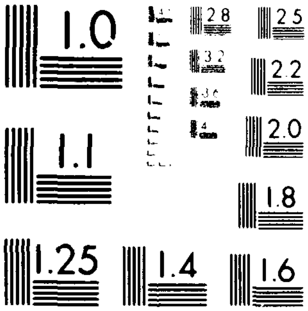
AD-A085 006 NAVAL OCEANOGRAPHIC OFFICE NSTL STATION MS F/G 8/1
MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFO--ETC(U)
MAY 74 R G BEAUCHAMP
UNCLASSIFIED N00-SP-250 NL

1 of 3
AD
A085006


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

NAVAL OCEANOGRAPHIC OFFICE SPECIAL PUBLICATION NO. 250

12

MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFOLK NAVAL OPERATING AREA

MAY 1974

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE.

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

DEPARTMENT OF THE NAVY
WASHINGTON, D.C. 20373

ERRATA

Page 2, Line 3 from bottom: "entrace" should read "entrance."

Page 16, Line 1 from top: "categores" should read "categories."

Page 75, in Legend: "NON-F DERAL PUBLIC" should read "NON-FEDERAL PUBLIC."

Page 82, Line 21 from top: "expecially" should read "especially."

Page 98, Line 16 from bottom: "is" should read "are."

Page 101, Number 6. "Osciliatoria" should read "Oscillatoria."

Page 126, Line 21 from bottom: "concentrations" should read "concentrators."

Page 133, Line 18 from top: "halogentated" should read "halogenated."

Page 138, Line 26 from top: "upmost" should read "utmost."

Page 163, 4th reference from top: "menhade" should read "menhaden."

Page 261, "cucumber" should read "sea cucumber."

NOO SP-250

MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFOLK NAVAL OPERATING AREA

ROBERT G. BEAUCHAMP, EDITOR

MAY
1974

[illegible]

U. S. NAVAL OCEANOGRAPHIC OFFICE
~~WASHINGTON, D. C.~~ 20373
N[illegible]

FOREWORD

The data presented in this document for the Hampton Roads/ Norfolk Naval Operating Area provide a single environmental reference source for Navy operational planners. This Marine Environmental Planning Guide will enable civilian and military marine activity planners to estimate and minimize the impact of their operations upon the marine environment. The guide will permit selection of the best locations and proper timing to conduct marine operations in order to limit the environmental stress caused by many of man's activities at sea.

J Edward Snyder Jr

J. EDWARD SNYDER, JR.
Oceanographer of the Navy

ACKNOWLEDGEMENTS

In the course of this study numerous people and organizations provided information at our request. We would like to thank the following:

Alexandria Drafting Co., Alexandria, Va.
Army Corps of Engineers, Norfolk, Va. J. J. Lawless.
Atlantic Estuarine Fisheries Service, Beaufort, N.C. Ms. P. Keney, Dr. T. Rice.
Atomic Energy Commission, Materials Branch, Wash., D.C. N. Bassin.
Bureau of Sport Fisheries and Wildlife, Narragansett Labs. D. Deuel.
Coastal Engineering Research Center, Washington, D.C., Edward P. Meisburger.
Coastal Plains Center for Marine Development Services, Wilmington, N.C. R. Hines.
Environmental Protection Agency, Office of Hazardous Materials, Wash., D.C.
National Marine Fisheries Service, Wash., D.C. and Sandy Hook, N.J.
D. Fitzgibbon, Dr. W. G. Smith.
National Oceanographic and Atmospheric Administration (NOAA). Dr. E. V. Collins,
R. Wildman.
Office of the Oceanographer of the Navy, Lieutenant Commander L. Riley,
Lieutenant W. Pine.
University of Delaware, Lewes, Del. Dr. K. Price.
Virginia Institute of Marine Sciences, Gloucester Pt., Va. Dr. J. Wood,
J. B. Pleasants.

This publication was prepared by a study group under the direction of R. G. Beauchamp, Oceanographic Analysis Division, with the advice of Mr. W. E. Maloney, Director, Marine Products Department, U.S. Naval Oceanographic Office. Researchers and originators of individual manuscripts include the following: R. B. Blumenthal; W. E. Boisvert, Jr.; B. S. Brun; N. T. Edwards, Jr.; T. R. Frontenac; D. T. Gibson; A. F. Hall; K. R. Hollingshead; P. B. Land; E. R. Long, and Ms. Sandra E. Seim; Editorial assistance was provided by C. R. Coleman; W. A. Erb, and R. A. Martino. Special thanks to Mrs. Thelma Hall and Mrs. Eileen Pigott for the typing of the manuscript, and to Mrs. Viola Luttrell for compilation of the page layouts.

CONTENTS

SUMMARY

ENVIRONMENTAL ANALYSIS

CONTENTS (CON.)

CONTENTS (CON.)

APPENDIXES

APPENDIXES (CON.)

FIGURES

SUMMARY

ENVIRONMENTAL ANALYSIS

FIGURES (CON.)

TABLES

TABLES (CON.)

SUMMARY

A. Introduction

In November of 1971 the Assistant Secretary of the Navy for Research and Development requested initiation of studies of the environmental impact of naval operations and maritime-generated pollution on coastal waters. The Office of the Oceanographer of the Navy tasked the U.S. Naval Oceanographic Office to prepare this report as a prototype marine-environmental planning guide. A team of oceanographers examined the Hampton Roads/Norfolk Naval Operating Area (fig. S1).

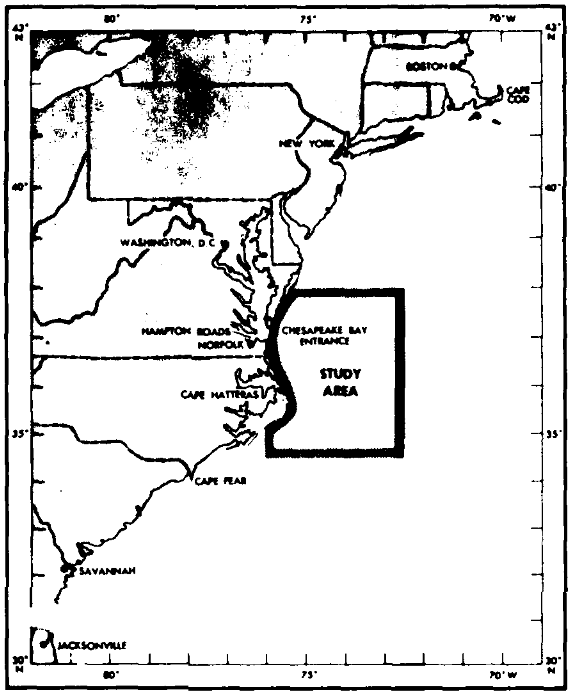


FIGURE S1. LOCATOR CHART HAMPTON ROADS/NORFOLK STUDY AREA

Explicit guidelines are necessary for the control of pollutants which degrade or endanger human health; jeopardize marine life, wildlife populations, or other economic resources; and impair recreational and aesthetic values.

Two major approaches were implemented in developing the planning guide. The first is a detailed description of the environment with emphasis on the physical, biological, and geological processes operative in the Area. The second deals with the interactions of possible pollutants with these processes, and interpretations and applications of this information as it relates to good environmental quality control practices.

The planning guide is intended primarily for use by naval at-sea commands, district commands, and Chief of Naval Operations (CNO) levels responsible for initiating sound operational and disposal practices and for evaluating practicality and/or the validity of future disposal standards. The guide may be utilized by Army Corps of Engineers, U.S. Coast Guard, the Environmental Protection Agency, and other agencies which are responsible for the surveillance, control, and cleanup of pollutants. State and local agencies, as well as private corporations, which are engaged in marine disposal operations or oil exploration, will find this planning guide valuable for assessing possible effects on the physical and biological regimes of the Area.

B. Environmental Summary

The planning guide incorporates detailed descriptions of the physical and biological regimes, including their interactions, of the Hampton Roads/ Norfolk Naval Operating Area and provides tentative models for the prediction of material dispersion on the sea-surface and over the seabed. The findings are useful to agencies concerned with environmentally acceptable marine disposal practices and coastal zone maritime planning.

Generally, the factors responsible for the dispersion of material in the marine realm include winds, wave currents, and tides.

Surface winds play an important role in the transport and dispersal of pollutants. Floating, dissolved, or suspended materials may be transported landward or seaward by the actions of the wind on the water. Additionally, mixing of materials in the water by the downward transport of momentum can be initiated by the surface flow.

In the Hampton Roads/Norfolk Area prevailing winds are predominantly offshore during summer and winter. An exception is in the autumn (September and October) when onshore winds prevail. The combination of waves generated by the wind (sea) and wind stress generates a wind drift current which, in the Area, is usually parallel to or away from the coast approximately two-thirds of the time in all months but September and October. During most of the year, any offshore surface pollutant will eventually be forced into the Gulf Stream at some point along its course; the rate of transport increases from northwest to southeast. During September and October, the wind-induced flow tends to move surface pollutants toward the coast more rapidly as distance to shore decreases.

On a short-term basis, wind stresses are directed shoreward ahead of northward-moving coastal lows. These extratropical cyclones are particularly frequent from late autumn through early spring, many of them originating in the region near Cape Hatteras.

The prevailing direction of seas generally coincides with that of the surface winds. Swell is more likely to be directed onshore than seaward during winter and usually emanates from intense extratropical cyclones located in the north and northeast. During summer, swell frequently originates from the persistent southerly to southwesterly winds of the subtropical high.

The Gulf Stream is present in the eastern part of the Area and sets strongly toward the northeast (fig. S2). Materials on the sea-surface or in suspension likely will be transported toward the northeast and out of the Area if entrained within the stream. Over the continental shelf in the Area, the southward flow of the Labrador Current Extension also influences the dispersal directions of material.

The tidal currents are rotary and weak over the Continental Shelf whereas at the entrace to Chesapeake Bay they are strong and reversing (U.S. Naval Climatic Center, 1972). Disposal is not advisable at or near the Bay entrance.

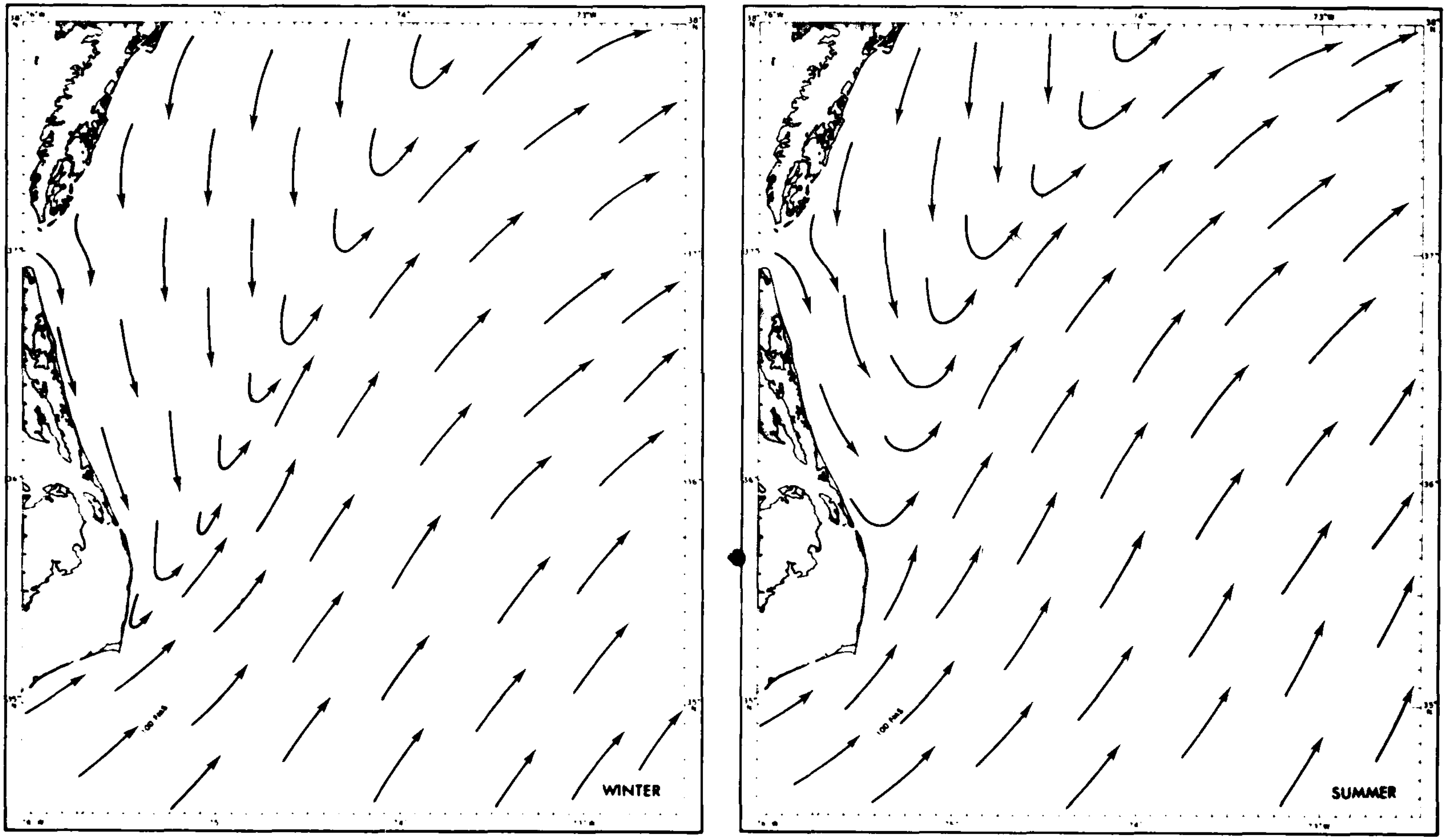


FIGURE S2 SURFACE CURRENTS

Breakers thoroughly mix all suspended matter and pollutants, and longshore currents subsequently transport this material laterally. There is no predominant direction of flow at beach A. The currents throughout the year flow predominantly northward at beaches B, G, and H, and southward at beaches C1, C2, D, E, and F (fig. S3). This information can be used for locating cleanup equipment in the event of a nearshore oil spill.

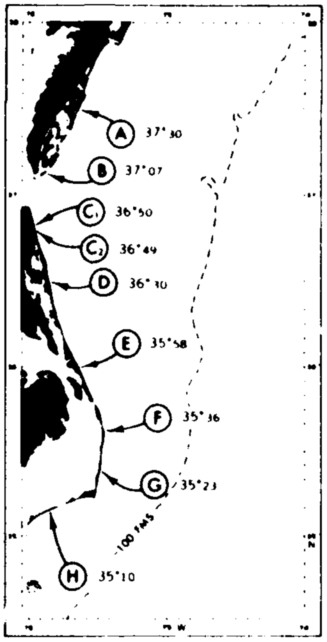
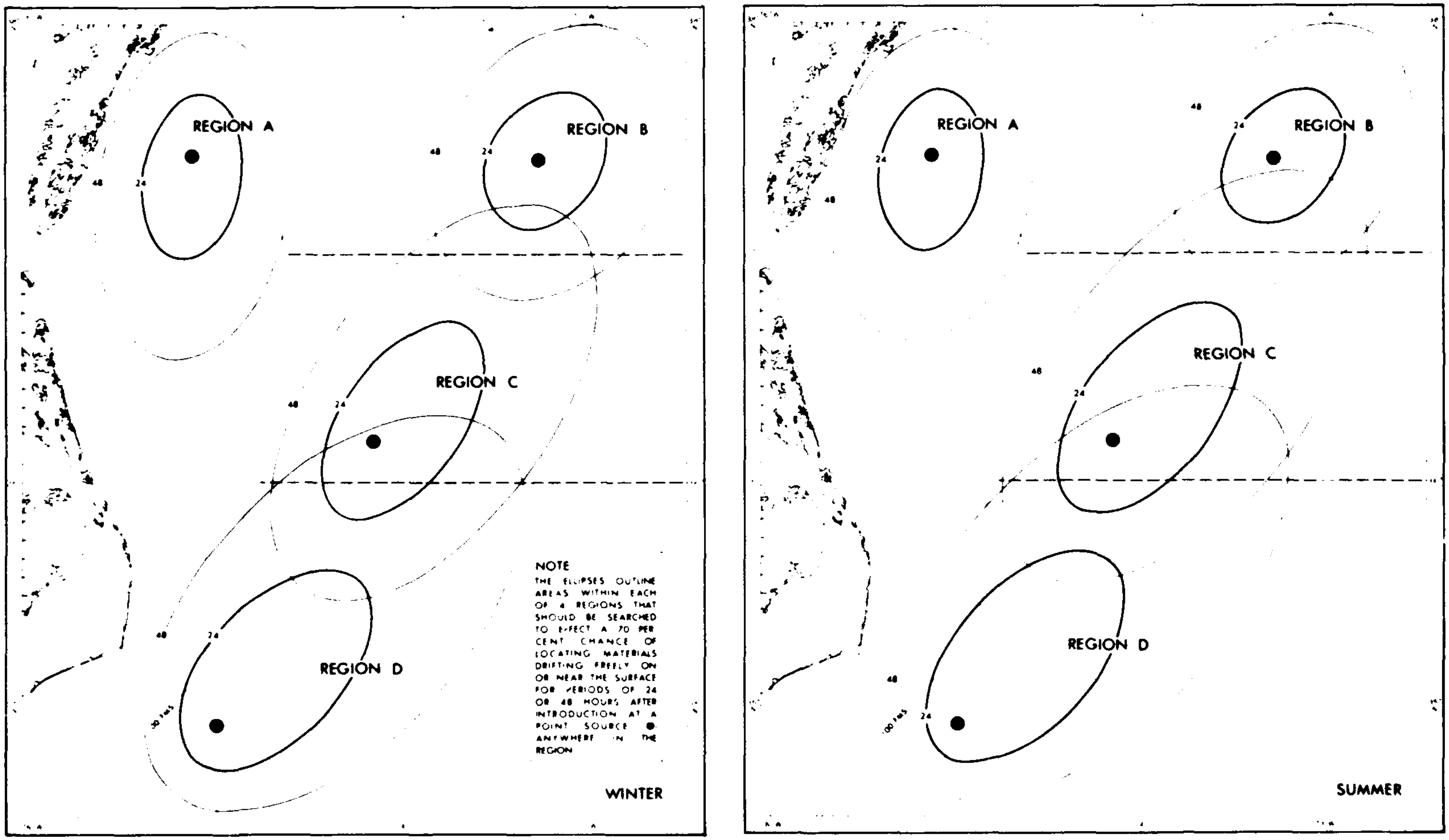


FIGURE S3. BEACH INTERCEPT LOCALITIES OF CLOSE INSHORE DUMP MATERIAL

A model has been constructed for predicting dispersion directions of surface or suspended material in the Area. The data are used as input to a vector analysis program provided by Yergen (1962), and surface drift ellipses are derived for winter and summer (fig. S4). The ellipses are closely related to the surface currents and are elongated in the direction of prevailing flow. The ellipse technique designates an axis of regional search for free drifting objects or contaminants such as oil spills and wastes, under average conditions, based on the percent probability desired and time from initial point of pollutant discharge. For example, if an oil spill occurs in the Area, the closest ellipse can be moved over the spill site to determine dispersion paths the oil may take and approximately how much time remains before the coastline is threatened.

Orbital motions of long-period waves generated by distant winds often extend to great depths. In general, the greater the period and height, the greater the depth of penetration with a resulting greater likelihood that the bottom will be disturbed. The percent frequency of waves touching bottom is shown for months representative of each season in figure S5. These isolines are a measure of the seasonal variations in the depth of wave penetration. Waves penetrate deepest in winter and are more likely to disturb bottom material during this season than at any other time. This subsurface wave motion also causes increased vertical mixing and a more rapid dispersal of pollutants.



