsch (1971a) considered the approach that phytoplankton in the ocean are not nitrogen deficient. They reported on studies about the rate of dark fixation after the addition of ammonium ion to cultures of marine phytoplankton and to natural populations in the Strait of Florida. Their studies suggested that nitrogen deficiency in tropical oceanic populations does not occur to the degree that can be induced in culture. They suggest that the reason tropical phytoplankton populations are small is that the population size is limited by the level of nitrogen introduced into the system. They state that the difference between a limitation and a deficiency of the nutrient is that the physiological processes are not markedly affected by a limitation. An interesting association with current transport and the development of an algal bloom off the Florida coast is discussed by Murphy, Steidinger, Roberts, Williams and Jolley (1975). They indicate that a Gulf of Mexico loop current anomaly transported large volumes of water containing red tide blooms of *Gymnodinium breve* from the southwest coast of Florida to eventually reach the Florida east coast. Bloom conditions were realized north of Fort Lauderdale. This pattern of entry to Florida coastal waters by phytoplankton in the Florida current illustrates the importance of the coastal current systems as transportation for a variety of tropical and nontropical species to enter the southeastern coastal waters of the United States. Morris, Yentsch and Yentsch (1971b) indicated that between the coast of Florida and the open waters of the Florida current off Fort Lauderdale there is a decrease in chlorophyll concentrations.

They refer to eutrophic coastal waters with the surface waters in the Strait of Florida as rather nutrient poor. They conducted experiments on natural populations in the Florida Strait and with cultures to evaluate the C-14 technique for assessing primary productivity, and discuss results of experiments regarding the rate of dark fixation in response to specific environmental parameters, and its relationship to cell density.

2.4 Additional Areas of Study

Fornshell, Frydenlund and Christensen (1977) reported on a net survey of surface phytoplankton during a cruise between Cape Canaveral and Cape May. They identified seven *Ceratium* species and *Polykrikos schwartzi* in the samples with *C. tripos* and *C. macroceros* as dominant forms. A high level of developmental synchronization of at least nine dinoflagellates was noted in collections coming from the Gulf Stream about 100km east of Cape Lookout by Doyle and Poore (1974). They propose that the synchronizing agent in the Gulf Stream is the diurnal fluctuation in nutrients. A mathematical model is offered and they suggest that this division synchrony represents an indicator of nutrient competition that increases with the severity of such limitations to the phytoplankton. In modeling studies with phytoplankton in areas such as the Gulf Stream, O'Brien and Wroblewski (1973) discuss the importance of advection in relation to biological productivity. They offer a new non-dimensional number to define the importance of advection by organized fluid motion in spatial models of marine food chains.

The importance of marine benthic diatoms in the stabilization of sediments was discussed by Holland, Zingmark and Dean (1974). Using both unialgal cultures and a mixed microalgal community from an intertidal mud flat from a South Carolina estuary, they found diatoms that secreted large quantities of mucilage were effective sediment stabilizers. This was in contrast to benthic diatoms that secreted little or no mucilage. In their discussion they bring out the selective advantage that would exist to such autotrophic plants that could reduce the resuspension of sediments, and broader implications to the effect of increased sediment stability to benthic meiofaunal communities.

Using an estuarine diatom, Ferguson, Collier and Meeter (1976) examined the exponential growth rate as a function of illumination intensity, temperature, and nitrogen source. The exponential phase cell division rate was proportional to day length, while division rate saturation intensity was similar with 12 or 24 hours of light per day. The growth rate was influenced by interactions among the variables and concentrations.

Studies concerning the effects of mercury on estuarine and oceanic phytoplankton by Zingmark and Miller (1975) included samples taken in Clambake Creek, South Carolina. There, results illustrated the inhibitory effect of mercury on phytoplankton production that was directly related to the mercury concentrations.

2.5 Summation of Research to Date

Past phytoplankton studies between Cape Hatteras, North Carolina and Cape Canaveral, Florida have been concentrated in several of the major estuarine systems within this area. Scattered along the southeastern coast, a concerted system of studies have been underway to more fully understand the dynamics and ecological relationships that exist in these estuarine complexes. Examples of such areal studies would include those in the Pamlico River estuary, the Cape Fear area, the north and south Edisto and Cooper Rivers, Kiawah Island, Doboy and Altamaha and Sapelo Sounds, Indian River, and the Hutchinson Island studies. Offshore studies include those in Onslow Bay and several extensive cruises over the shelf region. Basic population studies, as well as ecological monitoring and the collection of related physical and chemical data have been underway in several long term based programs.

The past and ongoing studies offer information on the numbers and types of phytoplankton that are present in shelf waters and associated estuaries. Seasonal patterns of abundance and dominant species have also been identified. Scattered productivity studies for several of the estuaries, nearshore and to the more distant sections near the shelf break, have been conducted. The results show a significantly high productivity value for the offshore waters of the area. Of note are studies regarding the interaction of the phytoplankton to other trophic levels in the surrounding food webs of these waters, and the source of nutrients for these autotrophs. Another major area of interest is the overall interaction that exists between the shelf phytoplankton populations and the associated ecology and productivity of the marsh-estuary systems inshore. This factor is of importance when considering possible impact that may result to these phytoplankton populations from changes to the shelf water quality due to offshore activities related to drilling, oil spills, and other perturbations by man.

Significant knowledge has been gained by the recent estuarine phytoplankton studies. These have included not only basic research efforts to better understand population dynamics, composition, and interactions with other biota and the environment, but include many applied studies that may have value to offshore conditions. It will be possible to apply much of the knowledge gained in these estuarine studies to shelf populations. In addition, these estuarine and nearshore programs have trained specialists, and fostered a development of an experienced staff, that could allow for an expansion of effort seaward where this need exists.

3.0 IDENTIFICATION AND LOCATION OF RAW DATA AND UNWORKED SAMPLES

There will always be a certain amount of unworked samples associated with ongoing studies and those collections recently completed for this region. It is assumed that the majority of these data will be gradually incorporated into reports and/or publications in the near future. The ongoing research programs presented in Appendix A offers several sources of raw data (e.g. U. S. Geological Survey water quality study in South Carolina) that may have broad application and represent a long term data base. In several laboratories, extensive monitoring programs will include phytoplankton-related data (e. g. composition, counts, productivity, chlorophyll), which may or may not have been worked on with the other parameters. The extensive collections in the South Carolina estuaries include considerable samples and information related to the phytoplankton compositions. These samples are located at the Marine Resources Research Institute, South Carolina Wildlife and Marine Resources Department, in Charleston, South Carolina and are being processed by Dr. John Manzi. Associated physical and chemical parameters for these sample station sites would also be available at the Institute (Manzi, 1978, personal communication). Additional samples for a major program involving phytoplankton and zooplankton collections in shelf waters off the Georgia coast are presently being processed at the Skidaway Institute of Oceanography, Savannah, Georgia under the supervision of Drs. G. Paffenhöfer and William Dunstan (Paffenhöfer, 1978, personal communication). Samples from the shelf waters of the area are also part of a broader base study of east coast plankton by Marshall and are located and being worked at Old Dominion University.

In addition, two years of weekly station data has been obtained for a portion of the Indian River between Fort Pierce and Vero Beach. During the first year of the study, seven stations were sampled, with collections reduced to three stations the second year. Phytoplankton samples were taken, plus physical and chemical parameters measured, which included basic nutrients. This program is under the direction of Dr. M. Youngbluth and Robert Gibson of the Harbor Branch Foundation, Fort Pierce, Florida. The majority of the phytoplankton samples have not been examined to date, but will be processed at the Harbor Branch Foundation (Gibson, 1978, personal communication).

4.0 IDENTIFICATION OF DATA GAPS

Due to the intensive efforts of investigators at several universities, state, and federal agencies within the states of North Carolina, South Carolina, Georgia, and Florida, phytoplankton studies have not been neglected for this coastal region of southeastern United States. A data base has been established in recent years that has allowed a better understanding regarding the nature and ecology of the phytoplankton populations that are present. The vast majority of these studies have been centered in estuarine habitats with common areas of concern the effects of man's perturbation to this particular group, to other biota, or general environmental impact. No doubt future estuarine studies will continue to be directed to specific problems of a certain locale, eutrophication, and other conditions associated with changing water quality, pollution, etc. It is apparent that biotic assessment and long term monitoring studies have been established in the major estuary systems along the coast.

In the VIMS (1974) appraisal of the status of phytoplankton work in this area, seven gaps in available information were identified. These were as follows:

1. Descriptions of community structure for many estuaries between North Inlet, South Carolina and Cape Canaveral are lacking.
2. There are lacking measurements of primary production in most estuaries between Cape Hatteras and Cape Canaveral.
3. Nutrient limitation has not been evaluated.
4. Synoptic information on shelf phytoplankton populations is not available.
5. Rates of energy flow to higher trophic levels are not available.
6. Specific aspects of various pollutants, especially oil, on phytoplankton in regard to community structure and productivity are inadequately known, to predict long term effects of exposure.
7. Many available data are ten years old and may not represent present conditions.

An appraisal of what has taken place since this 1974 report was completed would indicate that many of these gaps have been either addressed or under study. For instance, significant gains have not only been realized in estuarine investigations in each of these four states, but they also include several established broad-based monitoring programs. Recent productivity measurements have not been as extensive and are certainly lacking in the more distant shelf waters, but they have increased significantly over the past few years, and are continuing. Of importance here are the additional relationships now under investigation concerning the source of nutrients to the shelf waters and the role of phytoplankton populations to the estuaries and their overall contributions to the productivity of shelf and coastal waters.

Seasonal phytoplankton studies are now taking place over extended areas of the continental shelf. In addition to these broad surveys, more local type monitoring, consisting of cruises having greater sampling frequency and scope are in progress. For instance, sections of the continental shelf are being more systematically sampled in the Georgia Bight area. The blending of such information with data from the broad coverage type cruises will certainly offer a greater understanding of total plankton dynamics and seasonal fluctuation for the region.

Not fully addressed in recent years are the fifth and sixth areas, or information gaps, mentioned above in the VIMS (1974) report. These refer to energy flow studies and studies concerning the influence of oil and its by-products on phytoplankton populations and production. The last item mentioned as a possible data gap was that the age of the past studies may make the past information outdated. This point appears to be covered by the more expanded and recent phytoplankton studies that are now underway.

The following are considered to be topics needing additional information for the near future:

1. More complete information of seasonal production patterns for nearshore and offshore areas over the continental shelf.
2. Additional work on the degree of importance and interrelationships of the phytoplankters to the coastal and associated estuary ecosystem.
3. Identification of the seasonal nutrient relationships that exist between the shelf and the various estuary ecosystems along this coast.
4. More information is needed as to the seasonal relationship of phytoplankton composition and production to the different water masses, to the herbivores, and nutrient levels.
5. Although the influence of the various pollutants (especially oil, PCB's, etc.) need not be limited to laboratories

along this coast (Fisher, 1975) to be applicable to these phytoplankton, there is a lack of such studies coming from this region. This is not considered a major shortcoming since such studies are being conducted at numerous laboratories in the United States. However, there are numerous toxicological studies that have not involved several of the dominant phytoplankton common to these waters, and there would be value in expanding such efforts in this direction.

5.0 RECOMMENDATIONS FOR FUTURE STUDIES

The following are recommendations for future phytoplankton studies between Cape Hatteras and Cape Canaveral.

1. Monitoring programs in the estuaries of the region should be continued. However, present and future programs need to be systematically appraised to evaluate efficiency of the sampling program and significance of the parameters being measured. Unless information from such studies are routinely processed and evaluated the information has little value.
2. Additional nearshore and offshore productivity studies are needed to better appraise seasonal patterns and understand relationships to the various water masses that enter this area, and the associations to local herbivores and existing food webs.
3. Additional laboratory studies concerning the effects of oil, and its by-products, on the major phytoplankton species in these waters would be helpful. Additional laboratory studies concerning trace metals, vitamins, growth inhibitors, and growth stimulators, would also be recommended with direct application to the local areas.
4. Long term composition and distribution information for the shelf region would provide a valuable information base for denoting major population shifts, changes in water quality, and other influences to these waters.

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V. ZOOPLANKTON

Dr. Raymond Alden
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

1.0 INTRODUCTION

1.1 Scope of the Evaluation

The purpose of this chapter is to review the literature concerning zooplankton research in the southeastern U. S. and to update the information presented in a previous review by Roberts (1974). Although the present project concentrates on the summarization and evaluation of research published since 1973, it also includes any studies conducted before this time that are considered to be important to the understanding of zooplankton ecology, yet were not covered in the 1974 review. The geographic coverage of this review (hereafter referred to as the inventory area) includes all estuarine, coastal, and offshore waters from Cape Hatteras, North Carolina, to Cape Canaveral, Florida, although research done in peripheral Gulf Stream and Sargasso Sea areas is also considered.

In order to make this review useful to planktologists, extensive use is made of figures and tables to present new data on zooplankton communities, especially in the summarization of unpublished work such as theses and technical reports. Analyses of general trends are made at the ends of each section, although it is recognized that many of the studies are not directly comparable. It is hoped that the patterns presented and data gaps identified will serve to inspire further research to define and clarify the ecology of zooplankton species from various ecosystems.

1.2 Information Sources

Information for this study was gathered from published and unpublished sources, as well as from personal contacts with scientists involved in zooplankton research. Table V-1 gives the major information sources used in finding published and unpublished materials and in identifying researchers for the mailing lists. State and Federal agencies located in the inventory area, as well as most of the major southeastern universities and research institutions were contacted for information on published and unpublished articles, ongoing research programs and raw data banks. Nearly 40 percent of the researchers contacted responded to the mailing survey, providing a firm data base to supplement the literature review.

TABLE V-1. Information Sources

A. Printed Matter

1. Ocean Abstracts 1974-present
2. Aquatic Sciences and Fisheries Abstracts 1975-present
3. The Environment Index 1975-present
4. Environment Abstracts 1975-present
5. Biological and Agricultural Index Aug. 1974-present
6. Monthly Catalog of U. S. Government Publications 1974-present
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1.3 General Review of Studies Prior to 1973

In reviewing the literature for this chapter, efforts have been concentrated on research since 1973. It is recognized, however, that there are a number of articles prior to 1973 which have not been reviewed previously, but which contribute significantly to the knowledge of zooplankton communities of the southeastern coast of the U. S. In this section these references will be generally reviewed, but a more detailed discussion of the results of major works will be made in the appropriate sections of the chapter.

In order to begin to familiarize the reader with studies of the zooplankton of the South Atlantic Bight prior to 1973, a brief summary of the review article by Roberts (1974) appears appropriate. The most striking conclusion from this review was the dearth of zooplankton research within the area covered by the inventory. The geographic areas that were examined included the sounds and estuaries of Subzone I - North Carolina; Subzone II - South Carolina and Georgia; and Subzone III - Florida; as well as the offshore waters of the continental shelf along these states. The zooplankton research conducted in each of these areas varied considerably in scope and intensity of sampling effort.

Studies in Subzone I consisted mainly of work done by Sutcliffe (1950) on holoplankton and an extensive ten-year study of meroplankton by A. B. Williams and colleagues (Williams, 1955, 1959, 1969, 1971, 1972; Williams and Bynum, 1972; Williams and Deubler, 1968; Williams and Porter, 1971). The areas covered by these studies centered around Pamlico, Core, and Bogue Sounds and adjacent rivers.

Considerably less zooplankton research was identified in Subzone II. No quantitative studies were made in South Carolina, but reports on work done on larval stages of commercial species (primarily *Penaeus* sp. and several post-larval fish) did indicate general seasonal trends in dominant groups. A study was done on the copepods of the Doboy Sound and Duplin River in Georgia (Jacobs, 1968).

In Subzone III, the only zooplankton work that was found was an investigation into the distribution and seasonality of *Callinectes* larvae done in connection with a study of the biology of the blue crab in the St. Johns River, Florida (Tagatz, 1968).

Virtually all publications concerning continental shelf zooplankton communities resulted from work done on collections made on the R/V GILL cruises in 1953-1954. Various authors examined copepods (Bowman, 1971), chaetognaths (Pierce and Wass, 1962), *Lucifer* (Bowman and McCain, 1967), pteropods (Chen and Hillman, 1970) and *Callinectes* larvae (Nichols and Keney, 1963).

Roberts (1974) analyzed the patterns of composition, abundance (numerical and volumetric), distribution, and seasonality of the zooplankton communities described for each of the geographic areas.

Several of the more classical investigations of the zooplankton communities of the open oceans had collection sites in or near the South Atlantic Bight and therefore should be mentioned. Riley (1939) made a transect from Cuba to Woods Hole and collected zooplankton at a station in the OCS area off the coast of Georgia. He made volumetric determinations and counts of broad categories of zooplankton at each of the stations along the transect and concluded that the zooplankton standing crop was greater in northern than southern waters. Clarke (1940) studied the vertical and seasonal variation of the zooplankton community at a number of offshore stations, including one located in the Sargasso Sea off Cape Hatteras. Grice and Hart (1962) studied the abundance and seasonality of the zooplankton community of the Gulf Stream and Sargasso Sea in the same area. Sutcliffe (1960) studied the relationship between species diversity and standing crop in the Sargasso Sea and found an inverse relationship between diversity and productivity as measured by zooplankton volume. He further found that diversity in these open ocean areas may not be necessarily controlled by major environmental factors since similar values of Fisher's index of diversity were found under a variety of conditions of temperature, phytoplankton density, and geographic latitude.

A great deal of research was done by investigators from the University of Miami during the late 1950s and early 1960s in studying the zooplankton communities of the Gulf Stream (Bsharah, 1957; Moore and O'Berry, 1957; Owre, 1962; Moore and Foyo, 1963; Roehr and Moore, 1965). Although most of the work was done off south Florida, it is recognized that Gulf Stream zooplankton communities are carried along the entire southeastern OCS area, so material from these publications will be included in the discussion of the various section topics.

Unpublished technical reports, theses, and dissertation materials on research prior to 1973 provide a considerable amount of information on the composition, distribution, seasonality, and relative abundance of zooplankton communities of the southeastern U. S. Peters (1968) did an environmental survey in Pamlico Estuary North Carolina in order to determine relationships between selected environmental parameters and zooplankton abundance. The abundance of general groups of holoplankton was observed at various depths, localities, and seasons, and attempts were made to explain the general patterns of abundance by multiple linear regression analysis.

Dudley and Judy (1971) investigated the numerical abundance, distribution, and seasonality of crab larvae in the coastal waters off Beaufort, North Carolina. Thirteen plankton stations extending from Beaufort Inlet to 13km offshore were sampled at depths of 1m and 8m biweekly from May through November. The horizontal, vertical, and temporal patterns of 27 larval forms were observed.

By far the most intensive study of the composition, distribution, and seasonality of a zooplankton community in a southeastern estuary was reported by McCrary (1969). Zooplankton collections were made four times per week at two stations in Wrightsville Sound, North Carolina during the course of a three year study. Extensive taxonomic work was done on both the holoplankton and meroplankton, with larval forms not previously described in the literature being identified by rearing to adulthood or by comparisons with offspring of known parentage. Seasonal trends were described for most species and distinct water masses (sound, inner coastal, and outer coastal water) were identified by the composition of the zooplankton communities. Details of the findings of these studies will be reviewed in Section 2.1.

Two studies (Wells and Gray, 1960; Vernberg and Vernberg, 1970) have examined the relationship between physiological tolerance and zoogeographic distribution, particularly as related to the significance of larval transport in the area of Cape Hatteras, North Carolina. Wells and Gray (1960) observed that *Mytilus edulis* populations could not survive due to the summer water temperatures found to the south of Cape Hatteras but were replenished seasonally by recruitment of larvae into the Carolinian subprovince periodically due to northeasterly wind patterns in the fall. The presence and abundance of temporary populations of *Mytilus* were correlated to the severity of northeast storms during the previous fall seasons. Vernberg and Vernberg (1970) experimentally examined the lethal thermal and salinity limits of adult and larval stages of species from the cold Virginian coastal waters to the north and the reeflike formations in the Gulf Stream to the south of Cape Hatteras. They concluded that temperature and salinity are major factors limiting the distribution of the marine species studied and that zoogeographic patterns seen in the areas around Cape Hatteras are correlated to tolerance of the larvae.

Investigators at the Duke University Marine Laboratory have done a great deal of research in the rearing of major crustacean species in order to describe larval stages and determine the physiological tolerances of these larvae. Obviously, such basic information is quite important to investigators attempting taxonomic or ecological studies of the zooplankton in waters where these species are abundant. In the literature prior to 1973, descriptions have been published for the larval stages of *Balanus* (Costlow and Bookhout, 1957, 1958), *Callinectes sapidus* (Costlow and Bookhout, 1959), *Panopeus herbstii* (Costlow and Bookhout, 1961a), *Eurypanopeus depressus* (Costlow and Bookhout, 1961b), *Sesarma reticulatum* (Costlow and Bookhout, 1962b), *Hepatus epheliticus* (Costlow and Bookhout, 1962a), *Hexapanopeus angustifrons* (Costlow and Bookhout, 1966a), *Pinnotheres maculatus* (Costlow and Bookhout, 1966b). The physiological effects of such environmental factors as temperature, salinity, and the temperature-salinity interaction have been determined for a number of larval forms (Costlow, 1967; Costlow and Bookhout, 1971; and Costlow, Bookhout and Monroe, 1960, 1962, 1966).

Few physiological studies have been done on the open ocean zooplankton of the South Atlantic Bight prior to 1973. Hopper (1960) studied the effects of salinity on open ocean zooplankton from the South Atlantic and found that most forms tolerated a far greater range in salinities than would ever be encountered in the open ocean. Although he only examined survival and not subtle sublethal effects, he concluded that salinity did not limit the distribution of the species observed. Teal (1971) studied the effects of temperature and pressure on the respiration of five species of pelagic decapods collected in the Sargasso Sea. The significance of vertical migration in its effects on the metabolism of zooplankton was examined.

In reviewing the literature on the effects of man's activities on the zooplankton community, it becomes apparent that very little work was done prior to 1973. Odum and Chestnut (1970) investigated the effects of treated sewage on a microcosm designed to simulate a North Carolina estuarine ecosystem. One component of the study involved observation of the changes in the zooplankton community associated with increased organic and nutrient load (Section 2.6). In a general article on the analysis of pollutants in zooplankton, Grice, Harvey, Bowen and Backus (1972) identified potential sources of contamination during collection and suggested general sampling procedures. Even though the evidence of success of the methods was demonstrated on samples taken from open ocean waters outside of the area of the present inventory, the general approach would appear to be equally useful to investigators working in the waters of the inventory area.

2.0 SUMMARY AND ANALYSIS OF RESEARCH SINCE 1973

2.1 Composition and General Characteristics: Community Structure, Distribution and Abundance

2.1.1 Estuaries

Only a few zooplankton surveys have been made in the estuaries of each state of the inventory area. In this section, major results and conclusions concerning zooplankton community composition, distribution, and abundance from these studies will be discussed. A direct comparison of spatial (vertical and horizontal) and temporal (diurnal and seasonal) patterns of the zooplankton from various geographic areas will be reserved for Section 2.2.

Peters (1968) studied the zooplankton community of the Pamlico Estuary, North Carolina. Collections were made at various depths, times, and localities by pumping water through a 150 micron mesh net. The data presented were averages of counts made for each of the sampling dates regardless of time, depth or locality, so only a general analysis of abundance and composition can be made. Table V-2 shows a taxonomic list of groups occurring more than once during the study. Figures V-1 and V-2 present the seasonal abundance patterns of the major zooplankton groups. In extracting numerical abundance from Figure V-1, it was found that the total holoplankton population at stations near the mouth of the Pamlico River ranged from 20-8,900 organisms/m^3 and averaged 4,340 organisms/m^3. Calanoid copepods (primarily *Acartia tonsa*) accounted for the bulk of the numbers (range 3-6,700 organisms/m^3; mean 3,107 organisms/m^3).

Figure V-2 shows the data for other planktonic groups counted. Polychaete larvae were moderately abundant through the study, with numbers generally ranging from 100 to 150 organisms/m^3 from September to April but dropping to low numbers in August. *Rangia* larvae were found to reach peak abundance (100 organisms/m^3) in February and again in August. Barnacle and copepod nauplii were combined into the same category, so it is not surprising that no clear-cut seasonal trends could be seen: numbers range from 20 to 800 organisms/m^3 with a number of periods of peak abundance. Cyclopoid copepods accounted for less than 10 percent of the total numbers of zooplankters in any sample. The aforementioned category was dominated by *Oithona* spp., although *Ergasilus* sp. was enumerated separately due to the economic importance of the adult female as a parasite on fish gills. Cladocerans (primarily *Podon*) were relatively scarce through the year, but showed a period of peak abundance in the winter.

TABLE V-2. Zooplankton found in Pamlico Estuary, North Carolina (from Peters, 1968).

The following taxa occurred one or more times.

Protozoa	*Rhoefax*			
Rotifera	*Synchaeta*			
	Keratella			
	Filinia			
Annelida	Polychaeta			
Mollusca	Gastropoda			
	Pelecypoda			
	Rangia cuneata			
Arthropoda	Arachnida			
	Crustacea	Brachiopoda	Cladocera	
			Daphnidae	
			Evadne	
			Podon	
		Ostracoda		
		Cirripedia		
		Balanus		
		Branchiura		
		Argulus		
		Copepoda	Calanoida	
			Acartia tonsa	
			Eurytemora	
			Cyclopoida	
			Oithona	
			Ergasilus versicolor	
			Harpacticoida	
			Microsetella	
			Canuella	
		Malacostraca	Isopoda	
			Aegathoa oculata	
			Amphipoda	
			Gammarus	
			Mysidacea	
			Decopoda	Brachyura
				Macrura

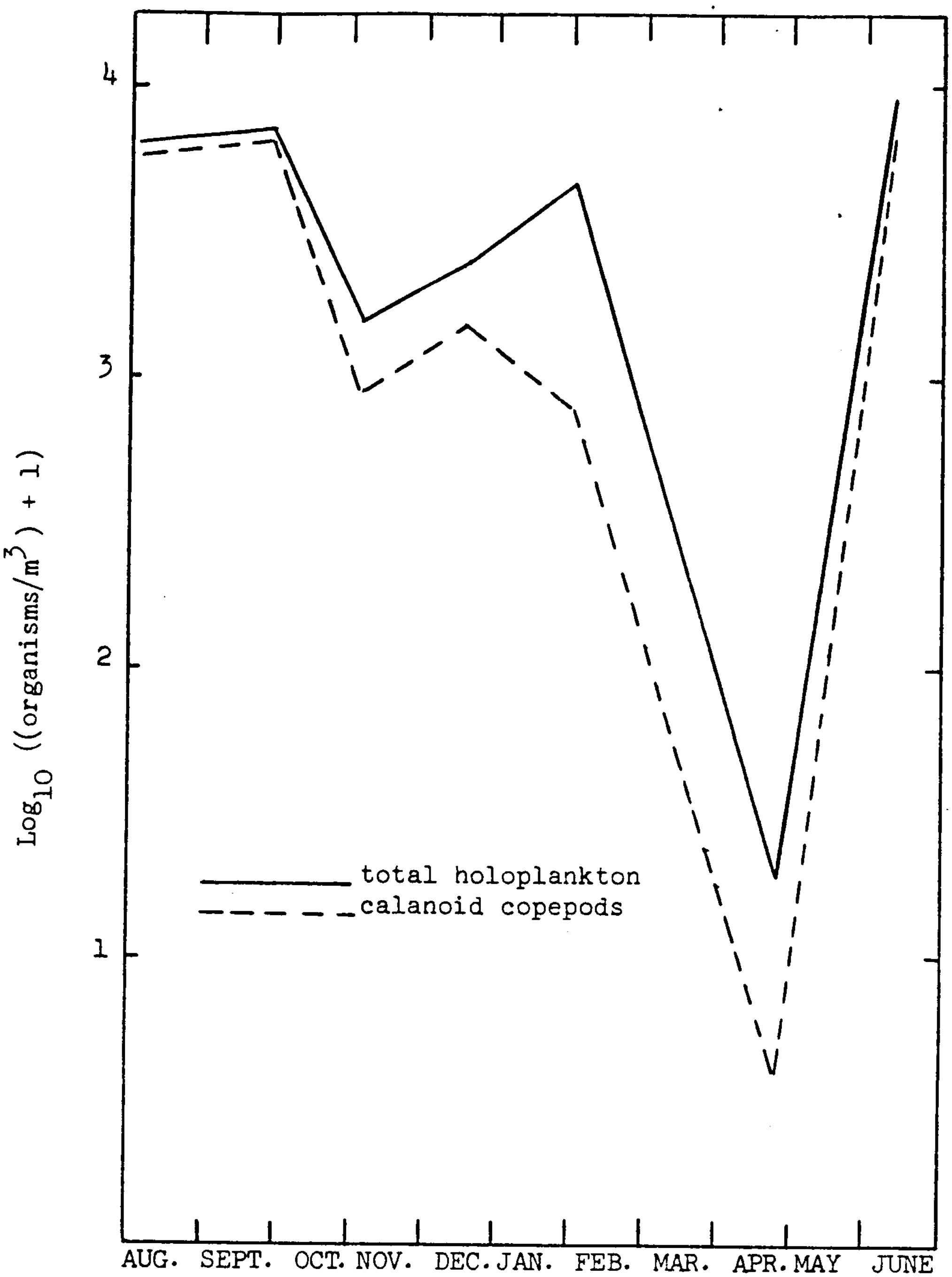

FIGURE V-1. Seasonal changes in abundance of calanoid copepods and total holoplankton at Stations A and D (from Peters, 1968).

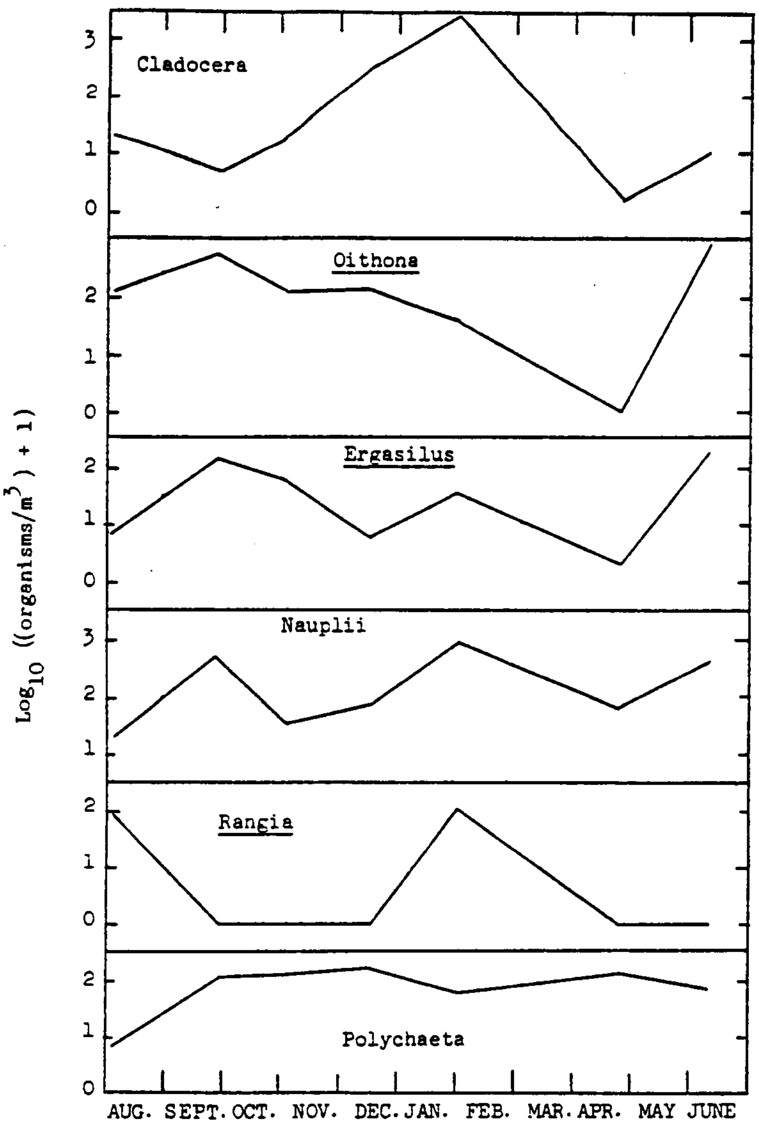

FIGURE V-2. Seasonal changes in abundance of selected zooplankters at Stations A and D (from Peters, 1968).

The abundance data for the harpacticoid copepods were presented separately (Table V-3) because the numbers were so erratic. It was concluded that the harpacticoids were generally found in greatest numbers in the night collections and mainly when the wind/current speeds were high. At peak abundance, the harpacticoids were seen to have over twice the highest density of all other zooplankton encountered during the study. Peters concludes that further work is needed to better describe the conditions under which harpacticoids appear and the ecological importance of these organisms to the plankton community.

Multiple regression techniques were employed to analyze data on calanoid copepod abundance as related to environmental variables: salinity, temperature, oxygen, turbidity, light intensity, and food (as both phytoplankton and detritus). The analysis was performed on data from zooplankton communities from two different areas: at the mouth of the Pamlico Estuary, and at a station approximately 16 nautical miles upstream. In each case, approximately 75 percent of the variation in calanoid concentration could be explained by the measured variables, with most of the variation being attributed to joint effects. The single most important independent variable in the lower sections of the river was temperature, while the concentration of dissolved oxygen was important in the upstream area. The reader must be cautioned, however, that no cause and effect interactions may be attributed to these relationships. Ecological interpretation of the regression equations cannot be made for a number of reasons: samples at the upstream stations were only collected on two dates, eliminating the possibility of random sampling of variables; no estimate was made of the covariance of independent and dependent variables with such factors as tidal, diurnal, or seasonal cycles; and many of the independent environmental variables are not truly independent of the concentration of copepods (e.g. dissolved oxygen and food concentration).

Thayer, Hoss, Kjelson, Hettler and Lacroix (1974) studied the numerical abundance, biomass, and caloric content of the zooplankton community of the Newport River Estuary, North Carolina, from 1970-1972. Biweekly samples were taken at three stations within the estuary with a 30cm diameter #10 plankton net. Table V-4 shows the taxonomic composition and the relative abundance of the most common zooplankters in the Newport River Estuary. Copepods dominated the zooplankton community (81 percent of the total), with Acartia tonsa, Oithona spp., Corycaeus spp. and Centropages spp. contributing most of the numbers and the bulk of the biomass.

Seasonal changes in the density, biomass and caloric content of

TABLE V-3a. Average planktonic harpacticoid copepod abundance over different substrates, during daylight and dark, Pamlico River, North Carolina (from Peters, 1968).

Location	Date	Number/m^3 Daylight	Number/m^3 Dark	Substrate
A	8/4/66	0	4	Mud
A	11/4/66	0	3	Mud
A	12/16/66	0	1	Mud
A	1/3/67	1	97	Mud
B	3/15/67	444	10,168	Mud
B	4/15/67	189	13,543	Mud
C	9/19/65	0	418	Sand
C	10/3/65	1	3	Sand
D	4/24/66	40	2,255	Sand
E	4/24/66	55	10,258	Sand
F	4/24/66	29	735	Mud
G	4/24/66	95	1,232	Mud

TABLE V-3b. Nocturnal planktonic harpacticoid copepod abundance and wind speed, Pamlico River, North Carolina (from Peters, 1968).

Wind speed measured miles/day	36			97			123	140	290
Wind speed estimated miles/day		50	80		100	120			
Average number of harpacticoids/m^3	1	3	3	96	4	418	13,543	3,641	10,168

TABLE V-4. Zooplankton Composition Newport Estuary, North Carolina (adapted from Thayer et al., 1974).

Dominant Forms:	% of Total Numbers	% of Estimated Dry Weight Biomass
Copepoda	81	85
Acartia tonsa	30	34
Oithona spp.	17	14
Corycaeus spp.	14	11
Centropages spp.	6	14

Other Frequent Forms:

Copepoda
- *Temora* spp.
- *Euterpina acutifrons*
- Copepod nauplii

Seasonally Abundant Forms:

Cirripedia nauplii

Polychaete larvae

Ostracoda

Bivalve veligers

Gastropod veligers

Crab and Shrimp zoea

Cladocerans

Sagitta spp.

the zooplankton community are shown in Figures V-3 and V-4. All three parameters showed maximum values during early fall and again in late winter. Similar patterns were seen in previous zooplankton studies in the area (Williams, Murdock and Thomas, 1968; see also review by Roberts, 1974), but the magnitude of the biomass was as much as double that reported by Williams et al. (1968). Even during the course of the study, the average density and biomass values varied drastically: during 1970 the average density was 4,000 organisms/m^3 and the mean biomass was 14mg dry wt/m^3, while during 1971 the mean values were 8,400 organisms/m^3 and 21mg dry wt/m^3. Even though there is a relative dearth of zooplankton in comparison to the standing crops found in deeper coastal waters, Thayer et al. (1974) concluded that some years may be much more productive than others.

A very significant aspect of the study by Thayer et al. (1974) involves the influence of predation by larval fish on zooplankton community composition and abundance. Channel nets were used to collect the larval stages of fish entering the estuary in order to determine months of peak migration (Table V-5) and to estimate the standing crop of predators (Table V-6). Pinfish (Lagodon rhomboides), spot (Leiostomus xanthurus) and menhaden (Brevoortia tyrannus) represented 98 percent of all larval fish entering the estuary from November 1969 to April 1970. The periods of peak density of larval fish coincides with the decline in zooplankton abundance (density, biomass, and caloric content), so it was hypothesized that zooplankton abundance controls the survival of larval fish and that predation by fish explain the apparently low standing crop of zooplankton, particularly in spring. Thus, the importance of the zooplankton community to the energy flow of shallow water estuaries may be greatly underestimated if evaluated in terms of standing crop alone, as was done by Williams et al. (1968). The turnover rates, dynamic production and flux of energy from the zooplankton community to higher trophic levels must be examined to assess properly the role of the zooplankton community in the ecosystem.

A study designed to observe the seasonal distribution of zooplankton in Wrightsville Sound, North Carolina was conducted by McCrary (1969). An intensive sampling effort (see general review, Section 1.3) was carried out using a number of different size plankton nets (130, 240 and 500 micron mesh) in order to observe changes in the composition of the entire zooplankton community on a day to day basis. Although qualitative rather than quantitative, the results of this study are quite important because the intensity of the sampling effort and of the taxonomic identification are unparalleled by any of the other studies covered in this review. A species list can be assembled from the

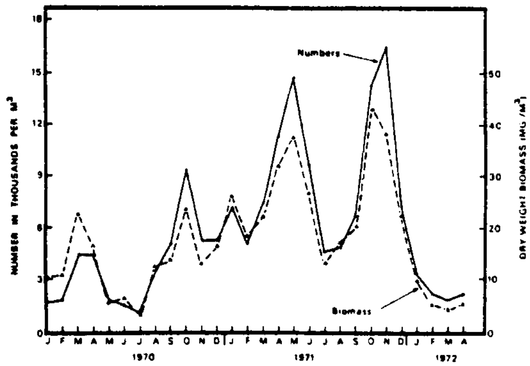

FIGURE V-3. Seasonal distribution of mean monthly zooplankton abundance (solid line) and of dry weight biomass (dotted line). (from Thayer et al., 1974).

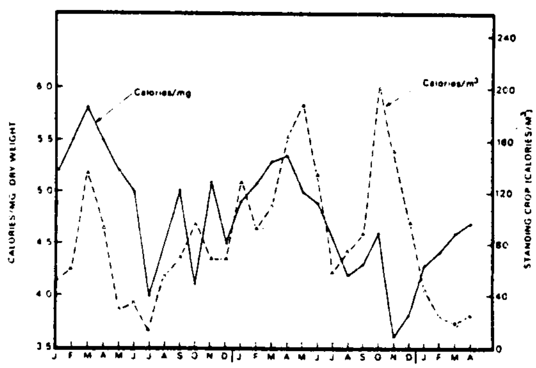

FIGURE V-4. Seasonal distribution of zooplankton energy per unit dry weight (solid line) and of zooplankton standing crop energy (dotted line) (from Thayer et al., 1974).

TABLE V-5. Estimated number of larvae entering the Newport River estuary during each month from November 1969-April 1970 (from Thayer et al., 1974).

Month	*Lagodon*	*Leiostomus*	*Brevoortia*	Other[1]	Sum
November 1969	1.5×10^6	0.0	0.0	$0.3 \quad 10^6$	1.8×10^6
December	35.1×10^6	0.0	1.0×10^6	3.5×10^6	39.6×10^6
January 1970	17.5×10^6	0.0	0.5×10^6	2.1×10^6	20.1×10^6
February	221.2×10^6	0.0	4.4×10^6	6.6×10^6	232.2×10^6
March	248.8×10^6	189.1×10^6	64.7×10^6	0.7×10^6	503.3×10^6
April	2.5×10^6	4.7×10^6	20.0×10^6	1.5×10^6	28.7×10^6
Sum	526.6×10^6	193.8×10^6	90.6×10^6	14.7×10^6	825.7×10^6

[1]Includes *Micropogon undulatus, Menidia menidia, Paralichthys* spp., *Anchoa mitchilli, Myrophis punctatus, Syngnathus* spp. For other species commonly collected see Lewis and Wilkens (1971).

TABLE V-6. Mean cumulative abundance of larvae in the lower estuary of the Newport River. Values in parentheses are larval densities per m^3 (from Thayer et al., 1974).

Month	*Lagodon*	*Leiostomus*	*Brevoortia*	Others	Sum
November 1969	0.8×10^6 (0.05)	0.0 (0.00)	0.0 (0.00)	0.1×10^6 (0.01)	0.9×10^6 (0.1)
December	19.1×10^6 (1.14)	0.0 (0.00)	0.5×10^6 (0.03)	2.0×10^6 (0.12)	21.6×10^6 (1.2)
January 1970	33.5×10^6 (1.99)	0.0 (0.00)	1.0×10^6 (0.06)	3.5×10^6 (0.21)	38.0×10^6 (2.3)
February	126.0×10^6 (7.50)	0.0 (0.00)	2.6×10^6 (0.15)	4.9×10^6 (0.29)	133.5×10^6 (7.8)
March	283.3×10^6 (16.86)	97.6×10^6 (5.81)	36.5×10^6 (2.17)	5.0×10^6 (0.30)	422.4×10^6 (25.1)
April	175.4×10^6 (10.44)	134.8×10^6 (8.02)	55.5×10^6 (3.30)	1.3×10^6 (0.08)	367.0×10^6 (21.8)
May	1.7×10^6 (0.10)	3.3×10^6 (0.20)	14.0×10^6 (0.83)	1.0×10^6 (0.06)	20.0×10^6 (1.2)

data in Tables V-7 through V-13. McCrary gives a brief literature review of each of the major species identified and describes the seasonal patterns of abundance in the plankton (see Section 2.2). The nearly continuous observations of the zooplankton community also allowed the identification and tracking of distinct water masses characterized by different species composition. Three holoplankton communities were identified: a community found to be living and maintaining populations within the Sound itself; a group of organisms living in the "inner" coastal waters which were brought through the inlet on flooding tides; and a third complex of organisms that were only observed when unusual conditions allowed an incursion of "outer" coastal waters. The Sound water community included Acartia tonsa, Centropages hamatus, Corycaeus americanus, Metis joussequmei, Oithona spp., Paracalanus parvus, Paracalanus crassirostris, Pseudodiaptomus coronatus and Saphirella sp. The community characteristic of the inner coastal waters consisted of Centropages furcatus, Corycaeus amazonicus, Eucalanus pileatus-subcrassus, Euterpina acutifrons, Labidocera aestiva, Macrosetella gracilis, Oncaea venusta, and Temora turbinata. Most of the species of the "outer" coastal waters were not identified but several forms were recognized: Rhincalanus sp., Anomalocera ornata, Fritillaria sp., salps and pteropods.

A fourth study of the zooplankton of a North Carolina estuary was done by Copeland, Birkhead and Hodson (1974) in connection with a baseline environmental survey of the ecological communities of the Cape Fear River Estuary prior to the construction of the Brunswick nuclear power plant. Collections were made with a 30cm diameter 120 micron mesh net or a Gulf-V high-speed plankton net with a 400 micron mesh. Several distinct ecological zones were recognized within the study area: tidal creek and nursery areas; estuarine areas; the nearshore ocean area and the intracoastal waterway. A number of stations were sampled in each zone during January, April, June, August, and October. The species composition, approximate abundance, distribution, and seasonality of the zooplankton community of the Cape Fear System are summarized in Table V-14. The average abundance for all stations throughout the year was 4,300 organisms/m^3. Copepods comprised 70 percent of all zooplankters collected and Acartia tonsa made up over 40 percent of the total catch. Other categories of zooplankton that were relatively abundant included: Paracalanus crassirostris, calanoid copepodites, barnacle nauplii, copepod nauplii, Oithona sp., crab zoea, barnacle cyprids, gastropod veligers, Oikopleura sp., Euterpina acutifrons, Pseudodiaptomus coronatus, shrimp nauplii, bivalve veligers, harpacticoid copepods and Centropages hamatus. Most of the dominant forms were widespread in distribution and occurred year-round. Seasonal trends were obscured, however, by the fact that different types of gear (120 and 400 micron mesh

TABLE V-7. The seasonal occurrence of hydromedusae in Wrightsville Sound (from McCrary, 1969).

	J	F	M	A	M	J	J	A	S	O	N	D
Obelia spp.	X	X	X	X	X	X	X	X	X	X	X	X
Persa incolorata	X	X	X	X	X	X	X					X
Nemopsis bachei	X	X	X	X	X	X					X	X
Ectopleura dumortieri	X	X	X	X								X
Proboscidactyla ornata	X	X		X	X	X	X	X			X	X
Euphysora gracilis	X		X	X		X	X				X	X
Eucheilota duodecimalis		X		X	X	X	X					X
Eutima mira		X					X	X				
Bougainvillia ramosa		X				X	X	X	X	X		X
Liriope tetraphylla			X	X	X	X	X	X	X	X	X	X
Podocoryne minuta			X									
Phialidium sp.				X	X	X	X	X		X	X	X
Podocoryne sp.				X	X	X						
Sarsia sp.				X	X	X	X		X			
Zanclea costata				X	X	X						
Amphinema sp.					X	X	X	X	X	X	X	X
Bougainvilliidae					X	X	X	X	X	X	X	X
Eucheilota sp.					X	X	X		X	X		X
Dipurena strangulata					X	X						
Laodicea sp.					X							
Podocoryne minima					X	X	X					
Turritopsis nutricula					X	X	X	X	X	X	X	
Eucheilota ventricularis					X	X						
Lizzia blondina					X							
Pennaria tiarella					X	X	X	X				
Phialidium folleatum					X							
Phialidium languidum					X	X						
Lovenellidae					X	X	X					
Linvillea agassizi						X	X					
Pandeidae							X					
Eirene pyramidalis							X		X	X		
Cunina sp.							X					
Bougainvillia carolinensis								X				
Narcomedusa								X			X	
Cunina octonaria									X	X		
Margelopsis gibbesi										X		X
Amphinema rugosa											X	
Unidentified medusae	X	X	X	X	X	X	X	X	X	X	X	X

TABLE V-8. The seasonal distribution of the larvae of minor groups. X̄ indicates peak abundance (from McCrary, 1969).

	J	F	M	A	M	J	J	A	S	O	N	D
Aurelia ephyrae				X		X	X	X				
Alcyonarian planulae					X	X	X	X				
Actinian planulae	X̄	X̄	X	X	X	X	X	X	X	X	X̄	X̄
Arachnactis					X	X	X	X	X	X		
Polyclad larvae	X		X	X		X̄	X̄	X	X	X	X	X
Pilidium brachiatum						X	X	X	X	X	X	X
Pilidium recurvatum		X	X		X							
Pilidia	X̄	X	X	X	X	X	X	X	X	X	X̄	X̄
Loxosomatid larvae	X			X	X	X	X̄	X̄	X	X	X̄	X̄
Bugula neritina	X	X	X	X	X	X						X
Cyphonautes	X	X	X	X	X	X	X	X	X	X̄	X̄	X
Gray cyphonautes	X	X	X	X								
Actinotrocha	X̄	X	X	X̄	X̄	X̄	X	X		X	X̄	X̄
Glottidia	X				X	X	X	X		X		
Echiuroid larvae	X	X	X									X
Sipunculid larvae								X	X	X	X	

TABLE V-9. Seasonal occurrence of annelid larvae in Wrightsville Sound. X̄ indicates peak abundance (from McCrary, 1969)

	J	F	M	A	M	J	J	A	S	O	N	D
Polydora	X	X	X	X	X	X	X	X	X	X	X	X
Scolelepis	X̄	X̄	X̄	X̄	X	X	X	X	X	X	X	X
Magelona	X̄	X̄	X	X	X	X̄	X̄	X	X	X	X̄	X̄
Sabellaria	X̄	X	X	X	X	X	X	X	X	X	X̄	X̄
Mitraria	X̄	X	X	X	X	X	X	X		X	X̄	X̄
Polygordius	X̄	X̄	X̄	X	X	X	X	X		X	X̄	X̄
Polynoidae	X̄	X̄		X̄	X̄	X̄	X̄	X	X	X	X	X̄
Nephtyidae	X̄	X̄	X̄	X̄	X̄	X					X	X̄
Spiophanes	X	X	X̄	X̄	X̄	X						
Glyceridae	X	X			X	X						
Typhloscolecidae	X	X	X			X	X					
Nereis	X				X	X	X̄	X̄	X	X	X	X
Capitellidae	X				X	X	X̄				X	X
Terebellidae	X				X	X	X̄	X̄	X	X	X	X
Phyllodocidae		X		X	X̄	X̄	X				X	X
Chaetopterus		X			X	X	X	X	X	X	X	X
Pectinariidae			X			X				X		
Syllidae				X	X	X	X	X		X		
Streblospio				X̄	X̄	X̄	X	X	X	X		
Eunicidae				X̄	X	X						
Poecilochaetus					X	X	X		X			
Prinonospio					X	X		X	X			
Hesionidae						X	X					
Chrysopetalidae						X						

TABLE V-10. Seasonal occurrence of cladocera and ostracoda. X̄ indicates peak of abundance (from McCrary, 1969).

	J	F	M	A	M	J	J	A	S	O	N	D
Evadne tergestina						X̄	X̄	X	X	X	X	
Penilia avirostris					X	X	X̄	X̄	X	X	X	X
Podon leuckarti					X							
Podon polyphemoides	X̄	X̄	X	X̄	X̄	X̄	X				X	X̄
Conchoeciid ostracod	X	X							X	X	X	X

TABLE V-11. The seasonal occurrence of copepods (from McCrary, 1969).

	J	F	M	A	M	J	J	A	S	O	N	D
Acartia tonsa	X	X	X	X	X	X	X	X	X	X	X	X
Corycaeus americanus	X	X	X	X	X	X	X	X	X	X	X	X
Euterpina acutifrons	X	X	X	X	X	X	X	X	X	X	X	X
Paracalanus parvus	X	X	X	X	X	X	X	X	X	X	X	X
Paracalanus crassirostris	X	X	X	X	X	X	X	X	X	X	X	X
Pseudodiaptomus coronatus	X	X	X	X	X	X	X	X	X	X	X	X
Oithona spp.	X	X	X	X	X	X	X	X	X	X	X	X
Metis jousseaumei	X	X	X	X	X	X	X	X	X	X	X	X
Labidocera aestiva	X	X	X	X	X	X	X	X	X	X		X
Eucalanus	X	X			X	X	X	X	X	X	X	X
Temora turbinata	X	X	X		X	X	X	X	X	X	X	X
Centropages typicus	X	X	X	X							X	X
Saphirella sp.	X	X	X	X	X	X	X	X	X			
Caligoids	X		X		X	X	X	X	X	X	X	X
Centropages hamatus		X	X	X	X							
Anomalocera ornata			X									
Monstrilloids					X	X	X	X	X			
Macrosetella gracilis				X		X			X	X	X	X
Oncaea venusta							X	X			X	X
Calanopia sp.									X		X	

TABLE V-12. The seasonal occurrence of malacostracan crustacea (from McCrary, 1969).

	J	F	M	A	M	J	J	A	S	O	N	D
Squilla				X		X	X	X	X			
Epicarid isopods				X	X	X	X	X	X	X	X	X
Acetes americanus					X	X	X	X				
Lucifer faxoni					X	X	X	X	X	X	X	
Sergestid protozoea						X	X	X	X	X	X	
Peneid and Sergestid nauplii						X	X	X	X	X	X	
Peneid protozoea					X	X	X	X				
Peneid larvae and post-larvae		X	X	X	X	X	X	X	X	X	X	
Alpheidae			X	X	X	X	X	X	X	X	X	
Hippolysmata wurdemanni					X	X	X	X	X	X		
Hippolyte sp.				X	X	X	X	X	X	X	X	
Latreutes sp.				X								
Tozeuma carolinense					X							
Palaemonetes sp.			X	X	X	X	X	X	X	X	X	
Periclimenes sp.				X	X	X	X	X	X	X	X	
Callianassa sp.					X	X	X					
Naushonia sp.				X		X						
Upogebia affinis			X	X	X	X	X	X				
Polyonyx gibbesi			X	X	X	X	X	X	X	X		
Clibanarius vittatus						X	X	X	X			
Pagurid zoea	X	X	X	X	X	X	X	X	X	X	X	X
Pagurid glaucothoe		X	X	X	X	X	X	X			X	X
Emerita talpoida					X	X	X	X	X			
Callinectes megalops	X	X	X	X	X	X	X	X	X	X	X	X
Cancridae (megalops)												X
Panopeus herbstii					X	X	X	X	X			
Eurypanopeus depressus						X	X	X	X			
Neopanope texana						X	X	X	X			
Rhithropanopeus harrisii						X	X	X	X			
Xanthidae				X	X	X	X	X	X	X		
Pinnotheres ostreum					X	X	X	X	X	X	X	X
Pinnotheres maculatus				X	X	X	X	X	X	X	X	
Pinnixa chaetopterana				X	X	X	X	X	X	X	X	X
Pinnixa sayana	X	X	X	X	X	X		X	X	X	X	X
Uca spp.				X	X	X	X	X	X			

TABLE V-13. The seasonal occurrence of echinoderm and protochordate larvae. $\overline{\underline{X}}$ indicates peak of abundance. (from McCrary, 1969)

	J	F	M	A	M	J	J	A	S	O	N	D
Asterias bipinnaria	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	X	X	X	X	X
Asterias brachiolaria	X	X	X	X	X						X	X
Arbacia punctulata					X	X	X	X	X	X	X	
Lytechinus variegatus						X	X		X		X	
Mellita quinquiesperforata					X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	X	
Moira atropos	X	X			$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X
Ophiothrix angulata						X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X
Ophiopluteus					X	X	X	X	X	X		
Leptosynapta					X	$\overline{\underline{X}}$	$\overline{\underline{X}}$		X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X
Cucumaria sp.				X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	X		
Balanoglossus tornaria	X	X	X	X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$
Ascidian larvae	X	X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X
Ascidia interrupta			X	$\overline{\underline{X}}$	$\overline{\underline{X}}$	$\overline{\underline{X}}$	X	X	X	X		X
Amphioxus				X	X	X	X	X				X

TABLE V-14. An annotated list of the zooplankton taxa collected in the Cape Fear River Estuary, and environs, and the adjacent nearshore ocean (from Copeland et al., 1974).

Taxa*	Approx $\log_{10}$ Abundance	Zone	Season
Protozoa			
Rhizopoda			
Foraminifera	4	Estuary, Nursery	Summer, Fall, Winter
Cnidaria			
Hydromedusae	3	Widespread	Summer, Fall, Winter
Chaetognaths	2	Ocean	All Year
Arthropoda			
Arachnida			
Hydracarina	2	Widespread	All Year
Crustacea			
Cladocera A	1	Nursery	Winter
Bosminidae			
Bosmina	2	Nursery, Estuary	Fall, Winter
Chydoridae			
Chydorus	0	Nursery	Winter
Daphnia			
Ceriodaphnia	1	Estuary	Fall
Polyphemidae			
Evadne sp.	3	Ocean, Estuary	Summer
Podon	3	Nursery, Ocean	Winter, Spring
Sididae			
Penilia	3	Widespread	Summer, Fall, Winter
Ostracoda			
Conchoecia	2	Ocean	Winter
Notodramus	0	Nursery	Winter
Calanoida			
Acartiidae			
Acartia tonsa	5	Widespread	All Year
Diaptomidae			
Pseudodiaptomus coronatus	4	Widespread	All Year
Eucalaridae			
Eucalanus	2	Nursery, Ocean	Summer
Centropagidae			
Centropages furcatus	2	Ocean	Summer
Centropages hamatus	3	Ocean, Estuary	Spring
Centropages typicus	1	Ocean	Summer
Centropages sp.	2	Estuary, Ocean	Spring, Summer
Centropages copepodites	3	Estuary, Ocean	Summer, Winter
Copepod nauplii			
Calanoid copepodites			
Paracalanidae			
Paracalanus crassirostris	4	Widespread	All Year
Paracalanus parvus	3	Estuary, Ocean	All Year

TABLE V-14 Cont.

Taxa*	Approx $\log_{10}$ Abundance	Zone	Season
Tachidiidae			
Tachidus	0	Nursery	Winter
Temoridae			
Eurytemora herdmani	1	Nursery	Winter
Eurytemora sp.	2	Estuary, Nursery	Summer
Temora stylifera	2	Estuary, Ocean	Summer, Fall
Temora turbinata	3	Estuary, Ocean	Fall
Temora copepodites	2	Nursery	Fall
Cyclopoid A	0	Nursery	Winter
Cyclopoid B	0	Nursery	Winter
Cyclopoid C	0	Nursery	Winter
Cyclopoid copepodites	2	Estuary, Ocean	Summer, Winter
Clausidiidae			
Saphirella	3	Widespread	All Year
Corycaeidae			
Corycaecus	2	Estuary, Ocean	All Year
Cyclopidae			
Halycyclops	3	Nursery, Estuary	Summer, Fall, Winter
D'arcythompsoniidae			
Horsiella brevicornis	0	Nursery	Winter
Oithonidae			
Oithona	4	Widespread	All Year
Oncaeidae			
Oncaea	3	Widespread	All Year
Harpacticoid copepods	3	Widespread	Summer, Fall, Winter
Ameoridae			
Nitroca typica	1	Nursery	Winter
Cletodidae			
Cletodes	0	Nursery	Winter
Nannopus palustris	1	Nursery	Winter
Laophontidae			
Laophonte	2	Nursery, Estuary	Winter
Paronychocamptus	2	Nursery, Estuary	Summer, Winter
Tachidiidae			
Euterpina acutifrons	3	Widespread	All Year
Isopoda			
Epicaridian isopod larvae	2	Nursery, Estuary	Summer
Idoteidae			
Chiridotea	2	Nursery	Summer
Edotea	1	Nursery	Fall
Amphipoda	1	Nursery	Summer
Gammaridea	2	Nursery	Summer
Gammarus	1	Nursery, Estuary	Summer, Winter
Mysidacea	2	Estuary	Fall
Barnacle nauplii	5	Widespread	All Year
Barnacle cypris	4	Widespread	All Year
Malacostracan larvae	2	Ocean	Summer
Eucaridian larvae zoea	2	Ocean	Fall
Decapoda			
Shrimp nauplii	3	Widespread	Summer, Fall
Macrura larvae	1	Ocean	Summer

TABLE V-14 Cont.

Taxa*	Approx $\log_{10}$ Abundance	Zone	Season
Shrimp post-larvae	2	Estuary	Summer
Crangonidae post-larvae	1	Ocean	Summer
Crab zoea	4	Widespread	Spring, Summer
Cyphonautes larvae	2	Estuary, Ocean	Summer, Fall, Winter
Mollusca			
Gastropod veliger A	3	Widespread	Spring, Summer, Fall
Gastropod veliger B	2	Estuary, Ocean	Spring, Summer
Gastropod veliger C	2	Ocean	Summer
Bivalve veliger	3	Widespread	All Year
Gastropod veliger D	2	Estuary	Fall
Gastropod veliger E	2	Estuary	Fall
Gastropod veliger F	2	Estuary	Fall
Annelid trochophore larvae	2	Estuary, Ocean	All Year
Polychaetae larvae	2	Widespread	All Year
Spioniform larvae	3	Widespread	All Year
Oweniida			
Mitraria larvae	1	Ocean	Summer
Phyllodocida			
Nereidae			
Nereis	2	Nursery	Summer
Echinodermata			
Stelleroidea			
Bipinnaria larvae	2	Ocean	Winter
Ophiopluteus	2	Ocean	Summer, Fall
Chordata			
Larvacea			
Copelata			
Oikoplenridae			
Oikopleura	4	Widespread	All Year
Incidentals			
Invertebrate eggs	3	Widespread	Summer
Fish eggs	3	Widespread	Spring, Summer

*
Phylum
  Class
    Order
      Family
        Genus species

nets) were used at different times throughout the study.

Shannon-Weiner diversity indices were calculated for each of the ecological zones (Table V-15). Diversity and numerical abundance of the zooplankton communities were inversely related: nursery and estuarine zooplankton areas were low in diversity but high in abundance; while at the other end of the spectrum, oceanic plankton was more diverse but lower in density.

The only published study that is available to date on the composition of zooplankton communities in South Carolina estuaries is reported by Lonsdale and Coull (1977). The investigators took biweekly collections with a 30cm diameter #10 plankton net at four stations in the vicinity of North Inlet, South Carolina. The mean density of zooplankton was found to be 9,234 organisms/m^3 (range 377-84,414 organisms/m^3) and the average biomass was 16mg dry wt/m^3 (range 0.64-140mg dry wt/m^3). Peak periods of abundance were found during the summer months. The zooplankton community composition and relative abundance data have been extracted from the text and are presented in Table V-16. Copepods dominated the zooplankton community, representing 69 percent of total numbers and 67 percent of the biomass. Parvocalanus crassirostris (Paracalanus crassirostris) and Oithona colcarva (O. brevicornis) were the numerically dominant forms, but were outweighed in terms of biomass by the much larger Acartia tonsa. Unlike more temperate estuaries, Lonsdale and Coull found that the North Inlet zooplankton community had a major meroplankton component in terms of density and biomass.

Shannon-Weiner diversity (H^1) and evenness (J) indices were calculated for each station on each sampling data. The average value for H^1 was 1.32 $\pm$ 0.32 (ranging 0.43-2.11) and for J was 0.64 $\pm$ 0.13 (ranging 0.27-0.87). These values were seen to be comparable to those calculated for the zooplankton communities from temperate estuaries in Maryland and New Jersey. The general species composition and seasonal patterns of the zooplankton, however, were believed to be more like those found for communities in subtropical estuaries on the Gulf Coast of Florida than those reported for the more northern systems.

Stickney and Knowles (1975) conducted a zooplankton distribution survey at two estuarine stations near Savannah, Georgia. The zooplankton was collected at two hour intervals from various depths in the water column with Van Dorn bottles for a period of 11 consecutive days. Acartia tonsa was the dominant species collected, with Euterpina acutifrons, Oithona sp. and an unidentified harpacticoid also exhibiting numerical abundance. Avoidance of the bottles by larger zooplankters (Neomysis

TABLE V-15. Total catch zooplankton diversity by ecological zones, 1971-72. (from Copeland et al., 1974).

Zone	Stations	Species Diversity
Nursery	3	1.9
	7,8,15	2.0
	9,10	2.2
Estuary	1,2,5,6	2.1
IWW	11	2.2
Ocean	12,13,14,21	2.5

TABLE V-16. Zooplankton community composition North Inlet, S. C. (adapted from Lonsdale and Coull, 1977)

Dominant Forms:	% of Total Numbers	% of Estimated Dry Weight Biomass
Holoplankton		
Copepoda	69	67
Parvocalanus crassirostris	16	13
Acartia tonsa	7	20
Oithona colcarva	6	6
Euterpina acutifrons	1.8	2.8
Tunicata	2.2	2.6
Oikopleura sp.	0.4	2.6
Chaetognatha	0.4	2.6
Meroplankton		
Cirripedia nauplii	13	7.6
Polychaete larvae	3.6	3.5
Bivalve veligers	3.5	1.2
Gastropod veligers	1.8	0.6
Crab and shrimp zoea	2.3	8.6

Other Frequent Forms:

Copepoda
- *Saphirella* sp.
- *Oncaea venusta*
- *Pseudodiaptomus coronatus*

Seasonally Abundant Forms:

Copepoda
- *Temora turbinata*
- *Corycaeus* sp.
- *Labidocera aestiva*
- *Paracyclopina* sp.
- *Centropages typicus*
- *Centropages hamatus*

americana, Pseudodipatomus coronatus and adult Acartia tonsa) was stongly suspected, so the samples were not considered completely quantitative. The mean density at the two stations were 51.8 organisms/l (51,800 organisms/m^3) and 47.2 organisms/l (47,200 organisms/m^3); so even with the loss of larger organisms due to avoidance, the numerical abundance was quite high. These data may indicate that the zooplankton communities in Georgia estuaries have much higher densities than those found in other studies, but a more likely explanation is that a sampling method that does not employ a net collects the abundant microzooplankton that are not generally considered in most zooplankton survey work. Even though the results of this study cannot be considered quantitatively comparable to findings already reviewed, they did allow a relative comparison of numerical trends through diurnal and tidal cycles to define clearly the distributional patterns of the zooplankton. Distribution polygon analysis was performed to determine the temporal and spatial distribution patterns for the major groups of the zooplankton community (see Section 2.2).

In comparing the abundance, composition, and general community structure of the zooplankton in each of the areas studied, it is clear that similar commmunities exist in most of the estuaries. Mean annual numerical abundance was similar for all studies: 4,000-8,400 organisms/m^3 from the Newport River Estuary; 4,340 organisms/m^3 (holoplankton) from the Pamlico Estuary; 4,300 organisms/m^3 for Cape Fear River Estuary; and 9,234 organisms/m^3 for North Inlet, South Carolina. Copepods dominate the zooplankton communities from all areas, representing 69 percent (North Inlet, South Carolina) to 81 percent (Newport River, North Carolina) of the total numbers. Acartia tonsa was the dominant zooplankter in most systems, with Oithona spp., Parvocalanus crassirostris (Paracalanus crassirostris), Euterpina acutifrons, Centropages spp., Corycaeus spp. and Pseudodiaptomus coronatus showing numerical abundance. Harpacticoid copepods were seen to be numerically significant in the studies that included night collections (Peters, 1968; Stickey and Knowles, 1975).

Recognizing the overall similarity between the zooplankton examined in each area, several contrasts can be made between certain of the communities. The zooplankton from the Newport River Estuary, North Carolina (Thayer et al., 1974) and the North Inlet, South Carolina (Lonsdale and Coull, 1977); were somewhat different in relative composition. The North Inlet zooplankton community was numerically dominated by small copepods (Parvocalanus crassirostris and Oithona sp.) and had a large meroplankton component (primarily barnacle larvae, mollusc veligers and crab zoea). The Newport River Estuary zooplankton had relatively more of the larger holoplankton (Acartia tonsa, *Centropages* spp., *Temora* spp.) and fewer of the small meroplankton. These differences may be attributed to different predation patterns observed in the two areas. Thayer et al. (1974) observed that the immigration of larval fish into the estuary in the spring appeared to cause the nature of the zooplankton community to change. The average size and caloric content of the zooplankton decreased and the large holoplankter species known to be the principal prey of fish larvae declined in biomass during the spring. The larval fish in the North Inlet, South Carolina system were shown to be present year round, giving a competitive advantage to smaller copepods and meroplankton which were not subjected to as much predation pressure as the larger forms (Lonsdale and Coull, 1977). Therefore, trophic relationships may have caused the observed differences in zooplankton community composition: small forms dominating year round in the South Carolina estuary while the large forms are numerically important to the standing crop of the North Carolina system except during a few months in the spring.

Another apparent difference between the zooplankton communities of the estuaries studied involves the diversity indices calculated for the Cape Fear River Estuary, North Carolina (Copeland et al., 1974) and the North Inlet, South Carolina system (Lonsdale and Coull, 1977). The Cape Fear zooplankton exhibited higher diversity indices than those calculated for the North Inlet community. In fact, the diversity indices for the Cape Fear zooplankton were believed to be underestimated because of the combination of many unidentified taxa into a few taxonomic categories. Although lower in diversity than the Cape Fear community, the North Inlet zooplankton was shown to exhibit similar diversity values to those found for other temperate estuaries (Lonsdale and Coull, 1977). The apparent differences between these two communities may be explained by differences in the hydrographic characteristics of the systems. The Cape Fear system has a much higher flushing rate than the North Inlet system, and would therefore be expected to have a larger component of the more diverse coastal communities introduced by tidal action. An examination of the data shows that many of the species identified by McCrary (1969) as being coastal species (e.g. *Euterpina acutifrons*, *Oncaea* sp., *Temora turbinata*, and *Eucalanus* sp.) were found in abundance in the estuary and nursery zones of the Cape Fear River system. Diversity in the Cape Fear system did decrease, however, along the gradient from the open ocean, through the estuary, to the nursery zone, so it appears that the mixing is not complete or that the full complement of introduced species cannot survive the estuarine conditions.

In conclusion, it is apparent that all of the estuaries that have been studied in the southeastern U. S. have similar zooplankton communities with minor differences possibly being attributable to local differences in the physical or biological environment.

2.1.2 Coastal Waters

A very limited amount of research has been done on coastal zooplankton. No surveys of the composition and distribution of entire zooplankton communities could be found for the period since 1973. Most of the studies that have been done in coastal waters concentrate only on certain specific components of the total zooplankton community.

Dudley and Judy (1971) examined the distribution and abundance of crab larvae at 13 stations near Beaufort, North Carolina. Clarke-Bumpus plankton samplers with 526 micron mesh netting were used for biweekly collections from May through November. Tables V-17, V-18 and V-19 show the abundance, vertical distribution, and seasonality of 27 types of crab larvae observed during the study. Blue crab (*Callinectes sapidus*) larvae dominated almost all of the counts and all species showed peak abundance during the summer and early fall months. Vertical, horizontal, and temporal patterns of the major species will be analyzed in Section 2.2.

Investigators from the Middle Atlantic Coastal Fisheries Center Sandy Hook Laboratory conducted a two year survey of the larval fish on the continental shelf between southern New England and Florida. The first year study involved collections in the coastal waters from Cape Cod, Massachusetts to Cape Lookout, North Carolina, while the research conducted during the second year extended sampling from New River, North Carolina to Palm Beach, Florida. Smith, Sibunka and Wells (1975) reported on the seasonal distribution of larval flat fishes in the northern study area. Table V-20 indicates the distribution and period of peak abundance for those species with a range extending to the south of Cape Hatteras, North Carolina. Pleuronectids spawned largely to the north of the inventory area while bothids, cynoglossids and the Soleidae originated in the coastal waters to the south of Cape Hatteras. The spawning that began in the spring proceeded from south to north while that observed in the fall proceeded from north to south. It was therefore speculated that spawning was triggered by spring warming and fall cooling. It was also observed that most species only spawned within a narrow range of temperature but breeding activities apparently were not influenced by salinity.

TABLE V-17. Mean number of larval crabs per 20 cubic meters of water collected from May through November 1962 at inshore stations (from Dudley and Judy, 1971).

Species	May		June		July		Aug.		Sept.		Oct.		Nov.	
	Depth													
	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m
Callinectes spp.														
Stage 1	81	62	430	287	303	243	88	80	46	23	50	50	2	--
Stage 2	--	--	--	--	20	--	2	4	5	--	5	4	--	--
Stage 3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stage 4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Stage 5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dissodactylus mellitae	4	4	--	2	1	6	--	8	2	4	2	6	--	--
Emerita talpoida	10	8	4	2	2	21	3	19	2	3	--	--	--	--
Eurypanopeus depressus	--	--	14	46	4	7	13	24	--	--	4	--	--	--
Hepatus epheliticus	--	--	10	4	64	13	5	2	40	7	5	7	--	--
Leucosiidae	--	--	--	19	48	14	3	26	7	15	6	--	--	--
Libinia spp.	--	2	--	--	--	3	--	2	--	--	--	--	--	--
Menippe mercenaria	--	--	10	7	6	10	7	20	--	--	--	--	--	--
Neopanope texana sayi	12	41	34	285	13	36	16	69	27	19	--	2	--	2
Pachygrapsus transversus	--	--	28	--	--	--	--	--	--	--	3	8	--	--
Panopeus herbstii	8	20	27	106	10	65	23	133	2	2	2	--	50	38
Pilumus spp.	--	--	--	2	1	7	5	11	4	--	--	--	--	--
Pinnixa spp.	49	39	39	206	9	98	40	272	100	71	75	367	--	--
Pinnotheres maculatus	--	2	--	2	4	5	8	20	16	--	4	13	--	--
Pinnotheres ostreum	--	--	--	7	--	1	5	8	4	7	--	5	--	--
Polyonyx gibbesi	5	3	3	18	12	48	--	2	8	6	15	14	3	13
Portunus gibbesii	116	44	23	114	122	20	24	3	11	4	--	--	--	2
Portunus sayi	13	8	--	11	--	--	--	--	30	6	9	5	15	18
Sesarma spp.	--	--	2	78	3	17	8	106	--	--	--	--	--	--
Uca spp.	40	60	657	1,347	459	70	515	792	31	20	--	--	--	--

TABLE V-17, cont.

Species	May		June		July		Aug.		Sept.		Oct.		Nov.	
	Depth													
	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m
Unknown zoeae[3]	A5	--	A14	A7	A2	--	A5	A10	C32	C16	C4	C52	--	C4
Unknown[3]	--	--	D8	D3	--	--	D2	D3	D5	D2	D7	D2	--	--
Megalops:														
Callinectes spp.	--	--	--	--	--	--	--	--	2	--	2	3	--	--
Eurypanopeus spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Neopanope spp.	--	--	--	2	--	--	--	--	--	--	--	--	--	--
Panopeus spp.	--	--	--	--	--	--	--	--	9	4	--	2	--	--
Uca spp.	--	--	13	--	--	10	3	38	4	1	--	--	--	--

[1]Zoeae raised from known crab, unpublished data Duke University Marine Laboratory, Beaufort, N. C.

[2]Zoeae raised from known crab, unpublished data National Marine Fisheries Service, Beaufort, N. C.

[3]The letters represent the larvae type, the number accompanying the letter is the mean number of crabs of that type in the sample.

TABLE V-18. Mean number of larval crabs per 20 cubic meters of water collected from May through November 1962 at offshore stations (from Dudley and Judy, 1971).

Species	May		June		July		Aug.		Sept.		Oct.		Nov.		
	Depth														
	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	
Callinectes spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6, 21
Stage 1	97	493	525	1,061	3,955	879	595	257	26	50	56	76	--	--	
Stage 2	--	--	43	91	64	17	124	21	--	--	10	4	4	--	
Stage 3	--	--	--	4	2	--	14	--	--	--	--	--	4	--	
Stage 4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Stage 5	--	--	--	--	--	--	--	--	--	--	--	--	2	--	
Dissodactylus mellitae	--	--	--	--	10	2	3	10	2	2	--	7	--	--	
Emerita talpoida	4	90	--	4	5	11	--	99	2	2	--	3	--	--	
Eurypanopeus depressus	--	9	4	14	2	10	--	5	--	2	2	3	--	--	
Hepatus epheliticus	--	--	4	8	157	17	109	29	51	18	11	7	2	--	
Leucosiidae	--	--	11	27	71	29	19	39	2	--	2	13	2	6	
Libinia spp.	--	--	--	--	--	2	--	--	--	--	--	--	--	--	
Menippe mercenaria	--	--	4	23	8	2	13	3	--	--	--	--	--	--	
Neopanope texana sayi	10	27	70	130	16	45	11	40	5	--	--	5	--	2	
Pachygrapsus transversus	--	--	4	--	--	--	--	--	--	--	--	--	--	--	
Panopeus herbstii	5	14	18	63	5	33	23	48	--	5	--	--	--	--	
Pilumnus spp.	--	--	--	8	--	5	3	23	--	--	--	--	--	--	
Pinnixa spp.	48	92	26	48	11	19	23	199	44	107	80	730	68	175	
Pinnotheres maculatus	--	--	--	--	--	--	--	5	--	9	5	7	2	--	
Pinnotheres ostreum	--	--	--	--	3	--	--	4	--	5	--	7	--	--	
Polyonyx gibbesi	--	3	--	4	16	3	--	15	2	9	5	30	6	29	
Portunus gibbesii	242	90	58	88	292	37	156	38	28	5	12	5	--	2	
Portunus sayi	68	54	--	--	--	--	--	--	12	2	13	4	24	58	
Sesarma spp.	--	--	63	10	--	5	5	13	--	3	--	--	--	--	
Uca spp.	56	185	857	372	444	239	448	223	7	14	--	--	--	--	

TABLE V-18, cont.

Species	May		June		July		Aug.		Sept.		Oct.		Nov.	
	Depth													
	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m
Unknown zoeae[3]	A6	3	D7	B2	A2	F3	A5	C22	C26	C3	C15	C25	25	A4 C40
Unknown[3]	D9	--	A7	--	F9	B2	D5	B3 D5	D5	--	--	--	G4	G6 D4
Megalops:														
Callinectes spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Eurypanopeus spp.	--	--	--	4	--	--	--	--	--	--	--	--	--	--
Neopanope spp.	--	--	--	--	--	--	--	2	2	--	--	--	--	--
Panopeus spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Uca spp.	--	--	--	4	--	3	--	8	--	--	--	--	--	--

[1]Zoeae raised from known crab, unpublished data Duke University Marine Laboratory, Beaufort, N. C.

[2]Zoeae raised from known crab, unpublished data National Marine Fisheries Service, Beaufort, N. C.

[3]The letters represent the larvae type, the number accompanying the letter is the mean number of crabs of that type in the sample.

TABLE V-19. Mean number of larval crabs per 20 cubic meters of water collected from May through November 1962 at stations furthest from shore (from Dudley and Judy, 1971)

Species	May		June		July		Aug.		Sept.		Oct.		Nov.	
Depth	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m	1m	8m
Callinectes														
Stage 1	36	342	48	1,505	436	586	1,283	810	118	107	--	53	--	--
Stage 2	--	43	--	736	88	28	755	126	--	5	14	--	--	--
Stage 3	--	--	--	8	--	--	345	165	--	--	--	--	--	--
Stage 4	--	--	--	--	--	--	--	35	--	--	--	--	--	--
Stage 5	--	--	--	--	--	--	--	9	--	--	--	--	--	--
Dissodactylus mellitae	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Emerita talpoida	--	--	--	25	--	63	17	--	--	22	--	6	--	--
Eurypanopeus depressus	--	--	--	25	--	20	--	--	--	--	--	--	--	--
Hepatus epheliticus	--	--	--	--	229	9	70	7	48	26	--	--	--	--
Leucosiidae	--	--	--	25	--	41	26	15	--	4	--	13	--	12
Libinia spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Menippe mercenaria	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Neopanope texana sayi	--	--	--	8	--	15	--	--	--	5	--	--	--	5
Pachygrapsus transversus	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Panopeus herbstii	--	21	--	--	5	72	--	17	--	--	--	--	5	--
Pilumus spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pinnixa spp.	--	21	--	16	--	--	--	27	10	11	19	520	7	207
Pinnotheres maculatus	--	--	--	--	--	--	--	--	--	--	--	6	11	--
Pinnotheres ostreum	--	--	--	--	--	--	--	--	--	--	--	7	--	--
Polyonyx gibbesi	--	--	--	--	--	5	--	--	--	16	--	13	--	32
Portunus gibbesii	--	149	267	524	87	85	634	51	54	50	34	26	--	--
Portunus sayi	--	43	--	--	--	--	61	--	12	10	169	104	35	73
Sesarma spp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Uca spp.	--	64	19	33	23	199	22	14	5	16	--	--	--	--

TABLE V-19, cont.

Species	May 1m	May 8m	June 1m	June 8m	July 1m	July 8m	Aug. 1m	Aug. 8m	Sept. 1m	Sept. 8m	Oct. 1m	Oct. 8m	Nov. 1m	Nov. 8m
Unknown[3]	--	--	--	--	--	A10	--	B4	--	D4	--	D14	D5	--
Megalops:														
Callinectes spp.	--	--	--	--	--	--	--	9	--	--	--	--	7	--
Eurypanopeus spp.	--	--	--	8	--	--	--	--	--	--	--	--	--	--
Neopanope spp.	--	--	--	8	--	--	--	--	--	--	--	--	--	--
Penopeus spp.	--	--	--	--	--	--	--	--	--	--	--	6	--	--
Uca spp.	--	--	--	--	--	--	--	9	--	30	--	12	--	--

Depth: 1m / 8m

[1] Zoeae raised from known crab, unpublished data Duke University Marine Laboratory, Beaufort, N. C.

[2] Zoeae raised fron known crab, unpublished data National Marine Fisheries Service, Beaufort, N. C.

[3] The letters represent the larvae type, the number accompanying the letter is the mean number of crabs of that type in the sample.

TABLE V-20. Distribution and period of peak larval abundance for flatfish collected during 1965-1966 (Adapted from Smith et al., 1975).

Species	Common Name	Distribution	Period of Larval Peak Abundance
Ancylopsetta quadrocellata Gill	Ocellated flounder	North -- Fla. and into Gulf of Mexico	Nov.-Dec.
Bothus spp.		Center of abundance: Cape Hatteras-Cape Lookout	May-June & Sept.-Dec.
Citharichthys arctifrons Goode	Gulf Stream flounder	Georges Bank -- Charleston, S. C. & Southward along both coasts of Fla., & Yucatan, Mexico.	Aug.-Oct.
Cyclopsetta fimbriata (Goode & Bean)	Spotfin flounder	N. Carolina -- Gulf of Mexico & Caribbean coast of Central & South America	1° - Sept.-Oct. 2° May
Etropus microstomus (Gill)	Smallmouth flounder	New England -- Fla.	1° Aug. 2° Sept.-Dec.
Hippoglossina dolonga (Mitchell)	Fourspot flounder	Georges Bank -- Cape Hatteras - 1° and some -- Fla.	1° Aug. 2° Sept.-Dec.
Monolene sessilicauda Goode	Deepwater flounder	New England -- Fla.	Immigrants (June)
Paralichthys dentatus (Linnaeus)	Summer flounder	Maine -- Fla. but 1° Cape Cod to S. C.	1° Sept.-Oct. 2° Dec.
Paralichthys spp.		Eastern seaboard	Dec.
Scopthalmus aquosus (Mitchell)	Windowpane flounder	Maine -- Fla.	1° Sept.-Dec. 2° May
Syacium papillosum (Lonnacus)	Dusky flounder	(N. Carolina -- Fla.) Southeast U.S. Atlantic coast	May-Oct.
Gymnachirus melas Nichols	Naked sole	Mass. -- Fla.	May-Nov.
Symphurus spp.	Tongue fishes	Cape Hatteras -- Fla.	May & Aug.

Fahay (1975) presented an annotated list of larval fish caught in the South Atlantic Bight during the second year of the study. Table V-21 gives a summary of the abundance and seasonality of the larval fish taken during the investigation. The distributional trends observed indicated that Anchoa mitchilli was an obvious inshore species and that istiophorids and exocoetids were offshore species. Histrio histrio and the flying fishes were found primarily in the Gulf Stream. A number of other species apparently spawned offshore and the larvae migrated toward inshore nurseries. Much of the ichthyoplankton, however, utilized floating Sargassum mats in the shelf and Gulf Stream waters as nursery areas. A general observation was made that schooling of the larvae was only apparent in very few species (anchovies, silversides, scads and butterfish) and it was speculated that the protective value of schooling is less necessary in surface waters where weed or debris are available for cover.

Wells and Gray (1960) examined the transport of Mytilus edulis larvae around Cape Hatteras, North Carolina. The investigators noted that Cape Hatteras represents a zoogeographic barrier for this species since neither adults nor larvae can survive the warm summer water temperatures to the south of this area. The barrier is occasionally breached, however, as Virginian coastal waters driven by northeasterly winter storms carry the mussel larvae to the North Carolina coast. The anomalous larval forms then settle and grow, but ultimately succumb to the subsequent warm summer temperatures. Such seasonal occurrences on the North Carolina coast were correlated to the severity of northeast storms occurring in the area during the previous fall and winter months. It was speculated that other sporadic occurrences of northern species seen to the south of Cape Hatteras could be explained by a similar larval transport mechanism.

Fleminger (1975) made extensive zooplankton collections within the American coastal zone as well as world-wide. He reported on the general distributional ranges of various species of the genus Labidocera. The major thrust of the research, however, was not to pinpoint specific distributional and seasonal patterns, but rather to observe evolutionary trends in morphological divergence and zoogeography within the genus. These results will be reviewed in Section 2.7.

2.1.3 Offshore

Most of the zooplankton studies that have included collections in the offshore waters (outer continental shelf, slope, Gulf Stream, and Sargasso Sea) of the South Atlantic Bight did not specifically focus on the characteristics of the zooplankton communities of

TABLE V-21. Summary of fish categories showing numbers caught and seasons present (from Fahay, 1975).

Category	Total Number caught	Number caught per occurrence	Seasons present
Elops saurus	12	1.09	SpSFW
Unidentified Muraenidae	33	1.94	SpSF
Unidentified Congridae	7	1.16	SFW
Bascanichthys sp.	1	1.00	W
Myrophis punctatus	1	1.00	W
Unidentified Ophichtidae	44	2.44	SpSFW
Unidentified Nemichthyidae	3	1.00	WSp
Brevoortia tyrannus	17	8.50	W
Brevoortia sp.	87	9.66	W
Etrumeus teres	34	11.33	W
Opisthonema oglinum	3	1.00	SF
Sardinella anchovia	49	9.80	SpSFW
Unidentified Clupeidae	112	7.46	SpSFW
Anchoa hepsetus	219	24.33	SpSFW
A. mitchilli	33	8.25	WSp
A. nasuta	81	13.50	SFW
Anchoa sp.	123	9.46	SpSFW
Engraulis eurystole	1	1.00	W
Unidentified Engraulidae	61	3.38	SpSFW
Synodus foetens	7	1.75	WSp
Unidentified Synodontidae	2	1.00	W
Unidentified Myctophidae	10	2.50	FW
Histrio histrio	48	1.65	SpSFW
Urophycis earlli	2	1.00	W
U. floridanus	15	2.14	W
U. regius	2,678	58.22	WSp
Urophycis sp.	5	2.50	Sp
Unidentified Ophidiidae	3	1.00	SpF
Chriodorus atherinoides	1	1.00	W
Cypselurus cyanopterus	1	1.00	F
C. exsiliens	1	1.00	F
C. furcatus	1	1.00	Sp
C. heterurus	75	1.70	SpSFW
Cypselurus sp.	1	1.00	F
Euleptorhamphus velox	1	1.00	F
Exocoetus obtusirostris	10	2.50	WSp
E. volitans	3	1.00	WSp
Hemiramphus brasiliensis	64	2.06	SpSFW
Hirundichthys affinis	2	1.00	WSp

TABLE V-21 Cont.

	Total Number caught	Number caught per occurrence	Seasons present
H. rondeleti	7	1.40	SpS
Hyporhamphus unifasciatus	40	3.07	SpSFW
Oxyporhamphus micropterus	5	1.66	SF
Parexocoetus brachypterus	164	3.72	SpSF
Prognichthys gibbifrons	62	1.59	SpSFW
Unidentified Exocoetidae	11	1.22	WSpS
Tylosurus acus	3	1.00	SpSF
Tylosurus sp.	1	1.00	F
Membras martinica	144	28.80	FW
Menidia menidia	41	5.85	FW
Holocentrus sp.	16	1.60	SpSF
Amphelikturus dendriticus	1	1.00	W
Hippocampus erectus	14	1.27	SpSFW
Hippocampus sp.	9	1.12	WSpS
Syngnathus elucens	2	1.00	WSp
S. fuscus	1	1.00	W
S. pelagicus	9	1.00	SpSFW
S. springeri	12	1.20	WSp
Syngnathus sp.	2	2.00	F
Pristigenys alta	44	3.66	S
Apogon maculatus	1	1.00	S
Apogon sp.	1	1.00	Sp
Astrapogon sp.	2	2.00	W
Pomatomus saltratrix	14	1.27	Sp
Remora remora	2	2.00	S
Caranx bartholomaei	19	1.26	SpSFW
C. fusus	59	3.10	SpSFW
C. hippos	5	1.66	SpS
C. latus	2	1.00	SpS
C. ruber	59	2.68	SpSF
Caranx sp.	11	1.57	WSpS
Chloroscombrus chrysurus	8	1.60	SpSF
Decapterus punctatus	826	12.32	SpSFW
Elagatis bipinnulata	8	1.14	SpS
Naucrates ductor	2	1.00	Sp
Selar crumenophthalmus	3	1.00	SpS
Seriola dumerili	11	1.57	FWSp
S. fasciata	2	1.00	SF
S. rivoliana	8	1.33	SF
S. zonata	1	1.00	Sp
Seriola sp.	73	1.97	SpSFW
Trachinotus carolinus	15	1.87	Sp

TABLE V-21 Cont.

	Total Number caught	Number caught per occurrence	Seasons present
T. falcatus	9	1.28	SpSFW
T. goodei	2	1.00	SF
Trachinotus sp.	4	1.00	SpS
Unidentified Carangidae	4	1.33	S
Coryphaena equisetis	16	1.60	SpSFW
C. hippurus	76	1.68	SpSFW
Rhomboplites aurorubens	1	1.00	S
Unidentified Lutjanidae	2	1.00	S
Lobotes surinamensis	1	1.00	F
Stenotomus chrysops	3	1.00	Sp
Unidentified Sparidae	637	26.54	FWSp
Cynoscion nothus	5	5.00	F
Larimus fasciatus	1	1.00	F
Leiostomus xanthurus	22	2.44	FW
Stellifer lanceolatus	1	1.00	F
Mullus auratus	126	4.06	WSp
Pseudupeneus maculatus	1	1.00	Sp
Unidentified Mullidae	23	2.87	WSp
Kyphosus incisor	9	1.12	SFW
K. sectatrix	9	2.25	F
Holacanthus tricolor	1	1.00	F
Pomacanthus arcuatus	1	1.00	F
Unidentified Chaetodontidae	1	1.00	S
Abudefduf saxatilis	17	1.70	FW
Chromis sp.	1	1.00	F
Unidentified Pomacentridae	2	1.00	Sp
Mugil cephalus	174	4.83	FWSp
M. curema	393	6.14	SpSFW
Mugil sp.	67	3.04	WSp
Sphyraena barracuda	2	1.00	S
S. borealis	10	1.11	FWSp
Unidentified Uranoscopidae	19	1.58	SpSFW
Unidentified Blanniidae	35	2.18	SpSFW
Unidentified Gofiidae	2	2.00	S
Diplospinus multistriatus	2	1.00	FW
Auxis sp.	31	2.81	WSpS
Euthynnus alletteratus	8	2.00	S
Scomber japonicus	6	1.20	WSp
Scomberomorus maculatus	4	1.00	SpS
Thunnus sp.	2	1.00	SpS
Xiphias gladius	8	1.33	FWSp

TABLE V-21 Cont.

	Total Number caught	Number caught per occurrence	Seasons present
Istiophorus platypterus	1	1.00	Sp
Makaira nigricans	1	1.00	S
Unidentified Istiophoridae (a)	5	1.66	Sp
Unidentified Istiophoridae (b)	27	1.92	SpSF
Nomeus gronovii	6	1.50	WSp
Peprilus triacanthus	166	6.15	SpSFW
Psenes cyanophrys	13	1.00	WSpS
Scorpaena sp.	8	1.14	SpSFW
Unidentified Triglidae	7	1.40	SpF
Dactylopterus volitans	3	1.00	SpS
Bothus ocellatus	266	4.29	SpSFW
Unidentified Bothidae	31	2.81	SpSFW
Gymnachirus melas	1	1.00	W
Symphurus sp.	1	1.00	F
Aluterus heudeloti	5	1.00	SpSF
A. monoceros	3	1.50	SF
A. schoepfi	9	1.12	SpSF
A. scriptus	13	1.44	SpSF
Aluterus sp.	1	1.00	Sp
Balistes capriscus	44	2.20	SF
Balistes sp.	4	2.00	S
Cantherhines pullus	7	1.40	SF
Canthidermis maculatus	17	1.42	SpSFW
C. sufflamen	8	4.00	SpF
Monacanthus ciliatus	154	2.96	SpSFW
M. hispidus	421	4.43	SpSFW
M. setifer	301	11.58	SpSFW
M. tuckeri	3	1.50	SW
Xanthichthys ringens	1	1.00	F
Unidentified trifferfishes	5	1.00	SpS
Unidentified filefishes	1,536	11.63	SpSFW
Unidentified Ostraciidae	4	1.00	FWSp
Sphoeroides sp.	312	3.95	SpSFW
Diodon holocanthus	1	1.00	S
Diodon hystrix	1	1.00	S
Unidentified	47	1.74	SpSFW
Totals	10,741	39.63	

these areas. Instead, most of the investigations were designed to observe general trends in the zooplankton of the circulation patterns of the Gulf Stream, Atlantic Ocean, or global macrocirculation systems. Collections from the inventory area were, therefore, only incidentally described. Although the results from these general studies are not very detailed in describing the communities, information can be derived to aid in the understanding of the zooplankton that may be expected in the offshore waters of the inventory area.

Investigators from the University of Miami have examined the zooplankton commmunities of the Gulf Stream off southern Florida and have published their findings in the Bulletin of Marine Science series entitled "Plankton of the Florida Current." Bsharah (1957) reported on the environmental conditions, standing crop, and seasonal and diurnal changes in the plankton of the Gulf Stream. Volumetric determinations of the zooplankton biomass are shown in Figures V-5 to V-7. The units of measurement were cubic centimeters of plankton volume per mile that the plankton nets (70cm diameter Discovery nets) were towed. The filtered volume in a one mile haul was assumed to be roughly equivalent to 600 m^3. The data indicated that peak volumetric standing crops occurred during the late spring and early summer months: a trend confirmed by copepod counts (Figure V-8).

The average weight and volume of the major planktonic groups are shown in Table V-22. The mean annual standing crop was found to be 0.45 mg/m^3 which was believed to be an underestimate due to collection techniques. The copepods, euphausids, chaetognaths, and siphonophores generally constituted 50 percent or more of the total weight of a bulk plankton sample throughout the water column (Figure V-9), although other groups such as pteropods and larval fish contribute to the total plankton dry weight values at night (Figure V-10). Extensive diurnal migrations were strongly indicated, changing both the standing crop and constitution of the zooplankton community found in the euphotic zone through the diurnal cycle. The diurnal patterns noted for specific planktonic groups are reported in Section 2.2.

Owre (1962) and Owre and Foyo (1964) have given species lists of copepods collected during the plankton studies. Tables V-23 and V-24 list the species found in the Gulf Stream off south Florida. Those marked with an asterisk were new records for the waters south of 40°N and west of 60°W. No abundance or distributional patterns were described, but other articles (Moore and O'Berry, 1957; Roehr and Moore, 1965) describe vertical migration patterns (see Section 2.2).

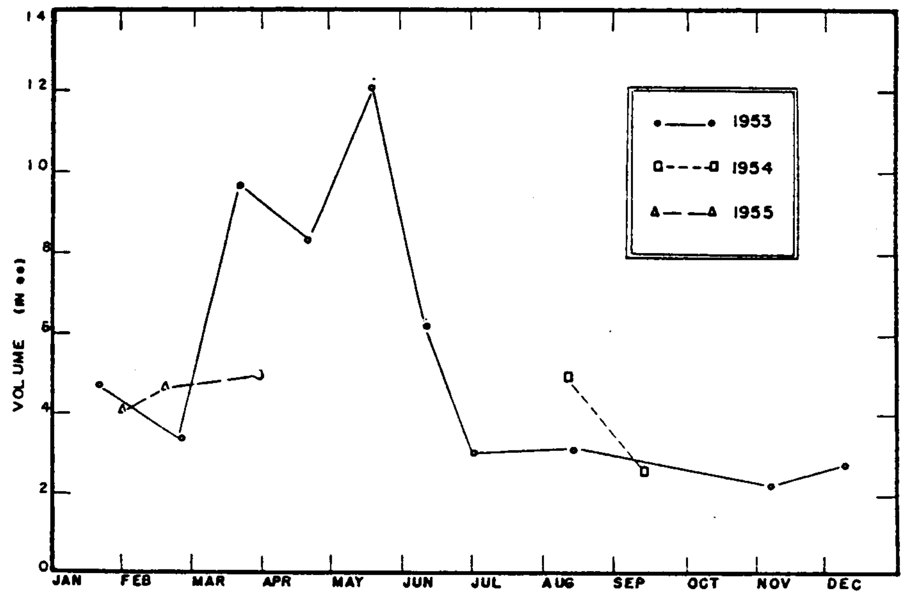

FIGURE V-5. Seasonal variation in the day volumes of plankton at the Forty-Mile Station under one square meter to a depth of six hundred meters (from Bsharah, 1957).

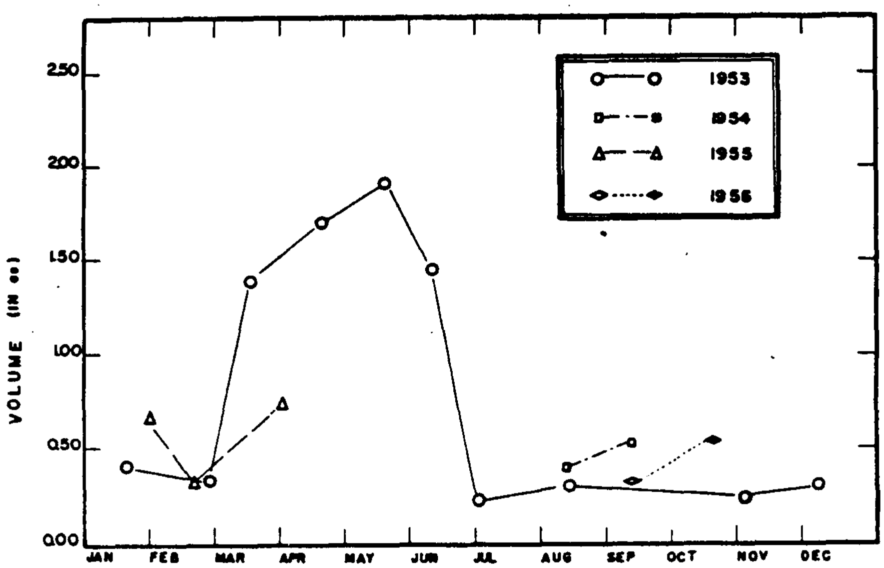

FIGURE V-6. Seasonal variation in the day plankton volumes of the euphotic zone at the Forty-Mile Station under one meter to a depth of one hundred meters (from Bsharah, 1957).

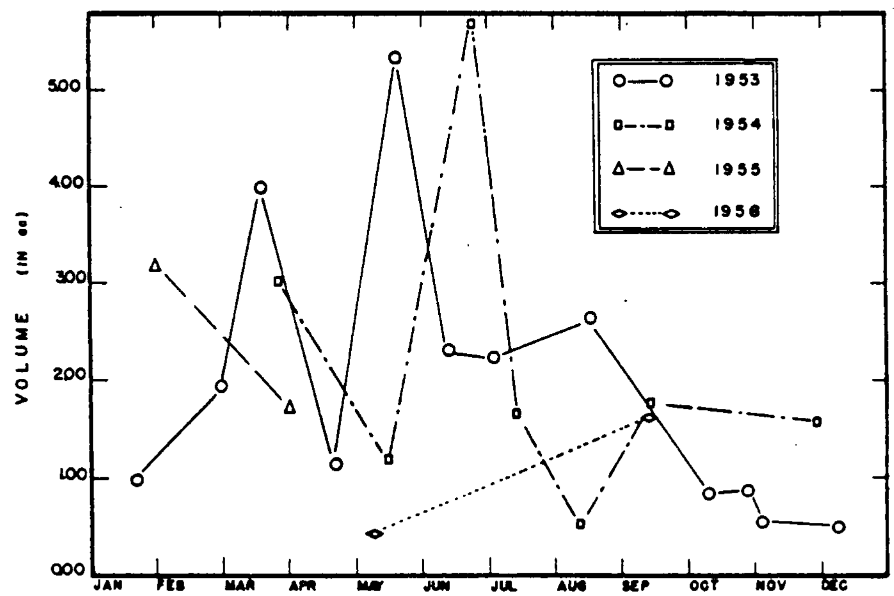

FIGURE V-7. Seasonal variation in night volumes of plankton in the euphotic zone at the Forty-Mile Station under one square meter to a depth of one hundred meters (from Bsharah, 1957).

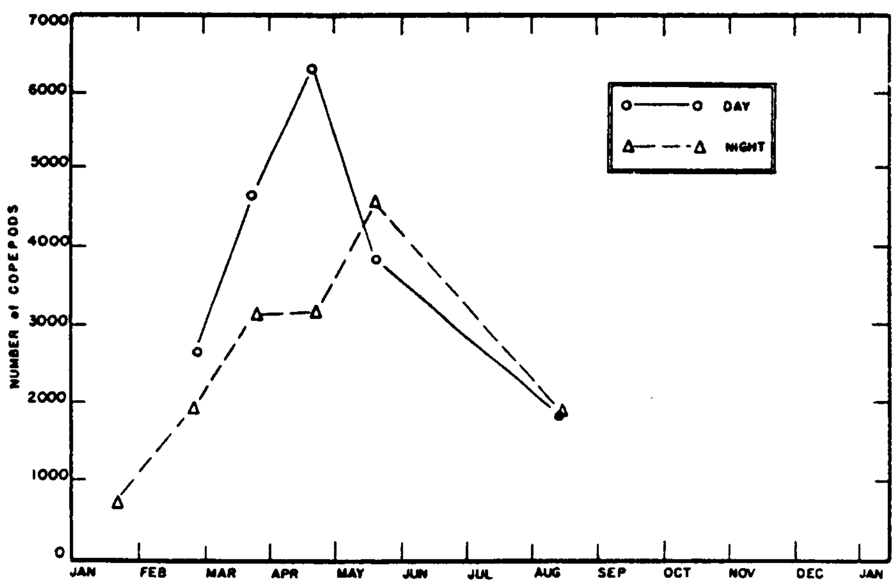

FIGURE V-8. Seasonal variation in the number of copepods at the Forty-Mile Station. Day values are the numbers under one square meter to a depth of six hundred meters. Night values are the numbers under one square meter to a depth of five hundred meters (from Bsharah, 1957).

TABLE V-22. Zooplankton dry weights and wet volumes. (from Bsharah, 1957).

Animal	Dry Wt. per Animal	Wet Vol. per Animal	Wt. per Unit Vol.
Euphausids	1.753 mg.	27.2µl	0.0645
Chaetognaths	0.063	4.5	0.014
Siphonophores	0.126	42.9	0.00294
Copepods	0.024	1.3	0.01845
Copepods (Euphotic Zone Daytime)	0.0065		

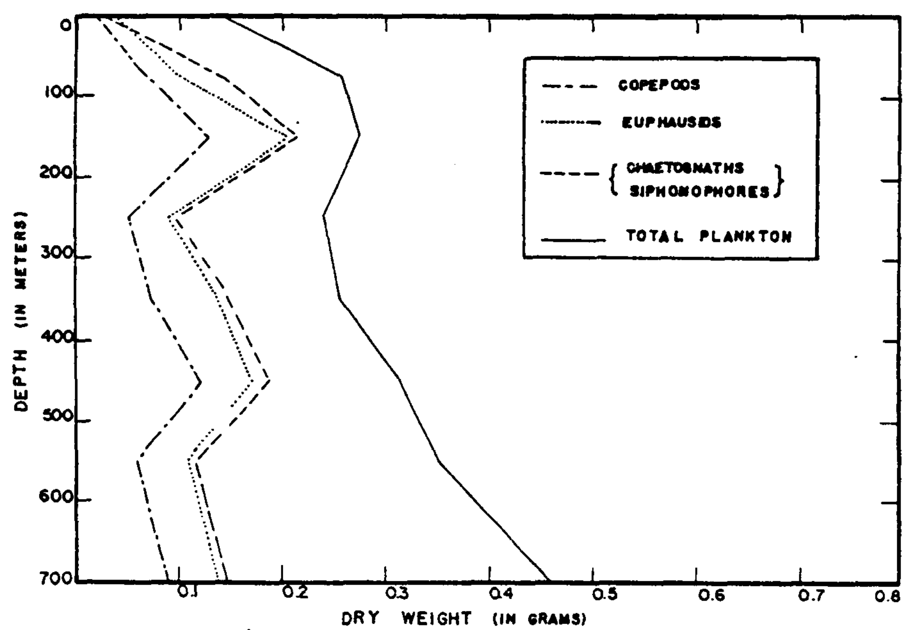

FIGURE V-9. Accumulative totals of the dry weight of copepods, euphausids, chaetognaths and siphonophores, as portions of the dry weight of total plankton in day hauls at the Forty Mile Station (from Bsharah, 1957).

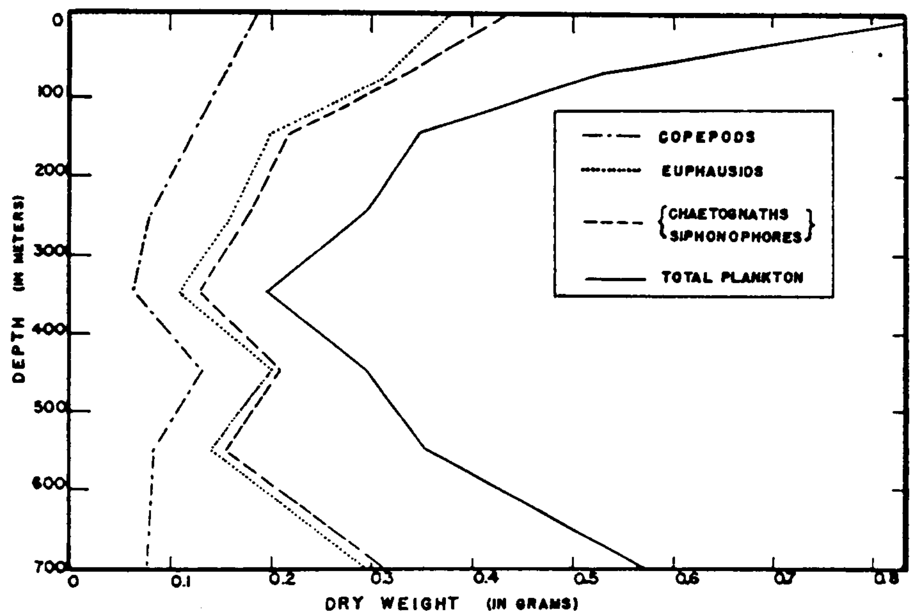

FIGURE V-10. Accumulative totals of the dry weights of copepods, euphausids, chaetognaths and siphonophores, as portions of the dry weight of total plankton in night hauls at the Forty-Mile Station (from Bsharah, 1957).

TABLE V-23. List of copepoda species of the Florida Current. (from Owre, 1962)

Suborder CALANOIDA

Family CALANIDAE

Calanus tenuicornis Dana
Nannocalanus minor (Claus)
Neocalanus gracilis (Dana)
N. robustior (Giesbrecht)
Megacalanus princeps Wolfenden
Bathycalanus richardi G. O. Sars
Undinula vulgaris (Dana)

Family EUCALANIDAE

Eucalanus elongatus (Dana)
E. attenuatus (Dana)
C. furcatus (G. Brady)

Family AETIDEIDAE

Aetideus armatus (Boeck)
**Euaetideus giesbrechti* (Cleve)
Chiridius poppei Giesbrecht
Gaidius tenuispinus G. O. Sars
Gaetanus miles Giesbrecht
G. minor Farran
G. latifrons G. O. Sars
Euchirella messinensis (Claus)
E. amoena Giesbrecht
**E. curticauda* Giesbrecht
E. rostrata Claus
E. bitumida With
Chirundina streetsi Giesbrecht
Undeuchaeta plumosa (Lubbock)

Family EUCHAETIDAE

Euchaeta marina (Prestandrea)
E. acuta Giesbrecht
E. media Giesbrecht
Pareuchaeta hansenii (With)
**P. tonsa* (Giesbrecht)

Family PHAENNIDAE

Phaenna spinifera Claus

Family SCOLECITHRICIDAE

Scolecithrix danae (Lubbock)
S. bradyi Giesbrecht
Scottocalanus persecans Giesbrecht
E. monachus Giesbrecht
Rhincalanus cornutus (Dana)
R. nasutus Giesbrecht
Mecynocera clausi J. C. Thompson

Family PARACALANIDAE

Acrocalanus longicornis Giesbrecht
Calocalanus pavo (Dana)
C. plumulosus (Claus)

Family PSEUDOCALANIDAE

Clausocalanus arcuicornis (Dana)

Family TEMORIDAE

Temora stylifera (Dana)
T. turbinata (Dana)
**Temoropia mayumbaensis* T. Scott

Family METRIDIIDAE

Metridia princeps Giesbrecht
Pleuromamma abdominalis (Lubbock)
P. xiphias (Giesbrecht)
P. gracilis (Claus)
P. piseki Farran

Family CENTROPAGIDAE

Centropages furcatus (Dana)
C. violaceus (Claus)

Family LUCICUTIIDAE

Lucicutia flavicornis (Claus)
L. clausi (Giesbrecht)

Family HETERORHABDIDAE

**Disseta palumboi* Giesbrecht
Heterorhabdus spinifrons (Claus)
H. papilliger (Claus)
**H. abyssalis* (Giesbrecht)
Hemirhabdus grimaldii (J. Richard)

Family AUGAPTILIDAE

Haloptilus longicornis (Claus)
H. oxycephalus (Giesbrecht)
**H. mucronatus* (Claus)
**H. fertilis* (Giesbrecht)
H. ornatus (Giesbrecht)

TABLE V-23 Cont.

S. securifrons (T. Scott)
**Lophothrix frontalis* Giesbrecht

**Centraugaptilus rattrayi* (T. Scott)
**C. horridus* Farran

Family ARIETELLIDAE
Arietellus setosus Giesbrecht
**A. plumifer* G. O. Sars
**Phyllopus impar* Farran

Family CANDACIIDAE
Candacia longimana Claus
C. pachydactyla Dana
C. curta Dana
C. bipinnata Giesbrecht
C. varicans Giesbrecht
C. bispinosa Claus
C. simplex Giesbrecht

Family PONTELLIDAE
Calanopia americana F. Dahl
Pontella atlantica (Milne-Edwards)
P. spinipes Giesbrecht
Labidocera acutifrons (Dana)
L. aestiva Wheeler
L. nerii (Kröyer)
Pontellopsis regalis (Dana)
**P. perspicax* (Dana)
**P. villosa* G. Brady
Pontellina plumata (Dana)

Family ACARTIIDAE
Acartia negligens Dana
A. danae Giesbrecht
A. spinata Esterly
A. bermudensis Esterly

Family MORMONILLIDAE
**Mormonilla phasma* Giesbrecht

H. spiniceps (Giesbrecht)
Euaugaptilus hecticus (Giesbrecht)

Suborder HARPACTICOIDA

Family MIRACIDAE
Miracia efferata Dana
Oculosetella gracilis (Dana)
Macrosetella gracilis (Dana)

Family CLYTEMNESTRIDAE
Clytemnestra scutellata Dana

Family AEGISTHIDAE
**Aegisthus mucronatus* Giesbrecht

Suborder CYCLOPOIDA

Family OITHONIDAE
Oithona plumifera W. Baird
O. setigera (Dana)
**Ratania flava* Giesbrecht
**R. atlantica* Farran

Family ONCAEIDAE
Oncaea venusta Philippi
O. mediterranea (Claus)
O. conifera Giesbrecht
Conaea rapax Giesbrecht
Lubbockia squillimana Claus
L. aculeata Giesbrecht
Pachos punctatum (Claus)

Family SAPPHIRINIDAE
Sapphirina angusta Dana
S. metallina Dana
S. stellata Giesbrecht
S. opalina Dana
S. ovatolanceolata Dana
S. nigromaculata Claus
Copilia vitrea (Haeckel)
C. mirabilis Dana
C. quadrata Dana

TABLE V-24. Additions to the list of copepoda species of the Florida Current. (from Owre and Foyo, 1964)

Suborder CALANOIDA
Family CALANIDAE
t**Megacalanus typicus* (A. Scott)
Family EUCALANIDAE
Eucalanus crassus Giesbr.
E. mucronatus Giesbr.
Family PARACALANIDAE
Paracalanus aculeatus Giesbr.
Family AETIDEIDAE
t *Gaetanus kruppii* Giesbr.
Gaetanus pileatus Farran
t**Euchirella maxima* Wolfenden
E. pulchra (Lubbock)
t *Pseudochirella obesa* Sars
Undeuchaeta major Giesbr.
Family EUCHAETIDAE
t *Euchaeta spinosa* Giesbr.
t *Paraeuchaeta barbata* (Brady)
t *P. bisinuata* (Sars)
t**P. malayensis* Sewell
t**P. withi* Sewell
t**Valdiviella brevicornis* Sars
t *V. insignis* Farran
Family PHAENNIDAE
**Xanthocalanus agilis* Giesbr.
t *Cornucalanus chelifer* (Thompson)
Family SCOLECITHRICIDAE
**Scolecithricella ctenopus* (Giesbr.)
S. dentata (Giesbr.)
S. tenuiserrata (Giesbr.)
S. vittata (Giesbr.)
**Scottocalanus australis* Farran
**S. helenae* (Lubbock)
Lophothrix latipes (T. Scott)
t**Amallothrix gracilis* (Sars)
Family METRIDIIDAE
t *Gaussia princeps* (T. Scott)
Family LUCICUTIIDAE
Lucicutia magna Wolfenden
Family HETERORHABDIDAE
Heterostylites longicornis (Giesbr.)
t**Hemirhabdús latus* (Sars)
Family AUGAPTILIDAE
t**Euaugaptilus californicus* (Esterly)
t *E. longimanus* (Sars)
t *E. magnus* (Wolfenden)
t**E. nodifrons* (Sars)
t**E. tenuispinus* Sars
Family ARIETELLIDAE
Phyllopus helgae Farran
Family CANDACIIDAE
Candacia paenelongimana Fleminger & Bowman
Family PONTELLIDAE
Pontella mimocerami Fleminger
Family BATHYPONTIIDAE
t**Bathypontia minor* Sars
Suborder HARPACTICOIDA
Family ECTINOSOMIDAE
Microsetella norvegica (Boeck)
M. rosea (Dana)
Suborder CYCLOPOIDA
Family OITHONIDAE
**Oithona frigida* Giesbr. var. *pseudofrigida* Rosendorn
O. robusta Giesbr.
Family CORYCAEIDAE
Corycaeus (*Onychocorycaeus*) *catus* F. Dahl

Riley (1939) made a transect from Cuba to Woods Hole which included collections in the OCS area off the coast of Georgia. Volumetric and numerical abundance were 0.07 cc/m^3 and 257,000 $organisms/m^3$ at this station. These values represent over twice the biomass found at the more tropical station but only 1 percent (volumetrically) to 18 percent (numerically) of that found in the northern waters. It was speculated that the turnover rate may be faster in the tropical waters, so that the relative abundance patterns do not necessarily reflect zooplankton productivity.