NOTE
THE ELLIPSES OUTLINE AREAS WITHIN EACH OF 4 REGIONS THAT SHOULD BE SEARCHED TO EFFECT A 70 PER CENT CHANCE OF LOCATING MATERIALS DRIFTING FREELY ON OR NEAR THE SURFACE FOR PERIODS OF 24 OR 48 HOURS AFTER INTRODUCTION AT A POINT SOURCE ● ANYWHERE IN THE REGION

FIGURE S4. SURFACE DRIFT ELLIPSES

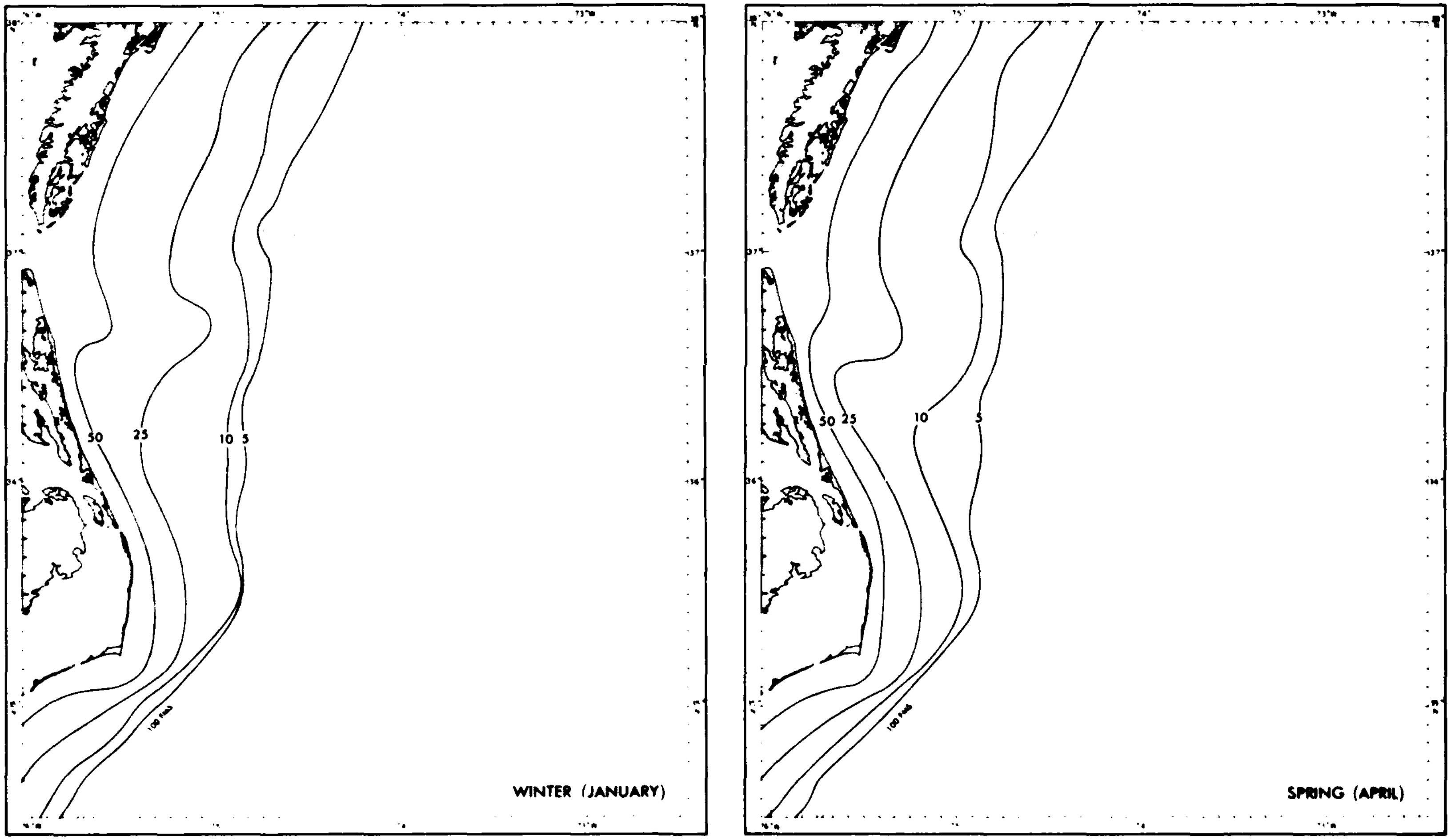


FIGURE S5. PERCENT FREQUENCY OF WAVES TOUCHING BOTTOM

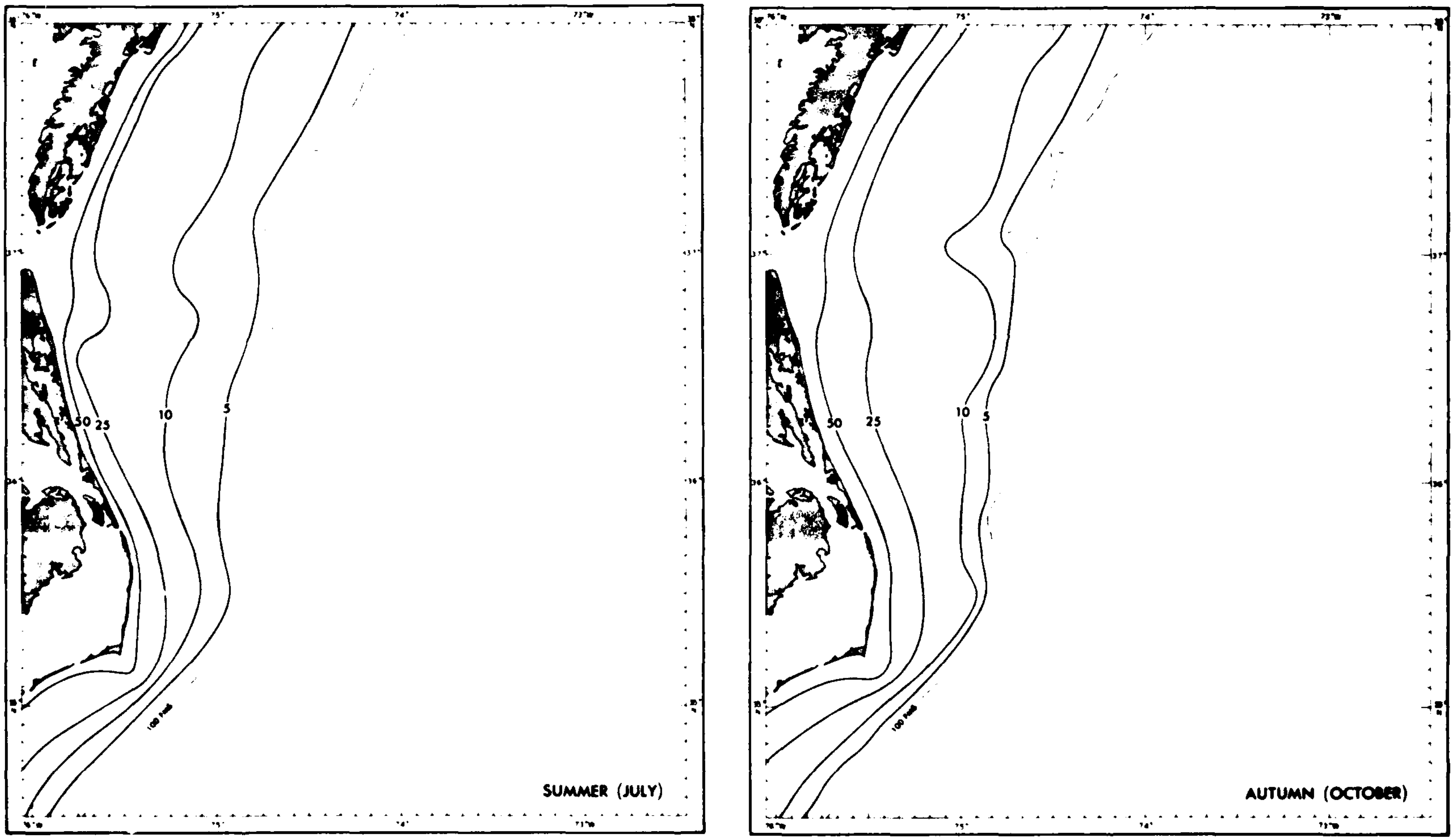
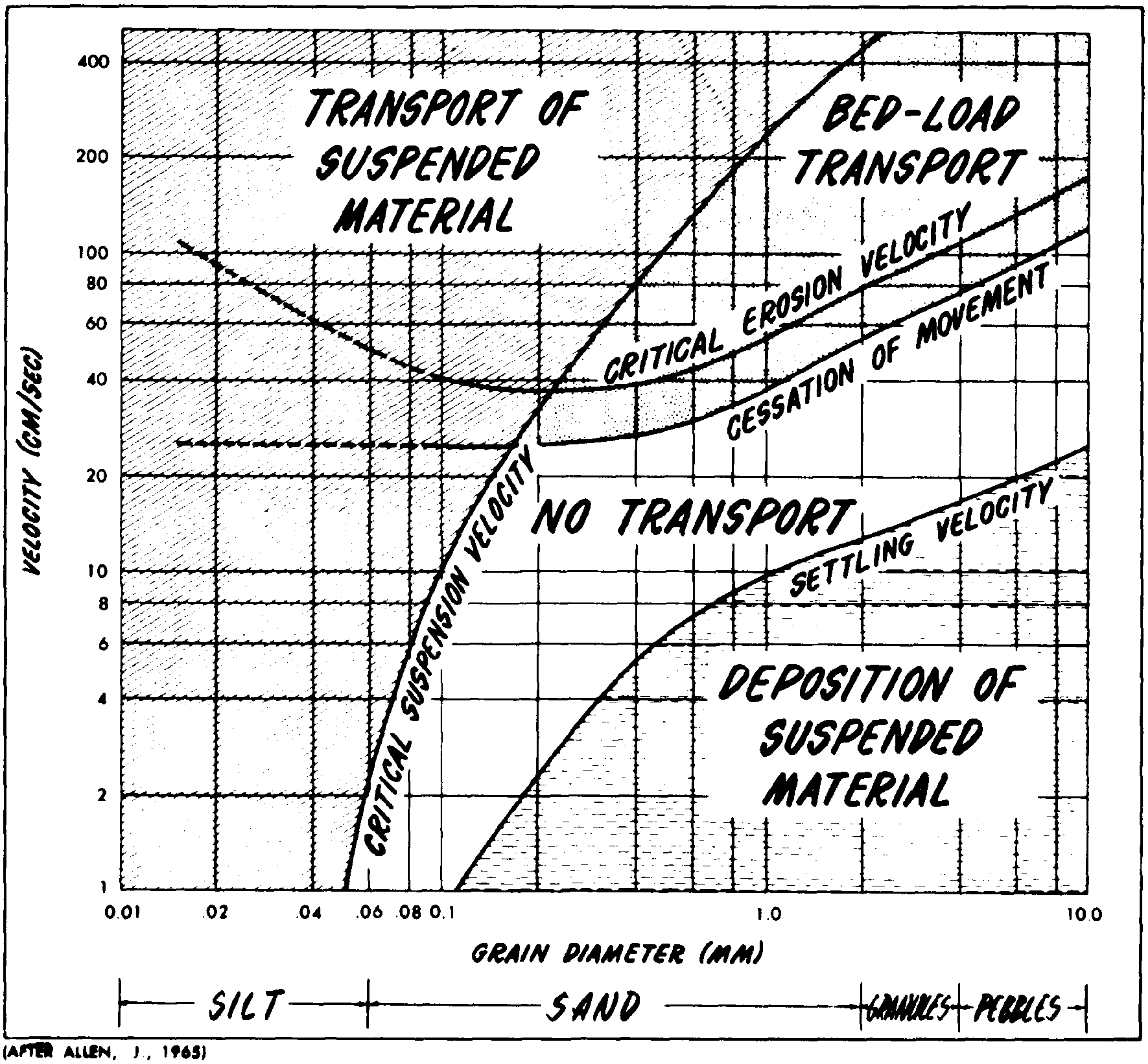


FIGURE S5. PERCENT FREQUENCY OF WAVES TOUCHING BOTTOM (CON.)

A tentative model was constructed to predict the dispersion of dredge spoil or contaminating deposits over the seabed. Resuspension of bottom material can occur whenever wave orbital motion (μ_o) close to the seabed is appreciable (see Appendix B). Once the bottom material is in suspension it can be transported by forward drift ($\bar{\mu}$) (see Appendix B). The competency diagram in figure S5 indicates the orbital velocities required to resuspend various sediment size materials. For example, orbital velocities close to the seabed must exceed 37 cm/sec, 48 cm/sec, and 54 cm/sec to resuspend medium sand (0.24 mm), fine sand (0.062 mm), and silt (0.052 mm), respectively. In order to transport the material after it is suspended, the forward drift velocity must exceed 37 cm/sec, 2.4 cm/sec, and 1.0 cm/sec, respectively.



(AFTER ALLEN, J., 1965)

FIGURE S6. COMPETENCY CURVE

The above orbital and forward velocities are frequently equaled or exceeded on the Continental Shelf in the Area during autumn, winter, and spring. Therefore sediment, such as dredge spoil, deposited on the shelf is subject to erosion and transportation much of the time (fig. S7).

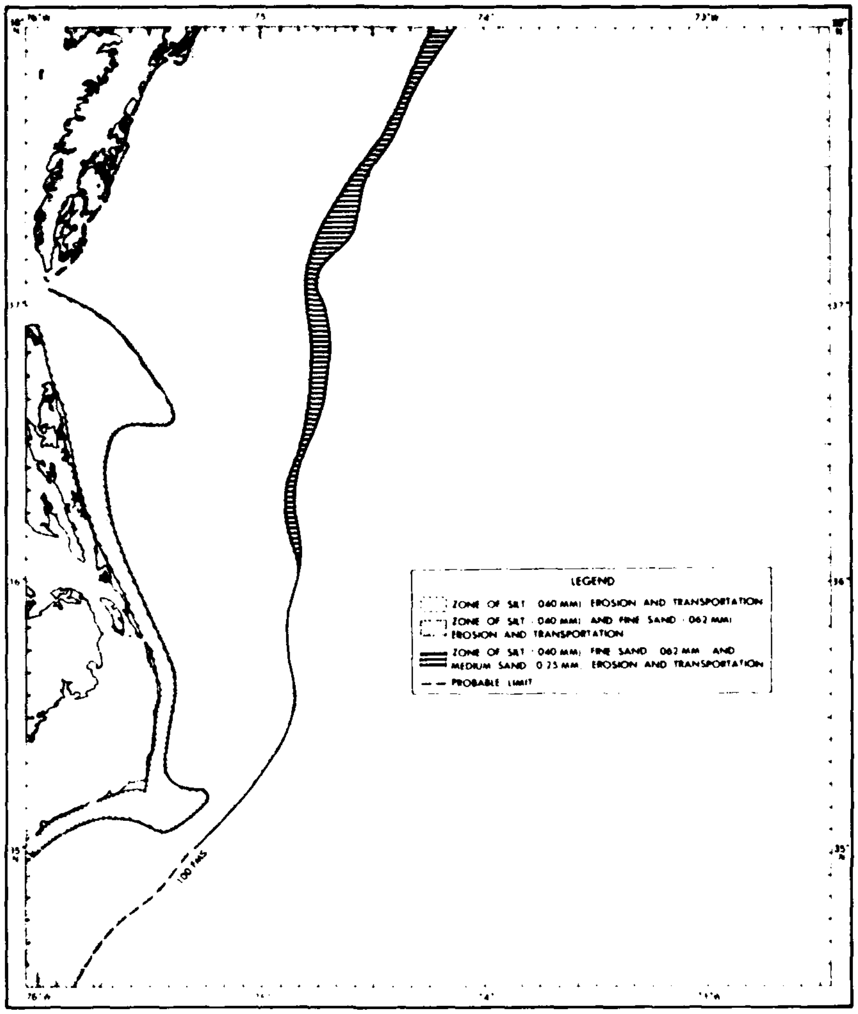


FIGURE S 7. ZONES OF SUSPENSION AND TRANSPORT RELATED TO GRAIN SIZE

The direction in which bottom material is transported is also an important consideration when selecting disposal sites. Harrison, et al. (1967) determined from bottom drifters that transport in the Area is predominantly toward the coast regardless of the season (fig. S8). While silt and sand on most of the shelf can theoretically be transported during autumn, winter, and spring, wave action in the summer is minimal and silt and fine sand are confined to within 20-30 nautical miles of the coast in the Area. Silt and fine sand, such as dredge spoil, deposited on the Continental Shelf, ultimately will be transported toward the coast. The rate of transport is not known and cannot be determined without on-site measurements. Dredge spoil containing sand and silt which is deposited seaward of the Continental Shelf, should eventually be incorporated with deep-sea sediments and not be entrained within the westward bottom drift present on the shelf.

THE BOTTOM DRIFT OF SHELF WATER IN CHESAPEAKE BIGHT SHOWS AREAL AND MONTHLY VARIATIONS, BUT TENDS TOWARD THE SOUTHWEST IRRESPECTIVE OF THE SEASON AND THE DIRECTION OF SURFACE FLOW. RECENT WORK BY THE U.S. DEPARTMENT OF COMMERCE STATES THAT THE DIRECTION OF THE INFERRED BOTTOM DRIFT INTO CHESAPEAKE BAY, DETERMINED FROM SEABED DRIFTER RECOVERY DATA, APPEARS TO BE RELATED TO CHANGES IN RIVER DISCHARGE AND SEASONAL PREVAILING WINDS. A MAJOR REASON FOR THE INWARD FLOW, NOT MENTIONED IN THE REPORT, APPEARS TO BE THE STRONG TIDAL CURRENTS THROUGHOUT THE ENTRANCE TO THE BAY WITH A NET RESULTANT FLOW INWARD ON THE FLOOD FROM MID DEPTH TO BOTTOM.

THE FOLLOWING INFORMATION HAS RESULTED FROM ANALYSIS OF SEABED DRIFTER DATA.

1. THE BOTTOM DRIFT WAS FOUND TO BE VARIABLE, AT TIMES NEARLY REVERSING, IN AREAS NORTH OF, AND IN NEARSHORE WATERS SOUTH OF, CHESAPEAKE BAY. DESPITE THESE VARIATIONS, THERE WAS A PRONOUNCED TREND TOWARD SHORE TO THE SOUTHWEST DURING ALL SEASONS.
2. ALTHOUGH THE GREATEST NUMBER OF SEABED DRIFTER RECOVERIES OCCURRED DURING WINTER WHEN OFFSHORE WINDS PREVAILED, SEABED DRIFTERS CONTINUED TO STRAND, THOUGH IN LESSER NUMBERS, IN SEASONS WHEN THE WINDS WERE MAINLY ONSHORE.
3. THERE WAS A PRONOUNCED TENDENCY FOR SEABED DRIFTERS TO TRAVEL TOWARD, AND EVEN TO ENTER, CHESAPEAKE BAY.
4. DURING PERIODS OF MAXIMUM FRESH WATER DISCHARGE, THERE WAS A WELL DEFINED NORTHWESTERLY BOTTOM DRIFT TOWARD CHESAPEAKE BAY FROM DISTANCES AS GREAT AS 35 NAUTICAL MILES SOUTHEAST OF CAPE HENRY.
5. THE SPEED OF SEABED DRIFTERS WAS NOT CONSTANT ACROSS THE SHELF. FURTHER, THE RATE OF DRIFT OF SEABED DRIFTERS RELEASED IN AUTUMN AND WINTER DIFFERED FROM THE RATE OF THOSE RELEASED IN SPRING AND SUMMER.
6. MINIMAL RECOVERIES OF SEABED DRIFTERS RELEASED IN AREAS NEAR THE EDGE OF THE SHELF INDIRECTLY INDICATES THAT THE FLOW OF BOTTOM WATER TRENDS OFFSHORE AT DISTANCES GREATER THAN 40 NAUTICAL MILES.
7. SEABED DRIFTERS RELEASED TO THE EAST AND NORTHEAST OF CAPE HATTERAS WERE SELDOM RECOVERED AND THIS SUGGESTS AN OFFSHORE DRIFT OF BOTTOM WATER IN THE VICINITY OF CAPE HATTERAS.

INFORMATION ON BOTTOM DRIFT, EXCEPT THE REFERENCE TO TIDAL CURRENT EFFECT AND THE GENERALIZED FLOW PATTERN, WAS OBTAINED FROM ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION PROFESSIONAL PAPER 3, U.S. DEPARTMENT OF COMMERCE. W. HARRISON, J.J. NORCROSS, N.A. PORE, F.W. STANLEY, 1967.