Clarke (1940) attempted to compare the zooplankton richness and seasonality between coastal and offshore waters. Although the coastal and slope water collections were made to the north of the inventory area (along a transect between New York and Bermuda), one station was located in the Sargasso Sea off Cape Hatteras. In comparing this region to the northern waters, Clarke observed that the average zooplankton volume was four times as great in coastal waters as in slope waters, which in turn exhibited four times the volumetric abundance of that found for the Sargasso Sea. No seasonality was observed for the zooplankton of the Sargasso Sea, even though strong seasonal trends were noted in coastal and slope collections. A final difference was identified between the zooplankton distribution in the three areas: coastal and slope water collections showed little difference in volumetric abundance of shallow and deep water zooplankton when diurnal samples were combined, while those taken from the Sargasso Sea indicated that most of the zooplankton community was found in the shallow strata (above 100m).

Grice and Hart (1962) also made a transect between New York and Bermuda, but established six stations in the Sargasso Sea and one station in the Gulf Stream for comparison with those in northern slope and shelf waters. Collections were made seasonally with a 75cm diameter #6 plankton net. The mean standing crops of the Gulf Stream and Sargasso Sea water were 0.03 cc/m^3 and 0.02 cc/m^3 respectively. The temperate slope waters exhibited three to four times the standing crop of these areas, while zooplankton biomass from shelf waters was nine times as great. Few seasonal trends were observed in the standing crops or species composition of the offshore areas. Copepods dominated the zooplankton, making up over 50 percent of the standing crop in the Gulf Stream and Sargasso Sea. Diversity was high in both areas: 43 species in the Gulf Stream and 92 species in the Sargasso Sea. The most abundant species are shown in Table V-25. Chaetognaths were the second most important contributors to the zooplankton standing crops, comprising 15 to 25 percent of the displacement volume. Figure V-11 shows the distribution of major chaetognath species in the offshore areas. _Sagitta enflata_ dominated the Gulf Stream

TABLE V-25. Numerically important copepod species in neritic, slope, Gulf Stream and Sargasso Sea waters (from Grice and Hart, 1962).

	Freq.	Mean no./m^3
NERITIC (14 SAMPLES)		
Pseudocalanus minutus	13	559
Centropages typicus	14	450
Oithona similis	13	151
Temora longicornis	8	59
Paracalanus parvus	8	39
Calanus finmarchicus	11	32
Metridia lucens	12	16
Candacia armata	9	9
SLOPE (15 SAMPLES)		
Centropages typicus	11	76
Pseudocalanus minutus	8	16
Oithona similis	6	14
Metridia lucens	11	15
Clausocalanus pergens	6	19
C. arcuicornis	7	13
Pleuromamma borealis	8	6
Oithona atlantica	12	6
GULF STREAM (3 SAMPLES)		
Clausocalanus furcatus	3	27
Lucicutia flavicornis	3	9
Oithona plumifera	3	9
O. setigera	3	7
Calocalanus pavo	2	9
Farranula gracilis	3	4
Mecynocera clausi	3	2
SARGASSO SEA (11 SAMPLES)		
Clausocalanus furcatus	9	7
Oithona setigera	11	6
Lucicutia flavicornis	11	4
Ctenocalanus vanus	6	3
Farranula gracilis	6	2
Mecynocera clausi	9	2

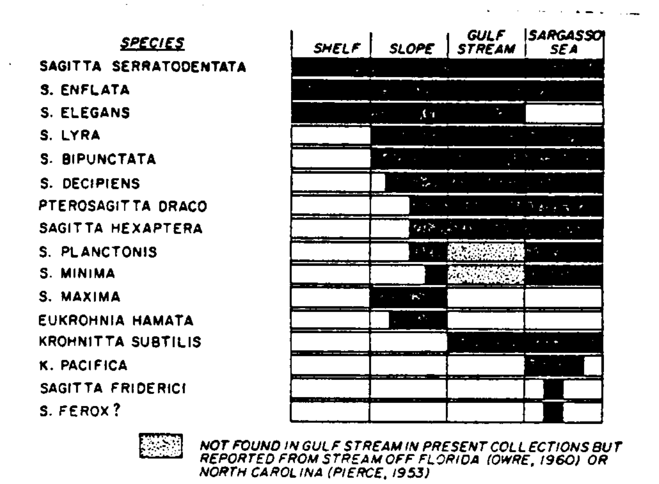

FIGURE V-11. Distribution of Chaetognatha (from Grice and Hart, 1962).

chaetognaths, while S. serratodentata dominated the Sargasso Sea, although a diversity of species (8-12) were also observed in the waters from both areas.

Table V-26 gives the diversity, abundance, and most common representatives of other groups of zooplankton found in the Gulf Stream and Sargasso Sea. Siphonophores are carnivores that also are quite important to the zooplankton community. In fact, the most notable trend in the character of the zooplankton of the offshore areas was the relatively larger component of carnivores and the fewer numbers of obligate herbivores in comparison to neritic communities. It was concluded that the sparse, yet diverse, communities of the offshore waters utilize most of the standing crop of phytoplankton and efficiently transfer the energy to higher trophic levels.

Sutcliffe (1960) also studied the zooplankton of the Sargasso Sea in order to examine factors that influence diversity. An inverse correlation between productivity (standing crop) and diversity was noted. The diversity was, however, more or less independent of environmental conditions. In the Sargasso Sea, the latitudinal, temperature, or food (phytoplankton concentrations) conditions appear not to be the causal factors in determining zooplankton community diversity.

Egan and Conrad (1975) reported on studies designed to follow a water mass as it moved along the Gulf Stream in order to observe changes in the zooplankton community. Samples were taken with a Clarke-Bumpus 100 micron mesh net from a boat drifting with the Gulf Stream. Although extensive taxonomic identification was not attempted, major groups were enumerated (Table V-27). The most significant result of the study was that there was no overall increase or decrease in the zooplankton population as it moved along the Gulf Stream. It was also noted that there was no consistent significant correlation of zooplankton abundance with depth, time of day, or location. It was suggested that the Gulf Stream zooplankton community is constantly being replenished by influxes of zooplankton-laden water from the continental shelf areas on the inshore side and the Sargasso Sea on the offshore side.

Cutler (1975) proposed that a zoogeographic barrier is located in continental slope waters off Cape Lookout, North Carolina (ca. 34^{o}N), between 150 and 2500m in depth. Benthic organisms such as Sipuncula and Pogonophora have a distributional pattern indicative of a partial barrier in this region. It was postulated that the deep Western Boundary Under Current counters the flow of the Gulf Stream and cuts across the Blake Plateau in this region, providing

TABLE V-26. Zooplankton composition, abundance and diversity from the Gulf Stream and Sargasso Sea (from Grice and Hart, 1962).

Group	Area	# of Species	% Volume	$\#/m^3$	Most Abundant Species
Siphonophora	Gulf Stream	14	14.4	0.9	*Abylopsis eschscholtzii A. tetragona*, *Bassia bassensis*, *Chelophyes appendiculata*, *Diphyes bojoni*, *Eudoxoides mitra*, *E. spiralis*, *Hippopodius hippopus*, *Leusia fowleri*
	Sargasso Sea	27	17.7	0.8	
Euphausiid	Gulf Stream	6	1.8	1.3	*Stylocheiron* spp.
	Sargasso Sea	20	4.8	0.7	*Euphausia* spp.
Amphipoda	Gulf Stream	26		0.2	*Hyperia schizogeneios*, *Phrosina semilunata*, *Lycaeopsis themistoides*
	Sargasso Sea	46	2.0	0.2	
Mollusca					
heterpods	Gulf Stream	11	---	---	
	Sargasso Sea	11	---	---	*Protatlanta souleyeti*
Pteropods	Gulf Stream	19	---	---	*Creseis acicula*
	Sargasso Sea	19	---	---	
Annelida	Gulf Stream	8	---	---	*Sagitella kowalevskii*
	Sargasso Sea	24	---	---	*Vanadis minuta*
					Tomopteris planktonis
Ostracoda	Gulf Stream	9	---	---	*Conchoecia acuminata*
	Sargasso Sea	12	---	---	*C. curta*
Chordata	Gulf Stream		---	---	*Salpa fusiformis*
	Sargasso Sea	9	---	---	*Thalia democratica*
Decapoda	Gulf Stream	2	---	---	*Lucifer faxonii*
	Sargasso Sea	2	---	---	*L. typus*

TABLE V-27. Average population per $100m^3$ over all 42 hauls, and correlation coefficients for depths and latitudes. (from Egan and Conrad, 1975)

TAXA	POPULATION	DEPTH CORRELATION	LATITUDE CORRELATION
Radiolaria and Foraminifera	833	-0.10	-0.07
Coelenterata	443	-0.19	-0.09
Polychaeta larvae	402	-0.18	-0.10
Mollusca larvae	1,000	-0.29	-0.12
Pteropoda	114	-0.24	-0.09
Cladocera	84	-0.14	-0.11
Ostracoda	794	0.29	0.02
Nauplii and Copepodids	1,079	-0.11	-0.13
Calanoida	23,590	-0.18	-0.09
Harpacticoida	275	-0.15	-0.07
Cyclopoida	1,321	-0.14	-0.18
Barnacle larvae	8	0.10	-0.25
Hyperidae	98	-0.23	-0.12
Euphausiacea	48	0.32	-0.10
Crustacean megalopas and zoeas	121	-0.20	-0.22
Echinodermata larvae	33	-0.27	-0.18
Chaetognatha	1,040	-0.16	-0.07
Salpida	100	-0.32	-0.11
Oikopleura	2,106	-0.19	-0.07
Teleost eggs	4,174	-0.17	-0.07
Miscellaneous	51	-0.10	0.05
TOTAL	37,714	-0.18	-0.09

a barrier to benthic organisms that produce short-lived larva which remain close to the bottom. Near-bottom plankton collections were made with a Clarke-Bumpus sampler but the larvae could not be identified, so the hypothesis could not be substantiated.

Finally, Bogorov, Lappo and Suyetova (1974) reported on a large-scale study of the total mesoplankton biomass of the macrocirculation systems of the world's oceans. The investigators found that maximum standing crops were found in cyclonic circulation patterns and minimum values were found in anticyclonic patterns. In fact, the difference in zooplankton standing crop of two adjacent circulations of opposite vortices was shown to be significantly greater than the difference in the biomass of widely separated regions of different oceans and climatic zones with water movement of the same vorticity. It was, therefore, suggested that there is a close relation between dynamic and biological phenomenon in the ocean. The term geobiology was coined to describe the study of these relationships. A final point was made that the estimated potential energy in the total biomass of living organisms in the ocean was more closely related in magnitude to the kinetic energy of ocean than to the energy of algal productivity. These relationshps compel greater thought and research into the interaction of biological and physical phenomena both on a local and global scale.

Since the studies that have been done on the offshore zooplankton community do not provide comparable data, only general trends can be observed. The zooplankton community of the Gulf Stream and Sargasso Sea areas are quite diverse, but standing crops are low. Volumetric abundance is generally three to four times greater in shelf waters than slope waters which in turn is 3-4 times greater than that found in offshore Gulf and Sargasso areas. The copepods, chaetognaths, siphonophores, and euphausiids appear to dominate the zooplankton, although a great number of species of each group may occur together, so no one species can be identified as being dominant. The zooplankton communities appear to be quite efficient and stable: most of the primary production is utilized and the energy is passed to an extensive carnivore component; and little latitudinal change or seasonality in biomass or diversity can be discerned. Gulf Stream zooplankton communities may be continuously replenished and stabilized through entrainment of water from neritic and Sargasso Sea areas, but the reverse situation apparently also occurs as inshore waters are periodically seeded by intrusions of offshore forms. Thus, the zooplankton communities of inshore and offshore waters may be intimately tied together by a number of biotic interactions.

The complex hydrography and many dynamic processes operating in the vicinity of the Gulf Stream may prove to be quite important in establishing zoogeographic barriers for short-lived meroplanktonic forms. On a much larger scale, the dynamic processes in the offshore waters may directly control the productivity and standing crops of zooplankton communities if the views of the geobiologists are correct.

Clearly, the role of biological and biological-physical interactions in shaping the characteristics of offshore zooplankton communities merits further study.

2.2 Spatial and Temporal Patterns

Characteristic horizontal, vertical, and temporal patterns of distribution have been identified for the zooplankton communities examined by many of the studies reviewed in Sections 2.1.1-2.1.3. Although the results of most of the studies are not directly comparable, the patterns for certain groups can be identified.

Horizontal patterns of zooplankton distribution within the major zones (estuaries, coastal areas, and offshore waters) have been examined in a number of studies. Jacobs (1968) proposed a mechanism to explain the clumped distribution of various species of zooplankton in a tidal sound in Georgia (see Roberts, 1974, for complete review). The combined action of tidal dynamics and species-specific vertical migration behavior caused striking density patterns of horizontal distribution to be set up within the estuary. High density areas, created by the interaction between the local hydrographic processes and the behavior of each species, were observed to shift up and down the estuary with the tides, but appeared to be fairly predictable in location through time.

Stickney and Knowles (1975) found evidence to support Jacobs' hypothesis by observing the zooplankton distribution of the Skidaway and Wilmington Rivers over a number of consecutive tidal cycles. The distribution of copepod nauplii was seen to be a function of dilution and concentration by tidally induced changes in water volume, but the more advanced copepod stages exhibited a complex distribution pattern linked with tidal mixing dynamics. Adult copepods clearly exhibited migratory behavior and consistently had maximum densities on high and falling tides. These patterns were taken as indirect evidence that the copepods were concentrated in the upstream areas of the river when the surface waters flooded the marshes. It was speculated that the copepods might even have strong enough swimming ability to actively avoid being carried out over the marsh areas (Jacobs, 1968; Stickney and Knowles, 1975). The concentrated population of copepods that forms in the bottom layers of the river during high tide is then carried back downstream on the next ebbing tide. Each species has slightly different behavior patterns which, when coupled with variations in local hydrography, cause complex density patterns throughout the estuary.

Lonsdale and Coull (1977) observed that zooplankton density in the North Inlet Estuary was significantly higher at the deeper stations near the mouth of the inlet than at stations in the upper tidal reaches of the marshes. It was speculated that a "funneling effect" caused the zooplankton populations to concentrate in the lower tidal reaches as the marshes drained. Subsequent unpublished observations indicate, however, that densities are significantly higher on high tides, more or less disproving this hypothesis (Stancyk, 1978, personal communication). Since the density pattern is similar to that observed by Jacobs (1968) and Stickney and Knowles (1975), it is conceivable that the interactions between the tidal dynamics and the migratory behavior of major species is causing the zooplankton to be concentrated in the deeper areas of the estuary as the marshes flood. Similar horizontal patterns might be expected in other southeastern estuaries with little or no freshwater input and low flushing rates.

Dudley and Judy (1971) observed the horizontal distribution of crab larvae in the coastal waters off Beaufort Inlet, North Carolina (Tables V-17, V-18, V-19). A number of species exhibited distinctly higher densities at the offshore stations: Callinectes sapidus, Portunus gibbesii, Portunus sayi and Hepatus epheliticus. The concentrations of larvae of other species were higher at inshore stations: Neopanope texana sayi, Menippe mercenaria, Panopeus herbstii, Polyonyx gibbesi and Sesarma spp. The remaining species either exhibited no obvious trend or were not taken in sufficient numbers to establish a pattern. It can be seen that the offshore forms are mainly represented by "swimming crabs" that migrate offshore to spawn, while the inshore forms were dominated by xanthid ("mud") crabs that would be expected to spawn in the more inshore areas. Most of the inshore forms were found in greater abundance in the 8m collections while the offshore forms were found to be denser in surface tows. Scheltema (1975) reviewed the literature on larval dispersal along the Atlantic coast of America and observed that meroplankton remaining in the bottom layers of the water column tend to be carried into inshore and estuarine areas. On the other hand, larvae of species such as Callinectes may follow the complex current patterns of surface waters and therefore potentially can be carried anywhere between Cape Hatteras and Cape Canaveral. Thus, behavioral differences in depth preference may drastically influence the dispersal patterns of the two groups: the more sedentary crabs spawn inshore and the larvae tend to remain near the parents' home range by selecting bottom layers with a net shoreward movement; while the more motile forms spawn offshore and the surface-dwelling larvae may be transported great distances before metamorphosis.

Fahay (1975) observed several distinct trends in the horizontal patterns of the surface ichthyoplankton of the South Atlantic Bight. Anchoa mitchilli was clearly an inshore species, while istiophorids and exocoetids were identified as offshore species. Histrio histrio and several species of flying fish were confined to the Gulf Stream. A number of species (Elops saurus, Mugil spp., Leiostomus xanthurus, Brevoortia sp., Synodus spp., Urophycis regius, Trachinotus carolinus and Scomberomorus maculatus) apparently spawned offshore but migrated inshore during development. Fahay noted that this type of migration only took place during the winter and early spring, while those species observed to spawn in the summer and fall used the floating mats of Sargassum in the offshore waters as a nursery area. He also noted that the peak of migratory behavior occurs when temperatures between inshore and offshore waters differ most greatly. Although not specifically stated, it was implied that the difference in temperature between the areas provides some sort of migratory (or navigational) cue to the larvae of those species that migrate into inshore nursery grounds.

A more recent work (Nelson, Ingham and Schaaf, 1977) provides an alternate hypothesis that may explain the observed migration patterns during the winter and fall months. Although specifically looking only at Brevoortia tyrannus (menhaden) larvae, the hypothesis proposed by these investigators could also be applied to any of the other species identified as exhibiting a shoreward migration pattern. Nelson et al. postulated that the menhaden larvae are passively transported shoreward by zonal wind-driven (Ekman) transport of surface water rather than by active migration. It was proposed that the winter-spring spawning of the menhaden in the offshore waters of the South Atlantic Bight has evolved to coincide with the peak period of Ekman transport of surface waters towards the coast. A multiple regression model indicated that there was a strong correlation between the strength of Ekman transport and the survival index, indicating that this mechanism is of major importance in the transport of larval menhaden from offshore spawning areas to inshore nursery grounds (i.e. the difference between good and poor years for menhaden fisheries may be related to this physical factor). Obviously, this mechanism should be studied further to determine its importance to the transport/dispersal of surface meroplankton.

Vertical patterns of zooplankton abundance are closely tied to diurnal migration behavior, so spatial and temporal distribution patterns must be considered together. As previously indicated, the vertical distribution of zooplankton can have very important effects on the horizontal patterns of the community in estuaries or the dispersal of meroplankton in coastal waters, so all patterns are closely interrelated. McLaren (1974) and Enright (1977) have reviewed the literature on vertical migration of zooplankton. These papers attempt to put into perspective the various theories that have been proposed to explain the evolution of this type of behavior. Although these articles do not specifically address any research in the inventory area, they provide a general background for anyone interested in the vertical patterns of distribution of zooplankton.

Peters (1968) observed migratory behavior in the harpacticoid copepods of the Pamlico estuary. The harpacticoids were virtually absent in the water column during the day, but migrated up from their epibenthic habitat at night. The magnitude of the concentration of abundance appeared to be directly related to the strength of wind-driven currents (Table V-3b). During periods of peak density, the harpacticoids were found to represent more than twice the concentration of all other zooplankton groups combined, leading Peters to conclude that this group may play an extremely important ecological role that is not detected by most studies which make collections during the day or during calm weather.

Stickney and Knowles (1975) reported that the adult stages of _Acartia tonsa_, _Pseudodiaptomus coronatus_, and harpacticoid copepods collected in a Georgia estuary exhibited vertical migratory behavior while the copepod nauplii did not. The adult copepods were found to be concentrated in the bottom layers of the water column (6m in depth) during the day but evenly distributed with depth at night. The juvenile stages of copepods were observed in greatest abundance in the surface waters throughout all diurnal or tidal cycle phases.

Vertical patterns of Gulf Stream zooplankton have been studied by several investigators. Moore and O'Berry (1957) and Roehr and Moore (1965) reported on the vertical distribution of common copepods from the Gulf Stream. The depth above which 30 percent of the population occurred was used as the modal depth in the characterization of the vertical pattern of each species. Table V-28 shows the vertical distribution and diurnal migration range of some of the copepod species. Either little or reversed

TABLE V-28. Vertical distribution of copepods. The figures in parentheses show the number of stations from which the mean values were obtained (Roehr and Moore, 1965).

Species	30 Per Cent Level Day (m)	Night (m)	Range (m)
Calocalanus pavo (Dana)	37 (26)	62 (21)	-25
Corycaeus lautus Dana	102 (11)	143 (5)	-41
Copilia mirabilis Dana	107 (21)	105 (19)	2
Corycaeus speciosus Dana	111 (19)	100 (17)	11
Pontellina plumata (Dana)	120 (6)	143 (8)	-23
Temora stylifera (Dana)	132 (20)	110 (17)	22
Undinula vulgaris (Dana)	134 (32)	85 (26)	49
Eucalanus attenuatus (Dana)	143 (29)	144 (26)	- 1
Macrosetella gracilis (Dana)	143 (28)	153 (23)	-10
Euchaeta marina (Prestandrea)	154 (33)	104 (29)	50
Haloptilus longicornis (Claus)	175 (12)	184 (8)	- 9
Lucicutia flavicornis (Claus)	185 (19)	141 (19)	44
Euaetidius giesbrechti (Cleve)	205 (2)	153 (4)	52
Pleuromamma gracilis (Claus)	244 (19)	158 (19)	86
P. abdominalis (Lubbock)	246 (30)	155 (29)	91
Rhincalanus cornutus (Dana)	246 (30)	186 (27)	60
Pleuromamma xiphias (Giesbrecht)	350 (15)	164 (19)	186

migraton (i.e. up in the day, down at night) was exhibited by species characteristic of surface waters (e.g. Calocalanus pavo). Species taken from intermediate depths generally showed moderate migration ranges (e.g. Undinula vulgaris), but a number of species exhibited little or reversed migration (e.g. Macrosetella gracilis). Roehr and Moore (1965) conclude that the latter type of migratory behavior is not aberrant, but may, in fact, be more common for species characteristic of moderate depths than previously supposed by Moore and O'Berry (1957). The copepods characteristic of the deeper layers (e.g. Pleuromamma xiphias) of the water column all showed extensive migrations through the diurnal cycle.

Bsharah (1957) made semiquantitative volumetric measurements of the zooplankton at various depths in the Gulf Stream. From these data vertical distributional patterns of the major plankton groups could be discerned. No significant diurnal changes were noted in the numerical abundance of copepods in the euphotic zone. It was suggested that copepods might exhibit less diurnal migration as a group than other plankters. It was pointed out, however, that larger deep-dwelling species migrate up at night and replace the small surface species that are migrating down, so mean copepod biomass tends to increase in collections taken at night. This trend of migration in opposite directions which tends to cancel large changes in numerical abundance may be of adaptive advantage in resource partitioning by the copepods. Pteropods (Thecosomata) showed strong migratory behavior, with nighttime standing crops in the euphotic zone representing up to 20 times that found during the day. Chaetognaths were found to have a bimodal vertical distribution pattern: one peak in the surface waters and a second just below the euphotic zone. Night populations in the euphotic zone increased up to five times over those found during the day, suggesting strong migratory behavior. Sight avoidance of the nets during daylight hours could, however, also explain this pattern. Active avoidance of the nets was identified as being a major problem in assessing the distribution patterns of euphasiids, though migration was suggested. Siphonophores decreased in abundance with depth but showed little or no migratory behavior. It was therefore speculated that this group may be trophically quite important throughout the water column at night.

Seasonal distributional patterns have been examined in many of the zooplankton studies reviewed in the previous sections. The dissertation by McCrary (1969) provides the most intensive description of seasonal patterns of estuarine zooplankton distribution; so results from other studies will be compared and contrasted to those presented by this work. Table V-29 is extracted from the narrative calender of major larval occurrences

TABLE V-29. Seasonal patterns of zooplankton distribution, Wrightsville Sound, N. C. (from McCrary, 1969).

Month	Relative Abundance/Nature of Change	Remarks
January	a) most abundant: Actinian planulae; nemertean pilidia; Bugula neritina; barnacle nauplii and cyprids; Polygordius trochophores.	
	b) abundant: annelid larvae: Megelona, Sabellaria, Scolelepis, glycerids, neplityids, spionphaids.	
	c) common: cyphonautes larvae; actinotrocha; echiuroid trochophores; mitraria; pagurid zoea; bipinnaria and brachiolaria of Asterias.	
February	Asterias larvae and pagurid larvae become abundant	Little change in composition except those noted.
March	a) most abundant: annelid larvae: Sabellaria, Scolelepis and Polydora.	
	b) common: bipinnaria and brachiolaria	
	c) forms declining: actinotrocha; pilidia; actinian planulae; pagurid zoeae and glaucothoe; and barnacle larvae.	
	d) forms that disappear: echiuroid trochophores; glycerid larvae; nephtyid larvae.	
	e) forms that first appear: Spiophanes	
April	a) most abundant: Nassarius veligers; barnacle larvae; and annelid larvae: Polydora, Spiophanes, Streblospio, eunicid.	Initiation of breeding season for a number of species.

TABLE V-29, cont.

Month	Relative Abundance/Nature of Change	Remarks
	b) common: actinian planulae; pilidia; Bugula larvae; actinotrocha; Crepidula veligers; Pagurid zoea bipinnaria; tornaria; and Sabellaria larvae.	
	c) forms that first appear: Chaetopterus, Nereis, Scololopis and Phyllodoce among annelids; Palaemonetes, Upogebia, Polyonyx, Uca, Pinnotheres maculatus, and Pinnixa chaetopterana among the decapods; adult sexual stages of Autolytus and other syllids found in the plankton.	
May	a) abundant: Nereis, Uca, Nassarius and barnacle larvae	Further burgeoning of planktonic larvae.
	b) common: actinian planulae; pilidia, Bugula larvae; actinotrocha; epicarid isopods (parasitic on copepods); Asterias bipinnaria; Moira plutei; Leptosynapta larvae; tornaria; and annelid larvae Polydora, Scolelepis, Spiophanes, Streblospio, Sabellaria, Chaetopterus, Phyllodoce, other phyllodocids and polynoids.	
	c) forms increasing in abundance: all decapod larvae reported in April; protozoeae of peneids; zoeae of Alpheus, Emerita, Pinnotheres ostreum and several xanthid crabs; and megalops of Callinectes.	
	d) taken occasionally: arachnactis larva of a cerianthid; loxosomatid larvae of entoprocts; plutei of Arbacia and Mellita; larvae of brachiopod, Glottidia; larval amphioxus; Polygordius trochophora; Megelona nectochaetae; mitraria larvae and sexual syllids.	
June	a) most abundant; eggs and early tornaria of Balanoglossus; early Megelona larvae; Nereis trochophores; barnacle larvae; Bittium veligers; and zoea of Alpheus, Palaemonetes and Uca.	

TABLE V-29, cont.

Month	Relative Abundance/Nature of Change	Remarks
	b) common: actinian planulae; pilidia, actionotrocha; annelids; Chaetopterus, phyllodocids, polynoids, Sabellaria, Polydora, Prionospis, Scolelepis, Streblospio, sexual stages of syllids, Crassostrea and many unidentified veligers.	
	c) regularly taken: plutei of Mellita and Moira.	
	d) present: all decapods reported in April and May; larvae of Callianossa, Clibanarius, Hippolysmata, Periclimenes; plutei of Arbacia, Lytechinus, Ophiothrix and an unidentified ophiopluteus; Asterias bipinnaria; Pilidium brachiatum; planulae of Renilla and Leptogorgia; Lima veligers; and Squilla larvae.	
	e) forms that disappear: Spiophanes	
July	a) dominant forms reported in June joined by: Moira plutei; zoeae of Upogebia; and polychad larvae.	Types of larvae and levels of abundance similar to June except where noted.
	b) forms becoming common: loxosomatid larvae; cyphonates; terebellid larvae.	
	c) forms declining: leptosynaptid larvae	Types of larvae similar to previous months except for a decline in levels of certain groups.
August	a) most abundant forms: loxosomatid larvae; barnacle larvae; plutei of Mellita and Moira; zoeae of Alpheus, Palaemonetes, Polyonyx and Uca.	
	b) common forms: those reported as abundant or common in previous months.	

TABLE V-29, cont.

Month	Relative Abundance/Nature of Change	Remarks
	c) forms declining: Magelona, polynoid, and Scolelepis larvae.	
	d) forms that disappear: phyllodocid larvae and glaucothoe.	
	e) forms that first appear: sipunculid larvae.	
September	a) most abundant: barnacle larvae; plutei of Moira and Ophiothrix; larval spionids and Sabellaria; Uca zoea; and Callinectes megalops.	
	b) forms declining: epicarid isopods; actinian planulae; loxosomatid larvae; polyclad larvae; Nereis larvae and most decapod larvae.	
	c) forms that disappear: alcyonarian planulae; actinotrocha; Polygordius trochophores; mitraria; polynoids; amphioxus larvae; Clibanarius and xanthid crab zoeae.	
	d) forms that first appear: the pteropod Creseis; and larvae of Leptosynapta.	
October	a) most abundant: barnacle larvae; Callinectes megalops; Ophiothrix plutei; ascidian tadpoles; Sabellaria nextochaetae; larval spionids.	
	b) common: larval Creseis; cyphonautes; sergestid protozoea; Moira plutei; and ophiopluteus.	
	c) forms that disappear: most decapod larvae: Callianassa, Emerita, Uca, Alpheus, Hippolysmata, Upogebia, xanthid zoeae; and Squilla.	
	d) forms that first appear: actinotrocha; pilidia; mitraria; and Magelona.	

TABLE V-29, cont.

Month	Relative Abundance/Nature of Change	Remarks
November	a) most abundant: actinian planulae; pilidia; Polygordius trochophores; Magelona larvae; barnacle larvae; and asidian tadpoles.	Mixture of lingering summer and the burgeoning new winter populations.
	b) summer forms still common: Ophiothrix and Moira plutei; Anomia veligers; Polyonyx, Callinectes, and Pinnixa chaetopterana.	
	c) winter forms becoming common: nephtyid larvae; loxosomatid; cyphonautes; actinotocha; mitraria and pagurid zoeae and glaucothoe.	
	d) forms that disappear: sergestid protozoeae; Hippolyte, Palaemonetes, Periclimenes, and Pinnotheres maculatus zoeae; larval Creseis; veligers of Lima; and plutei of Arbacia and Mellita.	
December	a) most abundant: actinian planulae; pilidia; Polygordius trochophores; Magelona; nephtyid metatrochophore; and barnacle larvae.	
	b) common: loxosomatid larvae; Bugula larvae; echiuroid trochophores; cyphonautes; actinotrocha; mitraria; Sabellaria; pagurid zoeae and glaucothoe; bipinnaria; and tornaria.	A few scattered elements of the summer plankton remained but by the end of December, the plankton had acquired a definite winter character.
	c) forms that disappear: Leptosynapta larvae; and remaining forms.	

presented by McCrary (1969) for the zooplankton of Wrightsville Sound, North Carolina.

Copepods numerically dominated the zooplankton communities throughout the year. Table V-11 shows the seasonal occurrence of the major species of copepods studied by McCrary. Many of the species were observed throughout the year, but qualitative observations indicated seasonal trends in abundance. Thayer et al. (1974) reported an apparent decrease in the abundance of certain species of copepods (Acartia tonsa, Centropages sp., Euterpina acutifrons, and Temora turbinata) during the spring due to the predation of larval fish. McCrary also observed a decrease in the abundance of most of these species, possibly due to the same mechanism. Paracalanus (Parvocalanus) crassirostris was present and abundant throughout the year, a trend similar to the lack of seasonality reported by Lonsdale and Coull (1977). Oithona spp. are cyclopoids that are fairly abundant throughout the year in most estuarine areas. Peters (1968), and Lonsdale and Coull (1977) reported low abundance of Oithona spp. during the spring. McCrary identified the spring as representing a period of replacement of the predominant winter species, Oithona nana, by the summer species, Oithona colcarva (brevicornis). Pseudodiaptomus coronatus was observed throughout the year but was seen to be particularly abundant in the spring and summer by Lonsdale and Coull (1977) and in the fall by McCrary (1969). Saphirella spp., Labidocera aestiva and Oncaea venusta were spring and summer species (McCrary, 1969; Lonsdale and Coull, 1977).

In considering other holoplanktonic forms, cladocerans were only periodically abundant in the estuarine plankton. Podon spp. were abundant in the winter (Peters, 1968; McCrary, 1969, see Table V-10) while Evadne tergestina and Penilia avirostris were abundant in the summer. Chaetognaths (primarily Sagitta hispida) and ctenophores (primarily Mnemiopsis) were most common during the summer, although the chaetognaths could be found throughout the year (McCrary, 1969; Lonsdale and Coull, 1977).

Decapod larvae were generally found in the zooplankton of estuarine and coastal waters during the spring and summer months (McCrary, 1969, see Table V-12; Dudley and Judy, 1971, see Tables V-17, V-18, V-19; and Lonsdale and Coull, 1977). Some of the decapod species restricted breeding to a few summer months (e.g. Clibanarius vittatus), while others exhibited an extended range from spring through fall (e.g. Palaemonetes sp.) (McCrary, 1969). Commensal or parasitic decapods (e.g. Polyonix gibbesi, Pinnixa chaetopterona and Pinnotheres ostreum) proved to be the exceptions to the general trend of warm weather seasonality, exhibiting extended breeding from early spring through the winter months.

In considering other meroplankton, polychaete larvae were moderately abundant in the zooplankton throughout the year (Peters, 1968; Lonsdale and Coull, 1977), but different species appear to occur at different times (McCrary, 1969, see Table V-9). While bivalve larvae were generally not identified to species, most were found to have a summer peak of abundance (Peters, 1968; McCrary, 1969; Lonsdale and Coull, 1977). Gastropods were also not identified, but most species appeared to have peak breeding activities in the late spring (McCrary, 1969; Lonsdale and Coull, 1977). Barnacle larvae were abundant throughout the year (Peters, 1968; Lonsdale and Coull, 1977), but McCrary (1969) reported that at least seven species were known in North Carolina waters, so it is quite likely that seasonality could be demonstrated if the larval forms of the species had been taxonomically identified. Among echinoderms, ophiopluteus and echinopluteus larvae appeared to be strictly summer forms (Lonsdale and Coull, 1977), but the asteroid Asterias forbesi breeds during the winter months (McCrary, 1969, see Table V-13). Finally, the coelenterate medusae were most abundant during the summer, even though some species apparently spawned throughout the year (Table V-7).

As previously pointed out, very little seasonal variation has been noted in the standing crop of zooplankton communities of offshore waters (Clarke, 1940; Grice and Hart, 1962). Bsharah (1957) did note, however, that the biomass of the zooplankton of the Florida current peaked in the spring. The exact cause of this seasonality was not identified, but it was suggested that it could represent a periodic change in the current system or a true biological cycle similar to that previously reported for zooplankton communities from the waters off Bermuda (Moore, 1949).

2.3 Relationships to Physio-chemical Parameters

2.3.1 Temperature Relationships

Temperature is one of the most important environmental factors that may affect marine organisms. Thermal effects are particularly important for planktonic forms because they lack the mobility required to avoid areas with adverse temperatures. Recently, the thermal additions by industrial cooling systems have become of particular concern to ecologists, so thermal tolerance and entrainment (the passage of the planktonic organisms through the condensers) studies have become quite common. It was, therefore, quite surprising that relatively few investigations into the relationship between zooplankton and temperature could be found for the inventory area.

Vernberg and Vernberg (1970) examined the lethal thermal limits for larval and adult stages of species to the north and south of Cape Hatteras, North Carolina. Table V-30 shows the results of the lower thermal lethal limits studies. The larvae of northern faunal assemblages were generally more resistant to low temperatures than the larvae of species taken from a reeflike formation south of the Cape in the Gulf Stream. Temperature, therefore, was proposed to be a major environmental factor in limiting the distribution of marine animals found in the vicinity of Cape Hatteras. Of interest to an understanding of larval transport was the finding that the larvae of some southern species were more tolerant to low temperatures than the adults. It was suggested that this physiological capability would allow larvae of the southern species to survive if temporarily entrained into colder currents.

Hoss, Coston, Baptist and Engel (1975) examined the effects of temperature and other factors on larval fish exposed to simulated entrainment conditions. In the thermal tolerance experiments, it was found that a cycling acclimation temperature reduced the effects of thermal shock on larval pinfish (Lagodon rhomboides) collected near Beaufort, North Carolina (see Figure V-12). Synergistic effects of chlorine or copper with high temperature were seen to reduce the ability of larval fish to survive the thermal shock of entrainment.

2.3.2 Salinity Relationships

Physiological ecologists have long recognized the importance of salinity to marine and estuarine organisms. Surprisingly, no published studies on the effects of salinity on zooplankton could be found for the inventory area since 1973.

Hopper (1960) studied the effects of salinity changes on open water zooplankton from South Atlantic waters. Table V-31 shows the range of salinities tolerated by major zooplankton groups in order of decreasing resistance. All of the forms through the copepods on the list were seen to be able to withstand much greater salinity changes than they would be expected to encounter in their normal environment of the open ocean. Hopper therefore suggested that salinity may not be a limiting factor in the distribution of these forms. It must be noted, however, only short-term acute effects were examined by this study, so no definite statement can be made concerning the significance of subtle sublethal effects of salinity in limiting distribution.

Vernberg and Vernberg (1970) examined the salinity tolerance of larval stages of species taken from waters to the north and a

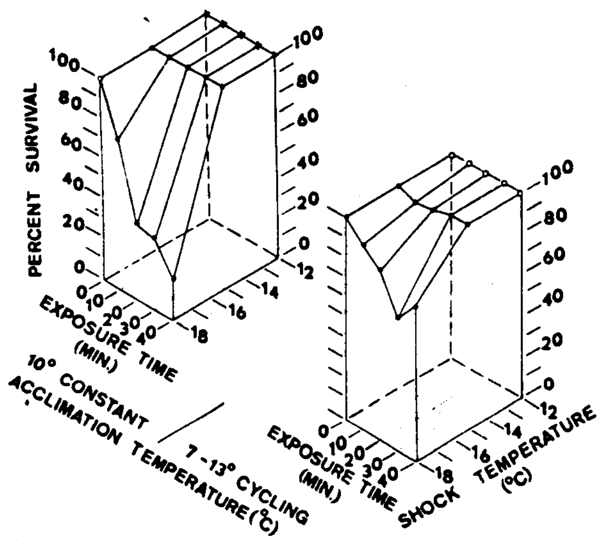

FIGURE V-12. Percent survival 24 hours after thermal shock of larval pinfish acclimated to a constant 10°C and a cycling 7-13°C. X indicates points from previous experiments (5). Open circles are estimated points. Each closed circle represents an average of 21 fish. The average wet weight of the fish was 24 mg (from Hoss et al., 1975).

TABLE V-30. Low temperature tolerance of first stage zoea in $30^{o}/_{oo}$C seawater. (from Vernberg and Vernberg, 1970).

Area and Species	Response
Cape Hatteras region _Cancer irroratus_	Zoea survived and were very active after 24 hours at 4°C
Reef region _Micropanope sculptipes_ _Microphrys antillensis_	Died within 3 to 4 hours at 4°C. At 10°C zoea were inactive but, if returned to room temperature after 24 hours, all recovered.
Caribbean region _Podochela gracilipes_ _Osachila tuberosa_ _Micropanope sculptipes_	Same response as reef animals

TABLE V-31. Salinity tolerance of open ocean zooplankton. (from Hopper, 1960).

Form	Maximum % salinity change allowing survival time as long as controls
Barnacle	-50 to ?
Brachyuran larvae	-20 to +20
Natantia	-20 to +15
Natantia (Lucifer)	-20 to ?
Annelida	-20 to +8
Sagitta	-18 to +3
Amphipoda	-15 to +5
Copepoda	-7 to +5
Euphausiacea	-2 to +2
Hydrozoan medusae	---
Tunicata	---

reeflike formation in the Gulf Stream to the south of Cape Hatteras. In general, the larvae of the northern species exhibited much greater tolerance to reduced salinity than the larvae of reef species (Table V-32). The investigators noted, however, that the northern species were more typical of inshore waters while the reef species were characteristic of offshore waters. The difference in salinity tolerance between the larvae taken from each area may not have been associated with latitude, but, instead, may have reflected a contrast between oceanic and coastal species. The larvae of inshore species would be much more likely to encounter a wide range of salinities than would oceanic forms, so the observed differences in resistance appear to be adaptive.

2.3.3 Relationships to Other Physio-chemical Parameters

Environmental factors other than temperature and salinity can have major effects on zooplankton communities. As previously discussed, hydrographic conditions, tidal flushing rates, and wind-driven current patterns can influence zooplankton community structure, abundance, and distribution. Other physio-chemical parameters undoubtedly affect the zooplankton, but this research area appears to be poorly studied for the zooplankton of the inventory area. Only two studies could be found that investigated the effects of natural physio-chemical conditions on zooplankton, and both were published prior to 1973.

Moore and Foyo (1963) examined the effects of temperature, illumination, and pressure in controlling vertical distribution of copepods of the Gulf Stream. Sensitivity of copepods to each of these factors was evaluated in terms of the tendency of change in condition to elicit vertical migratory behavior. The shallow-living species were the most responsive to temperature changes, while the deep-living were the least. On the other hand, deep-living species exhibited greater sensitivity to illumination changes than shallow species. A similar trend was noted within species of wide vertical range: temperature sensitivity decreases downwards through the population while illumination sensitivity increases. Although pressure was not specifically examined, it was speculated that pressure sensitivity was inversely related to the depth at which the species was found.

Teal (1971) examined the effects of pressure and temperature on the respiration of vertically migrating mesopelagic decapod crustacea from the Sargasso Sea. The respiration rates of the carideans *Oplophorus spinosus*, *Parapandalus richardi*, *Acanthephyra purpurea* and *Systellaspis debilis* and the penaeid *Sergestes crassus* were measured under various temperature and pressure

TABLE V-32. Survival of first stage zoea at various salinities (Vernberg and Vernberg, 1970).

Species	Temp. (°C)	Salinity (°/oo)	Survival
REEF AREA			
Pinnotheres maculatus	25	20	50% dead within 21 h.
		25	moderately active after 48 h.
		30	very active after 48 h.
Mithrax acutifrons	20	10	all dead within 17 h.
		20	all dead within 17 h.
		30	very active after 48 h.
Dromidia antillensis	20	10	all dead within 17 h.
		20	all dead within 17 h.
		30	very active after 48 h.
Osachila tuberosa	20	10	all dead within 16 h.
		20	all dead within 16 h.
		30	very active after 48 h.
CAPE HATTERAS AREA			
Cancer irroratus	20	10	inactive after 1 1/2 h. all dead within 22 h.
		20	moderately active after 48 h.
		30	very active after 48 h.
Hepatus epheliticus	25	10	all dead within 24 h.
		20	moderately active after 24 h.
		30	very active after 24 h.

conditions. Respiration rates of all species were directly related to both temperature and pressure. These results indicate a tendency for metabolism to remain relatively constant with depth, the decrease due to lower temperature offset by an increase due to rising pressure (Figure V-13). A previous study (Teal and Carey, 1967) reported that the euphausid Thysanopoda tricuspidata exhibited respiration rates that were inversely related to pressure (Figure V-13). It was speculated that epipelagic herbivores/detritivores such as the euphausids can save energy by the slowing of metabolism that occurs as they migrate into the cold temperatures and high pressures of deep water during the day. The mesopelagic decapods, on the other hand, are predators that follow the epipelagic prey through their diurnal migrations. It was speculated that these forms have evolved a respiratory response to pressure and temperature that allows a constant metabolism throughout their depth range, so that they remain effective predators by day as well as night. Similar metabolic patterns might be expected by other epipelagic and mesopelagic species that undergo extensive diurnal migrations.

2.3.4 Synergistic Effects

Interactions of natural and/or artificial factors quite often cause effects on aquatic organisms that are much more drastic than would be predicted from an additive response to the actions of all agents considered separately. Most of the governmental regulatory agencies now recognize the importance of synergistic effects and suggest that bioassay or other physiological experiments be run under a range of possible natural conditions. During the 1960s a lot of research was done by the investigators at the Duke Marine Laboratory in Beaufort, North Carolina to determine the effects of the temperature-salinity interaction on larval crustaceans (see Section 1.1.3). Mass culture techniques and response surface (contour graph analysis) methodologies were developed and refined during this work. It is surprising that little of this type of experimental design has been applied to the study of synergistic effects of environmental factors on the zooplankton of the inventory area since 1973.

Hoss et al. (1975) reported on the synergistic effects of temperature-chlorine, temperature-salinity and temperature-copper-salinity combinations on larval fish. Larval pinfish Lagodon rhomboides acclimated to 10 percent salinity had similar survival rates to those acclimated at 30 percent when exposed to thermal shock (Figures V-14-A, V-14-C). The thermal resistance of the larvae was reduced, however, when they were acclimated to water with 1 ppm copper prior to thermal shock (Figures V-14-B, V-14-D). Chlorine affected the survival of larval flounder Paralichthys

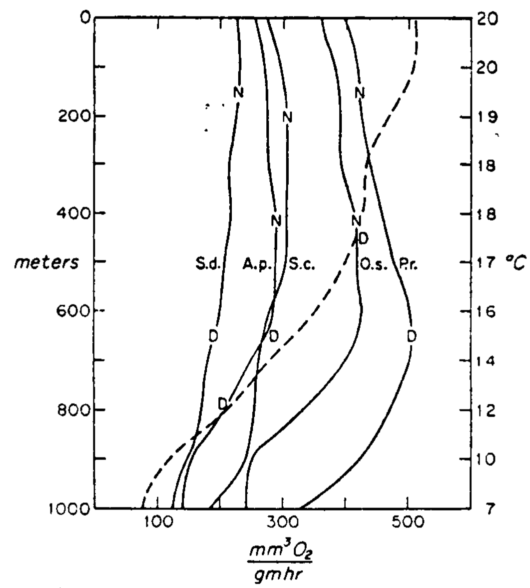

FIGURE V-13. Respiration of vertically migrating decapods in the Sargasso. Systellaspis debilis (S.d.), Acanthephyra purpurea (A.p.), Sergestes crassus (S.C.), Oplophorus spinoisus (O.s.), Parapandalus richardi (P.r.). Dashed line is respiration of euphausid Thysanopoda tricuspidata (Teal and Carey, 1967). N-position of nighttime population maximum, D-daytime population maximum from Foxton (1970) (from Teal, 1971).

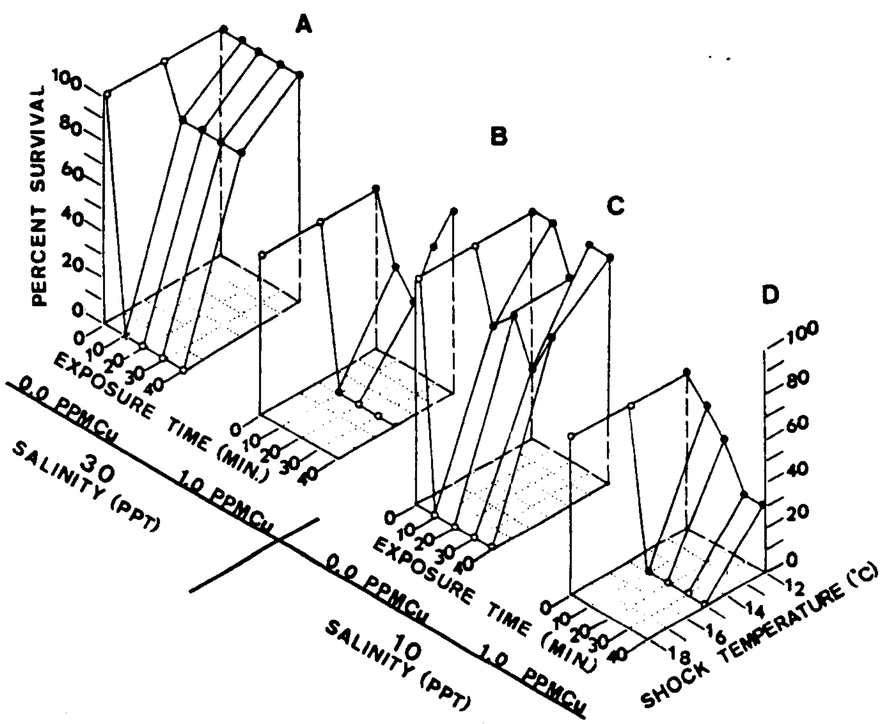

FIGURE V-14. Percent survival of larval pinfish 24 hours after subjection to combinations of thermal shock and increased copper (1.0 ppm) in the water. Fish acclimated to 15°C. X indicates points from previous experiments (5). Open circles are estimated points. Closed circles represent an average of 10 fish. The average wet weight of the fish was 32.8 mg (from Hoss et al., 1975).

sp., menhaden *Brevoortia tyrannus*, and mullet *Mugil cephalus* at ambient and elevated temperatures (Figures V-15, V-16, V-17). Synergistic effects of chlorine and temperature were suspected for the larvae of all three species, but simultaneous testing of temperature, chlorine, and the temperature-chlorine interaction was performed only for the mullet. The experiments with the mullet larvae confirmed that the interaction between heat and chlorine was synergistic (Figure V-17).

2.4 Energy Pathways: Metabolism, Nutrient Cycling, Trophic Relationships, and Production

Recently, a great deal of research has been done on the metabolism, nutrient cycling, trophic relationships, and secondary production of the zooplankton community. Much of the work, however, has been done outside of the inventory area. These investigations do provide a considerable amount of information concerning the energy/nutrient flow through the zooplankton, as well as the methodologies for studying the subject; so some of the major references will be listed in Section 4.0.

The most comprehensive study of energy and nutrient flow through zooplankton communities of the inventory area was done by Smith (1975). Zooplankton from the Beaufort Estuary, the nearshore and the offshore continental shelf waters of North Carolina were tested to determine their role in the cycling of nitrogen in each area. The amount of zooplankton ammonia released only supplied approximately ten percent of the phytoplankton ammonia and total nitrogen demand in the Beaufort Estuary (Figure V-18). Data on the ammonia release by individual species exposed to various environmental conditions are too extensive to include in this review, but values for *Centropages furcatus* populations (ca. 10 mg m^{-3} day^{-1}) were highest, with most species having rates closer to 1 mg m^{-3} day^{-1}. Urea formation and release by zooplankton in the estuary appeared to be a function of feeding state. Starved copepods released urea and ammonia in a relatively constant 1:5 ratio, while recently fed or feeding copepods released more urea relative to ammonia release (Table V-33). It was suggested that urea could be a much more important excretory product to the nutrient flow of the estuary than previously believed. In addition, the urea:ammonia release ratio was proposed to be a potentially useful index to the recent feeding history of freshly captured zooplankton.

During the course of the Beaufort Estuary investigation, carbon incorporation rates of *Centropages typicus*, *C. hamatus*, *C. furcatus*, *Labidocera aestiva*, *Pseudodiaptomus coronatus* and an unidentified pontellid copepod were determined (Table V-34).

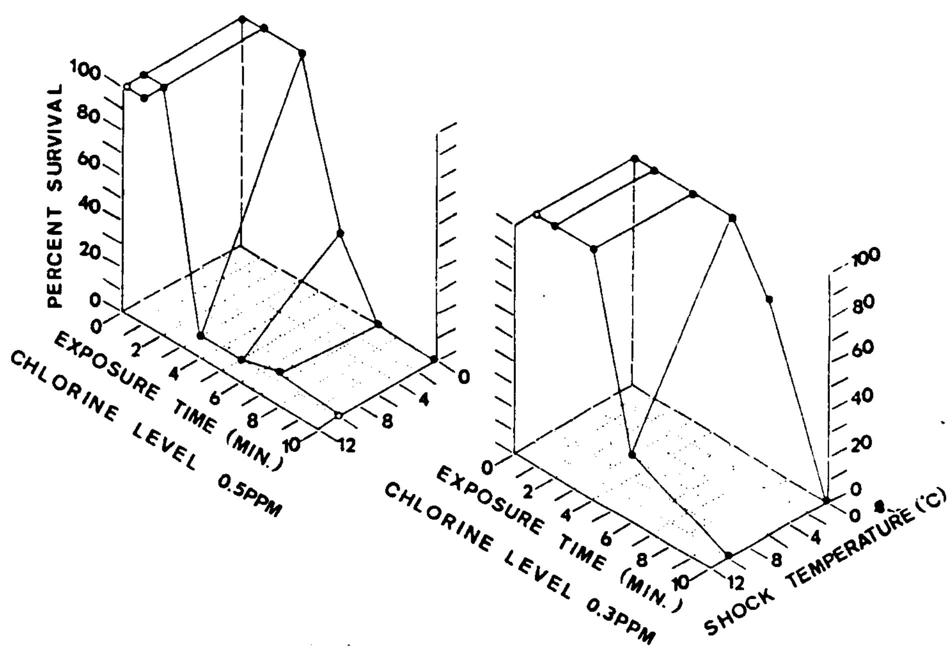

FIGURE V-15. Percent survival of larval flounder 25 hours after subjection to combinations of thermal shock and chlorine. Fish acclimated to 15°C. Open circles are estimated points. Closed circles represent an average of 10 fish. The average wet weight of the fish was 22 mg. (from Hoss et al., 1975).

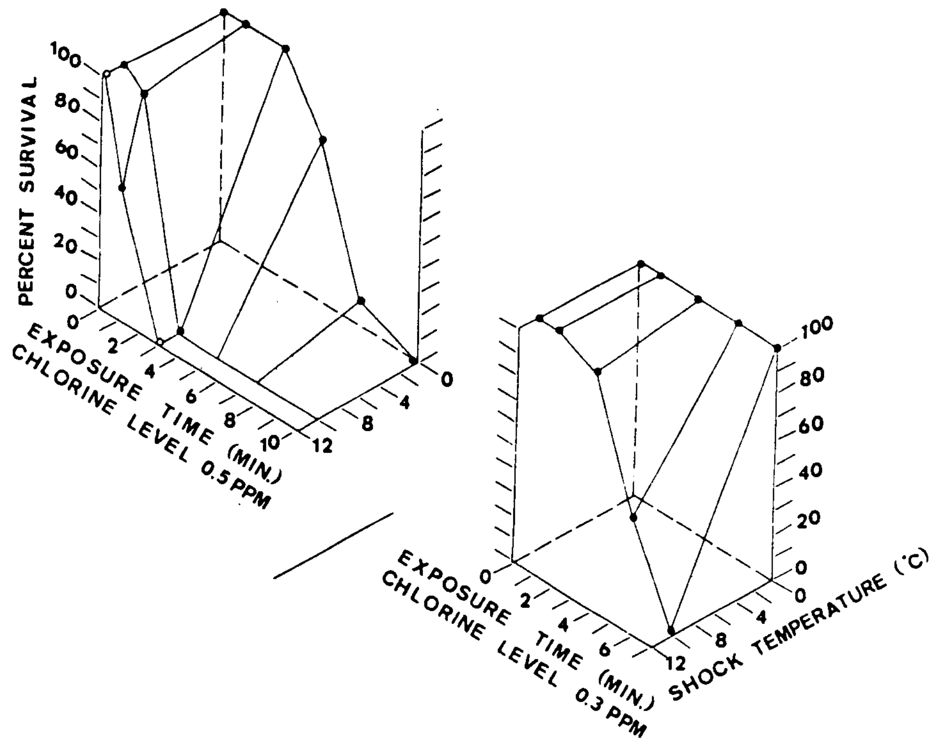

FIGURE V-16. Percent survival of larval menhaden 24 hours after subjection to combinations of thermal shock and chlorine. Fish acclimated to 15°C. Open circles are estimated points. Closed circles represent an average of 10 fish. The average wet weight of the fish was 46 mg. (from Hoss et al., 1975).

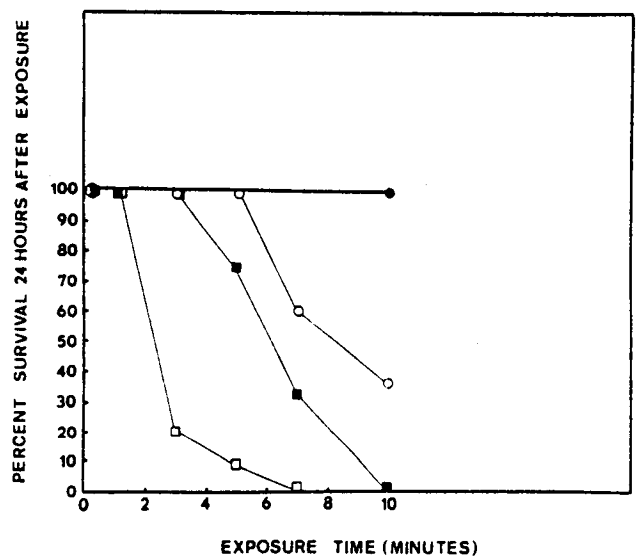

FIGURE V-17. Percent survival of juvenile mullet 24 hours after subjection to combinations of thermal shock and chlorine. Fish acclimated to 24°C. Closed circles represent a 10°C thermal shock alone. Open circles represent exposure to 0.3 ppm of chlorine alone. Closed squares represent exposure to o.3 ppm chlorine plus a 10°C thermal shock. Open squares represent exposure to 0.5 ppm chlorine plus a 10°C thermal shock. The average number of fish per point was 11. The average wet weight of the fish was 392 mg. (from Hoss et al., 1975).

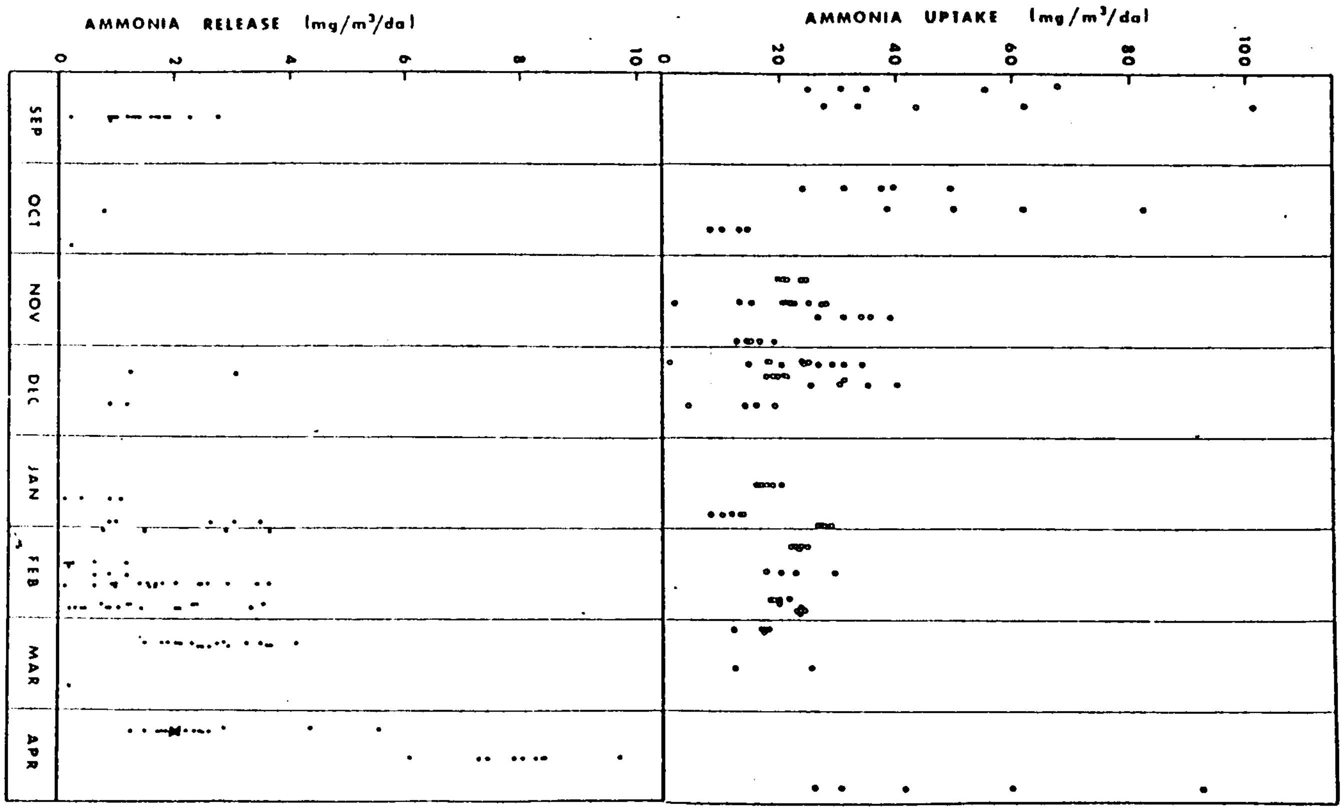

FIGURE V-18. Ammonia nitrogen uptake by phytoplankton and ammonia nitrogen release by zooplankton in the estuary during eight months of the year. Lines connect the mean value for each month (from Smith, 1975).

TABLE V-33. Zooplankton urea nitrogen release to ammonia nitrogen release ratios measured in the estuary. (from Smith, 1975).

Species	Feeding Status	Urea Release: Ammonia Release
Centropages typicus	Fed	0.99
" "	Fed	1.88
Centropages hamatus	Fed	2.04
" "	Fed	0.80
" "	Fed	1.20
Centropages furcatus	Fed	0.98
" "	Fed	0.50
" "	Fed	0.66
Labidocera aestiva	Fed	2.49
Pontellid, unidentified	Fed	1.36
Centropages typicus	Starved	0.11

TABLE V-34. Carbon incorporation by six species of copepod measured after 24-hour incubation in ^{14}C labelled phytoplankton (Smith, 1975).

SPECIES	N	$\bar{X}$	Standard Deviation
Centropages typicus	44	1.245	0.918
Centropages hamatus	8	1.259	0.912
Centropages furcatus	7	0.309	0.072
Labidocera aestiva	3	0.480	0.249
Pseudodiaptomus coronatus	2	0.796	0.905
Unidentified pontellid	10	0.407	0.223

Table V-35 compares the mean carbon incorporation for *Centropages typicus* with the other five copepod species. The carbon incorporation by *Centropages typicus* was not significantly different from that found for *C. hamatus* and *Pseudodiaptomus coronatus*. *Labidocera aestiva*, *Centropages furcatus* and the pontellid had significantly lower carbon incorporation rates when fed phytoplankton, suggesting that they may be mainly predatory in nature. The grazing estimates for the major species of copepods tested in feeding experiments are shown in Table V-36. The percentage of the daily primary production utilized by the copepods of the estuary ranged from less than 1 percent to over 38 percent.

The second investigation conducted by Smith (1975) examined the role of zooplankton in the nitrogen dynamics of continental shelf (both inshore and offshore) waters of North Carolina. Data on the zooplankton, phytoplankton, and nutrient levels were collected for the waters of Raleigh Bay and Onslow Bay and the nitrogen release rates of the plankters were experimentally tested. The nitrogen regeneration by zooplankton was greater offshore than nearshore (Table V-37) because of greater water column depth and the increased specific release by offshore forms. The nitrogen release:nitrogen demand ratio indicated that zooplankton offshore supplied relatively more nitrogen for phytoplankton primary productivity than did zooplankton nearshore. A conceptual model was proposed to describe zooplankton-phytoplankton interactions of nearshore, mid-shelf, and offshore waters (Figure V-19, Table V-37). In inshore waters, the zooplankton graze approximately half of the daily nearshore primary production, but zooplankton nitrogen release provides less than 10 percent of the total demand of the phytoplankton. Nonetheless, the phytoplankton standing stocks are relatively large because shallow water depth keeps phytoplankton in the euphotic zone and permits effective nitrogen regeneration from the benthos as well as the zooplankton and fish. Offshore, increased water depth restricts nitrogen regeneration to zooplankton input during vertical migration and excretion by some of the nekton. Zooplankton is not only important to the phytoplankton community in the regeneration of the nitrogen required, but also in the cropping of most or all of the primary production in these offshore waters. In the mid-shelf area, a depth-dependent, quasi-steady state was predicted for the zooplankton-phytoplankton interactions: zooplankton grazing, nitrogen regeneration, and phytoplankton growth are balanced.

TABLE V-35. Statistical comparison of carbon incorporation by *Centropages typicus* with carbon incorporation by five other copepod species (Smith, 1975).

SPECIES	Degrees of Freedom	t	Significance at 95%*
Centropages typicus vs. *Centropages hamatus*	50	0.040	N.S.
Centropages typicus vs. *Pseudodiaptomus coronatus*	44	0.685	N.S.
Centropages typicus vs. *Centropages furcatus*	49	6.638	S
Centropages typicus vs. *Labidocera aestiva*	45	3.844	S
Centropages typicus vs. unidentified pontellid	52	5.372	S

*N.S. = not significant; S = significant

TABLE V-36. Zooplankton grazing estimates for the Beaufort Estuary (from Smith, 1975).

Month	Copepod Species	(1) Copepod Abundance[a] (number·m^{-2})	(2) Mean Copepod Grazing Rate[b] (μgC·individual^{-1}·day^{-1})	(3) Range Copepod Grazing Rate[b]	(4) Estimated Copepod Fecal Production Rate[c] (μgC·ind^{-1}·day^{-1})	(5) Estimated Primary Production[d] (mgC·m^{-2}·day^{-1})	(6) Estimated Daily Grazing Rate by zooplankton [(2)+(4)]x(1)	(7) % (6)x100 / (5)
Sep	*Centropages furcatus*	8,400	0.039	0.25 - 0.44	0.433	496	6	1
Oct	*Pseudodiaptomus coronatus*	16,800	0.796	0.156-1.436	1.114	84	32	38
Nov	-	19,200	-	-	-	-	-	-
Dec	*Centropages hamatus*	8,760	0.044	0.044	0.062	250	1	<1
Jan	*Centropages hamatus*	8,760	0.248	0 -0.495	0.347	112	5	4
Feb	*Centropages typicus*	6,000	1.322	0 -3.281	1.851	157	19	12
Mar	*Centropages hamatus*	9,000	1.259	0.307-2.558	1.763	125	27	22
Apr	*Centropages typicus*	13,560	0.278	0 -0.509	0.389	(125)	9	(7)

[a] from Thayer et al. (1974)

[b] from Appendix 2

[c] calculated from ratios of Butler, Corner and Marshall (1970)

[d] from Thayer (1969)

TABLE V-37. Zooplankton and phytoplankton data collected on the N. C. continental shelf (Smith, 1975).

	1972 Near-shore	1972 Off-shore	1973 Near-shore	1973 Off-shore	1974 Near-shore	1974 Off-shore
(1) Phytoplankton standing stock[a] ($mgN \cdot m^{-2}$)	15.6	19.6	26.8	17.0	10.9	10.2
(2) Nitrogen primary production[b] ($mgN \cdot m^{-2} \cdot d^{-1}$)	12.9	15.6	2.4	-	49.3	31.4
(3) Zooplankton standing stock[f] ($mgN \cdot m^{-2}$)	108	594	86	455	179	614
(4) Zooplankton grazing impact[c] ($mgN \cdot m^{-2} \cdot d^{-1}$)	68.0	374.7	39.3	169.5	341.0	617.4
(5) Zooplankton grazing impact[d] ($mgN \cdot m^{-2} \cdot d^{-1}$)	4.6	25.6	2.7	16.6	23.2	42.3
(6) % $\frac{(4) \times 100}{(2)}$	527	2402	1638	-	692	1966
(7) Zooplankton nitrogen regeneration ($mgN \cdot m^{-2} \cdot d^{-1}$)	9.7[e]	53.4[e]	2.3	9.8	4.3	20.7
(8) % $\frac{(7) \times 100}{(2)}$	75	342	95	-	9	66

[a]Estimated from chlorophyll *a* measurements (Strickland, 1960; Strickland et al., 1969).

[b]Estimated from carbon primary production using a C:N ratio of 8:1 (Strickland et al., 1969).

[c]Estimated using estuary grazing data.

[d]Estimated using grazing rate from Northwest Africa.

[e]Estimated using estuary regeneration data.

[f]Estimated using wet weight:carbon ratio of Mullin (1969) and C:N ration of 8:1 (Strickland et al., 1969).

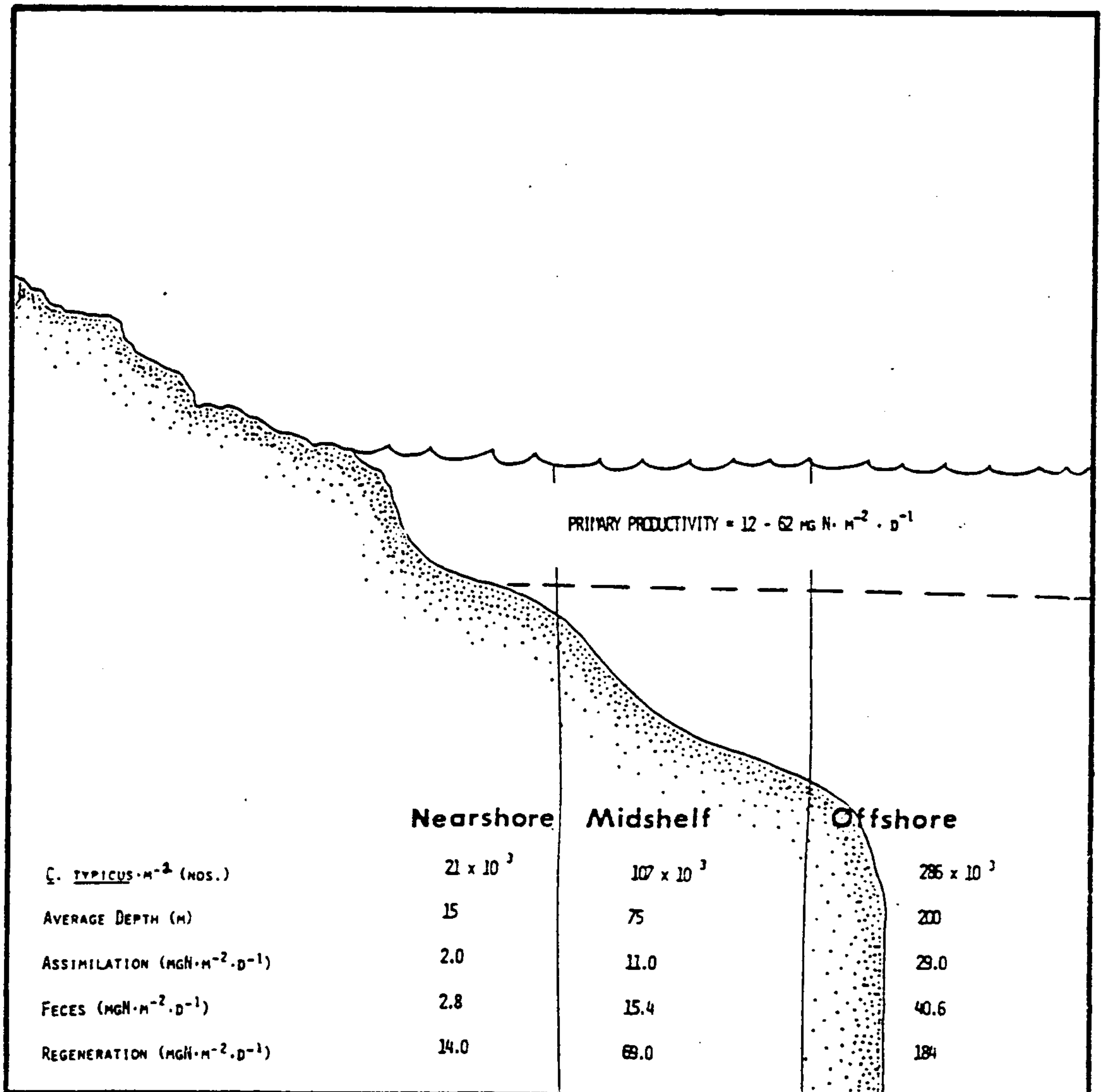

FIGURE V-19. Conceptual model of nitrogen dynamics in coastal North Carolina waters (from Smith, 1975).

To summarize the zooplankton-phytoplankton nitrogen dynamics in the systems studied by Smith (1975), the ratios of zooplankton nitrogen regeneration to total nitrogen demand by phytoplankton in the estuary and nearshore coastal areas were shown to be quite low, but quite similar to those found in other eutrophic systems (Table V-38). The offshore coastal waters were more typical of oligotrophic areas, with zooplankton regeneration providing the major nitrogen source. The phytoplankton was highest in the estuary, and moderate in nearshore and offshore continental shelf waters. The primary production was greater in nearshore waters than in the estuary or in offshore areas. Zooplankton standing crops increased from the estuary to offshore areas, as did the percent of the primary production grazed by the zooplankton. Thus, the persistence of zooplankton in the oligotrophic offshore system depends upon their phytoplankton food supply, while phytoplankton growth is supported primarily by zooplankton nitrogen release. In the eutrophic systems zooplankton compete with other communities for the phytoplankton food supply and provide relatively less of the total nitrogen demand. Smith concluded that most marine systems probably have quantitative biological characteristics which fit into a nitrogen dynamics spectrum whose boundaries are set by eutrophic and oligotrophic systems.

Alldredge (1972, 1976) studied the importance of discarded appendicularian houses to food chains of the Gulf Steam and the Gulf of California. The population densities of Oikopleuridae in the Florida Current are shown in Table V-39 and the density of abandoned appendicularian (larvacean) houses are shown in Table V-40. Alldredge (1972) observed that copepods and other crustaceans were found on the discarded appendicularian houses (Table V-40). Oncaea mediterranea (Copepoda:Cyclopoida), Microsetella norvegica (Copepoda:Harpacticoida), Paracalanus aculeatus (Copepoda: Calanoida), Conchoecia rotundata (Ostracoda) and euphausiid larvae were all observed resting and/or feeding on the discarded houses. Oncaea mediterranea was experimentally shown to be able to feed upon the houses, although it was suggested that the nannoplankton and other particulate matter clogging the filters of the discarded houses might be a major food source for other pelagic copepods. Since the discarding of houses occurs at a rapid rate (up to six times per day) and the rate appears to be directly proportional to the amount of particulate matter in the water (Figure V-20), the abandoned houses were proposed to be a previously unrecognized supplementary food source that allows higher trophic levels to assimilate effectively the energy from nannoplankton and other particulate organic matter previously considered too small or too dilute for suspension feeding (or predatory) mechanisms to capture. The houses were also suggested to be a source of

TABLE V-38. Data on zooplankton-phytoplankton interactions collected in four marine systems (from Smith, 1975).

	Phytoplankton Standing Stock[a] ($mgN \cdot m^{-2}$)	(2) Nitrogen Primary Production[b] ($mgN \cdot m^{-2} \cdot day^{-1}$)	(3) Zooplankton Standing Stock[c] ($mgN \cdot m^{-2}$)	(4) Zooplankton Grazing ($mgN \cdot m^{-2} \cdot day^{-1}$)	(5) % $\frac{(4) \times 100}{(2)}$	(6) Zooplankton Nitrogen Regeneration ($mgN \cdot m^{-2} \cdot day^{-1}$)	(7) % $\frac{(6) \times 100}{(2)}$
North Carolina Continental Shelf, Offshore	10.2	31.4	614	42[d]	1966	20.7	66
North Carolina Continental Shelf, Nearshore	10.9	49.3	179	23[d]	692	4.3	9
Newport River Estuary	16.5	36.1	2	2.6	7	7.0	19
Northwest Africa Upwelling	290.8	250.3	262	4.7	2	155.3	62

TABLE V-39. Population densities of *Oikopleuridae* in the Florida Current as determined by simultaneous Clarke-Bumpus opening-closing net tows and direct visual counting. The methods give statistically equivalent results using a t-test for paired observations (T = 1.25; P >0.25). (from Alldredge, 1976)

Date	Visual method (m^3 sampled)	Net method (m^3 sampled)	Oikopleuridae m^3 visual method	Oikopleuridae m^3 net method
4 Nov	0.43	25.34	9.9	13.7
12 Nov	0.38	20.40	30.0	31.4
17 Nov	0.42	14.66	91.3	140.6
20 Nov	0.42	22.86	14.7	29.9
24 Nov	0.26	17.10	83.3	80.4
26 Nov	0.10	20.39	100.0	148.1
20 Jan	0.20	11.37	150.0	109.4
8 Feb	0.39	13.47	84.0	74.3
16 Feb	0.29	10.78	13.7	25.0
23 Feb	0.42	8.30	49.5	50.0
24 Feb	0.18	13.00	93.0	120.0
2 Mar	0.41	8.32	9.8	10.9
4 May	0.40	4.96	7.5	7.2
M			56.4	64.7
SD			50.8	46.6
SE			14.1	12.9

TABLE V-40. Frequency of occurrence of copepods (predominantly *Oncaea mediterranea*) feeding on abandoned larvacean houses in the Florida Current. House densities were obtained by direct visual counts at depths of 10 to 15m. A Plexiglas rod grid (10 by 20 by 20cm, or 1/250m^3) held before the diver's faceplate served to delineate volume. One hundred such grids were counted on each dive; N, number of houses (from Alldredge, 1972).

Date	Abandoned larvacean houses (N/m^3)	Houses with copepods (%)
14 October 1971	114.0	13.2
19 October 1971	44.4	16.7
12 November 1971	58.9	14.3
17 November 1971	268.8	4.3
20 November 1971	74.5	5.2
24 November 1971	478.7	2.5
26 November 1971	496.0	6.5
12 January 1972	115.4	13.3
20 January 1972	603.4	10.1
8 February 1972	387.8	16.8
16 February 1972	623.0	0
23 February 1972	275.2	0
24 February 1972	399.9	9.3
30 March 1972	540.3	33.3
6 April 1972	466.5	25.7
Mean	329.8	10.7

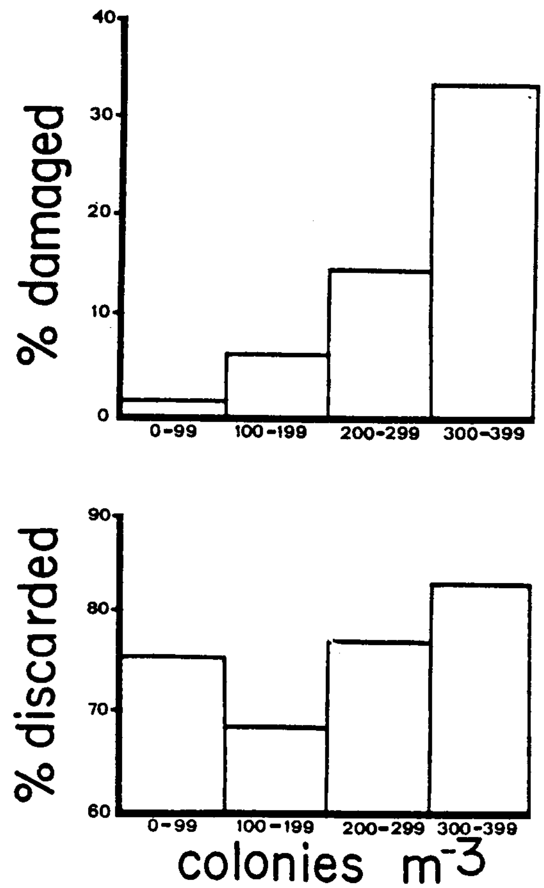

FIGURE V-20. The percentage of houses found discarded and the percentage of discarded houses found damaged by Trichodesmium as a function of Trichodesmium density in the Florida Current (from Alldredge, 1976).

particulate organic matter to the oceans, with absorption of dissolved organics and colonizatioon by microorganisms acting to increase the aggregate size and organic content. A further speculation was that the discarded houses provided sources of physical structure and spatial heterogeneity to the plankton community, which could have considerable impact on the adaptive strategies, resource partitioning, and microdistribution of the zooplankton, phytoplankton, and microorganisms of the system. Clearly, the ecology of macroscopic aggregates of zooplankton origin merits further study.

Briggs (1977) examined the respiration and ammonium excretion by open ocean gelatinous zooplankton of the tropical and subtropical waters of the Sargasso Sea. The respiration and excretion rates, as well as the oxygen:ammonium ratios for various groups of gelatinous zooplankton are shown in Tables V-41 and V-42. Ecological differences between the groups of gelatinous zooplankton contribute to differences in metabolism. Among the siphonophores (Table V-41) the cystonects had considerably lower respiration and excretion rates than the physonects, probably due to the lack of swimming bells in the former group. The calycophore siphonophores were highly variable in respiration and excretory rates, depending upon the relative activity of the particular species. Among other groups of gelatinous zooplankton observed by Biggs (1977) (Table V-42), most herbivores had high rates of respiration and excretion, especially small forms like doliolids. Cydippid and cestid ctenophores and many medusae had low rates of respiration and excretion, while muscular, active swimmers such as Pelagia noctiluca and Ocyropsis maculata had higher rates.

The oxygen:ammonium ratios varied considerably between the planktonic groups, depending upon trophic relationships. Carnivorous forms such as the medusae, siphonophores, ctenophores and heteropods generally had values ranging from eight (indicating primarily protein catabolism) to 24 (indicating catabolism of equivalent weights of proteins and lipids). In general, the ratios for the herbivorous forms were much higher, indicating a diet more dependent on lipids and carbohydrates. It was noted, however, that the siphonophore eudoxids had high oxygen:nitrogen ratios indicative of nonprotein catabolism because these reproductive forms appear to subsist on carbohydrate or lipid reserves during their relatively brief existence.

Biggs (1977) also examined the significance of gelatinous zooplankton in the cycling of nitrogen in the open ocean. Many of the larger physonect siphonophores, scyphomedusae, heteropods, and salps regenerated ammonium at rates exceeding 0.3 ug-atom NH_4^+-N h^{-1}. At average densities encountered during his study, Biggs

TABLE V-41. Respiration [$\mu l\ O_2$ (mg protein-h)$^{-1}$] and $O:NH_4^+$ ratio for siphonophores of three different sizes (from Biggs, 1977).

	Respiration [$\mu l\ O_2$ (mg protein-h)$^{-1}$]						Excretion [$\mu g\ NH_4^+$ (mg protein-h)$^{-1}$]						$O:NH_4^+$ ratio	
	0.1-1.0mg		1.1-10.0mg		10.1-100mg		0.1-1.0mg		1.1-0.0mg		10.1-100mg		all sizes	
	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S
Suborder Physonectae														
Agalma okeni	(7)	12±3.9	(46)	12±5.5	(5)	6±0.8	(3)	1.3±0.8	(15)	1.0±0.6	(4)	0.6±0.1	(22)	19±7.8
Agalma elegans	(4)	39±12.7	(3)	16±2.5	-		-		-		-		-	
Cordagalma cordiformis	(6)	27±4.0	-		-		(4)	2.5±0.7	-		-		(4)	16±1.9
Nanomia bijuga	(8)	31±5.1	(11)	14±3.3	-		(5)	1.5±0.7	(3)	1.0±0.5	-		(7)	38±20.5
Forskalia edwardsi; F. tholoides	(8)	20±7.1	(10)	17±4.7	(2)	15±0.1	(6)	1.1±0.5	(8)	1.3±0.2	-		(14)	25±8.0
Athorybia rosacea	(1)	86.2	(4)	11±2.3	(5)	5±2.3	(1)	0.9	(3)	0.8±0.2	(4)	0.7±0.2	(8)	17±14.1
Athorybia sp.	(3)	40±13.7	-		-		(1)	3.3	(2)	1.5±0.1	-		(3)	22±3.6
Suborder Cystonectae														
Bathyphysa sibogae	-		(1)	6.9	(4)	6±0.9	-		(2)	0.5±0.3	(4)	0.3±0.1	(5)	20±8.1
Rhizophysa filiformis	-		(2)	5±2.5	(6)	4±1.4	-		(2)	0.3±0.1	(5)	0.3±0.1	(5)	23± 7.6
Suborder Calycophorae														
Stephanophyes superba	(4)	22±3.2	(13)	14±6.3	-		(2)	1.8±0.4	(4)	1.1±0.6	-		(6)	22±8.1
Rosacea cymbiformis	(2)	8±3.6	(11)	8±2.5	-		(4)	0.8±0.4	(9)	0.6±0.3	-		(11)	23±10.3
Diphyes dispar	(7)	17±7.4	(4)	12±3.8	(6)	4±0.9	(2)	0.6±0.1	(3)	1.0±0.4	(5)	0.3±0.1	(10)	25±7.4
Sulculeolaria quadrivalvis	(3)	45±17.1	(6)	36±13.9	(1)	21.3	(2)	2.1±0.3	(7)	2.4±1.7	(1)	0.8	(9)	29±9.8
Sulculeolaria monoica	(7)	32±15.2	(2)	21±2.3	-		(6)	1.5±0.9	(2)	1.6±0.3	-		(7)	36±21.0
Sulculeolaria chuni	(4)	75±25.2	-		-		(4)	2.7±1.0	-		-		(4)	50±23.9
Sulculeolaria biloba	-		(2)	13±0.5	-		-		(2)	1.2±0.2	-		(2)	17±2.3
Abyla sp.	-		(3)	5±0.5	-		-		(3)	0.5±0.2	-		(3)	17±5.5
Chelophyes appendiculata	-		(5)	8±3.3	-		-		(3)	0.5±0.2	-		(3)	26±9.5
Hippopodius hippopus	(1)	17.3	(1)	3.5	-		-		-		-		-	
eudoxid phase, *Diphyes dispar*	(2)	78±20.2	-		-		(2)	1.4±0.7	-		-		(2)	121±78.7
eudoxid phase, *Ceratocymba* sp.	(1)	75.6	(1)	2.3	-		(1)	0.8	(1)	0.1	-		(2)	88±52.9

TABLE V-42. As Table V-41, but for gelatinous zooplankton, other than siphonophores, of three different sizes (from Biggs, 1977).

	Respiration [µl O_2 (mg protein-h)$^{-1}$]						Excretion [µg NH_4^+ (mg protein-h)$^{-1}$]						$O:NH_4^+$ ratio	
	0.1-1.0mg		1.1-10.0mg		10.1-100mg		0.1-1.0mg		1.1-10.0mg		10.1-100mg		all sizes	
	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S	N	Mean ± S
Hydromedusae														
Aequorea sp.	-		(3)	7±0.8	(1)	12.8	-		(3)	0.7±0.4	(1)	1.1	(4)	19±12.7
Orchistoma sp.	-		(3)	14±2.8	-		-		(3)	1.5±0.6	-		(3)	16±4.7
Cunina sp.	(5)	7±4.7	(2)	8±0.8	-		(3)	0.4±0.1	(2)	0.8±0.1	-		(5)	20±11.4
Scyphomedusae														
Pelagia noctiluca	-		(1)	16.0	(3)	16±7.7	-		(1)	0.8	(3)	1.2±0.6	(4)	23±5.4
Aurelia sp.	-		(1)	6.0	(2)	3±0.6	-		-		(1)	0.2	(1)	23.4
Ctenophora														
Eurhamphea vexilligera	(2)	21±0.9	(5)	11±2.9	-		(1)	1.0	(1)	1.2	-		(2)	22±8.5
Cestum sp.	(1)	22.6	(2)	17±3.5	-		(1)	1.1	(2)	1.0±0.1	-		(3)	27±4.5
Ocyropsis maculata	-		-		(3)	13±3.4	-		-		(3)	2.9±0.7	(3)	7±1.2
Heteropoda														
Pterotrachea hippocampus	-		(8)	19±2.5	-		-		(8)	3.0±0.9	-		(8)	13±6.1
Pteropoda: Pseudothecosomata														
Corolla spectabilis	(5)	18±2.9	(8)	16±3.0	(3)	11±2.3	-		(2)	0.2±0.1	(2)	0.3±0.2	(3)	89±37.6
Gleba cordata	-		(1)	16.5	(1)	8.7	-		(1)	0.5	(1)	0.2	(2)	54±4.6
Thaliacea														
Salpa cylindrica, solitary	(2)	55±1.4	(11)	30±6.5	-		(2)	3.1±0.6	(7)	1.8±1.1	-		(9)	31±13.6
Salpa cylindrica, aggregate	(7)	39±17.8	-		-		(7)	1.9±0.8	-		-		(7)	33±10.1
Salpa maxima, solitary	-		(3)	28±7.1	-		-		(3)	1.5±0.1	-		(5)	28±7.8
Salpa maxima, aggregate	(2)	41±1.5	(5)	14±1.9	-		-		(2)	1.2±0.1	-		(2)	18±1.8
Pegea confederata, solitary	-		(1)	35.5	-		-		(1)	0.9	-		(5)	41±14.6
Pegea confederata, aggregate	(14)	20±5.7	(7)	22±10.4	-		(11)	0.8±0.6	(5)	1.0±0.3	-		(15)	51±24.0
Thalia democratica, solitary	(6)	23±7.6	-		-		-		-		-		-	
Thalia democratica, aggregate	(9)	16±3.5	-		-		-		-		-		-	
Brooksia rostrata, aggregate	(4)	192±38	-		-		-		-		-		-	
miscellaneous doliolids	(4)	54±14.7	-		-		(3)	2.2±1.6	-		-		(6)	45±24.0

calculated that these gelatinous zooplankters would be able to supply 39 to 63 percent of the ammonium requirements of the phytoplankton community of the area. He noted that these forms would have the same excretion impact as all of the other zooplankton present in a cubic meter of water, if excretion rates for Atlantic zooplankton could be considered roughly equivalent to that found in previous studies on plankton from the North Pacific.

The nutrient recycling by gelatinous zooplankton can explain certain trends seen by Smith (1975) in the Atlantic Ocean. She reported that zooplankton (principally copepods) regenerated 66 percent of the total nitrogen demand of the phytoplankton in the oligotrophic open ocean waters off North Carolina. The conceptual model that she proposed predicted, however, that the zooplankton would regenerate more than enough nitrogen to meet the total nitrogen demand by the phytoplankton in oligotrophic waters. Smith attributed the discrepancies between the model and empirical data to be due to inaccuracies in certain basic assumptions. The recycle rates described by Biggs (1977) for the gelatinous zooplankton are of equal magnitude to that of the zooplankton community collected by Smith for excretion experiments. The combination of regeneration rates for the "net" zooplankton (i.e. those that appeared in good condition following collection with a plankton net) reported by Smith (1975) and the hand-collected gelatinous zooplankton reported by Biggs (1977) would likely equal or exceed the total nitrogen demand by the phytoplankton in offshore waters. The conceptual model by Smith (1975), therefore, may not have been inaccurate after all, but rather the nitrogen regeneration of the entire zooplankton community was not considered. A combination of collection techniques including plankton nets and hand sampling by scuba divers appears to be a fruitful approach in future work considering the nutrient/energy dynamics of the zooplankton community of the open ocean.

Several studies in the inventory area have examined the interaction between the zooplankton community and planktivorous fishes. Dixon (1975) studied the feeding habits of the vermilion snapper, Rhomboplites aurorubens, in the outer continental shelf waters of Onslow Bay, North Carolina. Table V-43 gives the results of stomach content analysis done on the vermilion snappers caught during the study. The vermilion snapper was seen to feed upon small mesopelagic organisms. Most (72.6 percent) of the food items were planktonic crustaceans smaller than 20mm in length. This estimation was felt to be conservative since the smaller forms are so fragile that they are digested rapidly. It was therefore concluded that the vermilion snapper feeds on small mesoplankton in the water column and does not substantially compete with bottom-foraging species.

TABLE V-43. Stomach contents of 15 vermilion snappers (281 to 586mm total length) collection from Onslow Bay, N.C., March 1972 to November 1972 (Dixon, 1975).

Stomach Contents	Number	Relative No. (%)	Frequency of Occurr.	Relative Freq. (%)
FISHES	7	7.4	4	26.7
Unidentified	7	7.4	4	26.7
INVERTEBRATES	88	92.6	8	53.3
Crustaceans	70	73.7	8	53.3
Copepod	7	7.4	2	13.3
Ostracod	4	4.2	1	6.7
Isopod	2	2.1	2	13.3
Rock shrimp	1	1.1	1	6.7
Euphausid shrimp	16	16.8	2	13.3
Crab, unidentified	1	1.1	1	6.7
Reptantia	1	1.1	1	6.7
Anomuran zoea	6	5.3	2	13.3
Amphipod	31	32.6	5	33.3
Stomatopod	1	1.1	1	6.7
Crustacea, unidentified	1	1.1	1	6.7
Molluscs	5	5.3	3	20.0
Squid	2	2.1	2	13.3
Gastropod	3	3.2	1	6.7
Annelids	12	12.6	1	6.7
Polychaete fragments	12	12.6	1	6.7
Sipunculid larva	1	1.1	1	6.7
TOTAL	95		15	
MISCELLANEOUS				
Egg mass			2	13.3
Algae, Ceratium	1		1	6.7
Unidentified food			3	20.0

Kjelson, Peters, Thayer and Johnson (1975) examined the food preferences, feeding intensity and chronology, gut evacuation rates, and daily rations of post-larval stages of menhaden, *Brevoortia tyrannus*; pinfish, *Lagodon rhomboides*; and spot, *Leiostomus xanthurus* from the Newport River estuary, North Carolina. Copepods composed 99 percent of the gut contents of the three fish species (Table V-44). *Acartia tonsa*, *Centropages* spp., *Temora turbinata* and *Harpacticoida* (later identified as *Euterpina acutifrons*; see Thayer et al., 1974) were the dominant species fed upon by the larval fishes. Apparently these copepods were the only zooplankters in the estuary that were of the appropriate size and present in sufficient abundance to be suitable food items. The larval stages of all three fish species had highest food content in their guts near midday (Figures V-21 through V-23). The data indicate that the larval fish have one major burst of feeding activity during the early daylight hours. The methods of capture and laboratory handling both had significant effects on the gut contents of the menhaden larvae, but not on that of pinfish or spot (Tables V-45 through V-47). Tables V-48 and V-49 show the regression equations that describe the gut evacuation rates of the three species. These evacuation rates were used in conjunction with information on chronology of gut contents to determine daily rations (Table V-50). Daily ration estimates as a percent of the fish's wet weight were: menhaden 4.9 percent, pinfish 3.5 percent, spot 4.3 percent and 9 percent. The ration estimates in terms of calories were similar to those determined from oxygen consumption measurements for spot larvae, but were lower than the estimates from oxygen consumption for menhaden and pinfish. It was proposed that more extensive sampling under varied environmental conditions and zooplankton abundance and repeated evacuation rate measurements would provide more accurate estimates of the daily rations of the fish larvae. The importance of copepods to the diets of juvenile menhaden, pinfish, and spot was obvious nonetheless.

Thayer et al. (1974) confirmed the importance of zooplankton to the diet of larval fish entering the Newport River estuary. Estimates of the energy content of zooplankton standing crop, the larval energy requirements, and the percent of the zooplankton standing crop utilized by the larval fish population are shown in Table V-51. *Acartia tonsa*, *Centropages* spp., *Temora turbinata* and *Euterpina acutifrons* appeared to be the major food items to the larval fish of the estuary. These species decreased from representing 81 percent of the biomass in early spring to 48 percent during the early summer. The greatest decrease occurred during the time of peak larval fish abundance in the estuary, indicating that the larvae have a significant effect in reducing the standing crop of certain major zooplankton species. Even

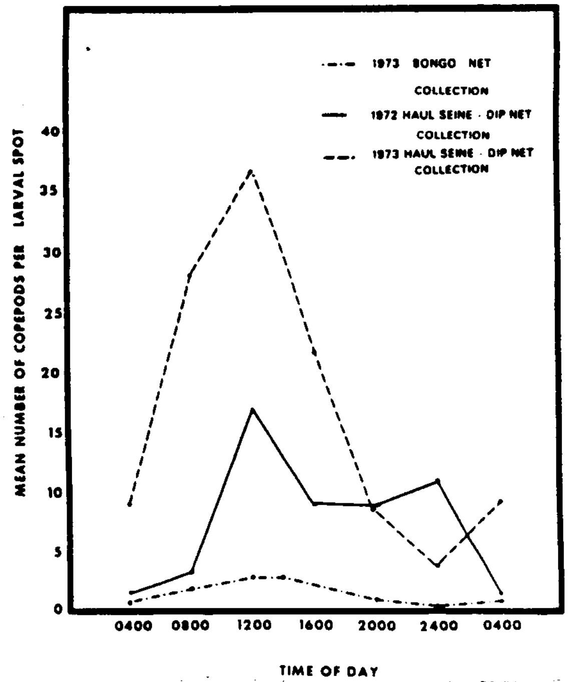

FIGURE V-21. Variation in diel cycle of gastrointestinal contents in postlarval spot (from Kjelson et al., 1975).

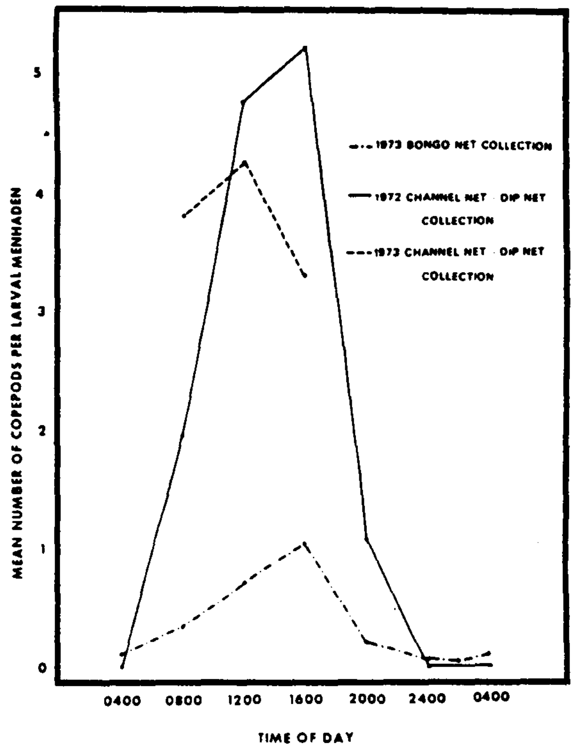

FIGURE V-22. Variation in diel cycle of gastrointestinal contents in postlarval Atlantic menhaden (from Kjelson et al., 1975).

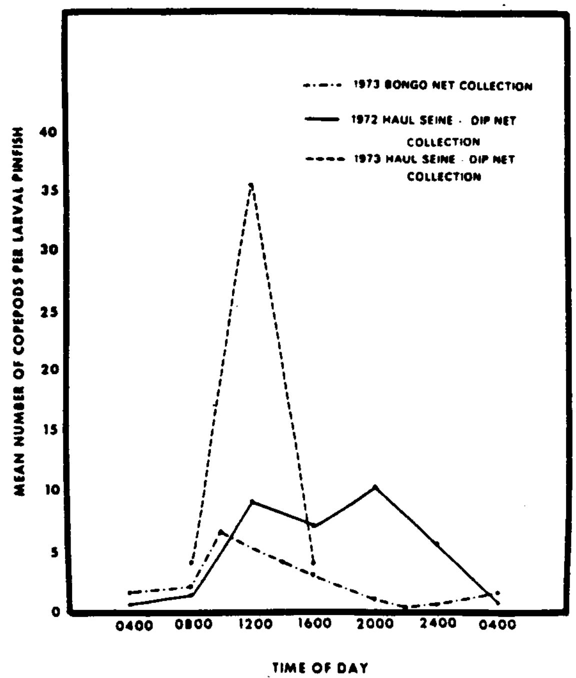

FIGURE V-23. Variation in diel cycle of gastrointestinal contents in postlarval pinfish (from Kjelson et al., 1975).

TABLE V-44. Relative (percent) composition by number of the major taxa in the total gut contents of three species of larval fish. (from Kjelson et al., 1975).

Taxa	Larval species Pinfish	Spot	Menhaden
Harpacticoida	32	32	22
Centropages	28	28	40
Temora	3	21	6
Acartia	13	8	30
Other copepods	23	10	1
Other organisms	1	1	1
Total	100	100	100

TABLE V-45. The effect of bongo net tow stress upon the amount of food observed in larval menhaden, pinfish, and spot. (from Kjelson et al., 1975).

Capture technique	Menhaden[1]	Pinfish[2]	Spot[3]
	Mean number copepods/fish ± one SE		
Channel net	7.4 ± 2	1.3 ± 0.6	6.4 ± 4.4
Channel net + bongo net tow	2.4 ± 0.7	0.8 ± 0.3	7.0 ± 2

[1]n = 22 larvae.
[2]n = 18 larvae.
[3]n = 5 larvae.

TABLE V-46. Comparison of food quantities, mean number of copepods per fish ± one SE, present in larval spot (22-33mm, $\bar{x}$ = 27mm) collected by haul seine using rough and gentle handling techniques. Ten fish were collected per sample. (from Kjelson et al., 1975).

Date	Gentle	Rough
April 2	84.5 ± 7.4	78.6 ± 5.3
April 3	69.7 ± 5.9	66.9 ± 5.5

TABLE V-47. The effects of handling on the retention of *Artemia nauplii* in digestive tracts of larval Atlantic menhaden, pinfish, and spot. Rough handling is approximately equivalent to field capture by dip net and haul seine. (from Kjelson et al., 1975).

Species (Range mm)	Experiment 1 Gentle	Experiment 1 Rough	Experiment 2 Gentle	Experiment 2 Rough
	----- Mean number ± one SE -----			
Menhaden[1] (28-32)	71 ± 15	29 ± 10	145 ± 10	76 ± 11
Pinfish[2] (16-20)	37 ± 4	34 ± 5	35 ± 9	43 ± 6
Spot[2] (19-23)	51 ± 5	47 ± 5	89 ± 7	92 ± 10

[1] n = 18 larvae per sample.
[2] n = 36 larvae per sample.

TABLE V-48. Linear regressions describing evacuation of copepods in Atlantic menhaden, pinfish, and spot larvae. $Y = A + Bt$ where $Y = \log_{10}$ (1 + mean number of copepods per larva) and t = hours since feeding. n = the number of data points. (from Kjelson et al., 1975).

Species	Mean TL (Range mm)	A	B	n	r^2	Temperature (°C)
Menhaden	29 (27-31)	1.14	-0.17	3	0.98	16
Pinfish	17 (15-20)	0.94	-0.10	3	0.86	16
Pinfish	16 (13-19)	0.68	-0.08	4	0.98	17
Spot	20	0.91	-0.10	5	0.98	17

TABLE V-49. Linear regressions describing evacuation of *Artemia nauplii* in Atlantic menhaden, pinfish, and spot larvae under varied handling conditions. $Y = A + Bt$ where $Y = \log_{10}$ (1 + mean number of *Artemia* per larva) and t = hours since feeding. n = the number of data points. (from Kjelson et al., 1975).

Species	Mean TL (Range mm)	A	B	n	r^2	Handling condition	Temperature (°C)
Menhaden	29 (27-32)	2.36	-0.28	5	0.96	Gentle	15
Menhaden	29 (27-32)	2.04	-0.34	3	0.86	Rough	15
Pinfish	16 (14-18)	1.64	-0.26	4	0.97	Gentle	16
Pinfish	16 (14-17)	1.73	-0.28	3	0.92	Rough	16
Spot	20 (18-23)	2.12	-0.19	5	0.94	Gentle	16
Spot	20 (18-23)	2.11	-0.18	5	0.95	Rough	16

TABLE V-50. Daily rations calculated from feeding studies and O_2 consumption measurements at $15^o - 17^oC$ for larval Atlantic menhaden, pinfish, and spot in the Newport River estuary, North Carolina. (from Kjelson et al., 1975).

Species (range mm)	Mean larvae wet weight (mg)	Number copepods/ fish day	Percent of body weight	Calories/ fish day	Calories/fish day estimated from O_2 consumption[1,2]
1972:					
Menhaden (27-32)	43	53	4.9	1.18	3.0
Pinfish (16-20)	32	38	3.5	0.63	1.2
Spot (17-23)	33	47	4.3	0.78	1.2
1973:					
Spot (17-23)	33	99	9.0	1.65	1.2

[1] From Hettler and Hoss, unpubl. data.
[2] 3.38 cal/mg O_2.

TABLE V-51. Estimates of zooplankton standing crop energy, daily larval energy requirements, and percent of the standing crop of zooplankton utilized to satisfy the energy requirements of the larval fish population in the Newport River estuary. (from Thayer et al., 1974).

Date	Zooplankton (cal m^{-3})	Larval energy needs (per day) (cal m^{-3})	Percent[1] utilized
January 1970	53.6	1.3	2.7
February	62.3	4.3	7.6
March	136.2	13.7	11.2
April	94.6	20.4	24.0
May	28.6	1.1	4.2
		mean	9.9

[1]Assumes a 90 percent assimilation efficiency.

though the energy content of the zooplankton community was seen as being an insignificant fraction of the total energy flow to carnivores in the Newport River estuary, it was proposed to control the survival of fishes during their transition from larvae to juveniles.

2.5 Simulation of Community Dynamics

A relatively new research area is the simulation of natural zooplankton community dynamics through experimental, mathematical, or computer models. Experimental microcosms allow the investigator to manipulate living models of natural systems to determine the effects of environmental perturbations on zooplankton community dynamics and energy flow (Beyers, 1963; Abbott, 1966). The use of large plastic bags (coined CEPEX for Controlled Environmental Pollution Experiment) to enclose components of natural systems has great promise for assessing the effects of pollution on zooplankton dynamics (Reeve, Grice, Gibson, Walter, Darcy and Ikeda, 1976). A number of methods have been proposed to mathematically or graphically estimate secondary production of natural zooplankton populations (Mullin, 1969; Winberg, 1971). These methodologies often use a combination of laboratory and field data along with hypothetical mathematical relationships to estimate energy or biomass production by the zooplankton. Analog and digital computer models have been used to simulate the dynamics and energy/nutrient flow of planktonic communities (Heinle, 1969; Kremer and Nixon, 1975) as well as entire ecosystems (Odum, 1970). These models simplify the real world to provide information concerning energy/nutrient flow, diversity and community structure dynamics, inputs and outputs from the system, and how the particular system can be stressed or disturbed. Although some research is now in progress that will utilize computer simulation to model the results of interdisciplinary ecosystem studies (see Appendix A Material Flux - Stancyk; Ecosystem Management - Kjelson), little previous work of this type could be found for the inventory area.

Odum and Chestnut (1970) reported on preliminary findings of a microcosm study designed to analyze the ecosystems that develop when treated sewage wastes are introduced into estuarine waters. One component of the program involved the monitoring of zooplankton and larval populations that become established in control and treated ponds. The ponds that were enriched with treated sewage wastes (P) had a much greater total secondary production than the control ponds (Table V-52). Copepods were quite abundant in all ponds, with reproducing populations of *Acartia tonsa*, *Pseudodiaptomus coronatus*, *Oithona* sp. and Harpacticoida dominating the plankton throughout most of the year

TABLE V-52. Total zooplankton-number per cubic meter (Odum and Chestnut 1970).

	C-1	C-2	C-3	P-1	P-2	P-3
Aug.	1,410	11	62	2,670	4,918	4,613
Sept.	4,883	45	254	4,217	59,696	12,239
Oct.	14	55	1,913	6,619	27,604	9,711
Nov.	57	2,200	2,532	7,443	2,709	27,929
Dec.	17	35	46	25	8	7,180
Jan.	76	34	23	51	12	18
Feb.	164	16,386	2,936	8,774	864	3,536
Mar.	346	15,235	550	36,106	301	2,167
Apr.	6,084	128,512	17,099	4,759	7,549	6,652
May	3,604	97,952	40,884	20,801	1,858	7,603
June	40,156	127,244	137,530	897,304	323,951	1,491,451
July	14,949	10,863	9,957	2,867,279	1,336,422	903,299

(Table V-53). Oithona sp. populations peaked during the summer months in the sewage enriched microcosms with numerical abundance soaring to millions per cubic meter and the virtual elimination of other planktonic copepods from these ponds. Palaemonetes were also successful inhabitants of the ponds, with active spawning during the summer months. Polychaete larvae (predominately Polydora ligni and Streblospio benedicti) were much more common in controls than in the treated microcosms, while Uca zoea exhibited greater abundance in the P ponds. In general, the level of diversity in the zooplankton was quite low in all ponds, but those forms which were successful were quite productive, especially in the sewage enriched ponds.

A computer model of the pond microcosm was designed to incorporate data from the various studies and simulate the energy and nutrient dynamics of the type of ecosystem that develops in sewage enriched estuarine areas (Figure V-24). The calculations of standing stock and metabolic flux for the zooplankton communities that are required for the model are shown in Table V-54. The model was not completed at the time the report was written (Odum and Chestnut, 1970), and, as far as can be determined, the final results from the project have never been published. The combination of an interdisciplinary approach and a systems model to give an overview analysis of the data does, however, hold great promise for future ecological work.

2.6 Man's Impact on Zooplankton Communities

Man's activities in the estuarine and marine environments can potentially have a great number of different effects on the zooplankton community. Unfortunately, natural sampling variability of the zooplankton often frustrates the interpretation of field data from areas impacted by pollution. There has been a recent trend, therefore, for investigators to use laboratory (bioassay) experiments and the combination of field and laboratory investigations to detect significant effects of various pollutants on zooplankton. Investigations into the effects of heavy metals, petrohydrocarbons, oil dispersants, chlorinated hydrocarbons, sewage wastes, dredge spoils, kraft process pulp wastes, and multiple industrial wastes on zooplankton have been conducted in recent years, but most research has been outside the inventory area (see Section 4.0). Though generally not as urbanized or industrialized as the Northeast, the estuaries and coastal areas of the southeastern U. S. are rapidly being developed; so it would appear that the effects of man on zooplankton communities will be a major research topic in the future.

TABLE V-53. Copepods-number per cubic meter (Odum and Chestnut 1970).

	C-1	C-2	C-3	P-1	P-2	P-3
Aug.	1,400	6	0	2,581	4,502	4,014
Sept.	4,768	0	0	4,150	59,598	12,139
Oct.	5	30	1,419	6,608	27,599	9,569
Nov.	57	1,888	2,528	7,425	2,627	27,918
Dec.	2	2	1	21	1	7,171
Jan.	3	0	1	46	1	7
Feb.	1	64	1	5,290	288	1,296
Mar.	35	0	9	16,256	96	672
Apr.	1,344	4,224	256	256	2,848	1,728
May	2,362	79,264	192	14,080	554	1,749
June	29,504	92,416	65,648	424,960	68,865	1,490,304
July	13,798	1,649	3,904	1,765,376	808,960	290,816

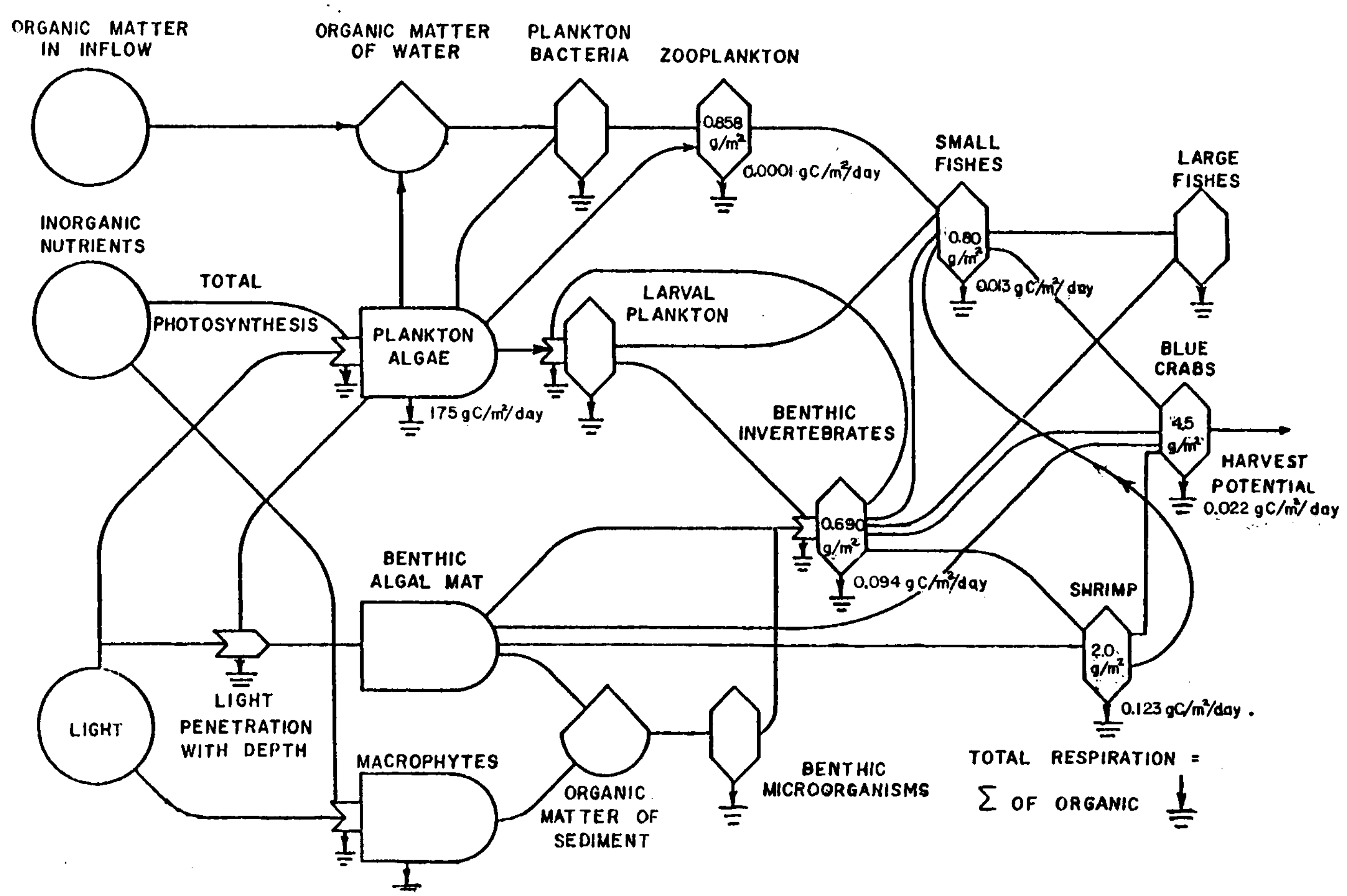

FIGURE V-24. Energy diagram of pond system in Summer 1969 with date included on some compartments in waste point P-1. (from Odum and Chestnut, 1970)

TABLE V-54. Calculations of stock and flux of the zooplankton community for use in pond system energy model (from Odum and Chestnut, 1970).

		Biomass (g/m^2)	Individual Metabolism ($gO_2/g/day$)	Total Metabolism ($gO_2/m^2/d$)	($gC/m^2/day$)
Control Pond	1	0.049	0.360	0.018	0.009
	2	0.027	0.360	0.008	0.004
	3	0.012	0.360	0.004	0.002
Experimental Pond	1	0.858	0.0003	0.0002	0.0001
	2	0.447	0.0003	0.0001	0.00005
	3	0.187	0.0003	0.00005	0.00002

Control: *Acartia*

Experimental: *Oithona*

Research into the effects of sewage wastes (Odum and Chestnut, 1970) and the thermal-copper-chlorine interaction from power plant effluents (Hoss et al., 1975) have been reviewed in previous sections. Several other studies have been conducted in the inventory area to assess the effects of man on estuarine zooplankton.

The entrainment of zooplankton through industrial cooling systems has received a considerable amount of attention in recent years. Most of the research data, however, are in technical reports that are not readily available to the public. Hodson, Schneider and Copeland (1977) reported on a study designed to assess the impact of entrainment of the Brunswick stream electric plant on the zooplankton of the Cape Fear River estuary, North Carolina. A field survey was conducted to detect density or distributional differences that could be attributed to entrainment by the power plant. The study revealed that population levels of zooplankton in the lower Cape Fear River and nearshore ocean were similar to those observed in a preoperational study (Copeland et al., 1974; see Section 2.1.1). It was, therefore, concluded that entrainment had no major effects on the overall standing crop of zooplankton in the estuary.

DeCoursey and Vernberg (1975) studied the effects of the dredging of Charleston Harbor, South Carolina on the physiology of larval zooplankton. Water samples were collected during dredging operations at the dredge site, 200 yards downstream, and at the outlet of the disposal site for each of three dredged areas in the harbor. The water from the various areas was then bioassayed with larval zooplankton to determine the lethal and sublethal effect of any toxicants that leached into the water during dredging. *Daphnia pulex* was used as the test organism for the freshwater dredge area, while *Palaemonetes pugio* larvae were used for the second location with intermediate salinities, and larvae of the polychaete *Polydora* were used for the location with the highest salinities. Lethal effects appeared to be greatest with water from the disposal sites (Figure V-25). Differences in the toxicity of the water from the dredge site and water from 200 yards downstream were less clear-cut (Figure V-26), but it was concluded that dredge water was less toxic than water from 200 yards downstream, but both were less toxic than water from the disposal site. Metabolic experiments indicated that respiration rates of the zooplankton were depressed in the experimental regimes (Figure V-27). Motility was also tested as a measure of toxicity (Figure V-28). Swimming rates of *Daphnia* were similar for control and 200 yard samples, while dredge and disposal site samples depressed motility. *Palaemonetes* motility experiments indicated that the dredge water depressed swimming activities, but

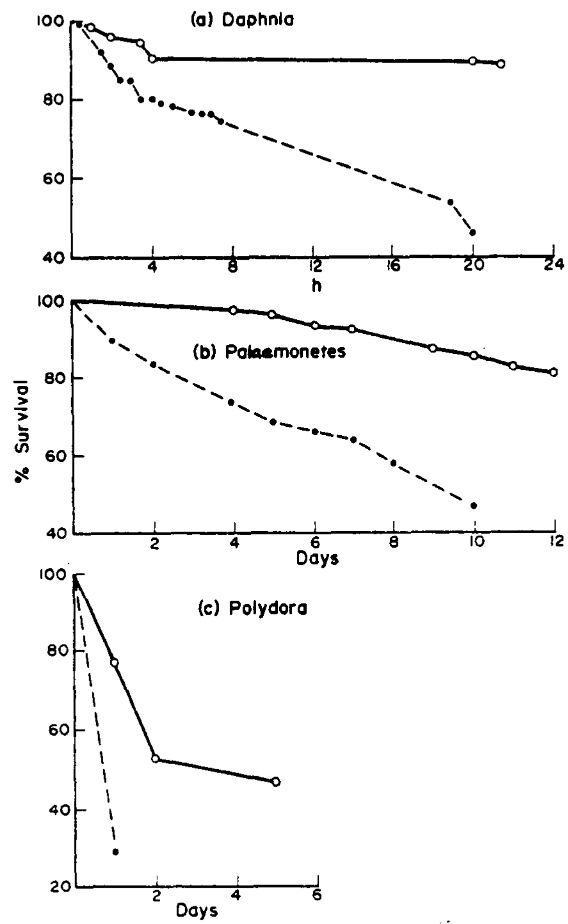

FIGURE V-25. Effect of weir water on survival. (a) Daphnia, 0°/₀₀; (b) Palaemonetes, 15°/₀₀ ; (c) Polydora, 25°/₀₀. Symbols: open circles = control, closed circles = water from the disposal site. (from DeCoursey and Vernberg, 1975).

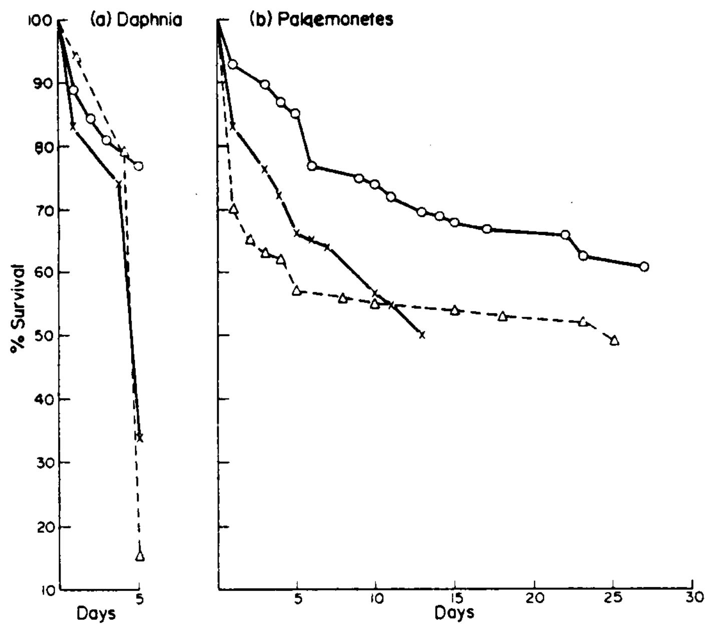

FIGURE V-26. Effects of water from the dredge area and 200 yards downstream on survival time. (a) Daphnia, 0°/₀₀ (b) Palaemonetes, 8°/₀₀. Symbols: open circles = control, open triangles = dredge site. X's = 20 yards downstream (from DeCoursey and Vernberg, 1975).

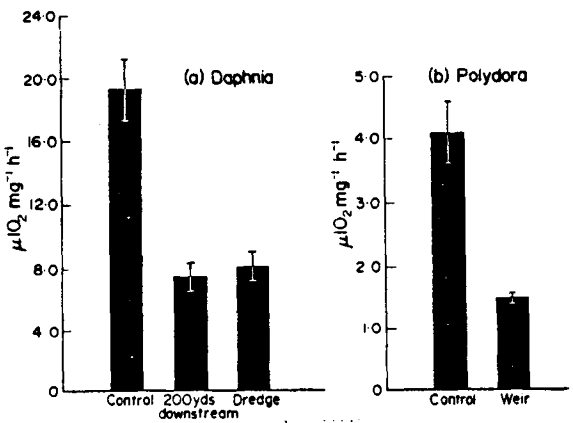

FIGURE V-27. Metabolism of zooplankton in water from the dredging operations (from DeCoursey and Vernberg, 1975).

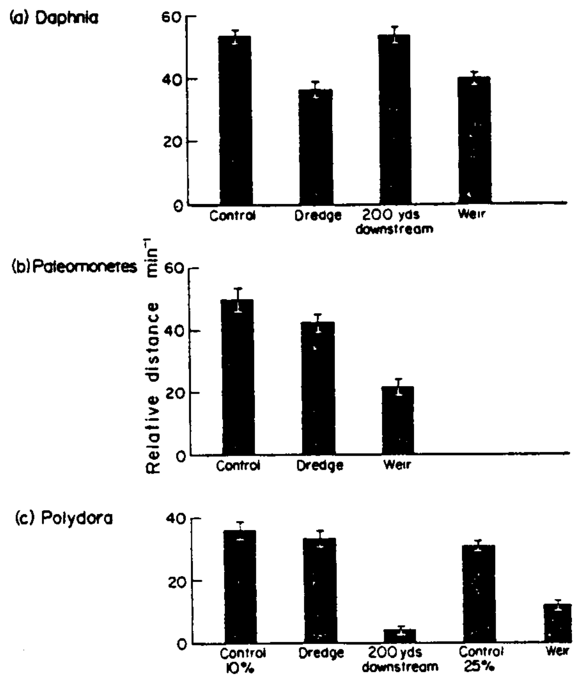

FIGURE V-28. Activity of zooplankton in water from the dredging operations (from DeCoursey and Vernberg, 1975).

not nearly as much as did disposal site water. Polydora larvae exhibited reduction of activity in the disposal site water and 200 yards downstream, but little or no effects at the dredge sites. In general, the results of the bioassay experiments indicated that toxic materials leach into the water at all locations during dredging. The water samples from the disposal sites were most toxic; from 200 yards downstream the samples were intermediate, and from the dredge site were least toxic. Although specific toxicants were not identified, heavy metals and ammonia were the suggested cause of the lethal and sublethal effects.

Hoss, Coston and Schaff (1974) also examined the effects of extracts of dredged sediments from Charleston Harbor, South Carolina. Larvae of menhaden, Brevoortia tyrannus; pinfish, Lagodon rhomboides; flounder, Paralichthys dentatus, P. albigutta, P.lethostigma; spot, Leiostomus xanthurus; and croaker, Micropogon undulatas, were exposed to sea water extracts of sediment from Charleston Harbor for periods of up to 14 days to determine toxic effects. Three concentrations (100 percent, 50 percent and 10 percent) of sediment extracts from seven locations were tested. Undiluted sediment extract (100 percent) from most stations proved lethal to pinfish larvae (Table V-55). The exception was the 100 percent solution from the station located the greatest distance upstream from Charleston (Station 7). A second set of experiments tested all the fish species for effects of the sediment extracts which were shown to be most toxic. It was concluded that different species exhibit different survival rates, with pinfish larvae being apparently more sensitive than menhaden or flounder larvae (Tables V-56 and V-57). Ammonia and heavy metals were implicated as the toxic agents in the sediment extracts.

2.7 Systematics and Taxonomy

The early study of zooplankton was heavily concentrated in the research areas of systematics and taxonomy: describing new species and establishing evolutionary relationships between groups. Although a lot of the research emphasis has shifted to more ecological areas, much work remains to be done on the systematics and taxonomy of zooplankton. As pointed out in Section 1.3, numerous articles have been published to describe new holoplankton species or the larval stages of common benthic species. It would be almost impossible to thoroughly review these articles since the species described cover a broad spectrum of taxonomic groups, with no common "key-words" indexed in the literature. It is not surprising, therefore, that only a few recent taxonomic articles could be found for the inventory area.

TABLE V-55. Survival of larval pinfish exposed to Charleston Harbor sediment extract (Hoss et al., 1974).

Station	Initial No. of test fish	Temp. Temp. (°C)	Test concentration (°C)	96 hours % survival
2	23	13.7	100	0
	21		50	33
	25		10	100
	28		2	100
	23		0	100
3	25	14.6	100	0
	30		50	100
	25		10	100
	25		2	100
	23		0	100
4	25	14.2	100	0
	33		50	42
	31		10	100
	24		2	100
	18		0	100
5	21	12.2	75	95
	20		50	100
	20		10	100
	22		2	100
	20		0	100
6	20	11.9	100	0
	19		75	95
	18		50	100
	21		2	95
	21		0	100
7	20	12.9	100	90
	20		75	90
	23		50	100
	21		10	95
	17		2	100
	20		0	100

TABLE V-56. Survival of larval pinfish and menhaden exposed to Charleston Harbor sediment extract, station 2a (Hoss et al., 1974).

Station	No. of Test Fish	Temp. (°C)	Test Concentration (%)	% survival (days) 1	2	4	7	14
Pinfish	10	14.7	100	0	0	0	0	0
	10		75	25	0	0	0	0
	11		50	82	82	82	45	9
	10		10	90	90	70	30	10
	10		0	100	100	100	90	80
Menhaden	10	15.5	100	100	80	60	0	0
	10		75	100	90	90	40	0
	10		50	100	100	100	100	50
	10		10	100	100	100	100	100
	10		0	100	100	100	100	100

TABLE V-57. Survival of larval pinfish and flounder after exposure to Charleston Harbor sediment extract from station 5 (from Hoss et al., 1974).

Species	Number of test fish	Temperature (°C)	Test Concentration (%)	% Survival (days) 1	2	4	7	14
Pinfish	21	12.2	75	100	95	95	62	0
	20		50	100	100	100	95	95
	20		10	100	100	100	100	100
	22		2	100	100	100	68	64
	20		0	100	100	100	100	100
Flounder	10	12.2	75	100	100	100	100	100
	10		10	100	100	100	100	100
	10		2	100	100	100	80	80
	10		0	100	100	100	100	100

Lang and Young (1977) published a description of the larval development of the hermit crab Clibanarius vittatus. These investigators reviewed the literature for previous descriptions of larvae of the family Diogenidae and found that only 16 species in 7 of the 15 genera were covered. Larvae of Clibanarius vittatus were reared on a diet of Artemia nauplii. Five, rarely four, zoeal stages and a megalopa were observed and detailed descriptions and figures of each were presented.

In a recently published note, Bowman (1975) corrects a taxonomic error concerning a cyclopod copepod that has been incorrectly called Oithona brevicornis. This species is very common in coastal and estuarine waters of the Gulf of Mexico and Atlantic coast south of Cape Cod, but is taxonomically distinct from the Oithona brevicornis orginally described from Hong Kong waters by Giesbrecht. Bowman therefore proposed that the new species Oithona colcarva be used for the American O. "brevicornis." Complete taxonomic description and figures are given for the identification of the new species.

Fleminger and Hulsemann (1974) published a monograph describing a global-scale study on the systematics and distribution of the copepod genus Pontellina. Morphology and distribution were utilized to determine phylogenetic relationships, as well as the nature of selection pressures operating on external characteristics. Pontellina plumata was the only species observed to occur in the inventory area. This species was shown to occur in oceanic, oligotrophic regions at tropical and subtropical latitudes, while the other three species, P. platychela, P. sobrina, and P. morii were found in various eutrophic sectors of equatorial waters. The morphological differences among the species were seen to be very subtle and restricted to secondary sexual structures. Geographical variation in morphology was observed among the P. plumata populations and it was suggested that the variation is the result of character displacement in areas of sympatry with the other three species. All Pontellina species exhibited relatively frequent occurrence within the limits of distribution, but abundance at any location was generally low. This pattern was taken to indicate high-order predation by these species, a trend confirmed by gut content analysis.

In a similar systematic study, Fleminger (1975) examined the geographical distribution and morphological divergence of copepods of the genus Labidocera. Two distinctive phylogenetic categories, the Darwinii and Jollae species groups, are represented by several species along the eastern and western coastal zones (Tables V-58 and V-59). Comparison between species groups indicated that co-occurrences of pairs of species are common. Morphological

TABLE V-58. Habitat and climate zones occupied by the species comprising each of the groups listed by the name of a known representative of the group. Species groupings and judgments as to distribution are based on published and unpublished data (from Fleminger, 1975).

Species-group	No. supp.	Depth range in epipelagic zone	Coastal[1]				Open neritic[1]				Eutrophic Oceanic[1]				Oligotrophic Oceanic[1]			
			P	B	Te	Tr	P	B	Te	Tr	P	B	Te	Tr	P	B	Te	Tr
Pontellina plumata	(4)	broad - 1 shallow - 3												4				
Eucalanus elongatus	(5)	deep										1	1	3				
Eucalanus attenuatus	(4)	deep - 2 shallow - 2											2	2				
Labidocera detruncata	(3)	shallow												3				
Eucalanus subtenuis	(7)	shallow							1	1			1	4				
Calanus finmarchicus	(7)	broad					1	2	4									
Centropages furcatus	(2)	shallow								2								
Temora stylifera	(2)	shallow								2								
Labidocera acuta	(2)	shallow								2								
Undinula vulgaris	(4)	shallow								4								
Eucalanus pileatus	(3)	shallow				3												
Labidocera darwinii	(13)	shallow			7	4				2								
Labidocera jollae	(6)	shallow			2	4												
13 groups	62 species																	

1. P = polar; B = boreal; Te = temperate; Tr = tropical

TABLE V-59. Lengths of coastal zone sectors occupied by species of the genus *Labidocera*. Estimates are approximate and do not include coastline irregularities (from Fleminger, 1975).

	Degrees of latitude		km	
West Coast Species				
jolliae	15		1900	
kilpos	7		650	
diandra	9		1300	
		$\bar{X}$ = 10.3°		$\bar{X}$ = 1280km
trispinosa	15		1900	
johnsoni a]	12			
johnsoni b]			1750	
lubbocki a	5		640	
lubbocki b	25		3860	
		$\bar{X}$ = 11.75°		$\bar{X}$ = 2080km
East Coast Species				
scotti	30		8700	
aestiva a	23		3200	
aestiva b	11		2700	
fluviatilis a	14		2900	
fluviatilis b	45		6400	
darwinii	15		2100	
		$\bar{X}$ = 21.6°		$\bar{X}$ = 3460km
mirabilis	?		?	
wilsoni	?		?	

differences between species were minor with respect to feeding and swimming appendages, but excessive divergence in sexually modified structures were seen to indicate essential differences in function. The divergence in sexually modified structures was seen to vary in proportion to the geographic extent of sympatry. It was proposed that there is a strong selection for the development of prezygotic mating barriers among coastal-zone species with common genetic and geographical background, but that there is little or no selection for partitioning food resources by morphological differentiation or body size.

3.0 IDENTIFICATION AND LOCATION OF RAW DATA AND UNWORKED SAMPLES

Raw data and unworked samples from zooplankton collections in the southeastern U. S. are identified in Appendix C to this report. The information listed in the appendix probably does not represent a comprehensive list of all data banks and unworked samples in the inventory area, but rather it represents the responses to a mail survey of nearly 200 univeristies, government agencies and individual investigators that were identified as having a potential interest in zooplankton research. The collections are in various stages of analysis and many are being examined in ongoing research projects. Geographically, two of the raw data banks are from collections from North Carolina, one from South Carolina, three from Florida and one from the entire southeastern Continental Shelf of the inventory area.

4.0 IDENTIFICATION OF DATA GAPS

4.1 Distribution and Abundance

Despite the fact that a major portion of the studies reviewed in this chapter were concerned with some aspect of distribution and abundance of zooplankton, much more research needs to be done to understand properly the similarities and differences observed in distribution patterns and community dynamics. Ongoing research projects explore areas of distribution and abundance of various zooplankton species in estuaries (Appendix A Anadromous Fisheries Research - Street; Ecology - Barclay; Zooplankton Ecology - Youngbluth; and Vertical Migration - DeCoursey), coastal areas (Appendix A Production - Paffenhöfer; Oceanographic Atlas - Atkinson; and Ecosystems Management - Kjelson) and the offshore waters (Appendix A Lobster/Tuna Recruitment - Richards; Radiolaria - Goll) of the inventory area. Most of the studies to date, however, are not directly comparable due to differing collection techniques, sampling regimes, and level of taxonomic analysis.

Long term surveys conducted with a standard sampling design and considering the entire zooplankton community need to be done in waters throughout the southeastern U. S. in order to observe spatial and temporal distribution patterns, especially with respect to year-to-year variability. The zooplankton communities of many of the estuaries of Florida, Georgia and South Carolina have never been studied. The zooplankton of southeastern coastal waters have been almost completely neglected in the past. Offshore zooplankton research appears to be mainly confined to studies in the Sargasso Sea near Bermuda or in the Gulf Stream near the Bahamas. Although studies in these idyllic areas provide some information on the character of offshore zooplankton communities of the inventory area, much more work should be concentrated in the outer continental shelf, slope and Gulf Stream waters of the South Atlantic Bight.

The relationship between spatial/temporal patterns of the zooplankton and environmental factors needs to be explored. Phenomena such as larval transport and large scale density and distribution patterns in zooplankton populations appear to be intimately linked to physical factors in the environment. The views of the geobiologists (Bogorov et al., 1974) relating productivities and standing crops of zooplankton communities to dynamic circulation patterns in the open ocean also appear to merit further study, both on a local and a global scale.

Biotic interactions within and between zooplankton communities also need to be investigated. Basic trophic relationships and subtle interspecific interactions are virtually unknown for many zooplankton populations. The studies done by Alldredge (1972, 1976) illustrate the importance of this research area by demonstrating a previously unknown commensalistic relationship between appendicularians and certain crustaceans which most certainly influences the microdistribution and density patterns of the latter group. Other biotic relationships such as predation, competition, mutualism or amensalism may be of major importance to the understanding of distribution patterns and associations of populations in the zooplankton community.

The introduction of planktonic forms from one water mass into another acts to "seed" new species into zooplankton communities. In some areas, these introductions occur on a periodic basis and cause drastic changes in the community structure and standing crop (e.g. "blooms" of forms such as salps seasonally dominate a zooplankton community to which they are periodically introduced; Grice and Hart, 1962); while in other areas such as the Gulf

Stream, the zooplankton community may depend upon replenishment by a continual influx of species from surrounding waters (Egan and Conrad, 1975). More research needs to be done on the nature and effects of the biotic interactions which occur when different zooplankton communities are mixed.

4.2 Relationships to Physio-chemical Parameters

Research is needed to more thoroughly determine the effects of physio-chemical conditions on zooplankton. Although some ongoing research addresses the effects of temperature on the larval stages of certain groups (see Appendix A, Anadromous Fisheries Research - M. W. Street; Thermal Effects - C. G. Bookhout), much more work is needed on other zooplankton species. It is ironic that most thermal pollution and power plant entrainment studies (Jensen, 1974; Coutant and Talmage, 1976, 1977) are from the Northeastern states or the Pacific coast, while the most serious conditions of artificial or natural thermal stress on zooplankton would be expected in the subtropical waters of the southeastern U. S. Clearly, the effects of temperature on the survival, metabolism and general distribution of all major larval/holoplankton groups from the inventory area need to be explored.

The effects of other physio-chemical factors such as salinity, pressure, light, and water chemistry on zooplankton also need to be studied. The preliminary studies that have been made indicate that these environmental parameters may be quite important to the physiology and distribution of zooplankton. Synergistic effects of combinations of various environmental conditions have been poorly investigated, but may be extremely important to the understanding of zooplankton community dynamics.

4.3 Energy Pathways

A great deal of research effort has recently been directed to the subject of zooplankton feeding and metabolism. Marshall (1973) reviewed much of the early research and pointed out the variability of data associated with experimental design variability, seasonal fluctuations, and diurnal variations. More comprehensive studies were called for due to the inconclusive data and inherent errors in the previous research. Since the publication of Marshall's review, much research has been done on feeding selectivity (Wilson, 1973; Poulet, 1973, 1974; Poulet and Chanut, 1975; Boyd, 1976; Nival and Nival, 1976; Richman, Heinle and Huff, 1977; and others); particle size modification by grazing (O'Connors, Small and Donaghay, 1976); the effects of food concentration on ingestion, growth efficiencies, and reproduction (Paffenhöfer and Harris, 1976; and Harris and Paffenhöfer, 1976a,b); and the carbon requirements and energy flow (Heinle and Flemer, 1975; and Heinle, Flemer and Ustach, 1977) of various species of copepods. Despite the considerable effort in the field of zooplankton nutrition and metabolism, none has come from the inventory area. Several ongoing research projects begin to explore the feeding relationships of zooplankton from the inventory area (see Appendix A Production - Paffenhöfer, Planktonic Copepod Biology - Paffenhöfer, and Planktonic Carnivores - Reeve), but the nutrition and metabolism of other zooplankton species should be studied. Zooplankton groups other than the well-studied copepods should be emphasized, and all groups should be examined under as natural a set of environmental conditions as can be approached experimentally.

The relationship of zooplankton to their predators is a research area that is shockingly underdeveloped. It is widely accepted that zooplankton species are the major dietary components for many juvenile fish as well as the larval stages of a number of benthic macroinvertebrates, but virtually nothing is known about the selectivity, feeding periodicity, or the daily rations of the predators. The complex interactions between zooplankton community structure, secondary production and the energy flow to planktivores need to be elucidated before realistic energy models or meaningful management decisions can be made. Workers at the University of Miami (see Appendix A - Larval Fish Survival - Houde) are currently conducting a laboratory simulation study designed to investigate the effects of the interaction of stocking density and feeding levels on the growth and survival of sea bream and bay anchovy larvae. Much more work needs to be done on the energy relationships of plankton-based food webs of waters throughout the inventory area.

Nutrient flow through zooplankton communities needs to be further explored, particularly with respect to the role of zooplankton in recycling nutrients (particularly nitrogen) to phytoplankton in various ecosystems. Knowledge of nutrient regeneration rates of major zooplankton species under various environmental conditions would provide insight into the relationships between community structure, standing crop, nutrient flux, and primary production of different ecosystems.

Large scale field studies of the secondary productivity and energy flow of zooplankton communities are practically nonexistant for the inventory area. Several ongoing research projects (Appendix A - Production - Gillespie, Paffenhöfer; Material Flux - Stancyk) examine various aspects of annual production and carbon flux of the zooplankton but more intensive work is needed. Standing crop and distribution information taken in the typical zooplankton study does not reflect the dynamic nature of community structure nor the rapid turnover of planktonic biomass. The importance of the zooplankton community to the energy flow of an ecosystem is therefore greatly underestimated when based on this type of static survey. Seasonal secondary production studies based on population structure dynamics and/or planktonic metabolism and biomass change are needed for the various ecosystems of the inventory area in order to assess the magnitude of energy flow through the zooplankton communities. Estimates of energy flow to predators and benthic detritivores should be particularly emphasized.

4.4 Simulation Models

Much work is needed in the development of simulation models of natural zooplankton communities. A number of graphical and mathematical methods have been devloped by Russian scientists to estimate secondary production (Winberg, 1971) and simulate zooplankton population dynamics (e.g. Menshutkin and Prikhod'Ko, 1970). Unfortunately, very little of this type has been applied to the zooplankton of the inventory area. Even systems computer models that are now frequently being applied to ecological research often neglect the energy flux through the zooplankton community or, at best, take very crude estimates from the literature.

The development of microcosms to assess the effects of environmental perturbations on zooplankton is also needed. In situ studies of the effects of pollution on zooplankton are very difficult due to the natural variability of plankton, so the controlled conditions of microcosms would appear to provide a more fruitful approach to the subject.

4.5 Man's Impact

Industrial, shipping, agricultural and domestic sewage wastes in the marine and estuarine environments may all have direct or synergistic effects on the zooplankton community, yet very little research has been done in the inventory area to address these topics. Techniques have recently been developed to assess the effects of petrohydrocarbons (Anderson, Neff, Cox, Tatem and Hightower, 1974; Kontogiannis and Barnett, 1973; Barnett and Kontogiannis, 1975; Lee and Nichol, 1977); detergent oil spill "removers" (Corner, Southward and Southward, 1968); heavy metals such as copper (Beers, Stewart and Hoskins, 1977; Gibson and Grice, 1977); and industrial wastes (Cooper and Copeland, 1973; Hoss et al., 1974; DeCoursey and Vernberg, 1975; and Gabriel, Dias and Nelson-Smith, 1975) on selected components of the zooplankton community. More research is needed on the sensitivity of all major species to common pollutants such as pesticides, heavy metals, acid wastes, dredge spoils and multiple industrial wastes. Particular attention should be paid to sublethal effects of pollutants on metabolism, growth, motility, reproduction, long term survival and competition under the range of environmental conditions that may be encountered in nature.

The chemical composition of zooplankton also needs to be studied to aid in the understanding of pollutant transfer through food webs. Pollutants with long half lives such as heavy metals (Maturo, Caldwell, Ingram and Hearne, 1974), organochlorines (Grice et al., 1972; Risebrough, Vreeland, Harvey, Miklas and Carmignani, 1974) and certain petrohydrocarbons should be monitored in the zooplankton biomass to provide an understanding of concentration factors of major species and the biomagnification that takes place in the transfer to higher trophic levels. Seasonal studies taken under a variety of environmental conditions should be made to elucidate the magnitude of pollution transfer in natural ecosystems. The levels of certain pollutants in the zooplankton biomass may in the long run provide a more effective indicator of the extent of recent industrial pollution in a water mass than water quality measurements.

4.6 Systematics and Taxonomy

Taxonomic keys to the identification of major zooplankton groups are few in number, if they exist at all. Most zooplankton researchers either rely on a few rather classic taxonomic keys originally published for distant geographic locations (e.g. for North Sea or European waters) or they painstakingly assemble a file of scattered publications that must be pieced together on a trial and error basis to describe the local zooplankton community. It is clear that coordinated taxonomic efforts on entire holoplankton or larval groups characteristic of the waters of the southeastern U. S. would be invaluable to researchers interested in any phase of zooplankton research.

5.0 RECOMMENDATIONS FOR FUTURE STUDIES

Long term distribution studies of large geographic areas should be made to observe the relationships between environmental factors and the spatial and temporal patterns of the zooplankton, especially with respect to year-to-year variability of the communities. One of the most urgent needs in this type of research is the establishment of standard methods of sampling, both in collection techniques and sampling design (i.e. periodicity and site selection). Until similar techniques are used at a number of locations, little useful information can be derived from the comparison of results. Laboratory analysis of the samples should likewise be standardized, with all samples being examined for a number of zooplankton groups, or being archived for future analysis of the entire zooplankton community. Finally, the experimental design of distribution studies should be amenable to standardized methods of statistical analysis. Multivariate and classification analysis techniques show great promise for the purpose of characterizing zooplankton communities and assessing the major environmental parameters that influence them significantly.

The interactions between environmental conditions and zooplankton distribution should be explored for estuaries with different hydrographics, tidal/current dynamics, and physiochemical parameters. The hypothesis that links the interaction of tidal flushing, hydrography and zooplankton behavior to horizontal patterns of species distribution (Jacobs, 1968) needs to be explored in a number of locations. Results of such studies would aid in the understanding of the spectrum of spatial and temporal density patterns that may be found in estuaries of the Southeast. A special emphasis should be made to study the zooplankton of the many estuaries of southeastern states that have not been previously surveyed in detail.

Similarily, the patterns and dynamics of neritic zooplankton of the South Atlantic Bight should be examined, with emphasis on the relationships to estuarine and offshore communities. The interactions between the breeding activities of marine organisms, the behavior of meroplankton, and physical factors in the environment (e.g. Ekman transport, and major current patterns such as the Gulf Stream and the Western Boundary Under Current) should be examined to determine major larval transport mechanisms and dispersal patterns.

Nutrition and metabolism studies need to be done on the zooplankton of the inventory area, with particular emphasis on groups other than copepods. Feeding experiments should be designed to expose plankton species to environmental conditions similar to those encountered in nature, so that ingestion, assimilation, respiration and growth efficiencies can be realistically estimated. The selectivity, feeding periodicity, daily rations and growth efficiencies of planktivores (e.g. larval stages of fish and benthic macroinvertebrates) should be examined in order to determine energy flux through major food webs and to aid in fisheries management.

The recycling of nutrients by zooplankton excretion and defecation should be explored, particularly in relationship to grazing and primary production rates. Standard collection techniques should be supplemented by "hand" sampling (with scuba or submersibles) whenever the metabolism, energy flow or nutrient regeneration of the zooplankton community is assessed, since macrozooplankton are frequently lost or damaged with plankton nets. Careful observations of live zooplankton should be made to observe any subtle biotic interactions between species that may influence distribution or energy/nutrient flow within the community.

The development of simulation models designed to assess zooplankton dynamics and productivity appears to be the most reasonable approach to the study of the ecology of a highly variable, often ephemeral community. Microcosms should be developed that allow the zooplankton community to live under near natural, yet controlled conditions. The lethal and sublethal effects of natural and man-made (i.e. pollution) conditions can then be assessed on entire zooplankton communities. The CEPEX bag experiments indicate that closed systems placed <u>in situ</u> may be a fruitful approach to zooplankton research.

Methods for the determination of secondary production of zooplankton populations have already been developed. These methods utilize mathematical or graphical models of population structure dynamics and/or metabolism and biomass change to determine energy flow through the zooplankton community. Secondary production studies utilizing comparable methods should be made in a number of locations to assess properly the role of the zooplankton in the energy budget of different ecosystems. Data from such studies would be important to systems models utilizing analog or digital computers to simulate the "energy signature" of various ecosystems.

Bioassay experiments to assess the effects of pollutants (e.g. organo-chlorines, heavy metals, dredge spoils, industrial, and domestic wastes) on zooplankton species should be supplemented with regular field monitoring designed to determine the concentration of the chemicals in the zooplankton biomass. Results from this type of study would not only allow the understanding of the ecological effects of pollution stress on the zooplankton, but would also provide insight into the processes of biomagnification and pollutant transfer through food webs.

Finally, it is recommended that a coordinated effort be made to assemble taxonomic keys that would be generally useful for the identification of holoplankton and meroplankton groups of the waters of the southeastern U. S. If these keys could be combined into a single publication (or series), it would prove invaluable to investigators interested in any aspect of zooplankton research. Such an effort is not unreasonable, since it has been done for a number of groups of marine organisms and for the zooplankton of European waters (Fiches Pour l'Identification du Zooplankton published by the Counsel International Pour l'Exploration de la Mer).

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VI. NEUSTON

Dr. Harold G. Marshall
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia

1.0 INTRODUCTION

The term neuston represents a biotic community unique in the marine ecosystem. The neuston refers to those forms that live directly in association with the surface film of the water. They may float, live on the surface, or be present directly below the surface film. It is this direct association with the air-water interface that distinguishes the neuston from the plankton community. However, numerous phytoplankton and zooplankton in various stages of development may be associated with the neuston and may be classified with this group. In fact, the composition of the neuston at the generic level includes a wide variety of both floral and faunal components. In addition to the more typical phytoplankters that may develop associated with the surface film, the floral types will include bacteria, fungi, and larger macroscopic algae (e.g. Sargassum). The faunal composition may be extremely varied, including eggs, different larval stages, and adults. The most common groups would include protozoa, crustacea, fish eggs, and fish larvae. In addition, a great amount of dead animals, partially decomposed bodies, organic by-products, and detritus may be associated with the surface waters. The majority of these non-living components are microscopic and would be in various stages of decomposition. In their review of neuston, Hempel and Weikert (1972) offer a classification for the group into three categories. Euneuston represent those organisms that have their maximum abundance in the immediate vicinity of the surface throughout day and night time periods. Faculative neuston are found at the surface only during part of a 24-hour day, usually during hours of darkness. The third category is the pseudoneuston, which do not have their maximum concentrations at the surface, but at lower depths.

The extent of the neuston habitat below the surface varies with different investigators, but is typically considered as the uppermost 5 to 10cm of the water column. This zone is subject to a specific set of environmental conditions that differ from other habitats due to its position between the air and water interface.

For example, the surface is exposed to a degree of light intensity and to spectral components that will be different than those at lower depths. The surface waters will also be subject to more rapid and frequent changes in air and water temperature, modifications to salinity, and disturbance to the surface by wave and wind action. In the neuston community may be found a wide assortment of different biotic types, ranging from autotrophic plants, bacteria, freely floating eggs, and a variety of fauna dominated by minute herbivore and carnivore types. Yet, this surface community has its share of tripton in the form of organic wastes, partially decomposed remains of plants and animals, and a variety of man-made products that float on, or are near, the surface. These products are typically represented by plastic and styrofoam particles, oil, and the various degradable oil products.

In his review of the ecological factors found associated with the neuston, Zaitsev (1971) characterizes the surface waters as follows.

1. Dead organic matter and exometabolites constantly accumulate in the surface biotope.
2. Since the surface biotope is distinguished by an abundance of dead organic matter, it is populated with reducers and consumers.
3. Organisms inhabiting the surface layers must be adapted to the specific conditions present, which would include strong solar radiation, ultra-violet rays, and predators from both the air and water.
4. The surface biotope must be mainly populated by temporary inhabitants. On leaving the surface biotope, these organisms return organic matter to the water mass and bottom, maintaining a dynamic equilibrium in the sea.

This concept of the disproportion of dead organic matter over the biomass has been reviewed by Zaitsev (1971). He indicates that the amount of dead organic matter may be 50 to 500 times greater than the amount of living organisms in a column of sea water. Zaitsev reviews the concept of a concentration of pieces and entire bodies of dead zooplankton at the surface, having a pattern where these rise to the surface, rather than sink. The addition to this surface zone of the varied types of suspended particles, dissolved, and colloidal materials, results in a vast array of abiotic substances that present a dominant stature over the living components. In addition, the presence and importance of bacterial decomposition to this microzone becomes more evident.

1.1 Scope of This Evaluation

It is apparent from the discussion above that the concept of the neuston community is based entirely on the relationship of a variety of different organisms to a very specific habitat in the marine (or fresh water) ecosystem. The majority of the past investigations on the neuston have been those in which specific components of this community have been studied, rather than the entire ecological relationships and interactions that exist in the surface layer. Thus, the task of identifying neuston studies becomes slightly ambiguous and difficult. An investigator may not consider his work as a neuston effort, but more appropriately, in an area of study not restricted to a surface zone. Examples of such approaches may include life cycle studies of demersal fish that have a brief period of their existence where the eggs are floating on the water surface as part of the neuston. The original scope of this review was to identify neuston studies between Cape Hatteras, North Carolina and Cape Canaveral, Florida that concentrated on the neuston communities and its life zone since 1973.

1.2 Definition of the Neuston Community

It soon becomes evident that there are differences in the definition of neuston. Zaitsev (1971) offers an historical review of the term going back to the Swedish hydrobiologist Naumann, who in 1917 used this term to refer to the "surface film community". The relationship to the surface soon became a factor with the use of the terms epineuston (those forms that live on the surface film) in contrast to the hyponeuston (referring to those found below the surface film). Further division into such terms as bacterioneuston and the classification previously given by Hempel and Weikert (1972) followed.

The depth of the surface zone associated with the neuston habitat is where there is the greatest disagreement. Zaitsev (1971) emphasizes the upper 5cm, whereas, Hempel and Weikert (1972) use collection gear that samples the upper 10cm. In their ichthyoneuston studies, Powles and Stender (1976) sample the upper 0.5 meters. The first collection criteria is to define the neuston zone; then use a sampling device that will obtain valid collections within this zone with as little contamination as possible from the lower depths.

Specifically, the term neuston has been used to refer to organisms that spend all or part of their lives associated with the near surface part of the water column. When organisms migrate or move out of this zone they are generally reclassified according to their mode of life, e.g. plankton, nekton. With this definition, a net which is towed at the surface, but has an opening so wide that it collects 1m below the surface, is not collecting neuston, but rather a combination of neuston and other plankters.

1.3 Information Sources

Letters of inquiry regarding neuston investigations were sent to the directors of marine laboratories located along the eastern coastal waters of the United States, south of Cape Hatteras; additional letters were mailed to various investigators and centers for marine studies outside of this region. This approach was accompanied by a search through the standard data retrieval systems and abstracts for neuston studies in the area between Cape Hatteras and Cape Canaveral. Visitations were also made to several of the coastal laboratories to personally make inquiries of neuston studies. There was only a sparse response regarding neuston studies in this area.

2.0 SUMMARY OF RESEARCH CONDUCTED SINCE 1973.

2.1 Composition of the Neuston

In their study of subtropical Atlantic waters, Hempel and Weikert (1972) discuss the composition of the neuston community. They found in their results that 94 percent of the neuston invertebrates were crustaceans and one-half of these were copepods, with 5.4 percent molluscs. The remaining amount consisted of a variety of marine faunal types. The fish specimens showed a high abundance, but a lower number of species as characteristic of shelf waters, with larger numbers associated with the upwelling areas along coastal regions. A definite microstratification was observed for the biomass, where some groups avoided the surface, and others would show diurnal migratory patterns in and out of the surface waters. The most obvious diurnal patterns were noted in the oceanic waters, and in many cases were related to growth stages or breeding patterns. They commented on the two major abiotic factors in the surface waters being irridation and a poor food supply. Apparently only the small larval forms would be able to find sufficient food at this site, which would also offer reduced levels of competition and predation, at least during the daylight hours.

A major source of neuston and fisheries data in Atlantic coastal waters of the United States has been the Marine Resources Monitoring Assessment and Prediction Program (MARMAP). In 1973 the Marine Resources Center of the South Carolina Wildlife and Marine Resources Department assumed responsibility for the MARMAP activities in the South Atlantic Bight of the United States. These activities included ichthyoplankton and groundfish surveys of continental shelf and slope waters between Cape Fear, North Carolina and Cape Canaveral, Florida. Of significance in the present program is that the ichthyoplankton survey includes equipment and a methodology designed to provide a quantitative assessment of the ichthyoplankton and ichthyoneuston.

In these collections a bongo sampler and a Boothbay neuston sampler were used. The bongo sampler consisted of two nets, each with a mouth diameter of 60cm (mesh sizes 0.505mm and 0.333mm), and was hauled in a double oblique pattern from 2m above the bottom, or from 200m of depth in deeper water. The Boothbay neuston sampler had a mouth opening 1m high by 2m wide, with mesh size of 0.947mm and a length of 8.5m, and was towed 10 minutes. In towing this net, one-half of the net mouth was out of the water, so the sampling depth was 0.5m. Collections were preserved in 5 percent buffered formalin. Standardized catches (catch per $100m^2$ sea surface area) were determined for comparison of catches. In these collections for ichthyoneuston, the neuston population was considered to include the uppermost 50cm (0.5m).

Powles and Stender (1976) reviewed the ichthyoneuston data from three MARMAP cruises. The purpose of these cruises was to obtain information on the distribution and abundance of fish eggs, larvae, and juveniles in the South Atlantic Bight. During a February-March cruise (D2-73), 73 neuston tows were made. The number of young fishes per station varied from 0 to 53,138. Powles and Stender (1976) proceed to describe the catch composition, which included fish larvae and juveniles from 13 orders and 60 families. In Figures VI-1 through VI-4 the collection stations for this cruise are noted with the distribution patterns given for four families. The Carangidae were found in 57 percent of the catches, having basically a rather uniform distribution with respect to latitude, with the Mugilidae wide-spread in the catches, and the Scombridae larvae concentrated in the more northern collections. The order and family breakdown for the neuston net collections is given in Table VI-1, with a listing of the most abundant families in Table VI-2.

Additional catch composition is provided for a May cruise (D3-73) where neuston catches ranged from 7 to 966 specimens per tow. Fish eggs were not discussed for either of the cruises. It was noted that in day-night collections about twice as many fishes were taken during the night in the February-March cruise, indicating either gear avoidance during the daytime or the presence of diel vertical migration patterns. Results from the May collections indicated few diel variations in total neuston catches. The order and family composition from the neuston collections during May is given in Table VI-3. Among the representative families (Table VI-4), the Mugilidae, Pomatomidae, and Carangidae were the most common. A further look at the distribution of the Carangidae and Mugilidae (Figures VI-5, VI-6) for the May cruise shows different concentrations than in the earlier February collections.

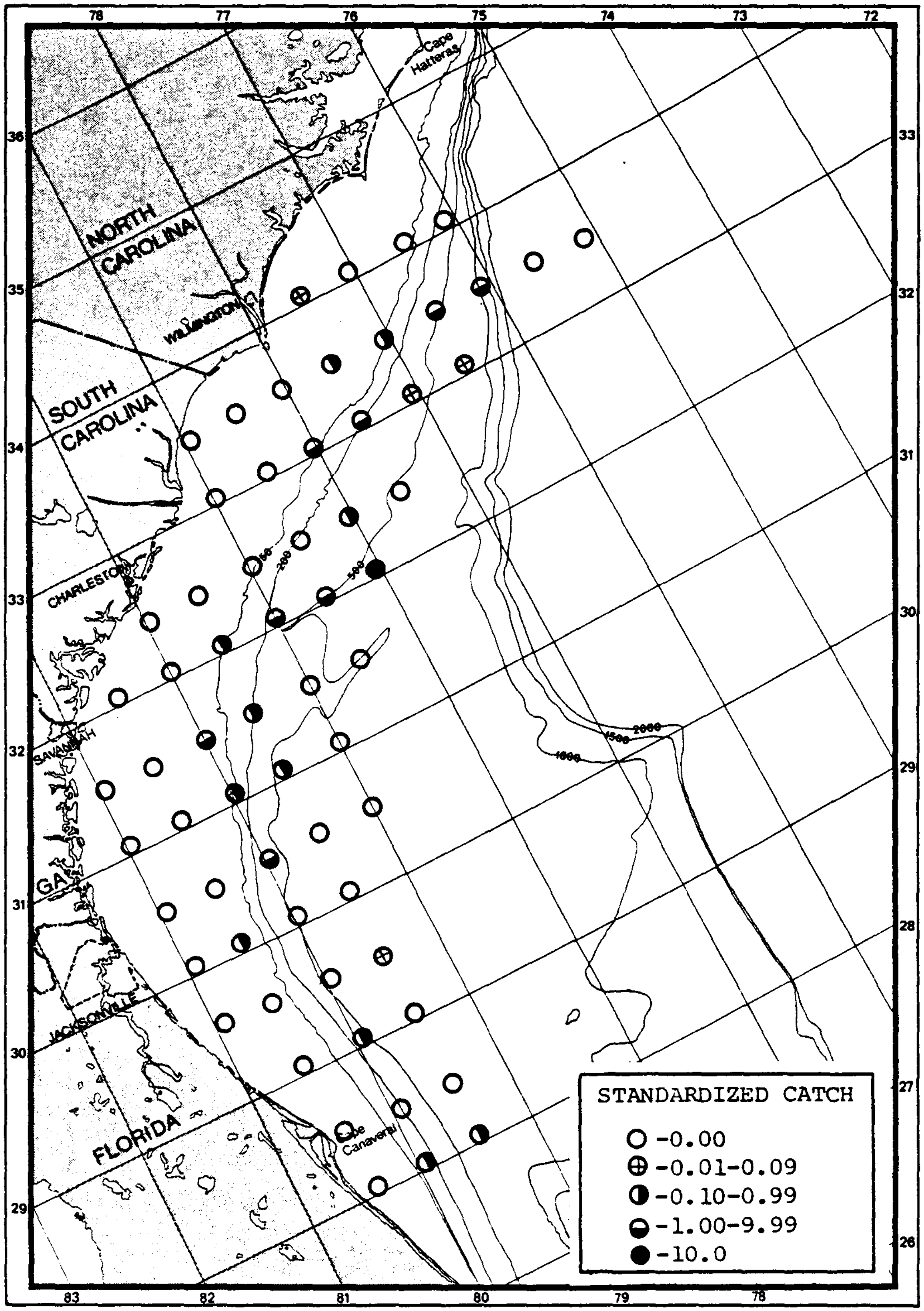

FIGURE VI-1. Distribution of young Mullidae from neuston collections during MARMAP cruise D2-73 (Powles and Stender, 1976).

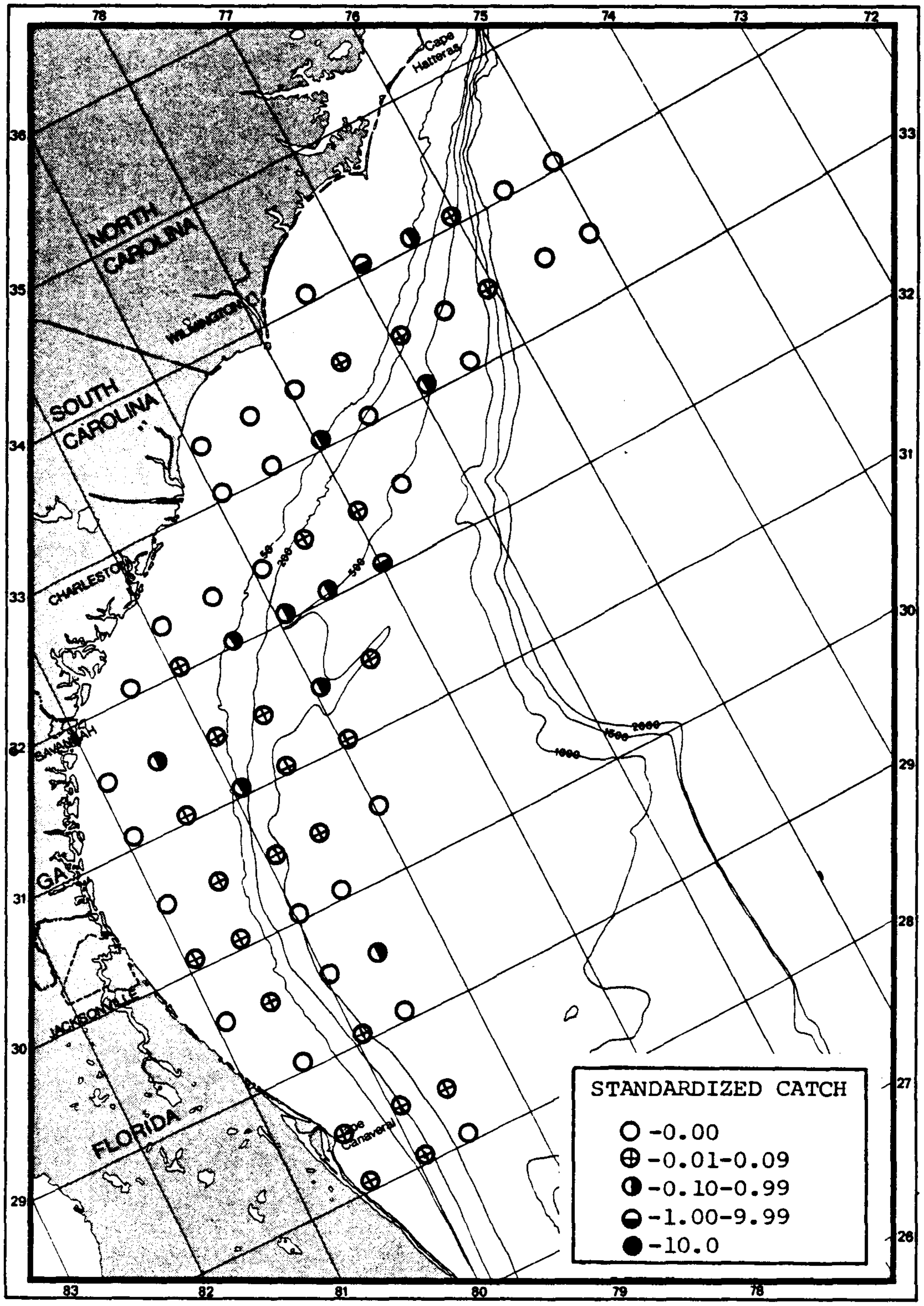

FIGURE VI-2. Distribution of young Carangidae from neuston net collections during MARMAP cruise D2-73 (Powles and Stender, 1976).

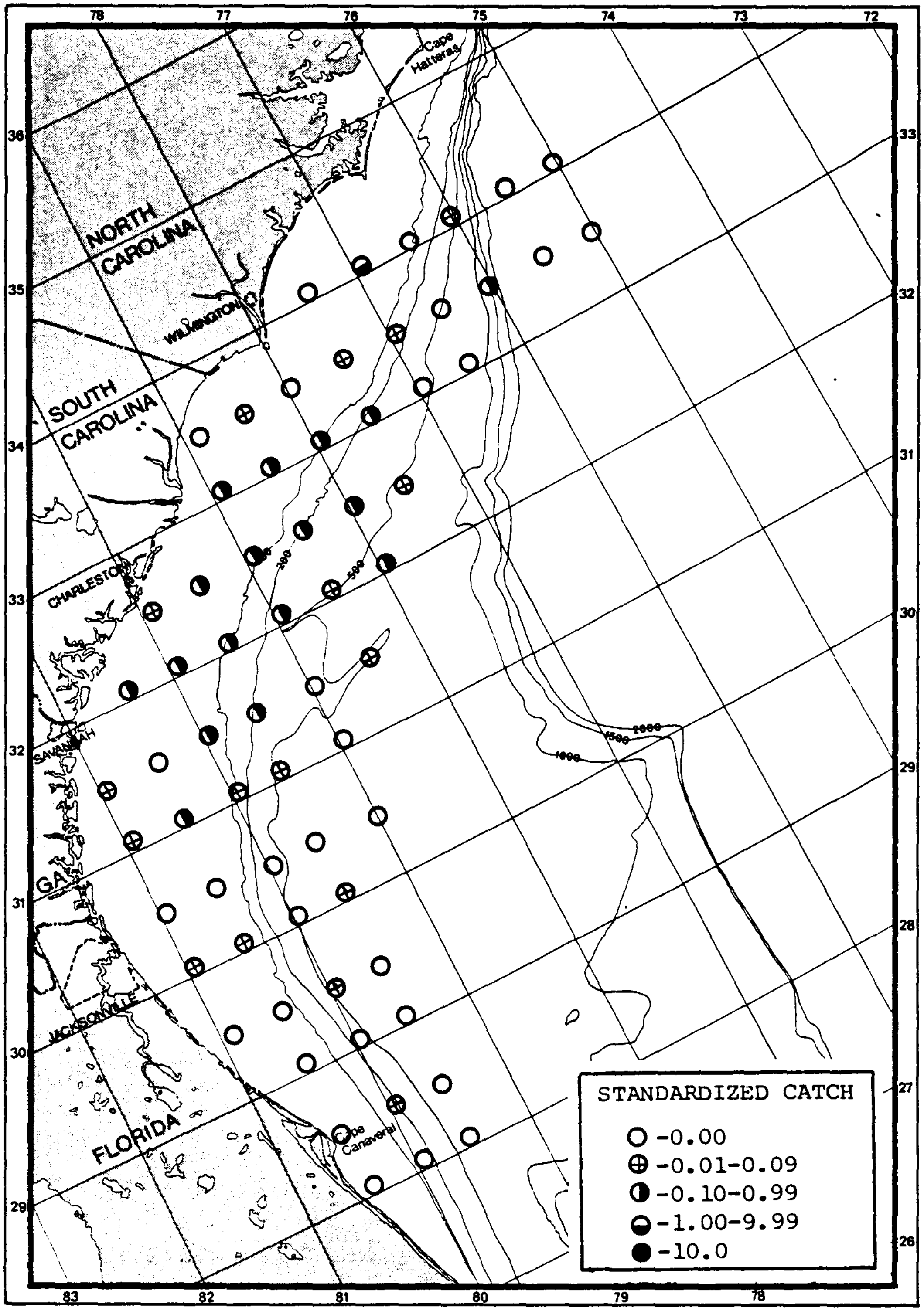

FIGURE VI-3. Distribution of young Mugilidae from neuston net collections during MARMAP cruise D2-73 (Powles and Stender, 1976).

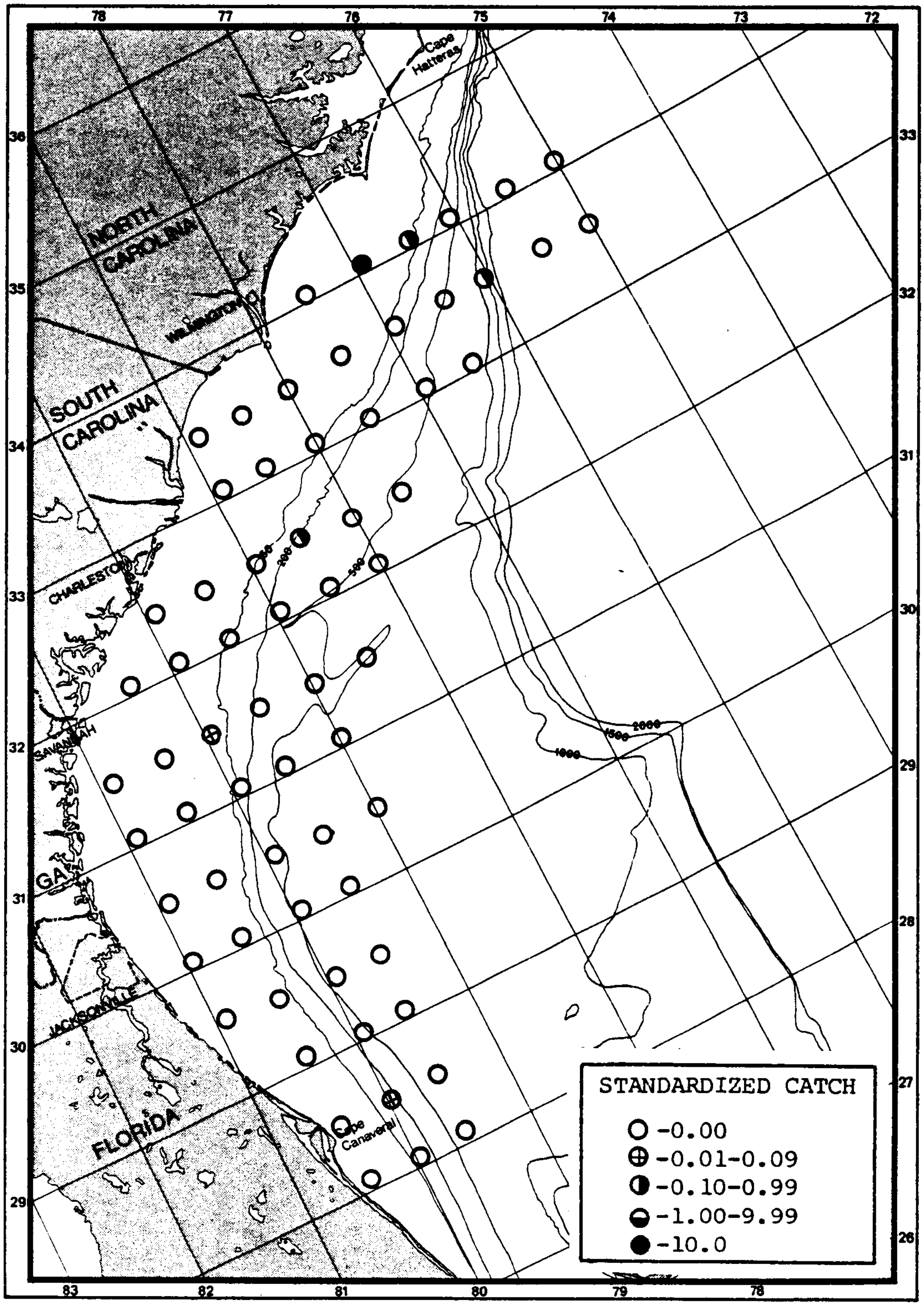

FIGURE VI-4. Distribution of young Scombridae from neuston net collections during MARMAP cruise D2-73 (Powles and Stender, 1976).

TABLE VI-1. Composition of catch of neuston net, MARMAP cruise D2-73 (Powles and Stender, 1976).

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Anguilliformes	49	0.07		17	23.3	
Atheriniformes	151	0.23		34	46.6	
Atherinidae	1	<0.01	50	1	1.4	49
Belonidae	11	0.02	35	6	8.2	25
Exocoetidae	106	0.16	19	33	45.2	3
Hemiramphidae	32	0.05	24	10	13.7	18
Beryciformes	1	<0.01		1	1.4	
Holocentridae	1	<0.01	50	1	1.4	49
Clupeiformes	8302	12.40		31	42.5	
Clupeidae	7921	11.84	2	30	41.1	7
Engraulidae	381	0.57	11	11	15.1	17
Elopiformes	25	0.04		2	2.7	
Elopidae	25	0.04	27	2	2.7	42
Gadiformes	*3906	5.84		33	45.2	
Bregmacerotidae	2	<0.01	45	2	2.7	42
Carapidae	1	<0.01	50	1	1.4	49
Gadidae	*3891	5.81	3	32	43.8	5
Ophidiidae	11	0.02	35	1	1.4	49
Gasterosteiformes	175	0.26		26	35.6	
Centriscidae	19	0.03	30	5	6.8	33
Syngnathidae	156	0.23	15	25	34.2	9
Lophiiformes	*27	0.04		15	20.5	
Antennaridae	*26	0.04	26	14	19.2	15
Lophiidae	1	<0.01	50	1	1.4	49
Myctophiformes	304	0.45		31	42.5	
Myctophidae	203	0.30	13	16	21.9	13
Paralepididae	2	<0.01	45	2	2.7	42
Synodontidae	95	0.14	20	14	19.2	15

TABLE VI-1. Cont.

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Perciformes	*49,821	76.44		70	95.9	
Acanthuridae	1	<0.01	50	1	1.4	49
Apogonidae	1	<0.01	50	1	1.4	49
Blenniidae	*117	0.17	18	8	11.0	21
Bramidae	2	<0.01	45	2	2.7	42
Callionymidae	3	<0.01	44	2	2.7	42
Carangidae	506	0.76	9	42	57.5	1
Chaetodontidae	6	0.01	41	3	4.1	41
Coryphaenidae	62	0.09	21	17	23.3	12
Dactylopteridae	8	0.01	39	5	6.8	33
Gempylidae	2	<0.01	45	2	2.7	42
Gerreidae	20	0.03	29	5	6.8	33
Gobiidae	19	0.03	30	8	11.0	21
Kyphosidae	1	<0.01	50	1	1.4	49
Labridae	36	0.05	22	5	6.8	33
Mugilidae	366	0.55	12	40	54.8	2
Mullidae	*2,083	3.11	5	30	41.1	7
Pomacentridae	5	0.01	43	4	5.5	39
Pomatomidae	28	0.04	25	6	8.2	25
Priacanthidae	11	0.02	35	6	8.2	25
Scaridae	8	0.01	39	1	1.4	49
Sciaenidae	44,664	66.74	1	15	20.5	14
Scomberesocidae	12	0.02	33	6	8.2	25
Scombridae	691	1.03	8	10	13.7	18
Scorpaenidae	25	0.04	27	8	11.0	21
Serranidae	34	0.05	23	6	8.2	25
Sparidae	767	1.15	6	8	11.0	21
Sphyraenidae	141	0.21	17	6	8.2	25
Stromateidae	171	0.26	14	18	24.7	11
Triglidae	12	0.02	33	5	6.8	33
Uranoscopidae	13	0.02	32	6	8.2	25
Xiphiidae	6	0.01	41	5	6.8	33
Pleuronectiformes	2285	3.41		32	43.8	
Bothidae	2131	3.18	4	31	42.5	6
Cynoglossidae	154	0.23	16	10	13.7	18
Salmoniformes	10	0.01		4	5.5	
Gonostomatidae	1	<0.01	50	1	1.4	49
Malacosteidae	1	<0.01	50	1	1.4	49
Sternoptychidae	1	<0.01	50	1	1.4	49
Tetraodontiformes	1125	1.68		46	63.0	
Balistidae	2	<0.01	45	2	2.7	42
Diodontidae	5	0.01	43	4	5.5	39
Monacanthidae	708	1.06	7	25	34.2	9
Ostraciidae	9	0.01	38	6	8.2	25
Tetraodontidae	401	0.60	10	33	45.2	3
Others	746	1.11		47	64.4	
Total	*66,927			73		

*Includes estimates from samples which were split before sorting.

TABLE VI-2. Most abundant families in neuston catch, MARMAP cruise D2-73 (Powles and Stender, 1976).

Numbers caught (N = 66,927)	Occurrences (N = 73)
1. Sciaenidae 44,664	1. Carangidae 42
2. Clupeidae 7,921	2. Mugilidae 40
3. Gadidae 3,891	3. Exocoetidae 33
4. Bothidae 2,131	4. Tetraodontidae 33
5. Mullidae 2,083	5. Gadidae 32
6. Sparidae 767	6. Bothidae 31
7. Monacanthidae 708	7. Mullidae 30
8. Scombridae 691	8. Clupeidae 30
9. Carangidae 506	9. Monacanthidae 25
10. Tetraodontidae 401	10. Syngnathidae 25
11. Engraulidae 381	11. Stromateidae 18
12. Mugilidae 366	12. Coryphaenidae 17
13. Myctophidae 203	13. Myctophidae 16
14. Stromateidae 171	14. Scianenidae 15
15. Syngnathidae 156	15. Antennariidae 14
	15. Synodontidae 14

TABLE VI-3. Composition of catch from neuston net, MARMAP cruise D3-73 (Powles and Stender, 1976).

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Anguilliformes	24	0.24		12	27.27	
Atheriniformes	468	4.72		30	68.18	
Belonidae	3	0.03	46	2	4.55	45
Exocoetidae	425	4.29	6	30	68.18	4
Hemiramphidae	40	0.40	28	11	25.00	23
Beryciformes	83	0.84		5	11.36	
Holocentridae	83	0.84	21	5	11.36	38
Clupeiformes	363	3.66		25	56.82	
Clupeidae	222	2.24	12	17	38.64	12
Engraulidae	141	1.42	17	17	38.64	12
Elopiformes	1	0.01		1	2.27	
Elopidae	1	0.01	50	1	2.27	48
Gadiformes	91	0.92		10	22.73	
Bregmacerotidae	1	0.01	50	1	2.27	48
Gadidae	2	0.02	47	2	4.55	45
Ophidiidae	88	0.89	20	7	15.91	35
Gasterosteiformes	13	0.13		11	25.00	
Fistulariidae	1	0.01	50	1	2.27	48
Syngnathidae	12	0.12	41	10	22.72	26
Lophiiformes	16	0.16		9	20.45	
Antennariidae	16	0.16	37	9	20.45	27
Myctophiformes	266	2.68		18	40.91	
Myctophidae	224	2.26	11	12	27.27	21
Synodontidae	42	0.42	26	11	25.00	23

TABLE VI-3. Cont.

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Perciformes	7465	75.28		44	100.00	
Apogonidae	30	0.30	29	5	1.63	38
Blenniidae	304	3.06	8	22	50.00	8
Callionymidae	30	0.30	29	8	18.18	29
Carangidae	784	7.91	3	39	88.64	1
Chaetodontidae	21	0.21	33	6	13.64	36
Coryphaenidae	248	2.50	10	20	45.45	11
Dactylopteridae	14	0.14	39	5	11.36	38
Gempylidae	13	0.13	40	5	11.36	38
Gerreidae	118	1.19	18	26	34.55	7
Gobiidae	82	0.83	22	14	31.82	18
Istiophoridae	23	0.23	32	8	18.18	29
Kyphosidae	18	0.18	36	8	18.18	29
Labridae	44	0.44	24	10	22.73	26
Lutjanidae	19	0.19	34	8	18.18	29
Mugilidae	2252	22.71	1	34	77.27	2
Mullidae	561	5.66	4	29	65.91	6
Pomacentridae	182	1.84	16	12	27.27	21
Pomatomidae	1299	13.10	2	15	34.09	15
Priacanthidae	6	0.06	44	3	6.82	44
Rachycentridae	1	0.01	50	1	2.27	48
Scaridae	42	0.42	26	8	18.18	29
Sciaenidae	44	0.44	24	5	11.36	38
Scombridae	539	5.43	5	21	47.73	9
Scorpaenidae	49	0.49	23	16	36.36	14
Serranidae	278	2.80	9	14	31.82	18
Sparidae	15	0.15	38	6	13.64	36
Sphyraenidae	19	0.19	34	9	20.45	27
Stromateidae	205	2.07	13	15	34.09	15
Triglidae	202	2.04	14	15	34.09	15
Uranoscopidae	11	0.11	42	8	18.18	29
Xiphiidae	10	0.10	43	7	15.91	35
Pleuronectiformes	312	3.15		23	52.27	
Bothidae	188	1.90	16	21	47.73	9
Cynoglossidae	118	1.19	18	11	25.00	23
Soleidae	6	0.06	44	5	11.36	38
Salmoniformes	3	0.03		2	4.54	
Gonostomatidae	2	0.02	47	1	2.27	48
Malacosteidae	1	0.01	50	1	2.27	48
Tetraodontiformes	624	6.29		43	97.73	
Balistidae	28	0.28	31	14	31.82	18
Diodontidae	2	0.02	47	2	4.35	45
Monacanthidae	200	2.02	15	30	68.18	4
Ostraciidae	1	0.01	50	1	2.27	48
Tetraodontidae	391	3.94	7	31	70.45	3
Others	187	1.88		27	61.36	
Total	9916	100.0		44	100.00	

TABLE VI-4. Most abundant families in neuston catch from MARMAP cruise D3-73 (Powles and Stender, 1976).

Rank	Numbers Caught (N = 9916	Rank	Occurrences (N = 44)
1.	Mugilidae 2252	1.	Carangidae 39
2.	Pomatomidae 1299	2.	Mugilidae 34
3.	Carangidae 784	3.	Tetraodontidae 31
4.	Mullidae 561	4.	Exocoetidae 30
5.	Scombridae 539	5.	Monacanthidae 30
6.	Exocoetidae 425	6.	Mullidae 29
7.	Tetraodontidae 391	7.	Gerreidae 24
8.	Blenniidae 304	8.	Blenniidae 22
9.	Serranidae 278	9.	Scombridae 21
10.	Coryphaenidae 248	10.	Bothidae 21
11.	Myctophidae 224	11.	Coryphaenidae 20
12.	Clupeidae 222	12.	Clupeidae 17
13.	Stromateidae 205	13.	Engraulidae 17
14.	Triglidae 202	14.	Scorpaenidae 16
15.	Monacanthidae 200	15.	Pomatomidae 15
		15.	Stromateidae 15
		15.	Triglidae 15

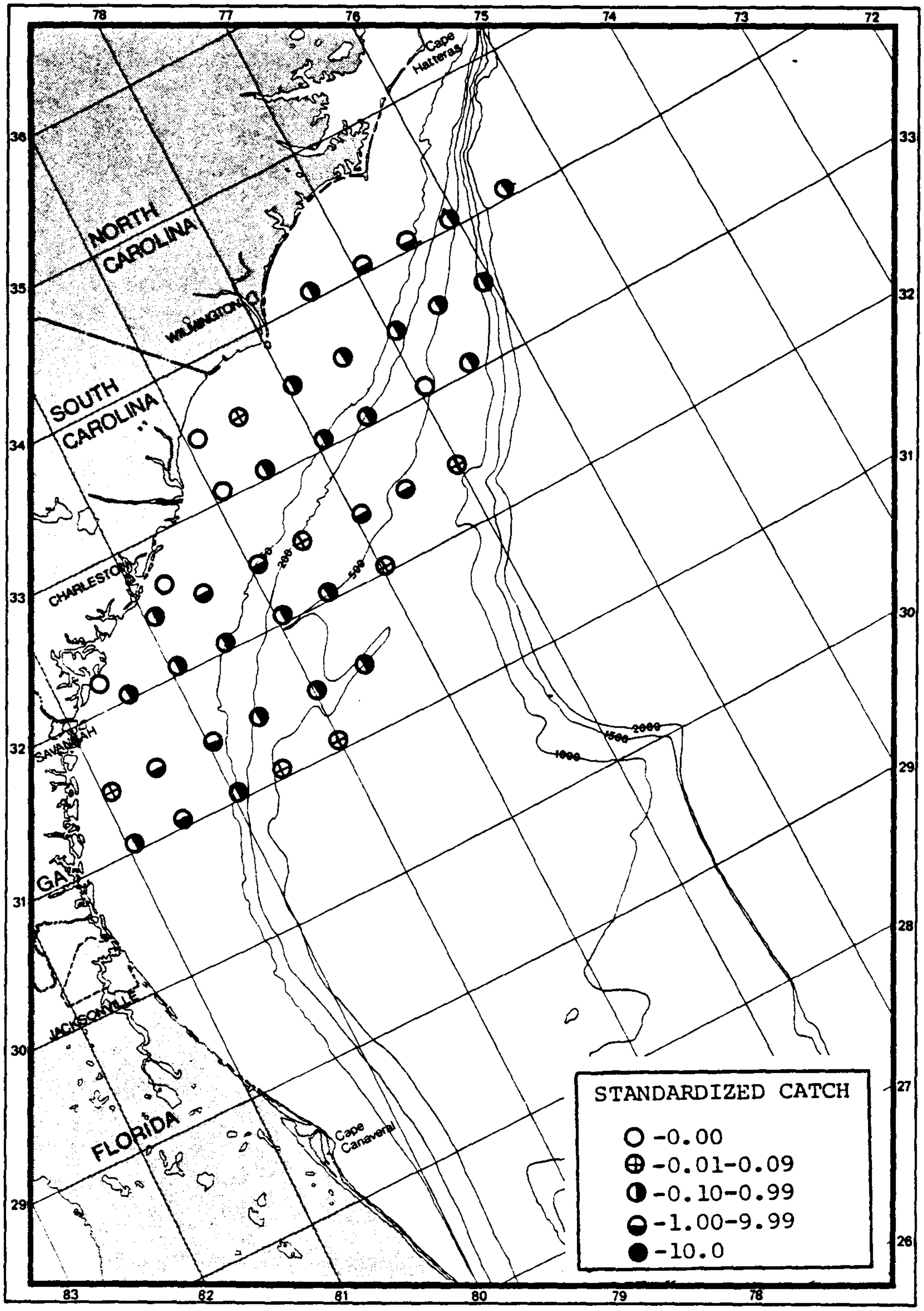

FIGURE VI-5. Distribution of young Carangidae from neuston net collections during MARMAP cruise D3-73 (Powles and Stender, 1976).

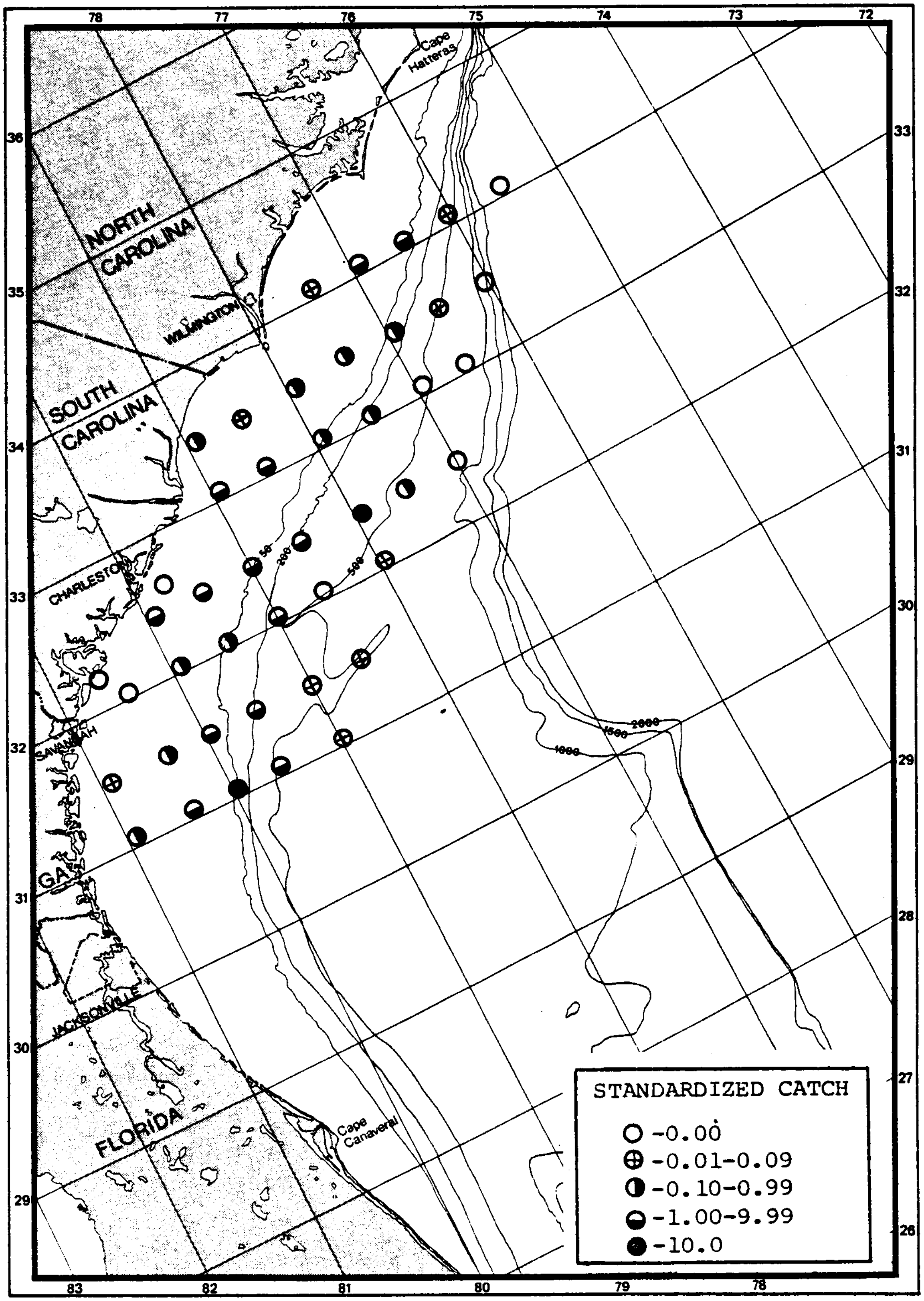

FIGURE VI-6. Distribution of young Mugilidae from neuston net collections during MARMAP cruise D3-73 (Powles and Stender, 1976).

The third cruise (D5-73) in the Powles and Stender (1976) report occurred during the fall. Results showed neuston catches of young fishes ranged from 0 - 6,344 specimens per tow. The differences between the composition of neuston and bongo catches were not as great as compared to the two previous cruises, but both nets had certain families more dominant than were found in the other sampler. The order-family composition for the full neuston collections is given in Table VI-5, with the 15 most abundant families given in Table VI-6.

Results of these three cruises show a wide variety of young fishes from this area. Powles and Stender (1976) state that the variety of fish families (e.g. 67 from neuston nets) indicates a diversity of environments inhabited by the fishes whose larvae and juveniles were collected in the samples. Both tropical and warm temperate species were represented, showing the influence of the drift of young tropicals from the Florida current. Warm temperate species were associated with the faunal assemblages of the South Atlantic Bight shelf. The composition of the neuston collections was dominated by young fishes from the Gadidae, Balistidae, Carangidae, Exocoetidae, Monacanthidae, and Mugilidae. Differences in neuston seasonality were noted, where fish abundance was greatest in winter, lower in spring, and lowest in fall. Of significance as priority fish, the Bothidae were consistently abundant and widely distributed. Other important fishery types common in these waters were Carangidae, Clupeidae, Gadidae, Mugilidae, Pomatomidae, Sciaenidae, Scombridae, and Serranidae. By identifying the areas of concentration for these larval and juvenile stages of these important groups, an appreciation of the potential impact to the fish can be realized if water quality modifications occur and jeopardize these species.

Powles (1978) discusses results of ichthyoneuston studies involving larval distribution for snappers and groupers of the South Atlantic Bight. His samples were collected during five cruises from continental shelf and slope waters between Cape Fear, North Carolina and Cape Canaveral, Florida. Bongo and neuston samplers were used following MARMAP procedures previously described. Snapper and grouper larvae were in low numbers representing less than 1 percent of the total larval catch. It was noted that the neuston net sampled these species less effectively during the hours of daylight than at night, but these forms were all present in the middle and outer continental shelf waters where the bottom depth was less than 20 meters. The grouper and snapper larvae were found to be most abundant in spring and summer, respectively. Powles indicated that the data suggests that recruitment patterns for snappers may be different from groupers in the South Atlantic Bight. The snappers, spawning

TABLE VI-5. Composition of catch of neuston net from MARMAP cruise D5-73 (Powles and Stender, 1976).

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Anguilliformes	44	1.57		13	31.7	
Atheriniformes	143	5.11		25	61.0	
Atherinidae	1	0.04	44	1	2.4	41
Belonidae	7	0.25	33	5	12.2	28
Exocoetidae	117	4.18	8	21	51.2	5
Hemiramphidae	18	0.64	22	12	29.3	7
Beryciformes	3	0.11		3	7.3	
Holocentridae	3	0.11	41	3	7.3	32
Clupeiformes	40	1.43		12	29.3	
Clupeidae	2	0.07	44	2	4.9	33
Engraulidae	38	1.36	17	10	24.4	9
Elopiformes	14	0.30		4	9.8	
Elopidae	12	0.43	27	4	9.8	29
Gadiformes	40	1.43		8	19.5	
Gadidae	17	0.61	23	2	4.9	33
Ophidiidae	23	0.82	20	6	14.6	25
Gasterosteiformes	45	1.61		22	53.7	
Syngnathidae	45	1.61	13	22	53.7	4
Lophiiformes	5	0.18		4	9.8	
Antennariidae	3	0.11	41	2	4.9	33
Ogcocephalidae	1	0.04	46	1	3.4	41
Myctophiformes	64	2.29		10	24.4	
Myctophidae	55	1.97	10	9	22.0	14
Paralepididae	1	0.04	46	1	2.4	4
Synodontidae	8	0.29	31	4	9.8	29

TABLE VI-5. Cont.

Order/Family	Number Caught	% of Total	Rank	Number of Occurrences	% of Total Stations	Rank
Perciformes	1644	58.77		40	97.6	
Acanthuridae	11	0.39	30	5	12.2	28
Apogonidae	6	0.21	35	6	14.6	25
Blenniidae	46	1.64	12	10	24.4	9
Callionymidae	188	6.72	4	10	24.4	9
Carangidae	301	10.76	3	26	63.4	2
Chaetodontidae	2	0.07	44	2	4.9	33
Coryphaenidae	40	1.43	16	11	26.8	8
Dactylopteridae	1	0.04	46	1	2.4	41
Gempylidae	7	0.25	33	4	9.8	29
Gerreidae	135	4.83	7	23	56.1	3
Gobiidae	42	1.50	14	8	19.5	20
Kyphosidae	12	0.43	27	9	22.0	14
Labridae	17	0.61	23	8	19.5	20
Lobotidae	1	0.04	46	1	2.4	41
Lutjanidae	1	0.04	46	1	2.4	4
Mugilidae	20	0.72	21	10	24.4	9
Mullidae	17	0.61	23	8	19.5	20
Pomacentridae	30	1.07	18	9	22.0	14
Pomatomidae	50	1.79	11	8	19.5	2
Scaridae	169	6.04	5	9	22.0	1
Sciaenidae	92	3.29	9	7	17.1	2
Scombridae	1	0.04	46	1	2.4	41
Scorpaenidae	13	0.54	26	7	17.1	24
Serranidae	41	1.47	15	10	24.4	9
Sparidae	3	0.11	41	2	4.9	33
Sphyraenidae	8	0.29	31	6	14.6	25
Stromateidae	1	0.04	46	1	2.4	4
Triglidae	377	13.48	2	9	22.0	14
Uranoscopidae	6	0.21	35	5	12.2	28
Xiphiidae	4	0.14	38	2	4.9	33
Pleuronectiformes	161	5.76		14	34.1	
Bothidae	152	5.43	6	13	31.7	6
Cynoglossidae	4	0.14	38	2	4.9	33
Soleidae	1	0.04	46	1	2.4	4
Salmoniformes	9	0.32		5	12.2	
Gonostomatidae	4	0.14	38	2	4.9	33
Tetraodontiformes	502	17.95		30	73.2	
Balistidae	5	0.18	37	5	12.2	28
Canthigasteridae	1	0.04	46	1	2.4	41
Monacanthidae	459	16.41	1	30	73.2	1
Ostraciidae	12	0.43	27	9	22.0	14
Tetraodontidae	25	0.89	19	10	24.4	9
Others	83	2.97		13	31.7	
Total	2797	100.00		41	100.00	

TABLE VI-6. Most abundant families in neuston catch from MARMAP cruise D5-73 (Powles and Stender, 1976).

Numbers Caught (N = 2797)		Occurrences (N = 41)	
1.	Monacanthidae 459	1.	Monacanthidae 30
2.	Triglidae 377	2.	Carangidae 26
3.	Carangidae 301	3.	Gerreidae 23
4.	Callionymidae 188	4.	Syngnathidae 22
5.	Scaridae 169	5.	Exocoetidae 21
6.	Bothidae 152	6.	Bothidae 13
7.	Gerreidae 135	7.	Hemiramphidae 12
8.	Exocoetidae 117	8.	Coryphaenidae 11
9.	Sciaenidae 92	9.	Engraulidae 10
10.	Myctophidae 55	10.	Blenniidae 10
11.	Pomatomidae 50	11.	Callionymidae 10
12.	Blenniidae 46	12.	Mugilidae 10
13.	Syngnathidae 45	13.	Serranidae 10
14.	Gobiidae 42	14.	Tetraodontidae 10
15.	Serranidae 41	15.	Myctophidae 9
		15.	Kyphosidae 9
		15.	Pomacentridae 9
		15.	Scaridae 9
		15.	Triglidae 9
		15.	Ostraciidae 9

in summer, have larvae over the outer shelf and slope at this time. Powles indicated retention of these larvae in an eddy-like current system influenced by a later summer southerly flow of surface water, followed by a return pattern. The groupers, by spawning in spring, have larvae on the outer shelf and slope region subject to a surface water drift that is northerly in direction during April. The northerly current would influence larval drift, offering the possibility for recruitment of populations from the Caribbean or Gulf of Mexico.

One of the important representatives to the neuston community is the bacteria, yet there appears to be a paucity of information on a defined bacterioneuston community in these shelf waters. Ferguson and Rublee (1976) studied nearshore planktonic bacteria at depths from 1-20m near Cape Lookout, North Carolina for ATP analysis and numbers of bacteria. They obtained acridine orange direct count estimates for numbers, cell dimensions frequencies, standing crop, and relation to particulate matter. Their results indicated that the bacteria averaged 6.6×10^5 cells/ml and 0.09 cubic microns per cell. They seldom found bacteria on particles smaller than 6 microns, with particles of 6 to 50 microns having colonies of 5 - 40 cells. There were few particles larger than 50 microns in their samples. They noted that 80 percent of the bacteria were free living cocci. The average volume of these cells was 0.03 μ^3 and they composed about 40 percent of the bacterial carbon; whereas, 75 percent of the rodshaped cells were found on particulate matter, and had an average volume of 0.3 μ^3, representing over 60 percent of the bacterial carbon. These data showed that the rods associated with particulate matter comprised only 15 percent of the total cell numbers but accounted for 45 percent of the bacterial carbon.

Gallagher (1975) examined the microsurface layer in a Georgia salt marsh to determine if the algal component was concentrated in the surface film of water flowing over the marsh and to determine its contribution to total phytoplankton photosynthesis. He noted by using fluorescence of acetone extracts that the film development appeared to be greater (15 times more abundant) than in the underlying water with the rising tide. He noted these surface populations consisted mainly of diatoms. With the outgoing tide, the surface film populations decreased and were comparable to the underlying waters. Gallagher (1975) stated that the natural surface film appeared to lift off the soil and marsh plant surfaces, being present when water covers the marsh, so that many of these diatoms have a benthic origin. In addition, about 37 percent of the plankton net photosynthesis was concentrated in the surface film. The respiration values at the film surface averaged 21 percent of the gross photosynthesis with the photosynthesis to respiration (PS:R) ratios ranging from 10.9 to 2.5. The film was more autotrophic in early spring than in early summer.

2.2 Collection Procedures

One of the major problems in neuston research is the lack of an accepted definition for the neuston community. This in turn fosters different approaches in the collection of specimens and major difficulties in the comparison of data from different investigators. This point was brought out by Hatcher and Parker (1974) in their laboratory-based comparisons of four surface microlayer samplers. These included the rotating drum, a metal screen, a tray, and a glass plate. They found that the results obtained by one sampling method cannot be compared with those from another. Some of their results are questioned by Garrett (1974), who states a bias was built into their studies since the laboratory experimental techniques did not duplicate the natural environment. Garrett (1974) concludes that, ideally, a microlayer sampling device should remove only those organic molecules residing at the air sea interface, and leave behind all subsurface water and constituents not contributing to the modification of the surface.

Crow, Ahearn, Cook and Bourquin (1975) used a membrane adsorption technique for counting surface slick microbial populations. Surface slicks and microlayers were adsorbed on sterile Nuclepore membranes (47mm diameter, 0.4 μm pore size) floated on the surface. These were retrieved by submerging sterile plastic dishes under them and removing the filter and the underlying water. Additional sub-surface membranes (10cm depth) were also taken with a sterile syringe. Crow et al. (1975) found the microbial surface populations were at least 100 times greater than those at 10cm. The most common bacteria of these surface films were non-chromogenic, motile, gram-negative rods.

Zaitsev (1971) reviews a variety of neuston collection devices for bacteria, microphytes, and the marine fauna. He discusses a bacterioneuston collector designed to sample the upper 2cm layer. A collector for phytoplankton is also described which will obtain water samples up to 2-3cm below the surface. Nets become the major apparatus for obtaining neustonic animals, with those designed for protozoa and smaller faunal types having an opening generally 60 x 20cm and a length of 250cm. Many of the designs include a vertical series of nets, positioned so that they will collect at specific levels below the surface. The nets designed for the larger invertebrates and larval fish tend to vary more in size and design.

The Boothbay neuston net has been used extensively for the collections of ichthyoplankton in the MARMAP cruises of the South Carolina Marine Resources Center. In their recent report, Eldridge, Berry and Miller (1977) give field results for comparing two models of the Boothbay neuston net. They were concerned with the relative catching ability, their ease of handling, and specimen damage to the ichthyoplankton by the two nets. The two nets had a 0.947mm Nitex mesh, with frames of galvanized and aluminum pipe. Lengths were 4.9m and 8.5m with ratios of mouth to open mesh aperature areas of 1:6 and 1:11, respectively. Forty-eight neuston tow samples were taken during a 25-hour period in an area over the shelf southeast of Charleston. The nets were towed from a boom extending from the starboard side at speeds of 1 - 3 meters/second. After each tow the catch was drained through a 0.85mm mesh sieve and preserved with 5 percent buffered formalin. These nets sampled to approximately 0.5m depth. Eldridge et al. (1977) found the 4.9m net superior to the 8.5m net in regard to handling the net and processing the specimens. There was no significant difference in the two nets for catching ability, with specimen damage becoming greater with an increase in towing speed. Eldridge et al. concluded that the 4.9m net would be preferred for routine surveys, with acceptable towing speeds between 1 and 3m/second, and that consideration should be given to time of sampling because of population variations associated with changes in the light conditions.

2.3 Other Studies

The concept that the neuston represent a community assoicated with the surface film also leads to the association of these biota to the non-living substances found floating near the surface. Thus, as collection devices have been developed to obtain the characteristic neuston components, they have also been successful in collecting the non-living materials. For example, Colton, Knapp and Burns (1974) reported the wide occurrence of plastic particles in the surface waters of the northwestern Atlantic. Using neuston net samplers (2 x 1 meter with a 0.947mm nylon mesh), a variety of plastic materials were collected. These included polystyrene spherules and styrofoam plastic particles, among others. Sherman, Colton, Dryfoos, Knapp and Kinnear (1974) noted significant amounts of tar balls off the eastern coast of the United States that were collected during neuston net fish surveys in the Gulf Stream.

Morris (1971) modified a neuston net to obtain quantitative estimates of zooplankton and found it applicable to the measurement of petroleum lumps at sea. Since such petroleum lumps, or tar balls, are commonly taken in net tows, he provided estimates for the quantity of tar lumps in the North Atlantic. He did this using a basic neuston net that collected specimens to a depth of 10cm. His tows were made at 20 stations in the northwestern Atlantic. Every tow had some lumps, with quantities ranging from 0.7 to 96.9 mg/m^3. The corresponding wet weights for the zooplankton in the same tows varied from 22 to 176 mg/m^3 of filtered sea surface water. In these collections there was no apparent correlation between the zooplankton wet weight values and the amount of tar. However, Morris (1971) noted that the tar lumps represented on the average slightly over 20 percent wet weight of the neuston samples. Morris expressed concern that these values are higher than many of the previous estimates for the amount of oil pollution in world seas, and that these earlier estimates may be too low. The relationship of these oil and tar lumps to the neuston community places greater importance on this surface area for the location of future detection and monitoring efforts. No doubt many of the neuston collection devices will also be used for quantifying the petroleum lumps, polystyrene, and various plastic particles that will accumulate in the surface waters.

2.4 Summation of Research Since 1973

Neuston includes a broad assortment of fauna and flora. Past study programs for this geographical area have emphasized specific groups (e.g. bacterioneuston, ichthyoneuston) rather than the entire community, and the various inter-relationships that may occur in that surface zone. The only extensive neuston study identified for the South Atlantic Bight was the MARMAP program of the Marine Resources Center of the South Carolina Wildlife and Marine Resources Department. The objectives of this program include assessing the groundfish and ichthyoplankton resources in off-shore waters between Cape Fear, North Carolina and Cape Canaveral, Florida; to conduct a taxonomic survey of the sciaenid developmental stages; and, to note distribution patterns of the areal groundfish. Of significance is the attention given to the representatives of the fish populations that occupy the surface waters. No other broad-based neuston study was made known to this author. There is no doubt that other investigators working in these waters will include surface tows of samplers, but due to the collection technique (which may not be inclusive of the surface community) or limitation of an organism position in this surface zone, the work is generally not considered by these investigators as a neuston study. This has resulted in a general lack of "neuston" studies for the South Atlantic Bight region.

This brings out the possibility that the term neuston may not be a valid division for establishing broad biotic groupings. Many of the faunal forms found there are faculative neuston and pseudoneuston types, with only limited association to this zone. However, this air-water interface represents a unique habitat that deserves a distinct classification and does have its share of euneuston forms. Possibly it's the euneuston, the floral and faunal species, that have their maximum abundance in this surface zone that should be considered true neuston. However, if we were to identify neuston as the occupants of the sub-surface zone limited to the upper 5cm (e.g. Zaitsev, 1971), this would exclude ichthyoneuston collection methods used in the MARMAP studies mentioned above (their samples go to 0.5m).

3.0 IDENTIFICATION AND LOCATION OF RAW DATA AND UNWORKED SAMPLES

The only accumulation of unworked neuston data and unworked samples for collections in the South Atlantic Bight area appear to be the ichthyoneuston collections presently being continued in the MARMAP program. These samples are being worked up with results reported in the technical report series of the South Carolina Wildlife and Marine Resources Department (e.g. Powles and Stender, 1976). Their data on physical and chemical parameters is reported to the National Oceanographic Data Center, and biological information is processed for computer analysis and reported to the National Marine Fisheries Service.

4.0 IDENTIFICATION OF DATA GAPS

There is generally little work being done on the neuston community, with only the MARMAP studies previously mentioned producing an extensive long-term coverage of the ichthyoneuston over the shelf waters of the region. The following represent areas where data gaps occur in neuston studies.

a). Complete identification of the seasonal constituents of the neuston community: This would include the floral and faunal components of near and far-shore areas over the South Atlantic Bight.

b). Identification of ecological relationships that occur within this neuston community: Factors to consider would be photosynthesis and productivity rates compared to the lower zones, decomposition activity, respiration relationships, the presence of nutrients and various metabolic by-products released and utilized within this zone, predator and prey relationships, and the influence of faculative and pseudoneuston types in this surface zone.

c). Determination of the relationships of the neuston community to the increasing presence of oil lumps and the by-products of oil decomposition: The larval stages of important fish and invertebrate species are now sharing this zone with these contaminants. As pollution of this type increases, what will be the impact to the neuston community?

d). Further refinement and standardization in many of the collection procedures.

5.0 RECOMMENDATIONS FOR FUTURE STUDIES

A wide range of studies would be applicable to the understanding of the composition and activities of this zone. Such studies are necessary to appraise ecological impact of changes in water quality to the neuston community.

a). A clearer picture is needed of the interrelationships that exist between the region of the air-water interface and biota that visit this region from other areas.

b). Since many of the problems associated with oil spills result in the presence of oil and oil by-products on or near the surface, the impact of such pollutants to these biota and their interactions within the ecosystem must eventually be determined.

c). In order to accomplish the above task, greater knowledge is required about the diurnal and seasonal composition of the total neuston population. It is necessary to know what biotic associations are present and how these relationships are modified in near and far-shore waters over the shelf.

d). More information is needed as to the extent autotrophic neuston contribute to the productivity of the shelf area.

e). The bacterioneuston represent a major constituent involved in decomposition of the naturally occurring biotic components and their wastes, as well as degrading processes associated with the various petroleum types. Further information on these activities and the subsequent influence of increased oil pollution on these activities is essential.

f). The effect that changing water qualities will have on the neuston populations is needed to more fully ascertain sensitivity and tolerances to pollutants and changing environmental conditions.

g). There is a need to establish the degree of relationship between the neuston populations of offshore regions and adjacent estuary systems. Questions arise as to what influence these associations have on the concentration of nutrients, productivity, and exchange cycling of neuston populations to each zone. A similar concern is found in the relationship of Gulf Stream neuston to the shelf water neuston of the South Atlantic Bight.

h). Further work is needed as to the influence of styrofoam and other various types of synthetic particles found in the neuston habitat in increasing numbers. They not only occupy space, but offer additional surface area for the development of neuston biota.

It is apparent that first the significance of the neuston community must be identified in relation to the ecology of shelf waters and adjacent estuaries. Then, an understanding is needed as to what effect pollutants and other environmental variables may have on this population and what would be the subsequent repercussion to the other biota associated with, or dependant upon, the neuston if they were to be affected in such a manner.

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VII. NEKTON

Dr. F. John Vernberg
Ms. Donna Z. Mirkes
Belle W. Baruch Institute for
Marine Biology and Coastal Research
Columbia, South Carolina

1.0 INTRODUCTION

1.1 Overview

The physical, chemical, biological, and geological characteristics of a particular marine environment dictate its resident and transient nektonic forms (deSylva, 1975). The term nektonic, as defined by Webster, refers to "free swimming aquatic animals essentially independent of wave and current action." The nektonic forms considered in this report include primarily the fishes, but also the natant molluscs and crustaceans, i.e., squids, scallops, shrimp, lobsters, and crabs of the estuarine and oceanic geographic areas from Cape Hatteras, North Carolina to Cape Canaveral, Florida. This region is referred to as the Carolinian Province (Roberts and Able, 1974). Although outside the exact geographical limits of this study area, data from studies of Albemarle Sound, North Carolina have been included in this report, as these waters are contiguous with those of Pamlico Sound, and it is unlikely that the species stocks are separate.

As the nektonic marine mammals, birds, and turtles are covered exclusively in Chapters XII, XIII, and XIV, they are not included here. The commercial and sports fishery data have been used as sources for much of the biological information, but the strictly commercial or sports aspects, such as catch statistics, are the subjects of Chapters IX and X. The larval forms of nektonic adults are the subjects of the chapters on Zooplankton (Chapter V) and Neuston (Chapter VI). Although some consideration is given here to the influences of man's activities on nekton, the topic is thoroughly examined in Chapter XIX, Toxicity and Health Studies.

This report includes data on the composition, distribution, and abundance of nekton of the Carolinian Province, plus population characteristics, seasonal and diurnal activities, and various aspects of their ecology.

1.2 Characteristics of the Habitat and Fauna

Reports based on trawling surveys on the continental shelf between Cape Fear, North Carolina and Cape Canaveral, Florida indicate a diverse assemblage of fish species (Barans and Burrell, 1976), presumably due to the various available habitat types. The variety of bottom habitats in the study region provides for a rich diversity of those nektonic forms which interact with benthic environments. Barans and Burrell (1976, Table VII-1) have classified the habitats in this region as coastal, open shelf, live bottom, shelf edge, and lower shelf. The depth limits

TABLE VII-1. Bottom habitat of the continental shelf between Cape Fear, North Carolina and Cape Canaveral, Florida (modified from Struhsaker, 1969).

Habitat Type	Depth Limits (m)	Present Study Depth Limits (m)	Estimated Bottom Area (km^2)
Coastal[1]	0 - 18	0 - 9	
		10 - 18	18,083
Open-shelf	18 - 55	19 - 27	16,100
		28 - 55	22,367
Live-bottom	18 - 55	19 - 55	6,524
Shelf-edge	55 - 110	56 - 110	4,775
Lower-shelf	110 - 183	111 - 183	3,615
		184 - 366	9,724
TOTALS	0 - 183	10 - 366	81,188

[1]Classification by Barans and Burrell (1976)

(Struhsaker, 1969) are given for each habitat type. The largest habitat is that of the open shelf sand bottom. Interspersed within the smooth bottom areas are live or hard bottom habitats.

Within the scope of the coastal classification are various habitats created and modified by local geographic and oceanographic conditions. The coastline of this region is characterized by a series of variously sized and shaped sandy barrier islands which separate the open ocean from salt marshes reticulated by intertidal waterways, estuaries, bays, lagoons, and large inter-connecting sounds (Freeman and Walford, 1976a, b). These more sheltered areas provide nursery and spawning grounds for many commercial and recreational species, temporary feeding grounds for reproductive migrators, i.e., the catadromous and anadromous fishes, as well as seasonal migrators. The most numerous finfish species which utilize the estuaries as nursery grounds include the menhaden (Brevoortia tyrannus), star drum (Stellifer lanceolatus), spot (Leiostomus xanthurus), seatrout (Cynoscion spp.), kingfish (Menticirrhus americanus), and the Atlantic croaker (Micropogon undulatus). The major shrimp and crab species of the southeastern Atlantic, the pink shrimp (Penaeus duorarum), the brown shrimp (P. aztecus), the white shrimp (P. setiferus), and the blue crab (Callinectes sapidus) also use the regional estuaries as nursery grounds. The black sea bass (Centropristis striata), king mackerel (Scomberomorus cavalla) and the Spanish mackerel (Scomberomorus maculatus) are some of the more recreationally and commercially important fish that enter the shallow coastal water to spawn (Burrell, 1975).

About a third of the fish which occur in the estuaries and shallow coastal waters of this region tolerate the seasonal temperature changes, and thus are the resident species. The most abundant of the resident species are anchovies and silversides (Freeman and Walford, 1976a). Many of the resident species may not have commercial or recreational value, but are necessary components of the ecosystem as a whole by virtue of their interactions with other species.

There are a number of species which are estuarine, bay, or sound residents only during their first one or two years of life. The older fishes move offshore during the winter, and inshore in the spring, establishing a life-long migratory pattern. Included in this group are the drums, flounders, croaker, seatrout, kingfishes, and spots. The spots, croaker, and flounders spawn offshore during the winter, with the newly hatched larvae migrating inshore. The adults remain offshore until spring (Freeman and Walford, 1976a).

Most of the species occurring in this region are the seasonal migrators, arriving from warmer waters in spring and remaining until the colder months. The tarpon, Spanish mackerel, and pompano travel alongshore, while the sailfish, king mackerel, barracuda, white and blue marlins, skipjack tuna, Atlantic bonito and blackfin tuna migrate in the deeper offshore waters (Freeman and Walford, 1976a).

The anadromous fishes of this region, which migrate upstream to spawn, include the river herrings, shad, striped bass, alewives, and Atlantic sturgeon (Freeman and Walford, 1976a).

The Gulf Stream flows northward along the edge of the continental shelf (Figure VII-1). In the geographical region of this study the proximity of this warm water mass to the coastline varies from 20 miles off Fort Pierce, Florida to 75 miles off the Georgia coast, to about 20 miles off Cape Hatteras, thus affecting the inshore-offshore distribution of many species. Various subtropical and tropical pelagic species, including wahoo, blackfin tuna, king mackerel, and dolphins are associated with the Gulf Stream. The sargassum weed associated with the surface of the Gulf Stream harbors many small pelagic fishes and other species, including shellfish, dolphins, mackerels, marlins, tunas, and juvenile and larval jacks. Various demersal species, including the snappers and groupers, are found in the deeper Gulf Stream waters.

The geological, biological, physical, and chemical characteristics of the marine environment between Cape Hatteras, North Carolina and Cape Canaveral, Florida interact to create a multitude of varied ecosystems. The diversity of available habitats within these ecosystems is mirrored in the wide variety of existent nektonic species.

1.3 Characteristics of the Data Base

Data sources utilized in this report fall into several categories: 1) shelf-wide multi-faunal surveys; 2) surveys of a defined area, such as a bay, sound, or estuary; 3) species population studies; and 4) site-specific studies for environmental impact purposes. The broadest category is the shelf-wide survey, generally designed to provide information on the distribution, abundance, composition, and biomass of a variety of species. An example of this type of survey is the MARMAP (Marine Resources Monitoring Assessment and Prediction) program conducted by the South Carolina Marine Resources Institute in cooperation with the National Marine Fisheries Service. The primary aim of this program is and has been to survey the living marine resources between Cape Fear, North Carolina and Cape Canaveral, Florida. Beginning in 1973 at

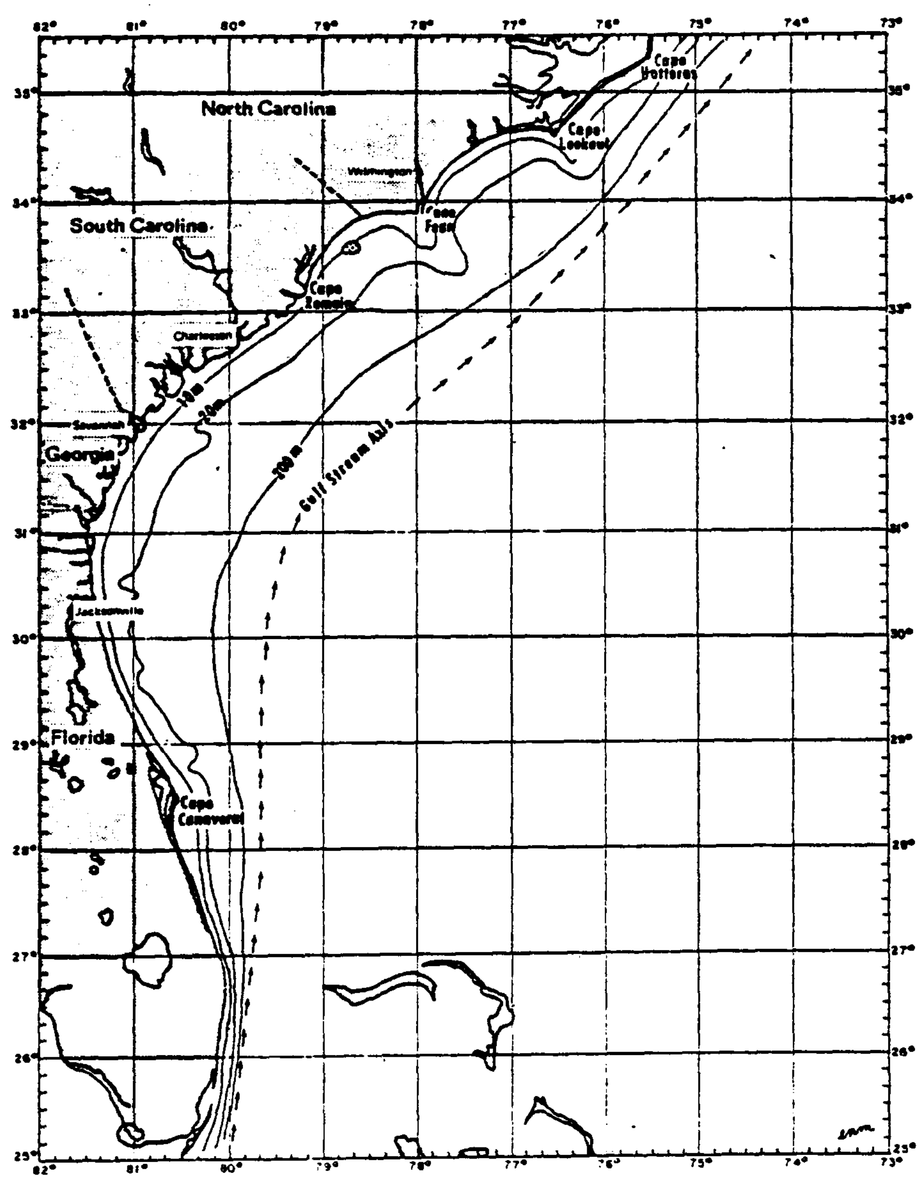


FIGURE VII-1. A map of southeastern United States coastal waters showing depth contour lines and main axis of the Gulf Stream (Burrell, 1978).

least two major cruises occur yearly to collect information on groundfish resources, life history studies of commercial and recreational species, benthic faunal composition, bottom type, salinity, temperature, dissolved oxygen, and available nutrients. Reports of these particular studies are available from the South Carolina Marine Resources Library as technical reports. Preliminary reports are also available from the principal investigators.

Surveys of particular areas within a state's boundaries are often conducted by various state agencies which deal with natural resources, or university-affiliated marine laboratories. Frequently these studies are aimed at collecting information pertinent to commercial or recreational fishery resource management, and provide a considerable range of biological data on one or more species. An example is the survey of Onslow and Long Bays conducted in 1977 by the North Carolina Division of Marine Fisheries to determine several areas for potential rock shrimp harvest. Reports of these kinds of studies are available as reprints from scientific journals, dispensed by authors, as technical reports from the research institutions, or through government agencies such as the National Marine Fisheries Service, which often supports this type of research.

Species population studies generally fall into two main categories, those aimed at 1) resource management; and 2) the assemblage of threatened or endangered species information. An example of the resource management population study is a recent report by Murawski and Pacheco (1977) entitled "Biological and Fisheries Data on Atlantic Sturgeon, Acipenser oxyrhynchus (Mitchill)." Marine Fishes by Schwartz, Hassler, Reintjes and Street (1977), presents various biological data on several endangered fish of North Carolina. These types of reports can usually be obtained from the institution involved.

Studies of a particular site are undertaken to predict the potential impact of power or industrial plant discharge on the biota of the immediate area, particularly if the species are of commercial importance. Carolina Power and Light Company, for example, has supported various ecological studies of a salt marsh in Brunswick County, North Carolina, where a nuclear-generated power plant was to be constructed (Schwartz, Clayton, Fast and Rohde, 1975). This information is being used as a standard against which to compare subsequent data, and is obtainable from the power company. Unlike data published in journals or federal agency publications, progress reports and final reports submitted to private companies, such as the Carolina Power and Light Company, or to state or Federal agencies, are not easily obtained. Although most of these reports have not undergone the same stringent review process as papers in journals, they contain valuable information.

For this chapter, two computerized information services were utilized: 1) ENDEX/OASIS (Environmental Data Index and the Oceanic and Atmospheric Scientific Information System) using the Biological Information Retrieval System (BIRS) as a data base; and 2) Biosis Previews, using Bioresearch Index and Bioabstracts as the data base.

The NOAA National Oceanographic Data Center generates and maintains the marine biology data base, BIRS. This information is available free to NOAA personnel, including NOAA-supported agencies and institutions. Subject areas referenced in this file include environmental factors, ecology, zooplankton, phytoplankton, benthos, productivity, growth, biodeterioration, nutrient cycles, food chains, microbiology, pollution, bioluminescence, deep scattering layers, poisonous and nonpoisonous organisms, dissolved and particulate organic matter, and drugs from the sea. This file includes references from 1955-1974. This system was searched using the descriptor "nekton."

Biosis Previews is a computerized bibliographic retrieval system utilized through the University of South Carolina's Cooper Library Reference Department. Seventy-two biological and geographical descriptors were used. The use of Bioresearch Index and Bioabstracts as a data base covers a large majority of published literature in the field of marine biology. In addition, numerous references were obtained by checking the literature cited in the papers listed by these computerized information services. Another source of references originated from investigators contacted in the survey of ongoing research programs (see Section 4.0). By cross checking all of the sources listed above, plus some key references not found in the earlier report on this region, a comprehensive review of the literature since 1972 was accomplished.

2.0 SUMMARY OF RESEARCH SINCE 1972-1973

2.1 Faunal Composition and Distribution

2.1.1 Introduction

While the latitudinal and longitudinal range of a particular nektonic species may be easily described by geographical locale, the vertical distribution, age-class composition, and relative abundance of that species is not so simply determined. Various biotic and abiotic factors interact to create the environments favorable to the various life history stages of a species. One of the most important determinants of distributional change is water temperature. As the climate from Cape Hatteras, North Carolina to Cape Canaveral, Florida changes from temperate to subtropical, seasonal changes in water temperature occur. The seasonal movements of nekton due to these changes in water temperature alter the limits of a species' distribution. Species composition of a specific community and abundance of a species' various life history stages within a given area--whether an entire coastline or the confines of an estuary--must be considered in terms of season, recruitment, water temperature, prevailing currents, depth, salinity, food availability, and competitive interactions, as well as a myriad of other ecological influences.

Data on biomass and density are not as plentiful as those for distribution and composition, but they do provide an added dimension to the biological information for an area. Therefore these data are incorporated into this section. Data for this portion of the report derive from two main sources: 1) commercial and recreational fisheries; and 2) resource management studies. The species discussed in depth include the following: white and blue marlin, albacore, bass, Atlantic thread herring, bluefish, tilefish, weakfish, scorpionfish, menhaden, basking shark, various anadromous species, several commercially important crustaceans, and cephalopod and bivalve molluscs. Incidental consideration is given to the leeches. Freeman and Walford (1976a, b) compiled an annotated list of the most commonly caught fish, including shellfish, of the marine environment from Altahama Sound, Georgia to Fort Pierce Inlet, Florida (see Appendix VII-A).

2.1.2 Fish

2.1.2.1 Open Ocean and Coastal Water Studies

The white marlin, *Tetrapturus albidus*, occurs throughout the Atlantic from $35^{o}S$ to $45^{o}N$ (Mather, Clark and Mason, 1975; Figure VII-2). Since most distributional data have come from Japanese catch statistics, the limits of its normal range and seasonal distribution are not well defined. Generally marlin occur in blue waters deeper than 100m, with salinities of 35-37 parts per thousand ($^{o}/oo$), and with surface temperatures higher than $22^{o}C$. The distribution of spawn, larvae, and juveniles is poorly known. In the North Atlantic from Cape Hatteras, North Carolina to Cape Cod, Massachusetts the white marlin is abundant along the continental shelf edge in the summer and early fall (Figure VII-3). The summer concentration in this region supports the largest sport fishery for the white marlin in the world. Bottom topography also apparently influences the distribution of this species. The white marlin seems to concentrate for feeding in areas of shoals,

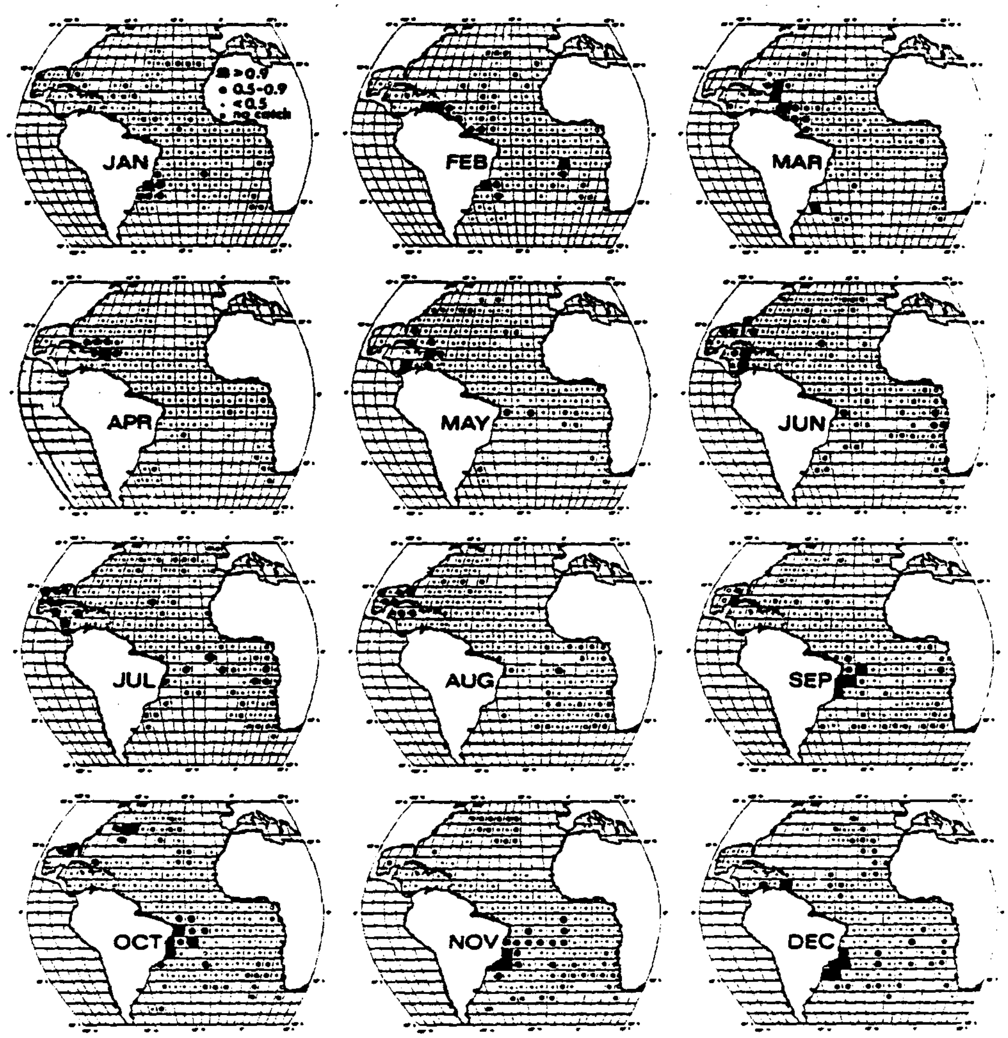


FIGURE VII-2. Distribution and apparent relative abundance of white marlin in the Atlantic Ocean. Data are from records of the Japanese longline fishery, 1956-67. The catch per unit effort (CPUE) for each month in rectangle is the arithmetic mean of the CPUE of each month that the area in the rectangle was fished in the 12-yr. period. CUE is the number of fish caught per 100 hooks. (from Mather et al., 1972, reprinted from Mather, Clark and Mason, 1975).