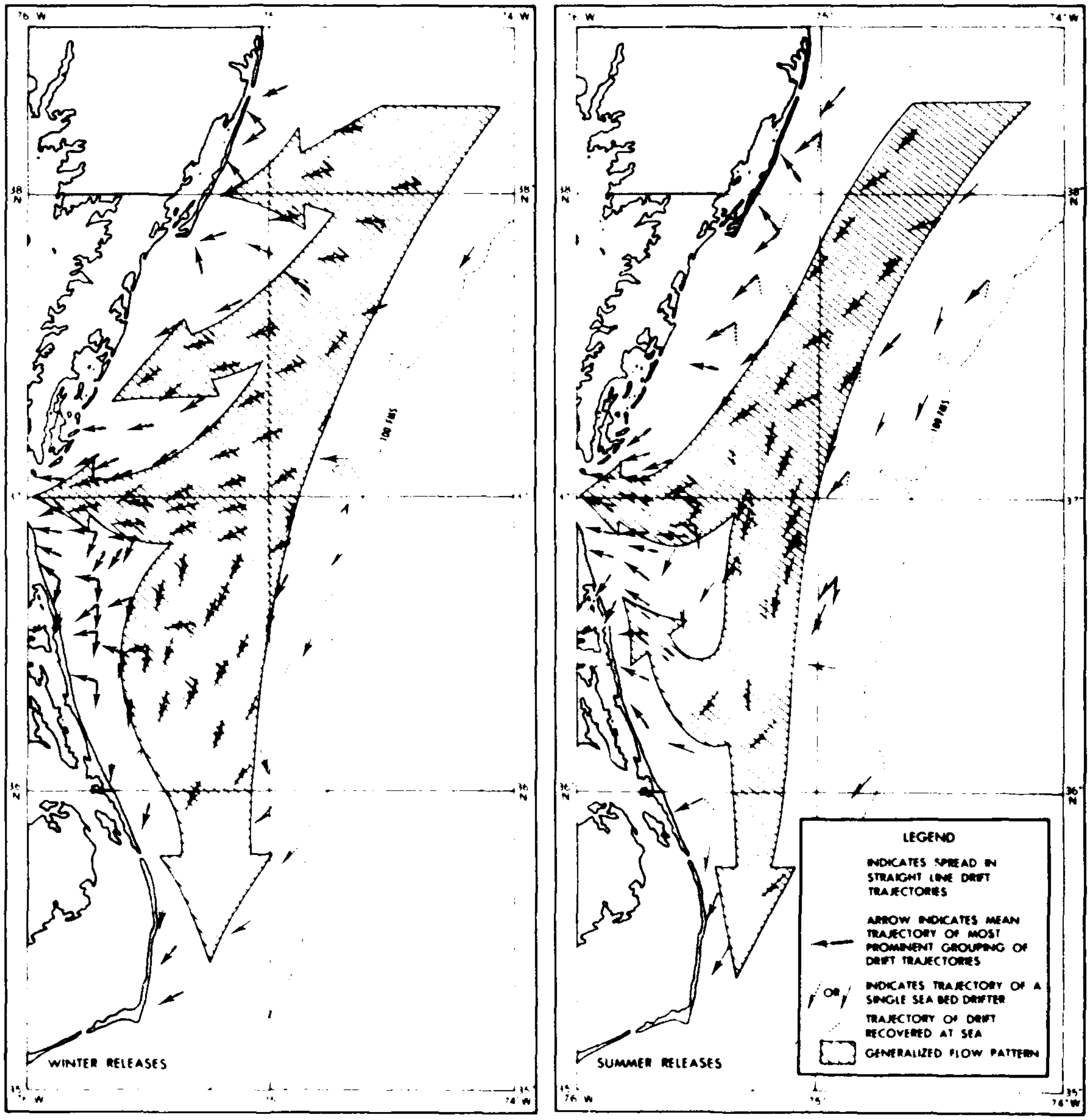


FIGURE S 8. INFERRED BOTTOM DRIFT

A pronounced salinity gradient occurs off Chesapeake Bay, and a surface pollutant (e.g., oil) may collect at the seaward interface parallel to the shoreline, especially during summer when the change in mean surface salinity is greatest (Kennedy and Wermund, 1971) (see fig. 14).

The northern boundary of the Gulf Stream is a sharp thermal gradient (front) that is most intense during winter. The occurrence and relative strength of this front may inhibit the spread of surface pollutants and may also influence the direction in which they move. For example, a pollutant introduced in winter in the coastal region of Cape Hatteras, where the general direction of flow is south, may travel as far as the cape and then be impeded by the strong thermal gradient. If such an incident occurs, collection equipment could be positioned near the cape to arrest the spread of surface contaminants.

Changes in seasonal density stratification may affect vertical movement of pollutants. In any region, regardless of season, that exhibits a strong density gradient, density layers in the upper water column will be shallower than in regions with weaker gradients. This density layer may act as a "false bottom" where material accumulates, migrates, and can possibly surface elsewhere. If the water column is homogeneous, pollutants lighter than the ambient density may easily reach the surface. However, pollutants premixed to the water density at the point of introduction may mix and spread within that density layer and not reach the surface.

The presence of some pollutants within the water column may also deplete ambient oxygen through oxidation processes.

Instability, the decrease in density with depth in the water column, will increase the possibility of mixing materials within the surface layers and cause more rapid sinking to the layer of equal density. This phenomenon is observed in the vicinity of the Gulf Stream during April and December, and probably is caused by temporary near-surface temperature inversions. Instability is more persistent in the coastal region and near the Continental Shelf edge, especially off Cape Hatteras.

Where unstable water is present at mid-depth, convective mixing occurs, and a pollutant at these levels may dissipate more rapidly. Instability in the coastal region suggests that mixing and dispersion of materials occurs and distinct layering is less likely. Summer appears to be the only season during which instability does not occur in the coastal region. Disposal plans should include consideration of stability, which can be determined by analysis of a thermal profile.

The study of density stratification with regard to pollutant dispersal can be highly useful, however, the reliability of dispersion predictions is a function of the amount and quality of oceanographic data. The density data available in the Area are limited.

The waters of the Hampton Roads/Norfolk Operating Area support an abundant biota which contribute significantly to the economy of Maryland, Virginia, and North Carolina. With the exception of Georges Bank, the area between Cape Cod and Chesapeake Bay contains larger volumes of phytoplankton and zooplankton than any other temperate coastal area on either side of the Atlantic. The abundance, diversity, and biomass of the benthic organisms on the Continental Shelf in the Area are also impressive.

A wide variety of commercially valuable fishes and shellfish are taken annually in the Area. In 1971, the catch amounted to approximately 280 million pounds with a market value of nearly $34,000,000. Marine sport fishing is a large recreational activity and $183,000,000 is spent annually for equipment, transportation, and fees (Bureau of Sport Fisheries and Wildlife, 1970). Figures and charts outlining the fisheries are presented in the "Fisheries" section.

Currents are responsible for providing the necessary nutrients and oxygen to marine organisms, thereby controlling the location and abundance of herbivores and carnivores (including commercially valuable fishes). Currents also disperse and transport pollutants, thereby producing potential hazards to marine organisms.

For example, oil, pesticides, heavy metals, industrial wastes, and dredge spoils introduced in the nearshore waters off Maryland and Delaware will be transported southwestward along the Delmarva Peninsula, and Virginia and North Carolina coasts and endanger the biota of these areas. Material sinking near the entrance of Chesapeake Bay may be swept by bottom currents into the bay. Pollutants spilled or dumped off Cape Hatteras will be transported northeasterly by the Gulf Stream, where pelagic organisms may be contaminated.

Surface, subsurface, and bottom currents probably least affect introduced pollutants seaward of the Continental Shelf (100 fm contour) from 38°00'N, 73°30'W to 38°00'N, 72°30'W and from 36°30'N, 74°00'W to 37°00'N, 72°30'W. In this region, depths are great and the relatively slow currents produce a net northeast drift out of the Area.

Additions of highly acidic or highly basic materials may create physiological stresses upon some organisms, especially if a pH stress is accompained by some other simultaneous and/or synergistic stress. Basic pH conditions increase the precipitation of heavy metals and thereby possibly increase the exposure of benthic animals to these metals.

Dumping of dredge spoils and other activities adjacent to shellfish beds and centers of primary productivity increase the turbidity of surface water layers and the amount of suspended material which together can lower productivity by reducing the penetration of sunlight into the water and by interfering with filter-feeding activities of benthic and planktonic organisms. The detrimental effect on productivity can be worsened if the water is already turbid due to meteorological effects.

Stresses that reduce the biomass of autotrophs or cause a loss in their production efficiency will tend to decrease the productivity of the entire ecosystem. Decreases in primary productivity in the euphotic zone will be reflected, after a time lag, in the fish, mammal, and invertebrate population size. Therefore, populations which are not themselves directly exposed to pollution may be affected by a disturbance of productivity in a distant part of the food chain.

ENVIRONMENTAL ANALYSIS

A. Introduction

In November of 1971 the Assistant Secretary of the Navy for Research and Development requested initiation of studies of the environmental impact of naval operations and maritime-generated pollution on coastal waters. The Office of the Oceanographer of the Navy tasked the U.S. Naval Oceanographic Office to prepare this report as a prototype marine-environmental planning guide. A team of oceanographers examined the Hampton Roads/Norfolk Naval Operating Area (fig. 1).

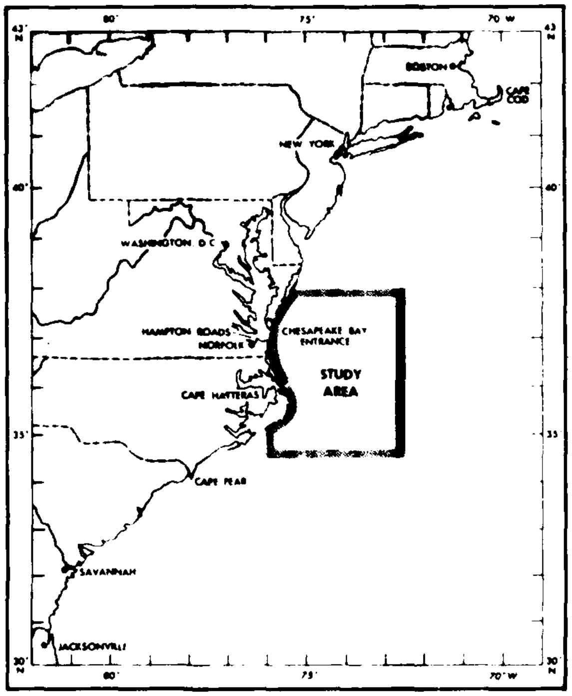


FIGURE 1. LOCATOR CHART OF HAMPTON ROADS NORFOLK STUDY AREA

Explicit guidelines are necessary for the control of pollutants which degrade or endanger human health; jeopardize marine life, wildlife populations, or other economic resources; and impair recreational and aesthetic values.

Two major approaches were implemented in developing the planning guide. The first is a detailed description of the environment with emphasis on the physical, biological, and geological processes operative in the Area. The second deals with the interactions of possible pollutants with these processes, and interpretations and applications of this information as it relates to good environmental quality control practices.

The planning guide is intended primarily for use by naval at-sea commands, district commands, and Chief of Naval Operations (CNO) levels responsible for initiating sound operational and disposal practices and for evaluating practicality and/or the validity of future disposal standards. The guide may be utilized by Army Corps of Engineers, U.S. Coast Guard, the Environmental Protection Agency and other agencies which are responsible for the surveillance, control, and cleanup of pollutants. State and local agencies, as well as private corporations, which are engaged in marine disposal operations or oil exploration, will find this planning guide valuable for assessing possible effects on the physical and biological regimes of the Area.

B. Physical Processes Affecting Surface and Subsurface Dispersion

1. Introduction

The major physical processes important in formulating acceptable, routine disposal practices or in determing remedial steps to control accidental or planned spills (i.e., oil spills, industrial waste, sewage, etc.) in the Hampton Roads/Norfolk Operating Area include wind effects, currents, waves, and breakers.

The wind generally prevails from the south and southwest during June, July, and August, from the north and northeast during September and October, and from the north and northwest from November through March; it is variable in April and May. Wind waves (sea) and wind stress generate a wind-drift current which is usually parallel to or away from the coast approximately two-thirds of the time in all months but September and October. The wind-induced flow converges on shore during these two months.

Three distinct areal regimes were delineated by the application of Ekman's wind drift theory (1905): A wind-drift regime which covers most of the Continental Shelf and is most extensive in winter, an offshore regime consisting of a layer of uniform motion between surface and bottom layers of frictional influence, and a transition regime separating the wind-drift and offshore regimes.

All the major types of currents occur in the Area. The Gulf Stream sets strongly toward the northeast. On the Continental Shelf north of Cape Hatteras, there is a permanent south-setting nontidal current with very little seasonal change, although reversals occur at times. The tidal currents are rotary and weak. In the entrance to Chesapeake Bay, reversing tidal currents predominate with net flow outward at the surface and inward from middepth to bottom. The subsurface currents at intermediate depths appear to be permanent and flow in the same direction as surface currents. Bottom drift tends toward the southwest. Surface current ellipses will aid planners in determining search areas for free drifting objects and contaminants such as oil spills. The ellipses provide a 70 percent probability of detection under average conditions.

The prevailing direction of seas in the Area generally coincides with that of the surface winds. Swell tends to be from the north and northeast from autumn through spring and from the south and southwest during summer.

During winter the depth of wave action increases as the wave period and height increase. Material on the floor of the Continental Shelf is therefore more likely to be disturbed and transported during this time. In addition, increased vertical mixing resulting from subsurface wave motion may cause more rapid dispersal of pollutants.

Along the coast, breakers and longshore currents also contribute to the transport of suspended matter, including possible pollutants, throughout the year.

Storm surges associated with intense cyclones and hurricanes can raise the sea level appreciably along the shore and force water pollutants into low-lying coastal regions. This hazard is intensified by concurrent high tides and onshore winds.

Offshore pollutants may also be diffused laterally into the surface tongue of low-salinity water that flows out of Chesapeake Bay. This process is most pronounced near the southern entrance to the bay and during spring.

2. Wind effects

a. Surface winds--Surface winds play an important role in the transport and dispersal of pollutants. Airborne particles may be transported in any direction by the wind. Floating, dissolved, or suspended pollutants may also be moved by the action of wind on the water. Contaminants may be mixed into the water to various depths by the downward transport of momentum initiated by the surface flow.

Figure A1 (Appendix A) shows the monthly distribution of surface winds for eight directions and five speed categories. These roses, constructed from wind data available at the U.S. National Climatic Center (1972), provide an indication of the direction and speed of transport of airborne particles such as harmful dusts and contaminated sprays. For example, the probability of coastal contamination can be deduced from the frequency of onshore winds.

In the Hampton Roads/Norfolk Operating Area, surface winds generally prevail from the north and northwest from November through March, from the south and southwest from June through August, and from the north and northeast during September and October. The direction is most variable in April and May. Airborne particles are thus more likely to float seaward than coastward in all months but September and October. However, the frequency of landward winds is at least 15 percent even during winter. For example, during February, the month of strongest winds, the flow is directly offshore (northwest and west) 37 percent of the time along the northern beaches. During August, these values are respectively 11 and 21 percent.

Figure A1 also gives the frequency of various speed categories. Thus, gale-force winds (≥ 34 knots) are most likely from October through March and are usually directed seaward. Such winds are usually associated with intense coastal storms between late autumn and midspring, and with tropical storms in summer and early autumn. The roses also give the frequency of calms. In this Area, this "stagnation index" is greatest in summer and least in winter.

Wind stress, an important parameter in meteorological and oceanographic investigations, is a measure of the force exerted by low-level winds on the sea surface. It is one of the variables entering in the calculation of wind drift. The wind stress relationship is expressed by the following quadratic resistance law:

$$\tau = \rho C_d V^2$$

Where τ is the wind stress in dynes/cm^2
ρ is the air density in gm/cm^3
C_d is the drag (or resistance) coefficient (dimensionless)
V is the horizontal downstream wind velocity in cm/sec

The drag coefficient is usually assumed to be a function of wind velocity. The following simple relationship was chosen from among the many available because it best suited the available wind data (i.e., according to

Beaufort speed categores):

For $V < 670$ cm/sec (Beaufort 0-3), $C_d = 0.8 \times 10^{-3}$
$V = 670$ cm/sec (Beaufort 4), $C_d = 1.7 \times 10^{-3}$
$V > 670$ cm/sec (Beaufort 5-12), $C_d = 2.6 \times 10^{-3}$

The mean air density (1.22×10^{-3} gm cm^{-3}) was calculated from the following equation (Hellerman, 1967):

$$\rho = (0.0022\,\phi + 1.136) \times 10^{-3}$$

Where ϕ is the latitude in degrees.

The calculations, which were performed according to the method outlined in the literature (Scripps Institution of Oceanography, 1948), yielded a field of vectors for each month (fig. A2).

The resultant wind stress direction is generally eastward or southeastward from November through April, variable in May, and north or northeastward during June, July, and August, with increasing magnitude toward the southeast. The wind stress is southwestward during September and southward with magnitude increasing shoreward in October. Thus, the resultant wind stress is onshore only during September and October, and only in September is the resultant stress directed toward the coast along its entire length.

It should be emphasized that the wind stresses depicted here represent vectorial summaries of all observed stresses. Although deflected away from the shore much of the time, the surface water may nevertheless be directed shoreward for several days in a row by the winds of stagnating pressure systems (e.g., the March 1962 "Great Atlantic Coast Storm"). The longer a low-pressure system remains in or south of this Area and the greater its size, the more likely that the surface waters and therefore any pollutants will be forced toward the beaches.

On a short-term basis, wind stresses are directed shoreward "ahead" of northward-moving coastal lows. These extratropical cyclones are particularly frequent from late autumn through early spring, many of them originating in the region near Cape Hatteras. The likelihood of coastward and seaward wind stresses can be deduced from the wind roses in figure A1.

b. Wind drift-The wind sweeping over the surface of the sea generates a drift current which combines the transport due to the wind stress and that resulting from wind waves ("sea"). This wind effect, or "wind drift current," is additive to any existing current.

Since continuous wave and wind data were not available, the wind drift current was determined graphically from historical wind data (James, 1966), under the assumption of fully developed conditions (i.e., that the current has reached its maximum attainable speed). Thus, the speeds shown on the drift roses (fig. A3) represent the maximum possible wind drift, a criterion met only when both the fetch and wind duration exceed certain threshold values. The higher velocities occur only if the duration of the wind and the fetch are long enough to generate maximum conditions. For this reason, the magnitudes of the wind drift current along the coast were attenuated to reflect the shortened fetches resulting from the brief over-water trajectory of offshore winds.

The directional frequency, which is independent of speed (i.e., the length of the rose arms), remains constant whatever the wind speed. Thus, when wind speeds are not sustained over the required period, drift current will be less than indicated in figure A3.

The angle of drift was assumed to be 35° to the right of the wind direction, probably 10° to 15° too far in the clockwise direction. The selection of this value resulted from the coarseness of the original data. The maximum wind drift values, determined by the above method, were plotted in figure A3 as current roses whose arms indicate the direction toward which the current is flowing.

The following categories were used to determine the values of wind-drift currents:

Wind speed, Beaufort	Maximum wind drift current (knots)	Required duration (hours)	Required fetch (miles)
1- 3	> 0 - 0.19	4-6	15--< 25
4- 5	0.20 - 0.49	6-14	25--< 125
6- 7	0.50 - 0.89	14-28	125--< 375
8-12	≥ 0.90	28-50	375-->1000

In general, the wind-drift current is predominantly southward to southwestward from November through March, northeastward to eastward from April through August, and southwestward to westward in September and October. Thus, the current is usually directed parallel to or away from the coast about two-thirds of the time in all months but September and October. During most of the year, any surface pollutant will eventually be forced offshore into the Gulf Stream at some point along its course; the rate of transport increases from northwest to southeast. During September and October, the wind-induced flow tends to move surface pollutants toward the coast more rapidly as distance to shore decreases.

c. Ekman elementary model--Surface winds are a determining factor in the layering of coastal waters. In general, this region consists of three distinct regimes whose horizontal and vertical extents are delimited by the mean wind speed and its resultant depth of frictional influence. A homogeneous wind-drift regime within the southward extension of the Labrador Current extends seaward from the shore; beyond this boundary, a transition zone leads into a fully developed offshore regime that is dominated by the Gulf Stream (fig. 2).

The wind-drift regime is a relatively shallow region whose circulation at all depths is generally determined by the mean surface winds. In the presence of other currents, as in this region, the wind drift is added vectorially to the permanent circulation, reinforcing it when the directions coincide, weakening it when the directions are opposed. The wind-drift zone is defined as that region where the total water depth (d) is less than one-half the depth of influence (D).

The offshore regime is a three-layered region whose depth is more than twice the frictional depth (fig. 2). This regime consists of a geostrophic layer whose flow is generally constant, sandwiched between surface and bottom frictional layers whose flows are determined by the Ekman theory.

The transition regime, bounded by water whose depth lies between D/2 and 2 D, separates the wind-drift regime from the offshore regime.

The depth of frictional influence, D, is represented by the following general equation (Neumann and Pierson, 1966):

$$D = \pi \sqrt{\frac{A}{\rho\omega \operatorname{Sin} \phi}}$$

Where A is the coefficient of eddy viscosity in gm cm^{-1} sec^{-1}
ρ is the density of sea water in gm/cm^3
ω is the angular velocity of the earth (7.2921×10^{-5} rad/sec)
ϕ is the latitude in degrees.

Because of the difficulty in determining the variables in available equations, Thorade (1914) derived the following expression for wind speeds in excess of 6 meters per second:

$$D = \frac{7.6\ \bar{V}}{(\operatorname{Sin} \phi)^{1/2}}$$

Where D is the depth of frictional influence in meters
$\bar{V}$ is the mean wind speed in meters per second
ϕ is the latitude in degrees.

Thorade (1914) established a different relationship for low wind speeds (< 6 meters per second):

$$D = \frac{3.67\ \bar{V}^{3/2}}{(\operatorname{Sin} \phi)^{1/2}}$$

Where: D is the depth of frictional influence in meters
$\bar{V}$ is the mean wind speed in meters per second.

Mean and maximum depths of frictional influence were calculated from the wind data (U.S. National Climatic Center, 1972). Average seasonal conditions, which are most likely during prolonged periods of high winds, were derived from the 50th-percentile wind speed; maximum seasonal conditions, which are most likely during prolonged periods of high winds, were derived from the 95th-percentile wind speed.

The surface limits of the three regimes discussed above are delineated in figure 2 for four months representative of each season. This illustration shows that the boundaries of the wind-drift regime fluctuate widely during the year owing to the relative shallowness of the water over the Continental Shelf. The wind-drift regime is most extensive in winter, when it covers much of the Continental Shelf, and least extensive in summer, when it is restricted to a narrow coastal strip.

The boundary between the offshore and transition regimes fluctuates only slightly during the year, from just shoreward of the 100-fathom contour in summer to a short distance beyond it in winter. Thus, the three-layered system is assumed to be fully established at the 100-fathom isobath.

The transition zone, whose structure also is determined to a large extent by the surface wind, is widest in summer and narrowest in winter. Thus, the surface wind plays a major role in establishing the vertical circulation of the water within the 100-fathom isobath, particularly during winter.

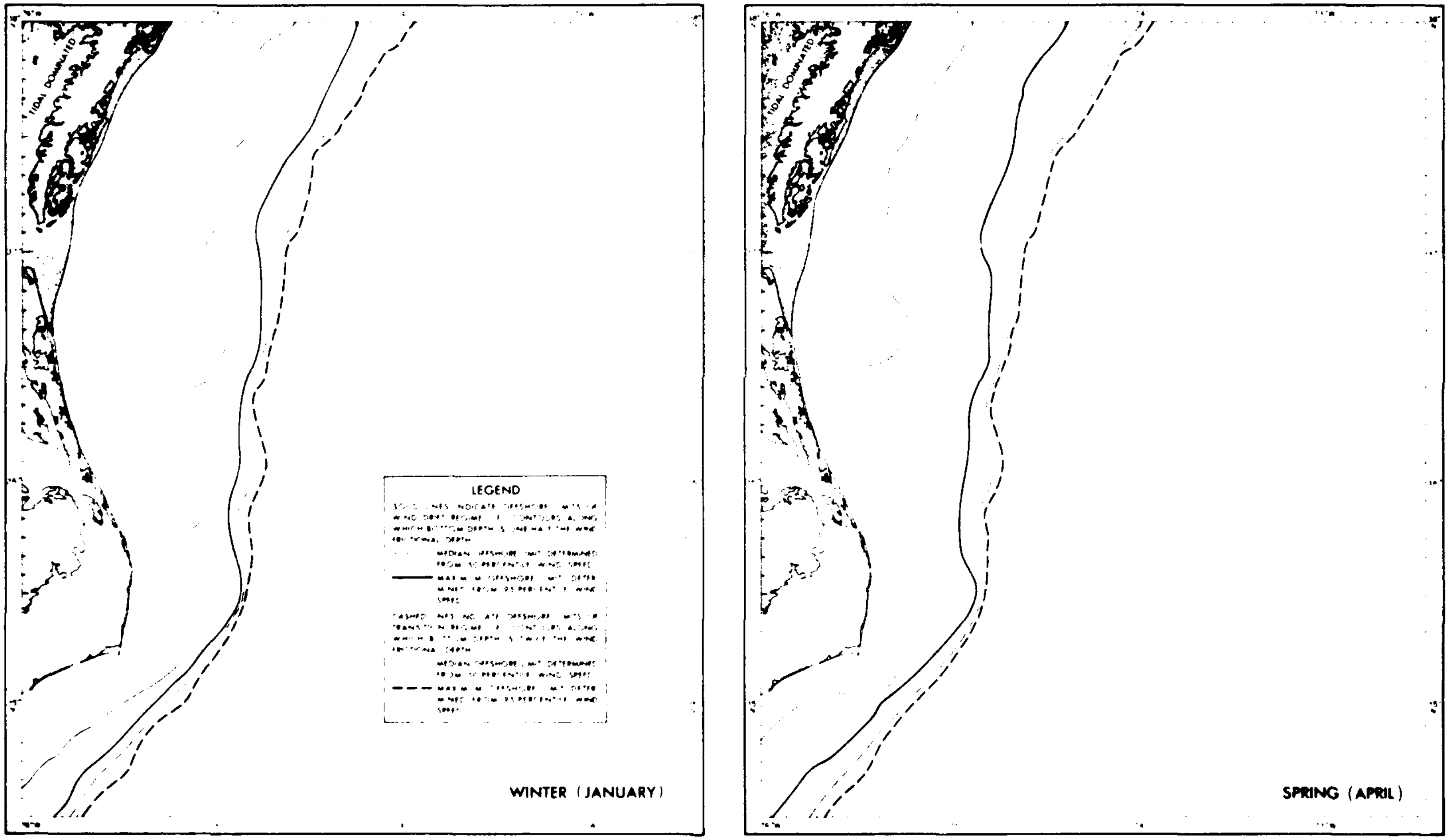


FIGURE 2 EKMAN CURRENT REGIMES

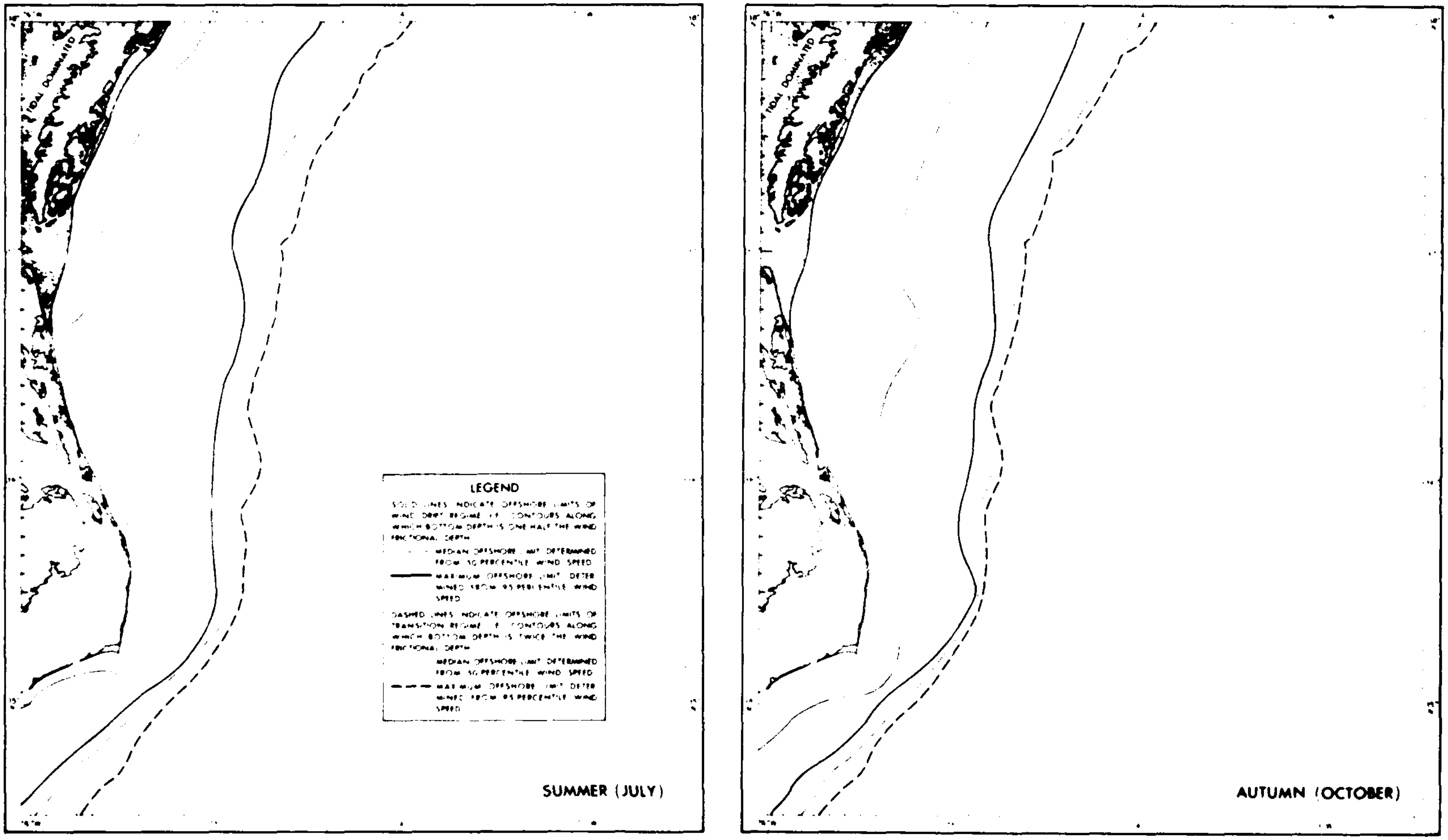


FIGURE 2. EKMAN CURRENT REGIMES (CON.)

3. Currents

a. Surface currents

(1) Nontidal--The surface currents in the southeast part of the Area (Boisvert, 1967), east of a line connecting 38°N, 74°W and Cape Hatteras, are part of the Gulf Stream which sets northeast throughout the year with minor changes in direction (fig. 3). The speeds vary slightly seasonally and are higher during summer than in the other seasons. Highest speeds, generally ranging between 2.0 and 3.9 knots, are in an 8- to 10-mile-wide axis.

The mean axis of the Gulf Stream passes through 34°36'N, 75°05'W, according to surface ship drift observations recorded along a straight-line track between the Bahamas and Cape Hatteras. The axis changes position daily (Fisher, 1973), but seasonal changes occur; from March through August it is located at about 34°34'N, from September through November at about 34°35'N, and from December through February at 34°40'N, with sets between 031° and 070T.

Observations for the 1° quadrangle 34°-35°N, 75°-76°W show only a slight seasonal change in direction. In summer, mean speed is higher by 0.2 knot, and the frequency of the northeast flow is greater by about 4 percent than during winter. During all months, the current in this quadrangle sets northeast 77 to 95 percent of the time; mean speed is 2 knots and maximum speed more than 5 knots.

The surface currents in the northwest portion of the Area set southwest along the coast (fig. 3). This coastal current originates from a branch of the Labrador Current which flows clockwise around the southeast tip of Newfoundland and generally is referred to as the Labrador Current Extension. Speeds are fairly constant throughout the year and average about 0.6 knot. The greatest seasonal fluctuation appears to be north of the Area; south of 38°N to Cape Hatteras, the current shows very little seasonal change.

Surface currents are also shown by seasonal roses (fig. 4) comprised of ship drift data (U.S. Naval Oceanographic Office, unpublished data) summarized for nearly homogeneous regions. The roses define the percent frequency of flow by specific speed categories in each of eight compass directions.

(2) Tidal--Over the Continental Shelf north of Cape Hatteras, the tidal currents are rotary and weak as described in figure 5. The currents in the entrance to Chesapeake Bay mainly are strong reversing tidal currents (see tabulations, figure 5). The currents exhibit a net outward flow at the surface and a net inward flow from middepth to the bottom.

(3) Model of dispersal trajectories--Surface current data also are used to derive surface drift ellipses (fig. 6). The ellipses are used primarily as a first order approximation of search areas for free drifting objects and contaminants such as oil spills, wastes, etc. The input data consist of summarized surface current observations depicting variability of flow. The methods are programmed according to Pritchard (1947), Burns (1965), and Yergen (1962).

The ellipses are closely related to the surface current roses (fig. 4) and are elongated in the direction of prevailing flow. The ellipse technique designates an axis of regional search under average meteorological conditions

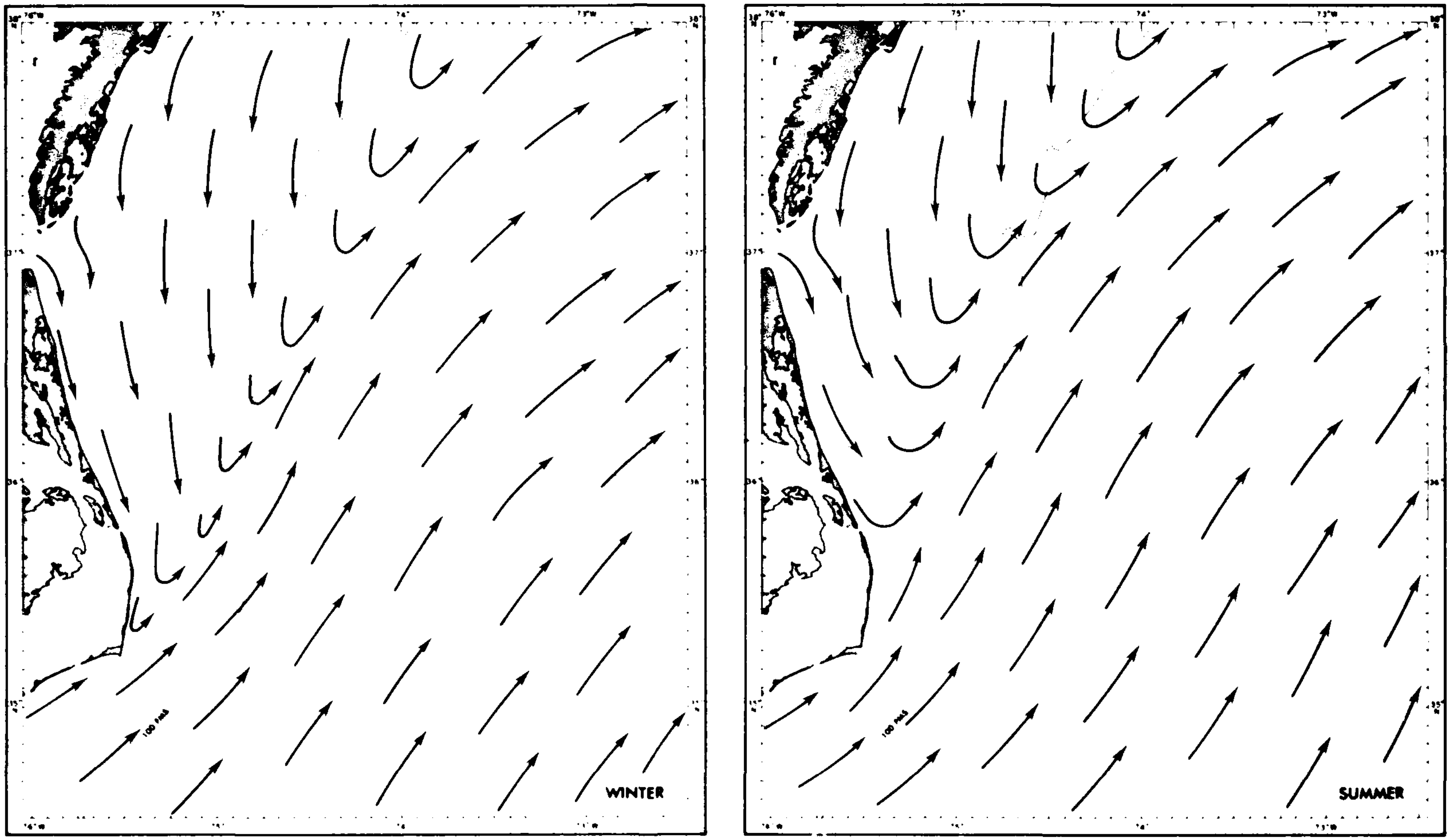


FIGURE 3. SURFACE CURRENTS

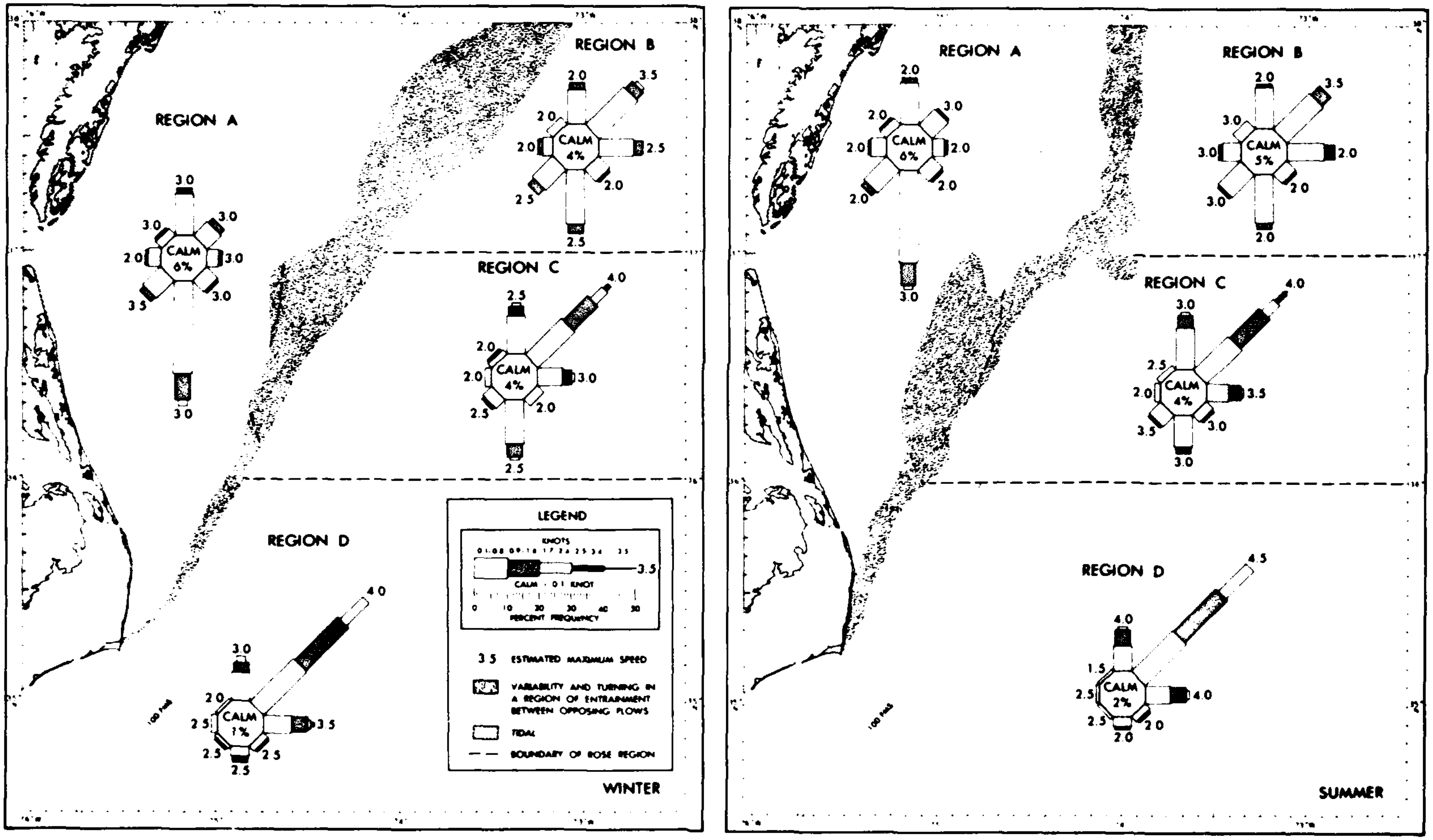
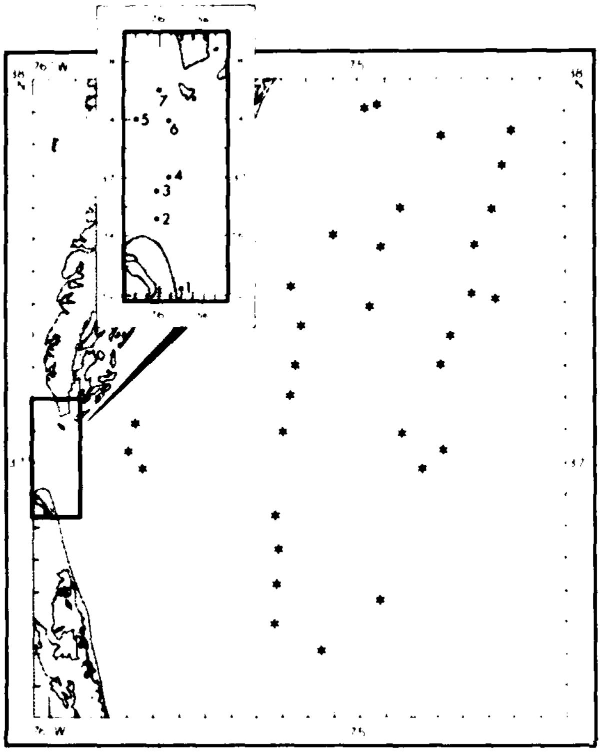


FIGURE 4. SURFACE CURRENT ROSES



NOTES

THE EFFECT OF TIDAL CURRENTS IS SIGNIFICANT ONLY A SHORT DISTANCE SEAWARD OF CHESAPEAKE BAY ENTRANCE. THE NUMBERED STARS WITHIN THE INSET SHOW LOCATIONS OF TIDAL CURRENT STATIONS FOR WHICH SURFACE CURVES AND OR SUBSURFACE DATA ARE TABULATED. THE TIDAL CURRENTS ARE SEMIDIURNAL WITH SOME INEQUALITY IN THE SPEEDS OF SUCCESSIVE FLOODS AND EBBS. DURATIONS ARE NEARLY THE SAME FOR FLOOD AND EBB AVERAGING ABOUT 6 HOURS. AT ALL THE STATIONS SHOWN IN THE INSET THE NET FLOW FROM MID DEPTH TO BOTTOM IS INTO THE BAY ON THE FLOOD AT A RESULTANT SPEED OF ABOUT 0.1 KNOT. THE STRONGEST NET FLOW IS AT STATION 2.