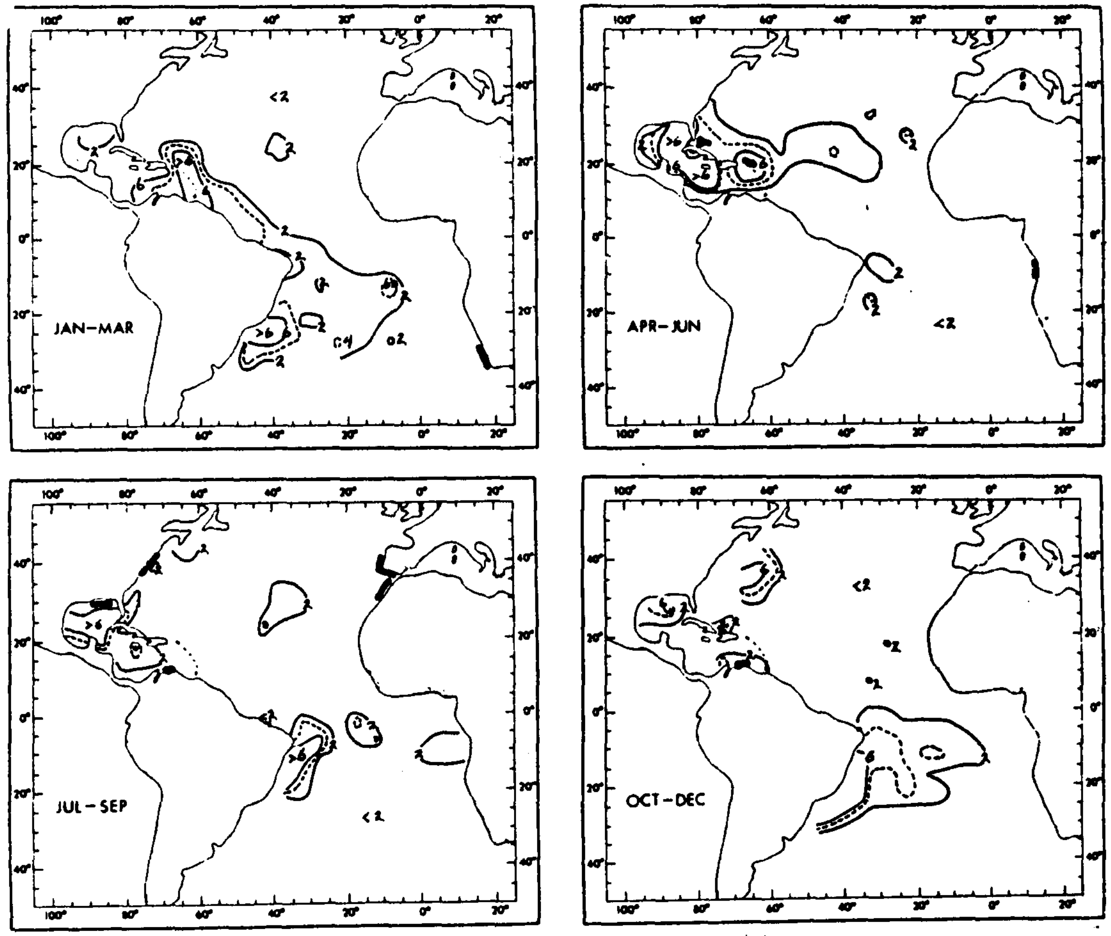


FIGURE VII-3. Distribution of catches of white marlin (per 1000 hooks) in the four quarters of the year, 1956-68 (from Wise and Davis, 1963, reprinted from Mather, Clark and Mason, 1975).

submarine canyons, and steep drop-offs.

Rivas (1975) has provided a review of biological information on the blue marlin. The latitudinal range for the blue marlin (Makaira nigricans, Lacepede 1802) in the Atlantic Ocean extends from 45°N to 35°S. A seasonal concentration occurs from June to November between 10° and 35°N in the western North Atlantic. Larvae have been collected off the Georgia coast and northeast of Fort Pierce, Florida. Various ecological determinants affect the distribution of the blue marlin. (See Sections 2.3 and 2.4 for further information.) Off the southeastern United States catches have been reported in surface water temperatures from 21.7°C in February to 30.5°C in July.

The sailfish belong to one species, Istiophorus platypterus (Jolly, 1975). This species is found throughout the warm waters of the world (Beardsley, Merrett and Richards, 1975), preferring temperatures greater than 21°C (Jolley, 1975). In the western Atlantic its range has been reported from latitude 30°S to 35°N by Beardsley et al., 1975, with the northern range extended to 35°N by Jolley (1977). The sailfish is most abundant in continental shelf waters and near land masses (Jolley, 1975; 1977). Its distribution is markedly seasonal (Figure VII-4). Although it is found off Florida's east coast during the entire year (Irby, Jolley and Joyce, 1976), becoming abundant offshore from the Jacksonville-Mayport area from May through October, in southeast Florida waters, it is most abundant December through February (Jolley, 1975). Sailfish larvae have been taken from the Gulf of Mexico and the western Atlantic, March through November, and it is thought that they develop in the warm currents (Beardsley et al., 1975). From October through December many immature sailfish are found along the Florida Keys. Presumably these immature specimens migrate south from the mid-Atlantic United States coast and the northern Gulf of Mexico due to various environmental changes, including lower water temperatures and salinity (Jolley, 1975). During spring and summer some spread northward as far as the Carolinas and Virginia, but tagging and recapture data have shown no distinctive annual migratory patterns of stocks. Some individuals migrate more than a thousand miles, going between the Atlantic and the Gulf of Mexico (Irby, et al., 1976).

The longbill spearfish, Tetrapturus pfluegeri, occurs in the western Atlantic from New England to Venezuela (Robins, 1975) but is considered rare in United States waters.

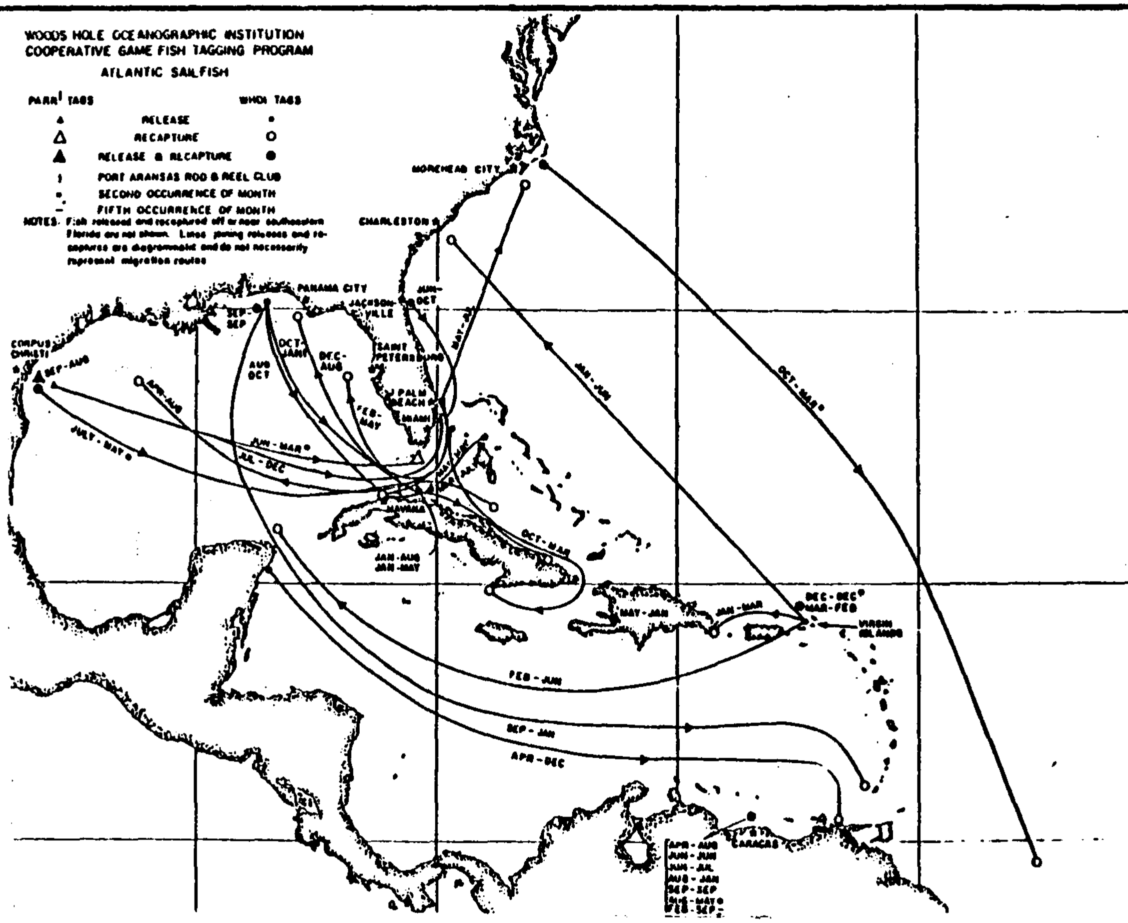


FIGURE VII-4. Releases and recaptures of sailfish in the North Atlantic Ocean (from Mather et al., 1974, reprinted from Beardsley et al., 1975).

The distribution of the swordfish, Xiphias gladius, in the Atlantic does not appear to be influenced by season, latitude, longitude, open ocean areas, or land masses (Wise and Davis, 1973; Figure VII-5). This conclusion is based on the catches of the Japanese longline fishery during the years 1956-1968.

The distribution of albacore, Thunnus alalunga in the Atlantic shows a seasonal movement, east in the warm months, west in the winter (Wise and Davis, 1973). These data represent Japanese longline fishery catches for the years 1956-1968. (See Figure VII-39; Section 2.3.2)

The striped bass, Morone saxatilis, which is found naturally along the Atlantic coast from the St. Johns River, Florida northward to the St. Lawrence River, inhabits nearshore coastal waters, adjacent bays, sounds, and tidal rivers. It is sufficiently abundant to have supported large commercial and recreational fisheries since the late 1930s (Smith and Wells, 1977). Koo (1970) reviewed the commercial landing of striped bass along the Atlantic coast of the United States from prior to 1930 to 1966. Yearly and geographical fluctuations were observed with North Carolina having its own distinctive pattern.

Information on distribution and abundance of sea bass (Centropristis striata and C. philadelphica) from Massachusetts to South Carolina based on interviews with fishermen was presented by Frame and Pearce (1973), especially as it relates to fishery problems. The black sea bass, C. striata, is found in the Atlantic coastal waters from Massachusetts to Cape Canaveral, Florida (Kendall, 1977), while C. philadelphica is found from North Carolina to the Gulf of Mexico. During the warmer months, these species are most abundant in inshore waters, but move offshore in the colder months.

Based on catch data on tagged specimens, Pristas and Cheek (1973) estimated the size of the Atlantic thread herring, Ophisthonema oglinus, populations in southeastern waters to be 702.6 million fish during September 1968 and 1,217.2 million fish from September through November 1969.

Wilk (1977) recently reviewed the literature on the bluefish, Pomatomus saltatrix, and described its seasonal distribution along the Atlantic coast (Figure VII-6). Two major areas and seasons of spawning exist: one is offshore near the inner edge of the Gulf Stream from southern Florida to North Carolina in the spring; the second is in the Mid-Atlantic Bight over the continental shelf in summer. Spawning at each site probably proceeds "sequentially", as waves. This species is gregarious, migratory, and pelagic.

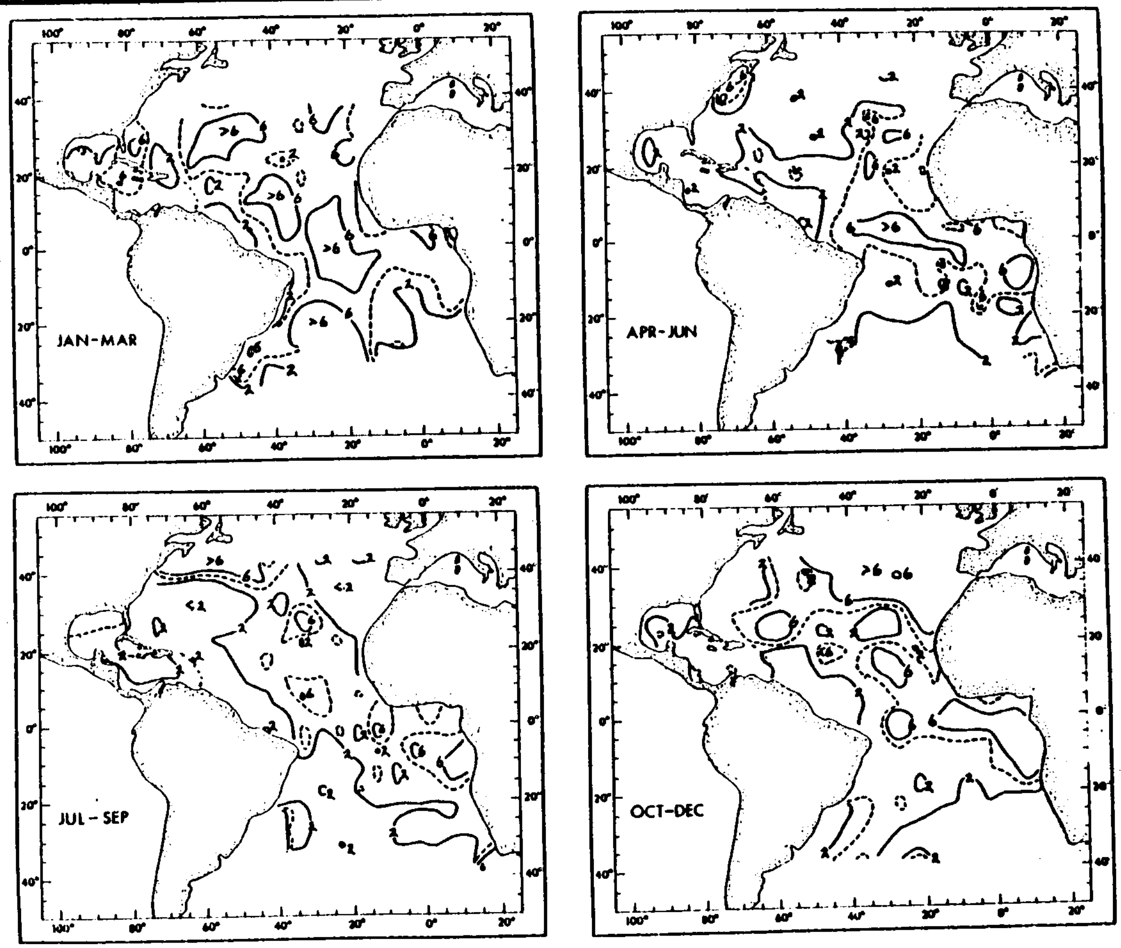


FIGURE VII-5. Distribution of catches of swordfish (per 10,000 hooks in the four quarters of the year, 1956-68. (Reprinted from Wise and Davis, 1973).

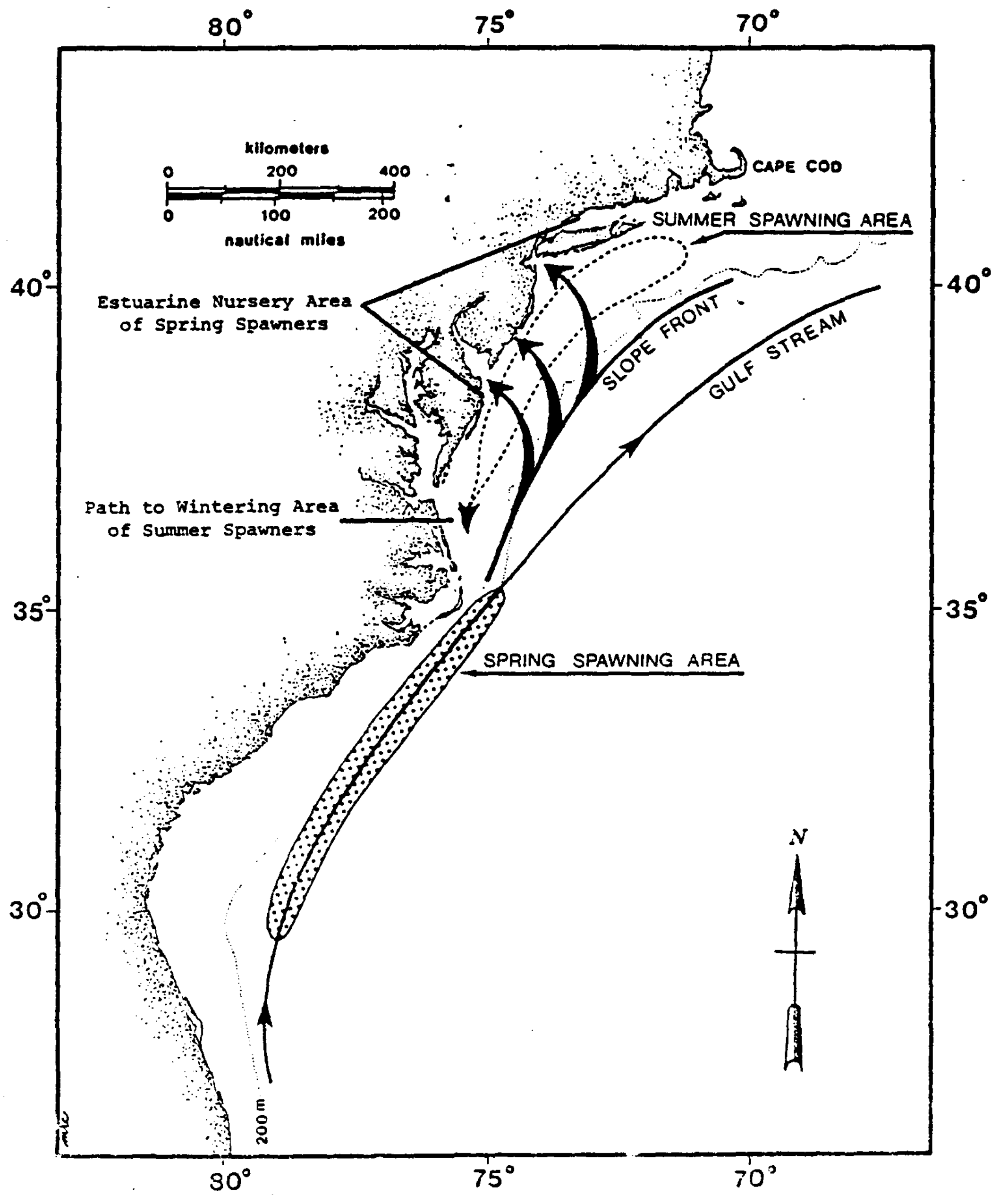


FIGURE VII-6. Diagrammatic representation of bluefish, Pomatomus saltatrix, early life history along east coast of U. S. (from: Kendall, ms.,; reprinted from Wilk, 1977).

Generally, aggregations move northward in spring and summer and southward in fall and winter.

Recently, Freeman and Turner (1977) updated information on the distribution of the tilefish, Lopholatilus chamaeleonticeps, which is found along the outer half of the continental shelf and the upper part of the continental slope bordering the entire coast of the United States. Within this area, the tilefish is restricted to a relatively narrow band about 37km (20 miles) wide which ranges in depth from 76 to 457m (250 to 1,500 feet), although tilefish farther south occur in greater depths. Also, larger sized individuals tend to be found at greater depths. Distribution of tilefish appears to be correlated with water temperatures in the range of 9.4^{o} to $14.4^{o}C$. This species appears to be the most abundant fish species occurring on the bottom along the outer edge of the continental shelf. Although little is known of the density of this species, Freeman et al. (1977) report that it occurs in clusters and that in a 4.8 by 4.8km area, some 5,000 individuals (36,400kg) were caught over a six month period. However, changes in density in a given area per unit time may change dramatically within a short period of time for unknown reasons.

The weakfish, Cynoscion regalis, occurs from southern Florida to Massachusetts Bay, occasionally straying northward into Canadian waters (Wilk, 1976). Distributional information on this species has originated almost entirely from commercial and recreational fishermen, supplemented by more incidental research vessel data.

McEachran and Eschmeyer (1973) reported a northerly range extension to North Carolina for the scorpionfish, Scorpaena isthmensis. The specimen was collected at a depth of 27.4m (15fms). In another study, the northeastward extension of the range of the spinythroat scorpionfish, Pontinus nematophthalmus, the deep reef scorpionfish, Scorpaenodes tredecimspinosus, and Ectreposebastes imus to the waters of the Carolinas was reported by Anderson, McKinney and Roumillat (1975). The occurrence of the plumed scorpionfish, Scorpaena grandicornis, in North Carolina (a northward range extension of about 1200km) was first reported by Burgess and MacPherson (1974). Scorpionfish have tropical affinities.

Kendall and Reintjes (1975) reported on the geographical distribution of menhaden, Brevoortia tyrannus eggs and larvae from Cape Lookout, North Carolina to Martha's Vineyard, Massachusetts. Larvae were equally distributed in shallow (0-15m) and deep (18-33m) tows during night and day. They were found in temperatures ranging from 0^{o} to $25^{o}C$ and a salinity range of 29 to 36 o/oo.

Seasonal shifts in geographic pattern of larvae indicated spawning started in summer off New Jersey and New York, became widespread in the Mid-Atlantic Bight in fall, and continued into winter off North Carolina.

Kemmerer, Benigno, Reese and Minkler (1974) developed eight empirical models to predict menhaden distribution based on combination of secchi disc transparency, water depth surface salinity, and Forel-Ule color measurements. Also they found that the Earth Resources Satellite No. 1 (ERTS-1, now called Landsat 1), Multispectral Scanner (MSS) Band 5 (600-700 bandpass) imagery density levels correlated with photographically-detected menhaden distribution patterns. An unusual distributional pattern in adult Atlantic menhaden was reported by Guthrie and Kroger (1974). Those adults which school in estuarine nursery areas are usually injured or parasitized with the isopod, Olencira praegustator.

Holland and Yelverton (1973) analyzed trawlsampling data for anadromous fish collected from 1 February 1968 to 1 July 1971, between Cape Romain, South Carolina and Cape Charles, Virginia, in depths from 5 to 500m. A total of 9,734 anadromous fishes representing seven species were collected (Table VII-2). In waters off North Carolina, the greatest abundance occurred from December through March. Also, few anadromous fish were collected in depths of more than 37m. However, other species of fish were collected at other depths. For example, at depths greater than 146m, the following species were numerous: smooth dogfish (Mustelus canis), spiny dogfish (Squalus acanthias), silver hake (Merluccius bilinearis), four-spot flounder (Paralichthys oblongus), goosefish (Lophius americanus), and butterfish (Peprilus triacanthus). At depths from 37 to 146m, concentrations of planehead filefish (Monacanthus hispidus), scup (Stenotomus chrysops), Atlantic mackerel (Scomber scombrus), northern searobin (Prionotus carolinus), and round herring (Etrumeus teres) were found. Samples taken from the surf zone out to 37m resulted in large catches of bluefish (P. saltatrix), spiny dogfish, summer flounder (Parlichthys dentatus), orange filefish (Aluterus schoepfi), butterfish, striped anchony (Anchoa hepsetus), goosefish, Atlantic herring (Clupea harengus harengus), and various Sciaenidae, chiefly weakfish (C. regalis), spotted seatrout (C. nebulosus), spot (Leiostomus xanthurus), silver perch (Bairdiella chrysura), Atlantic croaker (Micropogon undulatus), and red drum (Sciaenops ocellata).

Johnson, Holland and Keefe (1977) sampled anadromous fishes from Beaufort Inlet, North Carolina to Little Machipongo Inlet, Virginia at depths from just outside the surf zone to 31.1m. The greatest number of individuals were found north of Cape Hatteras.

TABLE VII-2. Relative abundance and depth distribution of offshore anadromous fishes of North Carolina (as indicated by total catch, average catch per sample, and percent of samples taking offshore anadromous fish) 1970-71 (Holland and Yelverton, 1973).

	INSHORE (332 samples) 0 - 10 fm.			MID-SHORE (17 samples) 11 - 20 fm.			OFFSHORE (8 samples) 21 - 300 fm.		
Species	Total catch	Avg. catch	Pct. with fish	Total catch	Avg. catch	Pct. with fish	Total catch	Avg. catch	Pct. with fish
Striped bass (<u>Morone</u> <u>saxatilis</u>)	894	2.7	31.0	0	0	0	0	0	0
American shad (<u>Alosa</u> <u>sapidissima</u>)	353	1.1	3.9	2	0.1	5.9	0	0	0
Shortnose sturgeon (<u>Acipenser</u> <u>brevirostrum</u>)	1	*	0.3	0	0	0	0	0	0
Atlantic sturgeon (<u>Acipenser</u> <u>oxyrhynchus</u>)	94	0.3	13.0	0	0	0	0	0	0
Blueback herring (<u>Alosa</u> <u>aestivalis</u>)	2371	7.1	10.8	494	29.1	41.2	0	0	0
Alewife (<u>Alosa</u> <u>pseudoharengus</u>)	316	0.9	6.6	49	2.9	29.4	0	0	0
Hickory shad (<u>Alosa</u> <u>mediocris</u>)	43	0.1	3.0	0	0	0	0	0	0
	4072			543					

*less than 0.1 fish/sample

Striped bass, Atlantic sturgeon, and hickory shad were encountered exclusively in the inshore zone. In contrast, American shad, blueback herring, and alewife occurred both in the inshore and midshore zones. An apparent decline in the numbers of river herring in 1976 relative to catches in 1972-1973 occurred despite restrictions placed on foreign fishing activity.

Murawski and Pacheco (1977) reviewed the literature on the distribution and biology of the Atlantic sturgeon, Acipenser oxyrhynchus. This anadromous species is no longer abundant in the region from Cape Hatteras to Cape Canaveral where once it supported a fishery. Sholar (1975) reported collecting only five specimens in 1975 and one in 1974 when surveying the New and White Oak River systems in North Carolina.

The distribution and recreational potential of four species of snappers (Lutjanus campechanus, L. vivanus, L. buccanella, and Rhomboplites aurorubens) along the coast of the Carolinas was discussed by Grimes, Manooch, Huntsman and Dixon (1977). Both L. campechanus (red snapper) and L. vivanus (the silk snapper) are found southward from North Carolina. Typically the red snapper is found at moderate depths of 46-91m on both high and low relief hard bottoms on the outer continental shelf. During warmer months they move to shallower waters, and migrate to deeper waters with the approach of winter. Normally the silk snapper is found in deeper water (55-128m) off the Carolinas. The usual habitat of the blackfin snapper, L. buccanella, is the edge of the continental shelf (82-146m), but they have been reported from live-bottom areas in depths from 9-219m. Of the four species, the vermillion snapper, R. aurorubens, is frequently caught by sports anglers. Along the northern North Carolina coast, they occur in numbers at depths between 64-128m, but in more southern waters they are most abundant at 33-64m. In northern Florida, they are found once again in deeper waters of about 91m.

Beach seining in the Hunting Island, South Carolina surf zone indicated the predominant species were the Atlantic silverside (Menidia menidia), striped (Mugil cephalus), and white (Mugil curema) mullet, bay anchovy (Anchoa mitchilli), and Florida pompano (Trachinotus carolinus) (Shealy, Boothe and Bearden, 1975). Beach seining near the Fripp Inlet (1967-1970) demonstrated that the area provided an important habitat for permit (Trachinotus falcatus), southern kingfish, juvenile Florida pompano, bay anchovy, striped and white mullet, Atlantic silverside, striped killifish (Fundulus majalis), blue crab (Callinectes sapidus and C. ornatus), brown shrimp (Penaeus aztecus), and white shrimp (P. setiferus). Spot (Leiostomus xanthurus), Atlantic menhaden (Brevoortia tyrannus), brown shrimp, several species of flounder, and mullet are at larval and postlarval recruitment peaks during February to mid-April

Occurrence of the ocean sunfish, Mola mola, from the beaches of South Carolina and adjacent waters since 1912 was reviewed by Anderson and Cupka, 1973.

Springer and Gilbert (1976) reported a range extension of the basking shark, Cetorhinus maximus, to the Gulf of Mexico and found some morphometric differences when compared to specimens from California and the southeastern North Atlantic waters (St. Augustine, Florida). Members of the requiem shark genus Carcharhinus dominate the estuarine, inshore, and shelf waters of North Carolina, with sizes ranging from 1.2-4.3m (Schwartz and Burgess, 1975). Thirty-five shark species are known from North Carolina waters, and ten more species may be added to this list (Table VII-7) with further sampling.

Schwartz and Safrit (1977) reported the unusual appearance of a white specimen of the southern stingray, Dasyatis americana, in Pamlico Sound, North Carolina. Other species of elasmobranchs exhibit this albinistic condition, but inadequate data exist to assess its ecological significance or causes.

The rosette skate, Raja garmani Whitley occurs from New England to the Dry Tortugas (McEachran, 1977). Specimens from north and south of Cape Hatteras demonstrate marked size differences at maturity (Figure VII-7). From Cape Hatteras north to Nantucket Shoals, mature individuals range from 330-439mm total length, while south of Cape Hatteras they range from 248-335mm. Other than size there is little difference between the two forms.

Huntsman summarized the research on bottomfish by the Southeast Fisheries Center, National Marine Fisheries Service, Beaufort, North Carolina during the period of 1972-1977 at a workshop on snapper/grouper resources of the South Atlantic Bight (Cupka, Eldridge and Huntsman, 1977). In 1976, a similar meeting was held to discuss the snapper-grouper fishery resources of the western central Atlantic Ocean (Beaumariage and Bullock, 1976). Based on a headboat survey, the distribution and abundance of various bottomfish species was described by Huntsman (1977). Since much of their data have economic implications, the reader is referred to the section on commercial fishing by Martin (Chaper IX). As part of the MARMAP program (Marine Resources Monitoring Assessment and Prediction Program), the area between Cape Fear, North Carolina and Cape Canaveral, Florida is being routinely sampled by the South Carolina Wildlife and Marine Resources Department. The data resulting from their surveys are computerized for rapid access and

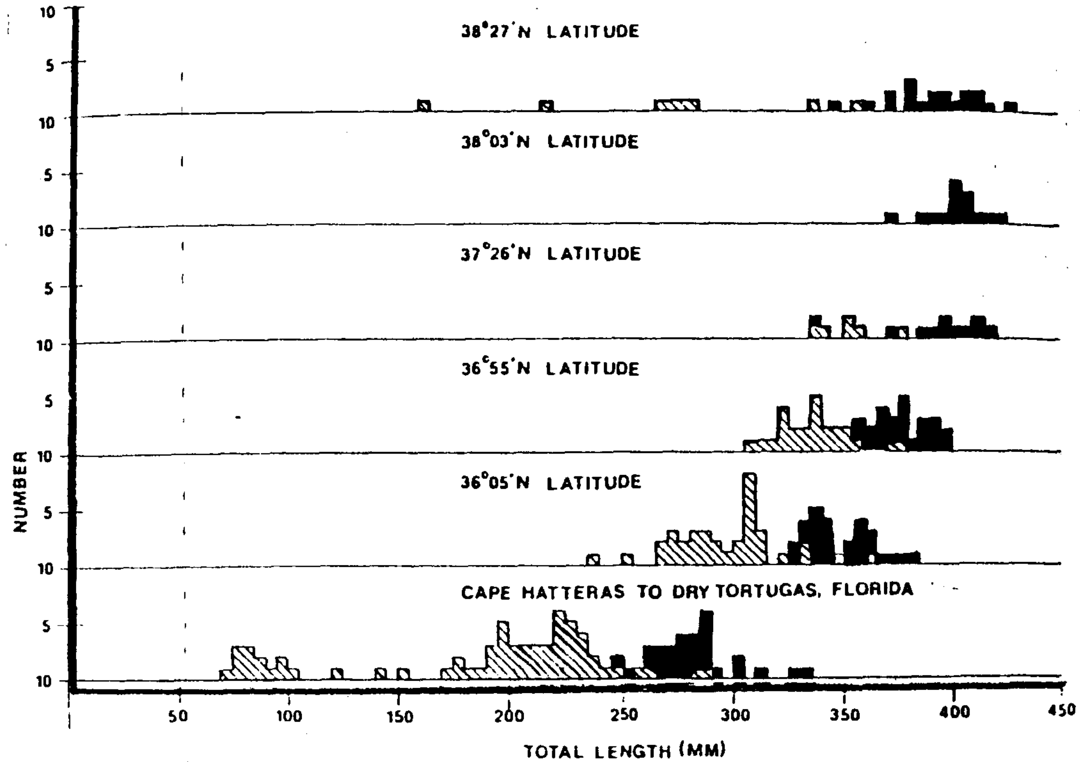


FIGURE VII-7. Length frequencies for Raja garmani by latitude north of Cape Hatteras and for the area south of Cape Hatteras. Solid bars represent mature specimens and cross hatched bars represent immature specimens. Modified from McEachran, 1977.

retrieval. Barans and Powles (1977) reviewed this program and Barans and Burrell (1976) reported on the preliminary findings of sampling during 1973-1975.

The results of a one-year survey designed to locate spawning grounds and to trace dispersion of fish eggs and larvae on the continental shelf from Cape Lookout, North Carolina to Cape Cod, Massachusetts were reported by Smith, Sibunka and Wells (1975). Larval flatfish, representing four families, seventeen genera, and fifteen species were identified (see life history section for details).

Preliminary results of trawling over a two year period (1973-1975) from Cape Fear, North Carolina to Cape Canaveral, Florida were presented by Barans and Burrell (1976). The weights of catches of major fish groups by season are summarized in Table VII-3 and the mean fish catch by habitat depths in Table VII-4. The twenty most common species ranked by weight are listed in Table VII-5. Although the distribution of groundfish appears to be influenced principally by substrate type and water temperatures, as stated earlier by Struhsaker (1969), demersal bony fish did not respond to seasonal temperature changes by onshore and offshore movements characteristic of similar species north of Cape Hatteras. Many pelagic species did appear to migrate north and south along the continental shelf.

During the period May 1967 to February 1968, quarterly samples of larval and juvenile fishes were taken in the South Atlantic Bight from New River, North Carolina to Palm Beach, Florida. Fahay (1975) analyzed this catch of 10,741 individuals including 107 identified species and his data are summarized in Table VII-6. Surface temperatures over the offshore part of the shelf varied little throughout the year, and this stability was reflected in a fairly uniform catch in all four seasonal samples. Over the inshore part of the shelf where the temperature ranged from 7.8^{o}C to 28.1^{o}C, those species strongly seasonal in occurrence were taken (*Mugil cephalus*, *Mullus auratus*, *Pomatomus saltatrix*, and *Urophycis regius*). With the exception of well-known inshore species, such as *Anchoa mitchilli*, and offshore species, such as istiophorids and exocoetids, a sharp demarcation line between inshore and offshore species was not noted. A more definite separation exists between species occurring primarily in the Gulf Stream and those over the continental shelf.

Keiser (1976a,b) reported on the fish which are caught incidental to shrimping activities in South Carolina. Sciaenids were the predominant family caught except for the months of January and April when clupeids and gadids, respectively, were the most

TABLE VII-3. Weights (kg) of catches of major fish groups by season (Barans and Burrell, 1976).

	Total No. Trawls	Demersal Teleosts	Elasmo-branchs	Pelagic Teleosts	Total	Seasonal Mean
Fall 1973	87	1,921	756	542	3,219	37.0
Spring 1974	115	1,931	5,307	329	7,568	65.8
Summer 1974	88	950	963	494	2,407	27.4
Winter 1975	90	1,644	2,298	229	4,171	46.3
TOTALS	380	6,446	9,325	1,594	17,365	45.7

TABLE VII-4. Mean fish catch (kg/tow) by habitat depths (Barans and Burrell, 1976).

Seasons	10-18 m	19-27 m	28-55 m	56-110 m	111-183 m	184-366 m	Seasonal Mean
	Habitat Depths						
Fall 1973	77.6	56.5	22.9	14.3	19.1	3.7	37.0
Spring 1974	79.6	70.4	65.8	117.6	25.3	3.2	65.8
Summer 1974	47.2	26.5	37.8	13.5	12.9	11.3	27.4
Winter 1975	40.9	97.8	58.4	20.8	23.5	2.3	46.3
Depth Mean	61.7	61.9	48.7	48.2	20.5	5.1	

TABLE VII-5. Twenty species ranked by weight of total catch over four seasons (Barans and Burrell, 1976).

Species	WT. (kg)
Dasyatis centroura	6,666.3
Stenotomus sp.	2,285.3
Myliobatis freminvillei	870.8
Aluterus schoepfi	738.8
Decapterus punctatus	528.8
Mustelus canis	325.5
Haemulon aurolineatum	307.7
Peprilus triacanthus	285.8
Ginglymostoma cirratum	283.5
Dasyatis americana	276.8
Sardinella anchovia	260.8
Etrumeus teres	256.2
Dasyatis sayi	252.5
Monacanthus hispidus	239.9
Synodus foetens	225.6
Rachycentron canadum	186.8
Diplectrum formosum	183.6
Odontaspis taurus	163.3
Urophycis regius	148.3
Calamus leucosteus	143.6
	14,629.9

TABLE VII-6. Summary of fish categories showing numbers caught and seasons present (From Fahay, 1975)

Category	Total number caught	Number caught per occurrence	Season present
Elops saurus	12	1.09	SpSFW
Undentified Muraenidae	33	1.94	SpSF
Unidentified Congridae	7	1.16	SFW
Bascanichthys sp.	1	1.00	W
Myrophis punctatus	1	1.00	W
Unidentified Ophichthidae	44	2.44	SpSFW
Unidentified Nemichthyidae	3	1.00	WSp
Brevoortia tyrannus	17	8.50	W
Brevoortia sp.	87	9.66	W
Etrumeus teres	34	11.33	W
Opisthonema oglinum	3	1.00	SF
Sardinella anchovia	49	9.80	SpSFW
Unidentified Clupeidae	112	7.46	SpSFW
Anchoa hepsetus	219	24.33	SpSFW
A. mitchilli	33	8.25	WSp
A. nasuta	81	13.50	SFW
Anchoa sp.	123	9.46	SpSFW
Engraulis eurystole	1	1.00	W
Unidentifed Engraulidae	61	3.38	SpSFW
Synodus foetens	7	1.75	WSp
Unidentified Synodontidae	2	1.00	W
Unidentified Myctophidae	10	2.50	FW
Histrio histrio	48	1.65	SpSFW
Urophycis earlli	2	1.00	W
U. floridanus	15	2.14	W
U. regius	2,678	58.22	WSp
Urophycis sp.	5	2.50	Sp
Unidentified Ophidiidae	3	1.00	SpF
Chriodorus atherinoides	1	1.00	W
Cypselurus cyanopterus	1	1.00	F
C. exsiliens	1	1.00	F
C. furcatus	1	1.00	Sp
C. heterurus	75	1.70	SpSFW
Cypselurus sp.	1	1.00	F
Euleptorhamphus velox	1	1.00	F
Exocoetus obtusirostris	10	2.50	WSp
E. volitans	3	1.00	WSp
Hemiramphus brasiliensis	64	2.06	SpSFW
Hirundichthys affinis	2	1.00	WSp

TABLE VII-6, cont.

Category	Total number caught	Number caught per occurrence	Season present
H. rondeleti	7	1.40	SpS
Hyporhamphus unifasciatus	40	3.07	SpSFW
Oxporhamphus micropterus	5	1.66	SF
Parexocoetus brachypterus	164	3.72	SpSF
Prognichthys gibbifrons	62	1.59	SpSFW
Unidentified Exocoetidae	11	1.22	WSpS
Tylosurus acus	3	1.00	SpSF
Tylosurus sp.	1	1.00	F
Membras martinica	144	28.80	FW
Menidia menidia	41	5.85	FW
Holocentrus sp.	16	1.60	SpSF
Amphelikturus dendriticus	1	1.00	W
Hippocampus erectus	14	1.27	SpSFW
Hippocampus sp.	9	1.12	WSpS
Syngnathus elucens	2	1.00	WSp
S. fuscus	1	1.00	W
S. pelagicus	9	1.00	SpSFW
S. springeri	12	1.20	WSp
Sygnathus sp.	2	2.00	F
Pristrigenys alta	44	3.66	S
Apogon maculatus	1	1.00	S
Apogon sp.	1	1.00	Sp
Astrapogon sp.	2	2.00	W
Pomatomus saltatrix	14	1.27	Sp
Remora remora	2	2.00	S
Caranx bartholomaei	19	1.26	SpSFW
C. fusus	59	3.10	SpSFW
C. hippos	5	1.66	SpS
C. latus	2	1.00	SpS
C. ruber	59	2.68	SpSF
Caranx sp.	11	1.57	WSpS
Chloroscombrus chrysurus	8	1.60	SpSF
Decapterus punctatus	826	12.32	SpSFW
Elagatis bipinnulata	8	1.14	SpS
Naucrates ductor	2	1.00	Sp
Selar crumenophthalmus	3	1.00	SpS
Seriola dumerili	11	1.57	FWSp
S. fasciata	2	1.00	SF
S. rivoliana	8	1.33	SF
S. zonata	1	1.00	Sp
Seriola sp.	73	1.97	SpSFW
Trachinotus carolinus	15	1.87	Sp
T. falcatus	9	1.28	SpSFW
T. goodei	2	1.00	SF
Trachinotus sp.	4	1.00	SpS
Unidentified Carangidae	4	1.33	S
Coryphaena equisetis	16	1.60	SpSFW
C. hippurus	76	1.68	SpSF

TABLE VII-6, cont.

Category	Total number caught	Number caught per occurrence	Season present
Rhomboplites aurorubens	1	1.00	S
Unidentified Lutjanidae	2	1.00	S
Lobotes surinamensis	1	1.00	F
Stenotomus chrysops	3	1.00	Sp
Unidentified Sparidae	637	26.54	FWSp
Cynoscion nothus	5	5.00	F
Larimus fasciatus	1	1.00	F
Leiostomus xanthurus	22	2.44	FW
Stellifer lanceolatus	1	1.00	F
Mullus auratus	126	4.06	WSp
Pseudupeneus maculatus	1	1.00	Sp
Unidentified Mullidae	23	2.87	WSp
Kyphosus incisor	9	1.12	SFW
K. sectatrix	9	2.25	F
Holacanthus tricolor	1	1.00	F
Pomacanthus arcuatus	1	1.00	F
Unidentified Chaetodontidae	1	1.00	S
Abudefduf saxatilis	17	1.70	FW
Chromis sp.	1	1.00	F
Unidentified Pomacentridae	2	1.00	Sp
Mugil cephalus	174	4.83	FWSp
M. curema	393	6.14	SpSFW
Mugil sp.	67	3.04	WSp
Sphyraena barracuda	2	1.00	S
S. borealis	10	1.11	FWSp
Undentified Uranoscopidae	19	1.58	SpSFW
Unidentified Blenniidae	35	2.18	SpSFW
Unidentified Gobiidae	2	2.00	S
Diplospinus multistriatus	2	1.00	FW
Auxis sp.	31	2.81	WSpS
Euthynnus alletteratus	8	2.00	S
Scomber japonicus	6	1.20	WSp
Scomberomorus maculatus	4	1.00	SpS
Thunnus sp.	2	1.00	SpS
Xiphias gladius	8	1.33	FWSp
Istiophorus platyterus	1	1.00	Sp
Makaira nigricans	1	1.00	S
Unidentified Istiophoridae(a.)	5	1.66	Sp
Unidentified Istiophoridae(b.)	27	1.92	SpSF
Nomeus gronovii	6	1.50	WSp
Perilus triacanthus	166	6.15	SpSFW
Psenes cyanophrys	13	1.00	WSpS
Scorpaena sp.	8	1.14	SpSFW
Unidentified Triglidae	7	1.40	SpF
Dactylopterus volitans	3	1.00	SpS
Bothus ocellatus	266	4.29	SpSFW
Unidentified Bothidae	31	2.81	SpSFW
Gymnachirus melas	1	1.00	W

TABLE VII-6, cont.

Category	Total number caught	Number caught per occurrence	Season present
Symphurus sp.	1	1.00	F
Aluterus heudeloti	5	1.00	SpSF
A. monoceros	3	1.50	SF
A. schoepfi	9	1.12	SpSF
A. scriptus	13	1.44	SpSF
Aluterus sp.	1	1.00	Sp
Balistes capriscus	44	2.20	SF
Balistes sp.	4	2.00	S
Cantherhines pullus	7	1.40	SF
Canthidermis maculatus	17	1.42	SpSFW
C. sufflamen	8	4.00	SpF
Monacanthus ciliatus	154	2.96	SpSFW
M. hispidus	421	4.43	SpSFW
M. setifer	301	11.58	SpSFW
M. tuckeri	3	1.50	SW
Xanthichthys ringens	1	1.00	F
Unidentified triggerfishes	5	1.00	SpS
Unidentified filefishes	1,536	11.63	SpSFW
Unidentified Ostraciidae	4	1.00	FWSp
Sphoeroides sp.	312	3.95	SpSFW
Diodon holocanthus	1	1.00	S
Diodon hystrix	1	1.00	S
Unidentified	47	1.74	SpSFW
Totals	10,741	39.63	

TABLE VII-7. Known and expected sharks from North Carolina and adjacent western Atlantic Ocean waters (Schwartz and Burgess, 1975).

Common Name	Scientific Name	STATUS Known From NC	Recorded Nearby
Sixgill shark	*Hexanchus griseus*	x	
Nurse shark	*Ginglymostoma cirratum*	x	
Whale shark	*Rhiniodon typus*	x	
Sand tiger	*Odontaspis taurus*	x	
Bigeye thresher	*Alopias superciliosus*	x	
Thresher shark	*Alopias vulpinus*	x	
White shark	*Carcharodon carcharias*	x	
Basking shark	*Cetorhinus maximus*	x	
Shortfin mako	*Isurus oxyrinchus*	x	
Porbeagle	*Lamna nasus*		N.Jersey,S.C.
	Apristurus laurussoni		Delaware
	Apristurus profundorum		Va.,Caribbean
Marbled cat shark	*Galeus arae*		S. Carolina
Chain dogfish	*Scyliorhinus retifer*	x	
Finetooth shark	*Aprionodon isodon*	x	
Blacknose shark	*Carcharhinus acronotus*	x	
Bignose shark	*Carcharhinus altimus*		No. Florida
Silky shark	*Carcharhinus falciformis*	x	
Bull shark	*Carcharhinus leucas*	x	
Blacktip shark	*Carcharhinus limbatus*	x	
Oceanic whitetip shark	*Carcharhinus longimanus*	x	
Spinner shark	*Carcharhinus maculipinnis*	x	
Sandbar shark	*Carcharhinus milberti*	x	
Dusky shark	*Carcharhinus obscurus*	x	
Tiger shark	*Galeocerdo cuvieri*	x	
Night shark	*Hypoprion signatus*		S. Carolina
Smooth dogfish	*Mustelus canis*	x	
Florida smoothhound	*Mustelus norrisi*		No. Florida
Lemon shark	*Negaprion brevirostris*	x	
Blue shark	*Prionace glauca*	x	
Atlantic sharpnose shark	*Rhizoprionodon terrenovae*	x	
Scalloped hammerhead	*Sphyrna lewini*	x	
Great hammerhead	*Sphyrna mokarran*	x	
Bonnethead	*Sphyrna tiburo*	x	
Smooth hammerhead	*Sphyrna zygaena*	x	
Black dogfish	*Centroscyllium fabricii*		Virginia
	Deania profundorum	x	
Bramble shark	*Echinorhinus brucus*		Virginia
	Etmopterus bullisi	x	
	Etmopterus gracilispinis		Va., N. Fla.
	Etmopterus hillianus	x	
Spiny dogfish	*Squalus acanthias*	x	
Blainville's dogfish	*Squalus blainvillei*	x	
Cuban dogfish	*Squalus cubensis*	x	
Atlantic angel shark	*Squatina dumerili*	x	

abundant group. Approximately 118 species were captured. No new species of fishes in South Carolina waters were reported. The fish to shrimp ratio of animals caught ranged from a low of 1.2:1 to a high of 4:1 (Keiser, 1977).

2.1.2.2 Estuarine Studies

Beginning in October 1968, extensive ecological studies of the Lower Cape Fear Estuary have been underway by North Carolina State University under contract from the Carolina Power and Light Company. Results are incorporated in various reports which describe seasonal distribution and abundance of many species (e.g., Hobbie, 1971; Copeland and Birkhead, 1972, 1973a, and 1973b; Copeland, Birkhead and Hodson, 1974a and 1974b; Hodson, Schneider and Copeland, 1977; Birkhead, Bennett, Pendleton and Copeland, 1977; and Copeland and Hodson, 1977). The data are too voluminous to present here.

During 1972-73 a survey of the nursery areas in Western Pamlico Sound, North Carolina revealed that 85 percent of the 78 species of fishes and 9 species of invertebrates collected are estuarine-dependent (Spitsbergen and Wolff, 1974). An analysis of Dutchman Creek Estuary, North Carolina as a nursery area was conducted by Copeland and Birkhead (1973a), who recorded 72 species (18 decapod crustaceans and 54 fishes) in 1972. Typically, most of the nekton inhabiting this estuary are juveniles, which remain there for varying lengths of time, grow, and then depart.

From June 1974 through June 1976 the Tar-Pamlico River and northern Pamlico Sound, North Carolina were sampled using seines, wing trawls, egg nets, and gill nets (Marshall, 1976). Field data from numerous seasonal sampling sites and 126 monthly stations were taken to determine spawning and nursery areas. Spawning areas were identified for river herring, American shad, hickory shad, and striped bass in the Tar River. The river herring was also found spawning in tributaries of the Pamlico River. Nursery areas were determined for blueback herring, alewife, striped bass, and American shad. Tagging studies revealed that striped bass populations in the Pamlico River remain in the area between Washington and Wades Point except for spawning migrations up the Tar River.

The abundance and distribution of anadromous fish in the White Oak and New River Systems, North Carolina were studied by Sholar (1975). Few anadromous fish were found in the New River, probably due to excessive stream channelization and a high level of development. In contrast, a substantial run of blueback herring (*Alosa aestivalis*) and smaller runs of alewife (*A. pseudoharengus*), American shad (*A. sapidissima*), and hickory shad

(A. mediocris) occur in the White Oak River.

In 1977, Street and Johnson reviewed the status in North Carolina of the striped bass, an abundant estuarine and coastal water species. They reported that Hassler and Hogarth (1970) tagged and released about 9,500 individuals during 1956-1976 in the lower Roanoke River. Virtually all recoveries came from Albemarle and Pamlico Sounds, their tributaries, and from the Roanoke River.

Turner and Johnson (1973) analyzed the results of monthly sampling of the Newport River, North Carolina during 1970, and found a total of 104 species of fishes within the system. Sampling covered a mid-channel distance of 34.87km, extending from the more saline estuarine waters upstream into tidal fresh waters. The sampling area was divided into six zones as shown in Table VII-8. The various collecting gear included surface trawl, haul seine, two sizes of bottom trawls and gill nets. Surface trawl yielded the greatest catch per unit effort and gill nets, while the least efficient, captured the greatest variety of species. Primarily marine forms were collected (Table VII-8). Fifteen essentially freshwater species were captured, and five of those (the gizzard shad, golden shiner, black crappie, white catfish, and longnose gar) were tolerant of more saline waters to varying extents. Of the total catch of 129,000 specimens, 97 percent was accounted for by seven marine euryhaline species utilizing the estuary as a nursery area. These species move well upstream into less saline and even to tidal fresh waters. These authors include discussions of the abundance and seasonal distribution of the dominant species as well as various other species which were collected in substantial numbers.

Twenty-four larvae of the tarpon, Megalops atlantica, were found in the Cape Fear Estuary, North Carolina for the first time during 1973-1974. They were collected near the bottom at about the time of low tide. Tucker and Hodson (1976) felt these larvae were spawned offshore and drifted into the estuary with shoreward currents.

Cain and Dean (1976), investigating on the annual occurrence and biomass of 51 species of fish in an intertidal creek in North Inlet Estuary, South Carolina, found that season had a significant effect on the number of species caught, but it had no effect on the number of individuals caught.

Burns (1974) reported that the abundance of larval fishes in an estuarine tidal creek in South Carolina varied seasonally, with the greatest abundance observed during the late fall and winter. Bozeman (1976) studied a different creek in the same estuary. It

TABLE VII-8. Occurrence of fishes in the Newport River, 1970. Salinity ranges represent extremes measured at times of collection (Turner and Johnson, 1973).

SPECIES	ZONE 1	2	3	4	5	6	SALINITY RANGE
Carcharhinidae - requiem sharks							
Carcharhinus milberti, sandbar shark						X	32.6
Rhizoprionodon terraenovae, Atlantic sharpnose shark					X		32.2-32.6
Sphyrnidae - hammerhead sharks							
Sphyrna lewini, scalloped hammerhead				X			24.7
Dasyatidae - stingrays							
Dasyatis sayi, bluntnose stingray					X		19.7-32.5
Myliobatidae - eagle rays							
Rhinoptera bonasus, cownose ray				X	X	X	22.9-32.6
Lepisosteidae - gars							
Lepisosteus osseus, longnose gar	X	X	X				0.0-3.3
Amiidae - bowfins							
Amia calva, bowfin	X						0.2
Elopidae - tarpons							
Elops saurus, ladyfish					X		30.4
Anguillidae - freshwater eels							
Anguilla rostrata, American eel	X		X	X	X		0.2-32.9
Congridae - conger eels							
Conger oceanicus, conger eel						X	30.6
Ophichthidae - snake eels							
Myrophis punctatus, speckled worm eel				X	X	X	23.8-31.2
Clupeidae - herrings							
Alosa aestivalis, blueback herring	X	X	X	X	X		0.4-23.7
Alosa mediocris, hickory shad		X		X			0.8-21.2
Alosa pseudoharengus, alewife				X		X	22.6-29.3
Alosa sapidissima, American shad	X						0.0
Brevoortia tyrannus, Atlantic menhaden	X	X	X	X	X	X	0.1-32.5
Dorosoma cepedianum, gizzard shad	X	X	X	X		X	0.0-28.7
Harengula pensacolae, scaled sardine						X	31.5
Opisthonema oglinum, Atlantic thread herring				X	X	X	19.3-31.0
Engraulidae - anchovies							
Anchoa hepsetus, striped anchovey			X	X	X	X	14.6-33.1
Anchoa mitchilli, bay anchovy	X	X	X	X	X	X	0.2-33.5
Synodontidae - lizardfishes							
Synodus foetens, inshore lizardfish				X	X	X	21.4-32.0
Cyprinidae - minnows and carps							
Notemigonus crysoleucas, golden shiner	X	X	X				0.1-1.4
Ictaluridae - freshwater catfishes							
Ictalurus catus, white catfish	X	X	X				0.0-1.3
Ictalurus natalis, yellow bullhead	X						0.1-0.5
Noturus insignis, margined madtom	X						0.5
Aphredoderidae - pirate perches							
Aphredoderus sayanus, pirate perch	X						0.2

TABLE VII-8, cont.

Batrachoididae - toadfishes							
Opsanus tau, oyster toadfish				X	X	X	16.7-29.9
Porichthys porosissimus, Atlantic midshipman					X	X	11.9-28.4
Gadidae - codfishes							
Urophycis regius, spotted hake				X	X	X	9.2-32.6
Exocoetidae - flyingfishes							
Cypselurus heterurus, Atlantic flyingfish						X	32.3
Hyporhamphus unifasciatus, halfbeak						X	30.9
Belonidae - needlefishes							
Ablennes hians, flat needlefish						X	31.5
Strongylura marina, Atlantic needlefish		X	X	X		X	0.4-32.3
Cyprinodontidae - Killifishes							
Cyprinodon variegatus, sheepshead minnow				X	X	X	19.1-33.4
Fundulus confluentus marsh killifish			X				0.2
Fundulus heteroclitus, mummichog			X	X	X	X	0.6-31.4
Fundulus majalis, striped killifish				X	X	X	22.3-33.0
Atherinidae - silversides							
Membras martinica, rough silverside						X	28.1-32.9
Menidia beryllina, tidewater silverside		X	X	X	X	X	0.8-32.9
Menidia menidia, Atlantic silverside		X	X	X	X	X	0.6-31.1
Syngnathidae - pipefishes and seahorses							
Hippocampus erectus, lined seahorse						X	30.6
Syngnathus florida, dusky pipefish					X		18.4
Syngnathus fuscus, northern pipefish					X		17.3-30.0
Syngnathus louisianae, chain pipefish					X	X	12.3-31.3
Percichthyidae - temperate basses							
Morone americana, white perch			X				0.2
Serranidae - sea basses							
Centropristis philadelphica, rock sea bass					X	X	27.4-32.3
Centropristis striata, black sea bass						X	32.0
Epinephelus nigritus, Warsaw grouper				X		X	24.2-28.8
Centrarchiade- sunfishes							
Enneacanthus gloriosus, bluespotted sunfish	X						0.1-0.4
Lepomis gibbosus, pumpkinseed	X	X					0.1-0.3
Lepomis gulosus, warmouth	X						0.0-0.1
Lepomis macrochirus, bluegill	X	X					0.0-0.2
Micropterus salmoides, largemouth bass	X	X					0.0-0.1
Pomoxis nigromaculatus, black crappie	X	X					0.3-1.2
Percidae - perches							
Etheostoma olmstedi, tessellated darter	X						0.2
Pomatomidae - bluefishes							
Pomatomus saltatrix, bluefish		X	X	X	X	X	8.7-32.5

TABLE VII-8, cont.

Rachycentridae - cobias							
Rachycentron canadum, cobia					X		28.4
Carangidae - jacks and pompanos							
Caranx hippos, crevalle jack			X	X		X	24.2-30.3
Chloroscombrus chrysurus, Atlantic bumper				X			16.3
Selene vomer, lookdown				X	X	X	20.4-32.2
Trachinotus falcatus, permit						X	31.5
Lutjanidae - snappers							
Lutjanus griseus, gray snapper				X			24.4
Lobotidae - tripletails							
Lobotes surinamensis, tripletail			X				24.4
Gerreidae - mojarras							
Eucinostomus argenteus, spotfin mojarra						X	35.3
Eucinostomus gula, silver jenny				X	X	X	23.4-31.6
Pomadasyidae - grunts							
Orthopristis chrysoptera, pigfish				X	X	X	21.4-32.1
Sparidae - porgies							
Archosargus probatocephalus, sheepshead					X	X	28.5-31.3
Lagodon rhomboides, pinfish			X	X	X	X	0.9-33.6
Sciaenidae - drums							
Bairdiella chrysura, silver perch			X	X	X	X	9.0-30.7
Cynoscion nebulosus, spotted seatrout			X	X	X	X	7.8-32.4
Cynoscion regalis, weakfish				X	X	X	9.4-30.2
Leiostomus xanthurus, spot		X	X	X	X	X	0.6-33.2
Menticirrhus americanus, southern kingfish				X			27.1
Menticirrhus saxatilis, northern kingfish				X	X	X	24.3-32.7
Micropogon undulatus, Atlantic croaker	X	X	X	X	X	X	0.8-31.2
Pogonias cromis, black drum				X	X	X	19.4-33.4
Ephippidae - spadefishes							
Chaetodipterus faber, Atlantic spadefish					X	X	27.4-29.2
Mugilidae - mullets							
Mugil cephalus, striped mullet	X	X	X	X	X	X	0.3-31.5
Sphyraenidae, barracudas							
Sphyraena barracuda, great barracuda						X	31.1
Gobiidae - gobies							
Gobionellus boleosoma, darter goby				X		X	17.4-26.9
Gobionellus hastatus, sharptail goby						X	28.4
Gobionellus shufeldti, freshwater goby		X		X	X		0.1-29.3
Microgobius thalassinus, green goby				X	X		19.0-24.3
Trichiuridae, cutlassfishes							
Trichiurus lepturus, Atlantic cutlassfish					X		21.3-29.9
Scombridae - mackerels and tunas							
Scomberomorus maculatus, Spanish mackerel				X	X	X	24.5-31.7

TABLE VII-8, cont.

Stromateidae - butterfishes							
Peprilus alepidotus, harvestfish				X			8.7-9.4
Peprilus triacanthus, butterfish				X	X	X	22.6-30.3
Triglidae - searobins							
Prionotus carolinus, northern searobin					X	X	29.2-32.8
Prionotus evolans, striped searobin						X	29.3
Prionotus scitulus, leopard searobin						X	29.3
Prionotus tribulus, bighead searobin				X		X	23.5-28.4
Bothidae - lefteye flounders							
Ancylopsetta quadrocellata, ocellated flounder					X	X	24.9-28.3
Citharichthys spilopterus, bay whiff				X		X	22.5-28.5
Etropus crossotus, fringed flounder				X	X	X	20.6-31.3
Paralichthys albigutta, Gulf flounder						X	30.2-34.5
Paralichthys dentatus, summer flounder			X	X	X	X	3.1-32.9
Paralichthys lethostigma, southern flounder	X	X	X	X	X	X	0.6-33.4
Scopthalmus aquosus, windowpane					X	X	23.2-29.9
Soleidae - soles							
Trinectes maculatus, hogchoker	X	X	X	X	X	X	0.1-30.4
Cynoglossidae - tonguefishes							
Symphurus plagiusa, blackcheek tonguefish				X	X	X	4.7-29.4
Balistidae - triggerfishes and filfishes							
Monacanthus hispidus, planehead filefish					X	X	9.4-30.2
Tetraodontidae - puffers							
Sphoeroides maculatus, northern puffer					X	X	28.3-30.2
Diodontidae - porcupinefishes							
Chilomycterus schoepfi, striped burrfish					X	X	29.1-31.5

[1] Zone 1 being the head of the Newport River (freshwater) and Zone 6 being the inlet mouth. The mean monthly salinity of Zone 6 ranged from 21.5 to 33.7 ppt, Zone 5 from 16.3 to 31.4 ppt, Zone 4 from 8.3 to 27.0 ppt, Zone 3 from 0 to 19.3 ppt, and Zone 2 from 0 to 1.1 ppt.

included a low marsh area with fewer apparent microhabitats, and was closer to the inlet. This area had less diversity in larval fish than reported by Burns. However, the absolute abundance of larval fish greatly exceeded those reported by Burns (1974). These differences might be ascribed to different sampling techniques or to biological causes, such as yearly variations in spawn size or a greater production in low marsh areas. This estuary, the North Inlet Estuary, is an important nursery ground, especially for Leiostomus xanthurus, Lagodon rhomboides, and Brevoortia tyrannus, which together accounted for 95 percent of the number of larval fish captured. Poole (1978) compiled a list of fish species for South Carolina and adjacent areas (Appendix VII-B).

Dörjes and Howard (1975) reported on the nekton associated with the Ogeechee River Ossabaw Sound, Georgia. Of the thirteen species found, three were restricted to freshwater, one to low salinity waters, and nine to high salinity waters. No species was endemic.

Hackney and Burbanck (1976) conducted a systematic survey of the Croaked Creek tidal area on the Georgia coast. Penaeus setiferus and Callinectes sapidus were frequently collected crustaceans of commercial importance. A frequently collected non-commercial species was the grass shrimp, Palaemonetes pugio. The fish species collected were found not to be general tidal creek species, but were characteristic of the narrower salinities in which they were found. Higher salinity areas commonly supported Bagre marinus, Arius felis, and Menticirrhus americanus. Less saline waters commonly yielded Ictalurus catus.

An otter trawl survey in 1972 of the lower Savannah River conducted by Stickney and Miller (1973, 1974) indicated the presence of 27 species of fish and nektonic invertebrates. Although the species composition is different from surrounding estuarine areas that are less impacted by human activities, the lower Savannah River is not a biological desert.

Hoese (1973) reported the results of a twelve month trawl sampling period during 1965-1966 of the Georgia inshore continental shelf and Doboy Sound. The distribution of many nektonic animals correlated with either the water masses or sediment type. The offshore fauna was more subtropical in geographical affinity than the inshore fauna.

The results of a three year sampling program on the blue crab, Callinectes sapidus, along the Georgia coast during the period of 1970-1973 were presented by Palmer (1974). This species is abundant in nearly all Georgia estuarine systems and is the second most important commercial species.

Marshall, Carnes, Pollard and Stirewalt (1975) in an abstract reported on fishes distribution in the Savannah River drainage system including the waters at Savannah, Georgia.

Harris (1977) reported on work in progress to determine the species composition, distribution, and abundance of fishes associated with artificial and natural reefs in Georgia's offshore waters. Similar studies are in progress in South Carolina (Barans and Powles, 1977) and in North Carolina (Huntsman, 1977).

Although not presenting any new scientific information, Hammond and Cupka (1975) published a sportsman's field guide to the billfishes, mackerels, little tunas, and tunas of South Carolina.

In a series of surveys, the fish, shrimp, and blue crabs inhabiting various Georgia estuarine systems were sampled with special emphasis on distribution, seasonal abundance, size composition, and life history observations (Mahood, Harris, Music and Palmer, 1974a, b, c and d). Three areas were studied: 1) Southern Section, St. Andrews Sound and St. Simons Sound Estuaries; 2) Central Section, Doboy Sound and Sapelo Sound Estuaries; and 3) Northern Section, Ossabaw Sound and Wassaw Sound Estuaries. The list of species collected is in Table VII-9. Extensive data on the catch of each species by month, location, pounds per hour of fishing, and percent of catch are presented in tabular form. It is beyond the scope of this report to include all of these data. The southern section of the state produced 39.1 percent of the total catch, the central section 38.6 percent, and the northern section 22.4 percent. Each estuary was divided into three main sectors: creeks, sounds, and outside waters. During this three-year project, the creeks produced 48.5 percent of the total catch taken trawling and 24 percent of the catch taken gill netting, the sounds produced 38.6 percent and 24.1 percent respectively, and the outside waters produced 12.9 percent and 51.9 percent respectively.

Kerr (1976) presented an inventory of the representatives of 22 phyla including many nekton species found in the Indian River Coastal Zone of central Florida. Gilmore, Kulczycki, Hastings and Magley (1977) have a continuing study of fish populations there. They reported 594 species, and in the past 31 months they captured over 1.6 million fish. The catch data have been analyzed in respect to spatial and temporal fish distributions and to abundance.

TABLE VII-9. List of scientific and common names of fish reported from Georgia. (Mahood et al., 1974d).

FAMILY	SPECIES	COMMON NAME
Acipenseridae	Acipenser oxyrhynchus Mitchill	Atlantic sturgeon
Elopidae	Elops saurus Linnaeus	Ladyfish
	Megalops atlantica Valenciennes	Tarpon
Clupeidae	Alosa aestivalis (Mitchill)	Blueback herring
	Alosa mediocris (Mitchill)	Hickory shad
	Brevoortia spp. (tyrannus and smithi)	Menhaden
	Clupea harengus harengus Linnaeus	Atlantic herring
	Dorosoma cepedianum (LeSueur)	Gizzard shad
	Etrumeus sadina (Mitchill)	Atlantic round herring
	Opisthonema oglinum (LeSueur)	Atlantic thread herring
Engraulidae	Anchoa hepsetus (Linnaeus)	Striped anchovy
	Anchoa mitchilli (Valenciennes	Bay anchovy
	Anchoa spp. (all other anchovies)	Anchovy
Synodontidae	Synodus foetens (Linneaus)	Inshore lizardfish
Ariidae	Bagre marinus (Mitchill)	Gafftopsail catfish
	Galeichthys felis (Linnaeus)	Sea catfish
Ictaluridae	Ictalurus spp. (largely catus)	Freshwater catfish
Anguillidae	Anguilla rostrata (LeSueur)	American eel
Ophichthidae	Ophichthus spp.	Snake eel
Belonidae	Strongylura marina (Walbaum)	Atlantic needlefish
Hemiramphidae	Hemiramphus brasiliensis (Linnaeus)	Ballyhoo
Cyprinodontidae	Fundulus heteroclitus (Linnaeus)	Mummichog
Gadidae	Urophycis spp.	Hake
Syngnathidae	Syngnathus spp.	Pipefish
Centropomidae	Centropomus undecimalis (Bloch)	Snook
Serranidae	Centropristes philadelphicus (Linnaeus)	Rock sea bass
	Centropristes striatus (Linnaeus)	Black sea bass
	Diplectrum formosum (Linnaeus)	Sand perch
	Roccus saxatilis (Walbaum)	Striped bass
Lobotidae	Lobotes surinamensis (Bloch)	Tripletail
Lutjanidae	Lutjanus griseus (Linnaeus)	Gray snapper (Mangrove snapper)
	Lutjanus synagris (Linnaeus)	Lane snapper (Spot snapper)
Priacanthidae	Pristigenys alta (Gill)	Short bigeye
Pomatomidae	Pomatomus saltatrix (Linnaeus)	Bluefish
Rachycentridae	Rachycentron canadum (Linnaeus)	Cobia
Carangidae	Caranx crysos (Mitchill)	Blue runner
	Caranx hippos (Linnaeus)	Crevalle jack
	Caranx ruber (Bloch)	Bar jack
	Chloroscombrus chrysurus (Linnaeus)	Bumper
	Selene vomer (Linnaeus)	Lookdown
	Seriola zonata (Mitchill)	Banded rudderfish
	Trachinotus carolinus (Linnaeus)	Pompano
	Vomer setapinnis (Mitchill)	Atlantic moonfish

TABLE VII-9, cont.

FAMILY	SPECIES	COMMON NAME
Gerridae	Eucinostomus spp.	Mojarra
Pomadasyidae	Bathystoma aurolineatum (Cuvier)	Tomtate
	Orthopristis chrysopterus (Linnaeus)	Pigfish
Sciaenidae	Bairdiella chrysura (Lacepede)	Silver perch (Yellowtail)
	Cynoscion nebulosus (Cuvier)	Spotted seatrout
	Cynoscion nothus (Holbrook)	Silver seatrout (White)
	Cynoscion regalis (Bloch and Schneider)	Weakfish (Summer trout)
	Equetus pulcher (Steindachner)	Striped drum
	Larimus fasciatus Holbrook	Banded drum
	Leiostomus xanthurus Lacepede	Spot
	Menticirrhus americanus (Linnaeus)	Southern kingfish
	Menticirrhus littoralis (Holbrook)	Gulf kingfish
	Menticirrhus saxatilis (Bloch and Schneider)	Northern kingfish
	Micropogon undulatus (Linnaeus)	Atlantic croaker
	Pogonias cromis (Linnaeus)	Black drum
	Sciaenops ocellata (Linnaeus)	Red drum (Channel bass)
	Stellifer lanceolatus (Holbrook)	Star drum
Sparidae	Archosargus probatocephalus (Walbaum)	Sheepshead
	Lagodon rhomboides (Linnaeus)	Pinfish
	Stenotomus caprinus Bean	Longspine porgy
Ephippidae	Chaetodipterus faber (Broussonet)	Atlantic spadefish
Trichiuridae	Trichiurus lepturus Linnaeus	Atlantic cutlassfish
Scombridae	Scomberomorus cavalla (Cuvier)	King mackerel
	Scomberomorus maculatus (Mitchill)	Spanish mackerel
Gobiidae	Various genera and species	Goby
Scorpaenidae	Scorpaena plumieri Bloch	Spotter scorpionfish
Triglidae	Prionotus spp.	Searobin
Cyclopteridae	Eumicrotremus spinosus (Muller)	Atlantic spiny lumpsucker
Uranoscopidae	Astroscopus spp.	Stargazer
Blenniidae	Various genera and species	Blenny
Ophidiidae	Rissola marginata (DeKay)	Striped cusk-eel
Stromateidae	Peprilus alepidotus (Linnaeus)	Southern harvestfish
	Poronotus triacanthus (Peck)	Butterfish
Sphyraenidae	Sphyraena guachancho Cuvier	Guaguanche
Mugilidae	Mugil cephalus Linnaeus	Striped mullet
	Mugil curema Valenciennes	White mullet (Silver)
Atherinidae	Menidia menidia (Linnaeus)	Atlantic silverside
Bothidae	Ancylopsetta quadrocellata Gill	Ocellated flounder
	Citharichthys macrops Dresel	Spotted whiff
	Citharichthys spilopterus Gunther	Bay whiff
	Etropus spp.	Etropus
	Paralichthys dentatus (Linneaus)	Summer flounder
	Paralichthys lethostigma Jordan and Gilbert	Southern flounder (Winter)
	Scophthalmus aquosus (Mitchill)	Windowpane

TABLE VII-9, cont.

FAMILY	SPECIES	COMMON NAME
Soleidae	Gymnachirus nudus Kaup Trinectes maculatus (Bloch and Schneider)	Naked sole Hogchoker
Cynoglossidae	Symphurus plagiusa (Linnaeus)	Blackcheek tonguefish
Echeneidae	Remora remora (Linnaeus)	Remora
Gobiesocidae	Gobiesox spp.	Clingfish
Balistidae	Various genera and species	Filefish
Tetraodontidae	Lagocephalus laevigatus (Linnaeus) Sphaeroides maculatus (Bloch and Schneider)	Smooth puffer Northern puffer
Diodontidae	Chilomycterus schoepfi (Walbaum)	Striped burrfish (Spiny boxfish)
Batrachoididae	Opsanus tau (Linnaeus)	Oyster toadfish
Ogcocephalidae	Ogcocephalus vespertilio (Linnaeus)	Longnose batfish
Penaeidae	Penaeus setiferus (Linnaeus) Penaeus aztecus Ives Penaeus duorarum Burkenroad Xiphopeneus krøyeri (Heller) Trachypeneus constrictus (Stimpson) Sicyonia brevirostris Stimpson	White shrimp Brown shrimp Pink shrimp Sea bob Rock shrimp
Portunidae	Callinectes sapidus Rathbun	Blue crab

Hogg (1976a, b) reported that eight species of exotic cichlid fish were present in Dade County, Florida in March of 1975. There are a total of 25 exotic fish established in the state's fresh and brackish waters. All available data indicate that cichlids are becoming important components of Florida's aquatic communities. Exotic fish representing twenty-five species and five hybrids are established in fresh and brackish waters of Florida (Courtenay, Sahlman, Miley and Herrema, 1974). Furture channelization projects could significantly alter dispersal patterns.

The current distributional range of oviparous killifishes (family Cyprinodontidae) in Florida was reviewed by Relyea (1975). In all, 19 to 21 species of these fish occur in Florida, inhabiting freshwater, brackish, and seawater environments. Since the spotted Tilapia became established in Florida in 1973, it has spread rapidly by means of drainage canals.

2.1.3 Crustaceans

2.1.3.1 Open Ocean and Coastal Water Studies

In the southeastern Atlantic, 95 percent of commercial shrimp catches are comprised of brown and white shrimp (Eldridge and Goldstein, 1975). The remaining 5 percent is made up of royal red, pink, and rock shrimp. Brown and white shrimp are the most abundant in Georgia, South Carolina, and on the Florida east coast; in North Carolina brown and pink shrimp are most abundant. Because of their short life span, shrimp are considered an annual crop. In considering the catches over the last twenty years, the authors concluded that fishing had not adversely affected the shrimp abundance.

Shrimp are taken May to December, primarily. Pink shrimp are most abundant between April to June and September to November. Brown shrimp are taken in mid-June to mid-August. White "roe" shrimp are taken in May and June, while their offspring are taken from September to December.

2.1.3.2 Estuarine Studies

Pamlico Sound, in North Carolina, is the major shrimping area of the state, making up 50 percent of the annual catch. Other significant shrimp fishery areas in North Carolina include Bogue and Core Sounds, Cape Fear, and the New, White Oak, Newport and Neuse River mouths. A recently developed area is in the ocean off southern North Carolina.

Among the inshore fishing grounds of South Carolina are Port Royal, Calibogue, and St. Helena Sounds and Bulls Bay. From Bulls Bay to Tybu Roads the offshore waters within six miles of the coast are the most productive. Inshore shrimping areas in Georgia include Cumberland, St. Andrews, St. Simons, Sapelo, Ossabaw, and Wassaw Sounds. Offshore waters within five to seven miles of the coast are also productive. In Florida the most productive shrimp areas include the waters of Cape Canaveral, New Smyrna Beach, St. Augustine, the mouth of the St. Johns River, and Fernandina.

Since the shrimp fishery of South Carolina represents the state's most valuable fishery resource, a study was done over a period of several years (February 1973 to January 1975) to survey the abiotic and biotic characteristics of the estuaries (Bishop and Shealy, 1977). Otter trawl samples were collected at thirty-three stations, selected to provide representative samples of the major South Carolina estuaries. For this chapter, we combined the data from all the estuaries to provide a general picture of the shrimp population of South Carolina. White shrimp, Penaeus setiferus, and brown shrimp, P. aztecus, were distributed throughout the state's estuaries, although not in a uniform fashion. Pink shrimp, P. duorarum, were caught only in very small numbers. P. setiferus comprised 92.5 percent of the total shrimp collected during this study. Brown shrimp comprised only 5.3 percent and pink shrimp only 0.1 percent or less of the total catches (Figures VII-8 to VII-11).

Marked differences were observed in regional species composition and abundance. The northern region extends from Winyah Bay to Bull Bay, the central to the south Edisto River, and the southern limit at Calibogue Sound. In general, the central coastal region accounted for 2.4 times more white shrimp and 4 times more brown shrimp than the northern region. In comparison to the southern region, the central region yielded 4.3 times more white shrimp and 2.6 times more brown shrimp. Although sample sizes were very small, more pink shrimp were taken in the central region. The Cooper River - Charleston Harbor estuary yielded greater numbers and biomass of the shrimp species than the other estuaries.

Young (1978) compiled a list of decapod crustaceans inhabiting South Carolina and adjacent waters (Appendix VII-C).

Some biological inferences can be drawn from the trawl data in a commercially-oriented report for the 1976 season presented by Theiling (1977). Table VII-10 presents the volumes and value of pink, white, and brown shrimp landed in South Carolina during each month of 1976. Only small quantities of pink shrimp were taken, and those were limited to May and June. This species was not

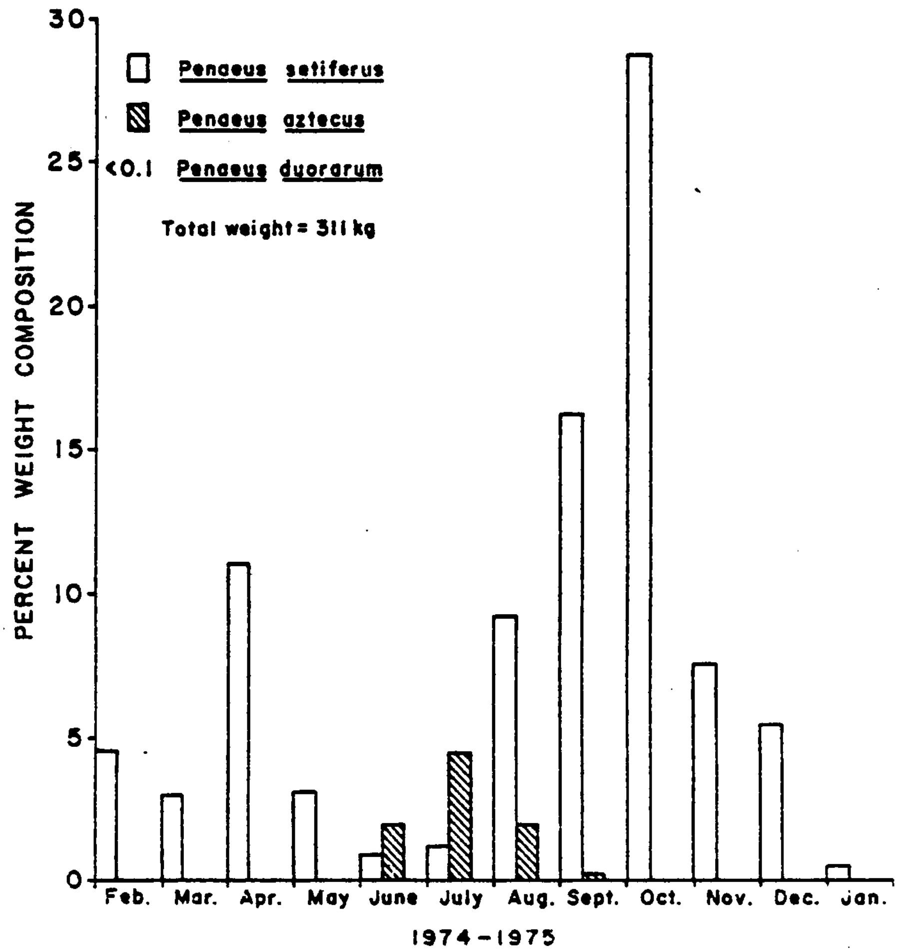


FIGURE VII-8. Penaeid shrimp species composition by weight in South Carolina estuaries (all stations combined) from February 1974 through January 1975. (From Bishop and Shealy, 1977)

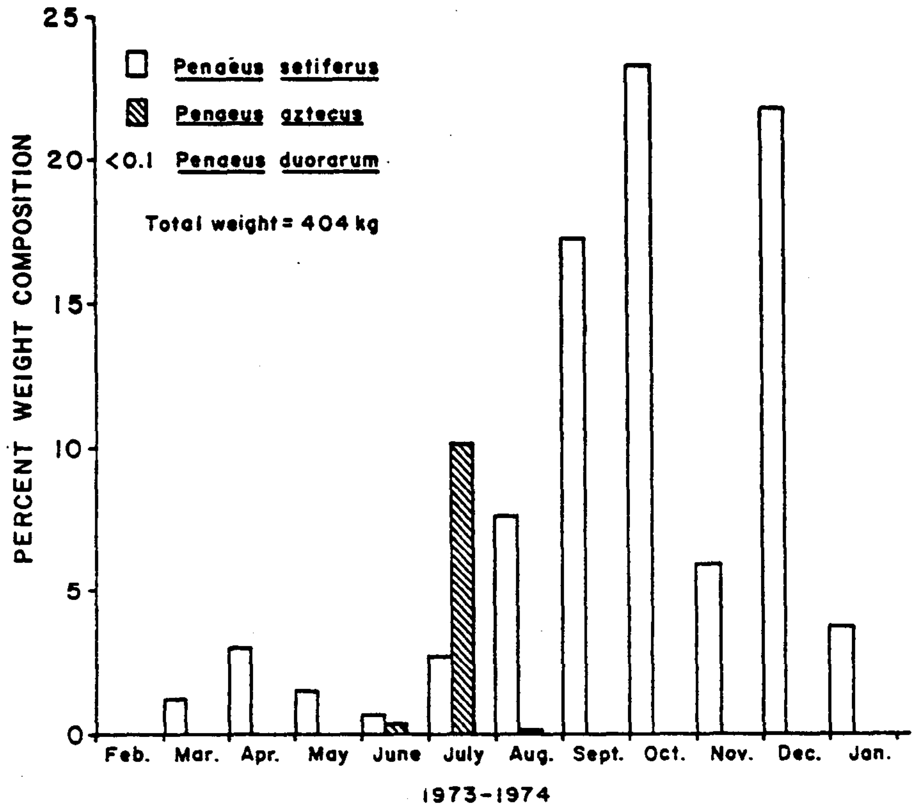


FIGURE VII-9. Penaeid shrimp species composition by weight in South Carolina estuaries (all stations combined) from February 1973 through January 1974. (From Bishop and Shealy, 1977)

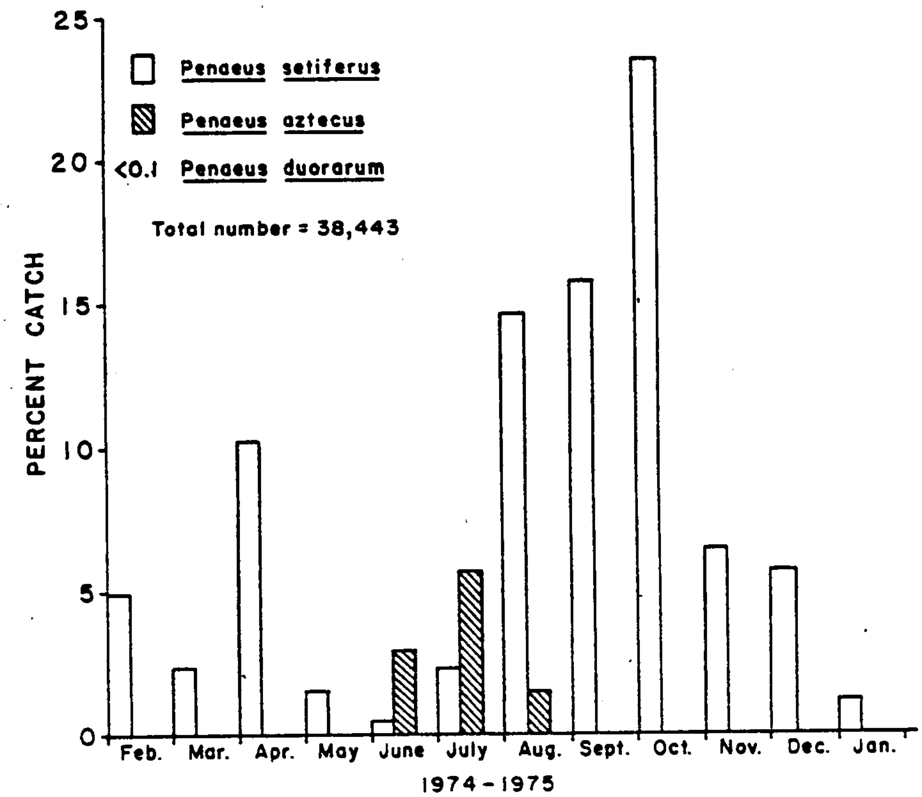


FIGURE VII-10. Penaeid shrimp species composition in South Carolina estuaries (all stations combined) from February 1974 through January 1975. (From Bishop and Shealy, 1977)

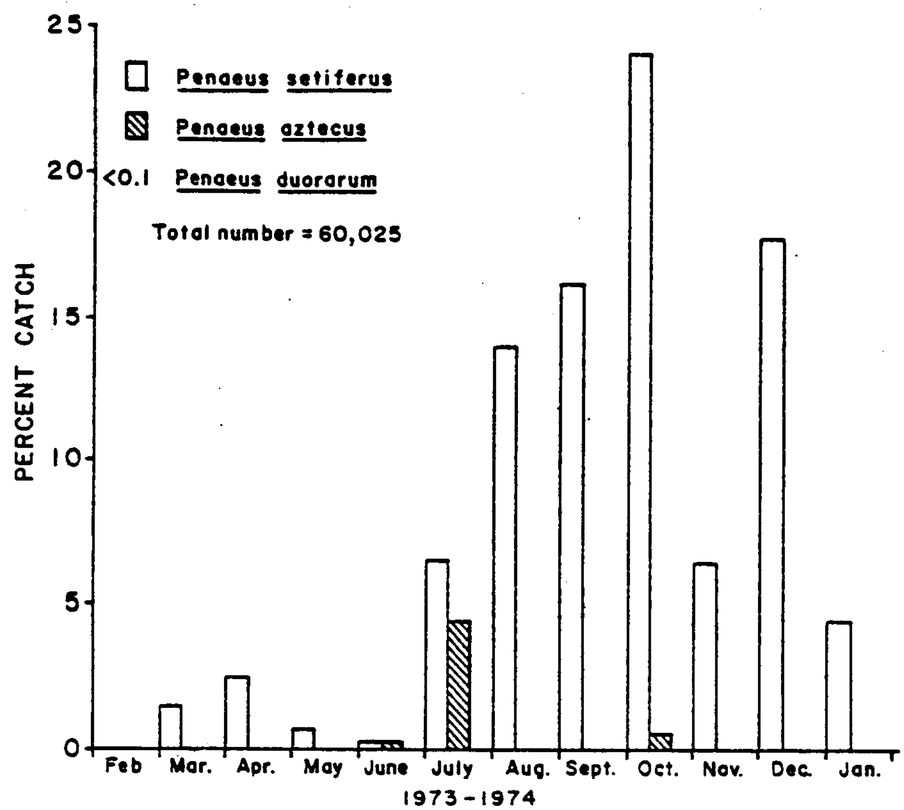


FIGURE VII-11. Penaeid shrimp species composition in South Carolina estuaries (all stations combined) from February 1973 through January 1974. (From Bishop and Shealy, 1977)

TABLE VII-10. Volume and value (in thousands of pounds and dollars) of white, brown, and pink shrimp (heads-off) landed in South Carolina each month of 1976 (Theiling, 1977).

	White Shrimp		Brown Shrimp		Pink Shrimp		All Shrimp		Accuml. Totals	
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
Jan.	21	23	0	0	0	0	21	23	21	23
Feb.	0	0	0	0	0	0	0	0	21	23
Mar.	2	4	0	0	1	2	3	6	24	29
Apr.	9	30	0	0	0	0	9	30	32	59
May	446	1,730	4	13	13	50	463	1,793	495	1,851
June	212	723	547	787	5	15	764	1,525	1,259	3,376
July	42	105	815	1,374	0	0	857	1,479	2,116	4,856
Aug.	388	692	280	473	0	0	669	1,166	2,785	6,021
Sept.	1,137	2,226	67	156	0	0	1,205	2,385	3,990	8,406
Oct.	893	1,725	1	1	0	0	894	1,726	4,884	10,132
Nov.	617	876	0	0	0	0	617	876	5,501	11,008
Dec.	72	82	0	0	0	0	72	82	5,573	11,090
TOTALS	3,839	8,216	1,714	2,804	19	67	5,573	11,090	-	-

Note: Totals may not agree due to rounding to thousands.

abundant in South Carolina waters in 1976. The white and brown shrimp, on the other hand, appeared to be plentiful. The greatest amount of the brown shrimp was taken from June to August, with a peak in July. The white shrimp, which was the most plentiful shrimp, peaked first in May, dropped to a low in July, and peaked again, higher, in September, continuing to be available through December. This author states that the white shrimp has been the most plentiful since 1967. The 1976 harvest was a South Carolina record.

Detailed information on the commercial aspects of shrimp are covered in the Commercial Fisheries Chapter (IX) by Martin. Pamlico Sound, North Carolina's largest estuary, is the most important area in the state for the brown shrimp, Penaeus aztecus. The North Carolina Department of Natural and Economic Resources has studied population dynamics of this commercially important species.

The catch of blue crab, Callinectes sapidus, brought to a commercial processing plant in the southern half of South Carolina by commercial fishermen was analyzed by Eldridge and Waltz (1977). Special emphasis was placed on commercial fishery topics, such as shell disease, trends in landings, and sexual composition of commercial pot catches.

The geographical area sampled by Kennedy, Crane, Schlieder and Barber (1977) for rock shrimp, Sicyonia brevirostris, populations is indicated in Figure VII-12 with shaded areas representing large aggregations. The bathymetric distribution of the species in this region ranges from 18-73m, with a concentration at about 40m. Salinity does not appear to delimit bathymetric distribution, but decreasing temperatures probably do. The reduced availability of suitable bottom habitat probably is the main factor in the bathymetric limitations, however. The factors which limit the inshore distribution are unknown. A major population of the rock shrimp is located off the east coast of Florida near Cape Canaveral.

A new distributional record for the solenocerid shrimp, Hadropenaeus affinis, was reported along the southeast coast of the United States with the northerly limit being Cape Lookout, North Carolina (Perez-Farfante, 1977).

The American lobster, Homarus americanus, has been captured off the coast of North Carolina but not in sufficient numbers to be a significant commercial fishery (Holland, Yelverton, McCoy and Webb, 1972). As part of an exploratory fishery study, lobsters were captured in depths from 93-432m with an average of 16 animals (23kg) caught per hour of towing time at an average depth of 212m.

FIGURE VII-12. *S. brevirostris* distribution by region on the Florida Atlantic Shelf based on catch per 15 minute tow. 25 and 100 shrimp per tow contour lines are presented (Kennedy et al., 1977).

Williams (1974) reported a new species of axiid lobster, Calocaris jenneri, near the edge of the continental shelf off Cape Lookout, North Carolina.

Wolff (1978) reported on the preliminary stock assessment of blue crabs in North Carolina and made specific recommendations for better management of this fishery. He found that the severe winter of 1976-1977 had an extremely detrimental effect on blue crab survival and on industry stability. He also noted that over the period of 1960 to 1976 the greatest catch was in 1964 and the lowest in 1975.

A new northerly distributional limit of the decapod crustacean, Callinectes bocourti, along the central east coast of Florida was reported by Gore and Grizzle (1974). Some concern was expressed since this species is frequently found, to the exclusion of C. sapidus, in areas of poor water quality.

Hendrix and Gore (1973) reported a new species of snapping shrimp, Alpheus thomasi, from the east coast of Florida in the Indian River system.

Gore and Becker (1975) reported the lysiosquilled Heterosquilla armata is now known from coastal waters south to central eastern Florida.

2.1.4 Biomass of Fish and Crustaceans

Barans and Burrell (1976) published data which indicated the relative density and biomass of fish caught in trawls between Cape Fear, North Carolina and Cape Canaveral, Florida (Table VII-5). The roughtail stingray, Dasyatis centroura, and the southern porgy, Stenotomus sp. represented 51.6 percent of the total catch by weight. The relative density of fish species varies with habitat depth (Table VII-11) and with type of habitat (Table VII-12).

Data on biomass of bottomfishes as reflected by fishing effort have been presented by Huntsman (1977) and Barans and Powles (1977). In addition, statistics on southern North Atlantic fisheries are published annually by the National Marine Fisheries Service, NOAA. Since most of these values are for commercial and sports fishing, they are not included in this report and the reader is referred to the chapter on Commercial Fisheries by Martin (Chapter IX).

TABLE VII-11. Habitat depth range (Barans and Burrell, 1976).

HABITAT DEPTH RANGE			
Season	10-18m	19-27m	28-55m
Fall	Stenotomus sp. Dasyatis centroura	Stenotomus sp. Dasyatis centroura	Stenotomus sp. Dasyatis centroura
Summer	Dasyatis centroura Stenotomus sp.[1]	Sardinella anchovia Aluterus schoepfi	Dasyatis centroura Decapterus punctatus[1]
Spring	Dasyatis centroura Myliobatis freminvillei	Dasyatis centroura Stenotomus sp.	Dasyatis centroura Stenotomus sp.
Winter	Dasyatis sayi Mustelus canis	Dasyatis centroura Stenotomus sp.	Dasyatis centroura Stenotomus sp.
	56-110m	111-183m	184-366m
Fall	Decapterus punctatus Syacium papillosum	Etrumeus teres Urophycis regius	Urophycis regius Raja garmani
Summer	Mycteroperca interstitialis Calamus nodosus	Dasyatis centroura Urophycis regius	Peprilus triacanthus Helicolenus dactylopterus
Spring	Dasyatis centroura Dasyatis americana	Dasyatis centroura Peprilus triacanthus	Urophycis regius Etrumeus teres
Winter	Dasyatis centroura Pagrus sedecim	Peprilus triacantus Etrumeus teres	Helicolenus dactylopterus Urophycis regius

[1]Single large specimen of Ginglymostoma cirratum omitted.

TABLE VII-12. Groundfish species commonly associated with sand and live bottom habitat areas of the continental shelf of the southeastern United States (Barans and Burrell, 1976).

Sand Bottom	Live Bottom
Diplectrum formosum	*Calamus leucosteus*
Aluterus schoepfi	*Pagrus sedecim*
Synodus foetens	*Lagodon rhomboides*
Monacanthus hispidus	*Rhomboplites aurorubens*
	*Lutjanus campechanus**
	Haemulon aurolineatum
	Haemulon plumieri
	Holocanthus bermudensis
	Chaetodon sp.
	Centropristis striata
	*Epinephelus drummondhayi**
	*Epinephelus niveatus**
	*Mycteroperca microlepis**
	*Mycteroperca phenax**
	Chromis enchrysurus
	Holocentrus bullisi

*Snappers and groupers were poorly represented in catches of the 3/4 Yankee trawl.

Turner and Johnson (1973) estimated that the biomass of fish in the Newport Estuarine System, North Carolina, based on haul seines, was 0.93 g/m^2 (wet weight) for the entire year. The values changed seasonally and with collecting site (Table VII-13). The Atlantic silversides made up 39 percent of the total biomass in littoral waters; striped mullet, 17.4 percent; spot, 15 percent; pinfish, 6.5 percent; and the remaining 20 percent was made up of a mixture of 33 other species.

Shealy, Miglarese and Joseph (1974) reported on the relative abundance, seasonal distribution, and length-frequency relationships of 88 fish species captured by bottom trawl as part of a survey of certain estuaries in South Carolina initiated in 1973 by the South Carolina Wildlife and Marine Resources Department. Twenty-two of these 88 species were ubiquitous and were found in all estuaries or regions sampled. Data on the relative biomass of these 88 species are represented in Table VII-14.

Gilmore et al. (1977) in an annual progress report indicate sources of biomass data for many species of fish from the Indian River Coastal Zone area. The species list is presented in Table VII-15 (see note at base of table).

Gore, Scotto and Becker (1976) present data on the biomass of various nektonic species of crustaceans found in the Indian River region of the mid-Florida coast.

In a study of the macrofauna of the surf zone off Folly Beach, South Carolina, the species Arenaeus cribrarius, Anchoa mitchilli, Fundulus majalis, Menidia menidia, Trachinotus carolinus, Menticirrhus littoralis, and Mugil curema accounted for 94 percent of the fishes collected. Forty-one fish species were found in the surf, and 16 in the tidal pool. Of the 5095 specimens, 54 percent were from the surf and 46 percent from the tidal pool. About 74 percent of the ichthyomass was seined from the surf and about 26 percent from the tidal pool. The mean weight of the tidal pool fishes was less than half that of those from the surf. The authors postulate that the smaller fishes may find refuge in the tidal pools, which are relatively predator-free, whereas the larger individuals may avoid entrapment in the shallow pools. In a comparison of the ichthyomass of corresponding seasons, the first year catches consistently yielded greater biomass.

During both years, a greater ichthyomass, more numbers, and more species were taken from the surf than from the tidal pool. The surf yielded higher species diversity in all seasons, larger numbers of specimens in all seasons except spring, and greater mass in all seasons but fall. The species Anchoa mitchilli,

TABLE VII-13. Biomass (g/m^2) of fishes collected from littoral waters of Newport River, 1970 (Turner and Johnson, 1973)

Month	Zone 4	Zone 5	Zone 6	Mean
January	1.29	1.43	0.04	0.92
February	0.82	3.35	0.08	1.42
March	7.48	1.61	1.90	3.66
April	1.64	0.94	1.18	1.25
May	2.98	0.85	1.47	1.77
June	2.04	0.87	1.42	1.44
July	2.53	0.25	0.23	1.00
August	2.12	1.71	5.00	2.94
September	3.36	0.96	2.36	2.23
October	0.70	1.38	2.52	1.53
November	0.63	0.92	5.49	2.35
December	0.44	0.49	4.18	1.70
Totals	26.03	14.76	25.87	22.22
Means	2.17	1.23	2.16	1.85

TABLE VII-14. Total numbers, total weights, rankings in order of abundance by number and weight, and percentage of total catch represented by 88 fish species captured by bottom trawl (all stations combined) in S. Carolina estuaries from February 1973 through January 1974 (Shealy et al., 1974).

	RELATIVE NUMBERS			RELATIVE BIOMASS		
Species	Total Number Caught	Numerical Rank	Percent of Total Catch	Total Weight (kg)	Biomass Rank	Percent of Total Catch
Stellifer lanceolatus	23,992	1	38.3	105.6	1	19.3
Anchoa mitchilli	12,074	2	19.3	19.4	7	3.5
Micropogon undulatus	9,030	3	14.4	95.5	2	17.4
Leiostomus xanthurus	5,347	4	8.5	57.1	3	10.4
Cynoscion regalis	2,136	5	3.4	31.0	6	5.7
Bairdiella chrysura	1,863	6	3.0	43.6	5	8.0
Ictalurus catus	1,732	7	2.8	54.2	4	9.9
Urophycis regius	1,612	8	2.6	17.6	8	3.2
Brevoortia tyrannus	823	9	1.3	8.9	11	1.6
Chloroscombrus chrysurus	578	10	0.9	3.4	20	0.6
Alosa aestivalis	462	11	0.7	1.5	33	0.3
Trinectes maculatus	407	12	0.6	3.5	19	0.6
Symphurus plagiusa	362	13	0.6	6.0	14	1.1
Dorosoma petenense	327	14	0.5	0.9	36	0.2
Anchoa hepsetus	216	15	0.3	1.7	30	0.3
Opisthonema oglinum	214	16	0.3	1.6	32	0.3
Trichiurus lepturus	189	17	0.3	7.6	13	1.4
Peprilus alepidotus	151	18	0.2	1.8	28	0.3
Arius felis	90	19	0.1	10.0	10	1.8
Ictalurus punctatus	77	20	0.1	3.2	23	0.6
Opsanus tau	76	21	0.1	4.1	17	0.8
Larimus fasciatus	75	22	0.1	2.1	26	0.4
Menticirrhus americanus	75	22	0.1	1.8	27	0.3
Ictalurus nebulosus	53	23	0.1	2.6	24	0.5
Vomer setapinnis	53	23	0.1	0.2	52	<0.1
Bagre marinus	50	24	0.1	0.4	45	0.1
Chaetodipterus faber	41	25	0.1	0.5	40	0.1
Cynoscion nothus	40	26	0.1	1.6	31	0.3
Selene vomer	39	27	0.1	0.4	43	0.1
Anguilla rostrata	35	28	0.1	4.0	18	0.7
Hypsoblennius hentzi	35	28	0.1	0.3	50	0.1
Morone saxatilis	33	29	0.1	0.2	55	<0.1
Alosa sapidissima	28	30	<0.1	0.2	53	<0.1
Paralichthys dentatus	25	31	<0.1	1.7	29	0.3
Paralichthys lethostigma	25	31	<0.1	4.9	15	0.9
Lepisosteus osseus	24	32	<0.1	17.5	9	3.2
Prionotus tribulus*	24	32	<0.1	0.1	67	<0.1
Citharichthys spilopterus	23	33	<0.1	0.2	57	<0.1
Caranx hippos	20	34	<0.1	0.3	51	<0.1
Peprilus triacanthus	18	35	<0.1	0.2	56	<0.1
Pomatomus saltatrix	17	36	<0.1	1.2	34	0.2
Scomberomorus maculatus	17	36	<0.1	0.4	41	0.1
Etropus crossotus	15	37	<0.1	0.1	61	<0.1

*Tentative identification.

TABLE VII-14, cont.

Species	Total Number Caught	Numerical Rank	Percent of Total Catch	Total Weight (kg)	Biomass Rank	Percent of Total Catch
	RELATIVE NUMBERS			RELATIVE BIOMASS		
Acipenser oxyrhynchus	14	38	<0.1	7.7	12	1.4
Centropristis striata	14	38	<0.1	0.3	47	<0.1
Astroscopus y-graecum	12	39	<0.1	0.1	63	<0.1
Scophthalmus aquosus	11	40	<0.1	0.3	48	<0.1
Monacanthus hispidus	9	41	<0.1	<0.1	69	<0.1
Centropristis philadelphica	7	42	<0.1	0.1	60	<0.1
Cynoscion nebulosus	6	43	<0.1	0.5	38	0.1
Lagodon rhomboides	6	43	<0.1	0.4	42	0.1
Urophycis earlli	6	43	<0.1	0.2	54	<0.1
Lutjanus griseus	5	44	<0.1	0.1	66	<0.1
Orthopristis chrysoptera	5	44	<0.1	0.4	44	0.1
Synodus foetens	5	44	<0.1	0.3	49	0.1
Ancylopsetta quadrocellata	4	45	<0.1	<0.1	70	<0.1
Gymnura micrura	4	45	<0.1	4.7	16	0.9
Pogonias cromis	4	45	<0.1	3.3	22	0.6
Dasyatis sabina	3	46	<0.1	2.4	25	0.4
Gobiesox strumosus	3	46	<0.1	<0.1	75	<0.1
Ictalurus natalis	3	46	<0.1	0.8	37	0.1
Menidia menidia	3	46	<0.1	<0.1	77	<0.1
Perca flavescens	3	46	<0.1	<0.1	72	<0.1
Prionotus carolinus*	3	46	<0.1	<0.1	76	<0.1
Urophycis floridanus	3	46	<0.1	0.1	59	<0.1
Gobiosoma bosci	2	47	<0.1	<0.1	79	<0.1
Ictalurus platycephalus	2	47	<0.1	0.3	46	0.1
Lagocephalus laevigatus	2	47	<0.1	0.1	65	<0.1
Mugil cephalus	2	47	<0.1	<0.1	71	<0.1
Mugil curema	2	47	<0.1	<0.1	73	<0.1
Rhizoprionodon terraenovae	2	47	<0.1	0.5	40	0.1
Rissola marginata	2	47	<0.1	0.1	62	<0.1
Chilomycterus schoepfi	1	48	<0.1	<0.1	82	<0.1
Conger oceanicus	1	48	<0.1	0.1	58	<0.1
Dorosoma cepedianum	1	48	<0.1	<0.1	78	<0.1
Gobionellus boleosoma	1	48	<0.1	<0.1	85	<0.1
Gobionellus hastatus	1	48	<0.1	<0.1	68	<0.1
Gobionellus stigmaticus	1	48	<0.1	<0.1	74	<0.1
Gobiosoma ginsburgi	1	48	<0.1	<0.1	86	<0.1
Ictalurus melas	1	48	<0.1	0.1	64	<0.1
Lepomis auritus	1	48	<0.1	<0.1	80	<0.1
Prionotus evolans*	1	48	<0.1	<0.1	83	<0.1
Rhinoptera bonasus	1	48	<0.1	1.1	35	0.2
Sphyraena guachancho	1	48	<0.1	<0.1	84	<0.1
Sphyrna zygaena	1	48	<0.1	0.5	39	0.1
Squalus acanthias	1	48	<0.1	34.	21	0.6
Syngnathus floridae	1	48	<0.1	<0.1	87	<0.1
Syngnathus fuscus	1	48	<0.1	<0.1	81	<0.1
GRAND TOTALS	62,684		100.0	< 547.7		100.0

*Tentative identification.

TABLE VII-15. Availability of biomass data for fish in the Indian River Coastal Zone area (Gilmore et al., 1977).

SPECIES	PREVIOUS° SURVEYS
Branchiostomidae	
Branchiostoma virginiae	13
B. sp.	NR
Orectolobidae	
Ginglymostoma cirratum	6
Rhincodontidae	
Rhincodon typus O	NR
Odontaspididae	
Odontaspis taurus	7,6
Alopiidae	
Alopias superciliosus NC	11
Lamnidae	
Carcharodon carcharias NC	6
Isurus oxyrinchus	6
Scyliorhinidae	
Galeus arae NC	8,7
Scyliorhinus retifer O	6
Carcharhinidae	
Aprionodon isodon	6
Carcharhinus acronotus	6
C. altimus	6
C. falciformis	7,6
C. leucas	6
C. limbatus	4
C. longimanus	NR
C. maculipinnis	12
C. milberti	7,6,1
C. obscurus	6
C. springeri	19
Galeocerdo curvieri	6
Mustelus canis	4
M. norrisi NC	8
Negaprion brevirostris	8,7,6
Rhizoprionodon terraenovae	7,1
Sphyrnidae	
Sphyrna lewini	6
S. mokarran	6
S. tiburo	7,4,1
S. zygaena NC	7.6.1
Squalidae	

TABLE VII-15, cont.

Squalus acanthias NC,?	1
S. sp. NC	7
Pristidae	
Pristis pectinata	4,1
P. perotteti NC,?	11
Rhinobatidae	
Rhinobatos lentiginosus	4
Torpedinidae	
Narcine brasiliensis	8,5,4
Torpedo nobiliana NC	8,7
Rajidae	
Raja eglanteria	8,7
R. garmani NC	8
R. texana NC	8
Dasyatidae	
Dasyatis americana	7
D. sayi	8,7,1
D. sabina	7,4,3,2,1
D. centroura	7
Gymnura micrura	8,7,1
Myliobatidae	
Aetobatus narinari	8,7,4
Myliobatis freminvillei	7,4
Rhinoptera bonasus	7
Mobulidae	
Manta birostris O	NR
Mobula hypostoma NC	11
Acipenseridae	
Acipenser brevirostrum NC	1
Lepisosteidae	
Lepisosteus osseus	NR
L. platyrhincus	4,3
L. spatula NC,?	1
Amiidae	
Amia calva	4
Elopidae	
Elops saurus	9,5,4,3,2,1
Megalops atlantica	9,5,4,1
Albulidae	
Albula vulpes	5,4
Anguillidae	
Anguilla rostrata	5,4,2,1
Xenocongridae	
Chlopsis bicolor	
Muraenidae	
Anarchias yoshiae	8
Enchelycore nigricans	5
Gymnothorax funebris	5,4

TABLE VII-15, cont.

G. moringa	5,4
G. nigromarginatus	NR
G. vicinus	4
Muraena miliaris	NR
Muraena retifera	5
Muraenesocidae	
Hoplunnis macrurus	8
Congridae	
Ariosoma impressa	NR
Congrina flava	NR
Paraconger caudilimbatus	NR
Ophichthidae	
Ahlia egmontis	5,4
Bascanichthys scuticaris NC	4
B. teres	4
Letharchus velifer	4
Myrichthys acuminatus	5,4
Myrophis punctatus	5,4,2
Mystriophis intertinctus NC	8
Ophichthus ocellatus	8,7,5
Gordiichthys springeri NC	14
Clupeidae	
Alosa sapidissima NC,?	1
Brevoortia smithi	16,8,7,5, 4,3,2
B. tyrannus	16,7,5,4,2,1
B. smithi x B. tyrannus	16
Dorosoma cepedianum	4,3
D. petenense NC	5,4,3,2
Etrumeus teres NC	8,7
Harengula clupeola	4
H. humeralis	5,4
H. jaguana	8,7,5,4,3
Jenkinsia sp.. NC	4
Opisthonema oglinum	8,7,5,4,1
Sardinella anchovia	8,7,5,4
Engraulidae	
Anchoa cubana	4
A. hepsetus	7,4,3
A. lamprotaenia	4
A. lyolepis	5,4,2
A. mitchilli	7,5,4,3,2,1
A. nasuta	12
Anchoviella perfasciata NC	12
Engraulis estauquae NC	12
E. eurystole NC	12
Argentinidae	
Argentina silus NC,?	8

TABLE VII-15, cont.

A. stewarti	NR
Glossanodon pygmaeus	NR
Synodontidae	
Saurida normani	8
S. caribbaea	NR
Synodus intermedius	7
S. foetens	7,5,4,3,2
S. poeyi	NR
S. saurus	NR
Trachinocephalus myops	8,7
Chlorophthalmidae	
Chlorophthalmus agassizi	7
Cyprinidae	
Notemigonus crysoleucas	4,3
Notropis maculatus	4,3
N. petersoni NC	4
Catostomidae	
Erimyzon sucetta	4,1
Ictaluridae	
Ictalurus catus NC	3,2
I. natalis NC	4
I. nebulosus	4
I. punctatus NC	3
Noturus gyrinus NC	4
Clariidae	
Clarias batrachus	NR
Ariidae	
Arius felis	8,7,5,4,3,2,1
Bagre marinus	8,7,5,4,3,1
Batrachoididae	
Opsanus tau	NR
Porichthys plectrodon	7
Gobiesocidae	
Gobiesox strumosus	5,4,2,1
Antennariidae	
Antennarius pauciradiatus	NR
A. scaber	4
A. radiosus NC	8,7
Histrio histrio	8,7,4
Chaunacidae	
Chaunax pictus NC	8
Ogcocephalidae	
Halieutichthys aculeatus	8,7
Ogcocephalus nasutus	8
O. radiatus	8
O. vespertilio	7
O. sp.	NR
O. sp.	NR

TABLE VII-15, cont.

Gadidae	
Enchelyopus cimbrius	NR
Urophycis floridanus	8
U. regius	8,7
U. tenuis	NR
Ophidiidae	
Lepophidium cervinum	8
L. jeannae	NR
L. sp.	7
Ophidion holbrooki	8,7
O. grayi	8,7
O. sp. nov.	8
O. selenops	NR
Ogilbia cayorum	5,4
Otophidium omostigmum	NR
Parophidion schmidti NC	4
Rissola marginata NC	7
Carapidae	
Carapus bermudensis	NR
Exocoetidae	
Cypselurus heterurus	7,5
Parexocoetus brachypterus	7
Prognichthys gibbifrons NC	7,5,4
Hemiramphidae	
Euleptorhamphus velox	NR
E. viridis NC	8
Hemiramphus brasiliensis	7
H. balao NC	8,7
Hyporhamphus unifasciatus	7,5,4,1
H. sp.	NR
Belonidae	
Ablennes hians	7
Platybelone argalus	NR
Strongylura marina	5,4,1
S. notata	5,4
S. timucu	2
Tylosurus acus	7
T. crocodilus	4
Cyprinodontidae	
Cyprinodon variegatus	15,9,5,3,1
Floridichthys carpio	21,5
Fundulus chrysotus	5,4,1
F. cingulatus NC	4
F. confluentus	15,9,4,3
F. grandis	9,5,4,1
F. heteroclitus NC	21
F. lineolatus NC	4,1
F. seminolis NC	4,3

TABLE VII-15, cont.