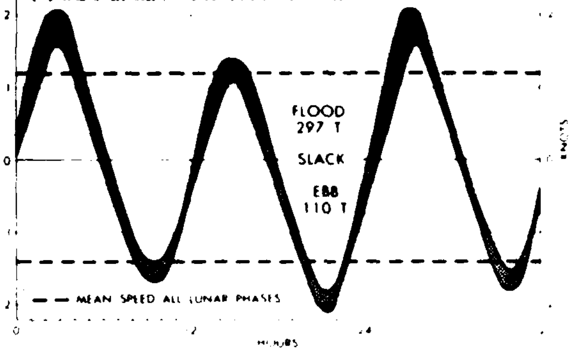
STARS IN THE OFFSHORE REGION SHOW WHERE OBSERVATIONS OF TIDAL CURRENTS ONLY HAVE BEEN MADE. THE CURRENTS ARE ROTARY CHANGING DIRECTION CONTINUOUSLY THROUGH ALL POINTS OF THE COMPASS WITHOUT DETECTABLE FLOOD OR EBB. SPEEDS ARE VERY LOW USUALLY 0.2 KNOT OR LESS.

STATION 1

SUBSURFACE CURRENTS	STATION 1		
CURRENT METER DEPTH (FT)	5	12 1/2	19
MEAN FLOOD DIRECTION (°T)	015	347	344
MEAN FLOOD SPEED (KN)	1.1	1.2	1.0
MEAN EBB DIRECTION (°T)	169	174	160
MEAN EBB SPEED (KN)	0.7	0.9	0.7
MAXIMUM SPEED (KN)	1.4	1.3	1.3
OBSERVED DURING	EBB	FLD	FLD
DEPTH OF BOTTOM	26 FEET		
REMARK: NET FLOW IS NORTHWARD 0.3 KNOT			

STATIONS 2, 3, AND 4

COMPOSITE CURVE OF MAXIMUM SURFACE TIDAL CURRENTS. SPRINGS NEAR PERIGEE. THE WIDTH OF THE CURVE SHOWS THE RANGE OF SPEED IN THE VICINITY OF STATIONS 2, 3, AND 4 (SEE INSET) IN CHESAPEAKE BAY ENTRANCE.

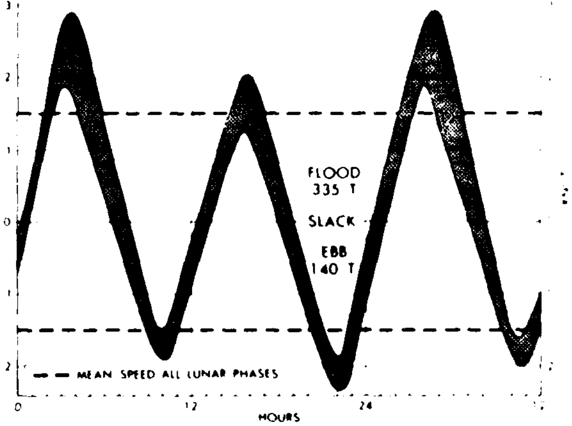


SUBSURFACE CURRENTS	STATION 2				STATION 4			
CURRENT METER DEPTH (FT)	7	13	32 1/2	52	[illegible]	[illegible]	23	33
ESTIMATED FLOOD DIRECTION (°T)	286	280	286	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OBSERVED FLOOD SPEED (KN)	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ESTIMATED EBB DIRECTION (°T)	092	090	085	[illegible]	[illegible]	[illegible]	[illegible]	
OBSERVED EBB SPEED (KN)	[illegible]	[illegible]	0.9	[illegible]			[illegible]	[illegible]
APPROXIMATE DEPTH OF BOTTOM	58 FEET				[illegible] FEET			

NO SUBSURFACE DATA FOR STATION 3

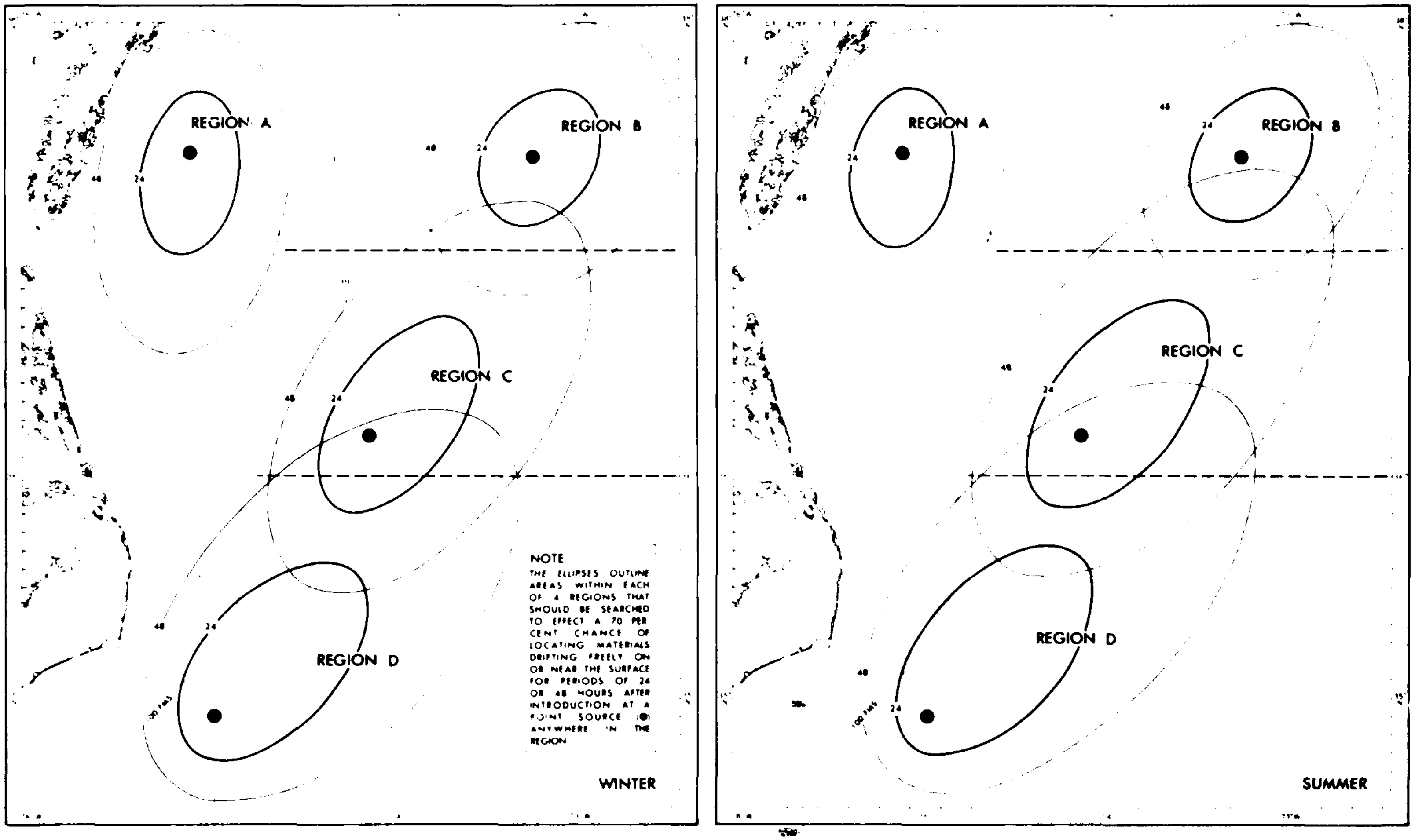
STATIONS 5, 6, AND 7

COMPOSITE CURVE OF MAXIMUM SURFACE TIDAL CURRENTS. SPRINGS NEAR PERIGEE. [illegible] THE VICINITY OF STATIONS 5, 6, AND 7 (SEE INSET) IN CHESAPEAKE BAY ENTRANCE.



SUBSURFACE CURRENTS	STATION 5			STATION 6			STATION 7		
CURRENT METER DEPTH (FT)	6 1/2	19 1/2	32 1/2	7 1/2	22 1/2	37 1/2	7 1/2	23	38
MEAN FLOOD DIRECTION (°T)	332	330	331	310	328	321	006	360	356
MEAN FLOOD SPEED (KN)	1.2	1.2	1.3	1.8	1.5	1.4	1.9	2.0	1.9
MEAN EBB DIRECTION (°T)	134	135	115	134	102	114	168	183	169
MEAN EBB SPEED (KN)	1.7	1.4	1.2	1.6	1.3	1.5	2.2	1.9	1.6
MAXIMUM SPEED (KN)	2.7	2.4	2.3	1.9	1.6	1.5	2.4	2.6	2.2
OBSERVED DURING	EBB	EBB	EBB	FLD	FLD	FLD	EBB	EBB	FLD
APPROXIMATE DEPTH OF BOTTOM	38 FEET			45 FEET			45 FEET		

FIGURE 5. TIDAL AND SUBSURFACE CURRENTS



NOTE
THE ELLIPSES OUTLINE AREAS WITHIN EACH OF 4 REGIONS THAT SHOULD BE SEARCHED TO EFFECT A 70 PER CENT CHANCE OF LOCATING MATERIALS DRIFTING FREELY ON OR NEAR THE SURFACE FOR PERIODS OF 24 OR 48 HOURS AFTER INTRODUCTION AT A POINT SOURCE (●) ANYWHERE IN THE REGION

FIGURE 6. SURFACE DRIFT ELLIPSES

for 24 or 48 hours in order to effect a 70 percent probability of detection.

Recent information concerning surface currents and meteorological conditions should be used in planning search operations; however, if such information is not available, figure 6 may be used. To use ellipses, a tracing of the ellipse for the appropriate region is placed on figure 6 with the dot over the point from which the search is to begin. When local wind conditions are known to differ greatly from the mean wind conditions in any region, the region of search should be extended in the direction of the local wind current.

b. Subsurface currents

(1) Intermediate depths--On the basis of sparse data, subsurface currents appear to have permanent features similar to surface currents. Current speeds are probably higher during summer than during other seasons.

Although current measurements have not been obtained near the bottom directly beneath the axis of the Gulf Stream, deep observations indicate that the current flows in essentially the same direction from the surface to bottom; and computations show that the current speed at the bottom is probably as high as 0.2 knot. For example, in 1960 direct measurements obtained outside the Area near 38°30'N, 74°30'W at depths of about 3,000 meters show the flow to be about 0.2 knot in the same direction as the surface current.

Data obtained in 1962, indicate a deep southwest flow near the bottom along the continental slope at depths below 800 meters with speeds up to 0.4 knot (fig. 7). There appears to be a well-defined boundary between this current and the northeast-flowing Gulf Stream a few miles to the east. The observed southwest set does not appear directly beneath the Gulf Stream axis but is probably part of the coastal Labrador Current Extension that frequently sets southwest past Cape Hatteras. In the vicinity of 35°00'N, 74°30'W, below 2,300 meters, there is also evidence of southwest flow near the bottom.

(2) Bottom drift--Inferred bottom drift (Harrison et al., 1967) is shown in figure 8. Seabed drift bottles were released from June 1963 through October 1964 over the Continental Shelf to make estimates of bottom drift trajectories between shore and the 183-meter isobath. Recovery of the drifters indicated that bottom drift exhibits areal and monthly variations but tends southwest, irrespective of the season and direction of surface flow. The inferred bottom drift toward Chesapeake Bay is probably related to changes in river discharge and seasonal prevailing winds. The speed of bottom drift, estimated to be highest when the water column is not thermally stratified, increases offshore to the edge of the Continental Shelf.

4. Waves and breakers

a. Sea and swell--The action of the wind on the sea generates waves. "Sea" refers to waves that are formed locally and "swell" to waves that travel into this Area from distant storms. Because of the variety of observing and coding practices over the years, the data are available in several forms. For example, the sea and swell information discussed below are less accurate but more numerous than the wave data (U.S. National Climatic Center, 1972) which are presented later.

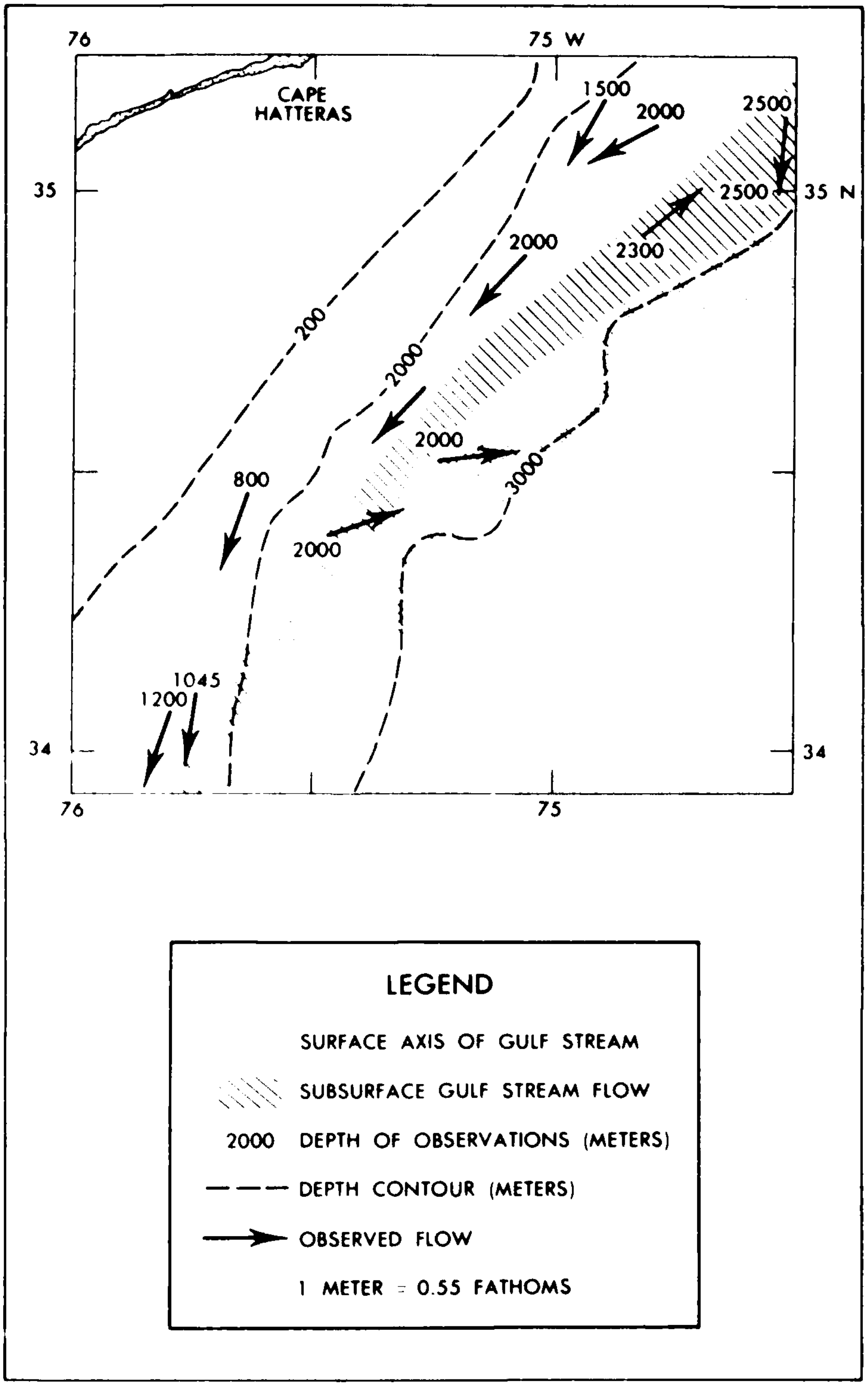


FIGURE 7 SUBSURFACE FLOW IN THE VICINITY OF THE GULF STREAM

THE BOTTOM DRIFT [illegible] CHESAPEAKE BIGHT [illegible] AREA AND [illegible] VARIABLE [illegible] THE [illegible] SEABED DRIFTER [illegible] DATA APPEARS [illegible] RIVER [illegible] AND SEASONAL PREVAILING WINDS [illegible] APPEARS [illegible] THE ENTRANCE [illegible] THE BAY [illegible]

THE [illegible] SEABED DRIFTER DATA.

1. THE BOTTOM DRIFT WAS FOUND TO BE VARIABLE AT TIMES NEARLY REVERSING IN AREAS NORTH OF AND IN NEARSHORE WATERS SOUTH OF CHESAPEAKE BAY. DESPITE THESE VARIATIONS THERE WAS A PRONOUNCED TREND TOWARD SHORE TO THE SOUTHWEST DURING ALL SEASONS.
2. ALTHOUGH THE GREATEST NUMBER OF SEABED DRIFTER RECOVERIES OCCURRED DURING WINTER WHEN [illegible] WINDS PREVAILED, SEABED DRIFTERS CONTINUED TO STRAND, THOUGH IN LESSER NUMBERS, IN SEASONS WHEN THE WINDS WERE MAINLY ONSHORE.
3. THERE WAS A PRONOUNCED TENDENCY FOR SEABED DRIFTERS TO TRAVEL TOWARD AND EVEN TO ENTER CHESAPEAKE BAY.
4. DURING PERIODS OF MAXIMUM FRESH WATER DISCHARGE, THERE WAS A WELL DEFINED NORTHWESTERLY BOTTOM DRIFT TOWARD CHESAPEAKE BAY FROM DISTANCES AS GREAT AS [illegible] NAUTICAL MILES SOUTHEAST OF CAPE HENRY.
5. THE SPEED OF SEABED DRIFTERS WAS NOT CONSTANT ACROSS THE SHELF. FURTHER THE RATE OF DRIFT OF SEABED DRIFTERS RELEASED IN AUTUMN AND WINTER EXCEEDED THE RATE OF THOSE RELEASED IN SPRING AND SUMMER.
6. MINIMAL RECOVERIES OF SEABED DRIFTERS RELEASED IN AREAS NEAR THE EDGE OF THE SHELF INDICATE THAT THE FLOW OF BOTTOM WATER TRENDS OFFSHORE AT DISTANCES GREATER THAN [illegible] NAUTICAL MILES.
7. SEABED DRIFTERS RELEASED TO THE EAST AND NORTHEAST OF CAPE HATTERAS WERE SELDOM RECOVERED AND THIS SUGGESTS AN [illegible] DRIFT OF BOTTOM WATER IN THE VICINITY OF CAPE HATTERAS.

[illegible]

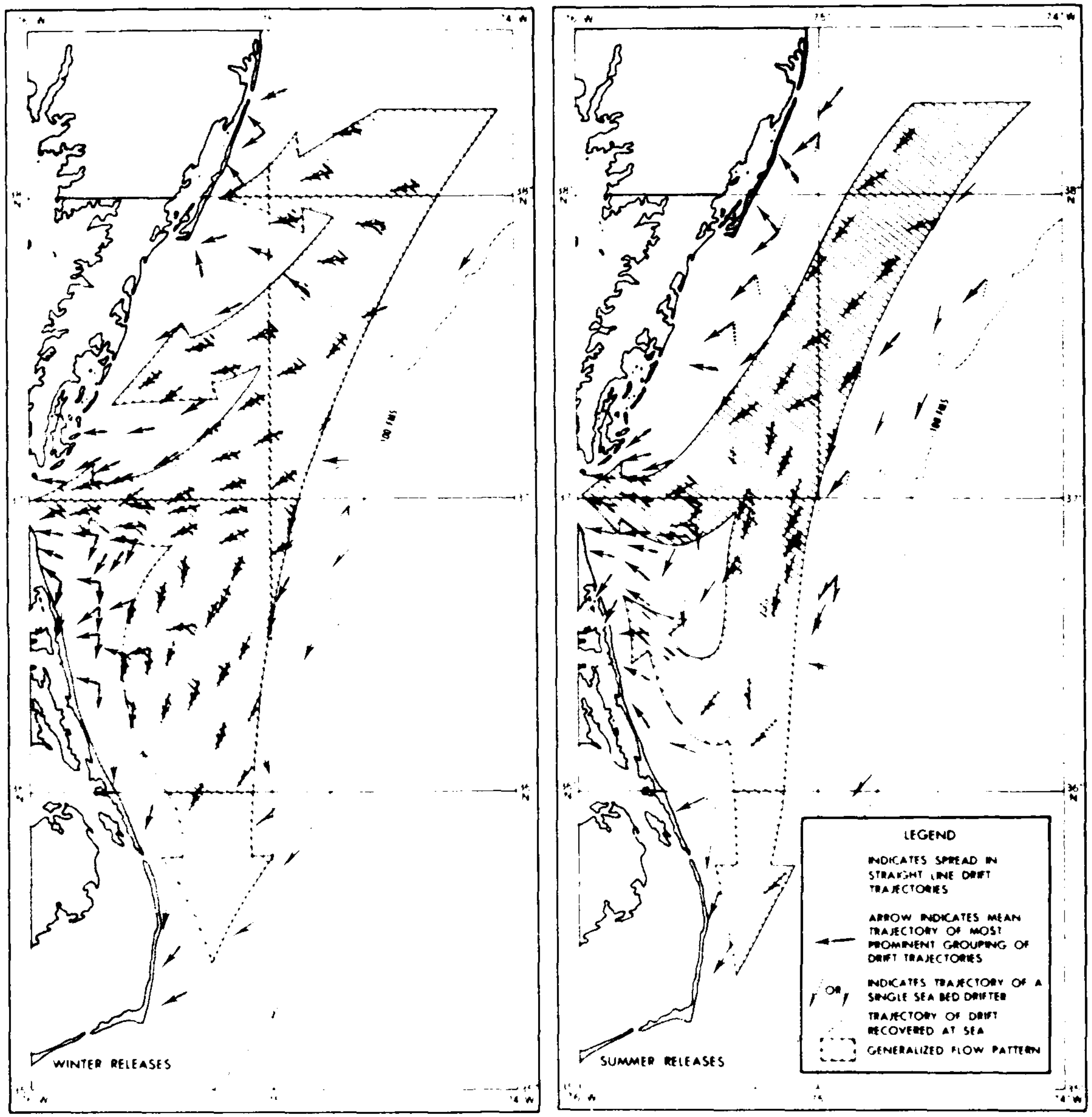


FIGURE 8 INFERRED BOTTOM DRIFT

(1) Sea--The following approximations may be used to determine the anticipated height (vertical distance from crest to trough) of a sea from observed wind conditions:

Wind speed (knots)	Sea height (meters)	Wind speed (knots)	Sea height (meters)
1	0	28-33	4.3
1- 3	0.1	34-40	5.5
4- 6	0.2	41-47	7.0
7-10	0.7	48-55	8.8
11-16	1.2	56-63	11.3
17-21	1.8	64-71	13.7
22-27	3.1		

In general, seas begin to break at a height of about 0.6 meter, eject spray at about 1.8 meters, and frequently become covered with whitecaps at 3.0 meters. Windblown streaks of foam which first appear when seas exceed 4 meters, steadily thicken with increasing height. Above 7 meters the combined foam and spray severely restrict visibility. Various sources provide more accurate methods for determining coastal wave heights and periods from the wind speed, duration, and fetch (e.g., Darbyshire and Draper, 1963; U. S. Army Coastal Engineering Research Center, 1966).

The sea conditions are illustrated in figure 9 as two sets of roses. In the offshore (east of 75°W) region each rose arm shows the percent frequency of seas from the quadrant centered on the cardinal direction. For example, in the southeast, 35 percent of all observed seas have a northerly component (i.e., directed southward) during January. Also included in the rose is the mean height (1.1 meters), which approximates the median height throughout the Area, and the frequency of calm seas (1 percent).

In the nearshore region, the roses are rotated to conform with the coastal configuration in order to provide a better measure of the relative frequency of onshore, offshore, and longshore seas. Thus, along the southern Virginia beaches during January, the frequency of seas with an offshore component is 27 percent and that of seas with an onshore component is 16 percent. In general, seas are lower nearshore than offshore.

The prevailing direction of seas generally coincides with that of the surface winds: north to northwest from November through March, variable in April and May, south to southwest from June through August, and north to northeast in September and October.

(2) Swell--Median swell conditions are summarized in figure 10. To avoid repetition of figure A4, which includes many swell observations, figure 10 was simplified to depict only the prevailing (modal) direction, an envelope encompassing 50 percent of the directions, and the mean height. Thus, off Cape Hatteras, northeast swells, with an average height of 1.3 meters, are most frequent during January (17 percent of the observations). Half of the observed swells originate from the offshore directions of northwest through southeast. The remaining 50 percent, besides encompassing the remaining directions, also include observations of negligible and no swell.

Swell, which by definition is generated outside the area, is more likely to be directed onshore than seaward. During winter, swell usually emanates from intense extratropical cyclones located to the north and northeast. During summer, swell frequently is derived from the persistent southerly to southwesterly winds of the subtropical high. However, it is often refracted shoreward in the region north of Cape Hatteras. Swell is highest during autumn and winter. Mean height during the period September through February increases from about 0.9 meter in the northwest to about 2.0 meters in the southeast.

b. Waves--When no distinction is made between sea and swell, the resulting observation is categorized as a "wave." The resulting wave data (U. S. National Climatic Center, 1972) were analyzed for height, period, and direction.

The relation between wave heights and periods is depicted in figure 11. These diagrams reveal a preponderance of low waves of short period and a corresponding low frequency of long waves in this Area. This condition is characteristic of locally generated waves. The superimposed curves of wave steepness (ratio of wave height to wavelength) provide an index of the relative frequency of developing waves (sea) versus diminishing waves (swell). For example, the frequency of developing waves, with a steepness ratio equal to or greater than 1:20, is greatest in the southeast and least in the northwest, whereas the frequency of diminishing waves, with a steepness ratio less than 1:60, is greatest along the Virginia beaches and least in the southeast. Waves also become increasingly steep as height (H) approaches depth(d) and begin to break at H = 1.3d. Breaking waves resulting from strong winds generally accelerate the horizontal mixing of foreign particles.

The height-direction relationship of waves is shown in figure A4. These eight-directional roses generally reflect the predominant wind field: northerly to northwesterly from November through March, variable in April and May, southerly or southwesterly from June through August, and northerly to northeasterly in September and October. As a result, waves tend to be offshore in all months but September and October.

Surface waves are highest from January through March. About 4 to 7 percent of all waves exceed 3.75 meters in the eastern part of the Area during winter compared with about 2 percent along the coast. Waves are lowest during summer when heights in excess of 3.75 meters are rare and confined to deep-water regions. A theoretical study (Thom, 1971) based on 13 years of North Atlantic data shows that significant wave heights as high as 9.1, 11.0, 12.2, and 13.1 meters may be expected at Ocean Weather Station (OWS) "E" (35°N, 48°W) about once in 2, 10, 25, and 50 years, respectively. For the same recurrence intervals, extreme heights of 16, 20, 22, and 24 meters are theoretically possible. However, the only reports of mountainous waves (exceeding 12 meters) in this area were associated with the "Great Atlantic Coast Storm" of March 1962. During this prolonged storm, the SS "Texaco California" (37.8°N, 74.5°W) was pounded by 13.7-meter waves from the north-northeast in 50-knot winds and Chesapeake Lightship (36°59'N, 75°42'W) was damaged by a 15.2-meter wave (Cooperman and Rosendal, 1962).

High waves may persist for several days, particularly during winter. The analysis for 4 years of continuous wave data for Chesapeake Lightship and Diamond Shoals Lightship (35°05'N, 75°20'W) indicates that waves may exceed 3.7 meters, 2.7 meters, and 1.8 meters for as long as 60, 90, and 110 hours, respectively (Kipper and Joseph, 1963). Such persistent high waves will rapidly disperse pollutants, both horizontally and vertically.

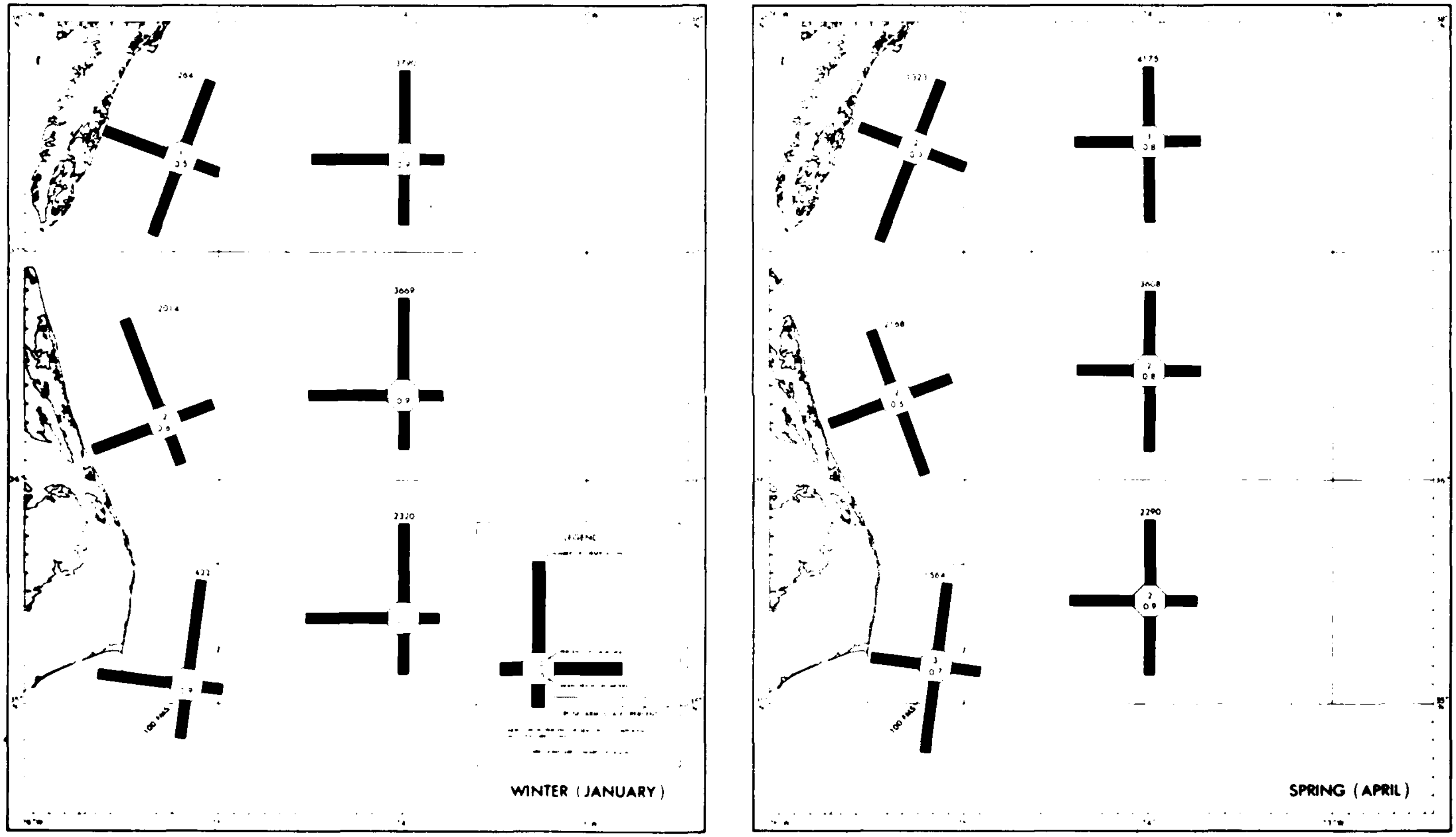


FIGURE 9 SEA ROSES

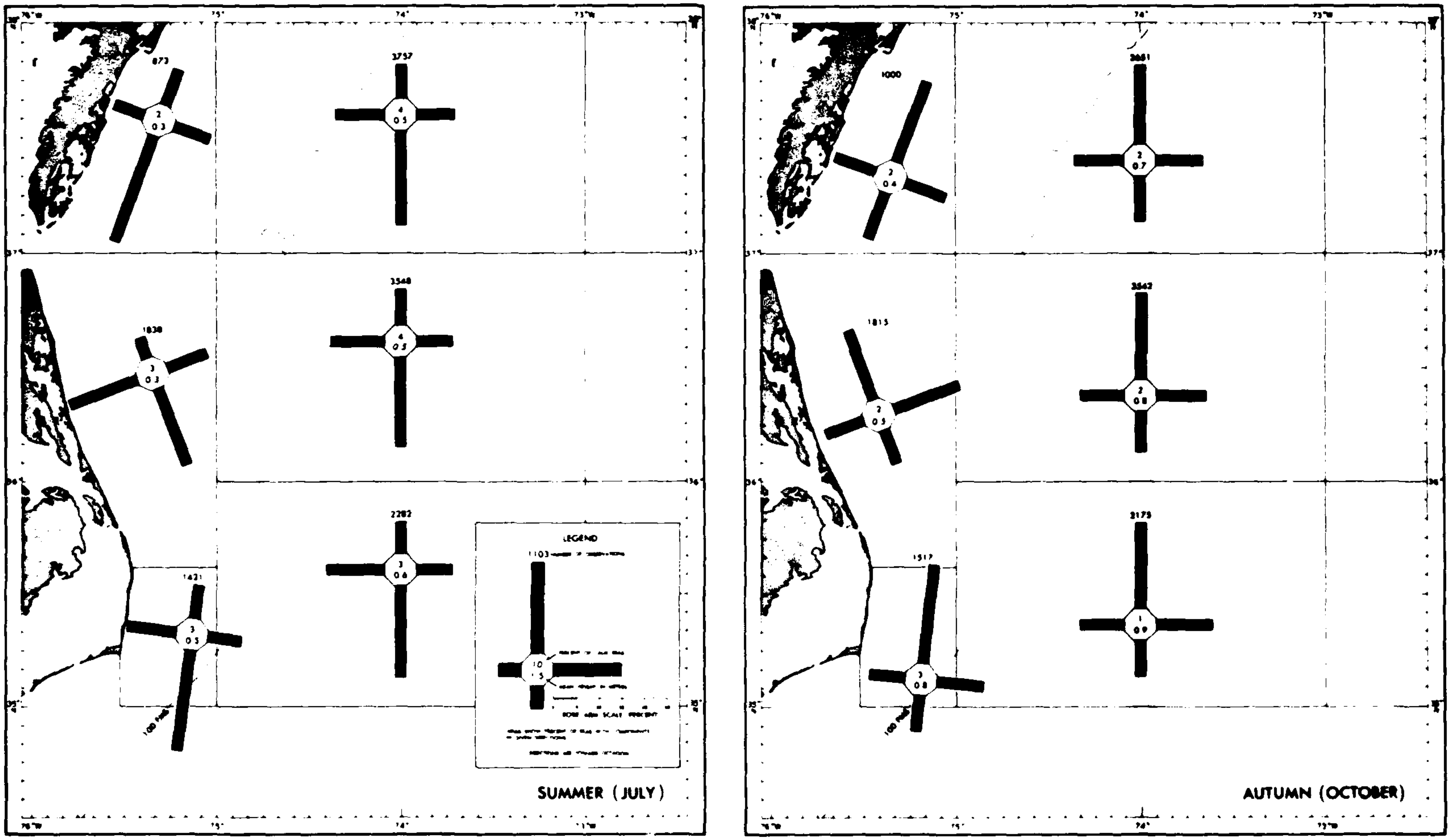


FIGURE 9. SEA ROSES (CON.)