F. similis	9,5,1
Jordanella floridae	4,3,1
Leptolucania ommata NC	15,1
Lucania goodei	4,3
L. parva	9,5,1
Rivulus marmoratus NC	15,9
Poeciliidae	
Gambusia affinis	15,9,5,4 3,2,1
Heterandria formosa	15,5,4,3,2
Poecilia latipinna	15,9,4,2,1
Poecilia (latipinna x velifera) NC	10
Xiphophorus variatus NC	10
X. helleri x X. variatus NC	10
X. maculatus NC	10
X. maculatus x X. helleri NC	10
X. maculatus x X. variatus NC	10
Atherinidae	
Allanetta harringtonensis	5,4
Labidesthes sicculus	5,4,1
Membras martinica	7,5,3
Menidia beryllina	9,5,4,3,2,1
M. peninsulae	9,5,4,3,2,1
Polymixiidae	
Polymixia lowei NC	8,7
Fistulariidae	
Fistularia tabacaria	8,7,5,4,2
Centriscidae	
Macrorhamphosus scalopax	8
Syngnathidae	
Corythoichthys albirostris	NR
C. brachycephalus	NR
Hippocampus erectus	8,4,3
H. reidi	4
H. zosterae	4
Oostethus lineatus	4
Syngnathus dunckeri	4
Syngnathus floridae	4,3,2
S. fuscus	4
S. louisianae	5,4,3,2,1
S. pelagicus	NR
S. scovelli	5,4,3,2,1
S. springeri	NR
Scorpaenidae	
Neomerinthe hemingwayi	NR
Pontinus longispinis	7
Scorpaena agassizi	NR
S. brasiliensis	8,7,5,4,1

TABLE VII-15, cont.

S. calcarata	8,7
S. dispar	NR
S. grandicornis	4,3
S. plumieri	5,4
Setarches guentheri NC	8
Triglidae	
Bellator brachychir	5
B. egretta NC	8
B. militaris	8,7
Peristedion miniatum	NR
Peristedion sp.	7
Prionotus alatus	NR
P. carolinus NC	8,7
P. evolans NC	8,7,1
P. martis	NR
P. ophryas	NR
P. roseus	8,7
P. scitulus	8,5,4
P. salmonicolor	8,7,5
P. tribulus	4,3,1
Centropomidae	
Centropomus pectinatus	5,4,2
C. undecimalis	9,5,4,3,2,1
Serranidae	
Anthias sp. NC	7
Centropristis ocyurus	8,7,5
C. philadelphica	8,7,5,4
C. striata	8,7,5,4
Diplectrum bivittatum	4
D. formosum	8,7,4
Epinephelus drummondhayi	NR
E. fulvus NC	5
E. itajara	5,4,2,1
E. morio	4
E. nigritus	NR
E. niveatus	7
E. striatus	NR
Hemanthias vivanus	8
H. sp. NC	7
Hypoplectrus gemma	NR
H. nigricans	NR
H. puella	NR
H. unicolor	4
Liopropoma eukrines	NR
Mycteroperca bonaci	5,4
M. microlepis	5,4
M. phenax	NR
Pikea mexicana	NR

TABLE VII-15, cont.

Plectranthias garrupellus	NR
Pronotogrammus aureorubens	NR
Serraniculus pumilio NC	8
Serranus baldwini	4
S. notospilus	8
S. phoebe	8,7
S. subligarius	5
Grammistidae	
Rypticus bistrispinus	NR
R. maculatus	4
R. saponaceus	5
R. subbifrenatus	NR
Centrarchidae	
Elassoma evergladei	4,1
Enneacanthus gloriosus	4,3
E. obesus NC,?	1
Lepomis gulosus	4,1
L. macrochirus	5,4,3,2,1
L. marginatus	4,3
L. microlophus	4,3
L. punctatus	4,1
Micropterus salmoides	4,1
Pomoxis nigromaculatus	3,2
Percidae	
Etheostoma fusiforme	4,1
Priacanthidae	
Priacanthus arenatus	NR
Pristigenys alta	8
Apogonidae	
Apogon binotatus	NR
A. maculatus	5,4
A. planifrons	NR
A. pseudomaculatus	5,4
Astropogon puncticulatus	NR
A. stellatus	5,4
Phaeoptyx conklini	5
P. pigmentaria NC	5
Branchiostegidae	
Caulolatilus cyanops	NR
Lopholatilus chamaeleonticeps	NR
Pomatomidae	
Pomatomus saltatrix	8,7,5,4,2,1
Rachycentridae	
Rachycentron canadum	7,5
Echeneidae	
Echeneis naucrates	7,5
E. neucratoides	NR
Remora brachyptera	NR

TABLE VII-15, cont.

R. osteochir	NR
R. remora	1
Remorina albescens	NR
Carangidae	
Alectis crinitus NC	8,5
Caranx bartholomaei	7,4
C. crysos	8,7,4,1
C. hippos	8,7,5,4,3, 2,1
C. latus	4,3
C. ruber	8,5,4
Chloroscombrus chrysurus	8,7,5,4,3,1
Decapterus punctatus	7,4
Elagatis bipinnulata	4
Oligoplites saurus	4,3,1
Selar crumenopthalmus NC	8,7,4
Selene setapinnis	8,7,3,1
S. vomer	8,5,4,3,2,1
Seriola dumerili	7
S. rivoliana	4
Trachinotus carolinus	8,7,5,4,3,1
T. falcatus	5,4,3,1
T. goodei	5,4,1
Trachurus lathami	8,7
Coryphaenidae	
Coryphaena equisetis	NR
C. hippurus	8,7,5,4
Lutjanidae	
Lutjanus analis	4,2
L. apodus	5,4,2,1
L. campechanus	17
L. cyanopterus	4
L. griseus	5,4,3,2,1
L. jocu	4
L. mahogoni	NR
L. synagris	5,4,3,2,1
Ocyurus chrysurus	4
Pristipomoides aquilonaris	NR
Rhomboplites aurorubens	8,7
Lobotidae	
Lobotes surinamensis	7,4,1
Gerreidae	
Diapterus auratus	5,4,3,2,1
D. plumieri	9,5,4,2
Eucinostomus argenteus	8,5,4,2
E. gula	5,4,3,2,1
E. havana	4
E. lefroyi	4

TABLE VII-15, cont.

E. pseudogula	4
Gerres cinereus	4
Pomadasyidae	
Anisotremus surinamensis	5,4,1
A. virginicus	5,4
Haemulon album	NR
H. aurolineatum	8,5,4
H. carbonarium	NR
H. chrysargyreum	4
H. flavolineatum	4
H. macrostomum	4,1
H. melanurum	NR
Haemulon parrai	5,4,2
H. plumieri	7,4
H. sciurus	4
Orthopristis chrysoptera	7,5,4,3,2,1
Pomadasys crocro	NR(15)
Sparidae	
Archosargus probatocephalus	5,4,3,2,1
A. rhomboidalis	5,4
Calamus arctifrons	4
C. bajonado	NR
Diplodus argenteus	4
D. holbrooki	5,1
Lagodon rhomboides	8,7,5,4, 3,2,1
Stenotomus chrysops	7
Sciaenidae	
Bairdiella chrysura	7,5,4,3,2
B. sanctaeluciae	18
Cynoscion nebulosus	8,7,5,4
C. nothus	7,5
C. regalis	8,7,5,4, 3,2
Equetus acuminatus	8,5,4
E. lanceolatus	7
E. umbrosus	5,4
Larimus fasciatus	8,7
Leiostomus xanthurus	8,7,5,4, 3,2,1
Menticirrhus americanus	7,5,3,1
M. littoralis	5,4
M. saxatilis	8,7,5,4,2
Micropogon undulatus	8,7,5,4, 3,2,1
Odontoscion dentex	NR
Pogonias cromis	8,7,5,4
Sciaenops ocellata	5,4,3,2,1

TABLE VII-15, cont.

Stellifer lanceolatus	7,5,4,3,2
Umbrina coroides	5,4
Mullidae	
Mullus auratus	7
Pseudupeneus maculatus	8,7,5,4
Pempheridae	
Pempheris schomburgki	NR
Kyphosidae	
Kyphosus incisor	8,7,4
K. sectatrix	8,7,5,4
Ephippidae	
Chaetodipterus faber	8,7,5,4,3,2,1
Chaetodontidae	
Chaetondon aya	8
C. capistratus	4
C. ocellatus	4
C. sedentarius	NR
Holacanthus bermudensis	NR
H. ciliaris	5,4
H. tricolor O	NR
Pomacanthus arcuatus	4
P. paru	5
Cichlidae (all introduced)	
Hemichromis bimaculatus NC	10
Tilapia melanopleura NC	10
T. mossambica NC	10
Pomacentridae	
Abudefduf saxatilis	8,5,4,3,2
A. taurus	4
Chromis enchrysurus	NR
Microspathodon chrysurus	NR
Pomacentrus dorsopunicans	4
P. leucostictus	5,4
P. partitus	5
P. variabilis	5,4
Labridae	
Bodianus rufus	NR
Doratonotus megalepis	5,4
Halichoeres bethyphilus	8
H. bivittatus	5,4
H. caudalis	NR
H. maculipinna	5
H. poeyi	8,5
H. radiatus	NR
Hemipteronotus novacula	NR
Lachnolaimus maximus	NR
Thalassoma bifasciatum	NR
Scaridae	

TABLE VII-15, cont.

Cryptotomus roseus	4
Nicholsina usta	5,4,1
Scarus coelestinus	NR
S. coeruleus	NR
S. croicensis NC	4
S. guacamaia	4
S. taeniopterus	NR
Sparisoma chrysopterum	4
S. radians	4
S. rubripinne	4
Mugilidae	
Agonostomus monticola	NR
Mugil cephalus	9,5,4,3,2,1
M. curema	7,5,4,3,2,1
Sphyraenidae	
Sphyraena barracuda	8,5,4,3
S. borealis	8,4
S. guachancho	NR
Polynemidae	
Polydactylus octonemus NC	5,2
P. oligodon	NR
P. virginicus NC	5
Opistognathidae	
Opistognathus macrognathus NC	15,NR
O. whitehursti	NR
O. sp.	5,2
O. sp.	NR
Percophididae	
Bembrops anathirostris	NR
B. gobioides	NR
Dactyloscopidae	
Dactyloscopus crossotus	4
D. tridigitatus	4
D. sp.	NR
D. sp.	NR
Gillellus greyae	5,4
G. rubrocinctus	4
G. sp.	2
Uranoscopidae	
Astroscopus y-graeum	7,5,4
Kathetostoma albigutta	8,7
Clinidae	
Enneanectes altivelis	NR
E. pectoralis	NR
Labrisomus gobio	NR
L. nuchipinnis	5,4
Malacoctenus macropus	5
M. triangulatus	5

TABLE VII-15, cont.

Paraclinus fasciatus	4
P. nigripinnis	5,4
Starksia ocellata	NR
Blenniidae	
Blennius cristatus	5,4
Blennius marmoreus	5,4
B. nicholsi	5,4,2
Chasmodes bosquianus	NR
C. saburrae	5,1
Entomacrodus nigricans	NR
Hypleurochilus aequipinnis	4
H. bermudensis	5
H. geminatus	5
Hypsoblennius sp. NC	7
Callionymidae	
Callionymus pauciradiatus NC	4
Eleotridae	
Dormitator maculatus	9,5,4,2
Eleotris pisonis	5
Erotelis smaragdus	4
Gobiomorus dormitor	4
Gobiidae	
Awaous tajasica	15
Bathygobius curacao	5
B. soporator	5,4,3,2,1
Coryphopterus dicrus	NR
C. glaucofraenum	4
Evermannichthys spongicola	NR
Evorthodus lyricus	9,5,4,1
Gnatholepis thompsoni	NR
Gobioides broussoneti	5,4,3
Gobionellus boleosoma	5,4,3,2,1
G. gracillimus NC	5,3
G. hastatus NC	5,3
G. oceanicus	2
G. Schufeldti	NR
G. smaragdus	5,4,2
G. stigmaturus	4,1
Gobiosoma bosci	5,4,3,2,1
G. ginsburgi NC	4
G. macrodon	NR
G. oceanops	NR
G. robustum	5,4,2
Lophogobius cyprinoides	5,4,2
Lythrypnus nesiotes	NR
Microgobius gulosus	5,4,2,1
M. microlepis NC	4
M. thalassinus	NR

TABLE VII-15, cont.

Risor ruber	
Varicus n.sp.	
Microdesmidae	
Cerdale floridana	4
Acanthuridae	
Acanthurus bahianus	5,4
A. chirurgus	5,4
A. coeruleus	NR
Trichiuridae	
Trichiurus lepturus	8,7,4,3
Scombridae	
Acanthocybium solanderi	7
Auxis thazard	NR
Euthynnus alletteratus	7
E. pelamis	NR
Scomber japonicus NC	7
Scomberomorus cavalla	7
S. maculatus	8,7,5,1
S. regalis	5
Thunnus albacares	NR
T. atlanticus	NR
Xiphiidae	
Xiphias gladius	7
Istiophoridae	
Istiophorus platypterus	NR
Makaira nigricans	NR
Tetrapterus albidus	NR
Stromateidae	
Nomeus gronovii	4
Peprilus alepidotus NC	8,7
P. triacanthus NC	8,7,5
Psenes cyanophrys	8,4
Bothidae	
Anclopsetta quadrocellata NC	8,7
Bothus ocellatus	8,4
B. robinsi	NR
Citharichthys arctifrons	8,7
C. arenaceus	4
C. macrops	8,7,5,4,3
C. spilopterus	7,5,4,3,2,1
Cyclopsetta chittendeni NC	8
C. fimbriata	8
Engyophrys senta	NR
Etropus crossotus	7,5,3
E. rimosus	8
Monolene antillarum	NR
M. sessilicauda	NR
Paralichthys albigutta	8,7,5,4,2

TABLE VII-15, cont.

P. dentatus	7,5
P. lethostigma	8,7,4,1
P. oblongus NC	7
P. squamilentus	8,7,5,4
Scophthalmus aquosus NC	7
Syacium gunteri	NR
S. micrurum NC	4
S. papillosum	8
Pleuronectidae	
Poeciliopsetta beani	NR
Soleidae	
Achirus lineatus	5,4,3,2,1
Gymnachirus melas	7
Trinectes maculatus	7,5,3,2
Cynoglossidae	
Symphurus civitatus	NR
S. diomedianus	8
S. minor	NR
S. plagiusa	8,7,5,4,3,2,1
S. urospilus	NR
Balistidae	
Aluterus heudeloti NC	4
A. schoepfi	7,4
A. scriptus	4
Balistes capriscus	8,5,4
B. vetula	NR
Canthidermis maculatus	NR
C. sufflamen	4
Cantherhines pullus	NR
Monacanthus ciliatus	8,5,4
M. hispidus	8,7,5,4
M. setifer	8,4
M. tuckeri	NR
Ostraciidae	
Lactophrys quadricornis	8,7,4
L. trigonus	7,5,4,2
L. triqueter	NR
Tetraondontidae	
Canthigaster rostrata	NR
Lagocephalus laevigatus	NR
Sphoeroides dorsalis	8
S. maculatus NC	3,1
S. nephelus	5,4,3,2
S. spengleri	8,5,4,1
S. testudineus	5,4,3,2,1
Diodontidae	
Chilomycterus antennatus NC	5
C. schoepfi	8,7,5,4,3,2,1

TABLE VII-15, cont.

Diodon histrix NC	1
D. holacanthus	4
Molidae	
Mola mola	NR
TOTAL SPECIES	
Total Continental Shelf	478
Total Indian River Lagoon and Tributaries	381
Combined Species	609
New Records	135

°Previous surveys and new records: NR=a fish not previously recorded from the study area, 1=Evermann and Bean (1897), 2=V. Springer (1960), 3=Gunter and Hall (1963), 4=Christensen (1965), 5=Powell et al., (1972), 6=S. Springer (1960, 63, 66), 7=Anderson and Gehringer (1965), 8=Bullis and Thompson (1965), 9=Harrington and Harrington (1961), 10=Courtenay (1972), 11=Bigelow and Schroeder (1948), 12=Daly (1970), 13=Cory and Pierce (1967), 14=Briggs (1958), 15=Harrington, R. H., ichthyological collection, Florida State Entomological Research Laboratory, Vero Beach, Florida, 16=Dahlberg (1970), 17=Moe (1963), 18=Bailey et al., (1970), 19=Stewart Springer, pers. comm., 20=Unpublished R/V Silver Bay station data compiled by Paul Struhsaker of the National Marine Fisheries Service, 21=Relyea (1975).

Arenaeus cribrarius, Menidia menidia, Fundulus majalis, Trachinotus carolinus, Mugil curema, and Menticirrhus comprised 74 percent of the total biomass. Arenaeus cribrarius accounted for 82 percent of the natant invertebrate specimens and 75 percent of the corresponding mass. Included is an annotated list of the following species: Arenaeus cribrarius, Alosa aestivalis, Dorosoma petenense, Anchoa mitchilli, Fundulus majalis, Menidia spp., Trachinotus carolinus, Menticirrhus littoralis, Mugil cephalus, Mugil curema, Paralichthys squamilentus, Sphoeroides spengleri, Chilomycterus.

2.1.5 Molluscs

According to the National Marine Fisheries Service northeastern survey, the short-finned squid, Illex illecebrosus appears to be widely distributed over the continental shelf in the fall (September to November) with presence on the shelf edge (>80m) occurring in the spring (March to May) (Rathjen, 1973). (See Figure VII-49, Section 2.4.1.1). Proceeding south from Cape Hatteras to Florida, this species occurs in deeper waters and has been observed at depths to 510m. In June this squid had been reported as numerous in depths where the water temperature ranged from 5-15^{o}C. The winter distribution and the reproductive habits of the short-finned squid remain virtually unknown.

In addition to the long- and short-finned squids, several other squid varieties occur along the western Atlantic continental shelf. These include Lolliguncula brevis, the brief squid, and Loligo pealei, the arrow squid. In the deeper waters off the continental shelf, less-known species have been reported, such as Pholidoteuthis adami and the orange back squid (Ommastrephes pteropus). Little is known about the giant squid, Architeuthis sp., which may reach 18m in length and weigh possibly more than one ton. There are about 20 species reported, occurring at depths of 200-400 meters or more.

Serchuk and Rathjen (1974) found a close relationship between the distribution of the long-finned squid, Loligo pealei, and bottom water temperature in the northwest United States, including the Cape Hatteras area. Best catches were made at sites where the temperature was above 10^{o}C. During August and September 1974, a survey of the oceanic waters of North Carolina and Virginia revealed that the squid, Loligo pealei, was most abundant in the southernmost portion of the study area, especially at depths of 73-183m (40-100fm) and a temperature of 13^{o}C (Holland and Keefe, 1976).

Although emphasizing more northerly areas, Clark and Brown (1977) reported on the changes in biomass of finfishes and squids from Cape Hatteras, North Carolina to the Gulf of Maine. Numerous commercially important species of fish declined over the period from 1963 to 1974. However, the squids Loligo pealei and Illex illecebrosus have shown pronounced increases coincident with declines in other species occupying similar ecological niches.

Kraeuter and Thomas (1975) reported the range extension from south Florida to Georgian coastal waters of the following cephalopod mollusks: Semirossia tenera, Octopus burryi, O. joubini, and Scaeurgus unicirrhus. These species are known from Mexican waters, implying a zoogeographic similarity between these shallow water cephalopod faunas.

The available data on the calico scallop, Argopecten gibbus, were reviewed by Allen and Costello (1972). Although this species is typically benthic, it may also be considered nektonic because of its limited locomotory ability. Its general distribution is depicted in Figure VII-13. Generally it is found on continental or insular shelves from depths less than 2m to depths of 370m.

2.1.6 Marine Leeches

Although normally exhibiting limited swimming ability, the leeches could be considered part of the nekton as a free swimming form or attached to a nektonic species. Sawyer and Shelley (1976) and Shelley (1978) published a checklist of marine leeches from North and South Carolina.

2.2 Population Characteristics

2.2.1 Fish

2.2.1.1 Open Ocean and Coastal Water Studies

From November 1972 through June 1973 anadromous fishes were sampled from Cape Lookout, North Carolina to Chesapeake Bay Entrance, Virginia by Holland and Powell (1975). Alosids (Alosa aestivalis, A. mediocris, A. pseudoharengus, and A. sapidissima) were not captured effectively by Yankee No. 36 and 41 section nets and midwater trawl. All local anadromous fishes were taken from depths to 36.6m, although yearly differences were observed in the bathymetric distribution of alewife (A. pseudoharengus), blueback herring (A. aestivalis), and American shad (A. sapidissima). There appeared to be no correlation with water temperature during the period from November through May. The area between Cape Hatteras and Chesapeake Bay entrance yielded the maximum concen-

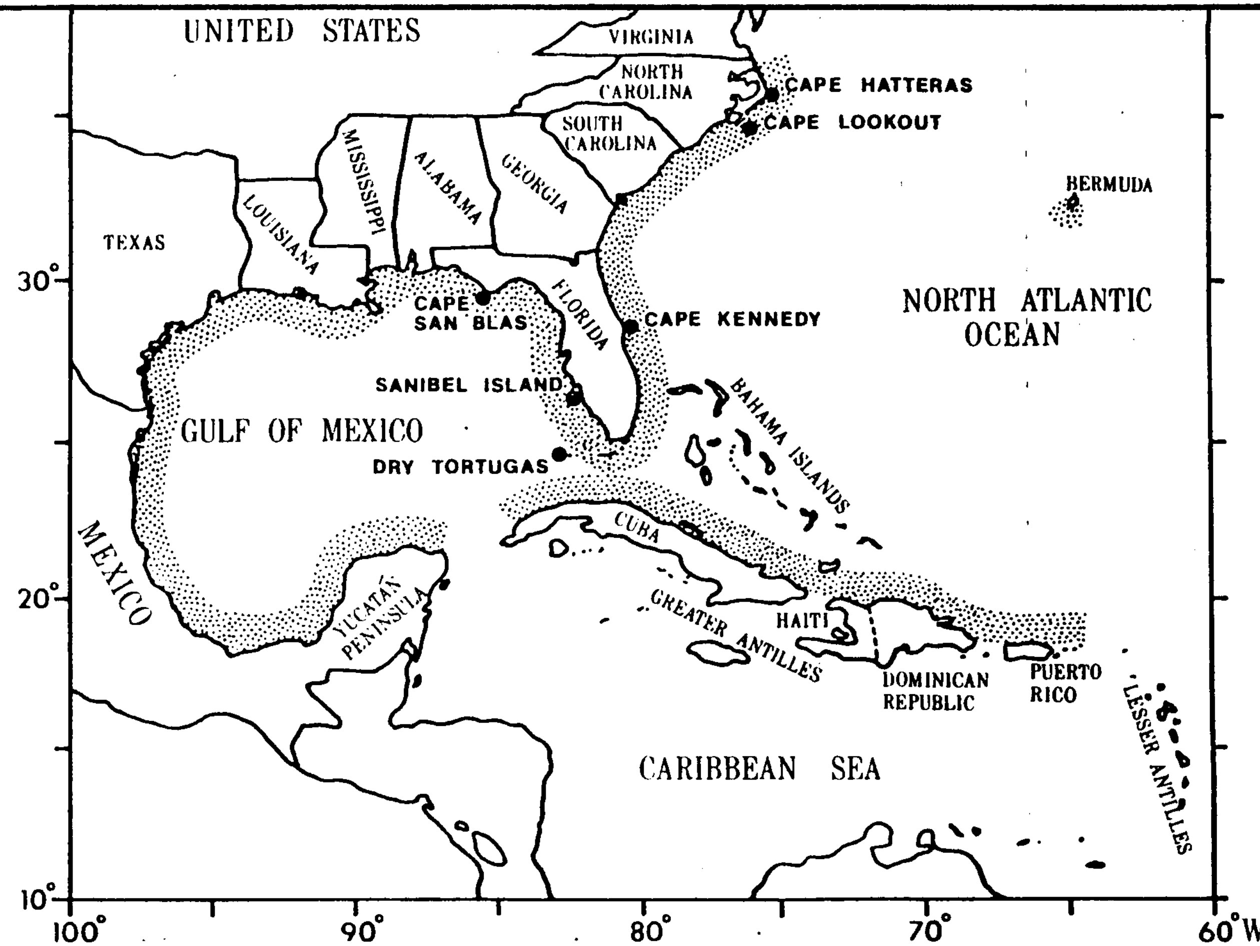


FIGURE VII-13. Distribution of the calico scallop (general distribution of the calico scallop is shown by the stippled area) (Allen and Costello, 1972).

trations. American shad, river herring (A. aestivalis and A. pseudoharengus), and hickory shad were most abundant from February through April. Striped bass, Morone saxatilis, were caught from November through April, and Atlantic sturgeon, Acipenser oxyrhynchus, from November through May. A decrease was evident in catches of American shad and river herring from the years 1972-1973 to 1973-1974. In the combined years, 2,244 alewife, 11,233 blueback herring, 40 American shad, 49 sturgeon, and 4 hickory shad were tagged and released. During their sixth year of life striped bass were recruited to the offshore stock. Striped bass males were infrequently captured. Age groups 3 and 4 were markedly absent from the alewife populations; however, age 2 alewife were encountered, and five year olds constituted the most frequently taken group. No significant differences were observed between alewife sex ratios. The five and six year old blueback herring were the predominant model age group. During the years 1973-1974 yearlings and age 3 fish were abundant, whereas age 2 and age 3 fish were the dominant younger individuals taken during 1972-1973. Males were significantly more predominant than females.

Holland and Yelverton (1973) reported on the growth characteristics of five species of anadromous fishes found in offshore waters of North Carolina during the period of 1968 to July 1971. These species are striped bass (Morone saxatilis), Atlantic sturgeon (Acipenser oxyrhynchus), American shad (Alosa sapidissima), alewife (A. pseudoharengus), and blueback herring (A. aestivalis). For these species fork length-weight relationships are represented in Figures VII-14 to VII-18 and age-fork length relationships in Figure VII-19 to VII-21, except for Atlantic sturgeon.

The alewife appeared to initiate ovarian development earlier in the season than blueback herring. During the 1973-1974 season both blueback herring and alewife had more developed ovaries. In warmer waters size at sexual maturation for females was approximately 210mm (FL) for alewife and 200mm (FL) for blueback herring. Analysis of spawning marks on river herring scales revealed that the majority of male blueback herring began spawning at age 4, while the majority of females did not begin spawning until age 5. The majority of alewife (sexes combined) spawned at age 6.

According to Huntsman (1977), complete life history information is available for only two (Epinephelus morio and Lutjanus griseus) of the 30 or more fishes important to the South Atlantic Bight headboat fishery. Research is in progress at the Beaufort Laboratory of the National Marine Fisheries Service on the life history, including growth rates, mortality rates, and reproduction, of the following species: the red porgy, Pagrus sedecim; the vermillion

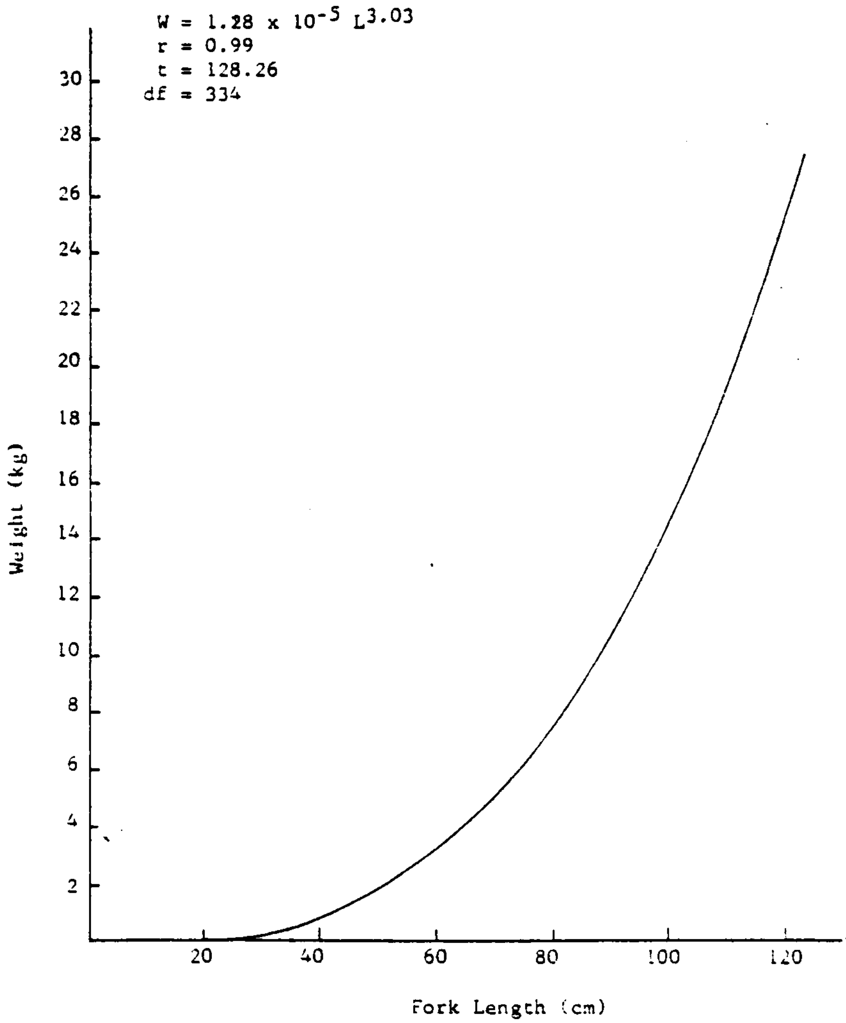


FIGURE VII-14. Fork length-weight relationship for striped bass, offshore North Carolina, 1968 - 1971. (From Holland and Yelverton, 1973)

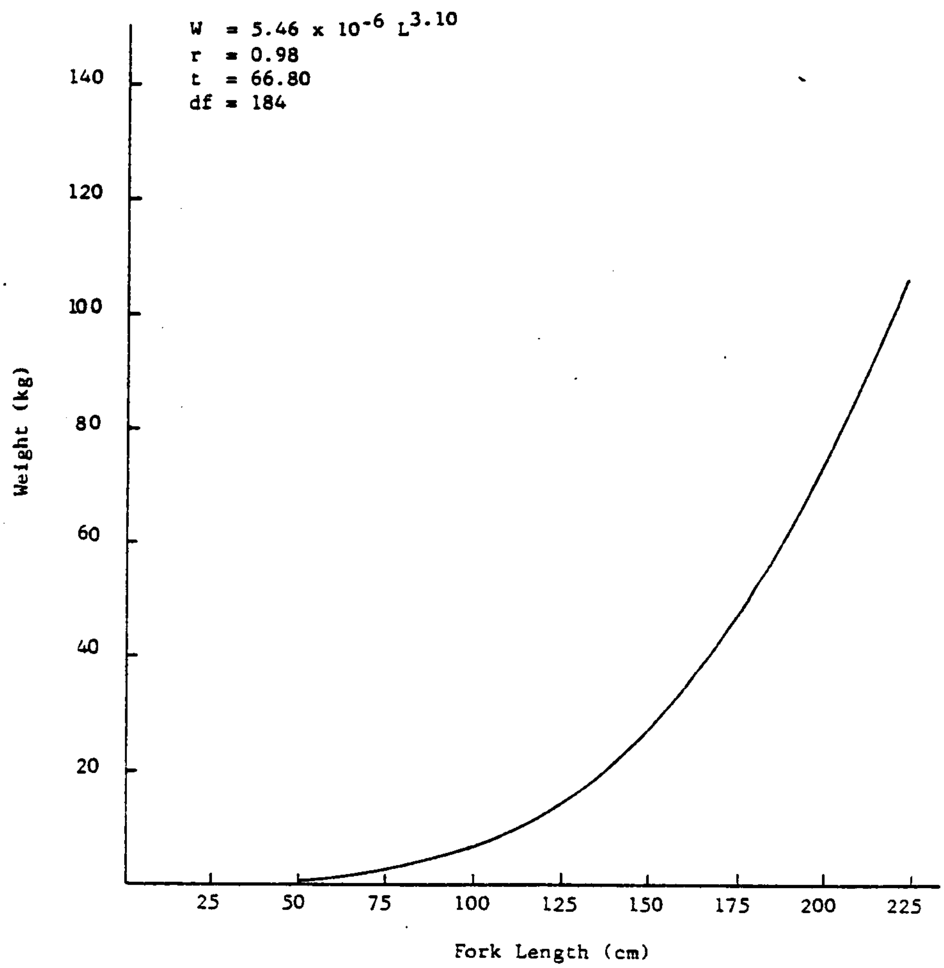


FIGURE VII-15. Fork length - weight relationship for Atlantic sturgeon, offshore North Carolina, 1968 - 1971. (From Holland and Yelverton, 1973)

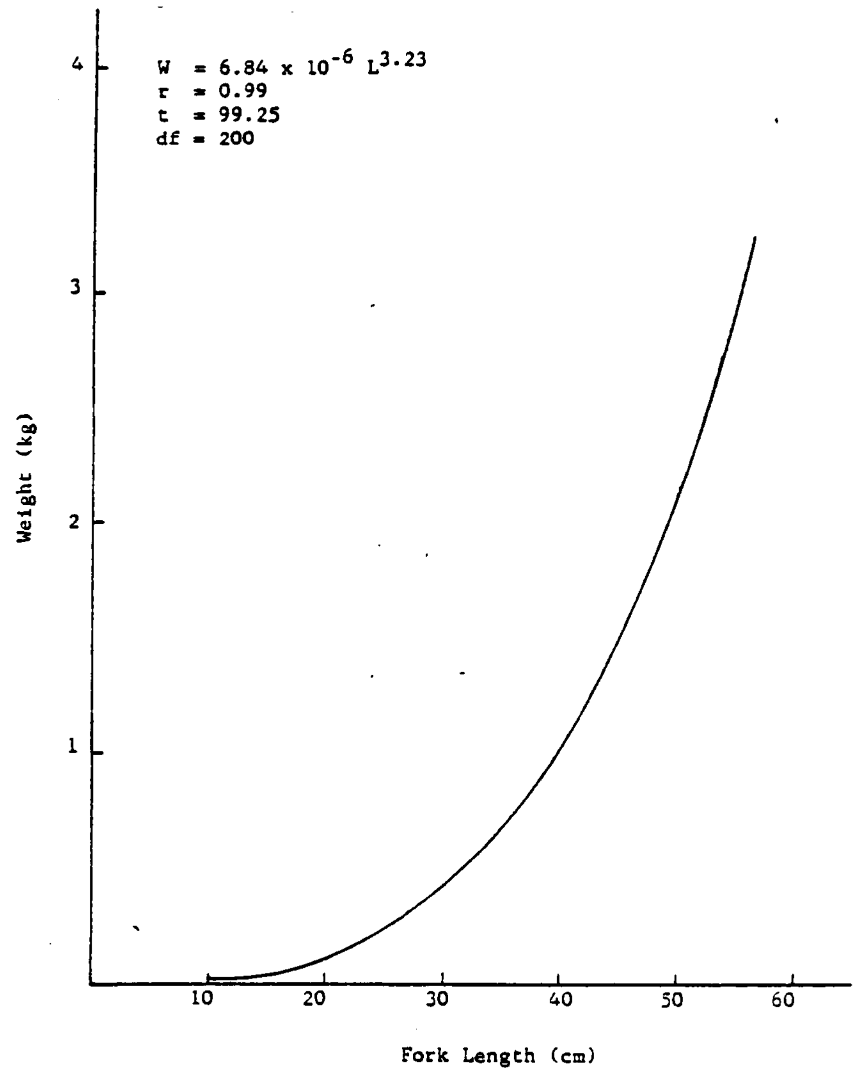


FIGURE VII-16. Fork length - weight relationship for American shad, offshore North Carolina, 1968 - 1971. (From Holland and Yelverton, 1973)

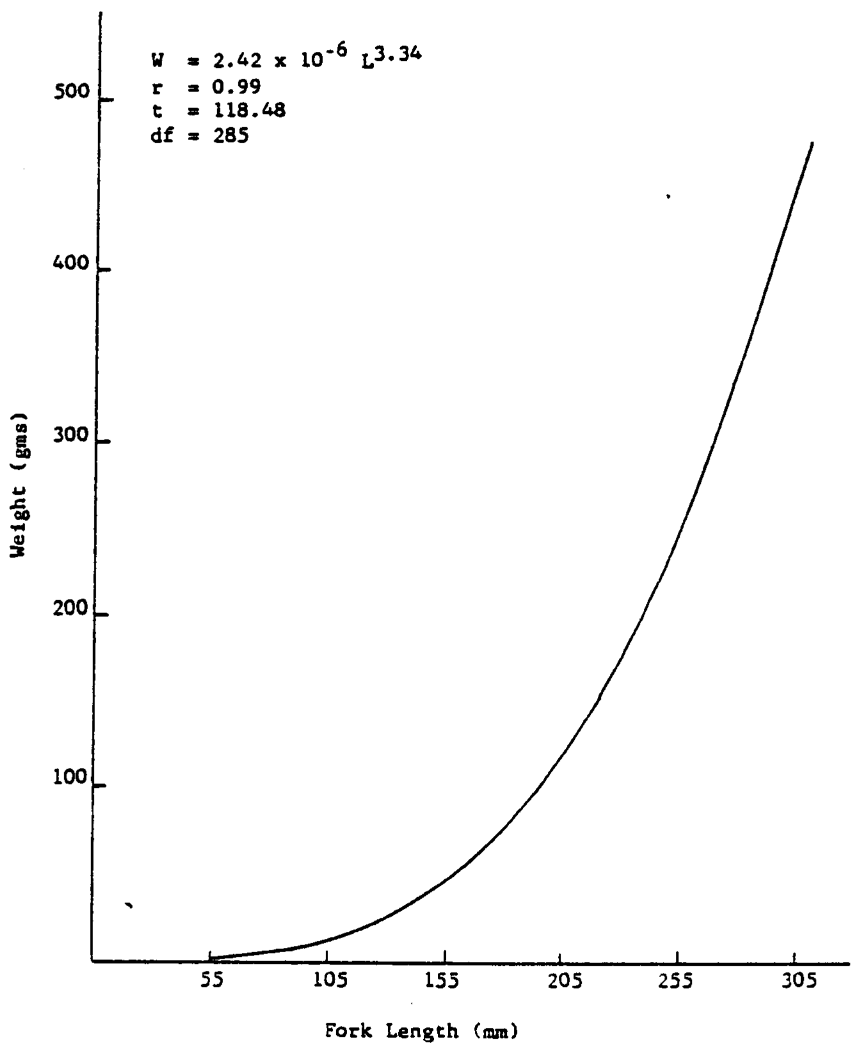


FIGURE VII-17. Fork length - weight relationship for alewife, offshore North Carolina, 1969 - 1971. (From Holland and Yelverton, 1973)

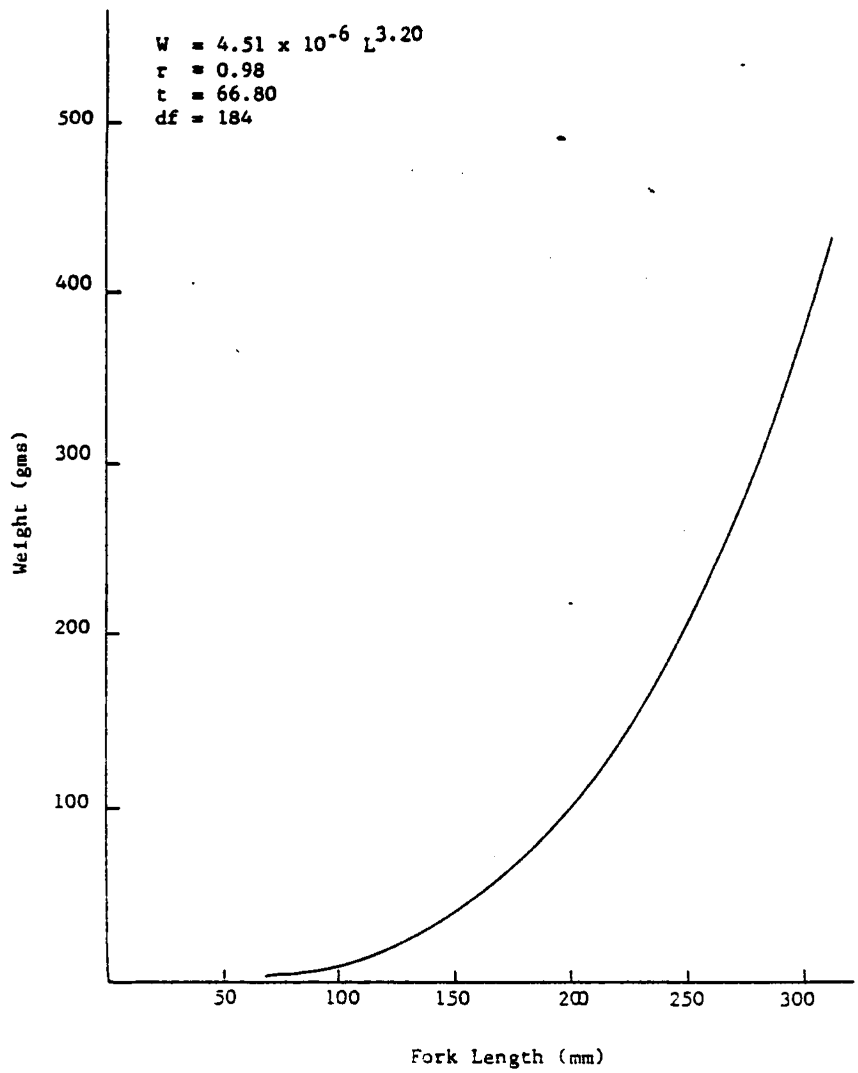


FIGURE VII-18. Fork length - weight relationship for blueback herring, offshore North Carolina 1969 - 1971. (From Holland and Yelverton, 1973)

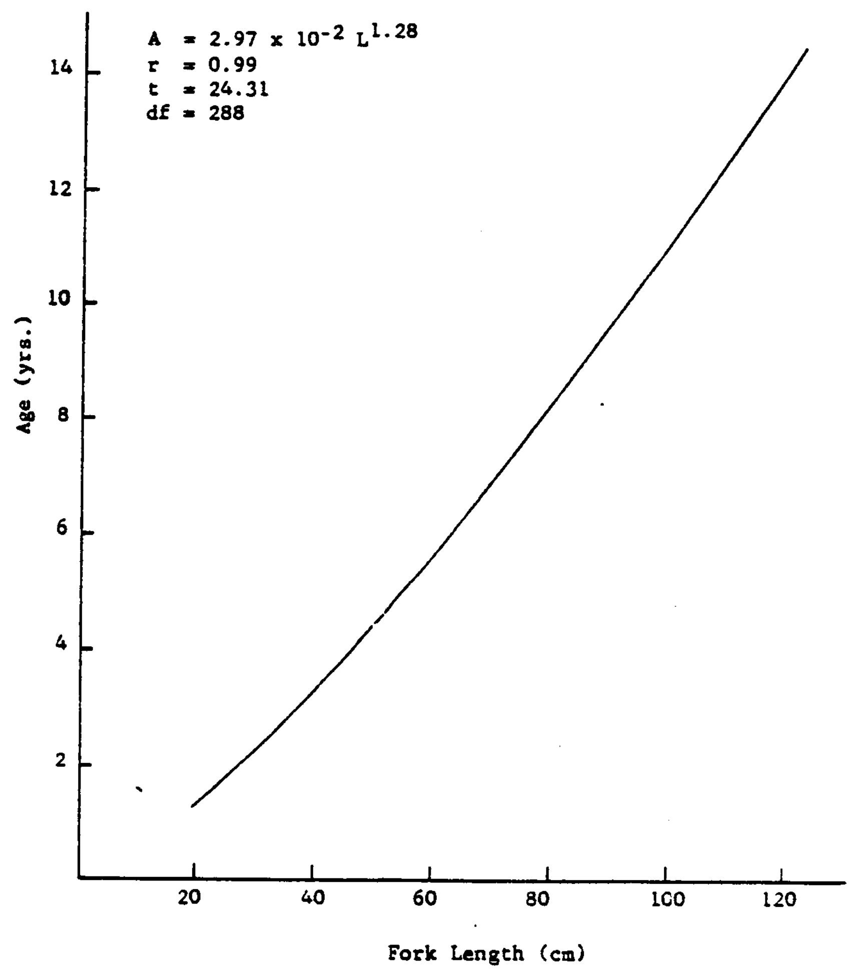


FIGURE VII-19. Calculated age - fork relationship for striped bass, offshore North Carolina, 1968 - 1971. (From Holland and Yelverton, 1973)

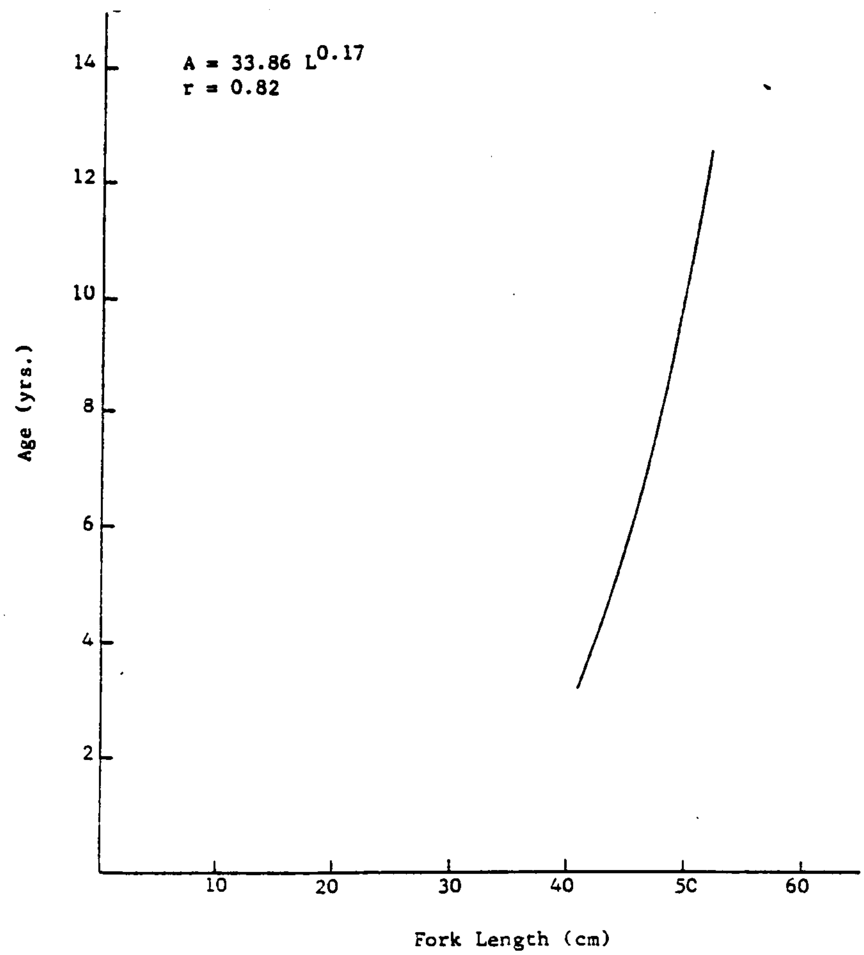


FIGURE VII-20. Fork length - age relationships for American shad sexes combined, offshore North Carolina 1970 - 1971. (From Holland and Yelverton, 1973).

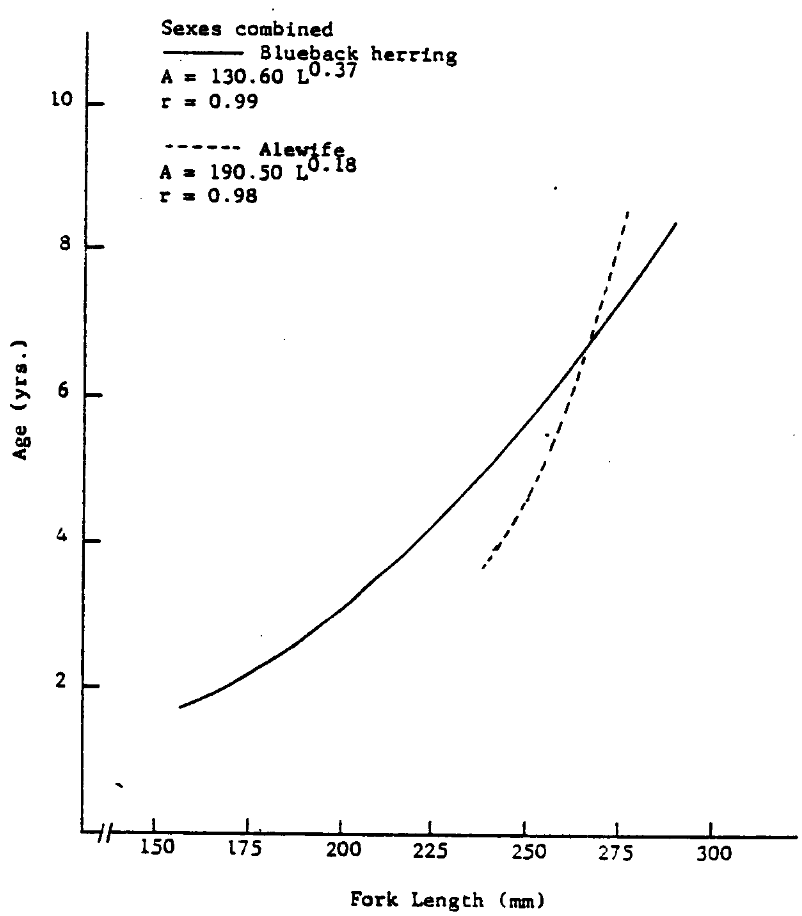


FIGURE VII-21. Fork length - age relationships for alewife and blueback herring offshore North Carolina 1970 - 1971. (From Holland and Yelverton, 1973) snapper, Rhomboplites aurorubens; the white grunt, Haemulon plumieri; the tomtate, H. aurolineatum; the gag, Mycteroperca microlepsis; the gray tilefish, Caulolatilus microps; the speckled hind, Epinephelus drummondhayi; and the snowy grouper, E. niveatus.

Grimes (1976 and 1978) compiled life history data on the vermillion snapper, Rhomboplites aurorubens, and plotted age and growth curves. Data are available on the reproductive cycle, fecundity, and sex ratios of the red porgy, Pagrus pagrus, from North Carolina waters (Manooch, 1976).

Nicholson (1975) summarized the data on age and size distribution of menhaden, Brevoortia tyrannus, catch in five areas of the Atlantic coast of the United States from 1963 to 1971. Numerous tables were presented on monthly mean length by sex, age, and port. The average age and size of fish in the total catch declined as the fishery north of Chesapeake Bay declined. Age 1 and Age 2 fish, which constituted most of the catch from Florida to Chesapeake Bay, increased in average length and weight.

Based on tag-recovery and catch data on 1 million adult Atlantic menhaden, Brevoortia tyrannus, Dryfoos, Cheek and Kroger (1973) reported annual survival rates averaging 0.23, calculated by the Robson-Chapman catch survival analysis. Each year 50 percent of the fish in this fishery are caught and 24 percent are dying from natural causes.

June (1972) discussed the significance of analyzing schools of menhaden in order to study population dynamics. He reported that the fish school by length and the average size of summer schools decreases as the apparent abundance of fish decreases in a given area of the coast.

Not all studies on life history stages are based on field observations; for example, Bailey (1973) reported differences between the lipid composition of the fertilized egg and the adult brain of the fish, Fundulus heteroclitus. Phospholipids accounted for 37 percent of the egg total lipid and 60 percent of the brain total lipid.

The paucity of life history data on the red grouper (Epinephelus morio) and the red snapper (Lutjanus campechanus) hampers developing sound management policies to assure the maximum sustained yield (Beaumariage and Bullock, 1976). Fewer than two dozen pertinent papers have been published.

In 1975, Bullis and Beardsley reported on the current status of bluefin tuna (Thunnus thynnus thynnus) stocks in the North Atlantic Ocean, with special emphasis on current and proposed research by the National Marine Fisheries Service. These efforts include collecting data on catch size and landings, describing migratory routes, and determining population size by aerial and directional hydroacoustic sensors.

Wilk (1976) updated information on the spawning of the weakfish (Cynoscion regalis), including data on number of eggs, size of eggs, and temperature. He also provided data on larval characteristics and growth rates based on published data for the period of 1901-1972.

In a taxonomic study, protein similarities in various species of western North Atlantic seatrouts were compared using acrylamide gel electrophoresis (Weinstein and Yerger, 1976a). Of the four forms (species) studied, Cynoscion nebulosus is the divergent. Also, these authors questioned the taxonomic status of C. arenarius as a distinct species. Detailed analyses of the serum protein patterns in populations of C. nebulosus from seven estuaries in Florida indicated that each estuary has a discrete population with differences among the populations increasing with geographic distance (Weinstein and Yerger, 1976b). Similar studies have been reported for shrimp (see Section 2.2.2).

Murawski and Pacheco (1977) summarized the existing data on the life history of the Atlantic sturgeon, Acipenser oxyrhynchus. It is an anadromous heterosexual species with virtually nothing known of spawning behavior. Spawning begins in February in Georgia. Data have been provided on the development of the fertilized egg, the larvae, the juvenile stages, and the adult. Data on relative and absolute growth rates of adults has been published.

The population structure of the striped bass, Morone saxatilis, is not known along the middle Atlantic coast because of seasonal migrations (Smith and Wells, 1977). However, it is generally assumed that river systems along the southeast Atlantic coast each contain their own populations of striped bass. Recently Smith and Wells (1977) summarized the existing data on the life history of the striped bass, based on information from populations throughout the United States. Spawning extends from April to June, but it begins as early as January or February in Florida, and appears to be governed largely by water temperature, with peak spawning activity occuring at about $18^{o}C$. The number of mature ova varies with age, weight, and fork length. The various preadult stages have been described as well as the rate of development. The adults are hardy, adaptable fish who are able to make the transition from salt to fresh water as well as being able to tolerate relatively high levels of domestic and industrial pollution. Growth curves for striped bass from Maryland waters have been published by Mansueti (1961).

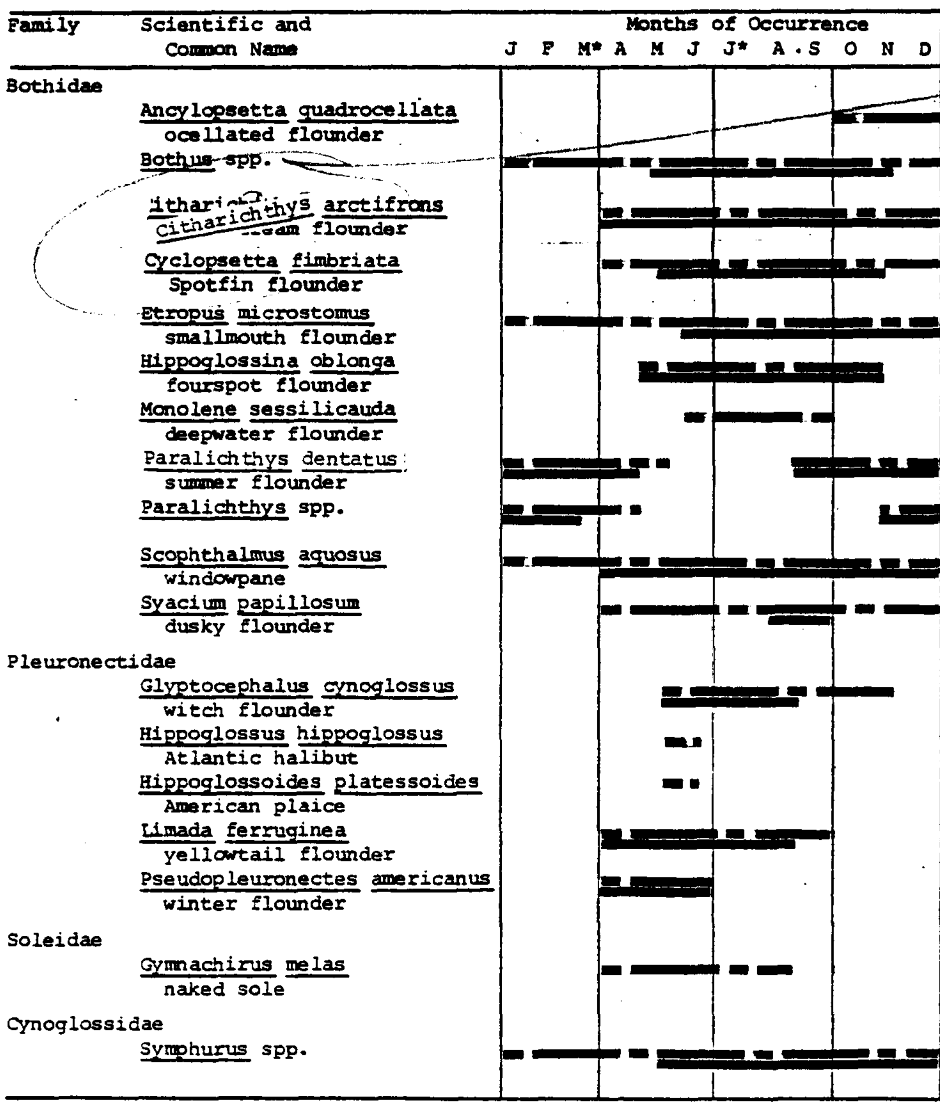
The results of a one year survey to locate the spawning grounds and trace dispersion of fish eggs and larvae on the continental shelf were presented by Smith, Sibunka and Wells (1975). Larval flatfishes representing 4 families, 17 genera, and 15 species were identified. The seasonal occurrence of flatfish larvae is represented in Table VII-16. Most flatfishes begin spawning in the spring, and for these species, the seasonal occurrence of the larvae progresses from south to north as the season progresses; spawning that starts in the fall proceeds from north to south. These observations suggest that the initiation of spawning is triggered by seasonal warming or cooling. Most species spawned within a relatively narrow temperature range, and salinity apparently did not influence spawning. Bothids had longer spawning seasons than pleuronectids and most spawned in the southern half of the survey area, starting in spring and continuing through early fall. Pleuronectids spawned largely in the northern half during the spring. Cynoglossids spawned incidentally off North Carolina, but their larvae were transported into the survey area from spawning grounds south of Cape Lookout.

The reproductive cycle, fecundity, and sex ratios of the red porgy, Pagrus pagrus, found in North Carolina waters were reported by Manooch (1976). March and April were the peak spawning months although ripe fish were collected from January to April in waters ranging in depth from 21 to 100m. The best prediction of fecundity is weight. Females were captured more frequently than males during every month of the three year study.

Wilk (1977) reviewed the existing data on the life history of the bluefish, Pomatomus saltatrix, on the Atlantic coast. Reproduction is by heterosexual adults who become sexually mature in their second year of life. Fertilization of eggs is external. Incubation of eggs takes about 48 hours at 21°C and the larvae are about 2.0mm long at hatching and metamorphose at 20-25mm. Lippson and Moran (1974) described in detail the development of eggs, larvae, and juveniles. The adults live at least nine years. Wilk graphically represented the relationship between age, length, and weight of the bluefish, Pomatomus saltatrix (Figure VII-22). These data are based on over 25,000 age determinations from scale readings and 7,500 weights of specimens sampled from Rhode Island to Florida.

TABLE VII-16.

The seasonal occurrence of flatfish larvae (▬ ▬) collected during 1965-66 plankton survey between Cape Cod and Cape Lookout. Solid line (▬▬) represents duration of spawning within the survey area, based on the occurrence of small larvae. Larvae were presumed to be present during months not sampled (*) if they were caught during preceding and subsequent months. (Smith et al., 1975).



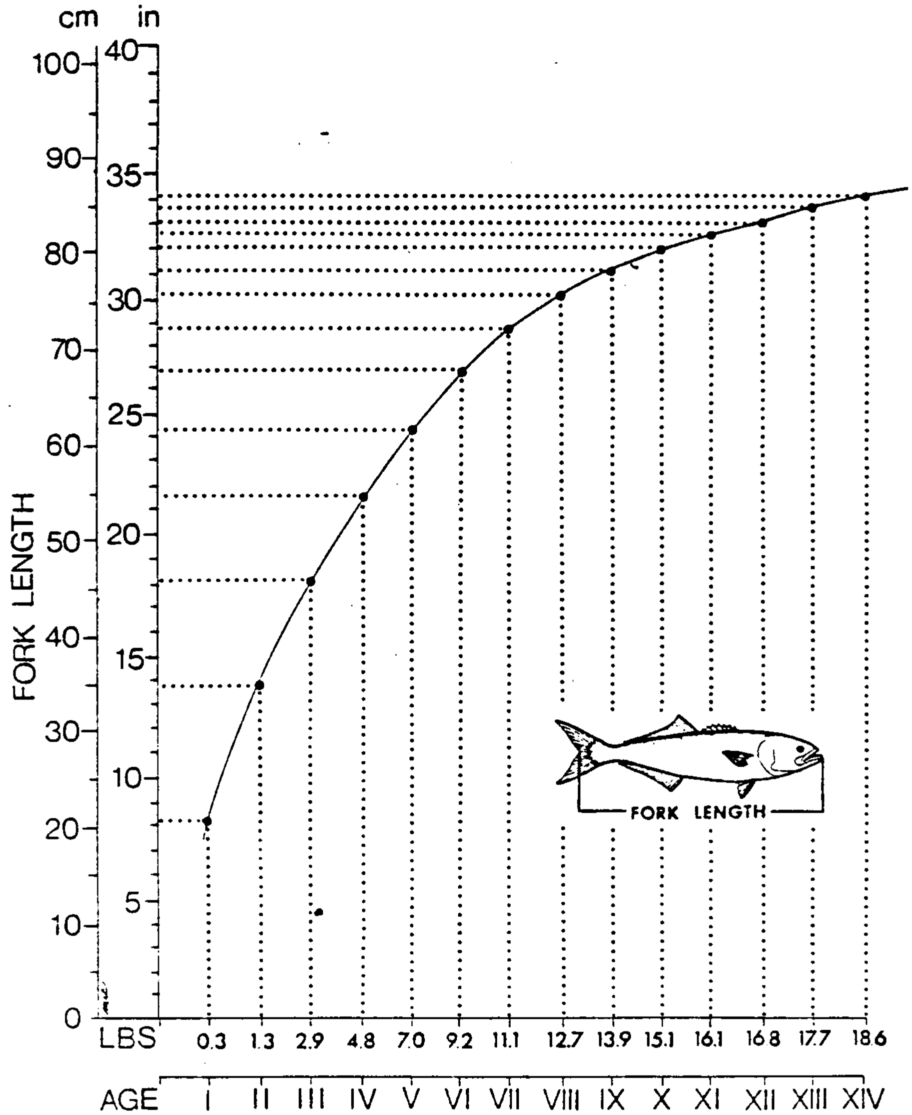


FIGURE VII-22. Relationship between age, length, and weight of bluefish, Pomatomus saltatrix. (From Wilk, 1977)

Freeman and Turner (1977) reviewed the literature on the life history of the tilefish, Lopholatilus chamaeleonticeps, and reported on reproductive phenomena, including sexuality, maturity, mating, fertilization, gonads, spawning, and spawn. In general, relatively little is known with the exception of various observations on the spawning period which extends from mid-March to mid-September. No information is available on the embryonic, larval, or adolescent phase of development. According to Freeman and Turner little is known of the age and size composition of populations of the tilefish, Lopholatilus chamaeleonticeps. They suggest that it is possible to determine annual growth by discernible marks on otoliths and they proposed a growth curve (length) for a forty year period.

The life history of four species of snappers was described by Grimes et al. (1977). For Lutjanus campechanus, L. vivanus, and Rhomboplites aurorubens spawning occurs through the warmer months. However, comprehensive age and growth data on Carolina populations are lacking and no information on the reproductive biology of the blackfin snapper, L. buccanella, in Carolina waters is available. Of these four species, most is known of the life history of the vermillion snapper, R. aurorubens.

Recently Kendall (1977) reviewed the data on the life history of the black sea bass. Although no new data were presented, this paper is an excellent source of information on reproduction, embryonic development, growth, and adult ecology.

To evaluate the long-term impact on a striped bass population of changes in mortality in the youngest age class, a population model was prepared by Van Winkle, Rust, Goodyear, Blum and Thall (1974). The model consists of a system of differential equations involving age-dependent fecundity and survival.

The longbill spearfish is rare in United States waters, and there is no information available on age and growth, age at maturity, reproductive strategies, food and feeding habits or population structure of those occurring in the western Atlantic (Robins, 1975).

The white marlin is an heterosexual species. For a given length, the females are somewhat larger than the males (see Figure VII-23) and they attain a greater size. The sex ratio of the species shows considerable variation depending on geographical area and season. Age determinations have not been reported (Mather et al., 1975). There are no estimates of population size available, although the apparent relative abundance of this species in the western North Atlantic has declined since 1966. The average size

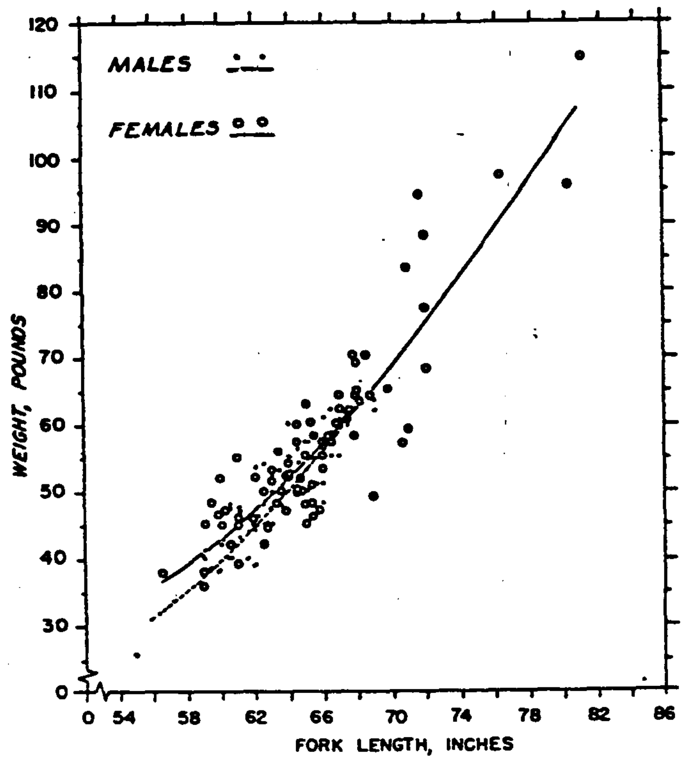


FIGURE VII-23. Length-weight relatioship of white marlin, Tetrapturus albidus, caught between Atlantic City, N. J. and Ocean City, Md., July-September 1959 and 1960. Males are represented by dotted line and closed circles; females are represented by solid line and open circles (Mather et al., 1975).

of marlin taken has also declined and significant catch rate reductions have occurred in those areas previously providing the largest catches, thus suggesting that the fisheries have contributed to the decline of white marlin stocks. White marlin spawn in pairs, the female releasing eggs as she heads into a current. The male heads with the current and expels the milt while they are side by side. They generally spawn in deep blue ocean waters with surface temperatures from 20.9°-29°C (Mather et al., 1975). Little is known about the eggs, larvae, or adolescent phases of this species, and there is no information on recruitment rates, annual variations, or seasonal patterns of recruitment.

The blue marlin is heterosexual, with the sexes being externally indistinguishable. The female attains a larger size than the male. Of 30 blue marlin taken in the northwestern Atlantic, 12 were females from 59-277kg, and 18 were males weighing from 46-94kg. Methods of age determination in this species have not been developed. Indications are, however, that the males become sexually mature at 35-44kg, while the females attain maturity at 47-61kg.

Spawning information on the blue marlin comes from deSylva (1963) who reports that off Cape Hatteras, recently-spawned marlin have been taken in June; May and June appear to be the spawning season in waters off Florida. The larval stages from about 3-52mm are reasonably known, but information is lacking for the stages between 52-194mm, and the postlarval and juvenile stages from 206-846mm. The growth rates, metabolism, and reproductive behavior are unknown. Blue marlin are not known to school. It is not known how this species responds to mechanical and chemical stimuli, nor is much known about reproduction rates, recruitment, mortality, morbidity and population dynamics.

The length-weight relationships for male and female blue marlin are given in accompanying graphs, (Figures VII-24 and VII-25) which are based on 104 females and 58 males recorded from the western Atlantic. Generally males ranging in length from 190-220cm weigh less than females of corresponding length. At lengths outside this range, the length weight relationship is similar for both sexes.

The growth, age, and mortality of the white grunt, *Haemulon plumieri*, from coastal Carolina waters were presented by Manooch (1977). Similar data have been published on the red porgy, *Pagrus pagrus* (Manooch and Huntsman, 1977) and on *Mycteroperca microlepis*, the gag grouper (Manooch and Haimovici, in press).

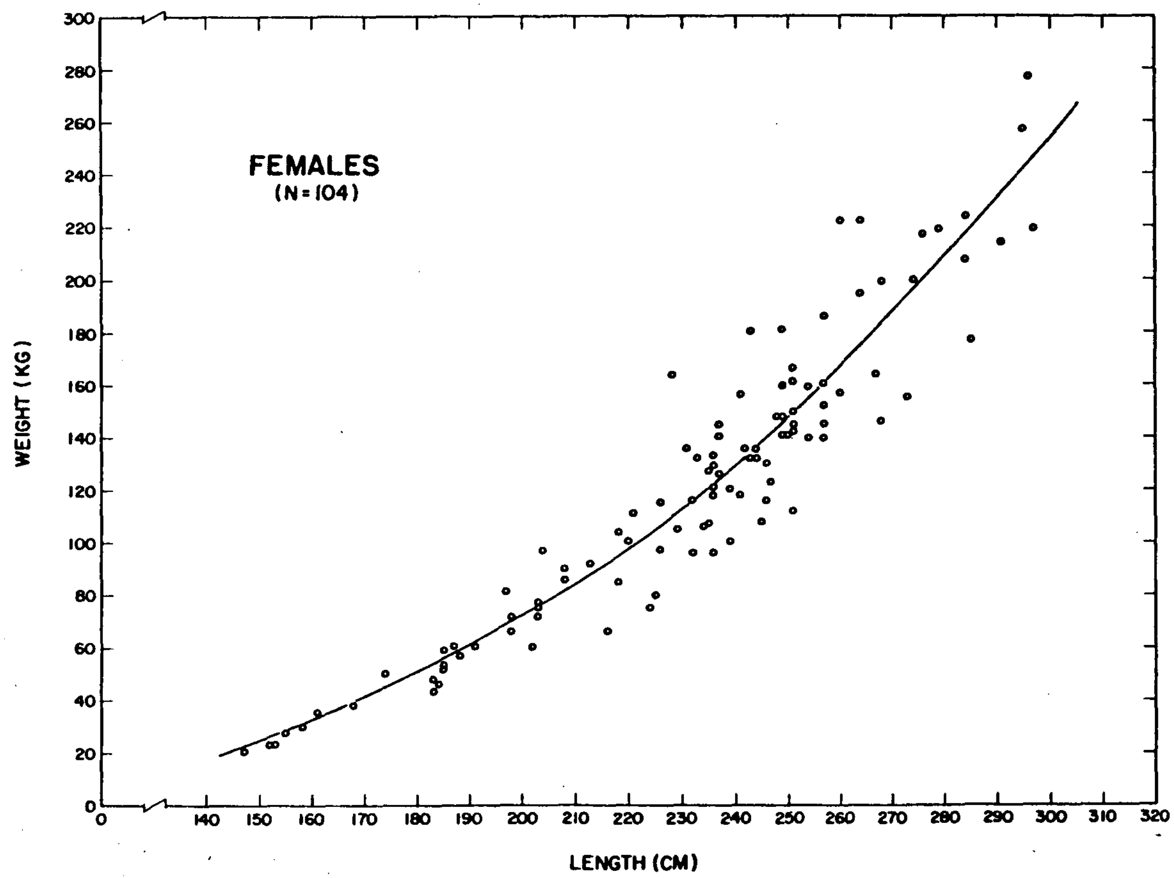


FIGURE VII-24. The length-weight relationship of female blue marlin in the western Atlantic Ocean. (Rivas, 1975).

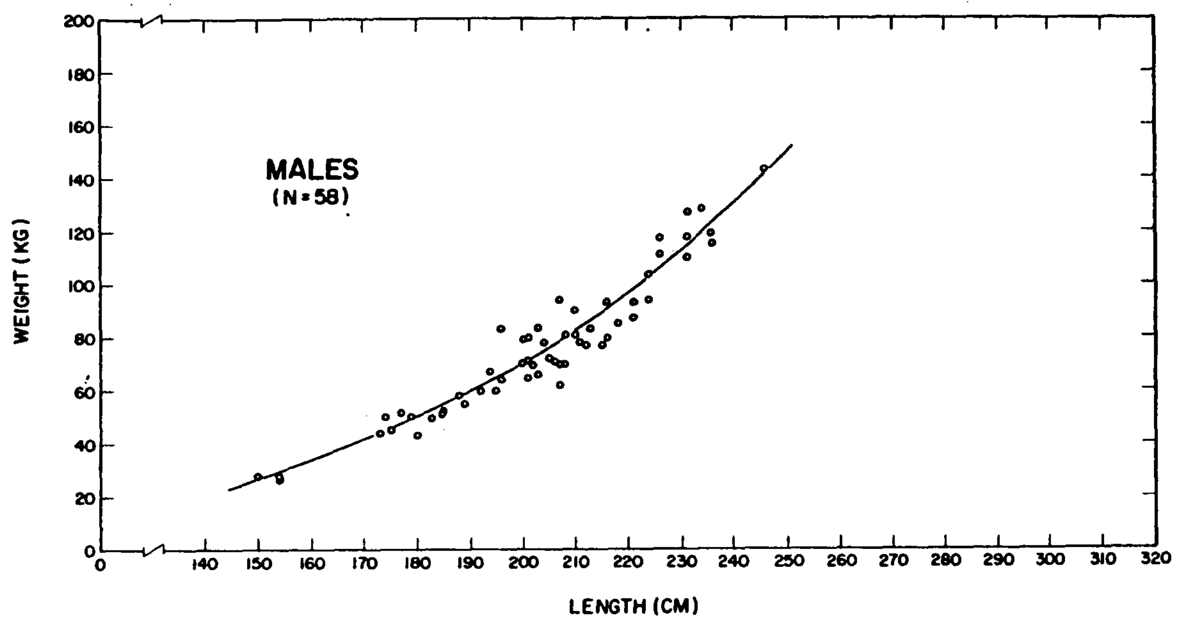


FIGURE VII-25. The length-weight relationship of male blue marlin in the western Atlantic Ocean (Rivas, 1975).

Dahlberg (1977) suggested a reliable method of separating the Atlantic stingray (*Dasyatis sabina*) from other sympatric species (*D. sayi*, *D. americana*, and *D. centroura*) on the United States Atlantic coast. The method was based on counting the middorsal spines.

Sailfish, *Istiophorus platypterus*, are heterosexual fish, without external sexual dimorphism. The larger fish, however, are usually females (Beardsley et al., 1975). During May through September, sailfish spawn along both coasts of Florida (Jolley, 1975; Irby et al., 1976). This seasonal reproductivity has been documented by histological examination of gonads (Figure VII-26) and monthly abundance of larvae (Figure VII-27; Jolley, 1977). The ovaries of ripe females constitute 10 percent of total body weight (Jolley, 1977). During mating (Beardsley et al., 1975), the females are accompanied by one or more males, and spawn while swimming sluggishly; in Florida's waters, spawning generally occurs over shallow sand or rocky bottom inshore water (Jolley, 1975; Beardsley et al., 1975). The time of breeding off the United States east coast from the Carolinas to Florida has been estimated to be April through November (Beardsley et al., 1975) and specifically late May through early September off both coasts of Florida (Jolley, 1975; Irby et al., 1976). One female may shed several million eggs during one season (Irby et al., 1976), and histological examination of the ovaries suggests that there may be several batches of eggs shed during one season (Jolley, 1975). Hatching occurs within 24-36 hours; sailfish larvae do not resemble the adult. Within the following 2-4 weeks, growth and metamorphosis result in juveniles which resemble the adult. Growth is rapid during the first year, but accurate estimates of growth rate are unavailable (Jolley, 1975). Various age determination techniques have been used to establish the age of this species (Jolley, 1977). Of the various parameters measured, including fin spines, length, and weight, weight consistently correlated better with age (Figure VII-28). Based on length frequencies, sailfish appear to have a rapid growth rate (Beardsley et al., 1975). Recent methodology indicates an average life span of about 4 years, possibly extending to 9 to 10 years (Jolley, 1975). Beardsley et al. (1975) report that the Florida sport fishery is based on the 1-2 year population, so it is suspected that the natural mortality in this species is high. In Florida, the average length of this species is about 2m, and weight is approximately 17kg. The average weight of 499 males was determined by Jolley (1977) to be 15kg, and that for 621 females was 19kg (Jolley, 1977). Females reach sexual maturity between 12-18kg, while males are mature at about 9kg. The males appear to be younger than the females at maturity (Irby et al., 1976). Females predominate by 1.2:1 and seem to attain larger weights (Jolley, 1975; 1977). However, the

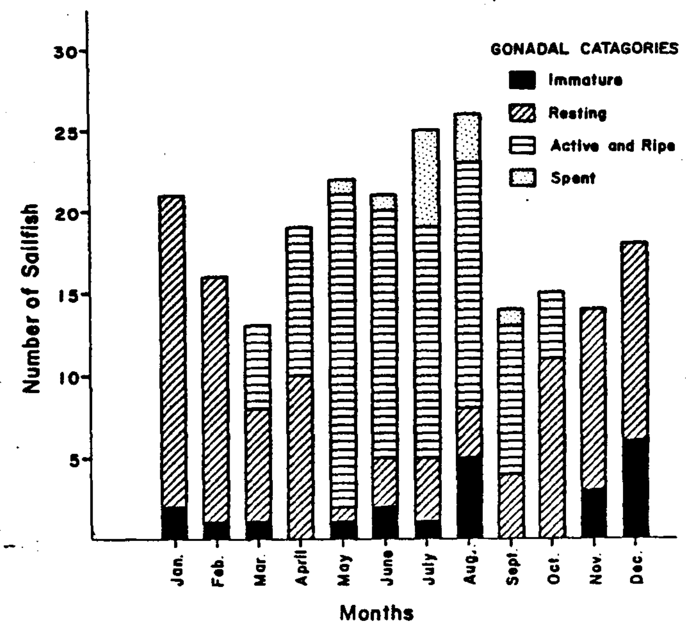


FIGURE VII-26. Reproductory activity of 224 Atlantic sailfish expressed as monthly relative prominence of each developmental ovarian category (collections 1970-71 combined; microscopic evaluations only) (Jolley, 1977)

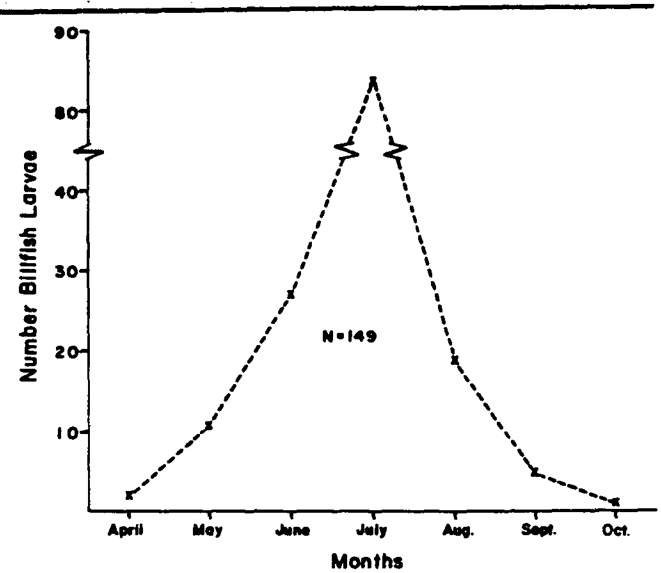


FIGURE VII-27. Monthly relative abundance of istiophorid larvae taken during Florida east coast plankton surveys 1962-1974 (Jolley, 1977).

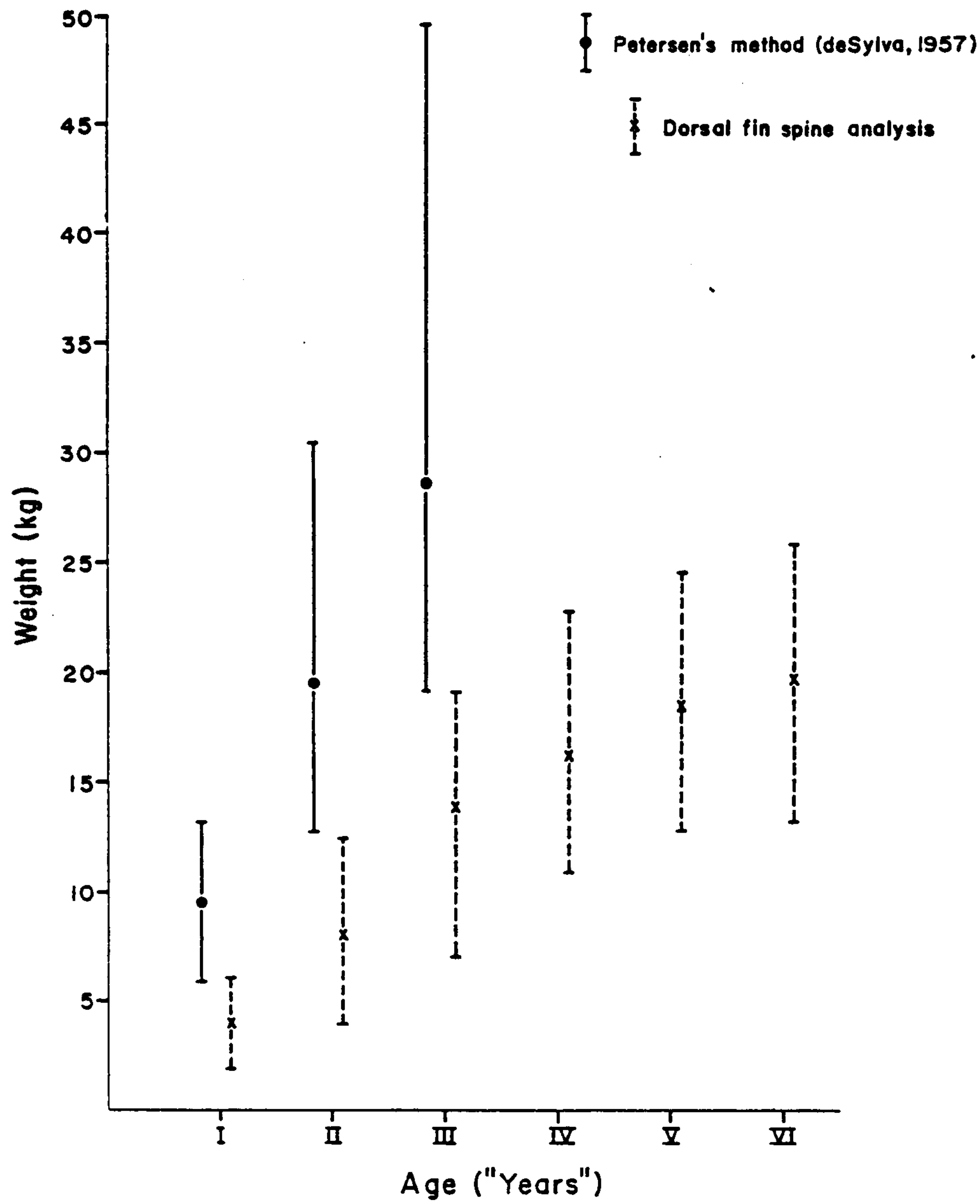


FIGURE VII-28. Comparison of the age-weight relationships of Atlantic sailfish (sexes combined) using two different aging techniques. Range and mean weight are plotted for each age group. Many large sailfish (20kg) could not be accurately aged by the fin spine method, and therefore maximum size of age group IV may both be inadequately represented. (From Jolley, 1977) sex ratios fluctuate sesonally (Figure VII-29) and it has been suggested that the females may outlive the males. It has also been suggested that this species may school or migrate by gender, but insufficient data render these hypotheses only tentative (Jolley, 1977).

2.2.1.2 Estuarine Studies

From August 1971 to June 1974 the Albemarle Sound area was sampled using trawls, seines, egg nets, gill nets, and pound nets. Commercial and recreational fisheries catches were also sampled. Alewife, blueback herring, and striped bass nursery areas were determined, and movement patterns of blueback herring juveniles were investigated. Relative abundance and growth were determined for the 1972 and 1973 year classes of blueback herring and alewife. Spawning history, year class composition, and sex ratios were determined for adults comprising the 1972-1974 spawning runs of blueback herring, alewife, hickory shad, and American shad. Age was also determined for striped bass during those years.

From July 1975 to June 1977 Sholar (1977) sampled the life stages of various anadromous species in the northeast Cape Fear River, North Carolina. Nursery areas for blueback herring, American shad, and alewife were tentatively identified, as were spawning areas of striped bass and river herring. Abundance, growth, and offshore migrations of the anadromous alosids were determined. The ages of the adult American shad ranged from three to eight years. One percent were repeat spawners. Of those individuals reaching the spawning grounds, the male:female ratio was approximately 5:1. The ages of blueback herring ranged from three to seven, hickory shad and alewife ranged from three to six, and striped bass ranged from two to nine. Adult blueback herring and American shad were more abundant during the 1977 run than the 1976 run. Fork lengths of American shad reaching the spawning areas were compared with those of commercially and recreationally harvested individuals. The data indicate that the fisheries were harvesting mainly age five females.

The age distribution for three species of anadromous fish in waters of North Carolina is presented in Table VII-17 (Holland Yelverton, 1973). These investigators also presented data on the year classes, numbers, and mean fork lengths of blueback herring, alewife, and American shad from offshore North Carolina and the Chowan River in comparison with animals from other areas along the Atlantic coast.

TABLE VII-17. Age distribution at capture, number of previous spawnings, and age at first spawning for American shad, blueback herring, and alewife, offshore North Carolina and Chowan River, January-April, 1971 (in percent) (Holland and Yelverton, 1973)

Age at capture (yr. class)	Amer. shad	Offshore	Chowan River	Blue-back herring	Offshore	Chowan River	Alewife	Offshore	Chowan River
I		--	--		--	--		--	--
II		1.5	--		6.6	--		--	--
III		--	--		10.5	--		--	1.5
IV		3.0	--		38.2	20.6		16	33.3
V		10.4	32.4		31.6	39.7		28	37.9
VI		39.6	38.2		6.6	23.5		32	15.2
VII		30.6	29.4		3.9	16.2		20	6.0
VIII		11.2	--		2.6	--		4	6.0
>VIII		3.7	--		--	--		--	--
No. of times spawned previously									
0		28.3	85.3		72.4	42.6		30.0	57.6
1		34.3	11.8		14.5	35.3		34.0	25.8
2		26.9	2.9		6.6	19.1		24.0	10.6
3		7.5	--		3.9	2.9		10.0	4.5
4		3.0	--		1.3	--		2.0	1.5
5		--	--		1.3	--		--	--
Age at first spawning (yr. class)									
III		1.0	--		33.3	--		--	1.5
IV		21.9	5.9		61.9	45.6		60.0	54.5
V		52.1	29.4		4.8	48.5		37.1	39.4
VI		21.9	38.2		--	5.9		2.9	4.5
VII		3.1	26.5		--	--		--	--

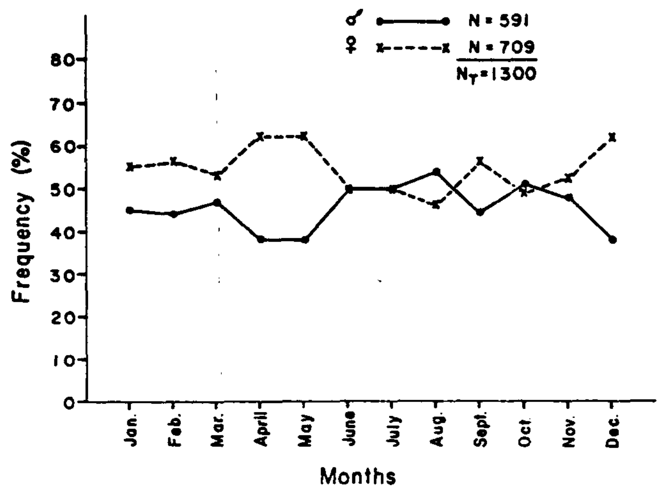


FIGURE VII-29. Monthly percent frequency distribution of male and female Atlantic sailfish examined during 1970-74 combined (Jolley, 1977).

Burgess and Schwartz (1975) reported the appearance of abnormalities such as jaw, snout, pugheadedness, lordosis, kyphosis, ankylosis, deformed or missing fins, and partial ambicoloration in 23 species of freshwater and marine fishes, with all but four species inhabiting North Carolina waters.

Street and Johnson (1977) updated the information on the life history of the striped bass in North Carolinian waters. The spawning and nursery grounds are represented in Figure VII-30. Spawning extends from early April to mid-May in the southern part of the state and from late April to early June in the north. Sampling for juvenile striped bass over the period of 1955-1976 by Hassler indicated yearly variation. Dominant year classes were found in 1956, 1959, and 1967 and above average year classes in 1961, 1965, 1970, 1975, and 1976. The age and size ranges of oceanic and estuarine striped bass have been similar in recent years.

The fecundity of striped bass and American shad in North Carolina waters was estimated by Holland and Yelverton (1973). Figures VII-31 and VII-32 represent the fecundity in relationship to age for these two species. Examination of gonads of striped bass, American shad, blueback herring, and alewife demonstrated a predominance of female striped bass, American shad, and alewife and male blueback herring.

Holland and Yelverton (1973) published data on the mortality of striped bass from North Carolina waters based on tagged fish studies (Table VII-18). They calculated that the annual fishing mortality rate for striped bass tagged in North Carolina waters and recaptured from North Carolina to Massachusetts (both oceanic and estuarine) was 35 percent. This disagrees with exploitation rates and indicates a much higher and probably more valid harvest than indicated by the percentage of recapture.

Merriner (1976) reported on the reproductive biology of the weakfish, Cynoscion regalis, in North Carolina. Weight and length of weakfish are better indicators of fecundity than is age. Both sexes reach sexual maturity as yearling fish. An extended spawning season from March to August contributes to the marked variability of size, within year class. Peak spawning occurs from late April through June.

Gravid female Fundulus luciae were collected from April through October in North Carolina and Kneib (1978) suggested the occurrence of a bimodel reproductive cycle. Young-of-the-year first appeared in June and grew rapidly to maturity by August.

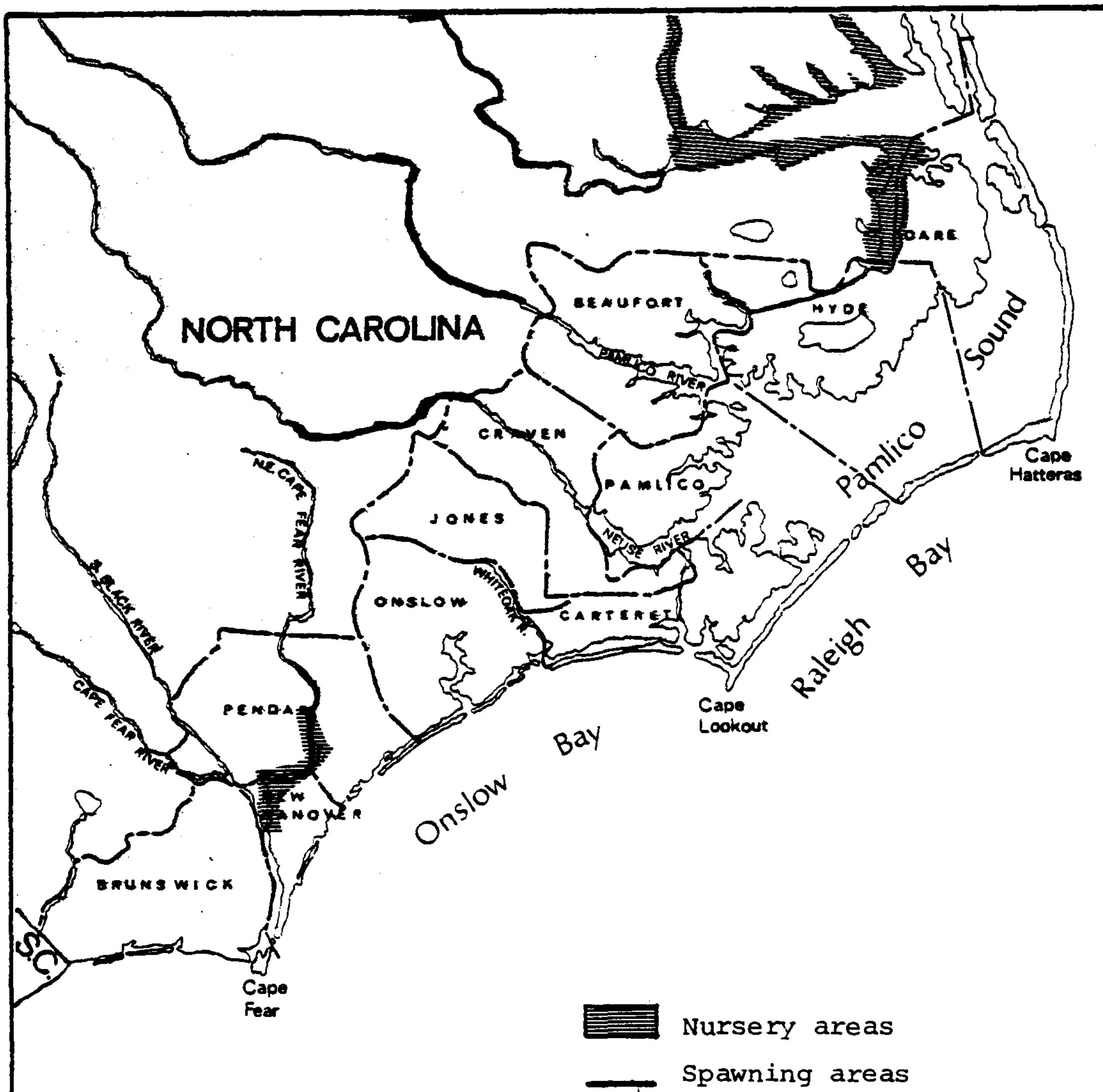


FIGURE VII-30. Spawning and nursery areas of striped bass in North Carolina (Street and Johnson, 1977).

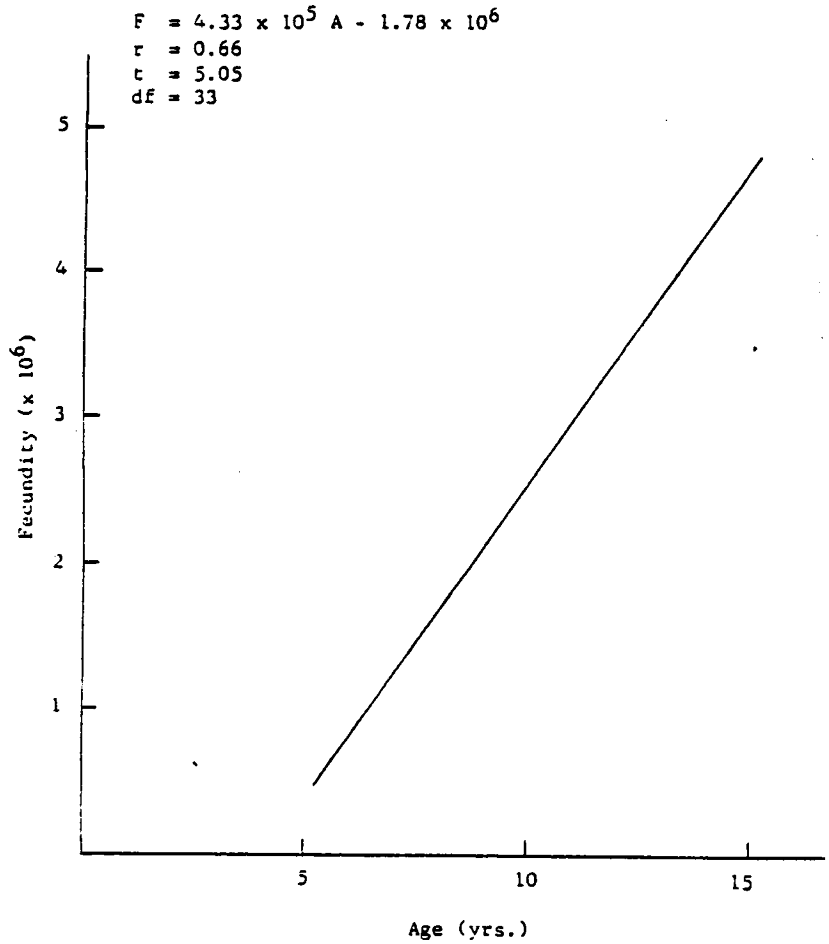


FIGURE VII-31. Fecundity - age relationship for 35 striped bass, offshore North Carolina, 1969-1971. (From Holland and Yelverton, 1973)

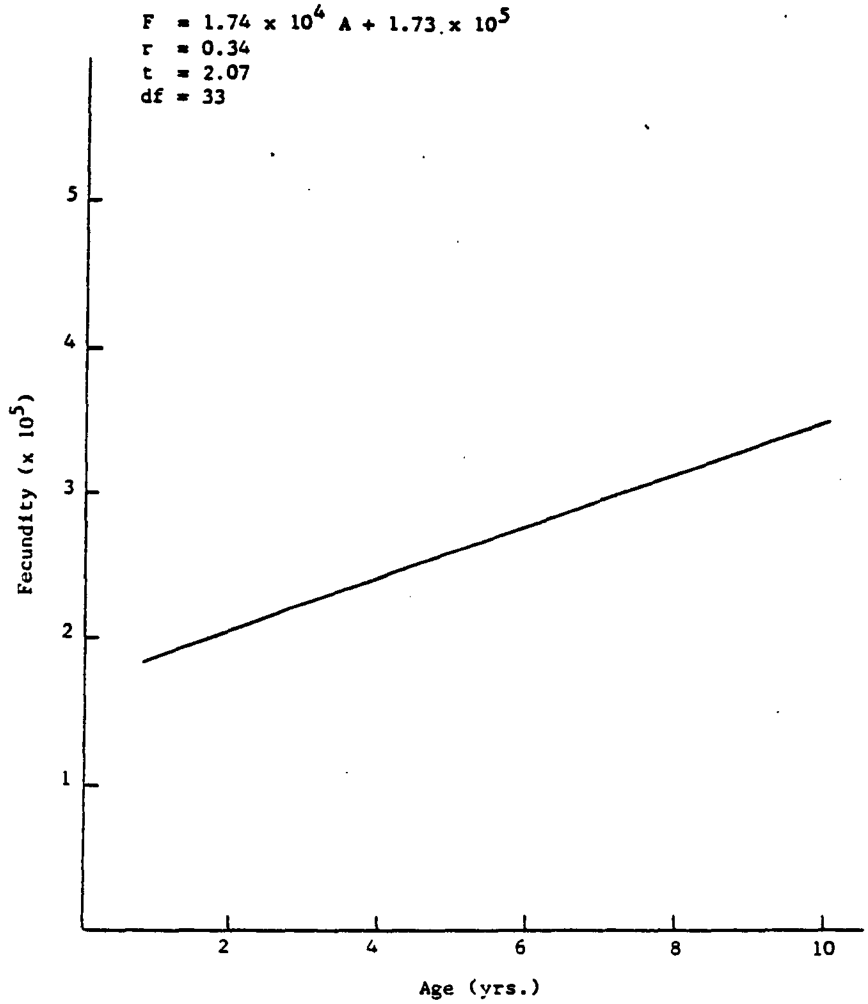


FIGURE VII-32. Fecundity - age relationship for 35 American shad, offshore North Carolina, March 1971. (From Holland and Yelverton, 1973)

TABLE VII-18. Instantaneous and monthly mortality rates calculated from striped bass tagging data, offshore North Carolina 1968-1971 (Holland and Yelverton, 1973).

Year period	Months released	Instantaneous Mortality rates Total (Z)	Fishing (F)	Other (X)	Monthly Mortality rates (percent) Total $(1-e^{-z})$	Fishing $(1-e^{-x})$	Other $(1-e^{-x})$
1968-1969	December-March	0.347	0.070	0.276	29.5	6.8	24.4
1969-1970	December-February	0.294	0.028	0.276	25.2	3.0	24.4
1970-1971	November-March	0.186	0.009	0.178	17.3	1.0	16.5
Monthly means		0.278	0.036	0.243	24.3	3.6	21.8

The sharks found in North Carolina waters range in length from several centimeters to almost 12.2m (Schwartz and Burgess, 1975; Figure VII-33). A 12.2m specimen Rhiniodin typus was taken near the mouth of the Cape Fear River, North Carolina in 1934. The major genus represented in North Carolina waters is Carcharhinus, and ranges in size from 1.2-4.3m. The smaller Rhizoprionodon terraenovae, found especially in the Newport and Cape Fear River areas, averages 1.1m in length. The black or brown sharks of North Carolina are the smallest. These include Scyliorhinus (0.2m), Deania (0.3m), Centroscyllium (0.3m) and Etmopterus (0.2-0.4m). The sharks range in swimming ability from the swift and powerful, e.g. Isurus oxyrinchus to the slow, sluggish Rhiniodon typus and Cetorhinus maximus. Most sharks bear live young, but some lay egg cases (Schwartz and Burgess, 1975).

The sharks commonly found in Georgia occur in both shallow and deep waters, and feed on fishes and benthic macroinvertebrates. Generally, the common sharks prefer warmer waters and leave Georgia in the winter, with the exception of the spiny dogfish, which migrates to Georgia in the winter from northern areas.

The length-frequency relationship of 23 species of fishes in South Carolina estuaries was presented by Shealy et al. (1974). Observations on the spawning and age classes of these species were also included.

A common fish in Georgia's estuarine environment, the spot, Leiostomus xanthurus, spawns from October through March, with November and December being peak times (Music, 1974). Although the major spawning grounds are in deeper offshore waters, some activity takes place in close inshore ocean waters in the northern part of the state. The growth rate is rapid during the first year with young reaching from 17mm in January to 142mm by October.

Over a three year period life history observations were made on the three species of seatrout inhabiting Georgia estuarine waters (Mahood, 1974). The spotted seatrout, Cynoscion nebulosus, begins spawning in April, reaches a peak in May, and continues into August. Recruitment of individuals under 20mm was noticeable through August, however, by September most juveniles taken were larger than 20mm. Length-frequency analyses were undertaken as well as age-length estimates. Growth was slow during the fall, winter, and spring, and rapid in the summer. Spawning in the summer trout, C. regalis, begins in March and continues into August, reaching a peak during March through May. Apparently the majority of spawning takes place in the deeper waters of the sounds with little activity in creeks and rivers.

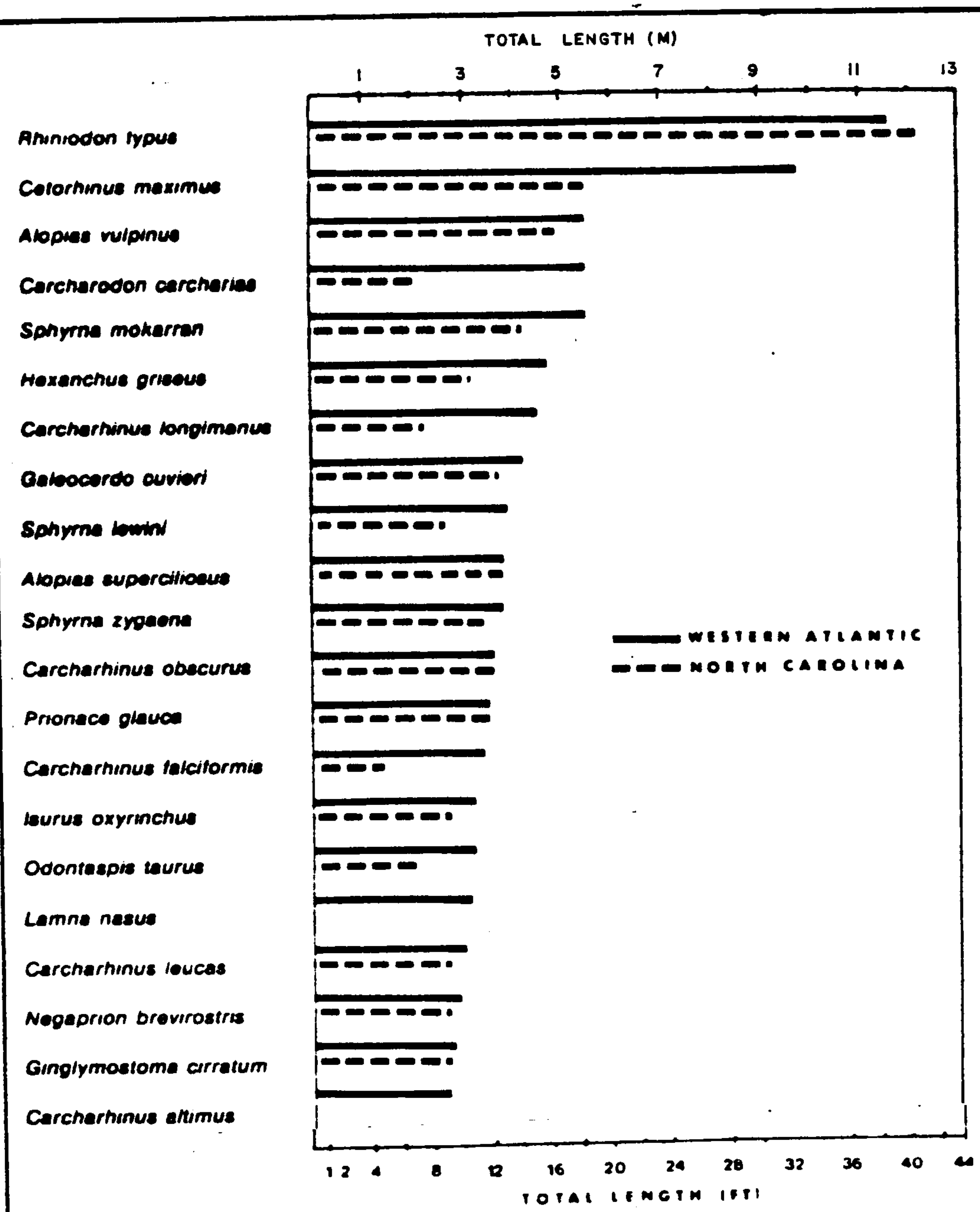


FIGURE VII-33. Maximum recorded total lengths of sharks found in N. C. and the western Atlantic Ocean. Note several N. C. shark lengths exceed published lengths for the species from the western Atlantic (Schwartz and Burgess, 1975).

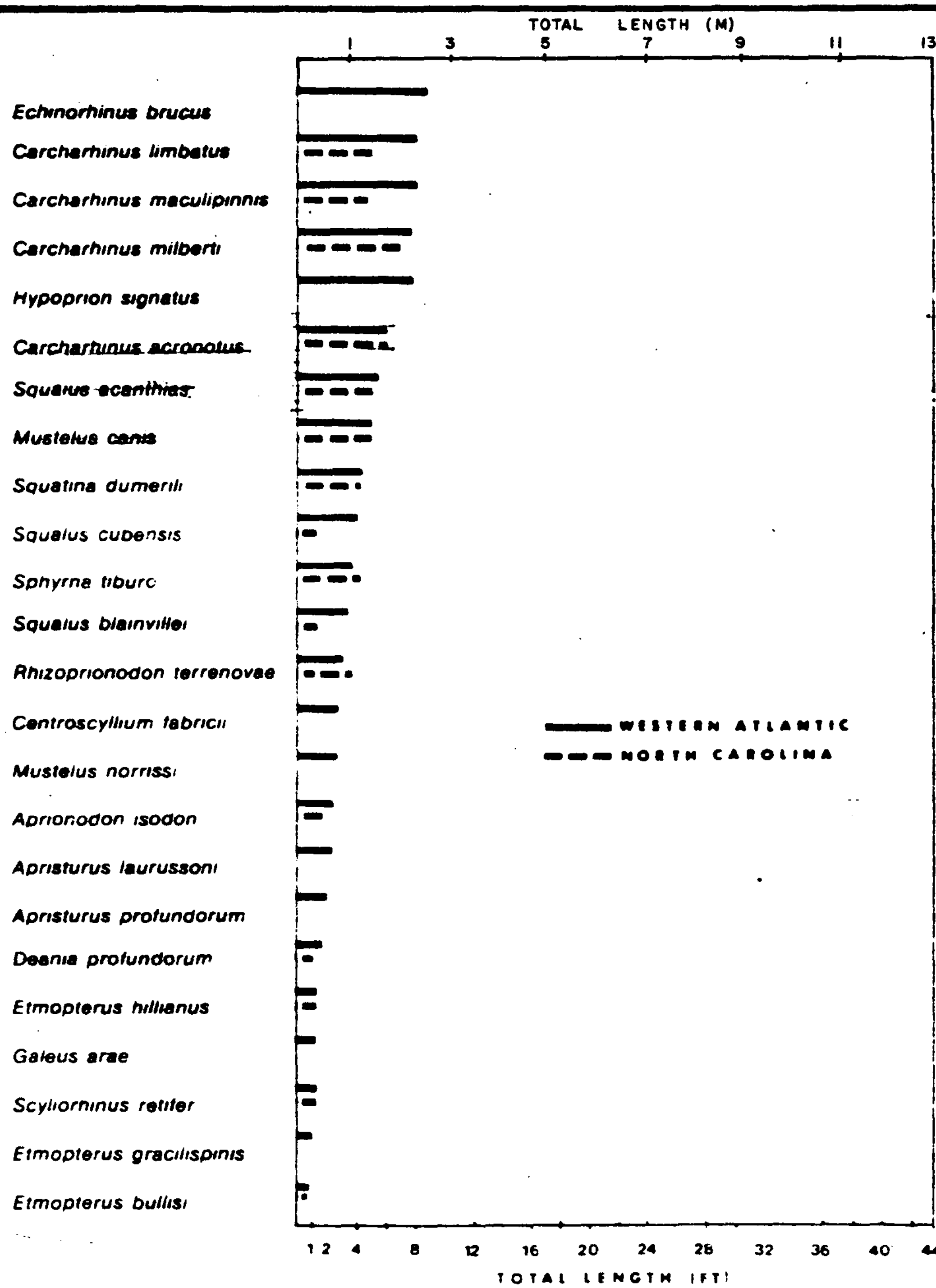


FIGURE VII-33, cont.

The age structure of populations of the Irish pompano, *Diapterus auratus*, and the bay anchovy, *Anchoa mitchilli*, found in the Indian River lagoon, Florida over the period of 1974-1976 was determined by Gilmore et al. (1977) (Figures VII-34 and VII-35). Preliminary observations were reported on life history studies and growth curves were plotted. The seasonal spawning periods of 40 species of fish were reported.

Since shrimp cannot be precisely aged, the maximum age of pink, white and brown shrimp of the United States southeast Atlantic coast remains unknown (Eldridge and Goldstein, 1975). Most appear to be caught before they reach one year, although some apparently are 18-24 months. Other information gaps are discussed in the Data Gaps section (5.0).

2.2.2 Crustaceans

Data on the length-frequency distribution of pink shrimp and brown shrimp in Pamlico Sound, North Carolina during the period of August through November 1975 and the spring of 1976 were presented by Purvis, Waters, Danielson and Easley (1976). Pink shrimp show rapid growth from August to November. The ratio of pink to brown shrimp increased from 1:1 in September to 50.9:1 in November.

In a study of the population dynamics of brown shrimp in Pamlico Sound, North Carolina, Purvis and McCoy (1974) mention that sex differences are evident in the growth rates and length-weight relationships. For the purpose of their study, they combine data for both sexes (Figure VII-36). The sex ratio for this species during this study was 1:1. Mortality data suggested that instantaneous mortality rates decreased with larger size or age.

In a study of the pink, brown, and white shrimp populations of the South Carolina estuaries, the females of a species outnumbered the males (Bishop and Shealy, 1977). The female:male ratio was 1.0:0.8 for *Penaeus setiferus*, 1.0:0.7 for *P. aztecus*, and 1.0:0.8 for *P. duorarum*. Length-frequency differences based on sex were not observed.

White shrimp, *P. setiferus*, spawn in South Carolina waters from May to June. The postlarvae enter the estuaries in late spring and early summer and leave in the fall as subadults. Mean total lengths for the three species were similar, 70-119mm for *P. setiferus*, 65-129mm for *P. aztecus*, and 55-130mm for *P. duorarum*. By region the southern coastal area yielded white and brown shrimp with the greatest mean total lengths. A maximum apparent growth rate of 30mm per month is given for *P. setiferus* in South Carolina estuaries.