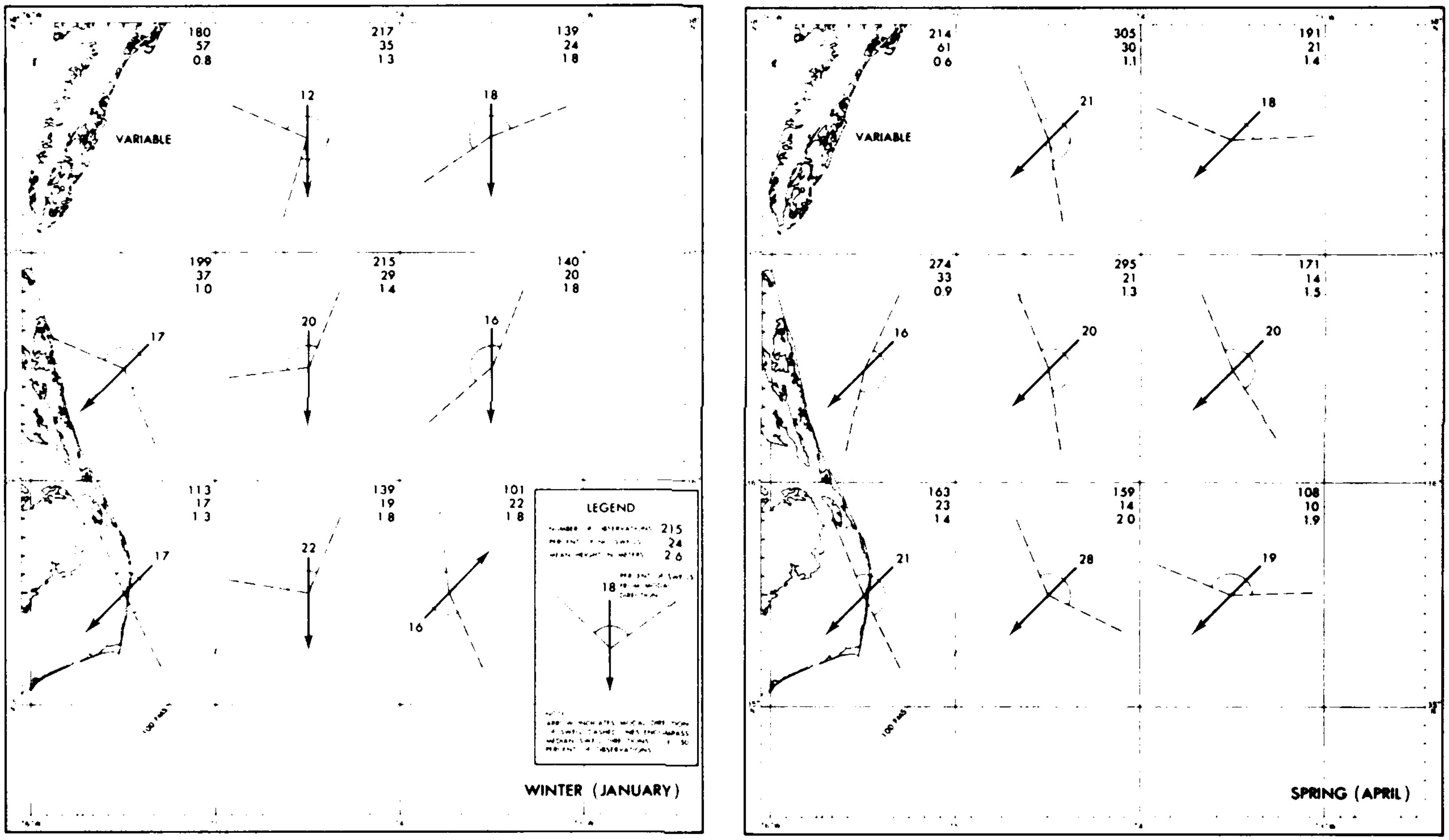


FIGURE 10. MEDIAN SWELL

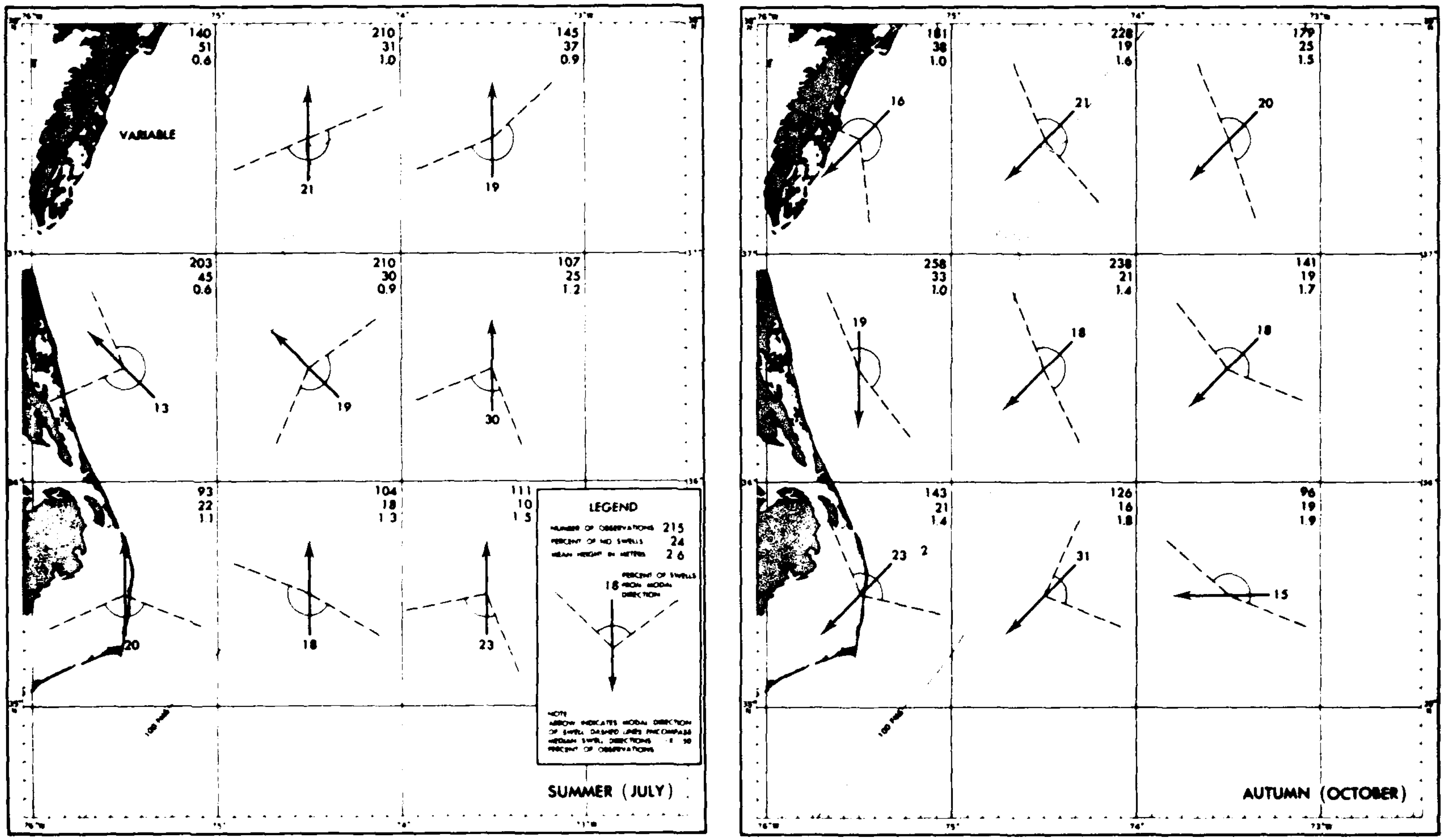
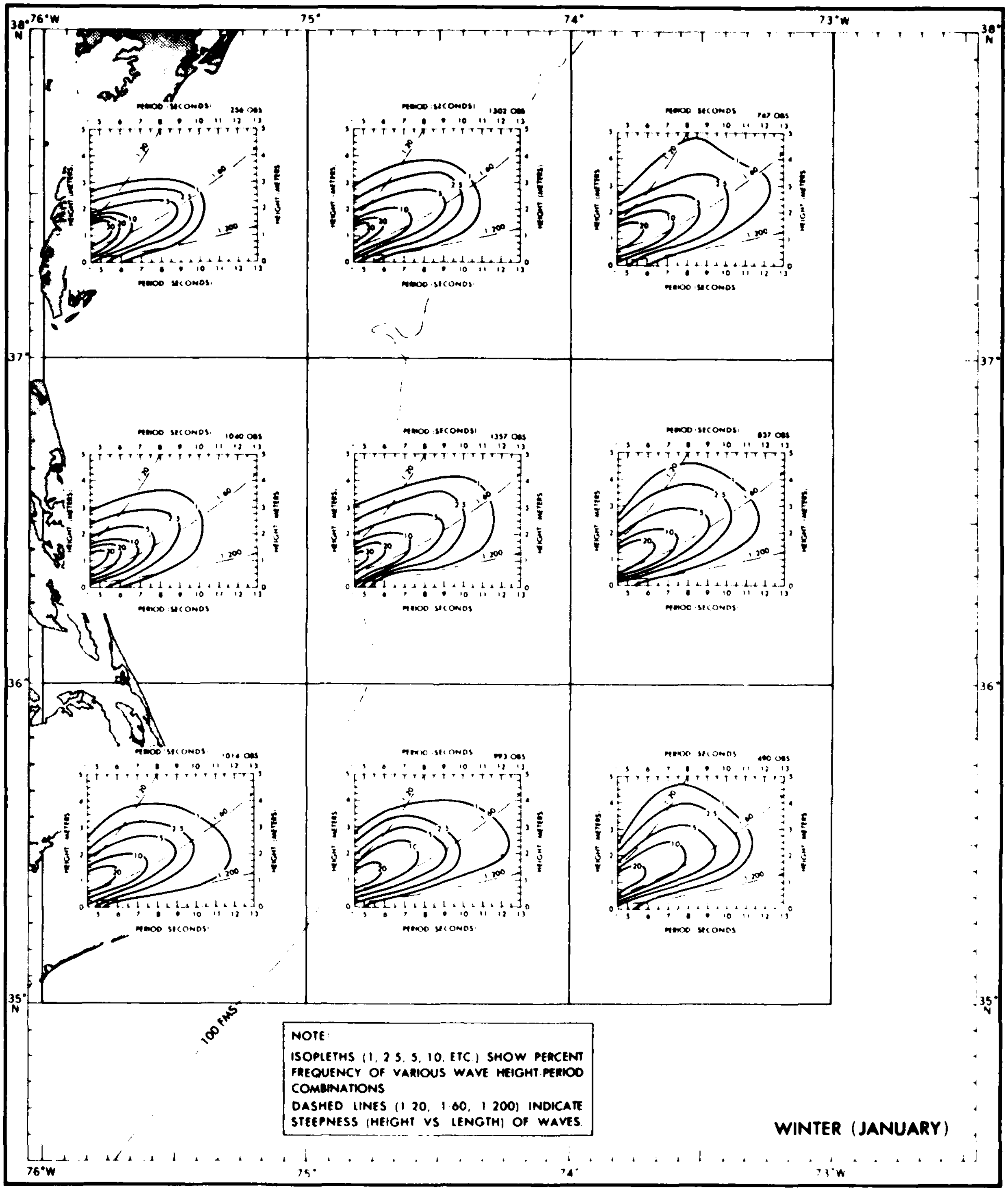


FIGURE 10. MEDIAN SWELL (CON.)



NOTE:
ISOPLETHS (1, 2.5, 5, 10, ETC.) SHOW PERCENT FREQUENCY OF VARIOUS WAVE HEIGHT-PERIOD COMBINATIONS.
DASHED LINES (1:20, 1:60, 1:200) INDICATE STEEPNESS (HEIGHT VS. LENGTH) OF WAVES.

WINTER (JANUARY)

FIGURE 11. WAVE HEIGHTS AND PERIODS

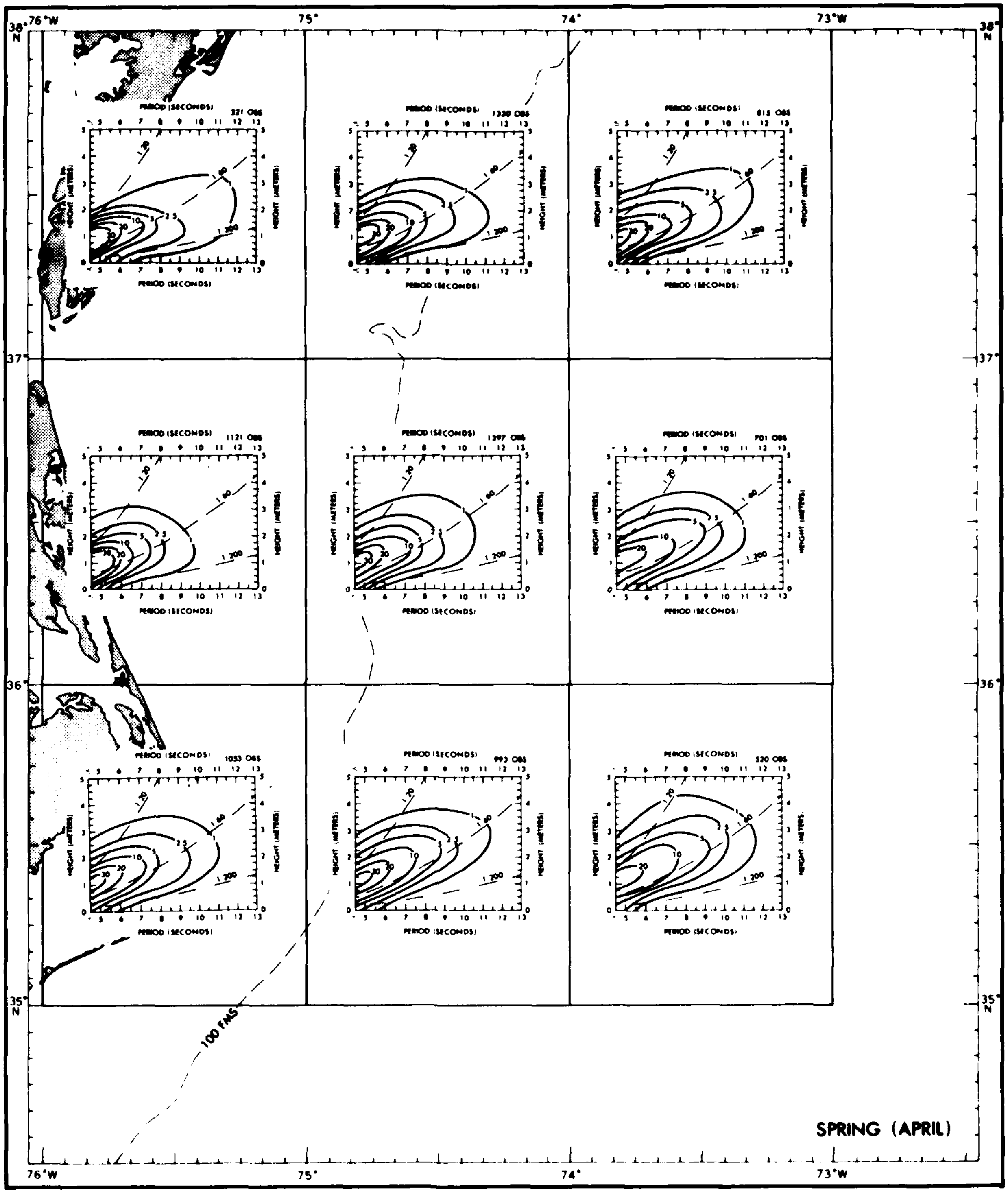
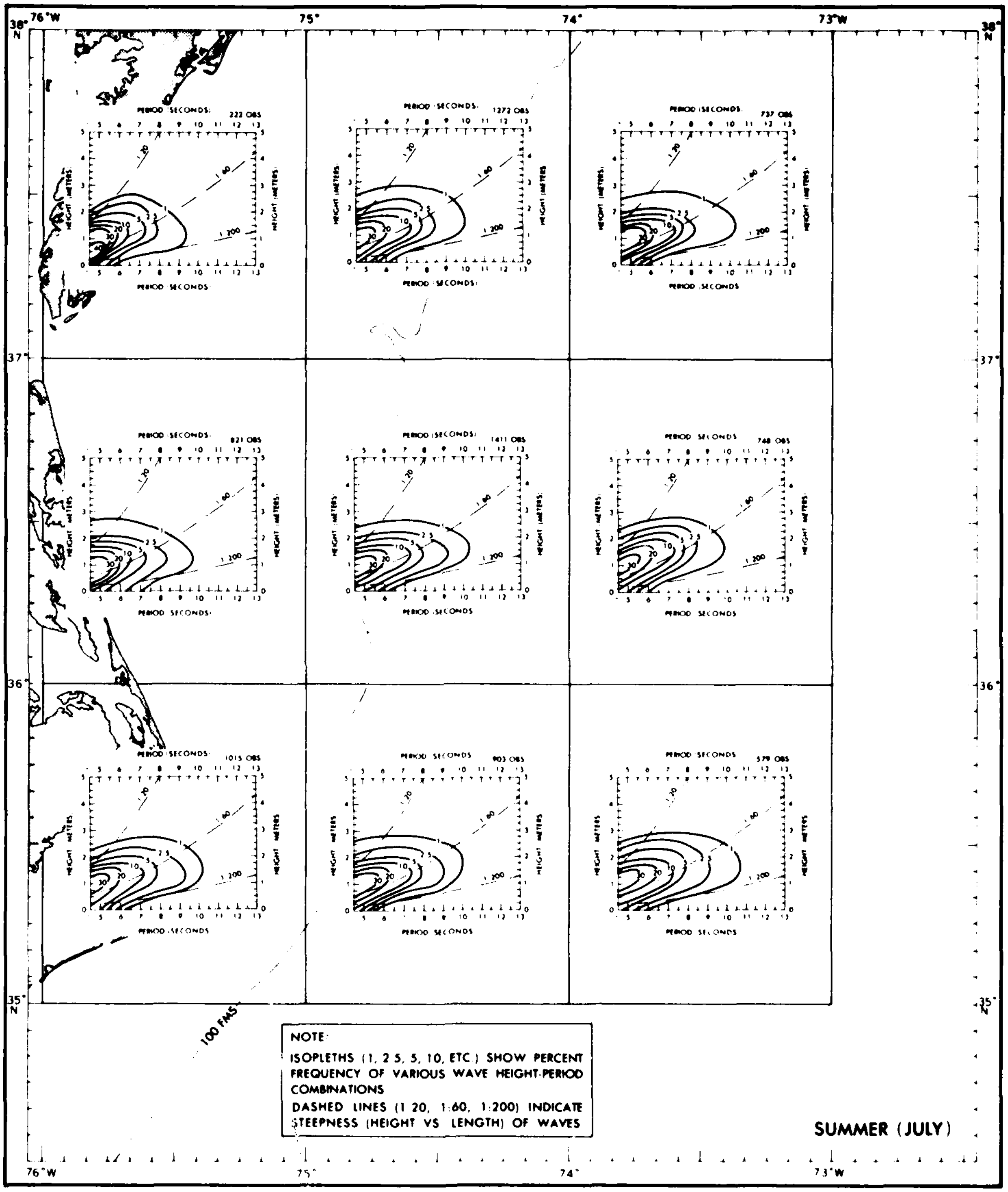


FIGURE 11. WAVE HEIGHTS AND PERIODS (CON.)



NOTE:

ISOPLETHS (1, 2.5, 5, 10, ETC.) SHOW PERCENT FREQUENCY OF VARIOUS WAVE HEIGHT-PERIOD COMBINATIONS.

DASHED LINES (1:20, 1:60, 1:200) INDICATE STEEPNESS (HEIGHT VS. LENGTH) OF WAVES.

FIGURE 11. WAVE HEIGHTS AND PERIODS (CON.)

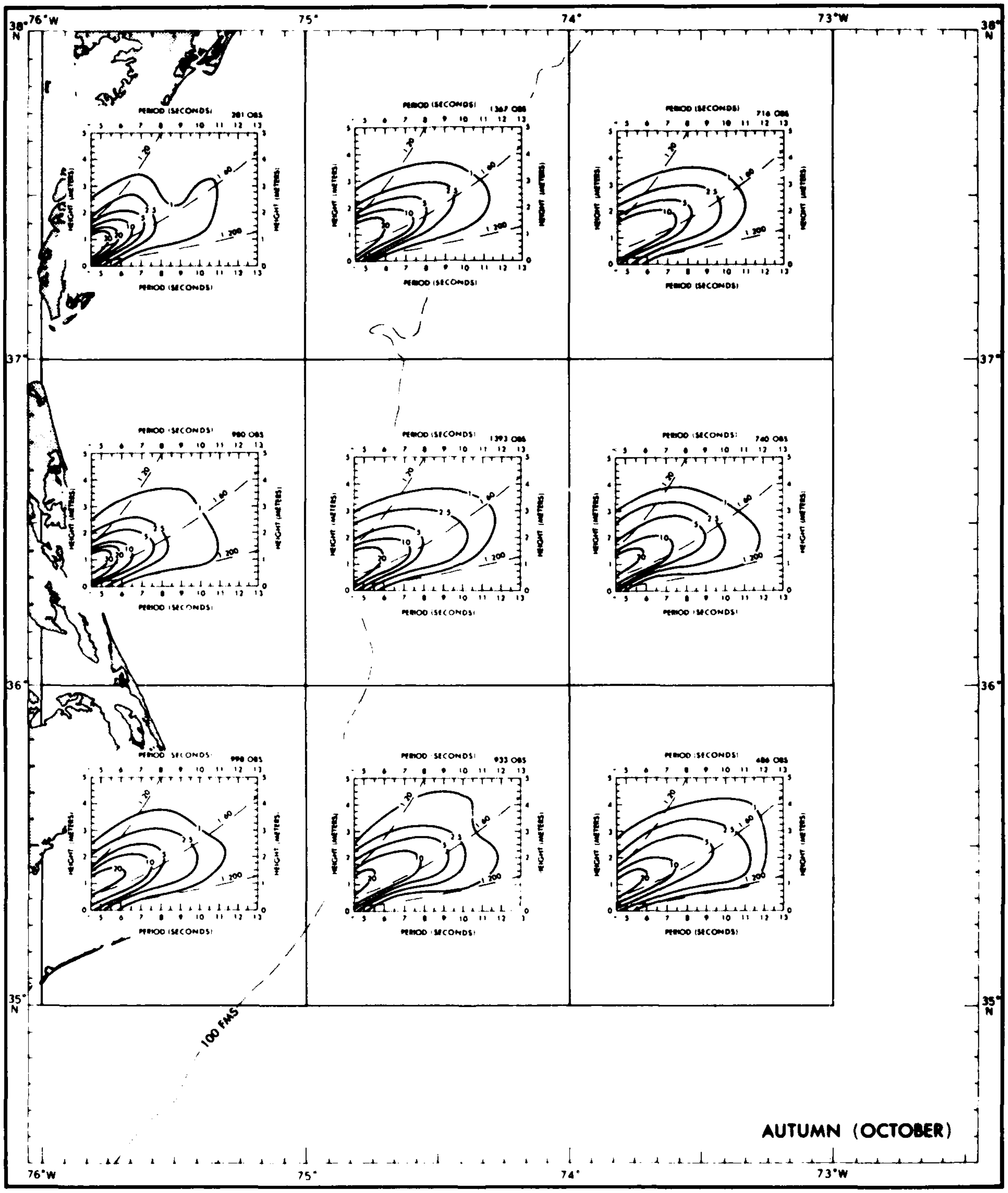


FIGURE 11. WAVE HEIGHTS AND PERIODS (CON.)

Long-period waves generated by distant winds often extend to great depths. In general, the greater the period and height, the greater the depth of penetration, with a resulting greater likelihood that the bottom will be disturbed. This subsurface wave motion also causes increased vertical mixing and a more rapid dispersal of pollutants. The percent frequency of waves touching bottom is shown seasonally in figure 12. This illustration indicates that the deepest penetration occurs in winter.

c. Breakers and longshore currents--Waves approach the coast with varying steepness characteristics, as shown in figure 13. Breakers form when this steepness exceeds a certain threshold. Plunging breakers are observed in regions of rapidly shoaling bottoms which can be hazardous to swimmers and damaging to boats and marine structures. Spilling breakers also occur along this coast but are less dangerous. In this Area the median depth of the breaker zone (i.e., the depth at which waves begin to break 50% of the time) is close to the beach in depths of 0.9 to 1.3 meters.

Breaking waves produce longshore currents which flow parallel to the coast and inside the breaker zone. These currents are usually less than 30 cm per sec, but may exceed 100 cm per sec. Characteristic values of breaker heights and their associated longshore currents were calculated for nine coastal locations and two conditions, i.e., those leading to "southward" and "northward" longshore currents, respectively. ("Southward" and "northward" currents refer to flows that are directed, respectively, to the left and to the right of an observer facing the shore.) These results are tabulated in figure 13.

As an example of the use of the table, Beach A with a relatively gentle slope of 1:180(0.0056) has during January a characteristic southward longshore-current speed of 33 cm per sec which is exceeded 6 percent of the time. This current is generated by 78-cm breakers. The maximum longshore-current speed of 44 cm per sec is associated with a breaker height of 244 cm. The maximum speed of any longshore current in the Area is 189 cm per sec at Beach C2 during August, and the maximum breaker height is 439 cm at Beach F during January. At Beach A longshore currents flow northward and southward with equal frequency in all months except July through September at which time they are primarily southward. The currents throughout the year flow predominantly northward (to the right) at Beaches B, G, and H, and southward (to the left) at Beaches C1, C2, D, E, and F.

Breakers thoroughly mix all suspended matter and pollutants; longshore currents subsequently transport this material laterally. The combination of current velocity, beach gradient, and breaker height also determines the amount of beach erosion and the rate of particle deposition on submarine ridges, shoals, and other underwater obstructions. Any realistic prediction of rate and quantity of transported material depends on further research.

d. Storm surges--The storm surge that usually accompanies intense storms may appreciably raise the sea level, especially when reinforced by high tides and onshore winds. Storm surges often flood low-lying coastal areas leaving water-borne pollutants in their wake, and damage coastal structures and beaches. The height of a storm surge increases with increasing wind stress and decreasing water depth. During hurricanes it may be further increased by a sharp decrease in atmospheric pressure. In this Area one hurricane or near-hurricane, attended by a storm surge, can be expected every 2 or 3 years, usually between August and October (Cry, 1965).

Studies of the basic properties of storm surges and on methods of forecasting their severity include Bodine, 1971; Harris, 1959 and 1963; Graham and Nunn, 1959; Nickerson, 1971; and U. S. Army Coastal Engineering Research Center, 1966. Storm surges as high as 4.8 meters (Jelesnianski, 1972) are theoretically possible along this coast; however, actual measurements are more conservative. For example, sea level rises of about 1.7 meters occurred at Norfolk, Virginia, during the March 1962 storm (Cooperman and Rosendal, 1962), and at Nags Head, North Carolina, during Hurricanes Diane (August, 1955) and Ione (September, 1955); and a 1.3-meter water-level increase was recorded along Virginia Beach during Hurricane Donna in September 1960 (Harris, 1963). Higher values have been reported inside Chesapeake Bay and in local waterways.

5. Eddy diffusivity

The horizontal coefficient of eddy diffusivity (k) is a measure of the lateral exchange of dissolved matter. It is expressed, in its simplified form as:

$$k = \frac{V\partial s/\ x}{\partial^2 s/\partial y^2}$$

Where: V is the mean speed of the surface current
$\partial s/\partial x$ is the gradient of the property in the direction of flow
$\partial s/\partial y$ is the change in the gradient of the property in the direction perpendicular to the flow.