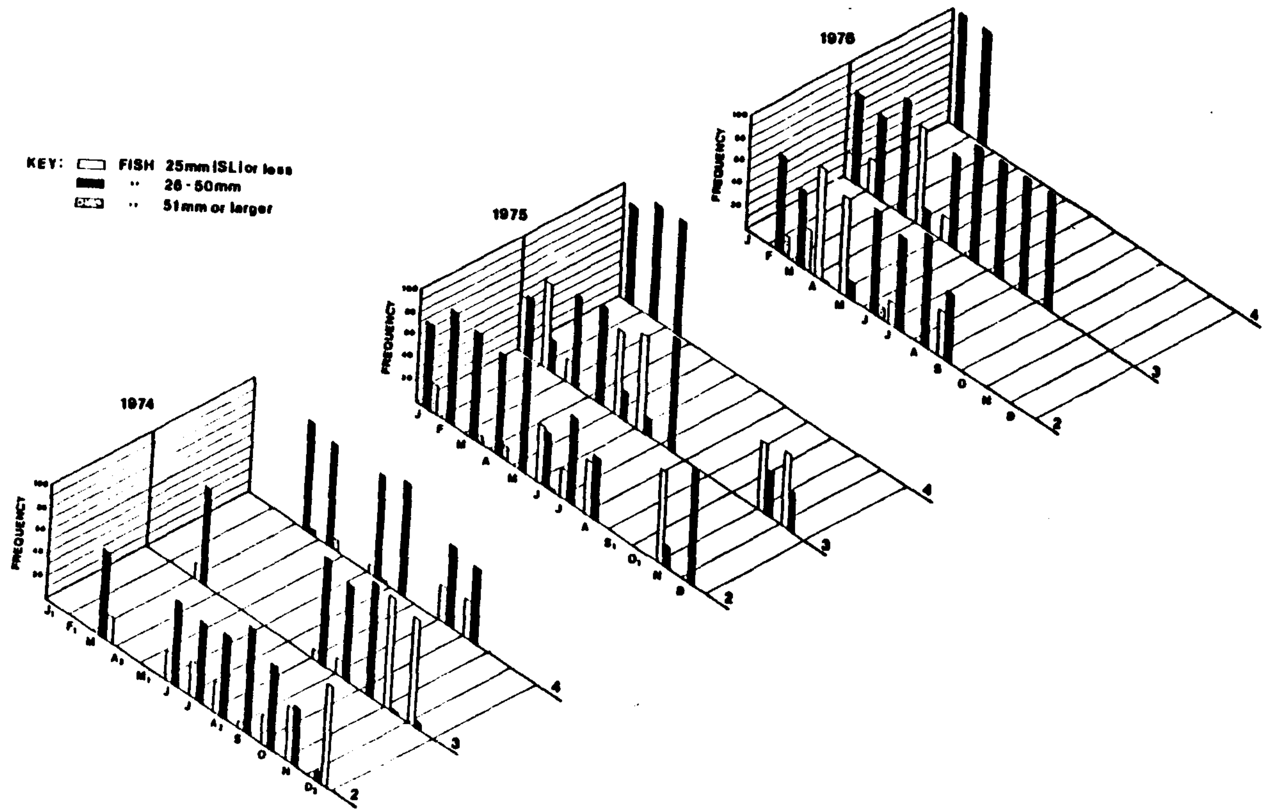


FIGURE VII-34. Size class distribution, temporal and spatial distribution of the bay anchovy, Anchoa mitchilli at seine stations 2,3 and 4 from 1974 to 1976. ([1]indicates months in which no samples were taken; [2]months in which one or two samples were not taken. (From Gilmore et al., 1977)

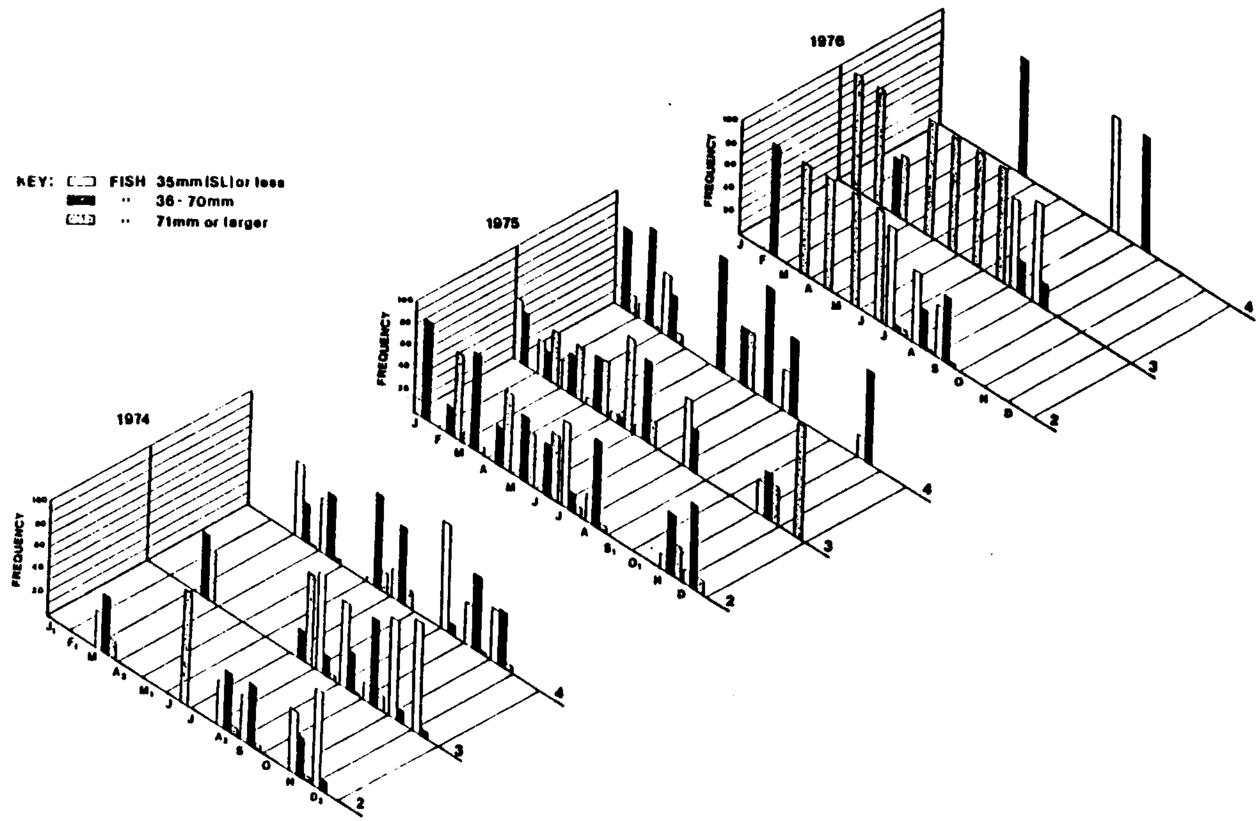


FIGURE VII-35. Size class distribution, temporal and spatial distribution of the Irish pompano, _Diapterus auratus_, at seine stations 2,3 and 4 from 1974 to 1978. ([1]indicates months in which no samples were taken; [2]months in which one or two samples were not taken). (From Gilmore et al., 1977)

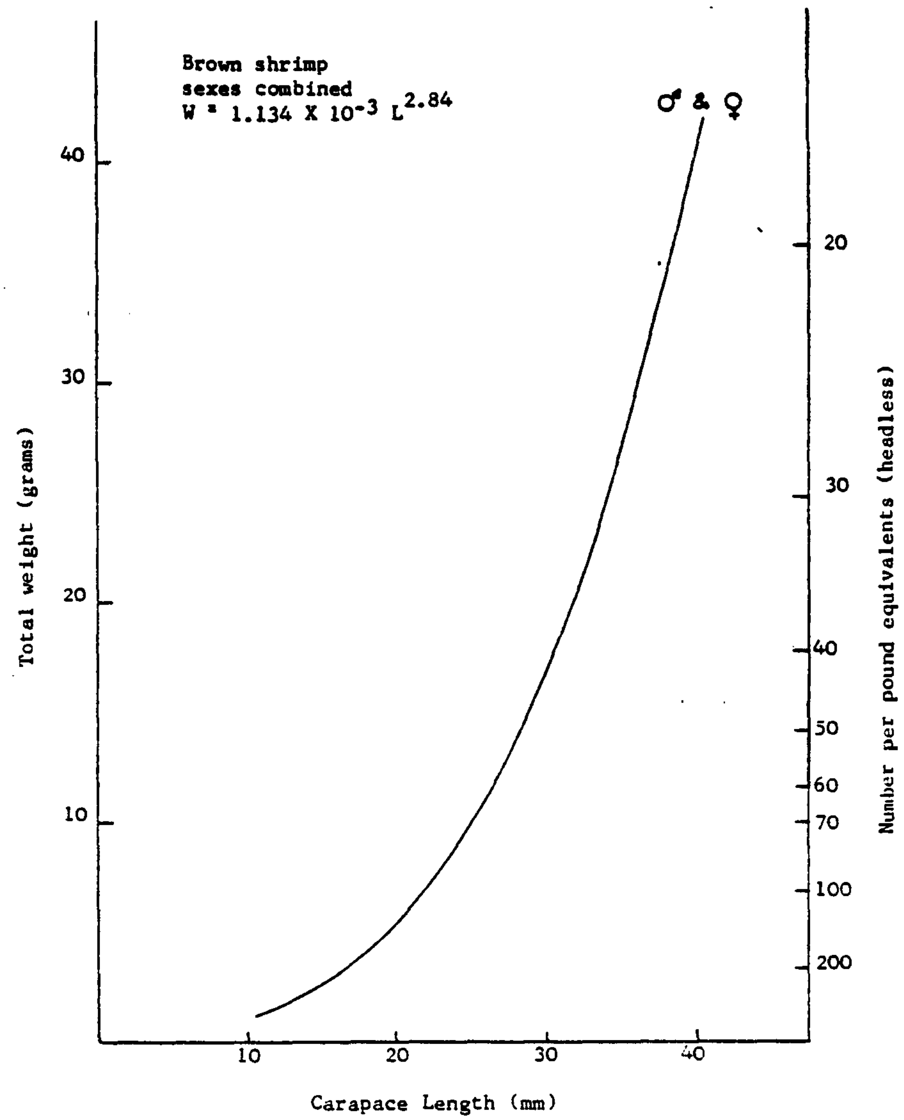


FIGURE VII-36. Total weight-carapace length relationship for brown shrimp (sexes combined). (From McCoy, 1972; Purvis and McCoy, 1974)

Postlarval P. aztecus immigrate into the South Carolina estuaries January through March. The estimated growth rate of this species is <1mm per day. For 1973-1974, the average total length ranged from 78-100mm in June of those years. Shrimp of the greater lengths were caught in higher salinity waters (Bishop and Shealy, 1977).

Harris (1974) reported on the size, sex, and stage of ovary development in 55,740 white shrimp, P. setiferus, collected in Georgia from October 1970 through September 1973. These data, when based on size composition, growth, sex ratios, and maturity, and when compared with other reports, indicate that the white shrimp population remains much the same as it was 40 years ago. Developing females were taken from March through August and ripe stages from May through August.

Marvin and Caillouet (1976), using starch-gel electrophoretic techniques, identified five phosphoglucomutase (PGM) alleles in the white shrimp (P. setiferus) and the brown shrimp (P. aztecus). Based on PGM phenotype distributions and allele frequencies, these two species appear to be closely related. Similar studies have been reported for seatrouts (see Section 2.2.1, Population Characteristics).

Population studies of the rock shrimp, Sicyonia brevirostris, were initiated by the Florida Department of Natural Resources to provide fishery resource information (Kennedy et al., 1977). Fishery and life history surveys were conducted along the continental shelf of Florida's Atlantic coast from January 1973 to December 1974. This report provides information on the histology of the gonads. Female rock shrimp attain sexual maturity by 24mm carapace length. The young shrimp grow rapidly throughout the summer, but the average growth rates vary from year to year. Males appear to gain weight faster than females. Length-weight relationships for males and females are expressed in Figures VII-37 and VII-38. The average life span of the rock shrimp is estimated to be 20-22 months. Females had a slightly lower mortality rate than males, and the male/female ratio was .93.

In 1972, Holland et al. reviewed the literature on the life history of the American lobster, Homarus americanus, a potentially commercially important species in offshore waters of North Carolina. They reviewed the results of other investigations on molting, growth, age, reproduction, hatching, larval development, and post larval molting frequency. Although little of the data was based on animals captured in North Carolina, these investigators reported on catches off the Cape Hatteras, North Carolina region. Females were most abundant. Also it was apparent that

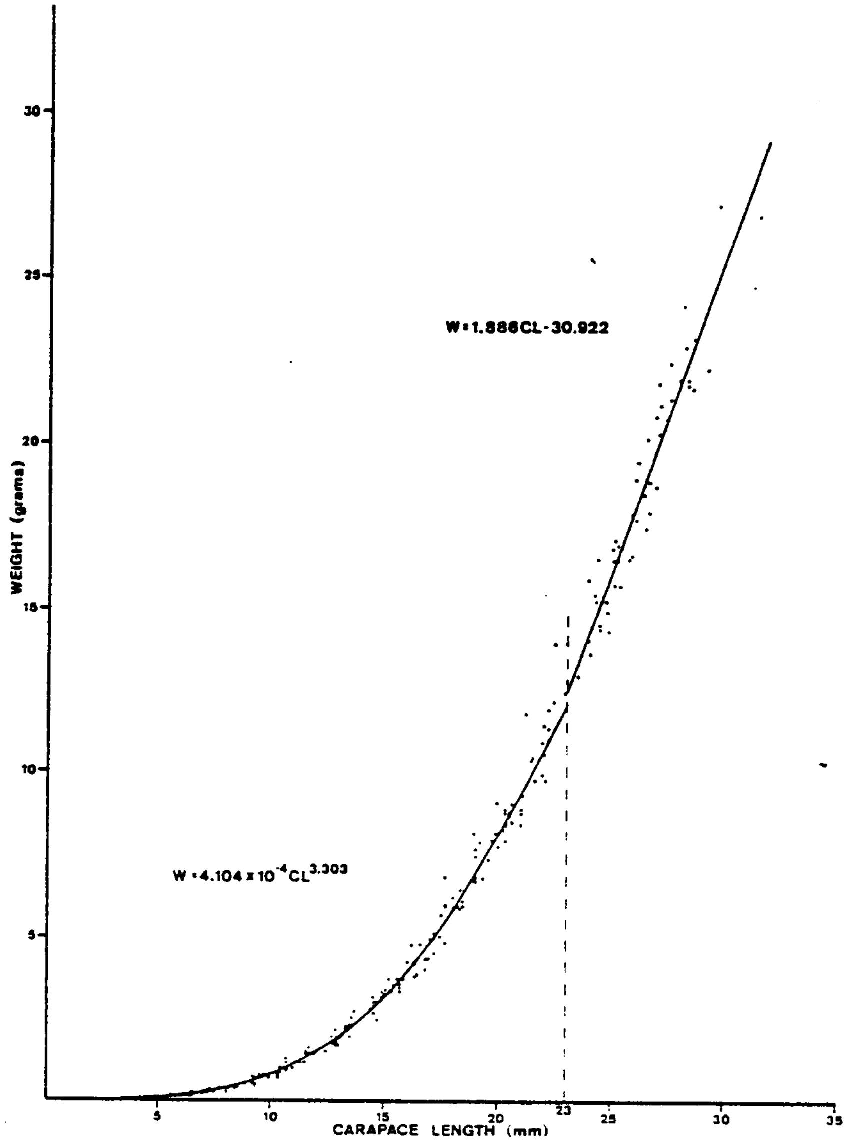


FIGURE VII-37. Relationship of carapace length to weight of 241 males. (From Kennedy et al., 1977)

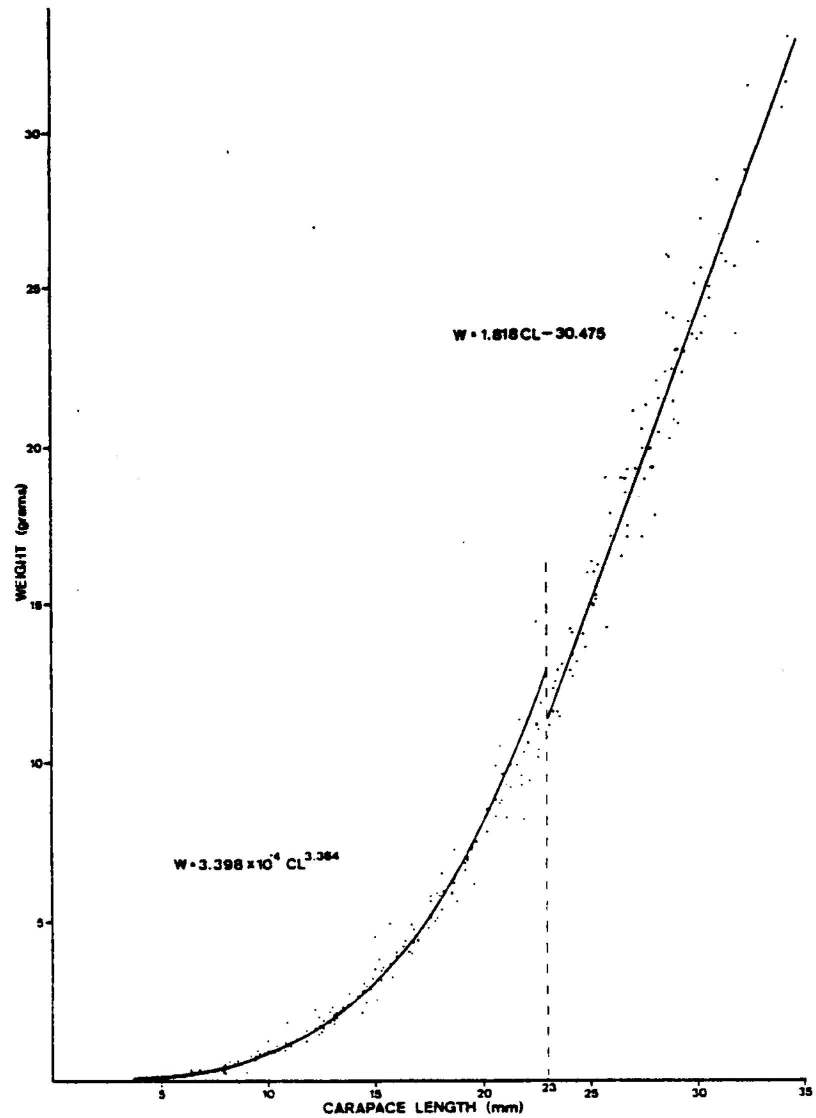


FIGURE VII-38. Relationship of carapace length to weight of 278 females. (From Kennedy et al., 1977) some mating, spawning, and hatching occurs throughout the year.

The population structure of the blue crab, Callinectes sapidus, in Georgian waters for a three year period is presented in detail by Palmer (1974). Highest percentages of juvenile males appeared on fishing grounds in February, while juvenile females appeared mostly in December and February. The highest percentage of commercial sized organisms appeared from October through December (April through September for males and females, and October additionally for females). Palmer indicated that reliable growth rates could not be estimated because the extended spawning season allowed different size groups onto the fishing grounds at one period of time. However, the total time from hatching to commercial size appears to range from 10 to 15 months. The sex ratio varied with habitat. In creeks, 46.3 percent of the specimens were females; in sounds, 58.6 percent; and outside waters, 82.1 percent.

Wolff (1978) reviewed work on the life history of the blue crab in North Carolina waters. Two spawning peaks were observed; one in March-April and a second in June-July.

Although 100 percent of juvenile blue crabs (Callinectes sapidus) from Florida have the crusher cheliped on the right side, only 74 percent of the larger adults exhibit this tendency (Hamilton, Nishimoto and Halusky, 1976).

Larvae of the spider crab, Libinia emarginata, reared in the laboratory have a similar morphology to that of larvae from plankton catches (Johns and Lang, 1977). However, some differences were noted between larvae of adults from South Carolina and Rhode Island: the first stage zoeae from South Carolina were smaller than Rhode Island specimens and the best percentage of survival was observed at $20^{o}C$ for larvae from Rhode Island and $25^{o}C$ for South Carolina larvae.

2.2.3 Molluscs

Although the bay scallop (Argopecten irradians) lives primarily in benthic-associated habitats, it is capable of active movements and thus is also nektonic. Spitsbergen (1977) reported that in North Carolina waters an increase in gonad weight during both the fall and spring was accompanied by a drop in meat weight. Scallops from the fall spawn showed little growth during the winter, but growth was sharply accelerated during April through August. Length-frequency data show small scallops in the samples as early as October, but they were most abundant during January through March.

Little information is available on population characteristics of squid. The site of greatest population biomass varies with season and temperature. For example, Rathjen (1973) found the greatest number of squid at depths where the water temperature ranged from 5°C to 15°C in the summer. The winter distribution and reproductive habits of the short-finned squid are essentially unknown. Squid are discussed further in Section 2.1.5 of this chapter.

2.3 Seasonal and Diurnal Relationships

2.3.1 Introduction

Information from both anglers and scientists has provided a basis for several generalizations regarding the movements of fishes and natant members of various phyla (Freeman and Walford, 1976b). For those marine species which inhabit the northern hemisphere and migrate northward in the spring or summer and southward in the fall or winter, these migrations generally correlate with water temperature. These fishes move along the coast, searching for an area of suitable prevailing temperatures. Once the migrating species locates a satisfactory temperature regime, local movements are influenced by factors such as salinity, food availability, and spawning or nursery area requirements. The various larval and juvenile stages may migrate into areas specifically suited for their developmental needs. In addition to species which migrate or are resident within the Carolinian Province, there are many, such as the tropical billfishes, which occur in transit northward to summering grounds or southward to wintering grounds. Various species in this study region demonstrate seasonal distributional changes which are the result of generalized movements rather than actual migrations. These distributional changes create changes in local species diversity.

Photoperiod is another important factor which influences the movements of fishes, although for this geographical study area, less information is available on diurnal movements than on temperature-correlated seasonal migrations.

The literature on seasonal and diurnal movements of nekton generally divides into 1) long range migrations, 2) migrations or local movements within the boundaries of a state, and 3) general distributional changes, with resultant changes in local species composition. Both the long and short range migrations include seasonal temperature-related responses and reproductive responses. Some photoperiodic data are included here.

2.3.2 Fish

2.3.2.1 Open Ocean and Coastal Water Studies

Those nektonic species of the Carolinian Province for which long-distance migrations have been documented include: blue fish, Pomatomus saltatrix; Atlantic sturgeon, Acipenser oxyrhynchus; albacore, Thunnus alalunga; weakfish, Cynoscion regalis; black sea bass, Centropristes striata; striped bass, Morone saxatilis; Atlantic thread herring, Opisthonema oglinum; blue marlin, Makaira nigricans; sailfish, Istiophorus platypterus; white marlin, Tetrapturus albidus; the ray, Raja eglanteria; long-finned squid, Loligo pealei; menhaden, Brevoortia tyrannus; and flatfish, Pleuronectiformes spp.

Wilk (1977) reported on the seasonal migration of the bluefish, P. saltatrix, from offshore to inshore waters (see Figure VII-6). Temperature and photoperiod appear to be important controlling environmental factors based on both field observations and experimental studies.

Adult Atlantic sturgeon, Acipenser oxyrhynchus, migrate from the sea to freshwater environments to breed during February in the southeast. Post-spawning migration to the sea occurs from October through December in Florida. The young are hatched in freshwater and spend up to five years there before descending to the sea. After emigration they make oceanic excursions of up to 900 miles. Holland and Yelverton (1973) published data on both the local and long distance movements of the sturgeon in North Carolina water using tagging-recapture techniques. One individual travelled 401 miles in 65 days; others were recaptured in the same area in which they were released.

Both the north and south Atlantic stocks of the albacore, Tetrapturus alalunga, demonstrate seasonal movements, eastward during the warm months, westward during the cold (Wise and Davis, 1973). These data reflect the Japanese longline fishery hauls for 1956-1968 (Figure VII-39).

The weakfish (Cynoscion regalis) migrate along the Atlantic coast as far south as Florida (Wilk, 1976). Typically they move south in the fall and winter and north in the spring and summer. Migratory habits change with the age of the fish: older and larger fish move south but offshore in the fall, probably at Cape Hatteras, while the smaller and younger fish may go to Florida waters in the fall, returning north in the spring and summer.

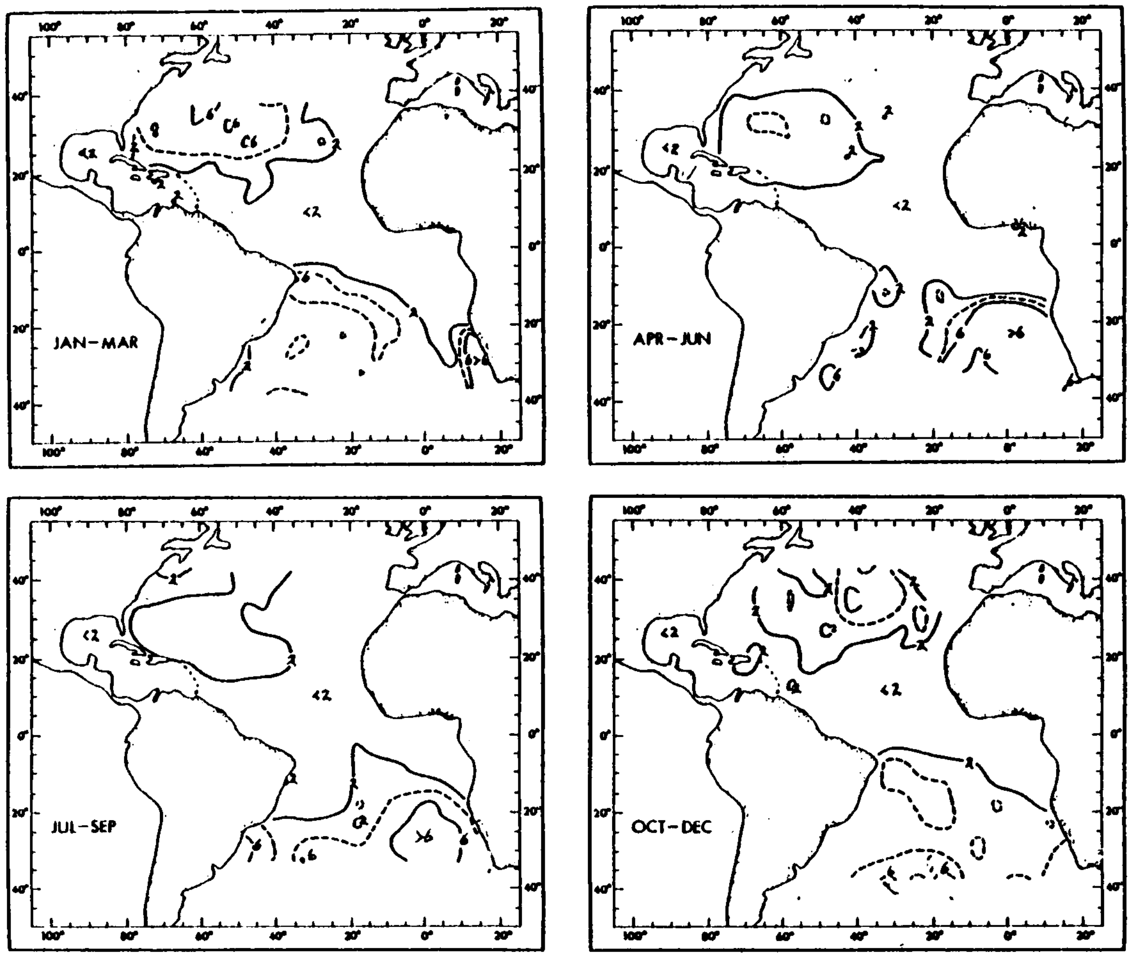


FIGURE VII-39. Distribution of catches of albacore (per 1,000 hooks) in the four quarters of the year, 1956-68. (From Wise and Davis, 1973)

The black sea bass, Centropristis striata, seems to move inshore and north in summer and offshore and south in winter in the Mid-Atlantic Bight but in the southeast it may remain in one place year round (Kendall, 1977). This author did not discuss mechanisms of response but these movements are possibly a response to temperature based on observations of Schwartz (1964).

The movements of striped bass, Morone saxatilis, in the Savannah River, Georgia were followed through the use of ultrasonic and radio transmitters. Dudley, Mullis and Terrell (1977) found that during March through May striped bass congregate and spawn in a tidally influenced, relatively small branch of the Savannah River about 30km upstream from the river mouth. Immediately after spawning, fish moved upstream, some as far as 301km from the spawning area.

Based on catch data on tagged specimens of the Atlantic thread herring, Opisthonema oglinum, Pristas and Cheek (1973) reported that this species migrates south in the autumn along the south Atlantic coast at a rate of six to seven miles per day.

There is disagreement among investigators as to whether one migrating population of blue marlin exists in the western Atlantic, or two populations which are differentially available to fishermen (Rivas, 1975).

The distribution of the sailfish, Istiophorus platypterus, is distinctly seasonal (Beardsley et al., 1975, Figure VII-40; Jolley, 1975). Along the east coast of Florida, wind and temperature have been shown to be important factors. During the summer months the sailfish move north, and in the winter they retreat south (Beardsley et al., 1975). It is thought that immature members of this species migrate southward during October through December, from the mid-Atlantic United States coast into the Florida Keys. In May to October, individuals of all sizes become abundant in the Gulf of Mexico, as well as off the east coast of Florida between Jacksonville and Mayport (Jolley, 1975). The strike and catch rates for the sailfish in the western Atlantic are the greatest during the morning and afternoon. Various reports indicate that the sailfish feeds during the day, and also during full moon nights (Jolley, 1975; 1977). Vertical distribution data on the larvae indicate that they are also more abundant near the surface during the daylight hours.

During the summer the large concentration of white marlin between Cape Cod, Massachusetts and Cape Hatteras, North Carolina creates the greatest sport fishing for this fish in the world (Mather et al., 1975). They occur here through the early fall. Their

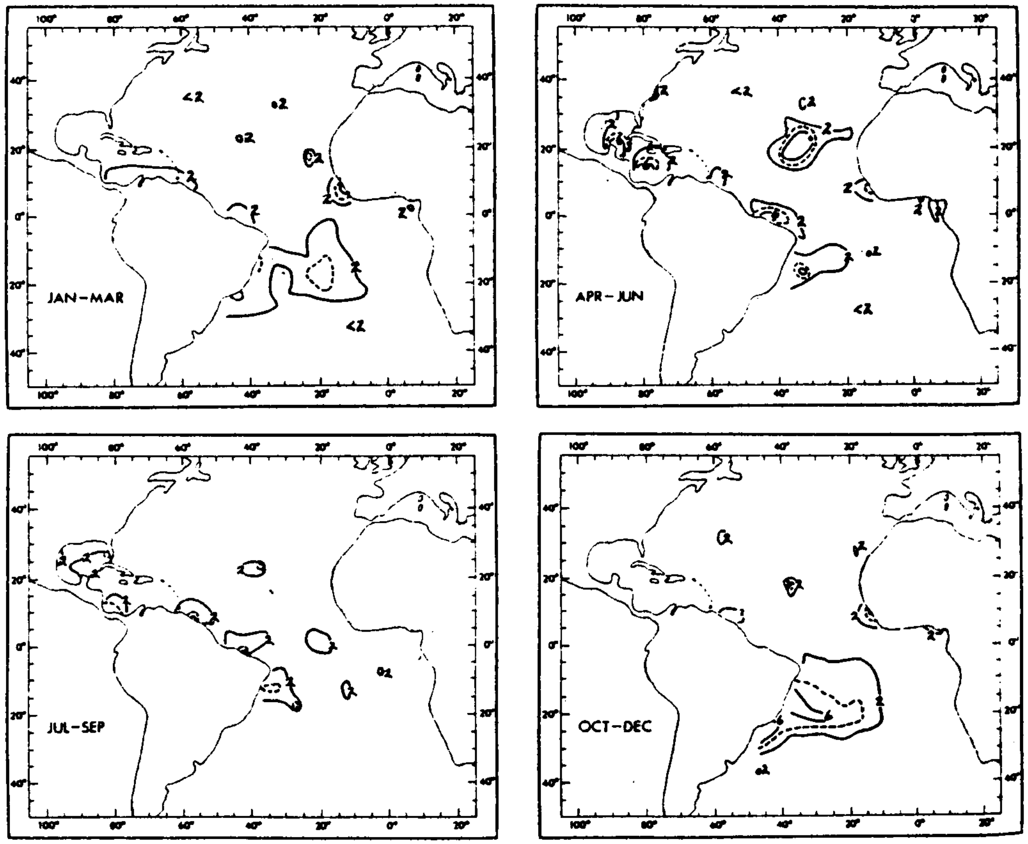


FIGURE VII-40. Distribution of catches of sailfish and spearfish (per 1,000 hooks) in the four quarters of the year, 1956-68. (From Wise and Davis, 1973; Beardsley et al., 1975) distribution is influenced mostly by food and spawning habitat. The Cape Hatteras-Cape Cod concentration appears to occur for the feeding purposes of post-spawners, and this geographical area is one of high productivity. Water temperature is also an important environmental influence for distribution of the white marlin. In the western north Atlantic longline catches of this species occur in waters with surface temperatures ranging from 21.1^{o} to 28.3^{o}C, and an average of 20.5^{o}C at estimated fishing depths of 52.7m. A tagging program by the Woods Hole Oceanographic Institute which released the marlin into Massachusetts coastal waters delineated seasonal migration patterns (Figure VII-41). The white marlin which become abundant in the Cape Cod-Cape Hatteras region in the summer enter at the southern area then move northward with the advancing season. During the summer they may move in various directions. In September and October, these fish move eastward. The late fall and winter find this species gathered off the northern coastline of South America. In the spring they move northward, via several passages, back to their summering area. Two groups of white marlin were tagged and released in more southern waters and show a less distinct migration pattern (Figure VII-42). The stocks of north and south Atlantic marlin appear to be distinct.

Although McEachran and Musick (1975) were primarily concerned with the distribution of skates between Nova Scotia and Cape Hatteras, North Carolina, they did report that Raja eglanteria, a Carolinian species, was abundant north of Cape Hatteras only during the warmer months.

Juvenile Atlantic menhaden, Brevoortia tyrannus, which had been tagged, migrated as far south as Florida in the fall and winter and then redistributed northward along the coast during the following spring and summer (Kroger and Guthrie, 1973). Also, tagging experiments utilizing over one million adult fish were conducted. A similar migratory route was observed by Dryfoos et al. (1973). Both of these studies used the techniques described by Pristas and Cheek (1973) and Parker (1972).

Seasonal changes in the larval distribution of eighteen species of flatfishes found between Cape Cod, Massachusetts and Cape Lookout, North Carolina were reported by Smith et al. (1975). Most flatfish began spawning in the spring, a time of marked seasonal thermal changes. Salinity had no apparent influence on spawning, but most species spawned within a relatively narrow range of temperature.

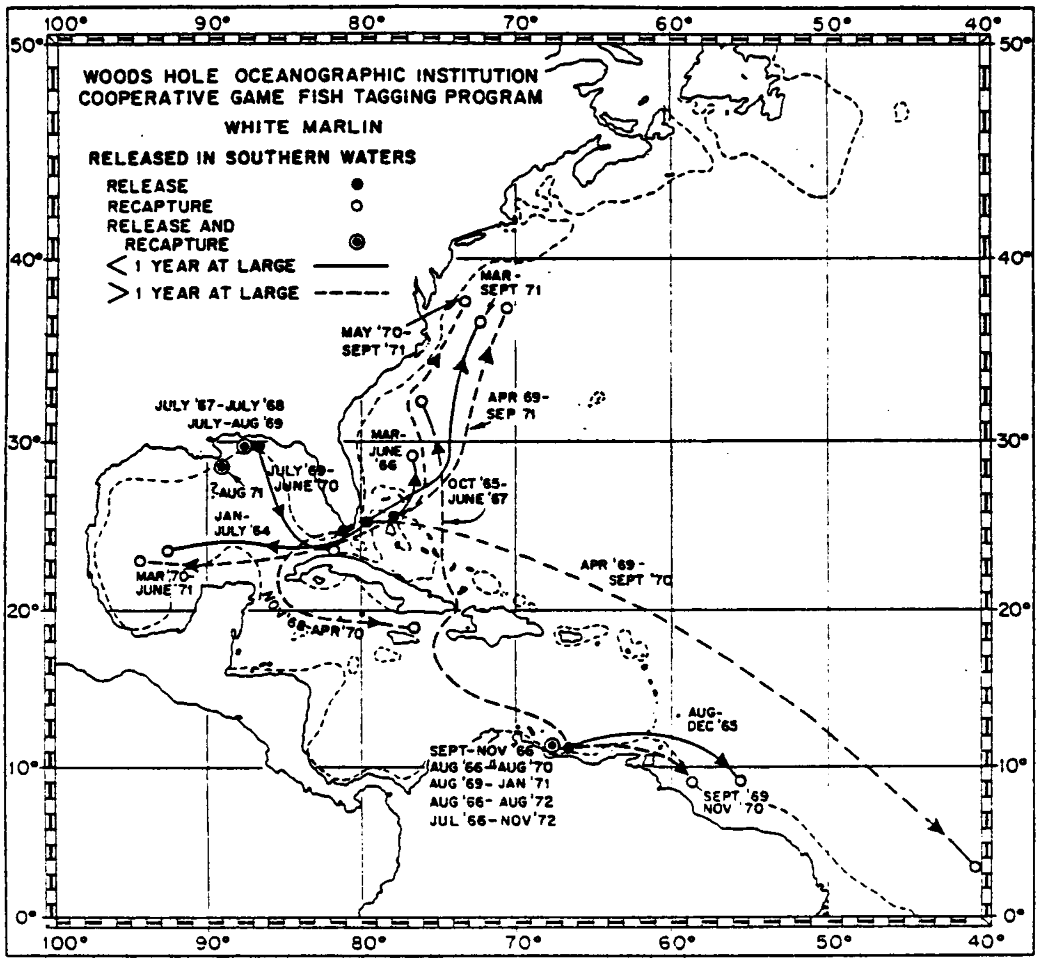


FIGURE VII-41. Tag returns from white marlin released in waters south of lat. 32°N. (Migration routes are diagrammatic.) (From Mather et al., 1975)

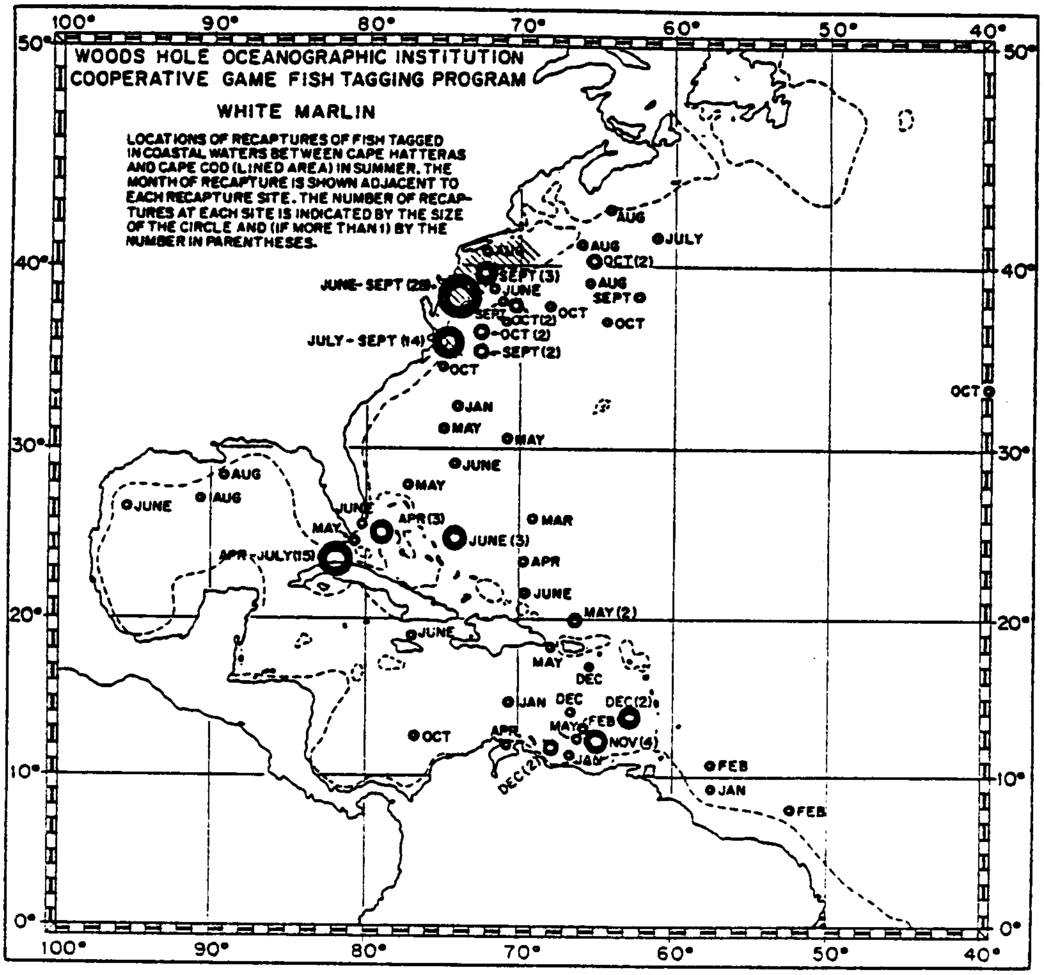


FIGURE VII-42. Tag returns from white marlin released in coastal waters between Cape Hatteras, N. C. and Cape Cod, Mass. (From Mather et al., 1975)

Barans and Burrell (1976) observed that demersal fish found between Cape Fear, North Carolina and Cape Canaveral, Florida do not respond to seasonal temperature changes by onshore and offshore movements characteristic of similar species found north of Cape Hatteras, North Carolina. However, they did report changes in distribution of various species with season (Figures VII-43 to VII-48).

Fahay (1975) reported on the seasonal occurrence of larval and juvenile fishes in the south Atlantic Bight between New River, North Carolina and Palm Beach, Florida. Although the larvae of many species were caught during more than one season of the year, spawning is at a maximum in the spring and summer. During the winter, the ranges of the few species found in inshore surface waters extend offshore and overlap with the ranges of Gulf Stream inhabitants, resulting in an area of increased variety over the middle shelf north of Cape Kennedy.

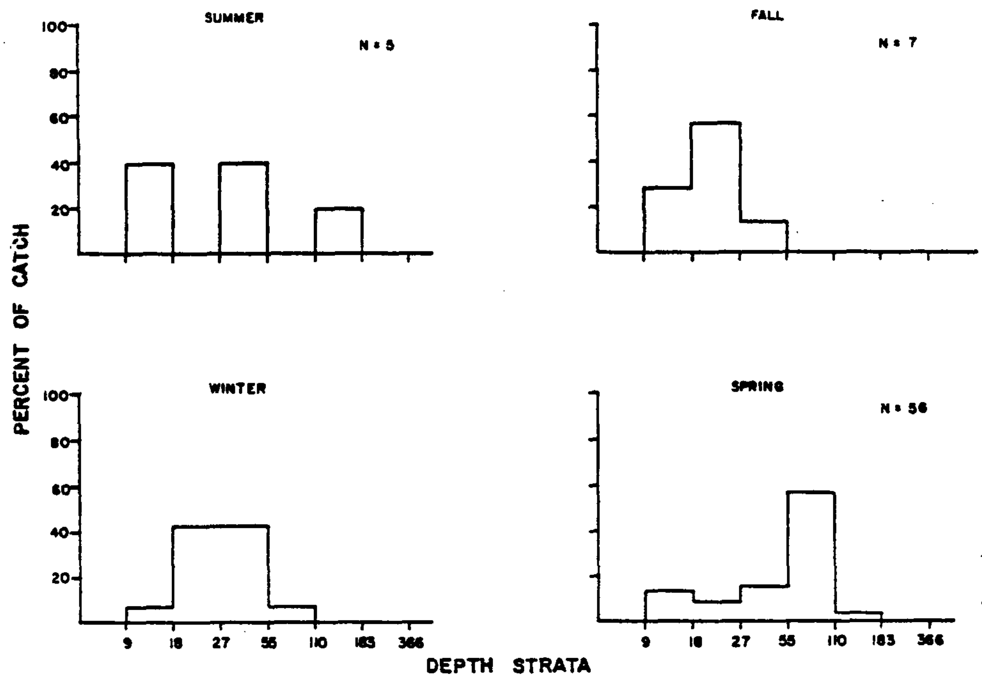
The black sea bass, *Centropristis striata*, migrates seasonally. Typically the adults move offshore during the colder months and inshore during the warmer months (Kendall, 1977). Based on a larval sampling program from North Carolina to New Jersey, there is an indication of northward progression of larval occurrences during the period of June to November. Juvenile fish apparently move inshore after early development offshore.

2.3.2.2 Estuarine Studies

Various studies report on the seasonal and diurnal movements of fish and crustaceans in geographically restricted areas, such as particular estuaries and inlets. Migrations to and from these particular areas result in seasonal changes in species diversity.

During the spring spawning runs of adult anadromous alewives (*Alosa pseudoharengus*) in North Carolina, the daily activity was greatest between dawn and noon and between dusk and midnight (Tyus, 1974).

In South Carolina the period from February through mid-April represents the major period for larval/postlarval recruitment for the following species: spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), brown shrimp (*Penaeus aztecus*), various flounder, and mullet species. May and August are the peak periods for the white shrimp (*Penaeus setiferus*), and a wide spectrum of fishes (Shealy et al., 1975).



A. Roughtail stingray (<u>Dasyatis centroura</u>).

B. Southern porgy (<u>Stenotomus</u> sp.).

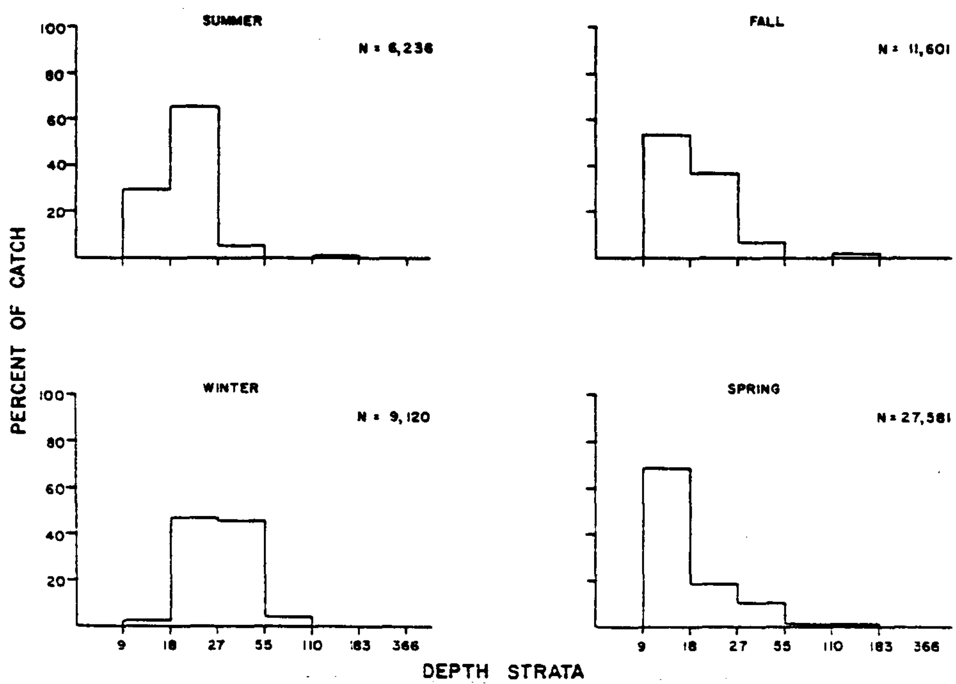


FIGURE VII-43. Seasonal depth distribution of two species of marine fish (Barans and Burrell, 1976).

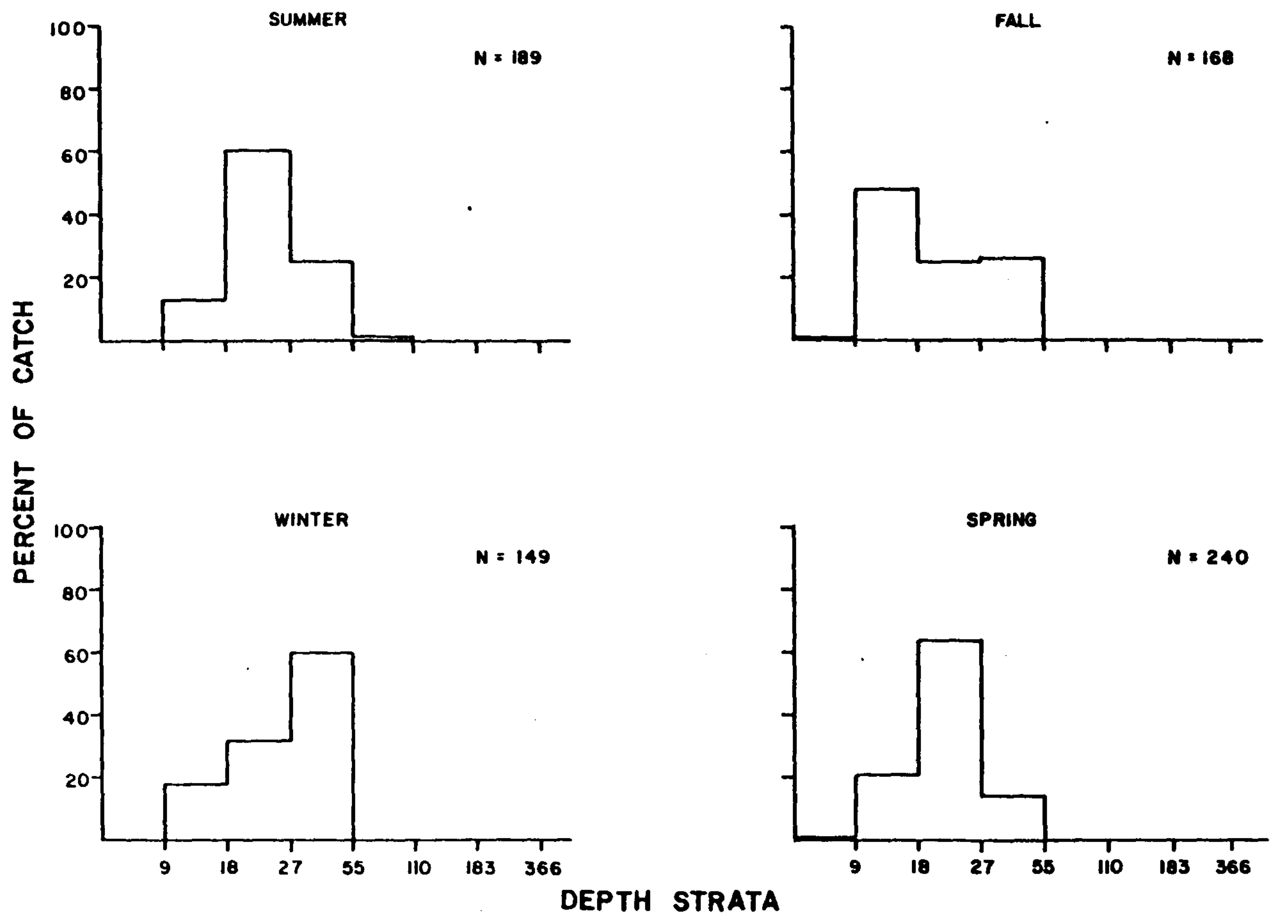
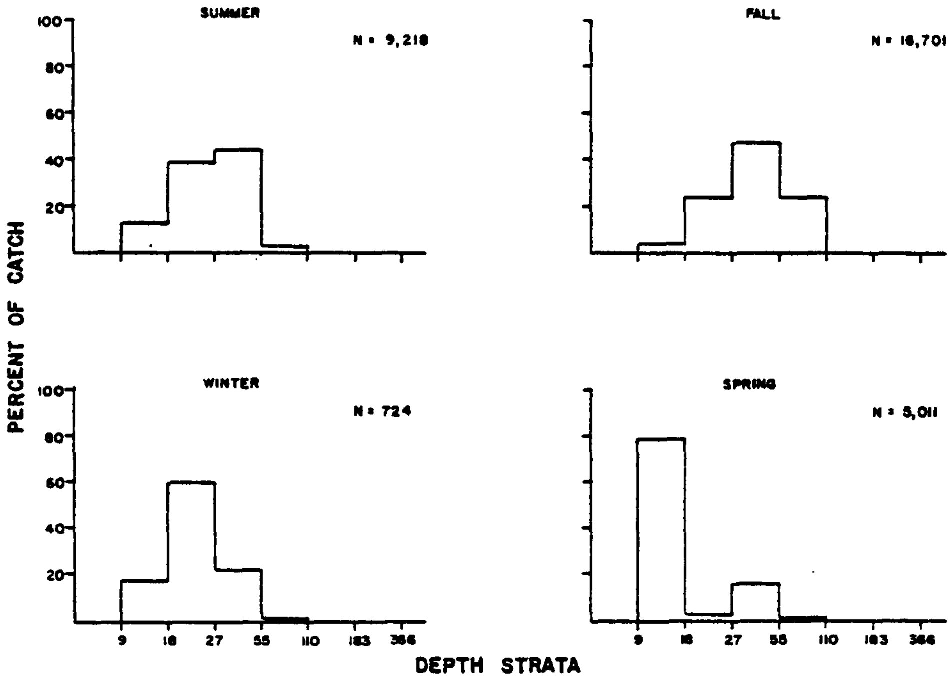


FIGURE VII-44. Seasonal depth distribution of the orange filefish (Aluterus schoepfi) (Barans and Burrell, 1976).



A. Round scad (Decapterus punctatus).

B. Butterfish (Peprilus triacanthus).

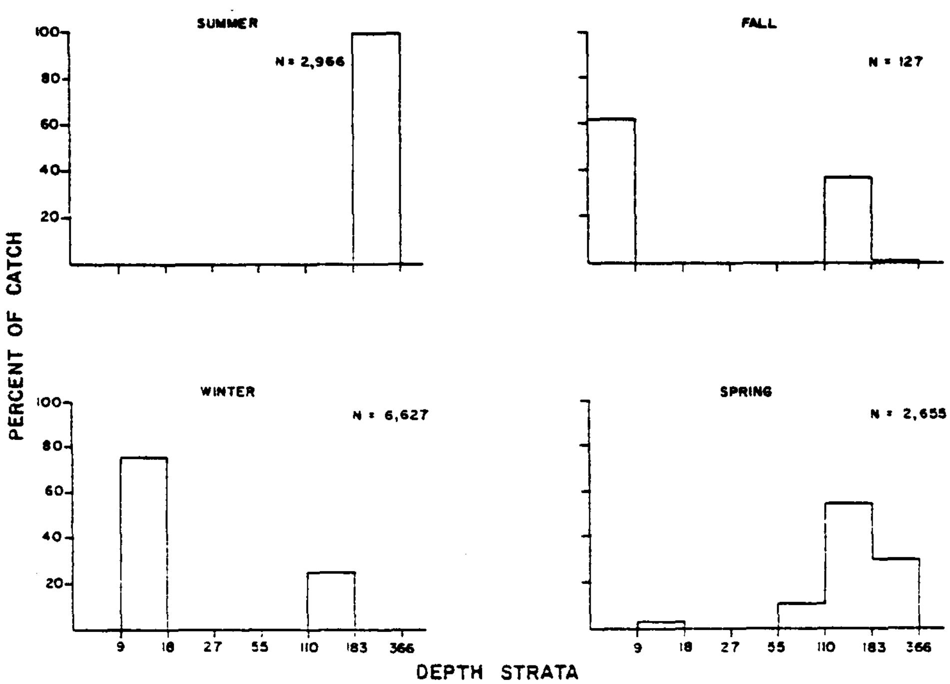
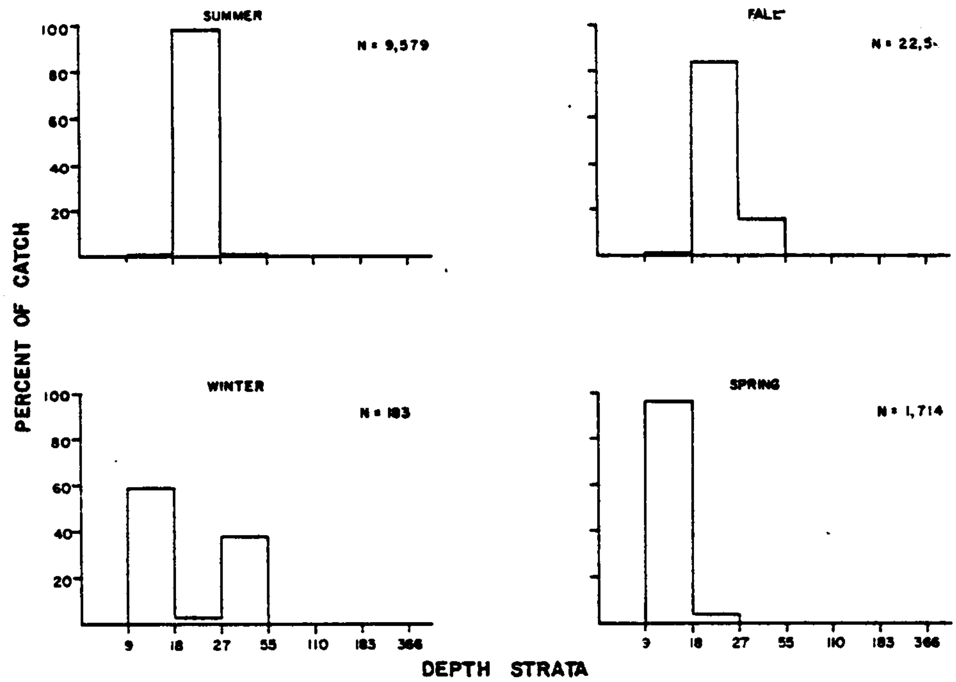


FIGURE VII-45. Seasonal distribution of two species of marine fish (Barans and Burrell, 1976).



A. Spanish sardine (Sardinella anchovia).

B. Round Herring (Etrumeus teres).

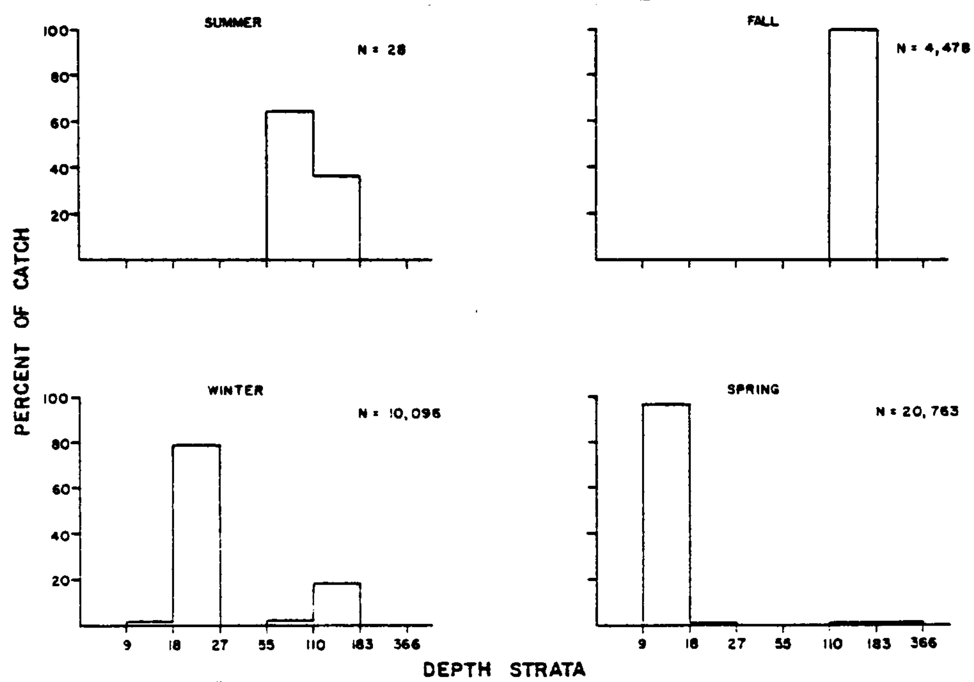


FIGURE VII-46. Seasonal distribution of two species of marine fish (Barans and Burrell, 1976).

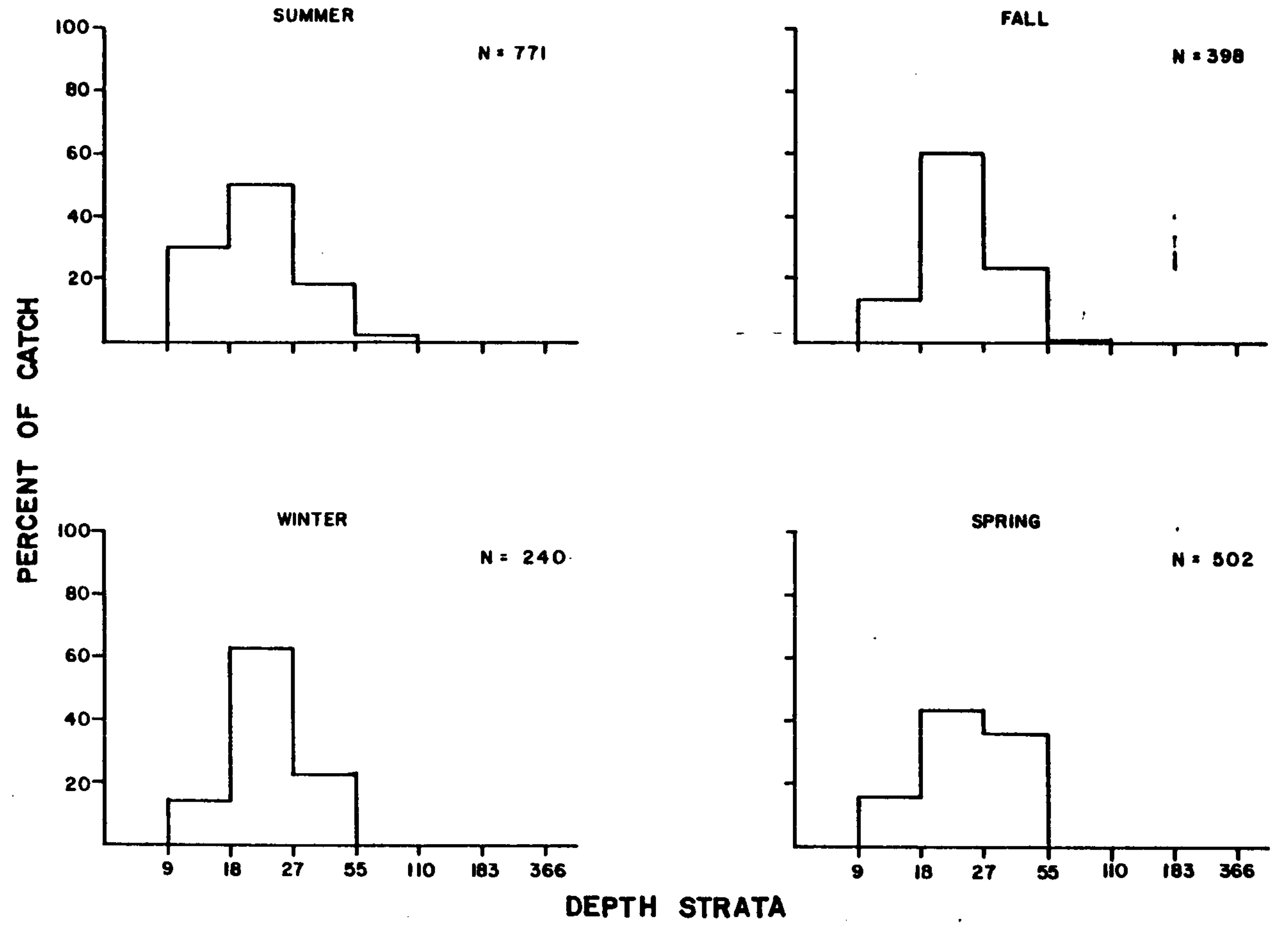
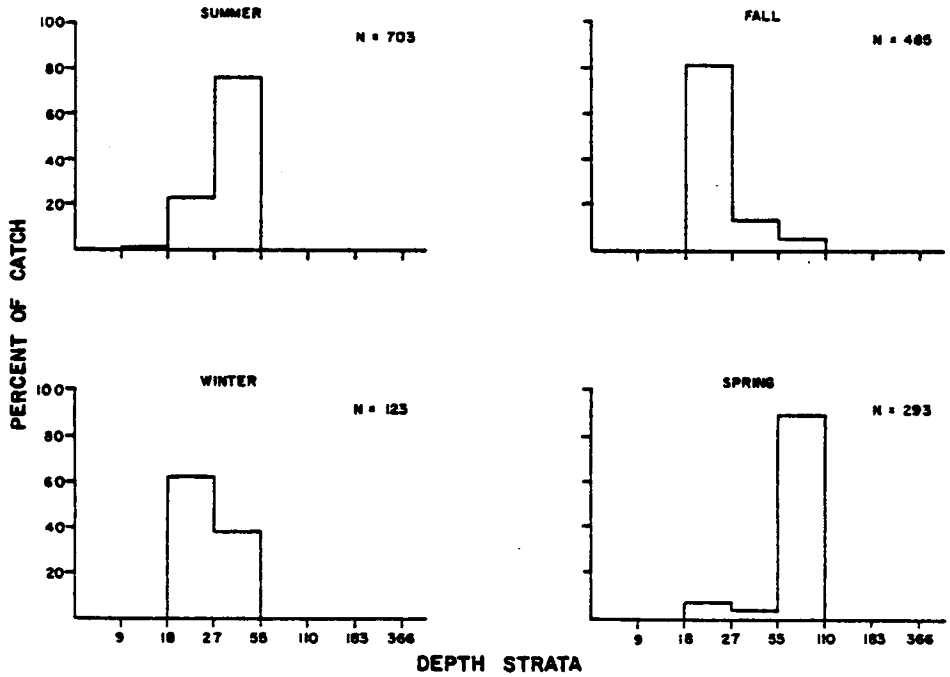


FIGURE VII-47. Seasonal depth distribution of the sand perch (*Diplectrum formosum*) (Barans and Burrell, 1976).



A. Vermillion snapper (Rhomboplites aurorubens).

B. Black sea bass (Centropristis striata).

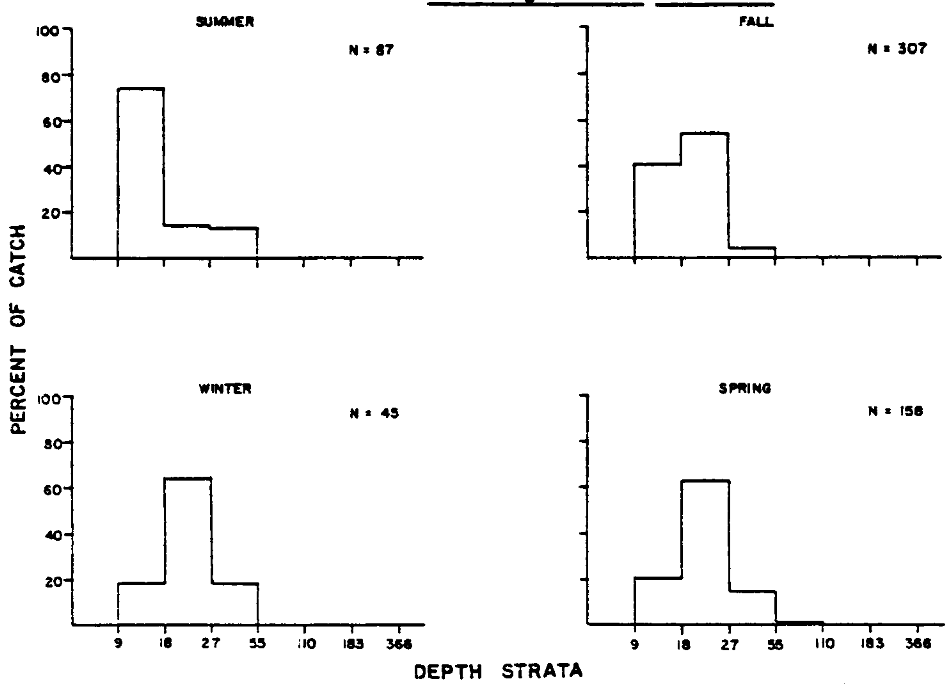


FIGURE VII-48. Seasonal depth distribution of two species of marine fish (Barans and Burrell, 1976).

Cain and Dean (1976) reported that season significantly affected the species diversity indices and the number of species found in an intertidal creek in the North Inlet Estuary, South Carolina. During their one year study, 16,611 individuals representing 51 species were collected. Their results are presented in Table VII-19. Obviously temperature had a pronounced effect on the seasonal appearance of fish. In addition, Cain and Dean emphasized that a shift in energy sources was observed.

A study conducted by Hackney, Burbanck and Hackney (1976) of the tidal areas near Crooked Creek in Georgia revealed seasonal variations in species distribution. These variations were correlated with seasonal salinity changes.

In Georgia estuaries adult spot, _Leiostomus xanthurus_, are most common along the beaches in the spring and summer, in the creeks and sounds in the fall, and in the offshore waters during winter (Music, 1974).

Seasonal cycles in H' and J species diversity indices for fish in estuaries have been reported. Dahlberg and Odum (1970), working in Georgia, reported maximum ranges of H' and J values of 0.5 and 0.3 respectively. In South Carolina, Cain and Dean (1976) found ranges for H' and J to be 1.8 and 0.65 respectively. However, Reis (1977) questioned the validity of making generalizations on seasonal fluctuations based on one sample per month because he found tremendous variation in fish community structure within a twelve hour period.

The abundance of fish in South Carolina estuarine intertidal creeks varies diurnally but not in a predictable manner. For example, Bozeman (1976) reported the greater numbers of individuals and biomass occurring at night, while Reis (1977) found the reverse. These workers worked in different estuarine systems in South Carolina: Bozeman's investigation was in the North Inlet Estuary where sciaenid fishes dominated, while Reis sampled in Anchovy Creek, a part of the Santee System, where engraulid fishes were the most common group of fishes. Apparently the temporal utilizaion patterns of intertidal creeks of these two families are different. Reis (1977) suggested that the movement of _Anchoa mitchilli_, _Fundulus heteroclitus_, and _Menidia menidia_ into intertidal estuarine creeks at different times of the day is indirectly related to peaks in feeding activity. Bozeman (1976) found that the majority of larval fish did not enter the intertidal creeks during the day. Presumably this behavior has adaptive significance in that larval fish would be less likely to be preyed upon.

TABLE VII-19. Seasonal occurrence and biomass of fish species from South Clambank Causeway Creek, North Inlet Estuary, South Carolina from June, 1971 to May, 1972. Presence of euryhaline species (E column) is indicated by an x (Cain and Dean, 1976).

Species	June 25	July 8	July 27	August 6	Sept. 4	Sept. 22	Oct. 17	Oct. 29	Nov. 19	Dec. 17	Jan. 15	Feb. 1	Feb. 15	March 12	April 9	May 26	E	Number and weight (g)
Dasyatis	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
americana	9,254.0	12,700.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-		22,224.0
Dasyatis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	x	1
sabina	-	-	-	-		1,102.0	-	-	-	-	-	-	-	-	-	-		1,102.0
Lepisosteus	-	-	-	-	3	-	-	1	-	-	-	-	-	-	-	-	x	4
osseus	-	-	-	-	2,721.0	-	-	1,320.8	-	-	-	-	-	-	-	-		4,041.8
Elops	-	3	-	-	-	-	1	-	-	-	-	-	-	-	-	-	x	4
saurus	-	36.7	-	-	-	-	57.1	-	-	-	-	-	-	-	-	-		93.8
Anguilla	-	-	1	-	4	1	-	-	-	-	3	-	-	-	1	1	x	11
rostrata	-	-	0.8	-	34.5	117.6	-	-	-	-	31.8	-	-	-	4.8	10.0		119.5
Alosa	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	x	2
aestivalis	-	-	-	-	-	-	-	-	-	1.3	-	-	2.0	-	-	-		3.3
Brevoortia	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	x	1
tyrannus	-	-	-	-	-	-	-	-	-	12.8	-	-	-	-	-	-		12.8
Dorosoma	-	4	-	-	16	-	2	6	-	5	1	-	-	-	-	-	x	34
cepedianum	-	251.7	-	-	741.6	-	227.4	672.5	-	99.7	8.6	-	-	-	-	-		2,001.5
Opisthonema	-	-	-	-	65	-	1	2	-	-	-	-	-	-	-	-	-	68
oglinum	-	-	-	-	195.8	-	3.3	14.0	-	-	-	-	-	-	-	-		213.1
Anchoa	-	8	33	29	99	73	112	1	-	-	-	-	-	-	-	-	-	355
hepsetus	-	16.1	88.0	59.9	295.1	312.6	589.7	5.0	-	-	-	-	-	-	-	-		1,165.5
Anchoa	2	4	1	-	416	14	107	6	1	3	-	-	1	-	22	225	x	802
mitchilli	1.1	6.0	1.0	-	295.4	16.8	117.7	8.7	3.1	4.3	-	-	2.8	-	30.8	248.4		736.1
Rissola	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	4
marginata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	148.2	-		148.2
Opsanus	1	2	1	2	4	-	2	4	-	-	-	-	-	-	1	-	-	17
tau	152.3	83.1	55.5	218.5	148.3	-	249.3	353.0	-	-	-	-	-	-	1.1	-		1,261.1
Strongylura	1	7	2	5	2	-	1	-	-	-	-	-	-	-	-	-	x	18
marina	3.9	46.6	12.0	66.1	25.5	-	5.9	-	-	-	-	-	-	-	-	-		160.2
Cyprinodon	-	-	-	-	1	-	-	-	-	-	3	-	-	8	10	-	x	22
variegatus	-	-	-	-	1.6	-	-	-	-	-	2.4	-	-	4.0	12.6	-		20.6
Fundulus	10	62	87	5	846	940	174	7	71	267	58	2	-	1887	473	40	x	4,929
heteroclitus	16.7	125.0	238.5	7.2	797.4	919.6	208.8	12.0	121.4	433.2	150.7	2.1	-	3461.7	1063.6	125.7		7,683.6
Fundulus	-	-	-	-	-	-	-	-	2	17	97	6	1	114	115	2	x	154
majalis	-	-	-	-	-	-	-	-	2.4	10.8	153.2	12.9	1.0	251.1	387.8	8.8		828.0

TABLE VII-19, cont.

Menidia	-	-	2	2	338	420	460	222	27	561	350	14	87	375	346	3	x	3207
menidia	-	-	2.8	1.7	431.2	550.4	747.4	374.0	64.0	1,461.3	933.0	50.4	309.5	1,382.2	1,165.6	9,3		7,541.6
Centropristis	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
striata	-	-	-	-	-	-	33.4	-	-	-	-	-	-	-	-	-		33.4
Pomatomus	8	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	11
saltatrix	111.6	18.4	-	48.4	-	-	-	-	-	-	-	-	-	-	-	-		178.4
Caranx	2	6	4	-	12	18	3	2	-	-	-	-	-	-	-	-	x	47
hippos	10.6	99.0	166.6	-	191.9	130.0	31.5	2.5	-	-	-	-	-	-	-	-		612.1
Caranx	-	-	-	-	23	4	15	6	-	-	-	-	-	-	-	-	x	48
latus	-	-	-	-	105.6	15.7	47.8	9.3	-	-	-	-	-	-	-	-		178.4
Chloroscombrus	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	20
chrysurus	-	-	-	-	142.3	-	-	-	-	-	-	-	-	-	-	-		142.3
Selene	27	34	14	3	4	2	-	1	-	-	-	-	-	-	-	-	-	85
vomer	36.8	186.1	227.4	64.4	35.6	5.5	-	57.2	-	-	-	-	-	-	-	-		613.0
Trachinotus	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
falcatus	-	-	-	-	-	-	1.1	-	-	-	-	-	-	-	-	-		1.1
Lutjanus	-	-	-	-	1	7	9	1	-	-	-	-	-	-	-	-	x	18
griseus	-	-	-	-	17.1	64.8	15.6	4.0	-	-	-	-	-	-	-	-		101.5
Diapterus	-	-	-	-	4	10	-	-	-	-	-	-	-	-	-	-	-	14
plumieri	-	-	-	-	17.4	21.5	-	-	-	-	-	-	-	-	-	-		38.9
Eucinostomus	22	58	28	16	23	109	219	17	11	-	-	-	-	-	-	-	x	583
argenteus	16.3	102.2	126.4	74.0	73.5	236.0	426.3	55.2	46.5	-	-	-	-	-	-	-		1,156.4
Eucinostomus	-	-	-	5	6	1	1	-	1	1	-	-	-	-	-	-	x	15
gula	-	-	-	15.1	45.0	8.5	8.5	-	28.0	17.2	-	-	-	-	-	-		122.3
Orthopristis	36	7	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	47
chrysoptera	26.3	9.0	4.8	-	-	76.1	-	-	-	-	-	-	-	-	-	-		116.2
Archosargus	2	1	2	2	3	-	-	-	-	-	-	-	-	-	-	-	x	10
probatocephalus	92.0	103.0	779.8	901.0	776.7	-	-	-	-	-	-	-	-	-	-	-		2,652.0
Lagodon	3	5	4	-	1	3	-	1	-	-	-	96	2	-	-	12	x	127
rhomboides	199.8	418.9	366.3	-	39.0	170.5	-	113.5	-	-	-	1154.2	43.6	-	-	230.1		2,735.9
Bairdiella	108	163	47	7	126	115	11	10	-	1	-	-	-	-	8	7		683
chrysura	185.6	146.2	91.8	22.9	1,538.8	1,978.2	321.5	260.4	-	18.0	-	-	-	-	378.7	291.0		5,235.1
Cynoscion	-	-	-	-	1	3	-	1	1	-	-	-	-	-	1	0	x	7
nebulosus	-	-	-	-	5.2	18.4	-	161.8	1.9	-	-	-	-	-	219.9	-		407.2
Leiostomus	272	342	146	44	98	112	30	11	69	1,534	-	-	-	1	128	430	x	3,237
xanthurus	3,206.2	2,177.4	1,665.0	573.6	1,771.3	1,520.3	1,294.0	746.1	4,063.0	30,401.0	-	-	-	69.4	3,705.3	4,022.9		55,215.5
Micropogon	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	x	4
undulatus	-	-	129.8	127.2	187.4	236.5	-	-	-	-	-	-	-	-	-	-		600.9
Sciaenops	-	2	1	-	-	-	-	-	-	7	-	-	-	-	1	-	x	11
ocellata	-	276.9	208.1	-	-	-	-	-	-	8.1	-	-	-	-	8.1	-		501.2
Sphyraena	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
barracuda	-	-	-	-	-	-	-	167.7	-	-	-	-	-	-	-	-		167.7

TABLE VII-19, cont.

Mugil	36	96	52	22	25	37	31	31	35	60	68	4	3	16	92	23		620
cephalus	4,478.7	5,798.3	9,622.6	2,537.3	1,762.5	1,607.8	3,101.4	8,475.6	6,239.2	6,547.8	722.3	679.6	389.5	1,380.7	3,599.9	3,004.2		59,947.4
Mugil	134	189	31	25	80	254	170	13	7	2	-	-	-	-	-	8	-	913
curema	445.6	578.9	933.3	228.4	760.7	3,649.5	2,391.4	125.3	80.9	35.1	-	-	-	-	-	2.2		9231.3
Hypsoblennius	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
hentzi	-	-	-	10.4	-	-	-	-	-	-	-	-	-	-	-	-		10.4
Gobionellus	1	-	1	-	-	4	-	-	8	84	26	5	1	2	27	2	-	161
boleosoma	0.1	-	0.2	-	-	1.1	-	-	3.3	33.9	12.5	3.1	0.5	0.5	11.3	1.1		67.6
Gobiosoma	1	1	2	-	1	-	-	-	1	3	-	1	-	-	2	3	x	15
bosci	0.5	0.5	1.1	-	3.0	-	-	-	1.3	2.2	-	3.1	-	-	1.6	3.0		16.3
Gobiosoma	-	4	1	-	1	-	-	-	-	1	-	-	-	-	-	-	-	7
ginsburgi	-	017	0.3	-	0.4	-	-	-	-	0.4	-	-	-	-	-	-		1.8
Scomberomorus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
maculatus	-	-	-	-	-	2.3	-	-	-	-	-	-	-	-	-	-		2.3
Citharichthys	4	1	2	1	5	-	-	-	-	-	-	-	-	-	-	-	x	13
spilopterus	9.9	6.7	10.0	3.4	56.9	-	-	-	-	-	-	-	-	-	-	-		86.9
Etropus	-	-	-	-	3	-	1	-	-	-	-	-	-	-	-	-	-	4
crossotus	-	-	-	-	11.5	-	3.7	-	-	-	-	-	-	-	-	-		15.2
Paralichthys	3	-	-	1	3	-	2	-	1	1	-	-	-	-	-	-	x	11
dentatus	11.7	-	-	82.4	148.0	-	101.4	-	77.4	25.4	-	-	-	-	-	-		446.3
Paralichthys	5	1	9	5	12	3	1	2	1	-	-	-	-	-	1	5	x	45
lethostigma	1,575.6	46.4	1,258.6	618.7	1,763.5	294.0	396.9	347.2	-	-	-	-	-	-	0.2	1,219.9		12,085.1
Symphurus	-	2	1	-	7	1	1	1	-	-	-	-	-	-	-	1	-	14
plagiusa	-	0.3	0.2	-	10.1	0.3	2.7	2.2	-	-	-	-	-	-	-	1.4		17.2
Monacanthus	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
hispidus	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-		0.3
Total no./ sample	759	1,005	474	177	2,254	2,217	1,356	351	281	2,557	558	128	96	2,404	1,232	762	-	16,611
Total weight/ sample	21,707.3	23,234.1	15,992.9	5,736.0	17,581.4	13,355.4	10,280.9	13,735.2	11,079.6	39.112.5	,015.3	1,905.4	748.9	6,549.9	10,739.5	9,178.0	-	202,454.1
No. of species	21	25	25	19	34	25	24	22	14	17	8	7	7	8	16	14		

Results of a two year study of the surf zone off Folly Beach, South Carolina indicate that the numbers of fish species caught in corresponding seasons were similar, except for the summer catches (Anderson, Dias, Dias, Cupka and Chamberlain, 1977). The summer catch of the second year yielded almost one third more species than that of the first year. In the second year, the spring, summer, and winter catches yielded more specimens than in the corresponding seasons of the preceeding year, particularly in the winter and summer. In comparing the data by seasons for the two years, it was found that more species were taken in summer, with the diversity being the least during the winter. By contrast, the greatest mass and most specimens were caught in the winter. The smallest mass was caught in the fall, and the least numbers of individuals were obtained in the spring. These authors reported they had expected the high diversity of the warm months, but were surprised by the great ichthyomass and large number of individuals taken during the winter. They postulated that these results might be due, at least in part, to 1) motility and 2) thermal preferences. They hypothesized that the larger fish taken from cold waters avoid capture in warm waters.

Gilmore et al. (1977) in an annual progress report indicate the availability of data on the seasonal and diurnal changes in fish populations in the mid-region of the east coast of Florida.

2.3.3 Crustaceans

The migratory characteristics of the crustaceans, the brown shrimp, Penaeus aztecus, the white shrimp, P. setiferus, the pink shrimp, P. duorarum, and the blue crab, Callinectes sapidus, have most often been investigated within a particular state's boundaries. These research efforts have primarily been directed at collecting fishery resource management data.

In the U. S. south Atlantic region, the larval and juvenile stages of brown, pink, and white shrimp utilize estuaries as nursery grounds (Eldridge and Goldstein, 1975). The adult brown and pink shrimp migrate offshore prior to spawning; the spawning areas, however, are little known. The white shrimp do not migrate to spawn, but generally spawn singly in 6-24m depths slightly offshore. The larger white shrimp migrate south, while the smaller individuals overwinter in the estuarine waters of the Carolina, Georgia, and Florida coasts.

A mark-recapture study of the brown shrimp, P. aztecus, in Pamlico Sound, North Carolina was initiated to determine population dynamics of the species (Purvis and McCoy, 1974). The collections were taken during the early morning and late afternoon, as those were the periods of greatest activity and feeding. Less than one percent of the brown shrimp released in Pamlico Sound during the two year study (1971-1972) were recovered from oceanic waters. The data indicate that the Pamlico Sound shrimp stocks constitute a self-contained fishery. The oceanic one percent was located toward the nearest oceanic inlets, Ocracoke and Drum Inlets.

In a two year study of the shrimp resource of South Carolina, Bishop and Shealy (1977) found that 86 percent of the white shrimp, P. aztecus, was collected from June through July. The largest pink and brown shrimp were caught in spring and summer, while the largest white shrimp were caught in spring and fall.

White shrimp, P. setiferus, spawns in offshore waters during May to September, with the postlarvae entering the estuaries in late spring and early summer (Bishop and Shealy, 1977). They develop into subadults and move offshore again in the fall.

Schwartz (1977) reported that colored floy anchor tags were useful in tagging the white shrimp, P. setiferus, for migration studies. Shrimp tagged and released in the Cape Fear River, North Carolina from 1973 to 1975 moved southward for 575km to near Jekyll Island, Georgia during late fall and winter. Although P. setiferus is generally considered diurnal, these authors' data contradict that idea, and conflicting data appear in the literature.

Postlarval P. aztecus immigrate into South Carolina estuaries during January through March (Bishop and Shealy, 1977). Data regarding diel versus nocturnal activity of this species was inconclusive.

Eldridge and Waltz (1977) reported seasonal differences in commercial crab catches of blue crabs in South Carolina with the lowest number caught during the period from December to March and the maximum number from July to October.

In observing the movements of juvenile shrimp, P. setiferus and P. aztecus, in Georgian tidal creeks, Hackney and Burbanck (1976) reported that shrimp were more common at the shallow upper portions of creeks where permanent fish populations were absent. However, during periods of low dissolved oxygen (1.5 ppm) few shrimp were found at the upper portion of creeks.

Palmer (1974) reported that in Georgian waters, blue crabs, Callinectes sapidus, move to deep, warm waters and become more inactive as the water temperature drops. In the summer crabs migrate toward shallower waters where food and shelter are favorable. The greatest percentage of females is found in outside waters.

Major seasonal recruitment of juvenile rock shrimp, Sicyonia brevirostris, off Cape Canaveral, Florida occurs April to August (Kennedy et al., 1977). The recruitment pattern does not vary by sex. During years of successful recruitment, the periodic pulses of off-season recruitment probably do not contribute to the overall population stability; however, in years of lesser seasonal recruitment success, these smaller influxes may indeed affect population stability.

2.3.4 Molluscs

The long-finned squid, Loligo pealei, migrates inshore annually in the spring (Rathjen, 1973, Figure VII-49). At this time, the squids spawn in depths from shore to about 90m. The young stay in the coastal waters until fall. From November to March, large concentrations of long-finned squid are distributed along the outer continental shelf.

2.4 Physical and Chemical Environmental Relationships

2.4.1 Community Structure and Dynamics

In general, detailed knowledge of the structure and dynamics of nektonic communities is lacking. The investigation by Mather et al., 1975, is one of the few that deals with this topic. Mather et al. found that large marlins, tuna, sharks, and to some extent, lancetfishes, compete with the white marlin, and are preyed upon by sharks and larger billfishes. These fish probably school according to size, returning to certain fishing grounds as groups. Trophically, the white marlin is beneath the swiftest and most powerful sharks (Figure VII-50).

Gore et al. (1976) report on the community dynamics of nektonic animals associated with seagrass beds. They discuss the community composition and standing crop estimates. Trophic relationships are being investigated by this ongoing study.

Reis (1977) emphasized the difficulty in assessing the community structure of fish in an estuary. Based on intensive sampling in a South Carolina estuary, he reported tremendous variation both in number of individuals, species, and biomass from day to day. For example, variation in numbers of individuals was from 27 to 7062; in biomass, 14.5 to 1402 gms; and in number of species, 0 to 12.

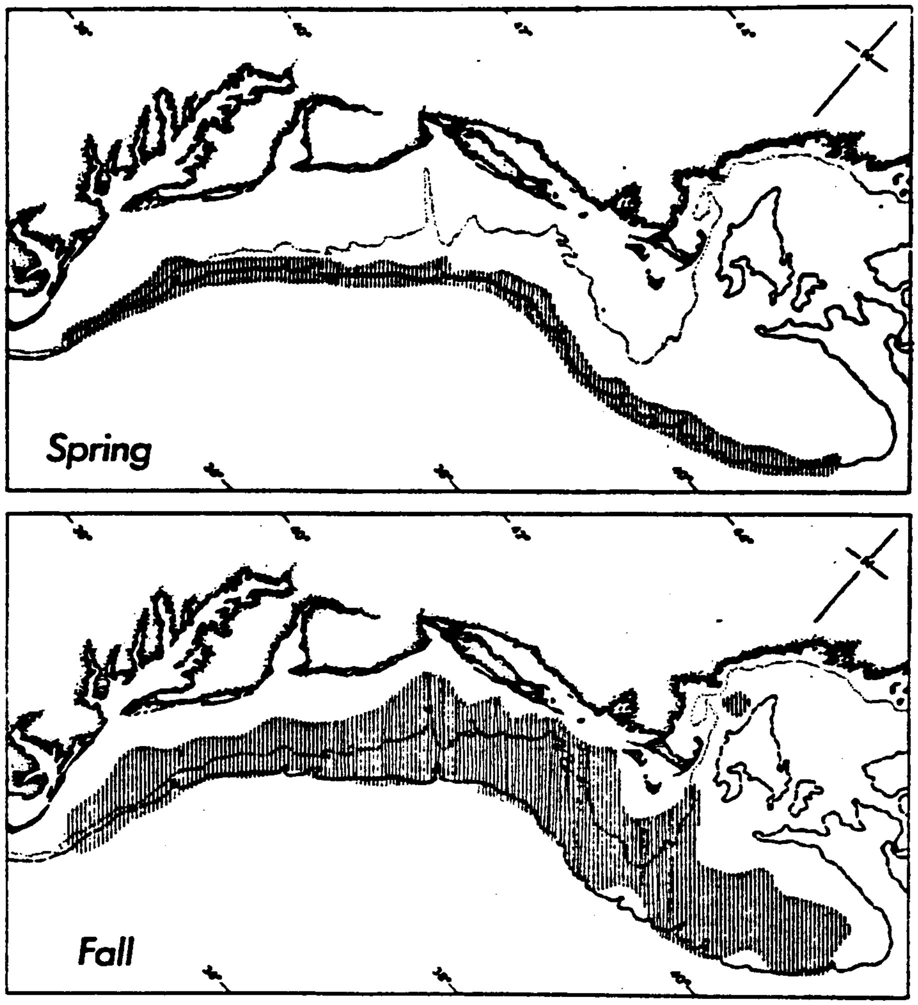
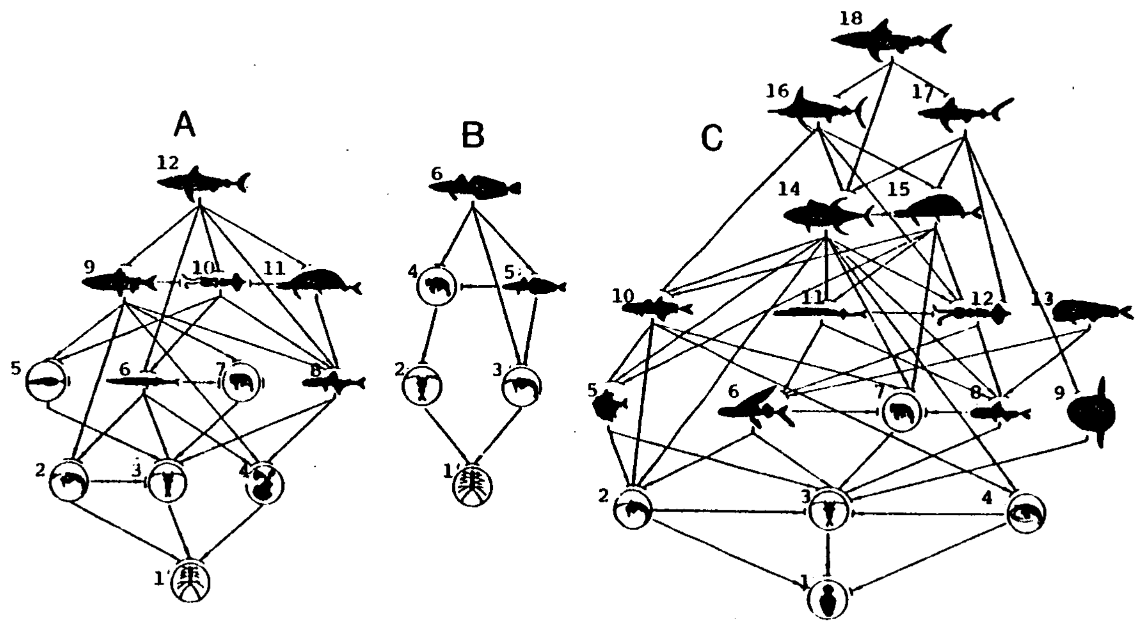


FIGURE VII-49. Shaded area represents typical distribution of long-finned squid over continental shelf in the spring (March-May) and fall (September-November). Data have resulted from Northeast Fisheries Center groundfish surveys which do not cover areas of less than 27 meters (Rathjen, 1973).



A—subarctic waters; level I—phytoplankton (1); level II—phytophagous zooplankton: euphausiids (2), copepods (3), Pteropoda (4); level III—predatory plankton and planktophagous fishes: fish juveniles (5), saury (6), hyperiids (7), myctophids (8); level IV—nektonic predators: Pacific salmon (9), squid (10), lancetfishes (11); level V—large nektonic predators: mackerel shark (12).

B—antarctic waters: level I—phytoplankton (1); level II—copepods (2), euphausiids (3); level III—hyperiids (4), planktophagous fishes (5); level IV—predatory fishes (6).

C—tropical waters: level I—phytoplankton (1); level II—euphausiids (2), copepods (3), shrimp (4); level III—fishes of the "shifting layers" (5), flyingfishes (6), hyperiids (7), "subsurface" lanternfishes (8), moals (9); level IV—small deepwater ichthyophages (Chiasmodon, etc.) (10), nyctoepipelagic predators (snake mackerel) (11), squid (12), Corphaena (13); level V—tuna (14), lancetfishes (15); level VI—marlins (16), medium-sized sharks (17); level VII—large sharks (18).

FIGURE VII-50. Diagram of the trophic links among epipelagic fishes (from Parin, 1968). Reprinted from Mather et al., 1975.

The introduction of a new species into an area can influence the dynamics of the resident community. Hogg (1976a, b) reported that when Tilapia is introduced into Florida waters it competes with native centrarchid fish populations for food and shallow water spawning habitat. In general, introduced species will tend to dominate in disturbed environmental areas.

2.4.2 Physical/Chemical Parameter-Physiological Ecology

2.4.2.1 Introduction

The ecology of offshore nekton and plankton is influenced by various abiotic factors acting singly or in combination. The patterns of surface water movement are of great importance to nekton in determining the distribution of near surface phytoplankton, zooplankton, and substances suspended in seawater. After reviewing the existing data relating to circulation of waters over the continental shelf south of Cape Hatteras, Bumpus (1973) concluded that this area is a very complex and variable system which is greatly affected by the shifting of the Florida Current. Since then additional observations have been reported. Atkinson and Jaffe (1978) reported a relationship between the presence of a strong geotrophic force and the predominately southerly drift observed inshore during September. The importance of Frying Pan Shoals on the inferred water movements was stressed by Barans and Roumillat (1976).

2.4.2.2 Fish

Physical and chemical data collected during 1973 on cruises ranging from Cape Fear, North Carolina to Cape Canaveral, Florida are summarized by Matthews and Pashuk (1977). These data have implications relative to the ecology of nekton species. The following environmental factors were studied: density, temperature, salinity, dissolved oxygen, and orthophosphate.

Although the tilefish, *Lopholatilus chamaeleonticeps*, is restricted to a narrow band of relatively warm water along the edge of the continental shelf, this species is the top carnivore in this warm-water community and depends mostly on species occurring only within this narrow band (Freeman and Turner, 1977).

The ecology of red snappers found in the coastal waters of the Carolinas was reviewed by Grimes et al. (1977). The presence of these species as far north as Cape Hatteras is due primarily to two factors: 1) abundant regions of rocky substrate on the outer continental shelf and along the shelf break; and 2) year-round warm water resulting from the nearby presence of the Gulf Stream.

Red snapper, Lutjanus campechanus, occupy rough bottom, reef-type habitats as adults, while juveniles occur on a smooth bottom. This species is an opportunistic bottom feeder, consuming a wide variety of invertebrates and fishes.

Temperature and wind appear to influence the latitudinal distribution of the sailfish, Istiophorus platypterus (Beardsley et al., 1975). Along the Florida east coast, these fish move northward in the warmer months and retreat south in the winter in response to colder temperatures and northerly winds. Temperature also influences the vertical distribution of the sailfish. Light appears to play a role, as well, since they inhabit well-illuminated waters. Sailfish have been shown to aggregate in areas of high productivity resulting from simultaneous increase in temperature and salinity.

The distribution of the blue marlin is influenced by temperature, the species being confined to waters with surface temperatures of 23.9^{o}-$28.3^{o}C$ off the northeastern United States and surface temperatures of 21.7^{o} to $30.5^{o}C$ off the southeastern United States, Gulf of Mexico, and Caribbean (Rivas, 1975). Information related to the influence of water masses, currents, and water color are only available from Gulf of Mexico blue marlin. These fishes seem to distribute along the "loop current" reaching their maximum northern extent in the summer. This stock of marlin also exhibits a preference for blue water.

The adult stripped bass, Morone saxatilis, are extremely hardy fish and can adapt to sea or freshwater as well as relatively high levels of domestic and industrial pollution. Also, they are active at temperatures between 7^{o} and $21^{o}C$. Below $7^{o}C$ they either move to warmer water or become dormant, while prolonged exposure to temperatures above $27^{o}C$ is probably lethal (Smith and Wells, 1977).

The swimming speed of the bluefish, Pomatomus saltatrix, increases as temperature slowly deviates from the fish's preferred range of 18-$22^{o}C$ (Wilk, 1977). At $11.5^{o}C$ and $29.5^{o}C$ signs of thermal stress (disruption of normal diurnal changes in swimming speed and schooling and changes in food satiation) were observed. This increase in activity may serve to move animals from regions of adverse temperatures. Day length also influences activity levels. When exposed to day lengths corresponding to those encountered from spring to fall, captive bluefish swam at significantly higher speeds than during the shorter photoperiods typical of the winter season.

The range of temperatures and salinity that 23 species of fishes encountered over a year in South Carolina estuaries was reported by Shealy et al. (1974). Some species were eurythermal and euryhaline while others appeared to be more stenothermal and/or stenohaline.

The white marlin, Tetrapturus albidus, demonstrate a distinct response to temperature and the pattern of distribution of this species varies seasonally (Mather et al., 1975). They prefer deep blue waters of submarine canyons and drop-offs, with surface water temperatures around $24^{o}C$.

The tilefish, Lopholatilus chamaeleonticeps, appears to be very sensitive to changes in the characteristics of seawater, especially temperature. This species is typically found in temperatures ranging from 9.4^{o} to $14.4^{o}C$. Mass mortality of tilefish has been reported and might be due to the temporary offshore movement of normally cold shelf water which traps and kills fish and other warm-water fauna living on the edge of the shelf.

In order to determine the energy requirement of a population of pinfish, Lagodon rhomboides, routine metabolism was measured at various temperatures for various-sized fish (Hoss, 1974). The yearly routine energy requirement was estimated to be 1.1×10^{9} calories.

Based on a seasonal study, Burns (1974) reported that the appearance of larval fish in estuarine creeks in South Carolina is correlated with temperature. A general temperature depression was observed approximately one month before the abundance peak. Based on this observation, Burns (1974) suggested that either the water temperature must decline in order for the larvae to migrate inshore or the drop in temperature initiates the spawning migrations of many estuarine-dependent species.

Seasonal variations in the distribution of fish species in the tidal areas around Crooked Creek, Georgia appeared to be correlated with seasonal salinity changes (Hackney et al., 1976). Stations with the greatest tidal salinity oscillations supported less diverse, but more stable, fish populations. A station with less salinity oscillations per tidal cycle contained a more diverse, but less stable, fish population. Stations subjected to great extremes in temperature and dissolved oxygen demonstrated fluctuating and sometimes non-existent populations. Food availability did not appear to be a limiting factor.

McMillan, Shealy and Miglarese (1975) reported that in South Carolinian waters the Atlantic croaker, Micropogon undulatus, is found in salinities ranging from 0.04 to 34.2 o/oo with smaller sized animals (total length 81mm) occurring in salinities less than 21 o/oo and those with a total length of 138mm occurring in salinities over 21 o/oo. They were found in waters where the temperature varied from 9.2^{o} to 31.4^{o}C.

Over 20 species of the teleost fish belonging to the genus Fundulus are found in estuarine and freshwater environments. Griffith (1974) reported that species found in brackish environments have upper salinity tolerances ranging from 74-114 o/oo, while most species characteristic of fresh waters are unable to survive in salinities above 29 o/oo.

2.4.2.3 Invertebrates

Juvenile penaeid shrimp, Penaeus aztecus and P. setiferus, left smaller Georgia tidal creeks when the dissolved oxygen dropped to a concentration of 1.5 ppm and afternoon temperatures were elevated to 33^{o}C (Hackney and Burbanck, 1976).

Penaeus setiferus in South Carolina do not appear to be distributed according to salinity alone, but rather by a combination of factors including salinity, shrimp size, geographic area, and season (Bishop and Shealy, 1977). Generally, the smaller shrimp seem to prefer lower salinities, i.e., <10 o/oo, and move to higher salinities as they increase in size. White shrimp from North Edisto, a high salinity region, have higher mean sizes than those from less saline waters. It is not known whether the shrimp are developing more rapidly or whether they are remaining in these waters for longer periods of time. Postlarval P. setiferus immigrate into the estuaries during late spring and early summer and leave during the fall as subadults. P. aztecus mean lengths from salinities <3 o/oo were 68mm, while those from higher salinities were longer, reaching 132mm in 33 o/oo.

Kennedy et al. (1977) investigated their data on seasonal spawning of the rock shrimp off Cape Canaveral, Florida in relation to lunar phase, photoperiod, bottom temperature, and salinity. Salinity and photoperiod were thought to have minimal influence on spawning. While temperature did not appear to influence spawning directly, increases in bottom temperatures apparently triggered ovarian development from a "developing" stage to a "ripe" stage. Intramonthly spawning was influenced by lunar phase, as the intense lunar light of the full moon triggered spawning.

Serchuk and Rathjen (1974) reported some ecological observations on the long-finned squid, Loligo pealei, in the Cape Hatteras area. This species occurred in greatest numbers (based on commercial catches) near sites where the bottom temperature was above $10^{o}C$. Squid were larger during the spring than in the fall.

2.4.3 Food, Feeding, and Trophic Relationships

2.4.3.1 Introduction

The food and feeding habits of a particular species are obviously important to the success of that species, but have broader implications regarding distributional change, migratory patterns, predator-prey interactions, competition, and community stability of other species.

2.4.3.2 Fish

2.4.3.2.1 Open Ocean and Coastal Water Studies

The food habits of five estuarine fish species living between Georgetown, South Carolina and Jacksonville, Florida were examined by Stickney, Taylor and White (1974). Bairdiella chrysura, Micropogon undulatus, and Stellifer lanceolatus were not highly selective in their food habits; Cynoscion regalis fed primarily on mysid shrimp and fish; and Leiostomus xanthurus appeared to prefer harpacticoid and calanoid copepods.

For postlarval stages of Atlantic menhaden, Brevoortia tyrannus, pinfish, Logodon rhomboides, and spot, L. xanthurus, the daily ration, food preference, feeding intensity and chronology, and evacuation rates were determined by Kjelson, Peters, Thayer and Johnson (1975). Four taxa of copepods made up 76-99 percent of the total gut contents. A direct relationship existed between the amount of food in the gut and the evacuation rates. The metabolic needs estimated from oxygen consumption measurements were similar to the ration estimates for spot, but were lower than the estimates from oxygen consumption for menhaden and pinfish.

Kjelson and Johnson (1976) reported that postlarval pinfish, L. rhomboides, fed at a reduced rate as water current velocity increased while the spot, L. xanthurus, fed faster under laboratory connditions when the current was slightly increased. The ration estimates for both species were greater than metabolic needs estimated from oxygen consumption measurements.

Mackerel, tuna, herring, jack, halfbeak, needlefish, and squid comprise the main diet of sailfish, Istiophorus platypterus, larger than 10mm. Smaller fish feed mainly on copepods. They do appear to be opportunistic, however, feeding on whatever is available. Some benthic species such as crab, parrotfish, shrimp, and sea bass have been found during stomach analysis, suggesting that the sailfish feed at or near the bottom (Jolley, 1975). Sailfish are believed to be diurnal feeders, as catch rates and stomach fullness peak during the day. They have also been observed to feed in bright, moonlit nights (Jolley, 1975). A most interesting feeding behavior has been reported. In the morning hours the fish begin to congregate in schools. These schools encircle groups of smaller fish, causing them to be concentrated. At short intervals, a single sailfish enters the small school, thrashing vigorously and stunning or killing the prey. That sailfish then swims under the school, retrieving the prey as they sink. It is thought that in the Atlantic the sailfish probably compete for spawning areas and food with the white and blue marlin, and other large related pelagic fishes. This idea is based on seasonal overlap of distributional areas. Predation on the sailfish is little known (Beardsley et al., 1975; Irby et al., 1976; Jolley, 1977).

White marlin feed during the day from inshore shallows to offshore deeper waters. Although the preferred foods vary geographically, squid is the most consistent food, and round herring are also important in the mid-Atlantic region (Mather et al., 1975).

Blue marlin, Makaira nigricans, apparently do not feed at night at the surface, and seem to feed most heavily between the morning hours of 1000 and 1100 (Rivas, 1975). They feed both in surface and deep watrs, inshore and offshore. Stomach content examination indicates that the food eaten varies with the region of occurrence. The blue marlin of the tropical western Atlantic feed primarily on cephalopods and fishes. It is considered a climax feeder, as it is a large predator.

Black sea basses, Centropristes striata, are opportunistic omnivores eating, in order of importance, crustaceans, fish, molluscs, echinoderms, and plants (Kendall, 1977). Feeding is heaviest following spawning. Apparently they are visual feeders and feed mostly during daylight.

The food habits of the red porgy, Pagrus pagrus, have been described by Manooch (1976).

The tilefish, Lopholatilus chamaeleonticeps, is primarily a daytime feeder. It feeds on prey located within 3m (10 ft.) of the bottom. Based on stomach analyses, this species feeds on a wide variety of food items ranging from sessile and slow-moving species to rapidly swimming fish, such as Atlantic mackerel, with crustaceans being dominant (Freeman and Turner, 1977). The tilefish appears to be the top carnivore in the small, relatively warm-water community found on the edge of the continental shelf.

Bluefish, Pomatomus saltatrix, feed throughout the water column on a wide variety of fishes and invertebrates (Table VII-20). The most frequently consumed food items are butterfish, menhaden, round herring, and the following invertebrates: shrimps, lobsters, squids, and crab. Although bluefish are responsive to various olfactory stimuli, they rely primarily on vision to locate and capture prey fish.

Captive juvenile lemon sharks, Negaprion brevirostris, showed a synchronous pattern of food intake. Although relatively short periods of deprivation enhanced feeding, an adequate explanation for the patterning of intake was not apparent (Graeber, 1974).

Large-sized American sturgeons, Acipenser oxyrhynchus, feed on molluscs and other bottom organisms (Murawski and Pacheco, 1977). This species roots in the sand or mud with its snout, like a pig, and sucks food items into its toothless mouth. Apparently adults do not feed during migration and spawning, but begin after spawning and rebuild themselves quickly. No data are available on the feeding habits of larval sturgeon, but observations on young sturgeon in freshwater exist. They are bottom feeders and root on the bottom with a tubelike suctorial mouth. Sludgeworms, chironomid larvae, mayfly larvae, isopods, amphipods, and small bivalve molluscs are eaten.

Because of their anadromous habits, stripped bass (Morone saxatilis) are exposed to a spectrum of habitats, and have a highly variable diet. The young feed predominately on fishes, polychaetes, and amphipods. Adults eat many species of fish, including alewife, herring, menhaden, and various invertebrates. Seasonal changes in diet are observed (Smith and Wells, 1977).

Rose and Hassler (1974) reported on the food habits of dolphin, Coryphaena hippurus, caught near Hatteras, North Carolina. Most of their prey belonged to the Exocoetidae and Scombridae. Sexual differences in distribution were noted: small females were usually associated with tide lines (areas where current patterns cause accumulation of Sargassum and other flotsam), while large females and males were found in the open ocean. Off the east

TABLE VII-20. Food items of bluefish, Pomatomus saltatrix, along the Atlantic coast (Wilk, 1977).

INVERTEBRATES:

Nereidae
Nereis virens - sand worm
Mysidacea
Mysid sp., - miside
Peneidae
Peneaus sp., - shrimps
Homaridae
Homarus americanus - American lobster
Hippidae
Hippa (Emerita) taloida - sand bug
Cancridae
Cancer irroratus - rock crab
Cancer borealis - northern crab
Portunidae
Poetunus sp. - portunus crabs
Callinectes sapidus - blue carb
Ovalipes ocellatus - calico crab
Carcinides maenas - green crab
Ocypodidae
Uca pugnax - fiddler crab
Loligindae
Loligo pealei - common squid
Loligo brevis - short-bodied squid
Ommastrephidae
Ommastrephes illecebrose - short-finned squid
Scutellidae
Echinarachnius parma - sand dollar

VERTEBRATES:

Petromyzontidae
Petromyzon marinus - sea lamprey
Carcharhinidae
Mustelus canis - smooth dogfish
Squalidae
Aqualus acanthias - spiny dogfish
Rajidae
Raja sp. - skates
Anguillidae
Anguilla rostrata - American eel
Clupidae
Alosa aestivalis - blueback herring
Alosa pesudoharengus - alewife
Alosa sapidissima - American shad

TABLE VII-20, cont.

Clupidae, cont'd.
- Brevoortia tyrannus - Atlantic menhaden
- Clupea harengus harengus - Atlantic herring
- Etrumeus teres - round herring
- Opisthonema oglinum - Atlantic thread herring
- Sardinella anchovia - Spanish sardine

Engraulidae
- Anchoa hepsetus - striped anchovy
- Anchoa mitchilli - bay anchovy
- Engraulis mordax - northern anchovy

Synodontidae
- Synodus foentens - inshore lizardfish

Gadidae
- Merluccius bilinearis - silver hake
- Microgadus tomcod - Atlantic tomcod
- Pollachius virens - pollock
- Urophycis chuss - red hake
- Urophycis regius - spotted hake

Ophidiidae
- Rissola marginata - striped cusk-eel

Zoarcidae
- Macrozoarces americanus - ocean pout

Exocoetidae
- Hemiramphus brasiliensis - ballyhoo
- Hyporhamphus unifasciatus - halfbeak

Cyprinodontidae
- Cyprinodon variegatus - sheepshead minnow
- Fundulus heteroclitus - mummichog
- Fundulus majalis - striped killifish

Atherinidae
- Menidia beryllina - tidewater silverside
- Menidia menidia - Atlantic silversides

Syngnathidae
- Hippocampus erectus - lined seahorse
- Syngathus fuscus - northern pipefish

Serranidae
- Centropristis striata - black sea bass

Pomatomidae
- Pomatomus saltatrix - bluefish

Carangidae
- Caranx crysos - blue runner
- Caranx hippos - crevalle jack
- Chloroscombrus chrysurus - Atlantic bumper
- Decapterus macarellus - mackerel scad
- Decapterus punctatus - round scad
- Selar crumenophthalmus - bigeye scad
- Selene vomer - lookdown
- Trachurus lathami - rough scad
- Vomer setapinnis - Atlantic moonfish

Pomadasyidae
- Orthopristis chrysoptera - pigfish

Sparidae
- Diplodus holbrooki - spottail pinfish
- Lagodon rhomboides - pinfish
- Stenotomus chrysops - scup

TABLE VII-20, cont.

Scianenidae
- *Bairdiella chrysura* - silver perch
- *Cynoscion nebulosus* - spotted seatrout
- *Cynoscion nothus* - silver seatrout
- *Cynoscion regalis* - weakfish (gray seatrout)
- *Leiostomus xanthurus* - spot
- *Menticirrhus saxatilis* - northern kingfish
- *Micropogon undulatus* - Atlantic croaker

Labridae
- *Tautoga onitis* - tautog
- *Tautogolabrus adspersus* - cunner

Mugilidae
- *Mugil cephalus* - striped mullet
- *Mugil curema* - white mullet

Ammodytidae
- *Ammodytes americanus* - American sand lance

Scombridae
- *Scomber scombrus* - Atlantic mackerel

Stromateidae
- *Peprilus alepidotus* - harvestfish
- *Peprilus triacanthus* - butterfish

Triglidae
- *Prionotus* sp. - searobins

Bothidae
- *Paralichthys dentatus* - summer flounder

Pleuronectidae
- *Limanda ferruginea* - yellowtail flounder

Cynoglossidae
- *Symphurus plagiusa* - blackcheek tonguefish

Tetraodontidae
- *Sphoeroides maculatus* - northern puffer

coast of Florida a 16.4kg dolphin, Coryphaena hippurus, was caught and its stomach content analyzed: one green turtle and eight loggerhead turtles were recovered (Witham, 1974).

2.4.3.2.2 Estuarine Studies

Kneib (1978) reported that Fundulus luciae living in a North Carolina marsh fed on unidentified organic material during the summer and fall, but at low temperatures in winter and spring small crustaceans and insects were dominant food items.

Based on a year's sampling of the striped bass, M. saxatilis, in Albemarle Sound, North Carolina, Manooch (1973) reported that their main food was fish, which occurred in 93 percent of the stomachs containing food. The most common food items were menhaden (Brevoortia tyrannus), blueback herring (Alosa aestivalis), and the bay anchovy (Anchoa mitchilli). Invertebrates were of secondary importance. Food habits varied substantially with size of fish, area, and season of collection.

An analysis of stomach contents of striped bass caught off the North Carolina coast is represented in Table VII-21 (Holland and Yelverton, 1973). Additional observations on 19 specimens of the American shad showed that the chief food item was Anchoa hepsetus (98 percent based on weight).

Reis (1977) reported that the rhythmic migration of certain fish into South Carolina intertidal estuarine creeks was indirectly related to peaks in their feeding activity, especially in the case of the anchovy, A. mitchilli.

Based on a seasonal study of the occurrence of larval fish in an intertidal estuarine creek in the North Inlet Estuary, South Carolina and the work of Cain (1973), Burns (1974) proposed a hypothetical food web for pelagic fish species. From late spring to early fall, larger carnivorous species, small detritivores, and omnivores dominate the creek. These species are highly dependent on a large zooplankton crop which was dependent on the winter bloom and spring peak of phytoplankton. The larger predatory species leave the creeks in the fall, presumably to spawn in deeper waters. In late fall, small pelagic larval fishes enter the estuary and feed on zooplankton. The absence of larger predatory fishes favors survival and growth of larval fish.

Cain and Dean (1976) reported on the seasonal appearance of fishes in an intertidal creek in the North Inlet Estuary, South Carolina. Their results indicate that a seasonal shift in energy sources occurs in fish inhabiting an intertidal area of the salt marsh.

TABLE VII-21. Results of stomach analyses of 52 striped bass caught off the North Carolina coast, 1970-1971 (Holland and Yelverton, 1973).

Food Item	Number stomachs	Percent	Number organisms	Percent
Brevoortia tyrannus	10	19.2	15	5.5
Etrumeus teres	2	3.8	3	1.1
Anchoa hepsetus	8	15.4	208	76.8
Strongylura sp.	3	5.8	4	1.5
Syngnathus sp.	1	1.9	3	1.1
Bairdiella chrysura	2	3.8	2	0.7
Cynoscion regalis	5	9.6	5	1.8
Ammodytes americanus	1	1.9	1	0.4
Peprilus triacanthus	2	3.8	2	0.7
Hepatus epheliticus	1	1.9	1	0.4
Portunis sp.	1	1.9	1	0.4
Callinectes sapidus	2	3.8	2	0.7
Aegathoa oculata	1	1.9	1	0.4
Loligo sp.	1	1.9	1	0.4
Unidentified fish	15	28.8	22	8.1
Empty	11	21.2		
			271	100

Species with the highest annual biomass and absolute numbers are detritivores, omnivores, or primary consumers. Also, none were limited to an exclusive trophic level.

Out of 62 species of elasmobranch and teleost fish, only 16 species of Georgia estuarine fish showed some cellulose activity in their stomachs, probably produced by the microflora (Stickney and Shumway, 1974). Animals captured over the continental shelf off Georgia lacked cellulose activity.

Based on stomach analyses, the food habits of four species of flounders (Ancylopsetta guadrocellata, Citharichthys spilopterus, Scophthalmus aquosus, and Etropus crossotus) from Georgia estuaries were described (Stickney, Taylor and Heard, 1974). With the exception of E. crossotus which primarily consumed the calanoid copepod, Pseudodiaptomus coronatus, the other three species fed heavily on the mysid shrimp, Neomysis americana. Some changes in food items consumed occurred with season and body size. On the other hand, the tonguefish, Symphurus plagiusa, feed primarily on benthic organisms including mollusks and various crustaceans (Stickney, 1976). In another study, Stickney, White and Miller (1973) reported on the importance of fin use in the feeding and resting behavior in various species of flatfishes.

Mahood (1974) reported that the spotted seatrout, Cynoscion nebulosus, is one of the major large carnivores in the coastal waters of Georgia. Of the consumed food items, fish represented 54 percent, shrimp 44.9 percent, and squid 0.8 percent. Seatrout appear to eat whatever is easiest to obtain. Summer trout, C. regalis, are voracious feeders. Fish (80.6 percent), shrimp (14.3 percent), and squid (5.2 percent) were devoured. Although the number of specimens studied was small, it appears white trout, C. nothus, have similar food habits as summer trout.

Howard, Mayou and Heard (1977) described the feeding activity of rays in making excavations in tidal flats along the Georgia coast. These animals flap their "wings" in order to erode the substrate hydraulically and thereby obtain benthic organisms for food.

The white catfish, Ictalurus catus, from an estuary in Georgia, consumed some 50 different species of organisms, with amphipods being the most frequently occurring and most numerous organisms encountered. The white catfish is an opportunistic, omnivorous feeder (Heard, 1975).

A long-term study of fish populations of the mid-Atlantic Florida coast is underway. Special emphasis was placed on the Indian River lagoon habitat (Gilmore, 1977). Based on biomass and the numerical catch of fishes in four basic feeding categories, an hypothetical trophic structure was proposed (Figure VII-51).

2.4.3.3 Invertebrates

The American lobster, *Homarus americanus*, is found in coastal waters of North Carolina (Holland et al., 1972). They reported that the adult lobster feeds on living or dead fish, other benthic invertebrates, and small quantities of algae and eel grass.

Rock shrimp off Cape Canaveral, Florida consume mainly mollusks, polychaetes, and crustaceans. This species is considered an opportunistic feeder (Kennedy et al., 1977).

Under laboratory conditions postlarval penaeid shrimp ingested an average of 8.60mg pelleted food (dry weight) per gram animal dry weight per hour when exposed for 4 hours, and 6.55mg when exposed for 8 hours. When the diet was supplemented with 30 percent *Artemia*, the shrimp then assimilated enough energy to approximate growth similar to field-research animals (Sick and Baptist, 1973). Sick, Andrews and Beaty (1973) studied the effects of various diets of lipids, carbohydrates, and proteins on the growth, survival, and body composition of *Penaeus duorarum*. Beef tallow was the best lipid source and corn starch the best carbohydrate source. Soybean meal yielded greater growth than any of the other types of supplements tested.

In another laboratory feeding experiment, Andrews, Sick and Baptist (1972) found that a diet of 28-32 percent protein was optimal for the juvenile white shrimp, *P. setiferus*. The addition of starch enhanced growth, but supplemental glucose caused a reduction in weight gains.

All squid are voracious eaters. The young short-finned squid, *Illex illecebrosus*, feed mainly on small crustaceans, gradually shifting with age to young fish, e.g., flounder, herring, and cod. This species also exhibits cannibalism; the larger of the species preying on the smaller (Rathjen, 1973).

2.4.4 Influence of Man's Activities

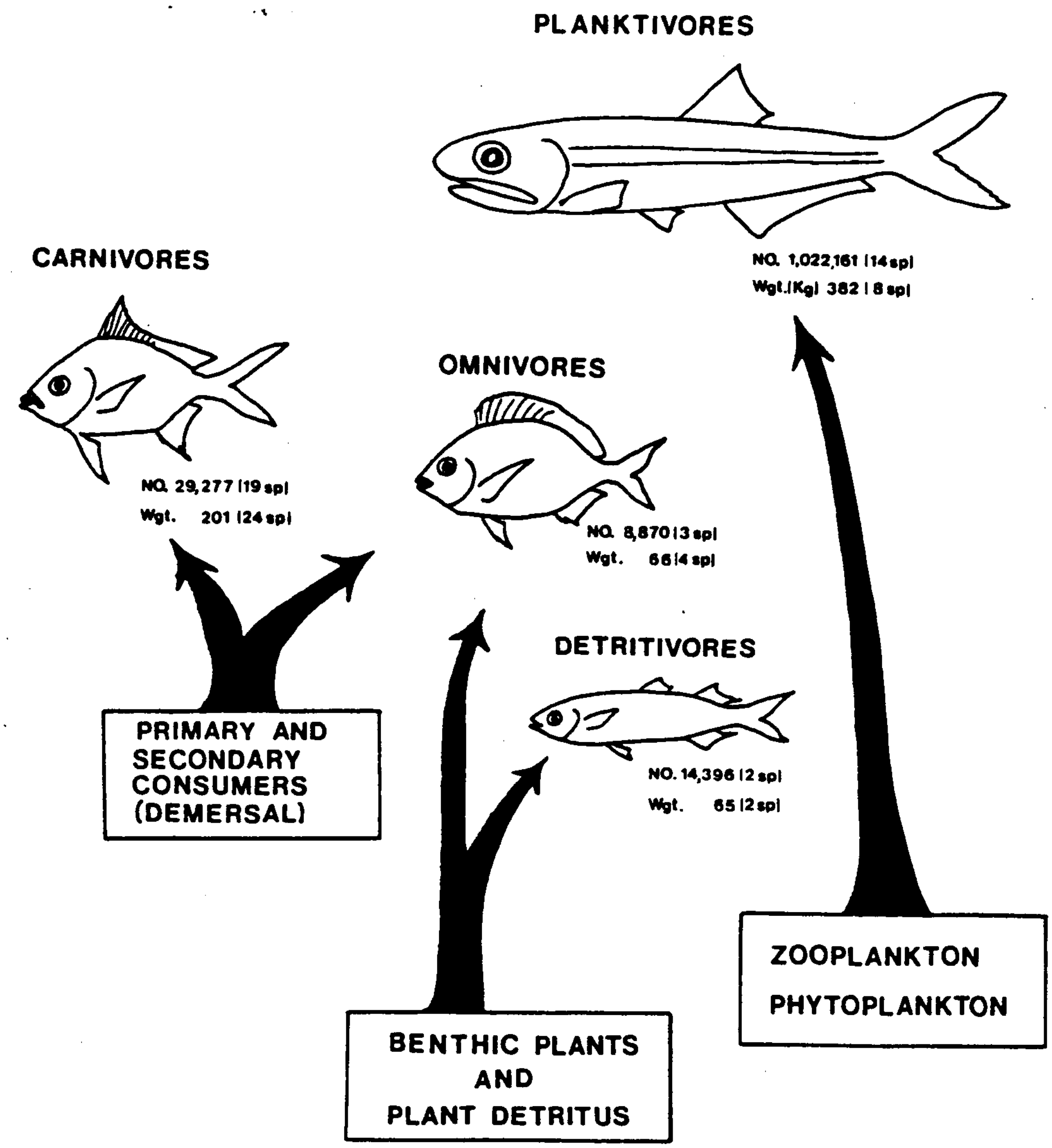


FIGURE VII-51. Hypothetical diagram of fish trophic levels composition based on seine data from 1974-1975. (Gilmore et al., 1977).

2.4.4.1 Introduction

Until recent years, little serious attention was given to the effects of man's activities on nekton, except in terms of fishery resources. However, because of numerous activities such as increased oceanic transport of oil, dumping of wastes in marine waters, and oceanic oil development and mining, the nekton faces new environmental threats. Since other chapters (Endangered or Threatened Species, Chapter XV; Unique or Endangered Environments, Chapter XVIII; Toxicity and Health Studies, Chapter XIX) will deal in detail with this topic, only a few selected examples are included here.

2.4.4.2 Power Plant Siting

Since 1968 an extensive ecological monitoring program has been conducted in the lower Cape Fear Estuary to provide a basis for assessing the environmental impact of the construction of Brunswick Power Plant. Various reports are available and much of the data has been cited earlier in this report (for a list of reports see Copeland and Hodson, 1977). However, a few examples of specific studies on directly measuring potential effects are cited here.

MacPherson, Laney and Birkhead (1977) reported that the Brunswick Steam Electric Plant had a minimal destructive influence on migrating white shrimp since only three percent of the shrimp in Walden Creek, one small creek in this estuarine system, failed to migrate past the intake canal. Copeland, Birkhead and Hodson (1974a, b) determined the influence of circulator pump operations of this plant on the nekton. Although much of the nekton seeks out the intake canal, particularly during the colder months, the intake activities do not affect the nursery utilization of Walden Creek. However, nekton organisms in the discharge canal did all but disappear between January and February samples.

In contrast, Young (1974) reported that any increase in the siting of power plants in estuaries could pose a threat to the menhaden fishery, as fish would be subjected to thermal shock, biocides, entrainment, and impingement on intake screens.

During the hot season of the year, the thermal effluent from a steam-electric station near Jacksonville, Florida, when discharged into a marshland creek, decreased the numbers and the biomass per unit area of juvenile fish by threefold to tenfold when compared to collections from another creek which experienced normal ambient temperatures (Carr and Giesel, 1975).

2.4.4.3 Pesticides

Although mirex is applied on land to control fire ants, this chlorinated hydrocarbon is found in estuarine waters and marshlands. Borthwick, Duke, Wilson, Lowe, Patrick and Oberheu (1973) reported the following accumulations of mirex in various organisms collected near Charleston, South Carolina: water <0.01 ppb; crabs, 0-0.60 ppm; fishes, 0-0.82 ppm; and shrimps, 0-1.3 ppm.

The concentration of DDT in the mullet, Mugil cephalus, from Florida waters was as follows: 0.002-0.064 ppm in flesh, 0.022-0.156 ppm in liver, and 0.001-0.075 ppm in gonads (Cubit, Deichmann and Macdonald, 1976). This species is suitable for determining the degree and extent of local pollution because it feeds on plant life, on plant detritus, and on the surface films. Accumulation and retention of dietary ^{14}C-DDT by young-of-the-year menhaden and its effect on growth were reported by Warlen, Wolfe, Lewis and Colby (1977). Uptake of this substance was dose-dependent and a function of exposure time. No effect on growth was observed at the level of feeding in this experiment.

As part of the Environmental Protection Agency's National Estuarine Monitoring Program, Reimold and Shealy (1976) reported on pesticides and heavy metals in young-of-the-year fish collected from eleven estuaries in South Carolina and Georgia from 1972 to 1974. Dieldrin was found in 2 percent of the samples, DDT and metabolites in 33 percent, PCBs in 4 percent and mercury in 47 percent.

2.4.4.4 Metals

Arsenic, cadmium, copper, mercury, and zinc levels were determined in 35 species of finfish collected both offshore in the vicinity of the Sargasso Sea and inshore along the coasts of South Carolina, Georgia, and Florida (Windom, Stickney, Smith, White and Taylor, 1973). Similar levels in offshore and inshore species were reported. Chondrichthys and osteichthys have similar concentrations of all metals, except arsenic which is higher in chondrichthys.

Middaugh and Dean (1977) demonstrated that eggs of Fundulus heteroclitus and Menidia menidia from South Carolina estuaries are not very sensitive to cadmium toxicity, perhaps because of the presence of the chorionic membrane. However, larvae were more sensitive than eggs or adults. Man-induced environmental increases in sublethal concentrations of cadmium decreased the thermal resistance of the estuarine fish, Fundulus heteroclitus, in South Carolina (McKenney, 1973; McKenney and Dean, 1975).

Tissue levels of cadmium, copper, lead, mercury, and zinc were determined for 11 species of fish from a Georgia estuary. No positive correlation between heavy-metal levels and food habits of fish were observed (Stickney, Windom, White and Taylor, 1975).

Juvenile menhaden, spot, and pinfish play an important role in cycling of manganese, iron, copper and zinc in highly productive coastal plain estuaries (Cross, Willis, Hardy, Jones and Lewis, 1975). The data indicate a significant fraction of the trace metal ingested by the fish is not assimilated and daily defecation of unassimilated trace metals is high: 1kg for zinc, 56kg for iron, 1kg for manganese, and 0.2kg for copper in populations of these three species in the Newport River Estuary, North Carolina.

Menhaden analyzed from Core Sound, North Carolina did not contain unusually high levels of mercury, but the menhaden mercury levels were about twice those in the plankton (Cocoros, Cahn and Siler, 1973). The viscera mercury levels ranged between 0.06 and 0.12 ppm wet weight. Cocoros et al. (1973) suggested that evisceration prior to processing of fish may reduce mercury levels in fish meal.

2.4.4.5 Introduction of Exotic Species

The major source of introduction of exotic fishes and their establishment in Florida arises from carelessness and convenience by the ornamental aquarium fish industry (Hogg, 1976a). High numbers of exotic species occur near fish breeding and rearing operations. In addition, when the environment is disturbed by man, there is a better possibility that introduced exotic species will be more successful in becoming established by out-competing the native biota. For example, the spotted tilapia and other introduced exotics tend to dominate in disturbed areas in Florida. Successful exotics seem to be tolerant in regard to environmental conditions, opportunistic in feeding, and efficient in reproduction (Hogg, 1976b).

2.4.4.6 Dredging

After sampling benthic macrofauna and considering previous ichthyofauna data, Shealy, Boothe and Bearden (1975) make various recommendations about specifically where dredging should and should not be done. In general, dredging should be avoided in seasons of reproduction and larval/postlarval recruitment of major species, i.e., February - mid-April and May-August in South Carolina.

Hoss, Coston and Schaaf (1974) reported that seawater extracts of sediments from Charleston Harbor, South Carolina differentially affected the survival of seven species of estuarine fishes. They suggested that in the selection of disposal areas for dredged material, consideration should be given to the relative toxicity to nektonic species of the dredged substances.

2.5 Evaluation

Studies since 1972-1973 have provided additional information on the nekton found between Cape Hatteras and Cape Canaveral which partially fill the data gap identified in the Roberts and Able (1974) report. Although a few investigations have been published which are broadly based and designed to provide comprehensive data, many of the new papers deal with isolated problems with the result that no master research plan exists to analyze the biological properties of the nekton of the southeast. In the past six years specific studies on various estuarine systems have been undertaken and more attention given to offshore species. Each study related to the previous historical data base, although no uniform centralization of a data base exists. In evaluating generally the research for this period, there is a hopeful note in that although serious data deficiencies still exist, increasing attention is being directed to this oceanic region.

3.0 IDENTIFICATION AND LOCATION OF RAW DATA AND UNWORKED SAMPLES

The sources of raw data on marine nekton of the study region include federal, state, and private research corporations. The principal federal source of raw data is the National Marine Fisheries Service, United States Department of Commerce, NOAA. Each of the states in this region has a marine research arm of a state agency which maintains at least one marine laboratory. These agencies are: North Carolina Department of Natural and Economic Resources, South Carolina Department of Wildlife and Marine Resources, Georgia Department of Natural Resources, Florida Department of Natural Resources, and Florida Department of Environmental Regulation. These state-affiliated laboratories have considerable amounts of raw data and unworked samples in the process of being analyzed. Some of these laboratories, such as the South Carolina Marine Resources Division, are entering their data into computer banks for easy retrieval. Additional sources of raw data include the marine science programs at various state and private colleges and universities, private research corporations, and power companies (see Appendix C for detailed information).

4.0 ONGOING RESEARCH PROGRAMS

The states of North and South Carolina, Georgia, and Florida each have many ongoing marine research programs. The main bulk of marine research is carried out by state or federally-funded laboratories. The research outlined in this section is based primarily upon the Summary of Marine Activities of the Coastal Plains Region, published by the Coastal Plains Center for Marine Development Services, current as of October 1977. Supplemental information is provided in Appendix A. If the reader desires additional information, he or she is referred to this publication or to the laboratories of interest. The Coastal Plains publication includes the names of principal investigators and a short description of their research.

Within the state of North Carolina, the Beaufort Laboratory, National Marine Fisheries Service, is conducting marine research aimed toward resource management of commercial and recreational nektonic species, i.e., population dynamics, distribution, abundance, migration, and anthropogenic effects. Basic ecological studies are being conducted in the estuaries of the state, which serve as nursery grounds for many commercial species, as well as provide habitats for other ecologically important species. The Division of Marine Fisheries, North Carolina Department of Natural Resources and Community Development is located at Morehead City. This division is charged with the management and conservation of North Carolina's marine resources, and all research carried out and sponsored by that division is aimed toward fisheries management. This Division additionally makes available its facilities to marine science investigators at the University of North Carolina at Chapel Hill. Research programs include estuarine surveys, anadromous fish studies, and shrimp, clam, and scallop research. For example, the Department is conducting a study of the anadromous fish of the Albemarle Sound-Roanoke River, aimed at collecting data for resource management. In addition, they are analyzing previously collected data. The Duke University Marine Laboratory at Beaufort conducts research in the areas of ecology, systematics, embryology, physiology, and biological oceanography as well as other marine investigations not applicable to this nekton report. The Institute for Coastal and Marine Resources, East Carolina University, and its associated Pamlico Estuarine Laboratory, conduct research on marine ecology (Pamlico River) and fisheries biology. The Institute of Marine Biomedical Research, University of North Carolina at Wilmington, supports research programs in the areas of experimental oceanography, comparative neuroendocrinology and the broad problems of adaptation of marine life at all developmental stages to the stresses characteristic of the marine environment. The Institute of Marine Sciences, University of North Carolina, conducts research in both basic and applied marine sciences. Various marine programs are associated with the universities and colleges of the state with research facilities both on campus and at the various coastal marine laboratories.

The Belle W. Baruch Institute for Marine Biology and Coastal Research and the Division of Marine Resources, South Carolina Wildlife and Marine Resources Department, are the main sites of marine research in South Carolina. The Baruch Institute, associated with the University of South Carolina, is a research institute with a field laboratory located near Georgetown, South Carolina. Currently underway at the station is a major interdisciplinary study of estuarine and tidelands processes including flux of materials and organisms between estuaries and coastal waters; additional research topics include biorhythms, fish production, reproductive strategies, community structure, and pollution effects. The South Carolina Marine Resources Division continues its participation (since 1973) in the MARMAP Program of the National Marine Fisheries Service. This program is committed to monitoring annual fluctuations in the abundance of groundfish resources of the southeastern United States and to delineating cause and effect relationships. The geographic survey area of the program is delimited by Cape Fear, North Carolina and Cape Canaveral, Florida. The Institute additionally conducts estuarine and marine studies as dictated by the needs of the state, federal government, and private industry. The Marine Resources Division is also currently preparing an ecological characterization of the Sea Islands and Coastal Plains of South Carolina and Georgia for the United States Fish and Wildlife Service. The main topics include physical, social, and economic biological/ecological characterizations of the region. Types of studies at the Institute include commercial fisheries research environmental studies, ichthyology, recreational fisheries studies, and pollution. The Environmental Protection Agency supports the Bears Bluff Field Station on John's Island, South Carolina where various pollution studies are underway.

The Skidaway Institute of Oceanography, Skidaway Island, Georgia, serves as the marine research arm of the University of Georgia system. The environmental research program focuses on animal-sediment relationships, chemistry, biology of estuarine and offshore ecosystems, and pollution research, and the environmental requirements for rearing shrimp, as well as various fresh-water species. The University of Georgia Marine Institute is located at Sapelo Island, Georgia. The Institute provides facilities for basic research in estuarine and salt marsh ecology. Aspects of research include studies of the flux of organic matter in the salt marsh estuarine system, biology of marine organisms, pesticide ecology, as well as other invertebrate and microbial studies.

The state of Florida through the Department of Natural Resources conducts marine research principally in the areas of mariculture, aquaculture, descriptive biology, ecological studies, fisheries biology, pathology, and seafood science and technology.

A major marine research facility located at Fort Pierce, Florida is funded by the Harbor Branch Foundation, Inc., and the Smithsonian Institution. The research at Harbor Branch has focused on the region south of Cape Canaveral although some projects have implications for research in all parts of the region.

5.0 IDENTIFICATION OF DATA GAPS

Data gaps appear in all areas of marine nekton research. Those areas which have been the more fully investigated are those with direct economic impact, i.e., the commercial and recreational fisheries. Those nektonic species of ecological rather than economic importance have been less examined, if at all. Distributional information in many cases has relied on fishing statistics which are, at best, partial.

Although the commercial and recreational nektonic species have been the most investigated, various authors have reported on specific data gaps in their particular research topics.

Burrell (1978) in his paper on the nekton of the Southeast Atlantic points out that for most nektonic species, population dynamics, migrations, spawning areas, and the effects of natural or anthropogenic environmental perturbations are incompletely, and often only indirectly, known.

The ecology of surf zone is little known (Anderson et al., 1977). This rather extensive habitat has economic significance as a sportsfishing recreational area and a nursery ground for commercial and sport species. A two-year bi-weekly seining survey was begun at Folly Beach, South Carolina in October 1969. The results of the first year of this survey are reported by Anderson, et al. At the end of the study the authors recommended that additional physical data (such as current velocity), additional sampling periods (e.g., lunar, tidal, longer sampling periods), and additional biological data (e.g., food habits, spawning), are all needed to provide the information necessary for the development of models to be used in identifying natural and artificial disturbances and in predicting their effects.

Huntsman (1977) reports that there is life history data available on only a few species of demersal fish, many of which have commercial and recreational importance.

In a recent review Wilk (1977) presented the data available on various aspects of the biology of the bluefish, Pomatomus saltatrix. He reported that no data are available on abundance and density of this species. Kendall (1977) reports that little is known on population dynamics of the black seabass, Centropristis striata such as mortality and morbidity, natality and recruitment, and abundance and density. No data are available regarding density and biomass. The role of this species in the ecosystem is poorly known.

During the International Billfish Symposium held in Hawaii in 1972, the participants, composed of scientists and sportsmen, made clear the need for research in all areas of billfish biology (Shomura and Williams, 1975). Among those areas particularly noted were range definitions; better tagging techniques to provide distributional data; age, growth and mortality studies; stock structure; identification of larval and young billfishes; migration patterns; and the effects of environmental factors. They stressed that these areas must be investigated in order for proper management of the billfish resource. Mather et al. (1975) reported that the early life history stages of the white marlin are poorly known; the distribution of the adults is known primarily from Japanese fishing fleets. As a result, areas not fished may or may not be included in distributional range. There is no literature available on seasonal patterns, reproductive rates, or annual recruitment fluctuations.

Jolley (1977) reported that data for the sailfish on growth rates, age and size composition, maximum longevity, and size and age at first maturity are insufficient. It is not known why females are heavier than males for a given length and attain a greater maximum size. Spawning frequency is unknown and fecundity estimates vary greatly.

Fewer than two dozen relevant studies have been published on the biology of snappers and groupers as related to fishery management requirements (Beaumariage and Bullock, 1976). Almost half of this research described migratory patterns delineated by tagging programs. There has been only one major effort on the life history of red grouper, Epinephelus morio, and only two studies on red snapper, Lutjanus campechanus, life history. These data gaps exemplify the need for similar life history studies, if management policies are to be adopted which assure maximum sustained yield.

Street and Johnson (1977) report that additional data on the size and age composition, mortality, juvenile abundance and relationship with subsequent adult stocks, and commercial and recreational catch effort, among other parameters, must be further examined to ensure proper resource management of the North Carolina striped bass stocks.

The shrimp resource of this region is of major economic importance. Yet, for these crustaceans, as with the fish, there is a paucity of data. Eldridge and Goldstein (1975) report that the shrimp fishery resource management in the southeastern United States has been hindered by a lack of information on the population dynamics of shrimp, as well as of related non-biological topics. The authors list the following important data gaps: 1) inadequately defined growth rates; 2) environmental impacts on shrimp populations; 3) unknown spawning-recruitment information; 4) natural and fishing mortalities; 5) emigration patterns; and 6) age and growth determinations.

In their report on the population dynamics of the brown shrimp, Penaeus aztecus, in Pamlico Sound, Purvis and McCoy (1974) recommend that future studies be done to determine the relationship between this species and its physical environment. They attribute fluctuations in the yearly harvest to natural and man-made environmental perturbations.

Joyce (1975) reports that the rock shrimp, Sicyonia brevirostris, has only achieved commercial importance within the last four years. Consequently it has not been under biological scrutiny until very recently. Nursery and spawning grounds, growth rates, movements, migration patterns, and seasonal abundance remain virtually unknown. Current research into these topics is being done at the Florida Department of Natural Resources Marine Research Laboratory and is included in the ongoing research section.

Serchuck and Rathjen (1974) report an inability to determine the total standing stock of squid due to a lack of available data. Rathjen (1973) reported that the reproductive habits and the winter distribution of the short-finned squid, Illex illecebrosus, are virtually unknown, and little is known of the biology, distribution, and abundance of the giant squid.

In an effort to create an endangered fish list for the state of North Carolina, Schwartz et al. (1977) reported that data gaps were so extensive for many species that their only option was to classify these fish as endangered until thorough data was available to evaluate their status. They recommended that the outer banks and Lower Cape Fear areas of North Carolina be managed correctly and sanctuaries established for the endangered species. They urged that all habitats of North Carolina estuarine-dependent and anadromous species be rehabilitated, stabilized, and rejuvenated. They additionally urged that the continental shelf and adjacent environments be protected to assist further the estuarine-dependent species. They further recommended additional studies toward these ends.

In summary, data gaps exist in all phases of nektonic research. The great majority of data available focuses on economically important species with little emphasis on those of lesser economic but often greater ecological importance.

6.0 RECOMMENDATIONS FOR FUTURE STUDIES

A number of developments make it imperative that a comprehensive knowledge be gained of the nekton found from Cape Hatteras to Cape Canaveral. These are 1) outer continental shelf developmental activities, 2) increased population growth in the southeastern coastal regions, 3) the development of coastal zone management plans by various southeastern states, and 4) the passage of the Fishery Conservation and Management Act of 1976. Data are needed not only to assess environmental impacts, but to provide a rational basis for commercial and recreational resource utilization.

The paucity of data on the nekton and specific data gaps are noted in Section 5.0. In general a few biological surveys of relatively short-term duration have been conducted by federal and/or state agencies and universities. No overall coordination of these surveys to provide a long-term basis for nekton assessment is apparent, with the exception of the MARMAP program. Not only is vital information lacking on the biology of most of the common nektonic species, but the role of these species in the trophic dynamics of marine ecological systems is poorly known.

To help fill this void in our knowledge of the nekton, the following recommendations are made:

1) Long-term investigations of the dynamics of ecological processes associated with nektonic species are needed. The enormous complexity of nektonic population dynamics necessitates that long-term studies are required to assess change. Population trends cannot be predicted with a high degree of success without a basic understanding of the entire life history of a species and how the various life cycle stages respond to environmental stresses. Since the life cycle of many species extends over a number of years, a one-year study cannot provide adequate baseline data.

2) A systems study of the various marine environments and the interaction between systems is necessary to assess the role of the nekton in the sea and its independence on other abiotic and biotic factors. The environment can be divided into a number of sub-ecological systems for greater convenience of study. The sea has been viewed as consisting of separate subunits, such as the abyssal benthic system, the continental shelf system, and coastal water column system. Because these systems are interrelated, comprehensive ecological systems studies need to be made not only on separate systems, but on how these systems interact. For example, what are the dynamic interchanges between estuaries and coastal ocean waters? Since the nekton is a diverse group of organisms respresenting various trophic levels, a comprehension of the role of the nekton in these interrelated systems is vital to development of oceanic resources.

3) A coordinative planning effort involving the Federal and state agencies as well as the universitites is necessary to utilize effectively the limited intellectual and financial resources available for oceanic studies. The need for the coordination of scientific efforts has long been recognized, but an adequate mechanism to accomplish coordination which is acceptable to various vested interest groups is difficult to implement. Although the Fisheries Conservation and Management Act of 1976 should help focus federal and state attention on specific fisheries problems, all marine-related research is not and should not be responsible to the Regional Fishery Management Councils. A continuing forum involving all segments of the marine research community must be established and actively perpetuated. The Regional Management Council could serve a leadership role to meet this need.

There is a need for better communication between research groups investigating various portions of this geographic range. Better integration and synthesis of research results would prevent needless duplication and provide a better basis for solving broad questions, such as population dynamics of migratory species.

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APPENDIX VII-A. Most Commonly Caught Fish from Altahama Sound, Ga. to Ft. Pierce Inlet, Fla. (From Freeman and Walford, 1976b).

BARRACUDAS

Great Barracuda, Sphyraena barracuda. Barracuda, cuda. Size: Largest recorded 106 lbs; tackle record 83 lbs; avg. 10-15 lbs; over 40 lbs unusual. Habits: Pelagic and migratory. Occur offshore, sometimes inshore, over any type of bottom. Barracuda often concentrate around wrecks or rock and coral bottom with high relief. Season: Late April or May -- October or November; best fishing July -- early October. Most are caught near the surface in water from 50-120 ft deep and temperatures warmer than 70°F. Fishing Methods: Trolling, casting and live lining from boats. Usually taken incidentally while trolling for other species. Baits: Spoons, stripbait, feathers, plugs and live fish.

BASSES, SEA AND GROUPERS

Black Sea Bass, Centropristis striata. Sea bass, blackfish, black bass, rock bass. Large ones called green heads. See rock sea bass. Size: Largest recorded 8 lbs; tackle record 8 lbs; avg. 1/2 - 3/4 lb; over 4 lbs unusual. Habits: Gregarious, year-round residents occurring on rock, coral or shell bottom and around wrecks, pilings, wharfs, rock jetties or breakwaters. They are common from a few feet below the tide-line to about 180 ft, some to 300 ft or more. They attain their largest size and greatest abundance on offshore grounds. Season: All year; best fishing April -- July. Fishing Methods: Most are caught in depths of 45-120 ft by bottom fishing from drifting or anchored boats. Small ones are taken from shore by bottom fishing. Baits: Squid, clams, crabs, worms, shrimp and cut fish.

Rock Sea Bass, Centropristis philadelphica. Sea bass, blackfish, rock bass. Distinguished from black sea bass by having 6 or 7 broad vertical bars or stripes on back and sides, and a distinct black spot at base of last three dorsal spines. Black sea bass have no vertical bars or stripes and no large distinct spot. Size: To 1 lb; avg. 1/4 - 1/3 lb; over 3/4 lb unusual. Most anglers make no distinction between rock sea bass and black sea bass. Habits, Season, Fishing Methods and Baits are the same as for the black sea bass.

Gag Grouper, Mycteroperca microlepis. Grouper, gray grouper. Sometimes miscalled black grouper. Usually distinguished from other groupers by the more or less plain coloration and the crescent-shaped edge of the tail. Size: To 51 lbs; avg. 4-9 lbs; over 35 lbs unusual. Habits: Occur to depths of 400 ft or more, especially on high relief bottom consisting of coral and rocks encrusted with living organisms or around wrecks. Small fish occur both inshore and offshore. As they grow larger they tend to remain offshore. Season: All year in depths of 90 ft or more; during warm months in shallower water. Fishing Methods: Bottom fishing, jigging or trolling near bottom from boats. Baits: Shrimp, squid, cut fish, and live fish; also stripbait, weighted bucktails, jigs, spoons and feathers.

Red Grouper, Epinephelus morio. Grouper. Distinguished from most other groupers by the edges of the membranes between the dorsal spines being slightly curved or nearly straight. In most other groupers they are deeply notched. Size: To 50 lbs; avg. 4-6 lbs; over 25 lbs unusual. Habits: Occur to depths of at least 900 ft on smooth sand or mud, but most frequently around wrecks or on high relief bottom of coral and rocks encrusted with living organisms. Season: All year in depths of 90 ft or more; during warm months in shallower water. Fishing Methods: Bottom fishing from anchored or drifting boats. Some are caught by jigging or trolling near bottom. Baits: Squid, shrimp, cut fish and live fish; also stripbait, weighted bucktails, jigs and feathers.

Speckled Hind, Epinephelus drummondhayi. Grouper, Kitty Mitchell. Distinguished from other groupers by being dark red or yellow-brown, densely covered with small white spots, and by the edge of the tail being nearly straight. Size: To 50 lbs; avg. 6-10 lbs; over 30 lbs unusual. Habits: These bottom dwellers occur on rock or coral bottom and around wrecks to depths of 300 ft or more. Season: All year in depths over 120 ft; during warm months in shallower water. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Cut or whole fish, squid and shrimp.

Warsaw Grouper, Epinephelus nigritus. Grouper, warsaw, black jewfish. Miscalled jewfish and black grouper. Distinguished from most other groupers by having 10 dorsal spines, and the edge of the tail being nearly straight. Size: To 500 lbs; avg. 20-30 lbs; over 200 lbs unusual. Habits: Occur to depths of 400 ft or more, especially around wrecks or on high relief bottom consisting of rocks and coral. Although usually near bottom, they may swim into mid-water in pursuit of prey. Season: All year in depths of 120 ft or more; during summer in shallower water. Fishing Methods: Bottom fishing, jigging or deep trolling from boats. Baits: Squid, cut fish, shrimp, clams, crabs and live fish; also stripbait, spoons, jigs, feathers and plugs.

Jewfish, Epinephelus itajara. Spotted jewfish, spotted grouper, giant sea bass. Distinguished from other groupers by the short dorsal spines, dark spots, and rounded tail. The young have 5 dark bars on each side which disappear with age. Size: To over 800 lbs; tackle record 680 lbs; avg. 30-60 lbs; over 250 lbs unusual. Habits: Although some occur in depths of 100 ft or more, most are inshore of the 70 ft bottom contour. They favor wrecks, ledges, caves, jetties, and deep holes near bridge abutments. Small ones are more active than large ones. Season: Most are caught during warm months, but a few all year. Fishing Methods: Bottom fishing from shore or boats. Small ones take artificial lures. Baits: Crabs, spiny lobsters, live or dead fish, and clams; also jigs, plugs and feathers.

BILLFISHES

Atlantic Sailfish, Istiophorus platypterus. Sailfish. Size: Maximum size unrecorded; Atlantic tackle record 128 lbs (Pacific tackle record 221 lbs); avg. 25-30 lbs; over 60 lbs unusual. Habits: Pelagic and migratory. Occur in continental-shelf water usually in depths over 40 ft, but they occasionally venture close enough to shore to be caught from ocean piers. Travel in small groups or singly. Sailfish usually feed more in mid water and near bottom than at the surface. Season: March — November; best fishing June -- August. Fishing Methods: Trolling and live lining from boats. A few are caught from shore. Check state regulation on daily catch limit. Baits: Stripbait, feather-stripbait or skirt-stripbait combination, whole rigged ballyhoo or mullet, and live bait. Some are caught on feathers, spoons, skirts and plugs.

White Marlin, Tetrapturus albidus. Distinguished from blue marlin by having the tips of the dorsal and anal fins rounded, and a conspicuous lateral line. Blue marlin have pointed dorsal and anal fin tips, and, except for very small fish, the lateral line is inconspicuous. Size: Maximum size unrecorded; tackle record 161 lbs; avg. 40-60 lbs; over 90 lbs unusual. Habits: Pelagic and migratory. Occur in oceanic and continental-shelf water, but during warm months some come close to shore in depths as shallow as 60 ft. Travel in small groups or singly. Season: April — November; best fishing May — September. Most are taken near the surface in water warmer than 70°F between the 100-600 ft bottom contours. Fishing Methods: Trolling and live lining from boats. Baits: Stripbait, feather-stripbait or skirt-stripbait combination, and whole rigged squid, ballyhoo, mullet or Spanish mackerel; also live bait. Some are caught on feathers, skirts and plugs.

Blue Marlin, Makaira nigricans. See white marlin. Size: To over 1,700 lbs in the Atlantic Ocean; Atlantic tackle record 1,142 lbs (Pacific tackle record, 1,153 lbs but fish over 2,000 are reported); avg. 15-250 lbs; over 400 lbs unusual. Habits: Pelagic and migratory. Occur in oceanic and continental-shelf water from the surface to depths of at least 300 ft. Travel in small groups or singly. Season: March or April — November, best fishing mid April -- June. Most are taken near the surface between the 200 and 600 ft bottom contours. Fishing Methods: Trolling and live lining from boats. Baits: Whole rigged squid, Spanish mackerel, mullet and ballyhoo; also stripbait, feather-stripbait combination, and live fish.

BLUEFISH

Bluefish, Pomatomus saltatrix. Blues. Small ones called snapper blues. Size: Largest recorded 35 lbs; tackle record 31 lbs 12 oz; avg. 3/4 - 1 1/4 lbs; over 3 1/2 lbs unusual. Habits: Pelagic, schooling and migratory. Bluefish occur throughout the water column in temperatures warmer than 55°F. They often concentrate around inlets, shoals, wrecks and artificial reefs. Large fish (to 14 lbs) are sometimes caught offshore betwen the 120 and 300 ft bottom contours. Abundance fluctuates from year to year. Season: November — June, but some throughout the year. Fishing Methods: Casting, bottom fishing, live lining and jigging from shore; these methods plus trolling from boats. Most bluefish are caught within 6 miles of shore in water of 65°-76°F. Check state regulation on size limit. Baits: Shrimp, mullet, cut fish and live fish; also spoons, feathers, weighted bucktails, jigs and plugs.

CATFISHES, SEA

Sea Catfish, Galeichthys felis. Sea cat, cat, hardhead. Size: To 3 lbs; avg. 1/3 - 2/3 lb; over 1 1/2 lbs unusual. Habits: These shallow water shore fish aggregate on any type of bottom. Although small ones occur in both salt and brackish water, large ones are almost always in salt water. More active during night than day. Season: All year; best fishing April — November. Fishing Methods: Bottom fishing from shore or boats. Most are caught incidentally while fishing for other species. Baits: Shrimp, crabs, cut fish and squid.

Gafftopsail Catifsh, Bagre marinus Sail cat, cat, hardhead. Size: To 6 lbs; avg. 3/4 - 1 1/2 lbs; over 3 lbs unusual. Habits: These inshore fish occur on any type of bottom in salt and brackish water, some in nearly fresh water. Although primarily bottom feeders, they sometimes pursue prey to the surface. Unlike sea catfish, gafftopsail catfish strike artificial lures. More active during night than day. Season: All year; best fishing April — November. Fishing Methods: Bottom fishing or casting from shore or boats. Baits: Shrimp, crabs, cut fish and squid; also weighted bucktails, plugs and streamer flies.

COBIA

Cobia, Rachycentron canadum. Ling, lemonfish. Size: To 120 lbs; tackle record 110 1/2 lbs; avg. 10–20 lbs; over 55 lbs unusual. Habits: Occur throughout the water column both inshore along beaches and around inlets, and offshore around deep reefs and high relief bottom of coral or rock. They usually occur singly or in small groups and are often around wrecks, buoys, floating debris, and about large sea animals such as turtles and rays; also with schools of other kinds of fishes. Season: Most are caught from March or April — November; best fishing May — September. Fishing Methods: Bottom fishing, chumming, live lining, jigging, or casting from shore; these methods plus trolling boats. Baits: Stripbait, ballyhoo, mullet, squid and live fish; also spoons, plugs and weighted bucktails.

DOLPHINS

Dolphin, Coryphaena hippurus. Small ones called school dolphin; large males called bulls. Size: To 85 lbs; tackle record 85 lbs; avg. 3–7 lbs; over 45 lbs unusual. Habits: Pelagic, schooling and migratory. these rapid swimmers occur near the surface in water warmer than 70°F. Although dolphin occasionally venture close enough to shore to be caught from ocean piers, they usually occur offshore of the 60 ft bottom contour. They often gather under floating debris and seaweed and around buoys. Season: Most are caught from March — November, but some all year within the Gulf Stream. Best fishing is in July and August. Fishing Methods: Trolling or casting from boats. Most are caught 8 or more miles offshore. Baits: Feathers, spoons, jigs, plugs, weighted bucktails, stripbait, feather-stripbait or skirt-stripbait combination, and whole rigged mullet, ballyhoo, squid or mackerel.

DRUMS

Spotted Sea Trout, Cynoscion nebulosus. Trout, speckled trout, winter trout. See gray sea trout and silver sea trout. Size: Largest recorded 16 1/2 lbs; tackle record 15 lbs 3 oz; avg. 3/4 - 1 1/4 lbs; over 6 lbs unusual. Habits: Occur in salt and brackish water, particularly the shallow water of estuaries, the

Intracoastal Waterway and along ocean beaches. Although favoring sandy areas, especially around turtle grass beds, they occur over any type of bottom in water warmer than 54°F. Season: All year; best fishing September — April. Fishing Methods: Bottom fishing, chumming, live lining, jigging and casting from shore; these methods plus trolling from boats. Check state regulation on size limit. Baits: Shrimp, mullet, soft or shedder crab, and live fish or live fish-float rig combination; also plugs, weighted bucktails, jigs and spoons.

Gray Sea Trout, Cynoscion regalis. Trout, gray trout, summer trout, sea trout, yellow-mouth trout, weakfish. See silver sea trout. Distinguished from spotted sea trout by having the dark blotches on its back often arranged in oblique rows, but no round, dark spots on 2nd dorsal fin and tail. In contrast, spotted sea trout have round, dark spots on the upper half of the body and on the 2nd dorsal fin and tail. Size: Largest recorded 30 lbs; tackle record 19 1/2 lbs; avg. 1/2 - 1 lb; over 3 lbs unusual. Habits: Occur throughout the water column in salt and brackish water to depths of at least 90 ft. Although found over any type of bottom, they favor sandy areas. Occur more often in ocean water than spotted sea trout. Season: Most are caught from March — December; best fishing mid March — May. Fishing Methods: Bottom fishing, live lining, casting, chumming and jigging from shore; these methods plus trolling from boats. Most are caught a few feet off the bottom in depths of 5 to 30 ft. Check state regulation on size limit. Baits: Shrimp, mullet, soft or shedder crab, worms, squid, clams and cut fish; also weighted bucktails, jigs, plugs, spoons, spinners and streamer flies.

Silver Sea Trout, Cynoscion nothus. Trout, white trout. Distinguished from gray sea trout by having a rounded tail and usually 9, but sometimes 8 or 10, anal fin rays. Gray sea trout have slightly forked tails and 11 or 12 anal fin rays. Differs from spotted sea trout in having no round, dark spots on the upper half of the body or on the 2nd dorsal fin and tail. Spotted sea trout have these spots. Size: To 2 lbs; avg. 1/3 - 2/3 lb; over 1 1/2 lbs unusual. Habits: Occur in salt and brackish water over any type of bottom to depths of 60 ft. Otherwise, the habits of silver sea trout are similar to those of gray sea trout. Season: Most are caught from March — December; best fishing is during June and July. Fishing Methods: Bottom fishing, jigging, live lining and chumming from shore; these methods plus trolling from boats. Check state regulation on size limit. Baits: Shrimp, squid, clams and cut fish; also small weighted bucktails, feathers and jigs.

Red Drum, Sciaenops ocellata. Channel bass, red bass, redfish. Small ones are called school bass and reef bass, large ones big reds. Size: Largest recorded 90 lbs; tackle record 90 lbs; small fish average 2-4 lbs and large fish 15-20 lbs; over 50 lbs unusual. Habits: Occur in brackish and salt water on mud and sand bottom, especially near shoals and shellfish beds. Small ones occur in shallow estuaries; large ones are around inlets and within 6 miles of the coast. However, during migrations large fish usually travel near the surface between 5 and 20 miles offshore. Season: All year. Best fishing for small ones August — October inshore, for large ones March — May and November — January offshore. Fishing Methods: Bottom fishing, live lining, jigging and casting from shore; these methods plus trolling from boats. Check state regulation on size limit. Baits: Shrimp, mullet, crabs, clams, cut fish, and live fish; also spoons, plugs, weighted bucktails, jigs, stripbait, feathers and streamer flies.

Black Drum, Pogonias cromis. Drum. Young ones called puppy or pompey drum have 4 to 6 broad, black bars on their sides which disappear with age. Size: Largest recorded 146 lbs; tackle record 111 lbs; barred fish average 1-3 lbs and large fish 20-30 lbs; over 60 lbs unusual. Habits: These inshore bottom feeders occur on any type of bottom in salt and brackish water but especially on clam and oyster beds. They also frequent breakwaters, jetties, pilings, bridge abutments and piers. Season: Most are caught from February — November, but a few all year. Best fishing for large fish late February — early May in inlets, bays and sounds; for small fish during June in the surf. Fishing Methods: Bottom fishing and chumming from shore or boats for large fish; these methods plus casting artificial lures for small fish. Baits: Shrimp, clams, soft or shedder crab, squid and cut fish; also spoons, jigs and weighted bucktails.

Southern Kingfish, Menticirrhus americanus. Whiting, king whiting. Large ones called bull whiting. See Gulf kingfish. Size: To 3 lbs; avg. 1/3 - 1 lb; over 2 lbs unusual. Habits: These bottom feeders aggregate on any type of bottom but adults favor sand or sand-shell along the beaches and around the mouths of sounds and inlets. Most occur in salt and brackish water from the tide-line to depths of 40 ft, some to at least 180 ft in the ocean. Season: All year; best fishing December -- May. Fishing Methods: Bottom fishing, chumming and jigging from shore and anchored or drifting boats. Baits: Shrimp, worms, cut fish, squid, clams, mussels and small crabs; also small jigs and weighted bucktails.

Gulf Kingfish, Menticirrhus littoralis. Whiting, beach whiting, silver whiting, king whiting. Distinguished from southern kingfish by the absence of dark markings on its silvery body, and by its pale gill cavity. In contrast, southern kingfish have dusky bars on back and sides, and a dark gill cavity. Size: To 3 1/2 lbs; avg. 1/3 - 1 lb; over 2 lbs unusual. Habits: Gulf kingfish prefer saltier water than southern kingfish. Although a few occur within sounds or bays, most remain along sandy beaches of the open ocean and near the outside mouths of sounds. Season, Fishing Methods and Baits are the same as for southern kingfish.

Spot, Leiostomus xanthurus. Large ones are called golden spot. See silver perch. Size: To 2 1/4 lbs; avg. 2-4 oz; over 1/2 lb unusual. Habits: These gregarious bottom feeders occur on mud, sand or sand-shell bottom in salt and brackish water; a few in fresh water. Spawned offshore in depths to 500 ft, the young move inshore and spend their first year of life in shallow estuaries. As they get older, they migrate offshore during fall and inshore during spring. Season: Most are caught from March — December; best fishing July — September. Fishing Methods: Bottom fishing from shore; this method plus chumming from boats. Baits: Shrimp, worms, mussels, clams, soft crab and cut fish.

Atlantic Croaker, Micropogon undulatus. Croaker. Large ones are called Virginia croakers. Size: To 5 lbs; avg. 1/4 - 1/3 lb; over 1 1/2 lbs unusual. Habits: These bottom feeders occur on mud, sand, shell or coral bottom and around rock jetties or wrecks in salt and brackish water; a few in nearly fresh water. Spawned offshore in depths to 300 ft, the young move inshore and spend their first year of life in shallow estuaries. As growth proceeds they gradually move seaward. Adults migrate inshore during the spring to water warmer than 61°F. Season: Most are caught March or April — November; best fishing July — September. Fishing Methods: Most are caught from a few feet below the tide-line to depths of 30 ft by bottom fishing, chumming, live lining and jigging from shore or boats. Baits: Shrimp, soft or shedder crab, clams, worms and cut fish. A few are caught on small jigs and weighted bucktails.

Silver Perch, Bairdiella chrysura. Yellowtail, perch, sand perch. Distinguished from spot by having no dark shoulder spot and a nearly square tail. In contrast, spot have a dark shoulder spot and a slightly forked tail. Size: To 3/4 lb; avg. 1/4 - 1/3 lb; over 1/2 lb unusual. Habits: Occur in salt and brackish water on mud, sand, shell and especially on sandy mud bottom with sea grass. Adults may migrate a short distance offshore during winter but young fish remain inshore the year round. Season: All year; best fishing March -- April and September -- October. Fishing

Methods: Bottom fishing from shore; this method plus live lining and chumming from boats. Usually taken incidentally with other fishes. Baits: Worms, shrimp, clams, soft crab and cut fish; also small weighted bucktails.

FLOUNDERS, LEFT-EYED

Southern Fluke, Paralichthys lethostigma. Flounder, southern flounder. See northern fluke. Size: To over 13 lbs; avg. 1-2 lbs; over 10 lbs unusual. Habits: These bottom feeders live on mud, sand and sand-shell bottom. They occur in salt and brackish water and often ascend fresh water streams or rivers for a considerable distance. During warm months many occur near the shore in shallow estuaries; during cold months they move into deeper water. Season: Most are caught late March or April — November; best fishing September — October. Night spearing on shallow flats is best June — August. Fishing Methods: Bottom fishing from shore; this method plus chumming, live lining and trolling near bottom from boats. Night spearing, called gigging or floundering, is commonly done either while wading or from boats. Check state regulation on size limit. Baits: Killifish, squid, mullet, clams, worms, and cut fish. A few are caught on jigs, spinners and weighted bucktails.

Northern Fluke, Paralichthys dentatus. Flounder, summer flounder. Distinguished from southern fluke by having 13 to 18, usually 15 or more gill rakers on the lower limb of the 1st gill arch. In contrast, southern fluke have 8 to 11, usually 9 to 10, gill rakers on the lower limb of the 1st gill arch. Size: Largest recorded 30 lbs; tackle record 20 1/2 lbs; avg. 1-3 lbs; over 12 lbs unusual. Habits: live on mud, sand, sand-shell or gravel bottom and around wrecks. Although most occur in salt and brackish water, some ascend fresh water streams. During warm months they usually occur within bays and sounds in depths of 40 ft or less; during cold months they retreat to deeper ocean water, some to depths of 150 ft or more. Usually feed near bottom but will pursue prey to the surface. Season, Fishing Methods and Baits are the same as for southern fluke.

GRUNTS

Pigfish, Orthopristis chrysoptera. Grunt. Often miscalled hogfish and sailors choice. See white grunt. Size: To 2 lbs; ag. 1/4 - 1/2 lb; over 1 1/2 lbs unusual. Habits: Occur in salt and brackish water on sand or mud bottom and around wrecks, piers, jetties or bridge abutments. Although common in estuaries, inlets and along ocean beaches, they also occur offshore to depths of 100 ft or more. Pigfish usually feed within a few feet of the bottom.

Season: All year; best fishing April — September. Fishing Methods: Bottom fishing and jigging from shore or boats. Although pigfish are plentiful, they are not highly sought. Most are caught incidentally with other bottom fishes. Baits: Shrimp, crabs, squid, worms, clams, mussels and cut fish; also small weighted bucktails and jigs. Pigfish are often used as live or cut bait for other species.

White Grunt, Haemulon plumieri. Grunt, common grunt. Miscalled scup. Distinguished from pigfish by its large mouth having an orange-red lining, and by its body scales larger above the lateral line than those below it. In contrast, pigfish have a small mouth with no bright color inside, and its body scales above the lateral line are about the same size as those below. Size: To 4 lbs; avg. 1/3 - 2/3 lb; over 2 lbs unusual. Habits: Occur in salt and brackish water on mud, sand, rock or coral bottom and around wrecks, piers, jetties or bridge abutments. Although common in estuaries, inlets and along ocean beaches, they occur offshore in depths of 100 ft or more. They usually feed within a few feet of the bottom. Season: All year; best fishing is during July and August. Fishing Methods: Bottom fishing and jigging from shore or boats. Baits: Shrimp, crabs, worms, clams and cut fish; also small weighted bucktails and jigs.

JACKS, SCADS AND POMPANOS

Great Amberjack, Seriola dumerili. Amberjack. Size: To over 180 lbs; tackle record 149 lbs; avg. 15-25 lbs; over 100 lbs unusual. Habits: These fast swimmers occur in schools in oceanic and continental-shelf water from the surface to depths of at least 1,000 ft. Although great amberjack may occur anywhere in the water column, they often concentrate over high relief rock or coral bottom and around wrecks or buoys. Season: Most are caught from March -- November; best fishing July and August. Fishing Methods: Trolling, bottom fishing, jigging, chumming and live lining from boats. Anglers catch many large amberjack while fishing for snappers and groupers in depths of 90-300 ft. Baits: Live and dead fish; also stripbait, plugs, spoons, feathers and jigs.

Crevalle Jack, Caranx hippos. Jack, crevalle, common jack, jack crevalle. Size: To over 70 lbs; avg. 1-3 lbs inshore, 8-15 lbs offshore; over 35 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur in salt and brackish water; sometimes in coastal rivers to nearly fresh water. Occur over any type of bottom, but congregate over wrecks and high relief rock or coral bottom. Small fish are common in shallow estuaries; as they grow larger, they tend to move offshore into deeper water.

Season: All year; best fishing April — September. Fishing Methods: Casting, jigging, live lining, chumming and bottom fishing from shore; these methods plus trolling from boats. Baits: Feathers, spoons, plugs, jigs, weighted bucktails and bucktail flies; also live or cut fish and shrimp.

Pompano, Trachinotus carolinus. This fish is more commonly referred to as the pompano than any of its other Atlantic coast relatives. Size: To 8 lbs; avg. 3/4 - 1 1/2 lbs; over 5 lbs unusual. Habits: These schooling fish are caught along ocean beaches, in estuaries and in inlets. Adults leave shallow water seasonally to spawn offshore, some as far as 60 miles from land. Pompano feed on or a few feet off sand and mud bottom in water warmer than 65°F. Many die when trapped in water colder than 60°F. Season: Most are caught from April — early December; best fishing May and mid August — early November. Fishing Methods: Bottom fishing, casting, live lining, chumming and jigging from shore; these methods plus trolling from boats. Check state regulation on size limit. Baits: Shrimp, sand bugs, cut fish and clams; also small weighted bucktails, jigs and feathers.

MACKERELS, TUNAS AND BONITOS

King Mackerel, Scomberomorus cavalla. Kingfish, kings. Small ones are called snakes. See Spanish mackerel. Size: Largest recorded 103 lbs; tackle record 78 3/4 lbs; avg. 6-12 lbs; over 50 lbs unusual. Habits: Pelagic, schooling and migratory. Occur over any type of bottom in salt water warmer than 67°F. Often congregate over wrecks, high relief rock or coral bottom and around buoys. Although some occasionally venture close enough to shore to be caught from ocean piers, most occur offshore of the 50 ft bottom contour. Season: Most are caught from March — December; best fishing inshore April — August, offshore in October and November. Fishing Methods: Most are caught by trolling from boats 5-15 miles offshore; some by casting, chumming and live lining from shore or boats. Check state regulation on size limit. Baits: Spoons, feathers, stripbait, feather-stripbait or skirt-stripbait combination, and plugs; also shrimp, whole rigged mullet or ballyhoo, and live fish.

Spanish Mackerel, Scomberomorus maculatus. Mackerel. Distinguished from king mackerel by the scaleless pectoral fins and the lateral line sloping downward gradually under the 2nd dorsal fin. King mackerel have scaled pectoral fins and the lateral line dips downward abruptly under the 2nd dorsal fin. Size: To 12 lbs; avg. 1/2 - 1 1/2 lbs; over 5 lbs unusual. Habits: Pelagic, schooling and migratory. Occur throughout the water column to depths of 80 ft in water warmer than 67°F.

Spanish mackerel will pursue bait fish through inlets into estuaries. Season: Most are caught from March -- October, but a few all year. Best fishing can be any time from April -- August. Fishing Methods: Casting, live lining, bottom fishing and jigging from shore; these methods plus trolling from boats. Most fish are caught within 2 miles of the beach and in or around inlets. Check state regulation on size limit. Baits: Spoons, feathers, stripbait, weighted bucktails, plugs and jigs; also shrimp, squid and whole or cut fish.

Little Tuna, Euthynnus alletteratus. Bonito, false albacore. Size: To 26 lbs; avg. 6-10 lbs; over 20 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur in salt water warmer than 65°F. They travel in groups varying from three or four fish to schools of many thousands. Although they occasionally venture close enough to shore to be caught from ocean piers, little tuna usually occur offshore of the 30 ft bottom contour. Season: Most are caught from late March or April -- November or early December, but a few all year. Best fishing June -- August. Fishing Methods: Most are caught by trolling and casting from boats; some by casting from shore. Baits: Feathers, stripbait, feather-stripbait or skirt-stripbait combination, spoons, jigs and plugs; also rigged ballyhoo and mullet.

Skipjack Tuna, Katsuwonus pelamis. Oceanic bonito, arctic bonito. Size: To 45 lbs; tackle record 39 lbs 15 oz; avg. 3-6 lbs; over 15 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers usually occur near the surface in continental-shelf and oceanic water warmer than 63°F, but offshore of the 90 ft bottom contour. Season: Late April -- November; best fishing June -- September. Fishing Methods: Most are caught by trolling near the surface 5 to 20 miles from shore. Also caught by casting from boats. Baits: Feathers, stripbait, feather-stripbait or skirt-stripbait combination, spoons, jigs and plugs.

Wahoo, Acanthocybium solanderi. The moveable upper jaw, the large number of dorsal fin spines (21-27), and the nearly straight edge of the tail are characters which distinguish the wahoo from other mackerel-like fishes. Size: Maximum size unrecorded; tackle record 149 lbs; avg. 25-45 lbs; over 85 lbs unusual. Habits: Pelagic and migratory. These rapid swimmers occur in oceanic and continental-shelf water offshore of the 100 ft bottom contour. They usually swim in small groups or singly. Often concentrate over high relief rock or coral bottom and wrecks. Season: Most are caught from mid April -- October, but a few year round offshore in the Gulf Stream. Fishing Methods: Trolling and live lining from boats. Never abundant, wahoo are taken incidentally with other pelagic fishes. Baits: Whole rigged Spanish mackerel, squid, mullet and ballyhoo, or live fish; also spoons, feathers and stripbait.

PORGIES

Pinfish, Lagodon rhomboides. Bream, salt water bream. Miscalled sailors choice. Size: To 1 lb; avg. 1/4 - 1/3 lb; over 3/4 lb unusual. Habits: Occur in salt, brackish and a few in nearly fresh water. Small fish remain year round in shallow estuaries, especially those abounding in sea grasses. Large fish spend the warm months in shallow estuaries but move offshore during cold months to spawn. Feed on or near bottom. Season: Taken all year; best fishing April — October. Fishing Methods: Bottom fishing from shore or boats. Baits: Small pieces of fish, worm, clam and shrimp. Pinfish are often used as live or dead bait for other fishes.

Whitebone Porgy, Calamus leucosteus. Porgy. Miscalled silver snapper. Size: To over 5 lbs; avg. 1/2 - 1 lb; over 3 1/2 lbs unusual. Habits: These bottom feeders occur on mud, sand and rock bottom, especially those with high relief, and around wrecks in depths of 30-300 ft. Small ones sometimes found inshore of the 30 foot bottom contour. Season: All year. Fishing Methods: Bottom fishing from anchored or drifting boats. Most are caught in depths of 90-150 ft. Baits: Shrimp, cut fish, squid and clams.

Red Porgy, Pagrus sedecim. Pink porgy. Miscalled silver snapper. Size: To over 13 lbs; avg. 2-5 lbs; over 8 lbs unusual. Habits: These bottom feeders occur on high relief rock or coral bottom in depths of 30-400 ft. Season: All year, but most are caught from March -- November in depths of 100-180 ft. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Cut fish, squid, clams and worms.

Sheepshead, Archosargus probatocephalus. Sheephead. Size: To 30 lbs; avg. 1-3 lbs; over 12 lbs unusual. Habits: Aggregate in salt and brackish water on sand, shell, gravel or rock bottom and around bridge abutments, jetties, breakwaters, rock piles and wrecks. Feed on or near bottom from a few feet below the tide-line to depths of 100 ft or more. Season: All year; best fishing March -- May and mid August -- October. Fishing Methods: Many are caught by bottom fishing and chumming, some by jigging, from boats or shore. Baits: Crabs, clams, shrimp, sand bugs and cut fish; also small jigs and weighted bucktails.

SNAPPERS

Red Snapper, Lutjanus aya. Snapper, Daytona red snapper, American red snapper. Common names vary with size. Starting with the smallest size and progressing to the largest, they are called: spot snappers or rats, chicken snappers, snappers, sow snappers, and mules. Size: To 40 lbs; avg. 5-8 lbs; over 25 lbs unusual. Habits: These bottom feeders aggregate on or a few feet above mud, sand, gravel, coral or rock bottom to depths of 800 ft or more. They often congregate in bottom depressions, known locally as gullies, or on high relief rock or coral outcrops encrusted with living organisms. Although a few occur close enough to shore to be caught from ocean piers, most are beyond the 60 ft bottom contour. Small ones occur in shallower water than large ones. Season: All year in depths of 120 ft or more; during summer in shallower water. Best fishing for small ones in March and April, for large ones in July and August. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Squid, cut fish, shrimp and crabs.

Mutton Snapper, Lutjanus analis. Snapper, muttonfish. Size: To 25 lbs; avg. 4-7 lbs; over 15 lbs unusual. Habits: Occur on mud, sand, coral or rock bottom, favoring rock or coral outcrops encrusted with live organisms. Although usually a bottom feeder to depths of 300 ft or more, they sometimes pursue prey into mid water. Season: All year in depths deeper than 90 ft; during warm months in shallower water. Fishing Methods: Bottom fishing, chumming, live lining and jigging from boats. A few caught by slow trolling near bottom. Baits: Cut fish, squid and shrimp; also weighted bucktails, jigs and plugs.

Gray Snapper, Lutjanus griseus. Snapper, mangrove snapper, white snapper. Size: To 20 lbs; avg. 1-2 lbs; over 7 lbs unusual. Habits: These bottom feeders aggregate on or a few feet above mud, sand, gravel, coral or rock bottom in salt and brackish water; sometimes in fresh water. They congregate on high relief rock or coral outcrops and wrecks, especially those encrusted with living organisms, to depths of 120 ft or more. Season: Some are caught all year, but most during warm months. Fishing Methods: Bottom fishing, live lining, chumming and casting from shore; these methods plus trolling near bottom from boats. Baits: Cut fish, shrimp, small crabs and clams; also weighted bucktails, jigs, plugs, feathers and streamer flies.

Vermilion Snapper, Rhomboplites aurorubens. Snapper, beeline snapper, California red snapper. Sometimes miscalled mutton snapper. Size: To over 9 lbs; avg. 3/4 - 1 1/2 lbs; over 4 lbs unusual. Habits: These bottom feeders aggregate on mud, sand, gravel, coral or rock bottom in depths of 90-350 ft. They often concentrate on high relief rock or coral outcrops and wrecks, favoring those encrusted with living organisms. Season: All year. Fishing success seems to be influenced by weather and not the availability of fish. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Squid, cut fish, shrimp and clams.

SNOOK

Snook, Centropomus undecimalis. Size: To over 55 lbs; tackle record 52 lbs 6 oz; avg. 3-7 lbs; over 30 lbs unusual. Habits: Occur throughout the water column in salt, brackish and fresh water from a few feet below the tide-line to depths of 60 ft or more. They often congregate around inlets and passes, favoring those with rock jetties, pilings and bridge abutments. Season: All year; best fishing mid June -- September. Fishing Methods: Most are caught in estuaries and within 1/4 mile of the coast by casting, live lining and bottom fishing from shore; these methods plus trolling from boats. Check state regulation on size and daily limit. Baits: Live shrimp, mullet, pinfish, croaker, pigfish and crabs; also plugs, feathers, spoons, weighted bucktails, jigs, spinners and streamer flies.

SPADEFISHES

Atlantic Spadefish. Chaetodipterus faber. Spadefish, angelfish. Size: To 16 lbs; avg. 1/3 - 1 lb; over 5 lbs unusual. Habits: Aggregate in salt water on sand, shell, coral or rock bottom and around buoys, wrecks, rock piles, bridge abutments, pilings, jetties and breakwaters. They usually occur inshore of the 90 ft bottom contour. Season: All year; best fishing in July and August. Fishing Methods: Bottom fishing from boats or shore. Baits: Clams, worms, shrimp, crabs and cut fish.

TARPON AND LADYFISH

Ladyfish, Elops saurus. Skipjack, ten-pounder. Size: To 9 lbs; avg. 3/4 - 1 1/4 lbs; over 4 lbs unusual. Habits: These schooling fish occur throughout the water column over any type of bottom in salt and brackish water; some in fresh water. They often congregate along the edges of deep holes or channels within shallow estuaries; also in inlets. Season: Late March or April -- November; best fishing August -- October. Fishing Methods: Bottom fishing, casting, jigging, live lining and chumming from shore; these methods plus trolling from boats. Most are caught within a mile of ocean beaches and in inlets and estuaries. Baits: Shrimp, small crabs and cut fish; also weighted bucktails, jigs, plugs, spoons, spinners, streamer flies and feathers.

Tarpon, Megalops atlanticus. Silver king. Size: To over 350 lbs; tackle record 283 lbs; avg. 30-80 lbs; over 130 lbs unusual. Habits: Pelagic and migratory. Occur over any type of bottom in salt and brackish water, sometimes in fresh water. Although during migrations some range 10 or more miles offshore, they usually occur in estuaries, inlets and within 3 miles of ocean beaches. Tarpon feed mainly at night in water warmer than 66°F. Season: April — October or early November; best fishing July — September. Fishing Methods: Live lining, chumming and casting from shore; these methods plus trolling from boats. Most are caught in water of 72°-84°F. Check state regulation on daily limit. Baits: Live mullet, spot, pinfish, croaker, kingfish, shrimp and crabs, or squid and cut fish; also spoons, plugs, weighted bucktails and bucktail flies.

TRIPLETAIL

Tripletail, Lobotes surinamensis. Chobie, buoyfish, buoy tender. Size: To over 30 lbs; avg. 4-8 lbs; over 20 lbs unusual. Habits: Occur from the surface to the bottom in depths of a few to 200 ft or more. Small fish enter inlets and estuaries; large ones tend to remain in the ocean. They usually are found singly or in small groups, but sometimes in compact aggregations along ocean beaches. Tripletail frequent buoys, floating debris, wrecks and underwater obstructions. Season: Most are caught from April -- October or November, but a few all year. Fishing Methods: Bottom fishing, jigging, casting, and live lining from boats; a few are taken by these methods from shore. Baits: Shrimp, cut fish, clams, crabs, squid and live fish; also weighted bucktails, jigs and plugs.

CRABS

Blue Crab, Callinectes sapidus. Crab, blue claw crab. Males are called Jimmies, females sooks, those bearing eggs, sponge crabs. Crabs about to shed their shells are called shedders or peelers. Immediately after shedding their shells, they are called soft crabs. Size is usually expressed as the width of the shell across the back measured from spine tip to spine tip. Size: To 10 inches; avg. 5 1/2 - 6 1/2 inches; over 9 inches unusual. Habits: Occur on mud, sand, sand-shell and gravel bottom in salt, brackish and sometimes in fresh water. Especially abundant in estuaries and the mouths of streams or rivers around sea grass. During warm months crabs frequent shallow water; during cold months they seek deeper water. Active in water warmer than 50°F. Large males tend to concentrate in the upper reaches of creeks and rivers, large females in river mouths, sounds and bays. Season: All year; best crabbing June -- October. Check state laws governing the taking of egg-bearing females. Fishing Methods: Hand lines or crab traps from shore or boats. Baits: Whole and cut fish or scrap meat.

Most Commonly Caught Fish from False Cape, Virginia to Altahama Sound, Georgia. (Taken from Freeman and Walford, 1976a).

BARRACUDAS

Great Barracuda, Sphyraena barracuda. Barracuda, cuda. Size: Largest recorded 106 lbs; tackle record 83 lbs; avg. 10-15 lbs; over 40 lbs unusual. Habits: Pelagic and migratory. Occur offshore, sometimes inshore, over any type of bottom. Barracuda often concentrate around wrecks or rock and coral bottom with high relief. Season: May -- October; best fishing in July and August. Most are taken near the surface in water from 50-120 ft deep and temperatures warmer than 70°F. Fishing Methods: Trolling, casting and live lining from boats. Usually taken as an incidental fish while trolling for other species. Baits: Spoons, stripbait, feathers, plugs and live fish.

BASSES, SEA AND GROUPERS

Black Sea Bass, Centropristis striata. Sea bass, blackfish, common bass, humpback bass. Small ones taken in estuaries are called black Willies. See rock sea bass. Size: Largest recorded 8 lbs; tackle record 8 lbs; avg. 1/2 - 3/4 lb; over 4 lbs unusual. Habits: Gregarious, year-round residents occurring on rock, coral or shell bottom and around wrecks, pilings, wharfs, rock jetties or breakwaters. They are commonest from a few feet below the tide-line to about 180 ft; some to 450 ft or more. They attain their largest size and greatest abundance on offshore grounds. Season: All year; best fishing in June and July. Fishing Methods: Most are caught in depths from 60 to 120 ft by bottom fishing from drifting or anchored boats. Small ones are taken from shore by bottom fishing. Baits: Squid, clams, crabs, worms, shrimp and cut fish.

Rock Sea Bass, Centropristis philadelphica. Sea bass, blackfish, sand bass. Distinguished from black sea bass by having 6 or 7 broad vertical bars or stripes on back and sides, and a distinct black spot at base of last three dorsal spines. Black sea bass have no vertical bars or stripes and no large distinct spot. Size: To 1 lb; avg. 1/3 - 1/2 lb; over 3/4 lb unusual. Most anglers make no distinction between rock sea bass and black sea bass. Habits, Season, Fishing Methods and Baits are the same as for the black sea bass.

Striped Bass, Morone saxatilis. Rock, rockfish. Size: Largest recorded 125 lbs; tackle record 73 lbs; avg. 1-2 lbs; over 25 lbs unusual. Habits: Anadromous. North of Core Banks, N. C., adults are migratory and occur in fresh, brackish and salt water. South of Core Banks, striped bass are resident and occur in fresh and brackish water, seldom in salt water. They occur throughout the water column over any type of bottom. Season: All year; best fishing October — January. A small run also occurs from mid February — April. Fishing Methods: Casting, jigging and live lining from shore; these methods plus trolling from boats. Baits: Weighted bucktails, jigs, plugs and spoons; also worms, shrimp, cut fish, pork rind and live fish.

Red Grouper, Epinephelus morio. Grouper. Distinguished from most other groupers by the edge of membranes between the dorsal spines being slightly curved or nearly straight. In most other groupers they are deeply notched. Size: To 50 lbs; avg. 4-6 lbs; over 25 lbs unusual. Habits: Occur to depths of at least 900 ft sometimes on smooth sand or mud, but most frequently on high relief bottom consisting of rock and coral or wrecks encrusted with living organisms. Season: All year in depths of 120 ft or more; during warm months in shallower water. Fishing Methods: Bottom fishing from anchored and drifting boats. Some caught by jigging or trolling near bottom. Baits: Squid, shrimp, crabs, cut fish and live fish; also weighted bucktails, jigs and feathers.

Warsaw Grouper, Epinephelus nigritus. Grouper, black jewfish. Miscalled jewfish and black grouper. Distinguished from most other groupers by 10 dorsal spines (instead of 11) and the end of the tail having a nearly straight edge. Size: To 500 lbs; avg. 20-30 lbs; over 300 lbs unusual. Habits: Occur to depths of 400 ft or more, especially on high relief bottom consisting of rock, coral or wrecks encrusted with living organisms. Although usually near bottom, they may occur halfway to the surface. Season: All year in depths of 120 ft or more; during summer in depths of 60 ft or more. Fishing Methods: Bottom fishing, jigging or deep trolling from boats. Baits: Squid, cut fish, shrimp, clams, crabs and live fish; also spoons, feathers and plugs.

Gag Grouper, Mycteroperca microlepis. Grouper. Distinguished from most other groupers by the gray color with no distinctive markings and by the slightly forked tail. Size: To 50 lbs; avg. 2-5 lbs; over 15 lbs unusual. Habits: Occur to depths of 400 ft on any type of bottom but concentrate around rock or coral outcrops and wrecks. Small fish occur both inshore and offshore, large fish usually in water deeper than 60 ft. Season: All year. Fishing Methods: Most are caught by bottom fishing in depths of 120 to 240 ft, some by jigging from boats. Baits: Shrimp, squid, clams, cut fish and live fish; also weighted bucktails and jigs.

Speckled Hind, Epinephelus drummondhayi. Grouper, Kitty Mitchell. Size: To 50 lbs; avg. 8-10 lbs; over 30 lbs unusual. Habits: These bottom dwellers occur on rock or coral bottom and around wrecks in depths of 150 ft or more. Season: All year in depths over 120 ft; during warm months in shallow water. Fishing Methods: Bottom fishing from anchored or drifting boats. Most are caught in depths of 175-250 ft. Baits: Cut or whole fish, squid and shrimp.

BILLFISHES

Blue Marlin, Makaira nigricans. See white marlin. Size: To over 1,700 lbs in the Atlantic Ocean; Atlantic tackle record 1,142 lbs (Pacific tackle record is 1,153 lbs but fish over 2,000 lbs are reported); avg. 250-300 lbs; over 600 lbs unusual. Habits: Pelagic and migratory. Occur in oceanic and continental-shelf water from the surface to depths of at least 300 ft. Travel in small groups or singly. Season: Late April or May -- November; best fishing mid May -- mid September. Most are taken near the surface between the 300 and 600 ft bottom contours. Fishing Methods: Trolling and live lining from boats. Baits: Whole rigged squid, Spanish mackerel, mullet, striped bass, eel and ballyhoo; also stripbait, feather-stripbait combination, and live fish. Some are caught on artificial lures.

White Marlin, Tetrapturus albidus. Distinguished from blue marlin by having the tips of the dorsal and anal fins rounded, and a conspicuous lateral line. In the blue marlin the tips of the dorsal and anal fins are pointed, and except in very small fish, the lateral line is inconspicuous. Size: To over 161 lbs; tackle record 161 lbs; avg. 40-60 lbs; over 90 lbs unusual. Habits: Pelagic and migratory. Occur in oceanic and continental-shelf water but during warm months some come close to shore into depths as shallow as 60 ft. Travel in small groups or singly. Season: Late April or May -- October or November; best fishing mid May -- mid September. Most are taken near the surface in water warmer than 70°F between the 100-600 ft bottom contours. Fishing Methods: Trolling and live lining from boats. Baits: Stripbait, feather-stripbait or skirt-stripbait combination, and whole rigged eel, squid, ballyhoo, mullet or Spanish mackerel; also live bait. Some caught on feathers, skirts and plugs.

Atlantic Sailfish, Istiophorus platypterus. Sailfish. Size: To over 141 lbs in the Atlantic Ocean; Atlantic tackle record 128 lbs (Pacific tackle record 221 lbs); avg. 25-35 lbs; over 70 lbs unusual. Habits: Pelagic and migratory. Occur in continental-shelf water usually in depths over 40 ft, but they occasionally venture close enough to shore to be taken from ocean piers. Travel in small groups or singly. Sailfish usually feed more in mid water and near bottom than at the surface. Season: May — October; best fishing July — September. Fishing Methods: Trolling and live lining from boats. A few are caught from shore. Baits: Stripbait, feather-stripbait or skirt-stripbait combination, whole rigged ballyhoo or mullet, and live bait. Some caught on feathers, spoons, skirts and plugs.

BLUEFISH

Bluefish, Pomatomus saltatrix. Blues, Hatteras blues. Small fish called snapper blues or sour blues. Size: Largest recorded 35 lbs; tackle record 31 lbs 12 oz; avg. 1/2 - 1 lb; north of New River Inlet, N. C., over 15 lbs unusual, south of this inlet over 4 lbs unusual. Habits: Pelagic, schooling and migratory. Bluefish occur throughout the water column in temperatures warmer than 50°F. They often concentrate around shoals, wrecks and artificial reefs. Abundance fluctuates from year to year. Season: Late March or April — mid December; best fishing May — June and October — early December. Fishing Methods: Casting, bottom fishing, live lining and jigging from shore; these methods plus trolling from boats. Most bluefish are caught in water 65°-76°F within 20 feet of the surface. Baits: Spoons, feathers, weighted bucktails, jigs and plugs; also cut fish, shrimp and small bait fish.

COBIA

Cobia, Rachycentron canadum. Crab-eater, sergeant fish. Size: To 120 lbs; tackle record 110 1/2 lbs; avg. 15-25 lbs; over 65 lbs unusual. Habits: Pelagic and migratory. Cobia occur both offshore and inshore, often in inlets and estuaries. They usually occur singly or in small groups and are often around buoys, wrecks, floating debris, and with schools of other fish, sea turtles and large rays. Season: May -- mid October; best fishing mid June -- August. Fishing Methods: Bottom fishing, live lining, casting and chumming from shore; these methods plus trolling from boats. Baits: Whole spot, eel and shedder crab or cut fish; also spoons, plugs and large weighted bucktails.

DOLPHINS

Dolphin, Coryphaena hippurus. Small ones called school dolphin; large males called bulls. Size: To 85 lbs; tackle record 85 lbs; avg. 2-5 lbs; over 45 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur near the surface in water warmer than 70°F. Although dolphin occasionally venture close enough to shore to be caught from ocean piers, they usually occur offshore of the 60 ft bottom contour. They often gather under floating debris and seaweed or around buoys and light towers. Season: Late April or May -- November; best fishing for large fish is during June, for small fish July -- September. Fishing Methods: Trolling or casting from boats. Most are caught 8 or more miles offshore. Baits: Feathers, spoons, jigs, plugs, weighted bucktails, stripbait, feather-stripbait combination, and whole rigged mullet, ballyhoo, squid or Spanish mackerel.

DRUMS

Spotted Sea Trout, Cynoscion nebulosus. Speckled trout, winter trout, trout. Fish less than 3/4 lb called school or pan trout. See gray sea trout and silver sea trout. Size: Largest recorded 16 1/2 lbs; tackle record 15 lbs 3 oz; avg. 3/4 - 1 3/4 lbs; over 6 lbs unusual. Habits: Occur in salt and brackish water, particularly the shallow water of estuaries and along ocean beaches. Although favoring sandy areas, especially around sea grass beds, they occur over any type of bottom in water warmer than 50°-54°F. Season: Most are caught from May or June -- December or early January, but a few all year. Best fishing October -- December. In South Carolina a small run usually occurs during June. Fishing Methods: Casting, bottom fishing, jigging, chumming and live lining from shore; these methods plus trolling from boats. In North Carolina, most are caught along the ocean beaches and in inlets. In South Carolina, they are caught both along the ocean beaches and in estuaries. Baits: Plugs, weighted bucktails, jigs and spoons; also shrimp, silversides, mullet, killifish and soft or shedder crab.

Gray Sea Trout, Cynoscion regalis. Gray trout, summer trout, trout, sea trout, yellow-fin trout, yellow-mouth trout, weakfish. Fish less than 3/4 lb called pan trout. See silver sea trout. Distinguished from spotted sea trout by having the dark blotches on its back often arranged in rows, but no round, dark spots on 2nd dorsal fin and tail. In contrast, spotted sea trout have round, dark spots on upper half of body, 2nd dorsal fin and tail. Size: Largest recorded 30 lbs; tackle record 19 1/2 lbs; avg. 1/2 - 1 lb; over 2 lbs unusual. Habits: Occur throughout the water column in salt and brackish water to depths of at least 90 ft.

Although found over any type of bottom, they favor sandy areas. Season: Most are caught from May — December; best fishing September — November. Fishing Methods: Bottom fishing, live lining, casting, chumming and jigging from shore; these methods plus trolling from boats. Most are caught a few feet off the bottom in depths of 4 to 45 ft. In North Carolina most are caught in sounds, bays and inlets. Although anglers usually do not take them during winter, gray sea trout are along the beaches and in the open ocean. In South Carolina they are caught in both estuaries and along the ocean beaches to depths of 60 ft. Baits: Spinners, spoons, plugs, jigs and weighted bucktails. Also shrimp, squid, silversides, mullet, soft or shedder crab, worms, clams, cut fish and killifish.

Silver Sea Trout, Cynoscion nothus. Trout, silver trout, sand trout. Distinguished from gray sea trout by having a rounded tail and 9, sometimes 8 or 10, anal fin rays. Gray sea trout have slightly forked tails, and 11 or 12 anal fin rays. Distinguished from spotted sea trout by having no round, dark spots on the upper half of its body, 2nd dorsal fin and tail. Size: To 2 lbs; avg. 1/3 - 2/3 lb; over 1 1/2 lbs unusual. Habits: Occur in salt and brackish water over any type of bottom to depths of 60 ft. Other habits of silver sea trout are similar to gray sea trout. Season: Most are caught from May — December; best fishing July — September. Fishing Methods: Bottom fishing, jigging, live lining and chumming from boats and shore. Baits: Shrimp, squid, clams and cut fish; also small weighted bucktials and jigs.

Southern Kingfish, Menticirrhus americanus. Whiting, king whiting, bullhead whiting, roundhead, kingfish, Carolina whiting. Miscalled sea mullet, Virginia mullet, mullet. See Gulf kingfish and northern kingfish. Size: To 3 lbs; avg. 1/4 to 3/4 lb; over 1 1/2 lbs unusual. Habits: These bottom feeders aggregate on any type of bottom but adults favor sand or sand-shell along the beaches and around the mouths of sounds. Most occur in salt and brackish water warmer than 50°F from the tide-line to depths of 40 ft, some to 180 ft in the ocean. Season: Most are caught from late March or April — mid December; best fishing April — May and October — November. Fishing Methods: Bottom fishing, chumming and jigging from shore and anchored or drifting boats. Baits: Shrimp, worms, cut fish, squid, clams, mussels, silversides and small crabs; also small jigs and weighted bucktails.

Gulf Kingfish, Menticirrhus littoralis. Whiting, surf whiting, silver whiting, king whiting, bullhead whiting, kingfish. Miscalled sea mullet, gray mullet and mullet. Distinguished from southern kingfish by the absence of any dark markings on its silvery body, and by its pale gill cavity. In contrast, southern kingfish have dusky bars on back and sides, and a dark gill cavity. Size: To 3 1/2 lbs; avg. 1/4 - 3/4 lb; over 1 1/2 lbs unusual. Habits: Gulf kingfish prefer saltier water than southern kingfish. Although a few occur within sounds or bays, most remain along sandy beaches of the open ocean and near the outside mouths of sounds. Season, Fishing Methods and Baits are the same as for southern kingfish.

Northern Kingfish, *Menticirrhus saxatilis*. Whiting, king whiting, bullhead whiting, roundhead, kingfish, Carolina whiting. Miscalled sea mullet, Virginia mullet and mullet. This fish is the least abundant of the three species of kingfish along the southeast coast. Distinguished from the southern kingfish by having 8, sometimes 9, soft anal rays, the largest spine of the 1st dorsal fin in adult fish reaching far beyond origin of 2nd dorsal fin, and the dark, oblique bars along the side forming a V just behind the head. In contrast, southern kingfish have 7, rarely 8, soft anal rays, the longest spine of the 1st dorsal fin in an adult reaches just beyond origin of 2nd dorsal fin, and the obscure, oblique bars along the side do not form a V just behind the head. Coloration of the northern kingfish and the dark inner lining of the gill cover are characters to separate this fish from the Gulf kingfish. See Gulf kingfish. Size: To 3 1/3 lbs; avg. 1/4 - 1/2 lb; over 1 lb unusual. Habits, Season, Fishing Methods and Baits are the same as for southern kingfish.

Red Drum, *Sciaenops ocellata*. Channel bass, drum, red bass, spot bass, sea bass. Names often vary with size. Fish to 5 lbs called puppy drum or spottail bass, those to 15 or 20 lbs called yearling drum or school bass, and those larger than 15 to 20 lbs called bull drum or channel bass. Size: Largest recorded 90 lbs; tackle record 90 lbs; small fish average 2-4 lbs and large fish 15-20 lbs; over 50 lbs unusual. Habits: Although red drum occur offshore during the winter, many remain within 6 miles of the beach and in sounds or bays on sand and sand-shell bottom. During spring migrations, schools occur near the surface along the shore, but usually beyond the breakers; during summer and fall, schools and large solitary fish occur near bottom within the breakers. Season: Most are caught from mid March or April — early December. Best fishing for large fish late March -- early June, for small fish late September -- November. Fishing Methods: During spring most are caught by trolling and casting from boats, during summer and fall by bottom fishing and casting from shore and boats. Check state regulations on size and catch limits. Baits: Jigs, feathers, and weighted bucktails; also soft or shedder crab, shrimp, squid, clams and cut mullet, spot, herring or menhaden.

Black Drum, <u>Pogonias cromis</u>. Drum. The young have 4 to 6 broad, black bars on their sides, which disappear with age. Size: Largest recorded 146 lbs; tackle record 111 lbs; barred fish average 1-3 lbs and large fish 10-20 lbs; over 45 lbs unusual. Habits: Occur in large aggregations during spring migration, but usually solitary during fall. Feed on any type of bottom but prefer mussel, clam or oyster beds. Also live around breakwaters, jetties, pilings, bridge abutments and piers. Season: Most are caught from April -- November, but a few all year. Best fishing for large fish in May and June, for small fish late September -- November. Fishing Methods: Bottom fishing an chumming from shore or boats for large fish; these methods plus casting artificial lures for small fish. Baits: Shrimp, clams, soft or shedder crab, squid, and cut fish; also spoons, jigs and weighted bucktails.

Spot, <u>Leiostomus xanthurus</u>. Small fish taken in the spring called white-eyes; large fish taken in the fall called yellowfins. See silver perch. Size: To 2 1/4 lbs; avg. 1/4 - 1/3 lb; over 3/4 lb unusual. Habits: These gregarious bottom feeders occur on mud, sand or sand-shell bottom in salt and brackish water; a few in fresh water. Spawned offshore in depths to 500 ft, the young move inshore and spend their first year of life in shallow estuaries. As they get older, they migrate offshore during fall and inshore during spring. Season: Most are caught from late April or May -- mid December; best fishing for large spot September -- November or early December. Fishing Methods: Bottom fishing from shore; this method plus chumming from boats. Baits: Shrimp, worms, clams, soft crab and cut fish.

Atlantic Croaker, <u>Micropogon undulatus</u>. Croaker, hardhead. Size: To 5 lbs; avg. 1/4 - 1/3 lb; over 1 1/2 lbs unusual. Habits: These bottom feeders occur on mud, sand, shell or coral bottom and around rock jetties or wrecks in salt and brackish water, a few in nearly fresh water. Spawned offshore in depths to 300 ft, the young move inshore and spend their first year of life in shallow estuaries. As growth proceeds they gradually move seaward. Adults migrate inshore during the spring to water warmer than 61°F. Season: Mid April or May -- late November; best fishing in August and September. Fishing Methods: Most are caught from a few feet below the tide-line to depths of 30 ft by bottom fishing, chumming, live lining and jigging from shore or boats. Baits: Shrimp, soft or shedder crab, clams, worms and cut fish. A few are caught on small jigs and weighted bucktails.

Silver Perch, Bairdiella chrysura. Perch, yellowtail, sand perch. Distinguished from spot by having no dark shoulder spot and a nearly square tail. In contrast, spot have a dark shoulder spot and a slightly forked tail. Size: To 3/4 lb; avg. 1/4 - 1/3 lb; over 1/2 lb unusual. Habits: Occur in salt and brackish water on mud, sand, shell and especially on sandy-mud bottom with sea grass. Adults may migrate a short distance offshore during winter but young fish remian inshore year-round. Season: April -- November; best fishing in September and early October. Fishing Methods: Bottom fishing from shore; this method plus live lining and chumming from boats. Usually taken incidentally with other fishes. Baits: Worms, shrimp, clams, soft crab and cut fish; also small weighted bucktails.

FLOUNDERS, LEFT-EYED

Northern Fluke, Paralichthys dentatus. Flounder, summer flounder. See southern fluke. Size: Largest recorded 30 lbs; tackle record 20 1/2 lbs; avg. 1-3 lbs; over 12 lbs unusual. Habits: Live on mud, sand, sand-shell or gravel bottom and around wrecks. Although most occur in salt and brackish water, some ascend fresh water streams. During warm months they usually occur within bays and sounds in depths of 40 ft or less; during cold months they retreat to deeper ocean water, some to depths of 150 ft or more. They usually feed near bottom but will pursue prey to the surface. Season: Most are caught from April or May -- December, but a few all year. Best fish May -- June and late September -- November. Fishing Methods: Bottom fishing from shore; this method plus chumming, live lining and trolling near bottom from boats. Night spearing called gigging or floundering is a common practice, done either while wading or from boats. Baits: Killifish, squid, silversides, clams, worms, and cut fish; also spinners, jigs and weighted bucktails.

Southern Fluke, Paralichthys lethostigma. Flounder, southern flounder. Distinguished from northern fluke by having 8 to 11, usually 9 or 10, gill rakers on the lower limb of the 1st gill arch. In contrast, northern fluke have 13 to 18, usually 15 or more, gill rakers on the lower limb of the first gill arch. Size: To over 13 lbs; avg. 1-2 lbs; over 6 lbs unusual. Habits: These bottom feeders live on mud, sand and sand-shell bottom. They occur in salt and brackish water and often ascend fresh water streams or rivers for a considerable distance. During warm months many occur near the shore in shallow estuaries; during cold months they move into deeper water. Season, Fishing Methods and Baits are the same as for northern fluke.

GRUNTS

Pigfish, Orthopristis chrysoptera. Grunt. Often miscalled hogfish and sailors choice. See white grunt. Size: To 2 lbs; avg. 1/4 - 1/2 lb; over 1 1/2 lbs unusual. Habits: Occur in salt and brackish water on sand or mud bottom and around wrecks, piers, jetties or bridge abutments. Although common in estuaries, inlets and along ocean beaches, they also occur offshore to depths of 100 ft or more. Pigfish usually feed within a few feet of bottom. Season: Most are caught March or April — November, but some the year round. Fishing Methods: Bottom fishing and jigging from shore or boats. Although pigfish are plentiful, they are not highly sought. Most are caught incidentally with other bottom fishes. Baits: Shrimp, crabs, squid, worms, clams, mussels and cut fish; also small weighted bucktails and jigs. Pigfish are often used as live or cut bait for other fishes.

White Grunt, Haemulon plumieri. Grunt, common grunt, red-mouthed grunt. Distinguished from pigfish by its large mouth having an orange-red lining and by its body scales above the lateral line being larger than those below this line. In contrast, pigfish have a small mouth with no bright color inside, and its body scales above the lateral line are about the same size as those below. Size: To 4 lbs; avg. 1/3 - 2/3 lb; over 2 lbs unusual. Habits: Occur in salt and brackish water on mud sand, rock or coral bottom and around wrecks, piers, jetties or bridge abutments. Although common in estuaries, inlets and along the beach, they occur offshore in depths to 100 ft or more. They usually feed within a few feet of bottom. Season: Most are caught from April — November, but some the year round. Fishing Methods: Bottom fishing and jigging from shore or boats. Baits: Shrimp, crabs, worms, clams and cut fish; also small weighted bucktails and jigs.

JACKS, SCADS AND POMPANOS

Great Amberjack, Seriola dumerili. Amberjack, jack hammer. Size: To over 180 lbs; tackle record 149 lbs; avg. 20-30 lbs; over 100 lbs unusual. Habits: Schooling and migratory. These swift swimmers occur in oceanic and continental-shelf water from the surface to depths of at least 600 ft. Although great amberjack may occur anywhere in the water column, they often concentrate over high relief rock or coral bottom and around wrecks or buoys. Season: Most are caught from March -- November, but a few all year in offshroe water. Fishing Methods: Trolling, bottom fishing, jigging, chumming and live lining from boats. Anglers catch many large amberjack while fishing for snappers and groupers in depths of 150-300 ft. Baits: Live and dead fish; also stripbait, plugs, spoons, feathers and jigs.

Crevalle Jack, Caranx hippos. Jack, common jack, jack crevalle, crevalle. Size: To over 70 lbs; avg. 2-4 lbs; over 10 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur in salt and brackish water; sometimes in coastal rivers to nearly fresh water. Small fish are common in shallow estuaries. As they grow larger they tend to move offshore into deeper water. Season: May — October or early November; best fishing in July and August. Fishing Methods: Casting, live lining, chumming and bottom fishing from shore; these methods plus trolling from boats. Baits: Feathers, spoons, plugs, jigs, weighted bucktails and bucktail flies; also live or cut fish and shrimp.

Pompano, Trachinotus carolinus. Size: To 8 lbs; ag. 1/3 - 2/3 lb; over 3 lbs unusual. Habits: Schooling and migratory. Pompano are caught within a few miles of the ocean beaches and in bays as well as the connecting inlets. Adults move offshore, some as far as 60 miles, to spawn. They feed on or a few feet off sand and mud bottom in water warmer than 65°F. Many die when trapped in water colder than 60°F. Season: April or May — November or early December; best fishing September -- November. Fishing Methods: Bottom fishing, casting, live lining, chumming and jigging from shore; these methods plus trolling from boats. Baits: Shrimp, sand bugs, cut fish and clams; also small weighted bucktails, jigs and feathers.

MACKERELS, TUNAS AND BONITOS

Spanish Mackerel, Scomberomorus maculatus. Mackerel. See king mackerel for distinguishing features. Size: To 12 lbs; avg. 1/2 - 1 1/2 lbs; over 5 lbs unusual. Habits: Pelagic, schooling and migratory. Occur throughout the water column to depths of 80 ft in water warmer than 67°F. Spanish mackerel will pursue bait fish through inlets into estuaries. Season: Late April or May — November; best fishing in August and September. Fishing Methods: Casting, live lining, bottom fishing and jigging from shore; these methods plus trolling from boats. Most fish are caught within 4 miles of the beach and in or around inlets. Baits: Spoons, feathers, stripbait, weighted bucktails, plugs and jigs; also shrimp, squid and whole or cut fish.

King Mackerel, Scomberomorus cavalla. Kingfish, kings. King mackerel have scaled pectoral fins and the lateral line dips downward abruptly under the 2nd dorsal fin. In cotrast, Spanish mackerel have scaleless pectoral fins and the lateral line slopes downward gradually under the 2nd dorsal fin. Size: Largest recorded 103 lbs; tackle 78 3/4 lbs spring - run fish average 6-8 lbs, fall - run fish 15-20 lbs; over 40 lbs unusual. Habits: Pelagic, schooling and migratory. King mackerel occur over any type of bottom in salt water warmer than 67°-69°F. They often congregate over wrecks, high relief rock or coral bottom and around buoys. Although some occasionally venture close enough to shore to be caught from ocean piers, most occur offshore of the 50 ft bottom contour. Season: Late March or April — November or mid December; best fishing late April — early June and September — November. Fishing Methods: Most are caught by trolling from boats 5 to 15 miles offshore, some by casting or live lining from shore or boats. Fishing is especially good around the various Capes. Baits: Spoons, feathers, stripbait, feather-stripbait or skirt-stripbait combination, and plugs; also whole rigged mullet or ballyhoo, and live fish.

Little Tuna, Euthynnus alletteratus. Bonito, false albacore, rum jugs. Miscalled albacore. Size: To 26 lbs; avg. 6-10 lbs; over 20 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur in salt water warmer than 65°F. They travel in groups varying from three or four individuals to schools of many thouands. Although they occasionally venture close enough to shore to be caught from ocean piers, little tuna usually occur offshore of the 30 ft bottom contour. Season: Most are caught from mid May — November, but a few all year. Best fishing September — November. Fishing Methods: Most are caught by trolling and casting from boats; some by casting from shore. Baits: Feathers, stripbait, feather-stripbait or skirt-stripbait combination, spoons, jigs and plugs.

Skipjack Tuna, Katsuwonus pelamis. Oceanic bonito, bonito, striped egg. Size: To 45 lbs; tackle record 39 lbs 15 oz; avg. 5-9 lbs; over 20 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers usually occur near the surface in continental-shelf and oceanic water warmer than 63°F but offshore of the 90 ft bottom countour. Season: Late April or May — November; best fishing in September. Fishing Methods: Most are caught by trolling near the surface 5 to 20 miles from shore. Also caught by casting from boats. Baits: Feathers, stripbait, feather-stripbait or skirt-stripbait combination, spoons, jigs and plugs.

Atlantic Bonito, Sarda sarda. Bonito. Size: To 15 lbs; avg. 2-4 lbs; over 7 lbs unusual. Habits: Pelagic, schooling and migratory. These rapid swimmers occur in continental-shelf water. They feed mainly at or near the surface and often jump clear of the water when in pursuit of prey. Season: April or May — October; best fishing in June and early July. Fishing Methods:

Caught at or near the surface by trolling in water warmer than 65°F; some by casting, jigging and chumming from boats. Most are caught incidentally while fishing for other pelagic fishes. Baits: Feathers, spoons, plugs, jigs, stripbait, feather-stripbait or skirt-stripbait combination, and cut fish.

Wahoo, Acanthocybium solanderi. The moveable upper jaw, large number of dorsal fin spines (21-27) and the slightly forked tail separate the wahoo from other mackerels. Size: To over 150 lbs; tackle record 149 lbs; avg. 20-30 lbs; over 75 lbs unusual. Habits: Pelagic and migratory. These rapid swimmers occur in oceanic and continental-shelf water beyond the 100 ft bottom contour. They usually swim in small groups or singly. Often concentrate over high relief rock or coral bottom and wrecks. Season: Most are caught from May — October, but a few year round offshore in the Gulf Stream. Fishing Methods: Trolling and live lining from boats. Never abundant, wahoo are taken incidentally with other pelagic fishes. Baits: Whole rigged Spanish mackerel, squid, mullet and ballyhoo, or live fish; also spoons, feathers and stripbait.

PORGIES

Pinfish, Lagodon rhomboides. Bream, salt water bream. Miscalled sailors choice. Size: To 1 lb; avg. 1/4 - 1/3 lb; over 3/4 lb unusual. Habits: Occur in salt, brackish and a few in nearly fresh water. Small fish remain all year in shallow estuaries, especially those abounding with sea grasses. Large fish spend the warm months in shallow estuaries but move offshore during cold months to spawn. Feed on or near bottom. Season: Taken all year; best fishing May — October. Fishing Methods: Bottom fishing from shore or boat. Most are caught incidentally with other bottom fishes. Baits: Small pieces of cut fish, worm, clam and shrimp. Pinfish are often used as live or dead bait for other fishes.

Scup, Stenotomus chrysops. Porgy, sea porgy, southern porgy (formerly considered a separate species, S. aculeatus). Size: Largest recorded 5 lbs; avg. 1/4 - 1/3 lb; over 3/4 lb unusual. Habits: These gregarious fish occur on mud, sand, gravel, coral or rock bottom and around pilings, wrecks or rubble in depths of at least 200 ft. Usually near bottom during daylight but move towards mid-depths at night. Season: Most are caught April — October. Fishing Methods: Bottom fishing, live lining and chumming from shore and boats. Baits: Shrimp, clams, squid, worms, cut fish and small crabs.

Red Porgy, Pagrus sedecim. Pink porgy. Miscalled silver snapper and Charleston snapper. Size: To over 13 lbs; avg. 2-5 lbs; over 8 lbs unusual. Habits: These bottom feeders occur on high relief rock or coral bottom in depths of 30 to 400 ft. Season: All year, but most are caught from March -- November in depths of 60-180 ft. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Cut fish, squid, clams and worms.

Jolthead Porgy, Calamus bajonado. Porgy. Small fish do not possess the characteristic blunt head. Except for the sheepshead, this is the largest fish in the porgy family occurring along the southeastern coast. Size: To over 17 lbs; avg. 1-2 lbs; over 10 lbs unusual. Habits: These bottom feeders occur in depths to at least 150 ft on mud and sand bottom but prefer the high relief provided by coral or rock outcrops. Often around wrecks or rubble. Season: Most are caught from April -- October, but a few all year. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Shrimp, clams, squid, cut fish and crabs.

Whitebone Porgy, Calamus leucosteus. Porgy. Miscalled silver snapper. Size: To over 5 lbs; avg. 1/2 - 1 lb; over 3 1/2 lbs unusual. Habits: These bottom feeders occur on sand and rock bottom, especially with high relief, and around wrecks in depths of 30 to 300 ft. Small ones sometimes found inshore of the 30 foot contour. Season: Most are caught from April -- October, but a few all year. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Shrimp, cut fish, squid and clams.

Sheepshead, Archosargus probatocephalus. Sheephead. Size: To 30 lbs; avg. 2-4 lbs; over 10 lbs unusual. Habits: Aggregate in salt and brackish water on sand, shell, gravel or rock bottom and around bridge abutments, jetties, breakwaters, rock piles and wrecks. Feed on or near bottom from a few feet below the tide-line to depths of at least 100 ft. Season: Most are caught from March -- October, but a few all year. Fishing Methods: Many are caught by bottom fishing and chumming from boats or shore, some by jigging from boats or shore. Baits: Crabs, clams, shrimp and sand bugs; also small jigs and weighted bucktails.

SNAPPERS

Red Snapper, Lutjanus aya. Snapper, American snapper, American red snapper. Size: To 40 lbs; avg. 5-8 lbs; over 25 lbs unusual. Habits: These bottom feeders aggregate on or a few feet above mud, sand, gravel, coral or rock bottom to depths of 800 ft or more. They often congregate on high relief rock or coral outcrops encrusted with living organisms. Most occur beyond the 60 ft bottom contour. Season: All year in depths of 150 ft or more;

during summer in shallower water. Best fishing for small ones in April and May, for large ones in July and August. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Squid, cut fish, shrimp and crabs.

Vermilion Snapper, Rhomboplites aurorubens. Snapper, beeline snapper, California red snapper. Size: To over 9 lbs; avg. 3/4 - 1 1/2 lbs; over 5 lbs unusual. Habits: These bottom feeders aggregate on mud, sand, gravel, coral or rock bottom in depths of 90 to 350 ft. They often concentrate on high relief rock or coral outcrops and wrecks, especially if encrusted with living organisms. Season: All year. Fishing success seems to be influenced by weather and not the availability of fish. Fishing Methods: Bottom fishing from anchored or drifting boats. Baits: Squid, cut fish, shrimp and clams.

SPADEFISHES

Atlantic Spadefish, Chaetodipterus faber. Spadefish, angelfish, porgy, moonfish. Size: To 16 lbs; avg. 1-3 lbs; over 10 lbs unusual. Habits: They aggregate in salt water on sand, shell, coral or rock bottom and around buoys, wrecks, rock piles, bridge abutments, pilings, jetties and breakwaters. During warm months most occur inshore of the 90 ft bottom contour; during cold months some retreat further offshore. Season: April — November. Fishing Methods: Bottom fishing from boats or shore. Baits: Clams, worms, shrimp, crabs and cut fish.

TARPON AND LADYFISH

Tarpon, Megalops atlanticus. Silver king, sprat. Size: To over 350 lbs; tackle record 283 lbs; avg. 20-50 lbs; over 150 lbs unusual. Habits: Pelagic and migratory. Occur over any type of bottom in salt and brackish water, sometimes in fresh water. Although durig migrations some are 10 miles or more offshore, they usually occur in estuaries, inlets and within 3 miles of ocean beaches. Tarpon feed mainly at night in water warmer than 66^{F}. Season: April — October or early November; best fishing July — September. Fishing Methods: Live lining, chumming and casting from shore; these methods plus trolling from boats. Baits: Live mullet, spot, pinfish, croaker, kingfish, shrimp and crabs or squid and cut fish; also spoons, plugs, weighted bucktails and bucktail flies.

TRIPLETAIL

Tripletail, Lobotes surinamensis. Size: To over 30 lbs; avg. 4-8 lbs; over 20 lbs unusual. Habits: Occur from the surface to the bottom in depths of a few to 200 ft or more. These fish usually occur singly or in small groups. Small ones enter inlets and estuaries; large ones tend to remain in the ocean. Tripletail frequent buoys, floating debris, wrecks and underwater obstructions. Season: April — October or November. Fishing Methods: Bottom fishing, jigging, casting and live lining from boats; a few are taken by these methods from shore. Baits: Shrimp, cut fish, clams, squid and live fish; also weighted bucktails, jigs and plugs.

CRABS

Blue Crab, Callinectes sapidus. Crab, blue claw crab. Males are called Jimmies, females sooks, those bearing eggs, sponge crabs. Crabs about to shed their shells are called shedders or peelers. Immediately after shedding their shells, they are called soft crabs. Size is usually expressed as the width of the shell across the back measured from spine tip to spine tip. Size: To 10 inches; avg. 5 1/2 - 6 1/2 inches; over 9 inches unusual. Habits: Occur on mud, sand, sand-shell and gravel bottom, in salt, brackish and sometimes fresh water. Especially abundant in estuaries and the mouths of streams or rivers around sea grass. During warm months crabs frequent shallow water; during cold months they seek deep water and may embed in mud. Active in water warmer than 50°F. Large males tend to concentrate in the upper reaches of creeks and rivers, adult females in sounds and bays. Season: Most are caught from march -- November, but a few all year. Check state laws governing size limit and the taking of egg-bearing females. Fishing Methods: Hand lines or crab traps from shore or boats. Baits: Whole and cut fish or scrap meat.

APPENDIX VII-B
Checklist of Fishes in South Carolina
(Poole, 1978)

Terms and Abbreviations

Northern Georgia.	That coastal area of Georgia north of St. Catherine's Sound.
Central Georgia.	That coastal area of Georgia between St. Catherine's Sound and Altamaha Sound.
Southern Georgia.	That coastal area of Georgia south of Altamaha Sound.
Probable.	This indicates that a species has not been recorded from SC, but has been recorded from surrounding states. This will be denoted by an asterisk before the species name.
Possible.	This indicates that a species has not been recorded from SC, but has been collected from Georgia.
Coastal Waters.	Oceanic waters seaward of the surf zone to approximately the continental shelf break.
Inshore Waters.	Oceanic waters in the surf zone.
Offshore Waters.	Blue waters seaward of the continental shelf break and under the influence of the Gulf Stream.

AFS	American Fisheries Soc. 1970 list	NI	North Inlet (Georgetown Co.)
BBL	Bears's Bluff Lab	OS	offshore
ChM	Charleston Museum	PRS	Port Royal Sound (Beaufort Co., SC)
esp.	especially	SC	South Carolina
fms	fathoms	SCWMRD	South Carolina Wildlife and Marine Resources Dept.
GMBL	Grice Marine Biological Lab, Charleston Co.		
KI	Kiawah Island	SE	southeast
cp	coastal plain	SW	southwest
usu.	usually	*	probable occurrence

Class Chondrichthyes

Order Squaliformes

Family Orectolobidae

Ginglmostoma cirratum (Bonnaterre). Nurse shark. Marine. Coastal waters. Occasional visitor, sometimes occurs in summer. (Bearden, 1965).

Family Odontaspididae

Odontaspis taurus (Rafinesque). Sand tiger. Marine. Close to shore, near bottom. Often found in tidal streams and inlets. Common in coastal waters April-Oct. (Bearden, 1961, 1965).

Family Alopiidae

Alopias vulpinus (Bonnaterre). Thresher shark. Marine. One specimen recorded April 1949 near the horn buoy in Charleston Harbor by E. Milby Burton. Reported by Dahlberg in Ga. as pelagic, but sometimes found inshore. (Bearden, 1965; Dahlberg, 1975).

Family Lamnidae

Carcharodon carcharias (Linnaeus). White shark. Marine. Several specimens recorded in April and May 1950 off Cape Romain, by E. Milby Burton. Dahlberg in Ga. reports it as mainly pelagic, but sometimes found inshore. (Bearden, 1965; Dahlberg, 1975).

Cetorhinus maximus (Gunnerus). Basking shark. Marine. One record: mid-April 1965 near Winyah Bay south jetty. This is its most southern record on the U. S. Atlantic coast. (Bearden, 1965).

Family Carcharhinidae

Aprionodon isodon (Valenciennes). Finetooth shark. Marine. Occasional in surf. Common in coastal waters. In Ga., common on coast in warmer months; July-Sept. (Bearden, 1965; Cupka, 1972; Dahlberg, 1975; Turner and Johnson, 1972).

Carcharhinus acronatus (Poey). Blacknose shark. Marine. NC - Brazil and Gulf of Mexico. One record: one taken Aug. 1964 at mouth of Dewee's Inlet. (Bearden, 1965; Dahlberg, 1975).

Carcharhinus leucas (Valenciennes). Bull shark. Marine-fresh. Occasional, although appears to be not uncommon in some years. According to Stewart Springer, it was frequently taken by commercial fishers prior to 1950, and there was a large run of sizable bull sharks in 1937. (Bearden, 1965).

Carcharhinus limbatus (Valenciennes). Blacktip shark. Marine to brackish. Very often ascend rivers to moderately brackish water. (Bearden, 1961, 1965).

Carcharhinus milberti (Valenciennes). Sandbar shark. Marine. Shallow inshore water, along beaches. One of most abundant shark species. (Bearden, 1961, 1965).

Galeocerdo cuvieri (Peron and Lesueur). Tiger shark. Marine. Fairly frequent summer visitor. In open ocean usually found near surface. (Bearden, 1961, 1965).

Hypoprion signatus Poey. Night shark. Marine. Coastal waters, inlets. Occasional. (Bearden, 1965).

Mustelus canis (Mitchill). Smooth dogfish. Marine. Bottom fish, usually in shallow inshore waters. Young born alive, spring, summer. (Bearden, 1961).

Negaprion brevirostris (Poey). Lemon shark. Marine. Common inshore but sometimes found well offshore. In Ga., common on coast in warmer months, June-Sept. (Bearden, 1965; Cupka, personal communication; Dahlberg, 1975).

Rhizoprionodon terraenovae (Richardson). Atlantic sharpnose shark. Marine. Poly-eu. 27.3-28.2°C. Bottom fish. Shallow coastal waters, tidal sounds, rivers, inlets, estuaries. Mud, sand, shell substrate. Common May-Nov. (Bearden, 1961, 1965; Shealy, 1974; Shealy et al., 1974).

Family Sphyrinidae

Sphyrna lewini (Griffith and Smith). Scalloped hammerhead. Marine. Reported from NI by Cain and Dean, and one reported June 1961 one mile off St. Helena's Sound (Beaufort Co.). Immature occur inshore with S. zygaena during warmer months. Large specimens, OS. Small specimens common in Ga. in warmer months. (Bearden, 1965; Cain and Dean, unpublished; ChM, cards; Dahlberg, 1975).

Sphyrna mokarran (Ruppell). Great hammerhead. Marine. Coastal waters and open ocean. NI. (Cain and Dean, unpubl; Cupka, personal communication).

Sphyrna tiburo (Linnaeus). Bonnethead. Marine. Shallow water in sounds, rivers, close to beach. Common during warmer months. April-Nov. (Bearden, 1961, 1965).

Sphyrna zygaena (Linnaeus). Smooth hammerhead. Marine. Polyhaline. Larger specimens almost always OS. Smaller specimens frequent inshore waters in spring and summer. Usually swims near surface. (Bearden, 1961, 1965).

Family Squalidae

Squalus acanthias Linnaeus. Spiny dogfish. Marine. Coastal waters, estuaries. Bottom fish; sand, shell substrate. Common Dec.-March where water is 15°C. Mostly pregnant females inshore. (Bearden, 1965; Shealy, 1974; Shealy et al., 1974).

Order Rajiformes

Family Pristidae

Pristis pectinata Latham. Smalltooth sawfish. Marine. Coastal waters. Rare visitor. (Bearden, 1965).

Family Rhinobatidae

Rhinobatos lentiginosus (Garman). Atlantic guitarfish. Marine. Coastal waters. Occasional in warmer months. Ga., uncommon; occurring inshore May - Sept. (Bearden, 1965; Dahlberg, 1975).

Family Torpedinidae

Narcine brasiliensis (Olfers). Lesser electric ray. Coastal waters. Four records between 1932-1958. One record from SC coast in Jan. 1961, and one in Jan. 1973. (Bearden, 1965; ChM, file; GMBL).

Family Rajidae

Raja eglanteria Bosc. Clearnose skate. Marine. Poly-eu; usu. 25°/oo. Bottom fish. Coastal waters. Common all year, esp. late fall-early spring. NI. Spawns summer. (Bearden, 1961, 1965; Cain and Dean, unpubl.).

Raja erinacea Mitchill. Little skate. Marine. NC. Known from the Carolinas to Halifax. Prefers shallow water, sandy substrate. Eggs laid in summer. (Breder, 1948; Johnson, unpubl.).

Family Dasyatidae

Dasyatis americana Hildebrand and Schroeder. Southern stingray. Marine. Euhaline. Coastal waters, intertidal creeks. Common April - Nov. in coastal waters. (Bearden, 1965; Cain, 1973).

Dasyatis centroura (Mitchill). Roughtail stingray. Marine. Coastal waters. Common; more common OS. Considered rare until recently. (Bearden, 1965).

Dasyatis sabina (Lesueur). Atlantic stingray. Marine - fresh. 17.1-27.5°C. Tidal rivers, sounds, estuaries, intertidal creeks, OS. Abundant all year, esp. night. Prefers mud, mud-sand bottom. Does not frequent intertidal areas during daylight. (Bearden, 1961; 1965; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Dasyatis sayi (Lesueur). Bluntnose stingray. Marine. Coastal waters. Common April - Nov. Occasional, surf zone. (Bearden, 1965; Cupka, 1972).

Gymnura micrura (Bloch and Schneider). Smooth butterfly ray. Marine. Euryhaline, 1.1-28.0°/oo. Coastal waters, estuaries. Bottom fish; sand, shell, mud substrate. Common May - Sept., where > 25°/oo. (Bearden, 1965; Shealy, 1974; Shealy et al., 1974).

Family Myliobatidae

Aetobatus narinari (Euphrasen). Spotted eagle ray. Marine. Coastal waters. Occasional. (Bearden, 1965).

Myliobatis freminville Lesueur. Bullnose ray. Coastal waters. Not uncommon. (Bearden, 1965).
Myliobatus goodei Garman. Southern eagle ray. Coastal waters. Rare. This is its northern limit. (Bearden, 1965).
Rhinoptera bonasus (Mitchell). Cownose ray. Marine. Bottom fish. Coastal waters, estuaries. Common April - Oct. (Berden, 1965; Shealy et al., 1974).

Family Mobulidae
Manta birostris (Walbaum). Atlantic manta. Marine. Common in coastal waters summer in mid and late 1800's. Now uncommon. (Bearden, 1965).
Mobula hypostoma (Bancroft). Devil ray. Marine. One record: one taken in 1850's from Charleston Harbor. (ChM, files).

Class Osteichthyes

Order Acipenseriformes

Family Acipenseridae
Acipenser brevirostrum Lesueur. Shortnose sturgeon. Marine. According to Smith, it is comparatively rare, and doubtless occurs in NC. Breder gives its range as Fla. - Cape Cod saying it is less common than *A. oxyrhynchus*. Dahlberg lists its range as Fla. - Canada. Ga., primarily in tidal waters, but does go into fresh water. Its habits are similar to those of *A. oxyrhynchus*. One SC record in ChM: June 1935, one specimen. (Breder, 1948; ChM, file; Dahlberg, 1975; Smith, 1907).
Acipenser oxyrhynchus Mitchill. Atlantic sturgeon. Marine - fresh. 16.2-29.9°C. Coastal waters, sounds, estuaries, rivers. Bottom fish; sand, shell, mud substrate. Common. Anadromus, entering sounds and rivers as far as tidal reach to spawn in fresh water, spring and summer. (Bearden, 1961; Breder, 1948; Shealy, 1974; Shealy et al., 1974).

Order Semionotiformes

Family Lepisoteidae
Lepisosteus oculatus (Winchell). Spotted gar. Coastal waters. (Bearden, 1961).
Lepisosteus osseus (Linnaeus). Longnose gar. Marine - fresh. 9.1-29.9°C. Coastal waters, estuaries, coastal zone streams, intertidal creeks. Bottom fish; sand, shell, mud bottom. Common all year. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Order Amiiformes

Family Amiidae

Amia calva Linnaeus. Bowfin. Fresh. Dark but clear coastal zone streams. NI. Sand, mud substrate. (Anderson, 1960; Cain and Dean, unpubl.).

Order Elopiformes

Family Elopidae

Elops saurus Linnaeus. Ladyfish. Marine - fresh. Close to shore, estuaries, intertidal creeks, sounds, tidal rivers, coastal zone streams. Sand, shell, mud substrate. Common, summer. (Anderson, 1960; Bearden, 1961; Cain, 1973).

Megalops atlantica Valenciennes. Tarpon. Marine. Around piers, in coastal streams and inlets, spring through fall. Ga., caught on beaches in warmer months; juveniles occur in low and high salinity tidal pools and creeks, July - Nov. (Bearden, 1961; Dahlberg, 1975).

Family Albulidae

*Albula vulpes (Linneaus). Bonefish. Marine. From all warm seas extending north to Cape Cod and Long Island. (ChM files).

Order Anguilliformes

Family Anguillidae

Anguilla rostrata (Lesueur). American eel. Marine - fresh. 15.6-32.2°C. Coastal waters, sounds, tidal rivers, estuaries, intertidal creeks, coastal zone streams. Usually around docks, submerged objects. Bottom fish, mud, sand, shell substrate. Common. Migrate to Bermuda in warmer months, spawn, die. larvae migrate back up coast, move inland to fresh water, complete life cycle. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Family Muraenidae

*Gymnothorax nigromarginatus (Girard). Blackedge moray. Marine. NC, around rocks in shoal water. Ga., OS reefs. (Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Muraena retifera Goode and Bean. Reticulated moray. Marine. NC. Known from off SC coast. In ChM, there is one record in 20 fms. SE of Charleston Sea Buoy in Feb. 1958. Tends to keep in deeper water. (Breder, 1948; ChM, files; Johnson, unpubl.).

Family Congridae

Conger oceanicus (Mitchill). Conger eel. Marine - fresh. Coastal waters, estuaries. Bottom fish; mud, sand substrate. Common. Ga., largely OS. (Bearden, 1961; Dahlberg, 1975; Shealy, 1974).

Family Ophichthidae

Myrophis punctatus Lutken. Speckled worm eel. Marine. NI. Ga., rare on coast. (Cain and Dean, unpubl.; Dahlberg, 1975).

Ophichtus gomesi (Castelnau). Shrimp eel. Marine. Two records from ChM: one caught by BBL, June 1961 at Wadmalaw River off Martin's Point Dock; one caught by BBL July 1961 at We Creek near Bear's Bluff. One rcord from GMBL: one caught July 1973 in breakers off Isle of Palms (Charleston Co.) in muddy water. (ChM, cards; GMBL).

Ophichthus ocellatus (Lesueur). Palespotted eel. Marine. Several records from inshore SC in ChM. NC. Ga., occasionally taken by trawling; Mahood reports this genus from inshore, but does not list species present. (ChM, files; Dahlberg, 1975; Johnson, unpubl.; Mahood, 1974).

Order Clupeiformes

Family Clupeidae

Alosa aestivalis (Mitchill). Blueback herring. Marine - fresh. 11.5-29.0°C. Surf zone, estuaries, intertidal creeks. Bottom fish; sand, shell, mud, silt substrate. Very common. Occasional in surf zone. Ga., anadromous, spring in large rivers. (Cain, 1973; Cupka, 1972; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Alosa mediocris (Mitchill). Hickory shad. Marine - fresh. One record in ChM: Jan. 1964, PRS. In NC, common in coastal waters; anadromous, spring; common in salt water sounds, winter. Northern Ga., Sept. - Dec. in creeks and inshore waters; anadromous in large rivers, spring. (ChM, cards; Dahlberg, 1975; Johnson, unpubl.; Mahood, 1974; Smith, 1907).

Alosa pseudoharengus (Wilson). Alewife. Marine - fresh. Two records in ChM: six caught Jan. 1961 in Ashepoo R. (Colleton Co.); four caught Jan. 1956 OS near KI. NC. According to Smith, Ga. and SC are possible southern limits, the fish occurring here rarely. According to Breder, it is known from Nova Scotia - Carolinas. Anadromous, April, May. Young return to ocean by fall. (Breder, 1948; ChM, cards; Johnson, unpubl.; Smith, 1967).

Alosa sapidissima (Wilson). American shad. Marine - fresh. 11.5-29.3°C. Coastal waters, coastal zone streams, estuaries. Bottom fish; sand, shell, mud substrate. Abundant, spawn, spring. Anadromous. (Anderson, 1960; Bearden, 1961; Shealy, 1974; Shealy et al., 1974).

*Brevoortia smithi Hildebrand. Yellowfin menhaden. Marine. Reported from NC by Johnson. Ga., May - Nov.; common along beaches, and also found in high marsh, tidal canals, tidal pools. Probably migrate south in winter. (Dahlberg, 1975; Johnson, unpubl.).

Brevoortia tyrannus (Latrobe). Atlantic menhaden. Marine - fresh. 12.0-31.0°C. Abundant, open ocean, estuaries, tidal rivers, coastal zone streams; occasional, surf zone. Very common, esp. winter. Sand, mud, shell substrate. Schools. Young in tidal creeks move seaward as they mature. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972; Shealy, 1974, Shealy et al., 1974).

Clupea harengus harengus Linnaeus. Atlantic herring. Marine. NC. Northern Ga., Sept. - Dec. in creeks and inshore waters. Smith and Breder report Cape Hatteras as its southern limit, although Breder states it straggles south in winter. However, in Mahood's study it is reported year round from southern Ga. One record from SC in GMBL file: four caught Sept. 1974 in Winyah Bay (Georgetown) on a mud substrate. (Breder, 1948; GMBL; Johnson, unpubl; Mahood, 1974; Smith, 1907).

Dorosoma cepedianum (Lesueur). Gizzard shad. Marine - fresh. 15.1-32.8°C. Coastal zone streams, estuaries, intertidal creeks. Mud, sand substrate. Common. Occasional in surf zone. May - Oct. (Anderson, 1960; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Dorosoma petenense (Gunther). Threadfin shad. Marine - fresh. 16.6-29.9°C. Bottom fish; sand, shell, mud, silt substrate. Common. Represented by a life stage each month in estuaries. Probably also along beaches, as in Ga. (Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Etrumeus teres (DeKay). Round herring. Marine. NC. Central Ga., close inshore waters, March. One record from SC in ChM: one taken May 1962, OS near KI. One record from GMBL: one taken Oct. 1974 OS. (ChM, cards; GMBL; Johnson, unpubl.).

Harengula pensacolae Goode and Bean. Scaled sardine. Marine-fresh. NC. Ga., June - Oct.; occasional at beaches and lower reaches of estuaries; rare in high marsh, more abundant OS and south. One record from SC in ChM: 36 caught Aug. 1966 on SW side of DeVeaux Bank (Charleston). (ChM, cards; Dahlberg, 1975; Johnson, unpubl.).

Opisthonema oglinum (Lesueur). Atlantic thread herring. Marine - fresh. 12.7-30.1°C. Estuaries, intertidal creeks. Sand, shell, mud, clay, silt substreate. Common. Aug. - Jan. Also along beaches, as in Ga. (Cain, 1973; ChM, files; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Family Engraulidae

Anchoa hepsetus (Linnaeus). Striped anchovy. Marine. Meso-poly-eu. 12.8-30.5°C. Abundant April - Nov. In surf, more abundant late spring, summer. In estuaries, intertidal creeks, more abundant fall. Occasional in coastal zone streams. Sand, shell, mud, silt substrate. Seasonal migrant. (Anderson, 1960; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Anchoa mitchilli (Valenciennes). Bay anchovy. Marine - fresh. 10.3-31.4°C. Surf zone, estuaries, intertidal creeks, coastal zone streams. Sand, shell, mud, clay, silt substrate. Abundant, esp. June - Oct., (surf zone) and fall, spring (estuaries). Resident. Spawns April - Sept., peak July. Represented by a life stage every month in estuaries. (Anderson, 1960; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Order Salmoniformes

Family Unbridae

Umbra pygmaea (DeKay). Eastern mudminnow. Fresh. Coastal zone streams. Clear, dark but clear water. Mud, sand substrate. Not uncommon. (Anderson, 1960).

Family Esocidae

Esox americanus americanus Gmelin. Redfin pickerel. Fresh. 17.8-30°C. Coastal zone streams. Clear, dark but clear, muddy water. Sand, mud, organic debris substrate. Abundant. (Anderson, 1960).

Esox niger Lesueur. Chain pickerel. Fresh. 20-23.9°C. Coastal zone streams. Clear, dark but clear, muddy water. Mud, sand, organic debris substrate. Common. (Anderson, 1960).

Order Myctophiformes

Family Synodontidae

Saurida brasiliensis Norman. Large scale lizardfish. Marine. One record in ChM; Sept. 1955 SE of North Edisto River Sea Buoy. (ChM, cards).

Synodus foetens (Linnaeus). Inshore lizardfish. Marine. Meso-poly. 25.5-30°C. Close inshore, estuaries, brackish coastal zone streams. Bottom fish; sand, mud, silt substrate. Occasional. Ga., occasional; April - Nov.; more common in coastal waters and OS than close inshore. (Anderson, 1960; ChM, files; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Synodus intermedius (Agassiz). Sand diver. Marine. One record in ChM: 5 caught Feb. 1958 SE of North Edisto River Sea Buoy in 37 fms. (ChM, files).

Synodus poeyi Jordon. Offshore lizardfish. Marine. One record in ChM: one taken Sept. 1955 SE of North Edisto River Sea Buoy, 30 fms. (ChM, cards).

Synodus synodus (Linnaeus). Red lizardfish. Marine. Bottomfish. NC, possibly SC. (Johnson, unpubl.).

Order Cypriniformes

Family Cyprinidae

Cyprinus carpio Linnaeus. Carp. Fresh. One record at GMBL: one taken Jan. 1973, near Magnolia Beach (Georgetown Co.), rough bottom. (GMBL).

Notemigonus crysoleucas (Mitchill). Golden shiner. Fresh. 23.3-35°C. Coastal zone streams. Dark but clear, muddy water. Sand, clay, mud substrate. Abundant. (Anderson, 1960).

Notropis altipinnis (Cope). Highfin shiner. Fresh. NC, common in clear tributaries of Cape Fear. There are six SC records of this fish in the ChM. (ChM, files; Johnson, unpubl.; Smith, 1907).

Notropis chalybaeus (Cope). Ironcolor shiner. Fresh. Coastal zone streams. Dark but clear water. Sand, mud substrate. Abundant. (Anderson, 1960).

Notropis cummingsae Myers. Dusky shiner. Fresh. Coastal zone streams. Clear water. Sand, mud substrate. Abundant. (Anderson, 1960).

Notropis hypselopterus (Gunther). Sailfin shiner. Fresh. Coastal zone streams. Clear water. Abundant. (Anderson, 1960).

Notropis maculatus (Hay). Taillight shiner. Fresh. Coastal zone streams. Dark but clear water. Sand, mud substrate. (Anderson, 1960).

Notropis petersoni Fowler. Coastal shiner. Fresh. Coastal zone streams. Clear water. Sand, mud substrate. Common. (Anderson, 1960).

Family Catostomidae

Erimyzon oblongus (Mitchill). Creek chubsucker. Fresh. Coastal zone streams. Dark but clear water. Sand, mud, organic debris substrate. Common. (Anderson, 1960).

Erimyzon sucetta (Lacepede). Lake chubsucker. Fresh. 24.4-35°C. Coastal zone streams. Dark but clear water. Sand, mud substrate. Common. (Anderson, 1960).

Order Siluriformes

Family Ictaluridae

Ictalurus catus (Linnaeus). White catfish. Fresh. 11.6-31.4°C. Estuaries. Abundant. Occasional in coastal zone streams. Bottom fish; sand, shell, mud substrate. Resident. Spawns May - July, peak June. (Anderson, 1960; Shealy, 1974; Shealy et al., 1974).

Ictalurus furcatus (Lesueur). Blue catfish. Fresh. In ChM there are 3 records stating the SCWMRD estuarine survey team collected a total of 21 fish in North Santee River. (ChM, cards).

Ictalurus melas (Rafinesque). Black bullhead. Fresh. Bottom fish in estuaries. One taken by Shealy in Jan. 1973 at the Tee, Cooper River (Station C001). (Shealy, 1974).

Ictalurus natalis (Lesueur). Yellow bullhead. Fresh - brackish. Coastal zone streams. Dark but clear, clear, milky, muddy water. Mud, sand substrate. Common. Occasional in estuaries. (Anderson, 1960; Shealy, 1974).

Ictalurus nebulosus (Lesueur). Brown bullhead. Fresh. olig 8.7-28.8°C. Estuaries. Bottom fish, sand, shell, mud substrate. Not uncommon. Occasional in coastal zone streams. Feb. and March in estuaries. (Anderson, 1960; Shealy, 1974; Shealy et al., 1974).

Ictalurus platycephalus (Girard). Flat bullhead. Fresh. Two collected at 0.1°/oo 14.2°C in Cooper River at the Tee (Station C001) by Shealy, March 1973. More common inland on SC cp. (ChM, files; Shealy, 1974).

Ictalurus punctatus (Rafinesque). Channel catfish. Fresh 8.7-27.8°C. Estuaries. Bottom fish; sand, shell, mud substrate. Common, esp. Dec. Collected during Shealy study Feb. - June, Nov., Dec. (Shealy, 1974; Shealy et al., 1974).

Noturus gyrinus (Mitchill). Tadpole madtom. Fresh. Coastal zone streams. Dark but clear water. Mud substrate. Not uncommon. (Anderson, 1960).

Noturus insignia (Richardson). Margined madtom. Fresh. Pa. - SC. Abundant in NC. Inhabits streams. (Johnson, unpubl.; Smith, 1907).

Family Ariidae

Arius felis (Linnaeus). Sea catfish. Marine - fresh. 16.8-33.3°C. Along beaches, streams. Bottom fish; sand, shell, mud, clay substrate. Very common spring - fall. Schools. Often associates with gafftopsail catfish, Bagre marinus. Ga., adults common in deeper waters; autumn, winter, migrate to ocean. (Anderson, 1960; Bearden, 1961; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Bagre marinus (Mitchill). Gafftopsail catfish. Marine. Mesopoly. 18.6-30.1°C. Along beaches, in sounds, estuaries, rivers. Bottom fish; sand, shell, mud substrate. Common May to fall. Coastal zone streams, occasional. Spawns: June, July. (Anderson, 1960; Bearden, 1961; Shealy, 1974; Shealy et al., 1974).

Order Percopsiformes

Family Amblyopsidae

Chologaster cornuta Agassiz. Swampfish. Fresh. Coastal zone streams. Dark but clear water. Sand, clay, mud substrate. Occasional. According to Charleston News and Courrier, Feb. 21, 1954, found in muddy backwaters and ditches in swamps and low land areas. Probably a top feeder. More common further inland in SE cp. (Anderson, 1960; ChM, files).

Family Aphredoderidae

Aphredoderus sayanus (Gilliams). Pirate perch. Fresh. Coastal zone streams. Clear, dark but clear, muddy water. Mud, sand, organic debris substrate. Abundant. Also abundant further inland on SC cp. (Anderson, 1960; ChM, files).

Order Batrachoidiformes

Family Batrachoididae

Opsanus pardus (Goode and Bean). Leopard toadfish. Marine. US South Atlantic and Gulf coasts. NC. Ga., OS reefs. (Dahlberg, 1975; Johnson, unpubl.).

Opsanus tau (Linnaeus). Oyster toadfish. Marine fresh. 11.6-30.4°C. Coastal waters, estuaries, intertidal creeks. Occasional in coastal zone streams. Around docks, shell beds. Bottom fish; sand, shell, mud, clay bottom. Stays concealed in debris. Resident. Common, esp. warmer months. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Porichthys porosissimus (Valenciennes). Atlantic midshipman. Marine. Fowler reports one from Magnolia Beach. Several records from SC in ChM. Breder reports in range as SC - TX. NC. Ga., OS in association with reefs. (Breder, 1948; ChM, files; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Order Gobiesociformes

Family Gobiesocidae

Gobiesox strumosus Cope. Skilletfish. Marine. Poly. Estuaries, sounds, near shore. Bottom fish; sand, shell, mud substrate. Ga., in lower and middle reaches of estuareis, in association with oyster reefs in shallow and deep waters. (ChM, files and cards; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Order Lophiformes

Family Lophiidae

Lophius piscatorius Goosefish. Marine. One record in ChM: one taken march 1934 from a trawler off Stono Inlet. Probably a misidentified L. americanus, the western Atlantic species. (ChM, files).

Family Antennariidae

Antennarius ocellatus (Bloch and Schneider). Ocellated frogfish. Marine. Bottom fish. NC. Ga., shallow water and open shelf. SC, one reported from Charleston by Fowler, and one recorded May 1957 at Bloody Point, Calibogue Sound (Beaufort Co.) in ChM. (ChM, cards; Dahlberg, 1975; Fowler, 1945; Johnson unpubl.).

Antennarius scaber (Cuvier). Splitlure frogfish. Marine. Two records in ChM: three taken July 1958 SE of North Edisto River Sea Buoy; one taken off Charleston. (ChM, cards).

Histrio histrio (Linnaeus). Sargassumfish. Marine. Mass. - Bermuda and Rio de Janiero. Involuntarily distributed from tropical Atlantic with Sargassum from Gulf Stream. May be common as far as Mass. in summer. Ga., pelagic in Sargassum which oftens rafts onto beaches. NC. SC, three reported by Fowler and several records from inshore in ChM, but probably more common. Spawns July - Oct. (ChM, files; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Smith, 1907).

Family Ogocephalidae

Halieutichthys aculeatus (Mitchill). Pancake batfish. Marine. Records in ChM from OS and SE of North Edisto River Sea Buoy. (ChM, files).

Ogocephalus parvus Longley and Hildebrand. Roughback batfish. Marine. NI. In ChM two records from SC coast. (Cain and Dean, unpubl.; ChM, cards).

Ogocephalus radiatus (Mitchill). Polka-dot batfish. Marine. Several records in ChM from Horry, Charleston, Georgetown Cos., OS and inshore waters. (ChM, files).

Ogocephalus vespertilio (Linnaeus). Marine. Longnose batfish. Northern Ga., in sounds, Oct. SC, several records in ChM from Charleston area. (ChM, files; Mahood, 1974).

Order Gadiformes

Family Gadidae

Gadus morhua Linnaeus. Atlantic cod. Marine. In ChM records: three or four taken Jan. 1951 off Georgetown jetties. (ChM, files).

Merluccius bilinearis (Mitchill). Silver hake. Marine. Grand Banks, Canada - NY; most common between Capes Sable and Cod. Usually found over sandy or pebbly substrate. Spawns midsummer in moderately deep water. Vertical range: surface - 300 fms. Reported from NC by Johnson. Possibly SC. (Breder, 1948; Johnson, unpubl.).

Urophycis earlii (Bean). Carolina hake. Marine. Estuaries, creeks, sounds. Bottom fish; sand, shell substrate. Several taken in Shealy's study, and 3 inshore records from ChM. (ChM, cards and files; Shealy, 1974).

Urophycis floridanus (Bean and Dresel). Southern hake. Marine. Estuaries, close inshore. Bottom fish; sand, shell substrate. Ga., common in estuaries Jan. - May; abundant OS. SC, 3 taken in Shealy's study and one record in ChM. (ChM, cards; Dahlberg, 1975; Shealy, 1974).

Urophycis regius (Walbaum). Spotted hake. Marine. Estuaries, rivers, inlets, sounds. Bottom fish; sand, shell, mud, silt substrate. Abundant in estuaries Jan. - May. Ga., also abundant OS. (ChM, files; Dahlberg, 1974; Shealy, 1974; Shealy et al., 1974).

Family Ophidiidae

Ophidion grayi (Fowler). Blotched cusk-eel. Marine. One record in ChM: one taken Oct. 1964 2 miles OS KI. (ChM, cards).

Otophidium omostigmum (Jordan and Gilbert). Polka-dot cusk-eel. Marine. One record in ChM: one taken July 1958, in 18-23 fms. SE of North Edisto River Sea Buoy. (ChM, files).

Rissola marginata (DeKay). Striped cusk-eel. Marine. Poly-eu. Estuaries, intertidal creeks. Bottom fish; mud, sand substrate, usually sand. Ga., in deeper water of lower and middle reaches of estuaries coastal waters; rare on beaches. (Cain, 1973; Dahlberg, 1975; Shealy, 1974).

Order Atheriniformes

Family Exocoetidae

Cypselurus heterurus (Rafinesque). Atlantic flyingfish. Marine. Fowler and ChM records report if from the Charleston area and OS. NC. Ga., probably OS. Warm waters. (ChM, files; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Smith, 1907).

Euleptorhamphus velox Poey. Flying halfbeak. Marine. One record in ChM: one take July 1949 at Isle of Palms (Charleston, Co.). (ChM, files).

Hemiramphus brasiliensis (Linnaeus). Ballyhoo. Marine. Two records in ChM: July 1953 and 1951 in surf at KI and near Sullivan's Island (Charleston Co.). Central Ga., close inshore waters, Nov.; Mahood took none in northern Ga. (ChM, files; Mahood, 1974).

Hyporhamphus unifasciatus (Ranzani). Halfbeak. Marine. West Indian species, straggles as far north as Mass. NC; visitor, spring, summer. Abundant around sandy islands and shoals in Beaufort, NC. SC, several records in ChM; close inshore or regurgitated by sea birds. (Breder, 1948; ChM, cards and files; Johnson, unpubl.; Smith, 1907).

Parexocoetus brachypterus (Richardson). Sailfin flyingfish. Marine. Two records in ChM: one taken Aug. 1961 OS, and 3 taken Nov. 1955, SE of North Edisto River Sea Buoy. (ChM, cards).

Family Belonidae

Ablennes hians (Valenciennes). Flat needlefish. Marine. Not uncommon around Fla. Strays north to Mass. Ga., primarily OS, but may occur inshore. NC. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.).

Strongylura marina (Walbaum). Atlantic needlefish. Marine - fresh. Surf zone, intertidal creeks, coastal zone streams. Summer - early fall. Seasonal migrant. Occasional. (Anderson, 1960; Cain, 1973; Cupka, 1972).

Tylosurus acus (Lacepede). Agujon. Marine. One record at GMBL: one taken May 1975 at surface, 130° heading from "C" buoy off Charleston. Frequents coastal OS waters. (Cupka, personal communication; GMBL).

Family Cyprinodontidae

Cyprinodon variegatus Lacepede. Sheepshead minnow. Marine - fresh. Estuaries at lower salinities, coastal zone streams. Common. Occasional in surf zone and intertidal creeks. (Anderson, 1960; Cain, 1973; Cupka, 1972).

Fundulus chrysotus (Gunther). Golden topminnow. Fresh. Coastal zone streams. Dark but clear water. Mud substrate. Not uncommon. (Anderson, 1960).

Fundulus confluentus Goode and Bean. Marsh killifish. Marine - fresh. NI. In Ga., common in fresh water on Sapelo Island, and in low salinity creeks and pools. (Cain and Dean, unpubl.; Dahlberg, 1975).

Fundulus diaphanus (Lesueur). Banded killifish. Marine - fresh. NC, abundant on coast and in lower parts of rivers. Smith reports its southern limit as NC. One record from ChM: one taken Oct. 1934 at Waverly Mills (Georgetown Co.). May be more common in SC. (ChM, files; Smith, 1907).

Fundulus heteroclitus (Linnaeus). Mummichog. Marine - fresh. Coastal zone streams, intertidal creeks. Mud, sand substrate. Abundant. Gravid March, April; some gravid throughout year. Ga., found at beaches, high marsh, lower to upper estuary reaches; abundant in shallow water and not found in deep water. (Anderson, 1960; Cain, 1973; Dahlberg, 1975).

Fundulus majalis (Walbaum). Striped killifish. Marine. Eu. 7.6-28.2°C. Surf zone, intertidal creeks. Common, esp. summer in surf zone. In creeks, winter, spring only. Abundant, in coastal zone streams. Resident. Inshore migration in winter may be spawning run. (Anderson, 1960; Cain, 1973; Cupka, 1974).

Fundulus notti (Agassiz). Starhead topminnow. Fresh. Coastal zone streams. Milky, muddy, dark but clear water. Mud, sand, organic debris substrate. Common. (Anderson, 1960).

Lucania parva (Baird). Rainwater killifish. Marine - fresh. In ChM, several from Berkeley, Charleston, Horry Cos. (ChM, files).

Family Poeciliidae

Gambusia affinis (Baird and Girard). Mosquitofish. Marine - fresh. 15.6-35.0°C. Coastal zone streams. Clear, dark but clear, muddy, milky water. Mud, sand, organic debris substrate. Abundant. Ga., more abundant in fresh water, but also in high marsh, olig. creeks, tidal pools, tidal canals, and sometimes at beaches. (Anderson, 1960; Dahlberg, 1975).

Heterandria formosa Agassiz. Least killifish. Fresh. Coastal zone streams. 17.8-30°C. Clear, dark but clear water. Mud, sand substrate. Not uncommon. Known to go into brackish water. (Anderson, 1960; Dahlberg, 1975).

Poecilla latipinna (Lesueur). Sailfin molly. Marine - fresh. Coastal zone streams in dark but clear water. Mud, sand, organic debris substrate. Common. NI. In ChM, several records from ponds, tidal creeks, rivers in Charleston and Beaufort Cos. (Anderson, 1960; Cain and Dean, unpubl.; ChM, files).

Family Atherinidae

Labidesthes sicculus (Cope). Brook silverside. Euhaline. Coastal zone streams. Clear, dark but clear water. Mud, sand, organic debris substrate. Common. (Anderson, 1960).

Membras martinica (Valenciennes). Rough silverside. Marine. Euhaline. Along beaches, surf zone. Common, esp. spring; coastal zone streams, occasional. Inlets. Sand, mud stubstrate. Seasonal migrant. Ga., present year round inshore: beaches high marsh, lower reaches of estuaries. (Anderson, 1960; ChM, files; Cupka, 1972; Dahlberg, 1975).

Menidia beryllina (Cope). Tidewater silverside. Marine - fresh. Prefers lower salinities. Coastal zone streams. Common. Occasional in surf zone. Sand, mud substrate. NI. Ga., also in upper reaches of estuaries; present all year round. (Anderson, 1960; Cain and Dean, unpubl.; Cupka, 1972; Dahlberg, 1975).

Menidia menidia (Linnaeus). Atlantic silverside. Marine - brackish. 7.1-32.2°C. Surf zone, intertidal creeks, coastal zone streams. Sand, mud, silt substrate. Abundant, less abundant summer. Spawns early March - early June. Resident. (Anderson, 1960; Cain, 1973; Cupka, 1972; Shealy, 1974).

Order Beryciformes

Family Holocentridae

Holocentrus ascensionis (Osbeck). Squirrelfish. Marine. Common. Fla. - Brazil. Hides in holes and overhanging coral. NC. Ga., OS. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.).

Order Gasterosteiformes

Family Fistulariidae

Fistularia tabacaria Linnaeus. Bluespotted cornetfish. Marine. A West Indian species straggling as far north as Mass. NC, inshore. Ga., primarily OS, but reported from along the coast. Two records in ChM: one caught Oct. 1956 in 18-20'water off KI by a trawler, and one caught Sept. 1960 in PRS. (Breder, 1948; ChM, cards and files; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Fistularia villosa Klunzinger. Red cornetfish. Marine. Occurs uncommonly on SE coast of Fla., NC. (AFS, 1970; Johnson, unpubl.).

Family Syngnathidae

Hippocampus erectus Perry. Lined seahorse. Marine. Records in ChM and GMBL from Ashepoo River, NI, Calibogue Sound (Beaufort Co.) and from farther OS. NC. Ga., rare in estuaries, but probably common OS. (ChM, cards; Dahlberg, 1975; GMBL, Johnson, unpubl.).

Syngnthus floridae (Jordan and Gilbert). Dusky pipefish. Marine. Poly. Bottom fish. One taken in Shealy's study June 1973 over sandy substrate in Daeho River, North Edisto River Estuary. (Shealy, 1974).

Syngnathus fuscus Storer. Northern pipefish. Marine. Euhaline. Surf zone, coastal zone streams, estuaries. Mud, sand substrate. Occasional. (Anderson, 1960; Cupka, 1972; Shealy, 1974).

Syngnathus louisianae Gunther. Chain pipefish. Marine. Inlets, coastal zone streams in brackish water, along beaches. Mud, sand substrate. Not uncommon. (Anderson, 1960; Cain and Dean, unpubl.; ChM, file).

Order Perciformes

Family Centropomidae

Centropomus undecimalis (Bloch). Snook. Marine - fresh. NC. Ga., young occur in upper creeks, tidal pools, tidal ditches. June - Nov. SC, several records in ChM and GMBL from coastal ponds. (ChM, file and cards; Dahlberg, 1975; GMBL; Johnson, unpubl.).

Family Percichthyidae

Morone americana (Gmelin). White perch. Marine - fresh. Canada - SC. May be land locked, but salt water is apparently necessary for healthiest development. Permanent resident. Streams, coastal waters. Sluggish in colder months. Anadromous. NC, in Albemarle Sound, spawning begins April 1-10, continues for 10 days. Abundant in NC. (Breder, 1948; Johnson, unpubl.; Smith, 1907).

Morone saxatilis (Walbaum). Striped bass. Marine - fresh. Estuaries, coastal streams, close inshore in open ocean, large lakes, reservoirs. Sand, mud substrate. Common. (Bearden, 1961; Shealy, 1974).

Family Serranidae

Centropristis ocyurus (Jordan and Evermann). Bank sea bass. Marine. Gulf of Mexico to Fla. in deep water. Bottom fish. Ga., OS. NC. SC., ChM records list 3 specimens from SC coast. (Breder, 1948; ChM, cards; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Centropristis philadelphica (Linnaeus). Rock sea bass. Marine. Olig-meso-poly. 21-30°C. Estuaries, coastal zone streams, sounds, close to shore. Sand, shell, mud, clay substrate. Occasional. (Anderson, 1960; Shealy et al., 1974).

Centropristis striata (Linnaeus). Black sea bass. Marine. Meso-poly-eu. 10.3-29.2°C. Estuaries, large, deep intertidal creeks, sounds, near shore. Hard, sand, shell, mud substrate. Resident. Common, esp. around piers, wrecks, other submerged objects. Occasional in coastal zone streams. (Anderson, 1960; Berden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Diplectrum formosum (Linnaeus). Sand perch. Marine. NC. Ga., OS. Also, in Mahood's study it was taken in northern Ga., sounds, inshore waters, June. Smith and Fowler report it from SC. ChM has records of it from SC coast close inshore and OS. (Breder, 1948; ChM, cards; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Mahood, 1974; Smith, 1907).

Epinephelus morio (Valenciennes). Red grouper. Marine. According to Smith, Brazil - Fla., regularly extending to Mass. According to Breder, Brazil - Va., young straggling to Mass. NC. Ga., OS. SC, two records at GMBL: one taken July 1975 in Toomer Creek behind Capers Island (Beaufort Co.); one taken Aug. 1973 at 122° from Charleston Sea Buoy 2C. One record at ChM: one taken Feb. 1958 SE of North Edisto River Sea Buoy in 37 fms. The file records Holbrook, 1860 as stating "....it is exceedingly rare on the Carolina coast..." (Breder, 1948; ChM, file; Dahlberg, 1975; GMBL; Johnson, unpubl.; Smith, 1907).

Epinephelus nigritus (Holbrook). Warsaw grouper. Marine. NC. Ga., OS. Fowler reports one from Charleston and ChM has records of it from off SC. (ChM, files; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Epinephelus niveatus (Valenciennes). Snowy grouper. Marine. A West Indian species occasionally found as far north as Mass. NC. Ga., OS. One SC record at GMBL: one taken May 1957 SE of North Edisto River Sea Buoy. (Breder, 1948; Dahlberg, 1975; GMBL; Johnson, unpubl.).

Hypoplectrus unicolor (Walbaum). Butter hamlet. Marine. West Indies north to Florida Keys, according to Breder. Johnson reports it from NC. Prefers rocky localities. (Breder, 1948; Johnson, unpubl.).

Mycteroperca bonaci (Poey). Black grouper. Marine. West Indian species, straggles as far north as Mass. NC. Ga., OS. SC, one record in ChM: one taken Oct. 1960 in Abbapoola Creek (Charleston Co.) near Stono River. (ChM, cards; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Mycteroperca interstitialis (Poey). Yellowmouth grouper. Marine. NI. (Cain and Dean, unpubl.).

Mycteroperca microlepis (Goode and Bean). Gag. Marine. Several from off wharfs and trawlers in Charleston and Beaufort Cos. NI. (Cain and Dean, unpubl.; ChM, file).

**Mycteroperca phenax* Jordan and Swain. Scamp. Marine. Ga., OS. NC. (Dahlberg, 1975; Johnson, unpubl.).

Ocyanthias martinicensis (Guichenot). Roughtongue bass. Marine. NC. Possibly SC. (Johnson, unpubl.).

Serranus notospilus Longley. Saddle bass. Marine. One record in ChM: one taken Sept. 1955 SE of North Edisto River Sea Buoy. (ChM, cards).

Serranus subligarus (Cope). Belted sandfish. Marine. NC. SC, Fla., usu. in deeper water. (Johnson, unpubl.; Smith, 1907).

Family Grammistidae

Rypticus maculatus Holbrook. Whitespotted soapfish. Marine. One record at ChM: one taken July 1958 SE of North Edisto River Sea Buoy. One record at GMBL: two taken Sept. 1972 OS. (ChM, cards; GMBL).

Rypticus saponaceus (Bloch and Schneider). Greater soapfish. Marine. One record at ChM: one taken July 1958 SE of North Edisto River Sea Buoy, 18-23 fms. (ChM, files).

Family Centrarchidae

Acantharchus pomotis (Baird). Mud sunfish. Fresh. 17.8-27.8°C. Coastal zone streams. Clear, dark but clear water. Mud, sand, shell substrate. Common. (Anderson, 1960; ChM, files).

Centrarchus macropterus (Lacepede). Flier. Fresh. Coastal zone streams. Clear, dark but clear, muddy water. Sand, mud, clay, organic debris substrate. Abundant. Also abundant on inner SC cp. (Anderson, 1960; ChM, files).

Elassoma evergladei Jordan. Everglades pygmy sunfish. Fresh. Coastal zone streams. Dark but clear water. Mud substrate. Occasional. More common in inner SC cp. (Anderson, 1960; ChM, files).

Elassoma zonatum Jordan. Banded pygmy sunfish. Fresh. Coastal zone streams. Clear, dark but clear water. Mud, sand substrate. Common. Also common on inland SC cp. (Anderson, 1960; ChM, files).
Enneacanthus chaetodon (Baird). Blackbanded sunfish. Fresh. Coastal zone streams. Clear Water. Occasional. (Anderson, 1960).
Enneacanthus gloriosus (Holbrook). Bluespotted sunfish. Fresh. Coastal zone streams, rice fields. Clear, dark but clear water. Sand, shell, mud substrate. Not uncommon. (Anderson, 1960; ChM, files).
Enneacanthus obesus (Girard). Banded sunfish. Fresh. Coastal zone streams. Dark but clear water. Sand, shell, mud substrate. Common. (Anderson, 1960).
Lepomis auritus (Linnaeus). Redbreast sunfish. Fresh. Coastal zone streams. Milky clear, dark but clear water. Hard, mud, sand, organic debris substrate. Common. Occasional in estuaries. Also common on inner SC cp. (Anderson, 1960; ChM, files; Shealy, 1974).
Lepomis gibbosus (Linnaeus). Pumpkinseed. Fresh - brackish. Coastal zone streams. Dark, clear but dark water. Mud substrate. Occasional. (Anderson, 1960).
Lepomis gulosis (Cuvier). Warmouth. Fresh. 17.8-28.3°C. Coastal zone streams. Clear, dark but clear, muddy water. Mud, sand substrate. Common. (Anderson, 1960).
Lepomis macrochirus Rafinesque. Bluegill. Fresh - brackish. Coastal zone streams. Milky, clear, dark but clear water. Mud, shell, sand, organic debris substrate. Abundant. (Anderson, 1960).
Lepomis marginatus (Holbrook). Dollar sunfish. Fresh. Coastal zone streams. Dark but clear water. Mud, sand substrate. Common. (Anderson, 1960).
Lepomis microlophus (Gunther). Redear sunfish. Fresh. One record in ChM: one taken probably in the late 50's or early 60's, presumably in SC coastal zone stream. (ChM, cards).
Lepomis punctatus (Valenciennes). Spotted sunfish. Fresh. Coastal zone streams. Dark but clear water. Mud, sand substrate. Not uncommon. (Anderson, 1960).
Micropterus salmoides(Lacepede). Largemouth bass. Fresh. Coastal zone streams. Milky, clear, dark but clear water. Mud, sand substrate. (Anderson, 1960).
Pomoxis annularis Rafinesque. White crapple. Fresh. Breder reports a single record of it on east U. S. coast in Chesapeake Bay region. Introduced onto the Atlantic slope by humans. Johnson reports it from NC. Possibly SC. (Breder, 1948; Johnson, unpubl.).
Pomoxis nigromaculatus (Lesueur). Black crappie. Fresh. Coastal zone streams. Dark but clear water. Mud substrate.

Occasional. (Anderson, 1960).

Family Percidae

Etheostoma fusiforme (Girard). Swamp darter. Fresh. Coastal zone streams. Clear, dark but clear, muddy water. Mud, sand substrate. (Anderson, 1960).

Etheostoma olmstedi Storer. Tessellated darter. Fresh-brackish. Smith and Breder give its range as Mass.-NC. Johnson report it from NC. Coastal streams. Possibly SC. (Breder, 1948; Johnson, unpubl.; Smith, 1907)

Etheostoma serriferum (Hubbs and Cannon). Sawcheek darter. Fresh. Coastal zone streams. Dark but clear water. Mud substrate. Occasional. (Anderson, 1960).

Perca flavescens (Mitchell). Yellow perch. Fresh. Up tidal rivers in estuaries. Hard mud substrate. Three taken by Shealy, Feb., March 1973 at the Tee, Cooper River (Station C001). (Shealy, 1974).

Family Priacanthidae

Pristigenys alta (Gill). Short bigeye. Marine. A West Indian species reported by Smith to be occasionally taken in large numbers as far north as SC, Ga., primarily OS, although one was taken inshore in southern Ga. during Mahood's study. NC. SC, there are three OS records in GMBL and ChM. (Breder, 1948; ChM, cards; Dahlberg, 1975; GMBL; Johnson unpubl.; Mahood, 1974; Smith, 1907).

Family Pomatomidae

Pomatomus saltatrix (Linnaeus). Bluefish. Marine. Euhaline. 16.2-30.5°C. Coastal water, surf zone, estuaries, intertidal creeks. Sand, shell, mud substrate. Common. Seasonal migrants. Spring-mid-fall. Schools. Small fish common inshore, larger fish stray OS. (Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Family Rachycentridae

Rachycentridae canadum (Linnaeus). Cobia. Marine. Mouths of sounds, rivers. May-Sept. Most often found around buoys, under floating objects. (Bearden, 1961).

Family Echeneidae

Echeneis neucratoides Zuieuw. Whitefin sharksucker. Marine. Cosmopolitan, warm seas. Usu. attached to larger shore sharks, tarpons, not uncommon in Beaufort, NC. Ga., one record in Doboy Sound, SC, several records in ChM and GMBL, close inshore and OS. (Breder, 1948; ChM cards and files; Dahlberg, 1975; GMBL; Smith, 1907).

Phtheirichthys lineatus (Menzies). Slender suckerfish. Marine. According to Breder from tropical seas ranging north to SC. Rare. Usu. found attached to barracuda. (Breder, 1948).

Remora remora (Linnaeus). Remora. Marine. U. S. east coast north to Mass. NC. Southern Ga., in close inshore waters, Aug. SC, records from ChM and GMBL, close inshore and OS. Usu. attached to large sharks. (Breder, 1948; ChM, files; GMBL; Johnson, unpubl; Mahood, 1974; Smith, 1907).

Family Carangidae

Alectis crinitus (Mitchill). African pompano. Marine. Not common Fla. - Mass. NC. Ga., coastal waters. (Dahlberg, 1975; Johnson, unpbl.; Smith, 1907).

Caranx bartholomaei Cuvier. Yellowjack. Marine. One record: one collected by Susan Norris Aug. 1933 Magnolia Beach (Georgetown Co.). (ChM, files).

Caranx crysos (Mitchill). Blue runner. Marine. Coastal waters, inshore and OS. Ga., estuaries and coastal waters; most abundant OS. (Bearden, 1961; ChM, cards and files; Dahlberg, 1975).

Caranx hippos (Linnaeus). Crevalle jack. Marine. Euhaline, 9.5-33.9°/oo. 17.0-29.3°C. Surf zone, estuaries, intertidal creeks. Occasional in coastal zone streams. Sand, shell, mud substrate. Not uncommon. Sometimes fairly common in warmer months. Summer - Dec. Exodus of larger fish from intertidal creeks and influx of juveniles July - Oct. Schools. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Caranx latus Agassiz. Horse-eye jack. Marine. Intertidal creeks. Common Sept., Oct. Occasional in surf zone. Spawning; prolonged season in summer. (Cain, 1973; Cupka, 1972).

Caranx ruber (Bloch). Bar jack. Marine. NC. Southern and central Ga., inshore waters. SC, Fowler reports one off Charleston; two records in ChM: one taken Sept. 1938 in Sargassum weed two or three miles beyond mouth of Charleston jetties; two taken Aug. 1961 OS, by R/V Silver Bay. (ChM, cards and files; Fowler, 1945; Johnson, unpubl.; Mahood, 1974).

Chloroscombrus chrysurus (Linnaeus). Atlantic bumper. Marine. Meso-poly-eu. 1.4-30.5°C. Estuaries, intertidal creeks, surf zone. Common. Occasional in coastal zone streams. Sand, shell, mud, substrate. Seasonal migrant. July - Nov.; abundant in Sept. Surf zone, present Aug. - Oct. (Anderson, 1960; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Decapterus macarellus (Cuvier). Mackerel scad. Marine. One record: July 1931 on DeVeaux Band (Charleston), regurgitated by young Royal terns. (ChM, files).

Decapterus punctatus (Agassiz). Round scad. Marine. NC. Ga., OS and coastal water. SC., reported by Fowler and in ChM from coastal waters, often picked up on beach after being regurgitated by sea birds. (Breder, 1948; ChM, cards and file;

Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).
Hemicaranx amblyrhychus (Cuvier). Bluntnose jack. Marine. Several close inshore records from inlets, bays, harbors, islands in July, Aug., Sept. from ChM. (ChM, cards and files).
Oligoplites saurus (Bloch and Schneider). Leatherjacket. Marine - brackish. Coastal zone streams and one record on beach. Sand, mud substrate. Ga., common June - Nov. along beaches; also occurs in high marsh, middle reaches of estuaries, high salinity tidal pools. (Anderson, 1960; ChM, cards; Dahlberg, 1975).
Selar crumenophthalmus (Bloch). Bigeye scad. Marine. Two inshore records in ChM: eight taken July 1931, and one taken July 1932, at Cape Romain (Charleston Co.), regurgitated by Royal Terns. (ChM, files).
Selene vomer (Linnaeus). Lookdown. Marine. Meso-poly. 16.9-30.1°C. Estuaries, intertidal creeks, occasional in surf zone. Sand, shell, mud, silt substrate. June through Dec. Common June through Oct, esp. June, July. Probably has extended breeding season. (Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).
Seriola dumerili (Risso). Greater amberjack. Marine. According to Breder, Brazil - Fla., straggling north to NJ and rarely Mass. NC. Ga., OS. SC, reported from coastal waters by Fowler, ChM, and GMBL. (Breder, 1948; ChM, files; Dahlberg, 1975; Fowler, 1945; GMBL; Johnson, unpubl.).
Seriola fasciata (Bloch). Lesser amberjack. Marine. One record in ChM: one taken Oct., 1956, Charleston. Two collected 1974 off Charleston in 180' water. (ChM, card; Cupka, personal communication).
Seriola rivoliana Valenciennes. Almaco jack. Marine. According to Breder, West Indian species not common along the U. S., but extending north to NC. NC. Ga., OS. SC, reported from coastal waters, sometimes in Sargassum, by Fowler, ChM, and GMBL records. (Breder, 1948; ChM, file; Dahlberg, 1975; Fowler, 1945; GMBL; Johnson, unpubl.).
Seriola zonata Mitchill. Banded rudderfish. Marine. According to Smith and Breder Cape Hatteras - Maine. NC. Ga., OS. SC, reported from coastal waters in ChM and GMBL records. Associates with sharks or other large fish; often found around rudders of vessels. (Breder, 1948; ChM, cards; Dahlberg, 1975; GMBL; Johnson, unpubl.; Mahood, 1974; Smith, 1907).
Trachinotus carolinus (Linnaeus). Florida pompano. Marine. Poly-eu. 12.8-28.5°C. Close inshore, surf zone, inlets. Seasonal migrant. Abundant. Late spring - early fall. (Bearden, 1961; Cain and Dean, unpubl.; Cupka, 1972).

Trachinotus falcatus (Linnaeus). Permit. Marine. Poly-eu. 12.8-38.5°C. Sounds, estuaries, intertidal creeks, coastal waters, surf zone. Seasonal migrant. Common, esp. young individuals, summer through early fall. Occasional, coastal zone streams. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972).

Trachinotus goodei Jordan and Evermann. Palometa. Marine. Poly-eu. Surf zone. Seasonal migrant. Late summer, early fall. Not uncommon. (Cupka, 1972).

Trachurus lathami Nichols. Rough scad. Marine. Two records in ChM: five taken late 50's - early 60's, presumably on SC coast; two taken May 1955 SE of North Edisto Sea Buoy. (ChM, cards).

Vomer setapinnis (Mitchill). Atlantic moonfish. Marine. Euhaline, 4.8-28.6°/oo. 18.5-30.1°C. Estuaries. Sand, shell, mud substrate. Common. July - Nov. (Shealy, 1974; Shealy et al., 1974).

Family Coryphaenidae

Coryphaena hippurus Linnaeus. Dolphin. Marine. Not rare SC - TX. Cosmopolitan. NC. Ga., OS. Prefers blue water. Spawns spring in the West Indies. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Family Lutjanidae

Lutjanus buccanella (Cuvier). Blackfin snapper. Marine. Breder gives its range as West Indies rarely north of Key West, tending to keep in deeper waters. Smith claims it is a shore fish in warm water. NC. Ga., OS. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Lutjanus campechanus (Poey). Red snapper. Marine. West Indian species, occasionally straggles as far as Mass. Smith reports it from shore and Breder from deep water. NC, Ga., OS, reefs and shelf edge. SC, several records from coastal waters in ChM. (Breder, 1948; ChM, file; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Lutjanus griseus (Linnaeus). Gray snapper. Marine - fresh. 17.0-27.4°C. Estuaries, intertidal creeks, beaches, sand, mud substrate. Has been taken July - Oct. Ga., primarily OS, buit a few juveniles inshore in shallow water of beaches, high marsh, lower estuary reaches. (Cain, 1973; ChM, files; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Lutjanus synagris (Linnaeus). Lane snapper. Marine. Fla. - Brazil, according to Breder. NC. Ga., OS; northern Ga., inshore waters, Oct. Warm waters. (Breder, 1945; Dahlberg, 1975; Johnson, unpubl.; Mahood, 1974; Smith, 1907).

Lutjanus vivanus (Cuvier). Silk snapper. Marine. Warm water. Shore fish, according to Smith. NC. Ga., OS. (Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Pristipomoides aquilonaris (Goode and Bean). Wenchman. Marine. One record in ChM: one taken Sept. 1955 SE of North Edisto River Sea Buoy. (ChM, file).

Rhomboplites aurorubens (Cuvier). Vermilion snapper. Marine. Charleston - Rio de Janiero, according to Breder. NC. Reported by Fowler, ChM, and GMBL records from SC coast. Deep water, sometimes enters shallow bays. Apparently spawns early spring. (Breder, 1948; ChM, cards and files; Fowler, 1945; GMBL; Johnson, unpubl.).

Family Lobtidae

Lobotes surinamensis (Bloch). Tripletail. Marine. Inshore and OS, usu. in deep water around buoys and wrecks. Warmer water. Common; spring - fall. Solitary fish. (Bearden, 1961).

Family Gerreidae

Diapterus olisthostomus (Goode and Bean). Irish pompano. Marine - brackish. Coastal zone streams. Sand, mud substrate. Occasional. Ga., beach, high marsh, low and high salinity tidal pools; rare, olig. creek, tidal canal; July - Nov. (Anderson, 1960; Dahlberg, 1975).

Diapterus plumieri (Cuvier). Striped mojarra. Marine - fresh. Estuaries, intertidal creeks. Occasional. (Cain, 1973; Cain and Dean, unpubl.).

Eucinostomus argenteus Baird and Girard. Spotfin mojarra. Marine - fresh. Estuaries, intertidal creeks, inlets. Common June - Nov.; abundant Sept. - Oct. Have extended breeding season. In Ga., mostly shallow waters; occasional on beach. (Cain, 1973; Cain and Dean, unpubl.; ChM, file; Dahlberg, 1975).

Eucinostomus gula (Quoy and Gaimard). Silver jenny. Marine - brackish. Near shores, estuaries, intertidal creeks, coastal zone streams. Sand, mud substrate. Occasional Aug. - Dec., in creeks. (Anderson, 1960; Cain, 1973).

Family Pomadasyidae

Haemulon aurolineatum Cuvier. Tomtate. Marine. NC. Ga., most abundant OS in reefs and shelf edge; sometimes in coastal areas. Fowler and ChM records report it from SC coast. (ChM, cards; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Haemulon flavolineatum (Desmarest). French grunt. Marine. Ga., more abundant OS around reefs and shelf edge, but sometimes coastal. NI. (Cain and Dean, unpubl.; Dahlberg, 1975).

Haemulon plumieri (Lacepede). White grunt. Marine. Common on SC coast according to Smith. Abundant West Indies, around Cape Hatteras according to Breder. ChM records: two taken 1935, at Carroll's Fish Market; one taken Aug. 1961, OS. (breder 1948; ChM, cards and files; Smith, 1907).

Orthopristis chrysoptera Linnaeus). Pigfish. Marine - fresh. Along coast estuaries intertidal creeks. Near bottom; sand, shell, mud, clay substrate. Common on sandy shoals, around jetties, piers, wrecks. (Bearden, 1961; Cain, 1973; Shealy, 1974).

Family Sparidae

Archosargus probatocephalus (Walbaum). Sheepshead. Marine - fresh. Coastal waters, estuaries, intertidal creeds, up tidal rivers. Around rock jetties, pilings, docks, oyster beds. Sand, mud substrate. Common June - Oct. Common in deeper water all year. Occasional in coastal zone streams. (Bearden, 1961; Cain, 1973).

Archosargus rhomboidalis (Linnaeus). Sea bream. Marine. One record at GMBL; one taken Aug. 1969 in NI by Freeman. (GMBL).

Calamus leucosteus Jordan and Gilbert. Whitebone porgy. Marine. Smith reports it as a shore fish from the Charleston market. Breder reports it as a deep water fish known principally from SC. Ga., OS., occasionally coastal. SC, one record at GMBL; one Nov. 1970 two miles east of 2C buoy off Charleston Harbor. (Breder, 1948; Dahlberg, 1975; GMBL; Smith, 1907).

Calamus nodosus Randall and Caldwell. Knobbed porgy. Marine. Shore fish according to Smith. NC. Ga., OS. One recorded at GMBL; one taken May 1973 off Charleston in less than 160' water. (Dahlberg, 1975; GMBL; Johnson, unpubl.; Smith, 1907).

Calamus penna (Valenciennes). Sheepshead porgy. Marine. West Indies - Fla. Shore. NC. (Breder, 1948; Johnson, unpubl.).

Diplodus argenteus (Valenciennes). Silver porgy. Marine. Shore fish according to Smith. NC. This genus is present OS Ga. (Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

Diplodus holbrooki (Bean). Spottail pinfish. Marine. Smith and Breder report it on U. S. east coast north to Cape Hatteras. Fowler reports it from the Charleston area. NC. Ga., OS. Two records at ChM: three taken Nov. 1935 at Carroll's Fish Market; one Sept. 1962 OS. The Museum records quote from Proc. U. S. Nat. Mus. (1822), Vol. 5 p. 605, "Taken abundantly with hook and line on the banks outside the Harbor (Charleston). None were seen in the harbor, although this species is very abundant around wharves at Beaufort, NC". (Breder, 1948; ChM, file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Smith, 1907).

Lagodon rhomboides (Linnaeus). Pinfish. Marine - fresh. Along shore, estuaries, intertidal creeks, coastal zone streams. Around piers, over shoal area. Sand, shell, mud substrate. Year round. More common, summer. Migrates to deeper water in colder months. Feeds on bottom. (Anderson, 1960; Bearden, 1961; Cain, 1973).

Pagrus sedecim Ginsburg. Red porgy. Marine. NC. Ga., OS. SC, NI; ChM and GMBL have OS records. (ChM, file; Cain and Dean, unpubl.; Dahlberg, 1975; GMBL; Johnson, unpubl.).

Stenotomus caprinus Bean. Longspine porgy. Marine. NC. Northern Ga., during Mahood's study, taken in sounds and close inshore. May, June, Oct., Nov.; most abundant Oct. SC, NI; several OS records in ChM. (Cain and Dean, unpubl.; ChM, files and cards; Johnson, unpubl.; Mahood, 1974).

Stenotomus chrysops (Linnaeus). Scup. Marine. NC. Ga., Coastal waters and OS. SC, records in ChM from creeks to OS; NI. (Cain and Dean, unpubl; ChM, cards; Dahlberg, 1975; Johnson, unpubl.).

Family Sciaenidae

Bairdiella chrysura (Lacepede). Silver perch. Marine - fresh. 7.2-31.4°C. Along beaches, surf zone, sounds, rivers, estuaries, intertidal creeks, coastal zone streams. Sand, shell, mud, clay, silt substrate. Common-abundant. Occasional in surf zone. Resident. Present in intertidal creeks in all but coldest months. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972; Shealy et al., 1974).

Cynoscion nebulosus (Cuvier). Spotted seatrout. Marine - fresh. 13.7-31.4°C. Along beaches, sounds, estuaries, intertidal creeks, tidal rivers. Occasional coastal zone streams. Sand, shell, mud substrates. Often around shell banks. Abundant, fall and winter. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Cynoscion nothus (Holbrook). Silver seatrout. Marine - brackish. 17.4-30.5°C, Sounds, estuaries, tidal river. Sand, shell, mud substrate. Resident. Not uncommon. (Bearden, 1961; Shealy et al., 1974).

Cynoscion regalis (Bloch and Schneider). Weakfish. Marine. Euhaline, 0.4-34.4°/oo. 13.7-31.4°C. Along shore, estuaries, sounds, tidal rivers. Sands, shell, mud, clay, silt substrate. Often around shell banks. Resident. Abundant, fall, winter. Occasional, coastal zone streams. Spawns May - Aug. (Anderson, 1960; Bearden, 1961; Shealy, 1974; Shealy et al., 1974).

Equetus acuminatus (Bloch and Schneider). High-hat. Marine. Central Ga., during Mahood's study, one taken in close inshore waters, Oct.; none from the northern station. SC, one record in ChM; one taken Sept. 1955 SE of North Edisto River Sea Buoy. (ChM, cards; Mahood, 1974).

Equetus lanceolatus (Linnaeus). Jackknife-fish. Marine. According to Breder a West Indian species reaching north to Pensacola coral reefs. NC. (Breder, 1948; Johnson, unpubl.).

Equetus umbrosus (Jordan and Eigenmann). Cubbyu. Smith records its range as Brazil - Charleston and Fowler as Brazil - NC. SC, two records in ChM: one taken July 1974 in Station Creek (Beaufort Co.); two taken Sept. 1955 SE of North Edisto River Sea Buoy. (Breder, 1948; ChM, cards; Smith, 1907).

Larimus fasciatus Holbrook. Banded drum. Marine. Meso-poly-eu. 16.0-30.5°C. Estuaries. Sand, shell, mud substrate. July - Dec. Not uncommon. (Shealy, 1974; Shealy et al., 1974).

Leiostomus xanthurus Lacepede. Spot. Marine - fresh. 11.6-31.4°C. Surf zone, estuaries, intertidal creeks, coastal zone streams, usually in water>10°/oo. Bottom fish; sand, shell, mud, clay, silt substrate. Resident. Abundant most of year. Seasonal migrant in surf zone; make fall "run" along beaches. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Menticirrhus americanus (Linnaeus). Southern kingfish. Marine. Euhaline, 0.9-34.2°/oo. 9.2-30.1°C. Coastal waters, surf zone, tidal rivers, coastal zone streams. Bottom fish; sand, shell, mud, clay substrate. Resident. Common most of year, possibly not in Feb., March. Occasional in surf zone and coastal zone streams. (Anderson, 1960; Bearden, 1972; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Menticirrhus littoralis (Holbrook). Gulf kingfish. Marine. Poly-eu. 12.8-28.5°C. Coastal waters, surf zone, inlets. Resident, mainly summer. Common most of year. Young are abundant over sandy substrate close to beaches in summer and fall. Occasional in coastal zone streams. Spawning May - Sept. (Anderson, 1960; Bearden, 1961; Cain and Dean, unpubl.; Cupka, 1972).

Menticirrhus saxatilis (Bloch and Schneider). Northern kingfish. Marine. Estuaries, surf zone. Seasonal migrant. Spring, summer. Spawns probably around April - May. (Cain and Den, unpubl.; Cupka, 1972).

Micropogon undulatus (Linnaeus). Atlantic croaker. Marine - fresh. 9.2-31.4°C. Coastal waters, estuaries, intertidal creeks, coastal zone streams. Bottom fish; sand, shell, mud, clay, silt substrate. Resident. Abundant, esp. spring, summer; esp. in estuaries. Common, coastal zone streams. (Anderson, 1960; Bearden, 1961; Cain, 1973; Shealy, 1974; Shealy et al., 1974).

Pogonias cromis (Linnaeus). Black drum. Marine. Euhaline. Coastal waters; sounds, estuaries, coastal zone streams. Sand, shell, mud substrate. Common, esp. spring, fall. Occasional, coastal zone streams. (Anderson, 1960; Bearden, 1961; Shealy, 1974).

Sciaenops ocellata (Linnaeus). Red drum. Marine - fresh. Coastal waters of sandy beaches, surf zone, tidal streams, estuaries, intertidal creeks. Resident. Common, esp. fall. Tend to move OS in winter. Surf zone, March - Nov. Young move in schools. (Bearden, 1961; Cain, 1973; Cupka, 1972).

Stellifer lanceolatus (Holbrook). Star drum. Marine. Euhaline. Eurythermal. Estuaries. Sand, shell, mud, clay, silt substrate. Resident. Abundant. Ga., sometimes beach habitats. (Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Family Mullidae

Mullus auratus Jordan and Gilbert. Red goatfish. Marine. According to Breder, a West Indian species, straggling as far north as Cape Cod. NC. Ga., OS; uncommon in coastal waters. SC, in ChM, two records SE of North Edisto River Sea Buoy; one record OS. (Breder, 1948; ChM, cards and files; Dahlberg, 1975; Johnson, unpubl.).

Pseudupeneus maculatus (Bloch). Spotted goatfish. Marine. Breder reports it as a West Indian species ranging north to Fla. NC. Ga., OS; uncommon in coastal waters. SC, Fowler reports one from DeVeaux Bank (Charleston) and ChM has a record of one from the mouth of the North Edisto River. Both were regurgitated by Royal Terns. (Breder, 1948; ChM, file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Family Kyphosidae

Kyphosus incisor (Cuvier). Yellow chub. Marine. Five records in ChM: five taken Sept. and Oct. 1934 from Magnolia Beach (Georgetown Co.); nine taken Sept. and Oct. 1938 from off Charleston Harbor in Sargassum. (ChM, file).

Kyphosus sectarix (Linnaeus). Bermuda chub. Marine. According to Smith, it is not uncommon on U. S. east coast. Ga., young occassionally straggle inshore. SC, several records from Charleston Harbor and Magnolia Beach, often in Sargassum and sometimes in large groups. (ChM, file; Dahlberg, 1976; Fowler, 1945; Smith, 1907).

Family Ephippidae

Chaetodipterus faber (Broussonet). Atlantic spadefish. Marine. Coastal waters, estuaries, sounds, coastal zone streams. Sand, shell, mud substrate. Around piers, wrecks, bridges. Young very common summer months. Schools. Occasional, coastal zone streams. (Anderson, 1960; Bearden, 1961; Shealy, 1974).

Family Chaetodontidae

Chaetondon ocellatus Bloch. Spotfin butterfish. Marine. NC. Ga., OS; occasionally coastal. SC, three records from ChM; two taken Sept. 1934 from Pawley's Island and taken summer 1936 from Magnolia Beach; three taken Jan. 1957 off Cape Romain. (Cain and Dean, unpubl.; ChM, file; Dahlberg, 1975; Johnson, unpubl.).

*Chaetondon sedentarius Poey. Reef butterflyfish. Marine. Ga. NC. (Dahlberg, 1975; Johnson, unpubl.).

*Chaetondon striatus Linnaeus. Banded butterflyfish. Marine. According to Breder, a West Indian form rare in southern Fla. Ga. NC. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.).

Holacanthus bermudensis Goode. Blue angelfish. Marine. NC. Ga. SC, one record off Cape Romain (Charleston Co.) and one OS. (ChM, file; Dahlberg, 1975; GMBL; Johnson, unpubl.).

Holacanthus ciliaris (Linnaeus). Queen angelfish. Marine. West Indian species reaching Fla., according to Breder. NC. Ga. SC, one record in ChM: Aug. 1950, one taken four miles off Folly Island. (Charleston Co.). (Breder, 1948; ChM, file; Dahlberg, 1975; Johnson, unpubl.).

Family Pomacentridae

Abudefduf saxatilis (Linnaeus). Sergeant major. Marine. SC, several records from Charleston, Myrtle Beach (Charleston Co.), Magnolia Beach, (Georgetown Co.), often in Sargassum or other seaweed. NC. Ga., primarily from reefs; occasionally along beaches. (ChM, file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Chromis insolatus (Cuvier). Sunshinefish. Marine. Two records in ChM: three taken May 1957, SE of North Edisto River Sea Buoy; one taken June 1956, OS. (ChM, file; Dahlberg, 1975).

Pomacentrus fuscus Cuvier. Dusky damselfish. Marine. NC, possibly SC. (Johnson, unpubl.).

Pomacentrus leucostictus Muller and Troschel. Beaugregory. Marine. West Indies - Fla., straggling as far as Maine. Around reefs and docks. NC. Ga., OS. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.).

Pomacentrus planifrons Cuvier. Threespot damselfish. Marine. NC, possibly SC. (Johnson, unpubl.).

Family Labridae

Halichoeres bivittatus (Bloch). Slippery dick. Marine. According to Breder, a West Indian form ranging to Fla. and straggling to NC. NC, Ga., OS near reefs and open shelf; in or near coastal waters. Reported from Blackfish Bank off Charleston and 5 miles off Pawley's Island (Georgetown Co.). Often around kelp, wharves, docks. (Breder, 1948; ChM, file; Fowler, 1945; Johnson, unpubl.; Smith 1907).

Halichoeres garnoti (Valenciennes). Yellowhead wrasse. Marine. NC, possibly SC. (Johnson, unpubl.).

Hemipterontus novacula (Linnaeus). Pearly razorfish. Marine. Smith reports its northern limit as Charleston, and Fowler reports one from Charleston. ChM as records from coastal waters but not close inshore. NC. Ga., in or near coastal waters. On broken or sandy bottoms; around coral reefs. (Breder, 1948; ChM, cards and file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Smit, 1907).

Tautoga onitis (Linnaeus). Tautog. Marine. Coastal waters, off northern SC. Around piers, shell banks, wrecks, jetties. Common. (Bearden, 1961).

Family Mugilidae

Mugil cephalus Linnaeus. Striped mullet. Marine - fresh. Coastal waters, surf zone, sounds, estuaries, intertidal creeks, coastal zone streams. Sand, shell, mud, silt substrate. Resident. Common, esp. winter. Large schools in surf zone, late summer, fall. Spawning, late fall and winter at sea. Juveniles probably appear Nov. until May when the majority have entered estuarine areas where development continues. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972; Shealy, 1974).

Mugil curema Valenciennes. White mullet. Marine. Euhaline. Surf zone, estuaries, intertidal creeks. Sand, shell, mud substrate. Common. Seasonal migrant: May - Dec. In surf zone, late spring, early summer. Probably spawn early spring in estuaries. Young are believed to migrate south at the onset of winter, and don't return. (Cain, 1973; Cupka, 1972; Shealy, 1974).

Family Sphyraenidae

Sphyraena barracuda (Walbaum). Great barracuda. Marine. Shallow waters close to shore, estuaries, intertidal creeks. Occasional in summer. Usu., solitary. Ga., young drift inshore, spring, spend first summer in shallow nursery grounds. Move OS, late fall. Enter mangrove habitat or deep weed beds, second summer. Enter coral reef habitat, third year. (Bearden, 1948; Cain, 1973; Cain and Dean, unpubl.; Dahlberg, 1975).

Sphyraena borealis DeKay. Northern sennet. Marine. Coastal waters. NI intertidal creek. (Bearden, 1961; Cain and Dena, unpubl.; GMBL).

Sypyraena guachancho Cuvier. Guaguanche. Marine. Coastal waters, sounds, estuaries, rivers. (Bearden, 1961; ChM, cards and files; Shealy, 1974).

Family Polynemidae

Polydactylus octonemus (Girard). Atlantic threadfin. Marine. South Atlantic. Dahlberg reports one from a Ga. estuary. SC, three records: one taken June 1921 off Charleston; one taken July 1965 Pelican Banks, St. Helena's Sound (Beaufort Co.); one taken April 1974 Myrtle Beach (Horry Co.) by D. L. Hammond. Prefers sandy shores. (Breder, 1948; ChM, cards and file; Cupka, personal communication; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Family Uranoscopidae

Astroscopus guttatus Abbott. Northern stargazer. Three records: two taken Aug. 1969 in Jones Creek (Georgetown Co.);

one taken April 1970 in Russell Creek. (Charleston Co.); one taken late 50's or early 60's, presumably SC coast. (ChM, cards; Cupka and Dias, 1972).

Astroscopus y-graecum (Cuvier). Southern stargazer. Marine. Estuaries, intertidal creeks. Occasional in surf zone. Common in sandy bays. Usu. in shallow inshore waters. Sand, shell, mud substrate. (Burns, 1974; Cupka, 1972; Shealy, 1974).

Kathetostoma albigutta (Bean). Lancer stargazer. Marine. Two records: one taken Feb. 1971, Hunting Island Beach (Beaufort Co.); one taken Jones Creek (Georgetown Co.). Previously only recorded OS. (Cupka and Dias, 1972).

Family Blenniidae

Chasmodes bosquianus (Lacepede). Striped blenny. Marine. Close inshore harbors, intertidal creeks, rivers. NC. Ga., along beach, in lower reaches of estuaries around oyster reefs and probably other cover. (Cain, 1973; ChM, file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Hypleurochilus geminatus (Wood). Crested blenny. Marine. Close inshore areas, coastal waters, OS. Often over mud or sand substrate. NC, most common blenny on coast. Ga., coastal reefs and nearby beaches, lower reaches of estuaries. (ChM, file and cards; Dahlberg, 1975; Fowler, 1945; GMBL; Smith, 1907).

Hypsoblennius hentzi (Lesueur). Feather blenny. Marine. Estuaries, intertidal creeks. Around oyster clumps. Sept. - Feb.; June. Not uncommon. Ga., also rare off beaches. (Cain, 1973; Dahlberg, 1975; Shealy, 1974).

Hypsoblennius ionthas (Jordan and Gilbert). Freckled blenny. Marine. According to Breder, known from SC - TX. One record at GMBL: one taken Oct. 1973 Fort Johnston east of GMBL (Charleston Co.). (Breder, 1948; GMBL).

Family Eleotridae

Dormitator maculatus (Bloch). Fat sleeper. Marine - fresh. According to Breder, common West Indian species ranging from Brazil - SC. Three SC records, all from below Goose Creek Dam (Charleston - Berkley Cos.): Oct. 1931, four; Nov. 1931, two; Sept. 1954, two. Also reported from NI. Ga., low salinity tidal pools. This species can survive in very stagnant water. (Breder, 1948; Cain and Dean, unpubl.; ChM, files; Dahlberg, 1975; Fowler, 1945).

Eleotris pisonis (Gmelin). Spinycheek sleeper. Fresh. There are only a few SC records from before 1887 to 1975, from creeks, to ponds. Doug Middaugh (through personal communicaiton with W. P. Davis) reports it as rare in SC. (ChM, file and cards; Middaugh, personal communication).

Family Gobiidae

Bathygobius soporator (Valenciennes). Frillfin goby. Marine. Fowler gives three records before 1900. ChM: one taken summer

1930 Waverly Mills (Georgetown Co.). GMBL: there are four records from 1973 and 1974. (ChM, file; Fowler, 1945; GMBL).

Evorthodus lyricus (Girard). Lyre goby. Marine. Three records in ChM: one taken summer 1934 Waverly Mills (Georgetown Cos.); three taken Oct. 1949 Isle of Palms (Charleston Co.); one taken summer 1964 Isle of Palms. (ChM, cards and file).

Gobioides broussonnneti Lacepede. Violet goby. Marine - fresh. SC, one record in ChM: one taken Sept. 1965 near menhaden plant in Dawho River (Charleston Co.). Also reported from NI. Ga., one specimen reported from lower reaches of estuary. (Cain and Dean, unpubl.; ChM, cards; Dahlberg, 1975).

Gobionellus boleosoma (Jordan and Gilbert). Darter goby. Marine - fresh. Estuaries, intertidal creeks, coastal zone streams. Sand, shell, mud substrate. Common. Occasional, coastal zone streams. Resident. (Anderson, 1960; Cain, 1973; Shealy, 1974).

Gobionellus hastatus Girard. Sharptail goby. Marine - brackish. Estuaries, coastal zone streams. Mud substrate. Occasional. Ga., also coastal waters. (Anderson, 1960; Dahlberg, 1975; Shealy, 1974).

Gobionellus oceanicus (Pallas). Highfin goby. Marine. NI. Dahlberg, however, reports that this species may not range north to Ga. (Cain and Dean, unpubl.; Dahlberg, 1975).

Gobionellus shufeldti Jordan and Eigemann. Freshwater goby. Marine - fresh. SC, close inshoe, rivers, ricefields. Ga., low salinity tidal pools, beachs. (ChM, cards; Dahlberg, 1975; Fowler, 1945).

Gobionellus stigmaticus (Poey). Marked goby. Marine. One taken by Shealy in May and one in June 1973 at Sampson Island, South Edisto Estuary (Station 002) and PRS (Station P002). NC. (Johnson, unpubl.; Shealy, 1974).

Gobiosoma bosci (Lacepede). Naked goby. Marine - fresh. Intertidal creeks, estuaries. Sand, shell, mud substrate. Attches to bottom or hides under debris. Resident. Not uncommon. (Cain, 1973; Shealy, 1974).

Gobiosoma ginsburgi Heldebrand and Schroeder. Seaboard goby. Marine. Estuaries, intertidal creeks. July - Feb. Occasional. (Cain, 1973; Shealy, 1974).

Ioglossus calliurus Bean. Blue goby. Marine. One record in ChM: one taken Nov. 1932 off Blackfish Banks (Charleston), 9 fm. (ChM, file).

Microgobius microlepis Longley and Hildebrand. Banner goby. Marine. NC. NI. (Cain and Dean, unpubl.; Johnson, unpubl.).

Microgobius thalassinus (Jordan and Gilbert). Green goby. Marine - fresh. Several SC records from ponds, streams, harbors, inlets. NC. Ga., collected in high salinity tidal pool may prefer sandy substrates. (Cain and Dean, unpubl.;

ChM, cards and file; Dahlberg, 1975; GMBL).

Family Microdesmidae

Microdesmus longipinnis (Weymouth). Pink wormfish. Marine. Only record: one taken April 1972 by D. L. Hamond at mouth of SCWMRD boatslip in Charleston Harbor at night, calm surface. Specimen was swimming on the surface; two taken April 1973 at same location. Previous range was Sea Island, Ga. - Cedar Bayou, TX and Cayman Islands. This family is tropical and subtropical, and known from estuaries and coastal waters to about 38m deep. It is seen in large numbers although it is sometimes locally abundant. (Hammond, 1973).

Family Gemphylidae

Gempylus serpens Cuvier. Snake mackerel. Marine. One record in ChM: 1921, off Charleston. (ChM, file).

Family Trichiuridae

Trichiurus letpturus Linnaeus. Atlantic cutlassfish. Marine. Euhaline, 0.7-34.4°/oo. 16.2-30.6°C. Sand, shell, mud, clay sustrate. Common. Warmer months. Ga., lower reaches of estuaries, coastal waters. Rare on lower shelf. (Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Family Scombridae

Acanthocybium solanderi (Cuvier). Wahoo. Very common off SC. (Hammond and Cupka, 1975).

Auxis rochei (Risso). Bullet mackerel. Marine. Taken by commercial and scientific gear, but not recorded from the sportsfish landings. More abundant than frigate mackerel. (Hammond and Cupka, 1975).

Auxis thazard (Lacepede). Frigate mackerel. Marine. Seldom reported, although it occurs here. None have been reported from sportsfish landings. One close inshore record: one taken April 1937 Folly Beach (Charleston Co.). (ChM, file; Hammond and Cupka, 1975).

Euthynnus alletteratus (Rafinesque). Little tunny. Marine. OS and near Gulf Stream. Common. Most comon of SC's little tunas. Chiefly in summer months. (Bearden, 1961; Hammond and Cupka, 1975).

Euthynnus pelamis (Linnaeus). Skipjack tuna. Marine. Fairly common. Usu. found in water >100' deep. (Hammond and Cupka, 1975).

Sarda sarda (Bloch). Atlantic bonito. Marine. Coastal waters. NI. Usu. more abundant in SC waters north of Georgetown. Spring - fall. Schooling fish of open ocean. (Bearden, 1961; Cain and Dean, unpubl; ChM, file; Hammond and Cupka, 1975).

Scomber japonicus Houttuyn. Chub mackerel. Marine. Has been caught in large quantities by commercial gear off SC. Capture with rod and reel hasn't been verified. (Hammond and Cupka, 1975).

Scomber scombrus Linnaeus. Atlantic mackerel. Marine. Breder reports Cape Hatteras as southern limit. Adults approach coast, spring; move OS, fall. Spawn, May - July NC. Seldom reported from SC. (Breder, 1948; Hammond and Cupka, 1975; Johnson, unpubl.).

Scomberomorus cavalla (Cuvier). King mackerel. Marine. Occasional around piers inshore. Abundant OS. Spring-early fall. Warmer open waters. (Bearden, 1961; Hammond and Cupka, 1975).

Scomberomorus maculatus (Mitchell). Spanish mackerel. Marine - brackish. Coastal waters, usually in open water, sometimes around piers, in estuaries, intertidal creeks, coastal zone streams. Common. Occasional, coastal zone streams. Summer - fall. Abundant off coast. (Anderson, 1960; Bearden, 1961; Cain, 1975; Hammond and Cupka, 1975; Shealy, 1974).

Scomberomorus regalis (Bloch). Cero. Marine. One record in ChM: one taken Dec. 1933 from Carroll's Fish Market, off Charleston. (ChM, file).

Thunnus alalunga Bonnaterre. Albacore. Marine - fresh. NC. Ga., OS. One SC record in GMBL: six taken July 1970 off SC. (Dahlberg, 1975; GMBL; Johnson, unpubl.).

Thunnus albacares (Bonnaterre). Yellowfin tuna. Marine. Landed regularly by SC fishers fishing in or near the Gulf Stream. (Hammond and Cupka, 1975).

Thunnus atlanticus (Lesson). Blackfin tuna. Marine. Most abundant of SC tuna. OS. (Hammond and Cupka, 1975).

Thunnus obesus . Bigeye tuna. Marine. Taken by longline gear off coast but has not been documented in the sports fishery of SC. (Hammond and Cupka, 1975).

Thunnus thynnus (Linnaeus). Bluefin tuna. Marine. These are known to migrate past SC but there is no record of it being taken here. (Hammond and Cupka, 1975).

Family Xiphiidae

Xiphias gladius Linnaeus. Swordfish. marine. There are a few records off SC, but no verified rod and reel catches. (Hammond and Cupka, 1975).

Family Istiophoridae

Istiophorus platypterus (Shaw and Nodder). Sailfish. Marine. Abundant OS and in Gulf Stream. Peak abundance, late summer. (Hammond and Cupka, 1975).

Makaira nigricans Lacepede. Blue marlin. Marine. Usually far OS near Gulf Stream. Common. Most abundant early spring, late fall. Largest billfish commonly caught off SC. (Bearden, 1961; Hammond and Cupka, 1975).

Tetrapturus albidus Poey. White marlin. Marine. OS and in Gulf Stream spring through fall. More abundant off north half of SC coast. Singly or small schools. (Bearden, 1961; Hammond and Cupka, 1975).

*Tetrapturus pfluegeri Robins and de Sylva. Longbill spearfish. Never reported off SC, although known north and south of SC. (Hamond and Cupka, 1975).

Family Stromateidae

Peprilus alepidotus (Linnaeus). Harvestfish. Marine. Euhaline. 0.9-33.2^o/oo, 17.4-30.1^{o}C. Estuaries. Common July through Dec., occasional April, May. Ga., also sometimes along beaches. (Dahlberg, 1975; Shealy et al. 1974).

Peprilus paru (Linnaeus). Northern harvestfish. Marine. GMBL lists two records of this: one taken June 1973 1 mi. OS north end of Capers Island (Beaufor Co.); one taken July 1972 off Ft. Johnston in Charleston Harbor. AFS excludes it from its listing because "it is extralimital, ranging from West Indies to Uruguay". (AFS, 1970; GMBL).

Peprilus triacanthus (Peck). Butterfish. Marine. Polyhaline. Coastal waters, intertidal creeks, estuaries. Sand, shell, mud substrate. Not uncommon in estuaries. Ga., also near beaches. In northern section, most abundant Dec. (ChM, file; Dahlberg, 1975; GMBL; Mahood, 1974; Shealy, 1974).

Family Scorpaenidae

Pontinus nematophthalmus (Gunther). Spinythroat scorpionfish. Marine. Bottom fish. NC, possibly SC. (Johnson, unpubl.).

Scorpaena brasiliensis Cuvier. Barbfish. Marine. Close inshore: creeks, sounds, inlets, coastal waters; OS. NC. Ga., coastal waters and OS. (Cain and Dean, unpubl.; ChM, cards and files; Dahlberg, 1975; Johnson, unpubl.).

Scorpaena calcarata Goode and Bean. Smoothhead scorpionfish. Marine. Two records in ChM show a total of five taken Sept. 1955 SE of North Edisto River Sea Buoy. (ChM, cards).

Scorpaena plumieri Bloch. Spotted scorpionfish. Marine. Northern Ga., taken in marshes, rivers, sounds, close inshore waters, Dec., April, May. SC, two records in ChM from coastal waters: one taken 1908 off Charleston; one taken June 1935 SSE of Charleston in 16 fms. (ChM, file; Mahood, 1974).

Scorpaenodes tredecimspinosus (Metzelaar). Deepreef scorpionfish. Marine. Bottom fish. NC, possibly SC. (Johnson, unpubl.).

Family Triglidae

Bellator militaris (Goode and Bean). Horned searobin. Marine. Two records in ChM: one taken Feb. 1956, off Charleston Airport 312^o; three taken Jan. 1967 SE of North Edisto River Sea Buoy. (ChM, cards).

Prionotus carolinus (Linnaeus). Northern searobin. Marine. Poly-eu. Coastal waters, estuaries, sounds, tidal rivers. Mud, sand substrate. Common. Warmer months. Occasional in surf zone. Also OS. Ga., coastal waters, lower reaches of estuaries, OS. Rare along beaches. (Bearden, 1961 Cupka, 1972; Dahlberg, 1974; GMBL; Shealy, 1974).

Prionotus evolans (Linnaeus). Striped searobin. Marine. Coastal waters, estuaries, intertidal creeks. Bearden reports this species is common, but Burns claims adults rarely occur this far south. He found occasional larval forms. In Ga., OS to lower and middle reaches of estuaries; rare in high marsh. (Bearden, 1961; Burns, 1974; Dahlberg, 1975).

Prionotus roseus Jordan and Evermann. Bluespottd searobin. marine. One record in ChM: five taken Sept. 1955 SE of North Edisto River Sea Buoy. One record GMBL: three taken Jones Creek (Georgetown Co.). Ga., OS. (ChM, cards; Dahlberg, 1975; GMBL).

Prionotus scitulus Jordon and Gilbert. Leopard searobin. Marine. Inshore and coastal waters, estuaries. Common in coastal waters. In Ga. OS to lower and middle reaches of estuaries; rare in mid reaches and beach. (Berden, 1961; Cain and Dean, unpubl; Dahlberg, 1974).

Prionotus tribulus Cuvier. Bighead searobin. Marine. Coastal waters, estuaries. Sand, shell, mud, clay substrate. Common. Warmer months. In Ga., OS to lower reaches of estuaries and beach; rare in high marsh. (Bearden, 1961; Dahlberg, 1975; Shealy, 1974).

Prionotus tribulus tribulus. Marine. Three records at GMBL: one taken March 1971 1 mile off north Morris Island lighthouse; one taken May 1971, Toogoodoo Creek off North Edisto River; one taken Aug. 1971 off Morris Island.

Family Dactylopteridae

Dactylopterus volitans (Linnaeus). Flying gurnard. Marine. One inshore record at GMBL: one taken Dec. 1969 Wadmalaw Isl. Two coastal water records in ChM: two taken Dec. 1931 and one taken April 1933 off Charleston; Fowler also has several listed from SC. (ChM, file; Fowler, 1945; GMBL).

Order Pleuronetiformes

Family Bothidae

Ancylopsetta quadrocellata Gill. Ocellated flounder. Marine - brackish. Along shore, estuaries, coastal plain streams. Sands, shell, mud substrates. In Ga., OS, coastal waters, lower and middle reaches of estuaries; inshore Jan. - May. (Anderson, 1960; Dahlberg, 1975; Shealy, 1974).

Bothus ocellatus (Agassiz). Eyed flounder. Marine. N.Y. - Rio de Janiero. NC. Ga., OS, but may enter coastal areas. Sandy shores. SC, two records in ChM: one taken May 1955 SE of North Edisto River Sea Buoy; one taken Oct. 1957 OS Charleston. (Breder, 1948; ChM, cards; Dahlerg, 1975; Johnson, unpubl.).

Citharichthys macrops Dresel. Spotted whiff. Marine. ChM has several records of it close inshore, Oct., Nov., July; most abundant Oct. (ChM, cards and file; Mahood, 1974).

Citharichthys spilopterus Gunther. Bay whiff. Marine - fresh. Estuaries, inlets, intertidal creeks, beaches, rivers. Usu. warmer months. Not uncommon. In Ga., OS to lower and middle reaches of estuaries, rare beach; inshore, May - Oct. In Mahood's study, specimens were taken in marshes, creeks, rivers, and close inshore waers all months except Aug. and Sept.; most abundant April and May. (ChM, file; Dahlberg, 1975; Mahood, 1974; Shealy, 1974).

Etropus crossotus Jordan and Gilbert. Fringed flounder. Marine. Estuaries, intertidal creeks, close inshore, coastal waters. Sand, shell, mud substrate. Common all year. In Ga., also rivers, marshes, sounds, close inshore waters, sometimes beaches; most abundant in Nov. in northern Ga. Spawns in Ga., April - June. (Cain, 1973; ChM, file; Dahlberg, 1974; Mahood, 1974; Shealy, 1974).

Etropus microstomus (Gill). Smallmouth flounder. Marine. Close inshore near islans, inlets, coastal waters. Ga., coastal waters and OS. The five records in ChM were taken in Aug., Nov., Dec., Jan. (Cain and Dean, unpubl; ChM, cards and file; Dahlberg, 1975).

Etropus rimosus Goode and Bean. Gray flounder. Marine. SC - Fla. Intertidal creeks (NI) in June and July; coastal waters. Ga., coastal waters, OS. (Cain and Dean, unpubl.; ChM, cards; Dahlberg, 1975; GMBL).

Paralichthys albigutta Jordon and Gilbert. Gulf flounder. Marine. Larvae use estuaries during development. Specimens were taken Jan. - March in NI by Burns in 1973. In Ga., rare inshore but known from coastal waters and lower reaches of estuaries. (Burns, 1974; Dahlberg, 1975.

Paralichthys dentatus (Linnaeus). Summer flounder. Marine. Estuaries, intertidal creeks. Sand, shell, mud substrate. June through Dec. Occasional in surf zone. Spawning OS. Young migrate to estuaries and then move OS to high salinities as adults. (Cain, 1973; Cupka, 1972; Shealy, 1974).

Paralichthys lethostigma Jordan and Gilbert. Southern flounder. Marine - brackish. 8.7-30.6°C. Coastal waters, sounds, estuaries, intertidal creeks, and rivers. Bottom fish. Prefers sand, mud, but found over other substrates. Often around shell banks or pilings. Shallow water. common warmer months. Occasionally surf zone and coastal zone streams. Moves to deeper water in winter. (Anderson, 1960; Bearden, 1961; Cain, 1973; Cupka, 1972; Shealy, 1974; Shealy et al., 1974).

Paralichthys oblongus (Mitchill). Fourspot flounder. Marine. Shallow water. Common. (Leonard, 1971).

Paralichthys squamilentus Jordon and Gilbert. Broad flounder. Marine. Estuaries, coastal waters, surf zone. Sand substrate. Juveniles in surf zone, spring and summer months; found in <30°/oo. Adults, deeper water, higher salinities. Seasonal migrant. (Bearden, 1961; Cain and Dean, unpubl.; Cupka, 1972).

Scophthalmus aquosus (Mitchill). Windowpane. Marine. Meso-poly. Close in shore, estuaries, sounds. Sand, shell, mud substrate. Taken Jan. - May. (ChM, cards; Shealy, 1974).

Syacium papillosum (Linnaeus). Dusky flounder. NC. Ga., primarily OS, sometimes coastal. Fowler reports one from Charleston, and the ChM records one Sept. 1955 from SE of North Edisto River Sea Buoy. (ChM, cards; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.).

Family Soleidae

Trinectes maculatus (Bloch and Schneider). Hogchoker. Marine - fresh. 6.6-30.5°C. Estuaries, coastal zone streams, rivers, close inshore. Sand, shell, mud, clay substrates. (Anderson, 1960; ChM, cards and file; Dahlberg, 1975; Shealy, 1974; Shealy et al., 1974).

Family Cynoglossidae

Symphurus civitatus Ginsburg. Offshore tongue fish. Marine. One record in ChM: one taken Nov. 1957 at Fenwick Isl. cut in South Edisto River. One record GMBL: one taken June 1973, one mi. OS Capers Isl. (Charleston Co.). (ChM, cards; GMBL).

Symphurus plagiusa (Linnaeus). Blackcheek tongue fish. Marine - fresh. 8.6-30.5°C. Estuaries. Sand, shell, mud, clay substrate. Common. Resident. Much less common in intertidal creeks and coastal zone streams. In creeks, only warmer months. Also coastal waters. (Anderson, 1960; Cain, 1973; GMBL; Shealy, 1974; Shealy et al., 1974).

Symphurus urospilus Ginsburg. Spottail tonguefish. Marine. One record in ChM: one taken late 50's or early 60's, presumably SC coast. (ChM, cards).

Order Tetraondontiformes

Family Balistidae

Aluterus schoepfi (Walbaum). Orange filefish. Marine. Close inshore: along beaches, sounds, rivers, inlets, intertidal creeks; coastal waters. Ga., occasionally coastal, usu. OS. NC. (Cain and Dean, unpubl.; ChM, cards and files; Dahlberg, 1975; GMBL; Johnson, unpubl.).

Balistes capriscus Gmelin. Gray triggerfish. Marine. Three records from Waverly Mills and Magnolia Beach (Georgetown Co.) summer, Sept., Oct., 1934 in ChM. Also OS NC. Ga., primarily OS. (ChM, cards and file; Dahlberg, 1975; Johnson, unpubl.).

<u>Canthidermis maculatus</u> (Bloch). Rough triggerfish. Marine. One record: one taken Nov. 1934 Seabrook Beach (Charleston Co.) "Probably taken by a shrimp trawler and thrown overboard as trash." (ChM, file).

*<u>Monacanthus ciliatus</u> (Mitchill). Fringed filefish. Marine. Common in Fla., rare Cape Cod and Maine. NC, abundant. Ga., primarily OS. (Breder, 1948; Dahlberg, 1975; Johnson, unpubl.; Smith, 1907).

<u>Monacanthus hispidus</u> (Linnaeus). Planehead filefish. Marine. Euhaline, 4.2-32.3 $^{o}/oo$. 9.2 - 30.6^{o}C. Estuaries, large intertidal creeks, surf zone. Sand, shell, mud substrate. Common. Seasonal migrant; summer. Also OS. Ga., only young inshore (Cain, 1973; Cupka, 1972; ChM, cards; Dahlberg, 1975; GMBL; Shealy, 1974; Shealy et al., 1974).

<u>Monacanthus tuckeri</u> Bean. Slender filefish. Marine. NC, possibly SC. (Johnson, unpubl.).

Family Ostraciidae

<u>Lactophrys quadricornis</u> (Linnaeus). Scrawled cowfish. Marine. Three records in ChM and GMBL from coastal waters. One inshore records, GMBL; one taken Jan. 1973 over rough bottom at GMBL. (ChM, file; GMBL).

<u>Lactophrys trigonus</u> (Linnaeus). Trunkfish. Marine. Common West Indian species. Not uncommon in Mass., summer. NC. Ga., OS. One reportsed Oct. 1927 Mt. Pleasant by Fowler. Two records in ChM: one taken Aug. 1932 off Charleston; two taken Apr. 1955 E of North Edisto River Sea Buoy. (ChM, file; Dahlberg, 1975; Fowler, 1945; Johnson, unpubl.; Smith, 1907).

Family Tetraondontidae

<u>Lagocephalus laevigatus</u> (Linnaeus). Smooth puffer. Marine. Close inshore coastal sounds, river mouths, beaches, coastal waters; OS. Ga., primarily OS but sometimes coastal waters. (ChM, cards and file; Dahlberg, 1975; Shealy, 1974).

<u>Sphoeroides dorsalis</u> Longley. Marbled puffer. Marine, NC. Ga., OS, young inshore; coastal waters, lower estuary reaches, beaches; April-Dec. SC, no inshore records, one record OS. (ChM, cards; Dahlberg, 1975; Johnson, unpubl.)

<u>Sphoeroides maculatus</u> (Bloch and Scheider). Northern puffer. Marine. Estuaries, close inshore over sandy bottoms, surf zone. Common, esp. late spring. Occasional, coastal zone streams. Seasonal migrant. (Bearden, 1961; Cain and Dean, unpubl.;Cupka, 1972).

<u>Sphoeroides spenbleri</u> (Bloch). Bandtail puffer. Marine. Reported from NI. Two records in ChM: one taken Feb. 1958 SE of North Edisto River Sea Buoy at 23.5 fms.; two taken Jan. 1967 OS. (Cain and Dean, unpubl.; ChM, cards and file).

Family Diodontidae

<u>Chilomycterus atinga</u> (Linnaeus). Spotted burrfish. SEE <u>C. spinosus</u>.

Chilomycterus schoepfi (Walbaum). Striped burrfish. Marine. Polyhaline. Coastal waters. Common, esp. summer. Resident. Occasional, surf zone, estuaries, coastal zone streams. Ga., marshes, rivers, sounds, creeks, sometimes along beaches; April - Dec., most abundant July and Aug.; also OS. (Anderson, 1960; Bearden, 1961; Cupka, 1972; Dahlberg, 1975; Mahood, 1974; Shealy et al., 1974).

Chilomycterus spinosus (Linnaeus). One record in ChM. Smith synonomizes it with C. atinga which Dahlberg reports from OS ga. Bill Roumellett (SCWMRD) believes the ChM record to be a misidentified C. schoepfi, although no one has been able to examine the specimen. The museum records seem to have this recorded under both C. schoepfi and C. spinosus (ChM, file; Dahlberg, 1975; Fowler, 1945; Smith, 1907; Bill Roumellett, personal communication).

Diodon holocanthus Linnaeus. Balloonfish. Marine. One record in ChM: one taken June 1926 at Folly Beach (Charleston Co.), washed ashore alive. The records quote Jordan and Evermann, 1898, p. 1745: "All warmer seas, north to the Fla. Keys." (ChM, file).

Family Molidae

Mola mola (Linnaeus). Ocean sunfish. Marine. Seven records of this inshore SC. Fishers in McClellanville area claim it isn't uncommon in Cape Romain area. Those inshore may be sick fish or fish which drifted too far from warm OS waters. Cupka and Anderson believe sitings will increase in coming years. (Anderson and Cupka, 1973).

APPENDIX VII-C
Decapod Crustacea of South Carolina
(Young, 1978)

Within the class Crustacea the order Decapoda is divided into two major suborders based upon general body morphology. The members of the suborder Natantia (natant = "swimming") are long-tailed and have a conspicuous abdomen which contains well-developed swimmerets (pleopods); the shrimps comprise this suborder. Members of the suborder Reptantia (reptant = "crawling") are generally adapted for crawling although some species have become secondarily specialized for swimming. The body is dorso-ventrally flattened and the abdomen shows various degrees of reduction which are the bases for the division of the suborder into three sections. The section Macrura ("large tail"), consisting primarily of the lobsters, is characterized by an extended abdomen and large tail fan; the section Anomura ("without tail") displays a variety of abdomen forms and includes such diverse groups as the hermit crabs, procelain crabs, and related families; and the section Brachyura ("short tail") contains the true crabs which have a greatly reduced abdomen flexed beneath the thorax.

The following checklist contains all species of decapods known or presumed to occur in South Carolina waters from the intertidal zone to the 200m contour. A great number of decapod species are found over a broad range of depths, from relatively shallow to relatively deep water; the mobility of many additional species together with the frequent occurrences of dead offshore specimens washed up on ocean beaches makes it impractical to limit any useable checklist to shallow or nearshore waters. This checklist is comprised of 272 species (74 natantians and 198 reptantians). Within each section there are the following:

Penaeidea -- 23 species representing 2 families
Caridea -- 51 species representing 9 families
Macrura -- 11 species representing 6 families
Anomura -- 40 species representing 7 families
Brachyura -- 147 species representing 17 families

The arrangement of all taxa above the genus is phylogenetic; genera and species are arranged alphabetically for greater utility.

In the preparation of this checklist extensive use has been made of Austin B. Williams' "Marine decapod crustaceans of the Carolinas" handbook published in 1965 with additions and revisions included when necessary. All fathom measurements have been converted to meters; depths are given to the nearest 5m interval, except those less than 5m. Only the common depth range is given; rare or unusual depth records are not included. The Venice system of estuarine classification is not used, because little is known of the salinity tolerances of most species. Only the portion of the geographic range which brackets South Carolina is given; the word "to" between two locations (e.g., N.C. to Fla.) indicates that the range is continuous between those points; a semicolon (N.C.; Fla.) indicates that the species has been reported from the two locations but not between; a plus (N.C. - Fla.+) indicates that the species is found at other locations beyond those cited but that the range is discontinuous.

Attempts have been made to confirm the collection of every species in South Carolina waters. South Carolina collectors listed in the literature are credited to the publication with author and date (collection sight is included if available). Unpublished reports and personal communications and observations are credited to the appropriate collector or agency of collection. The following abbreviations are used:

Collectors:
BBB — Billy B. Boothe, Jr.
RFD — Richard F. Dame
AFH — A. Fred Holland
WHL — William H. Lang
WBS — Walter B. Shore

AMY — Alan M. Young

Collection Sites:
OS — Offshore
CH — Charleston Harbor
NI — North Inlet
Collections:
GMBL — Grice Marine Biological Lab
MARMAP — Marine Monitering and Assessment Program (SCMRRI
SCMRRI — South Carolina Marine Resources Research Institute
USNM — United States National Museum

Species which are presumed to occur in South Carolina waters based upon geographic distribution records but for which no collections are known are preceded by an asterisk (*).

The brief list of references contains only those publications which (1) are cited for specific South Carolina collections, or (2) contain vital information relative to revisions and additions to Williams (1965a). All authorities for generic and specific names are cited in one or more of the publications listed.

The number and variety of organisms treated in this checklist makes it impractical to list specialists for each group. Workers desiring the name of a specialist for a particular subdivision may write to the author for this information. In general, questions about decapods should be addressed to: Dr. Austin B. Williams, Systematics Laboratory, National Marine Fisheries Service, NOAA, U. S. National Museum of Natural History, Washington, D. C. 20560.

The author would like to acknowledge the assistance provided by a number of colleagues, including Norman Chamberlain, William H. Lang, Isable Perez Farfante, Walter B. Sikora, Austin B. Williams and espcially Billy B. Boothe, Jr.

Colleagues having data supplemental to that provided herein are urged to send this information to the author for inclusion in future revisions of this checklist.

PHYLUM ARTHROPODA
CLASS CRUSTACEA
SUBCLASS MALOCOSTRACA
SERIES EUMALOCOSTRACA
SUPERORDER EUCARIDA
ORDER DECAPODA

SUBORDER NATANTIA
SECTION PENAEIDEA
FAMILY PENAEIDAE (true shrimps) (20 species)
GENUS HYMENOPENAEUS Smith, 1882

Hymenopenaeus robustus Smith, 1885. Royal red shrimp. Habitat: 180-550m. Range: Mass. to French Guiana; S.C. — (SCMRRI).

Hymenopenaeus tropicalis (Bouvier, 1905). Habitat: 30-360m. Range: N.C. to Gulf of Mexico+; S.C. — (GMBL).

GENUS METAPENAEOPSIS Bouvier, 1905

Metapenaeopsis goodei (Smith, 1885). Habitat: surface to 325m. Range: N.C. to Surinam+; S.C. -- (MARMAP). (Note: was formerly called Penaeopsis goodei).

GENUS PARAPENAEUS Smith, 1886

Parapenaeus longirostris (Lucas, 1849). Habitat: soft mud or muddy sand bottoms; 25-350m. Range: Mass. to Gulf of Mexico+; S.C. -- OS (MARMAP).

GENUS PENAEUS Fabricius, 1798

Penaeus (Litopenaeus) setiferus (Linnaeus, 1767). White shrimp; Common marine shrimp. Habitat: estuaries and inner oceanic littoral; predominantly on mud bottom; water's edge to 35m. Range: N.Y. to Fla.+; S.C. -- (SCMRRI).

Penaeus (Melicertus) aztecus Ives, 1891. Brown or Grooved Shrimp. Habitat: estuarine and oceanic littoral; predominantly on mud bottom; water's edge to 110m. Range: Mass. to Fla.+; S.C. — (Williams, 1965a).

APPENDIX VII-C, cont.

*Penaeus (Melicertus) brasiliensis Latreille, 1817. Habitat: sandy mud; firm bottoms; 20-90m. Range: N.C. to Brazil.

Penaeus (Melicertus) duorarum Burkenroad, 1939. Pink; Spotted; Brown spotted; or Grooved shrimp. Habitat: estuaries and inner oceanic littoral; predominantly on mud bottom; water's edge to 35m. Range: N.Y. to Gulf of Mexico; S.C. — (SCMRRI).

GENUS SICYONIA Milne Edwards, 1830

Sicyonia brevirostris Stimpson, 1871. Rock Shrimp. Habitat: offshore littoral; shallow waters to 180m. Range: Va. to Yucatan; S.C. — (SCMRRI).

*Sicyonia burkenroadi Cobb, 1971. Habitat: mud, mud-shell, mud-sand; 30-120m. Range: N.C. to Mexico+.

Sicyonia dorsalis Kingsley, 1878. Rock shrimp. Habitat: mud, mud and shells; 5-160m. Range: N.C. to Tex.+; S.C. — (SCMRRI).

Sicyonia laevigata Stimpson, 1871. Habitat: shelly bottoms of harbors; littoral; shallow waters to 90m. Range: N.C. to Fla.+, S.C. — NI (RFD).

Sicyonia parri (Burkenroad, 1934). Habitat: shallow water to 35 m. Range: N.C.; Fla.+; S.C. — (SCMRRI).

Sicyonia stimpsoni Bouvier, 1905. Habitat: mud; 70-140m. Range: to Gulf of Mexico; -- offshore (MARMAP).

Sicyonia typica (Boeck, 1864). Habitat: between tide marks to 65m. Range: N.C.; Gulf of Mexico; S.C. — (GMBL).

GENUS SOLENOCERA Lucas, 1849

Solenocera atlantidis Burkenroad, 1939. Habitat: mud, shell, coral; 20-145m. Range: N.C. to Mexico+; S.C. — (GMBL).

*Solenocera necopina Burkenroad, 1936. Habitat: mud, mud and shell; sand and shell; dead corals; 160-550m. Range: N.C. to Fla.+

*Solenocera vioscai Burkenroad, 1944. Habitat: mud; mud and sand; shells; 35-240m. Range: N.C. to Gulf of Mexico+.

GENUS TRACHYPENAEUS Alcock, 1901

Trachypenaeus constrictus (Stimpson, 1871). Habitat: sand or mud and shell; high salinity; shallow water to 55m. Range: Va. to Tex.+; S.C. — (SCMRRI); NI (WBS).

GENUS XIPHOPENAEUS Smith, 1869

Xiphopenaeus kroyeri (Heller, 1862). Habitat: along shore; sometimes in estuaries; 1-70m. Range: N.C. to Brazil; S.C. — (SCMRRI).

FAMILY SERGESTIDAE (3 species)

GENUS ACETES Milne Edwards, 1830

Acetes americanus Ortmann, 1893. Habitat: littoral oceanic and estuarine waters to 40m. Range: N.C. to Brazil; S.C. — (SCMRRI).

GENUS LUCIFER Thompson, 1829

Lucifer faxoni Borradaile, 1915. Habitat: oceanic and estuarine waters; surface to 90m. Range: Nova Scotia to Brazil; S.C. -- (Bowman and McCain, 1967).

Lucifer typus Milne Edwards. Habitat: offshore, usually over 180m. Range: N.C. to Fla.; S.C. — (Bowman and McCain, 1967).

SECTION CARIDEA

FAMILY PASIPHAEIDAE (4 species)

GENUS LEPTOCHELA Stimpson, 1860

*Leptochela bermudensis Gurney, 1939. Habitat: fairly deep water to 1280m. Range: N.C. to Mexico.

*Leptochela (Proboloura) carinata Ortmann, 1893. Habitat: coral and sand; rocks; shells; 10-50m. Range: Georges Banks; Gulf of Mexico+.

Leptochela (Leptochela) papulata Chace, 1976. Habitat: sand; sand with shell; gravel; rock; coral; 20-200m. Range: N.C. to Ga.+; S.C. — Charleston (Chace, 1976).

Leptochela serratorbita Bate 1888. Habitat: coastal; occasionally estuarine; surface to 40m. Range: N.C.; S.C.; Fla.+; S.C. — CH (Lunz, 1939).

FAMILY PALAEMONIDAE (13 species)

GENUS BRACHYCARPUS Bate, 1888

*Brachycarpus biunguiculatus (Lucas, 1849). Habitat: near shore on corals or rocks; on sea buoys; surface to 5m. Range: N.C. to Curacao+.

GENUS LEANDER Desmarest, 1849

Leander tenuicornis (Say, 1818). Sargassum prawn. Habitat: floating Sargassum; wharf pilings; submerged vegetation. Range: Newfoundland Banks to Falkland Islands+; S.C. — (Williams, 1965a).

GENUS MACROBRACHIUM Bate, 1888

Macrobrachium acanthurus (Weigmann, 1836). Habitat: coastal rivers and bays; usually near brackish waters. Range: N.C. to Brazil+; S.C. — (GMBL).

Macrobrachium ohione (Smith, 1874). River shrimp. Habitat: rivers and estuaries. Range: Va. to Ga.+; S.C. — (SCMRRI).

GENUS NEOPONTONIDES Holthuis, 1951

*Neopontonides beaufortensis (Borradaile, 1920). Habitat: coastal waters; with Leptogorgia; surface to several meters. Range: N.C. to La.+

GENUS PALAEMONETES Heller, 1869

Palaemonetes (Paleamonetes) intermidius Holthuis, 1949. Habitat: estuaries; submerged vegetation. Range: N.Y. to Tex.; S.C. — (SCMRRI).

Palaemonetes (Paleamonetes) pugio Holthuis, 1949. Grass shrimp. Habitat: estuaries; submerged vegetation; to 25m. Range: Gulf of St. Lawrence to Tex.; S.C. — NI (AMY).

Palaemonetes (Palaemonetes) vulgaris (Say, 1818). Grass shrimp. Habitat: estuaries; submerged vegetation; to 15m. Range: Mass. to Tex.; S.C. — NI (AMY).

GENUS PERICLIMENAEUS Borradaile, 1915

*Periclimenaeus schmitti Holthuis, 1951. Habitat: shallow water. Range: N.C.; Fla.

*Periclimenaeus wilsoni (Hay, 1917). Habitat: in sponges; 20-70m. Range: N.C.; Fla.

GENUS PERICLIMENES Costa, 1844

*Periclimenes (Harpilius) americanus (Kingsley, 1878). Habitat: sandy or rocky bottom; often between algae or coral; coastal; shallow water to 70m. Range: N.C.; Fla.+.

Periclimenes (Periclimenes) longicaudatus (Stimpson, 1860). Habitat: submerged vegetation, Leptogorgia, algae, Sargassum, sponges; surface to 10m. Range: N.C. to Fla.+; S.C. -- (SCMRRI).

GENUS PONTONIA Latreille, 1829

Pontonia domestica Gibbes, 1850. Habitat: commensal in lamellibranch molluscs; shallow water to 40m. Range: N.C. to La.+; S.C. -- (Williams, 1965a).

*Pontonia margarita Smith, 1869. Habitat: commensal in lamellibranch molluscs; tidal flats to 60m. Range: N.C.; Fla.+.

FAMILY GNATHOPHYLLIDAE (1 species)

GENUS GNATHOPHYLLUM Latreille, 1819

*Gnathophyllum modestum Hay, 1917. Habitat: coral; sponges; shallow water to 25m. Range: N.C. to Fla.

FAMILY ALPHEIDAE (snapping shrimps) (11 species)

GENUS ALPHEUS Fabricius, 1798

Alpheus armillatus H. Milne Edwards, 1837. Banded snapping shrimp. Habitat: under rocks or shells; in holes in rocks; shallow water. Range: N.C. to Brazil+; S.C. -- NI (RFD).

Alpheus formosus Gibbes, 1850. Striped snapping shrimp. Habitat: in holes and crevices in shell bars, rocks and dead corals; water's edge to 40m. Range: N.C. to Brazil; S.C. -- NI (AMY).

Alpheus heterochaelis Say, 1818. Big-clawed snapping shrimp. Habitat: among broken shells and stones; in burrows in mud among shells; water's edge to 30m. Range: N.C. to Tex.+; S.C. -- NI (AMY).

Alpheus normanni Kingsley, 1878. Green snapping shrimp. Habitat: shelly or rocky bottoms; in burrows in sand; on pilings; water's edge to 70m. Range: N.C. to Barbados+; S.C. -- NI (RFD).

GENUS AUTOMATE de Man, 1887

*Automate evermanni Rathbun, 1901. Habitat: unknown. Range: N.C. to Tex.+. (Note: this species is referred to incorrectly in Williams (1965a) as Automate kingsleyi (see Chace, 1972)).

Automate gardineri Coutiere, 1902. Habitat: shallow grass flats; sublittoral. Range: N.C.; Virgin Island. (Note: this species was formerly called Automate kingsleyi (see Chace, 1972)).

GENUS LEPTALPHEUS Williams, 1965

*Leptalpheus forceps Williams, 1965. Habitat: in plankton of estuaries; symbiotic in burrows of Upogebia affinis. Range: described from N.C.; range unknown.

GENUS SYNALPHEUS Bate, 1888

Synalpheus fritzmuelleri Coutiere, 1909. Habitat: often in sponges; low-tide mark to 50m. Range: N.C. to Tex.+; S.C. -- (SCMRRI).

Synalpheus longicarpus Herrick, 1892. Habitat: in sponges; 25-50m. Range: N.C. to Yucatan; S.C. -- OS (MARMAP).

Synalpheus minus (Say, 1818). Habitat: in dead corals; commensal in sponges; shallow water to 70m. Range: N.C. to Brazil+; S.C. — OS (MARMAP).

Synalpheus townsendi Coutiere, 1909. Small snapping shrimp. Habitat: in large sponges; low-tide mark to 100m. Range: N.C. to Yucatan+; S.C. — OS (MARMAP).

FAMILY OGYRIDIDAE (2 species)

GENUS OGYRIDES Stebbing, 1914

Ogyrides alphaerostris (Kingsley, 1880). Habitat: sand bars just offshore; surface to 10m. Range: Va. to Ga.+; S.C. — (SCMRRI).

Ogyrides limicola Williams, 1955. Habitat: muddy estuaries; surface to 5m. Range: Va. to La.; S.C. — (SCMRRI).

FAMILY HIPPOLYTIDAE (12 species)

GENUS EXHIPPOLYSMATA Stebbing, 1915

Exhippolysmata oplophoroides (Holthuis, 1948). Habitat: near shore; estuaries; 5-30m. Range: N.C. to Brazil; S.C. — (SCMRRI). (Note: formerly called Hippolysmata oplophoroides (see Chace, 1972)).

GENUS HIPPOLYTE (Leach, 1814)

Hippolyte curacaoensis Schmitt, 1924. Habitat: sand and mud flats; sublittoral. Range: N.C. to Curacao+; S.C. — (USNM). (Note: this species is incorrectly referred to in Williams (1965a) as Hippolyte zostericola (see Chace, 1972)).

Hippolyte pleuracanthus Stimpson, 1871. Habitat: in beds of vegetation in sounds and bays; rocks of jetties. Range: N.J. to Tex.+; S.C. — OS (MARMAP).

*Hippolyte zostericola (Smith, 1873). Habitat: beds of vegetation. Range: Mass; N.C. to Yucatan+. (Note: Hippolyte zostericola in Williams (1965a) is acutally Hippolyte curacaoensis (see Chace, 1972)).

GENUS LATREUTES Stimpson, 1860

Latreutes fucorum Fabricius, 1798. Gulf-weed shrimp. Habitiat: pelagic and sublittoral; in floating masses of Sargassum and submerged grasses. Range: Newfoundland to Tex.; S.C. — (GMBL).

Latreutes parvulus (Stimpson, 1866). Habitat: littoral; sponges; among shells and hydroids; surface to 45m. Range: N.C. to Tex.+; S.C. — (SCMRRI).

GENUS LYSMATA Risso, 1816

Lysmata wurdemanni (Gibbes, 1850). Habitat: stone jetties; among hydroids on pilings or buoys; surface to 30m. Range: Chesapeake Bay to Tex.; S.C. — (SCMRRI).

GENUS THOR Kingsley, 1878

Thor dobkini Chace, 1972. Habitat: grass flats; shallow water to 15m. Range: N.C. to Yucatan; S.C. — Little River Inlet (see Chace, 1972).

Thor floridanus Kingsley, 1878. Habitat: among sponges; ascidians, algae and soft corals; shallow water to 55m. Range: N.C. to Ala.+; S.C. — (GMBL).

*Thor manningi Chace, 1972. Habitat: grass flats; dead corals; submerged timbers; shallow water to 45m. Range: N.C. to Curacao.

GENUS TOZEUMA Stimpson, 1860

Tozeuma carolinense Kingsley, 1878. Habitat: beds of vegetation in shallow water; surface to 75m. Range: Mass. to Panama+; S.C. -- OS (MARMAP).

FAMILY PROCESSIDAE (5 species)

GENUS PROCESSA Leach, (1815)

Processa bermudensis (Rankin, 1900). Habitat: oceanic; surface to 325m.; usually shallow water. Range: N.C. to Fla.; S.C. -- (SCMRRI).

Processa fimbriata Manning and Chace, 1971. Habitat: broken shell, coral; in sponges; shallow water to 35m. Range: N.C.; Fla.+; S.C. -- (USNM).

*Processa tenuipes Manning and Chace, 1971. Habitat: 30-330m. Range: N.C. to Gulf of Mexico.

*Processa vicina Manning and Chace, 1971. Habitat: 45-95m. Range: N.C.; Gulf of Mexico+.

*Processa wheeleri Lebour, 1941. Habitat: 35-100m. Range: N.C.?; Bermuda.

FAMILY PANDALIDAE (1 species)

GENUS PANTOMUS Milne Edwards, 1883

*Pantomus parvulus Milne Edwards, 1883. Habitat: 135-450m. Range: N.C. to Yucatan+.

FAMILY CRANGONIDAE (2 species)

GENUS CRANGON Fabricius, 1798

*Crangon septemspinosa Say, 1818. Sand shrimp. Habitat: sand; low-tide mark to 90m. Range: Baffin Bay to Fla.+.

GENUS PONTOPHILUS Leach, 1817

*Pontophilus brevirostris Smith, 1881. Habitat: 25-350m. Range: Maine to Gulf of Mexico.