Calculations based on observed gradients of salinity near the entrance to Chesapeake Bay yield values of k that range between 0.6 to 1.4 x 10^8 cm^2 sec^{-1} in summer and 1.2 to 2.6 x 10^8 cm^2 sec^{-1} in spring. These estimates are comparable in magnitude to those determined by Neumann and Stommel (Neumann and Pierson, 1966) for the highly dispersive waters of the Gulf Stream (respectively, 2.3 x 10^8 and 5 x 10^8 cm^2 sec^{-1}). It is therefore apparent that concentrations of dissolved matter introduced in local waters will be rapidly dispersed by the eddying action of the Chesapeake Bay outflow.

FIGURE 12 PERCENT FREQUENCY OF WAVES TOUCHING BOTTOM

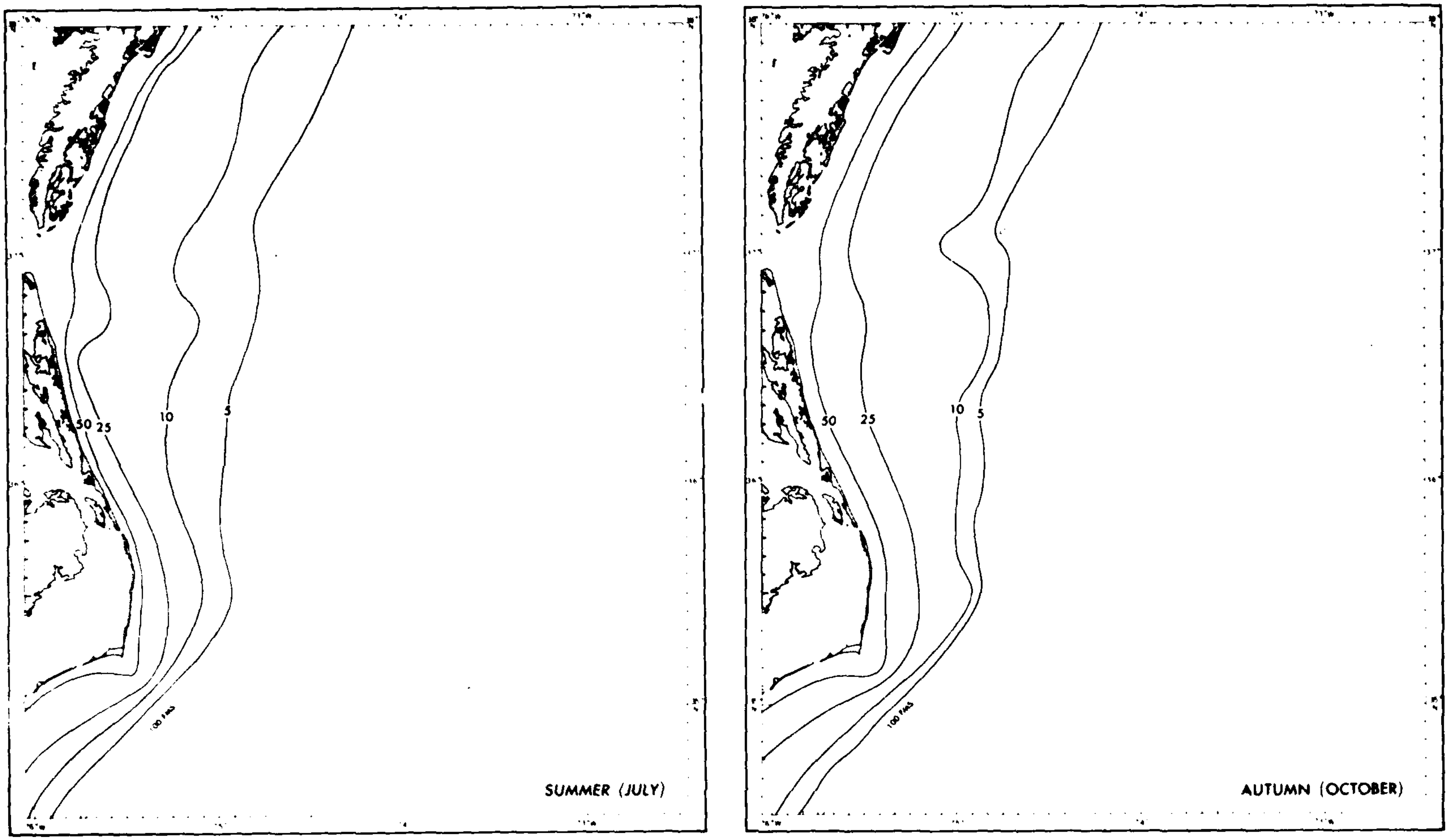
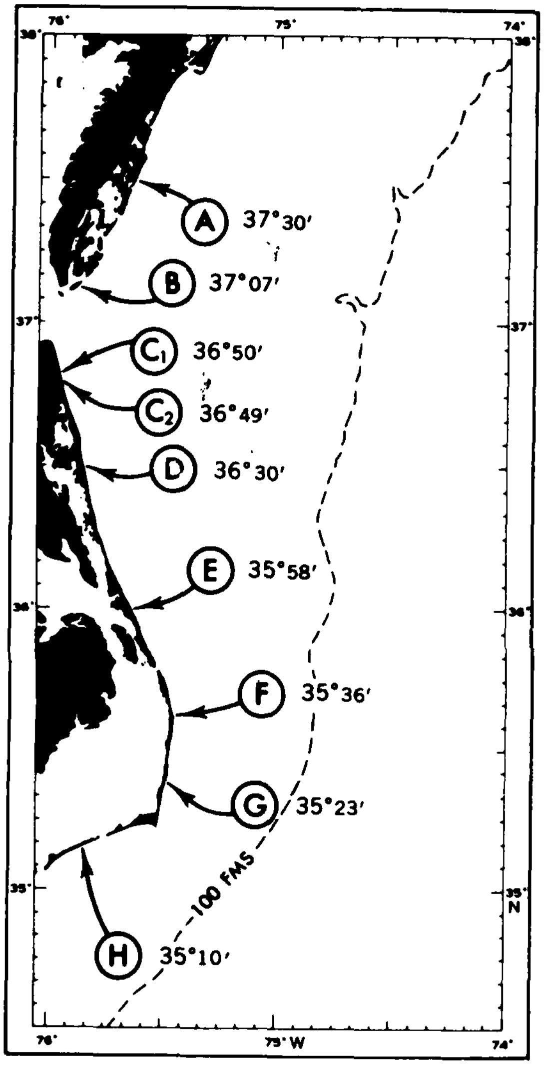


FIGURE 12. PERCENT FREQUENCY OF WAVES TOUCHING BOTTOM (CON.)



REGION LOCATOR CHART

	BEACH	LATITUDE	BEACH SLOPE	SOUTHWARD LONGSHORE CURRENT DIRECT REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED
JANUARY	A	37°30'	.0056	78	33	6
	B	37°07'	.0059	69	30	20
	C_1	36°50'	.02	74	37	15
	C_2	36°49'	.04	81	57	15
	D	36°30'	.013	78	39	15
	E	35°58'	.012	74	38	15
	F	35°36'	.011	78	33	20
	G	35°23'	.009	81	30	16
	H	35°10'	.022	71	51	3
FEBRUARY	A	37°30'	.0056	55	24	7
	B	37°07'	.0059	39	18	3
	C_1	36°50'	.02	74	37	18
	C_2	36°49'	.04	81	57	18
	D	36°30'	.013	74	44	18
	E	35°58'	.012	69	48	18
	F	35°36'	.011	69	42	15
	G	35°23'	.009	71	37	8
	H	35°10'	.022	69	52	5
MARCH	A	37°30'	.0056	69	24	5
	B	37°07'	.0059	69	30	2
	C_1	36°50'	.02	74	39	13
	C_2	36°49'	.04	81	60	13
	D	36°30'	.013	74	45	13
	E	35°58'	.012	69	44	13
	F	35°36'	.011	69	42	15
	G	35°23'	.009	74	34	3
	H	35°10'	.022	55	48	4
APRIL	A	37°30'	.0056	69	30	7
	B	37°07'	.0059	69	24	3
	C_1	36°50'	.02	74	39	17
	C_2	36°49'	.04	81	60	17
	D	36°30'	.013	74	45	17
	E	35°58'	.012	69	44	17
	F	35°36'	.011	69	42	15
	G	35°23'	.009	74	38	4
	H	35°10'	.022	69	45	3

*RELATIVE TO OBSERVER FACING LAND

FIGURE 13. BREAKERS AN

SOUTHWARD LONGSHORE CURRENT DIRECTED TO LEFT*					NORTHWARD LONGSHORE CURRENT DIRECTED TO RIGHT*				
REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)
78	33	6	244	44	69	22	7	125	33
69	30	20	158	57	62	24	10	162	39
74	37	15	183	61	42	33	1	101	55
81	57	15	201	92	51	46	1	113	83
78	39	15	271	58	42	27	1	107	46
74	38	15	280	63	69	39	3	155	58
78	33	20	439	80	78	33	1	104	43
81	30	16	405	63	76	21	7	125	36
71	51	3	155	69	71	44	10	158	66
55	24	7	165	48	66	26	6	146	39
39	18	3	98	31	62	24	9	131	39
74	37	18	182	74	74	42	2	101	75
81	57	18	201	112	81	63	2	113	113
74	44	18	271	59	74	35	2	107	60
69	48	18	280	68	69	33	5	98	63
69	42	15	405	85	69	42	2	183	57
71	37	8	232	63	74	33	3	204	50
69	52	5	155	78	69	48	11	158	78
69	24	5	101	39	66	26	4	146	39
69	30	2	91	40	62	24	10	131	39
74	39	13	162	74	74	47	2	152	75
81	60	13	180	112	81	71	2	168	113
74	45	13	247	64	74	45	5	183	60
69	44	13	259	68	69	39	5	155	58
69	42	15	290	62	39	25	1	183	57
74	34	3	204	50	57	27	5	192	40
55	48	4	155	70	69	35	10	152	78
69	30	7	165	48	66	22	11	155	39
69	24	3	98	40	62	21	18	140	39
74	39	17	162	74	42	33	3	155	82
81	60	17	180	112	46	40	3	170	67
74	45	17	247	64	42	22	3	155	36
69	44	17	259	68	55	36	8	170	51
69	42	15	341	73	78	33	3	183	57
74	38	4	256	50	71	33	14	204	49
69	45	3	98	78	44	44	19	91	78

FIGURE 13. BREAKERS AND LONGSHORE CURRENTS

				SOUTHWARD LONGSHORE CURRENT DIRECTED TO LEFT*					NORTHWARD LONGSHORE CURRENT DIRECTED TO			
	BEACH	LATITUDE	BEACH SLOPE	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENT (cm/sec)	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)
	A	37°30'	.0056	92	19	12	177	40	18	39	12	171
	B	37°07'	.0059	69	20	7	110	40	18	37	17	152
	C_1	36°50'	.02	74	39	17	161	74	33	42	4	101
	C_2	36°49'	.04	81	60	17	180	112	51	46	4	113
MAY	D	36°30'	.013	74	45	17	247	64	27	42	4	107
	E	35°58'	.012	69	44	17	259	68	27	39	4	98
	F	35°36'	.011	69	42	16	265	67	42	69	4	183
	G	35°23'	.009	74	34	6	204	50	27	71	16	192
	H	35°10'	.022	69	49	7	232	78	39	69	20	171
	A	37°30'	.0056	55	24	8	165	48	18	39	12	155
	B	37°07'	.0059	39	18	5	158	48	18	37	17	140
	C_1	36°50'	.02	74	35	11	143	74	33	42	4	152
	C_2	36°49'	.04	81	54	11	158	112	51	46	4	168
JUNE	D	36°30'	.013	74	39	11	201	59	45	120	4	183
	E	35°58'	.012	69	42	11	194	58	27	39	9	155
	F	35°36'	.011	69	42	13	265	67	42	69	3	183
	G	35°23'	.009	74	38	5	232	63	27	57	12	192
	H	35°10'	.022	69	55	7	201	78	35	55	17	152
	A	37°30'	.0056	69	20	12	116	39	16	66	8	113
	B	37°07'	.0059	69	62	5	110	152	19	62	20	152
	C_1	36°50'	.02	74	55	7	140	74	30	74	2	140
	C_2	36°49'	.04	81	83	7	155	112	45	46	2	134
JULY	D	36°30'	.013	74	45	7	177	74	27	42	2	134
	E	35°58'	.012	69	44	7	174	74	24	55	6	119
	F	35°36'	.011	74	36	8	207	53	26	69	3	131
	G	35°23'	.009	81	30	4	204	45	27	57	12	192
	H	35°10'	.022	69	33	5	119	78	35	55	20	152
	A	37°30'	.0056	69	30	14	177	65	16	66	10	113
	B	37°07'	.0059	69	30	14	165	66	15	62	10	101
	C_1	36°50'	.02	74	56	11	143	124	33	74	4	11
	C_2	36°49'	.04	74	84	11	158	189	51	81	4	11
AUGUST	D	36°30'	.013	74	45	11	201	100	45	74	4	18
	E	35°58'	.012	69	38	11	226	58	39	69	9	15
	F	35°36'	.011	69	42	12	265	67	39	69	3	20
	G	35°23'	.009	74	38	5	174	60	19	71	11	19
	H	35°10'	.022	69	46	6	168	78	39	69	16	14

*RELATIVE TO OBSERVER FACING LAND

FIGURE 13

RRENT DIRECTED TO RIGHT*		
OF TIME ERENCE SPEED CEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)
12	171	27
17	152	25
4	101	55
4	113	83
4	107	46
4	98	43
4	183	57
16	192	49
20	171	78
12	155	29
17	140	27
4	152	62
4	168	94
4	183	101
9	155	51
3	183	57
12	192	40
17	152	64
8	113	39
20	152	39
2	140	44
2	134	67
2	134	36
6	119	47
3	131	56
12	192	40
20	152	64
10	113	39
10	101	39
4	110	75
4	119	113
4	183	60
9	155	58
3	201	56
11	192	35
16	140	78

				SOUTHWARD LONGSHORE CURRENT DIRECTED TO LEFT*					NORTHWARD LONGSHORE	
	BEACH	LATITUDE	BEACH SLOPE	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)
SEPTEMBER	A	37°30'	.0056	74	26	14	265	40	39	18
	B	37°07'	.0059	69	27	8	183	40	37	18
	C_1	36°50'	.02	74	37	17	183	74	74	41
	C_2	36°49'	.04	81	57	17	201	112	81	62
	D	36°30'	.013	74	44	17	271	59	74	40
	E	35°58'	.012	69	44	17	280	63	69	35
	F	35°36'	.011	78	33	19	265	67	69	36
	G	35°23'	.009	81	30	9	256	55	71	37
	H	35°10'	.022	69	51	10	226	78	69	39
OCTOBER	A	37°30'	.0056	69	30	12	283	51	66	16
	B	37°07'	.0059	69	30	5	158	66	62	21
	C_1	36°50'	.02	74	37	21	183	74	42	33
	C_2	36°49'	.04	81	57	21	201	112	46	51
	D	36°30'	.013	74	44	2	271	59	42	27
	E	35°58'	.012	69	44	21	280	63	55	36
	F	35°36'	.011	74	36	23	372	68	69	39
	G	35°23'	.009	81	30	9	256	55	71	33
	H	35°10'	.022	71	47	7	168	67	71	45
NOVEMBER	A	37°30'	.0056	55	20	9	116	32	66	22
	B	37°07'	.0059	69	20	2	110	40	62	21
	C_1	36°50'	.02	74	36	18	188	74	74	47
	C_2	36°49'	.04	81	57	18	201	118	81	71
	D	36°30'	.013	74	44	18	271	59	74	45
	E	35°58'	.012	69	44	18	280	63	69	41
	F	35°36'	.011	69	42	17	290	62	69	28
	G	35°23'	.009	74	38	4	186	50	71	29
	H	35°10'	.022	69	53	7	155	78	69	39
DECEMBER	A	37°30'	.0056	69	30	7	369	42	66	26
	B	37°07'	.0059	69	30	3	326	40	62	21
	C_1	36°50'	.02	81	29	16	162	52	74	41
	C_2	36°49'	.04	81	60	16	180	112	81	62
	D	36°30'	.013	74	45	16	247	64	74	40
	E	35°58'	.012	69	44	16	259	68	69	35
	F	35°36'	.011	69	42	9	341	73	78	33
	G	35°23'	.009	74	38	7	256	55	74	31
	H	35°10'	.022	71	46	3	168	67	69	44

*RELATIVE TO OBSERVER FACING LAND

FIGURE 13. BREAKERS AND LONGSHORE CURRENTS (CON)

WARD LONGSHORE CURRENT DIRECTED TO LEFT*				NORTHWARD LONGSHORE CURRENT DIRECTED TO RIGHT*				
SPEED OF ASSOCIATED CURRENTS (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)	REFERENCE BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)	% OF TIME REFERENCE SPEED EXCEEDED	MAXIMUM BREAKER HEIGHT (cm)	SPEED OF ASSOCIATED CURRENTS (cm/sec)
26	14	265	40	39	18	11	171	27
27	8	183	40	37	18	10	91	23
37	17	183	74	74	41	4	165	75
57	17	201	112	81	62	4	183	113
44	17	271	59	74	40	4	201	60
44	17	280	63	69	35	12	171	58
33	19	265	67	69	36	4	223	56
30	9	256	55	71	37	8	168	82
51	10	226	78	69	39	12	140	78
30	12	283	51	66	16	5	113	39
30	5	158	66	62	21	8	140	39
37	21	183	74	42	33	3	110	44
57	21	201	112	46	51	3	119	67
44	2	271	59	42	27	3	119	39
44	21	280	63	55	36	9	201	54
36	23	372	68	69	39	3	201	56
30	9	256	55	71	33	8	158	49
47	7	168	67	71	45	8	131	66
20	9	116	32	66	22	9	155	39
20	2	110	40	62	21	13	140	39
36	18	188	74	74	47	3	152	75
57	18	201	118	81	71	3	168	113
44	18	271	59	74	45	3	183	60
44	18	280	63	69	41	7	201	58
42	17	290	62	69	28	5	116	56
38	4	186	50	71	29	7	174	49
53	7	155	78	69	39	9	140	78
30	7	369	42	66	26	6	146	39
30	3	326	40	62	21	9	140	39
29	16	162	52	74	41	2	165	75
60	16	180	112	81	62	2	183	113
45	16	247	64	74	40	2	201	60
44	16	259	68	69	35	5	171	58
42	9	341	73	78	33	2	183	57
38	7	256	55	74	31	7	204	44
46	3	168	67	69	44	9	158	78

C. Seawater Properties Affecting Dispersion

1. Introduction

In this guide, the coastal (Continental Shelf) region is bounded by the 100-fathom (183-meter) isobath; the offshore region is seaward of this isobath. Bays, inlets, and sounds are not included in the data presentations.

Temperature is presented in degrees Celsius (°C), salinity in parts per thousand (o/oo), density* in units of sigma-t (σ_t), and oxygen in ml/l. Seasons used here are defined as: winter (January through March), spring (April through June), summer (July through September), and autumn (October through December).

The water column is considered to be isothermal, or to have a mixed layer, when the vertical temperature gradient is equal to or less than 2.5°C per 100 meters; a column of water is said to be isohaline when it is nearly of uniform salinity. Vertical density structure is isopycnic, i.e., of uniform density, if the change in σ_t gradient is equal to or less than 0.65 per 100 meters. A pycnocline, or vertical density gradient, exists when the change in density with depth exceeds the stated isopycnic limits.

Mean sea surface temperature for all months is presented in figure A5 of the Appendix. Monthly variability of sea surface temperatures at selected locations is presented in figure A6 of the Appendix. Mean oxygen traces are presented by season in figure A7 of the Appendix.

2. Description of seawater properties

a. Winter

(1) Coastal--Mean sea surface temperatures are lowest during February, when cold (6°C) water flows south to about 36°20'N (although some 6°C water remains in March just south of Chesapeake Bay). Water of 9°C extends slightly south of Cape Hatteras during March. Generally, the water column in the shallow part of this region is isothermal. Farther offshore a mixed layer within the upper 50 meters becomes evident (figs. 14 and 18).

Mean sea surface salinity generally ranges between about 30 o/oo and 34 o/oo, except near Chesapeake Bay where winter values may be as low as 24 o/oo and near the Continental Shelf edge south of Cape Hatteras where values are slightly greater than 36 o/oo. At most locations on the Continental Shelf, the water column is either isohaline or has a shallow mixed layer; however, the vertical salinity structure near the entrance to Chesapeake Bay is characterized by a sharp increase in salinity with depth.

---

* Density as used in this publication is equivalent to specific gravity and represents the ratio at atmospheric pressure of the weight of a given volume of seawater to that of an equal volume of distilled water at 4°C. It is conveniently expressed as sigma-t, an abbreviated form wherein water whose density is 1.0240 has a sigma-t value of 24.0 (Neumann and Pierson, 1966).

Mean sea surface density is lowest off the bay ($\sigma_t \approx 18$) and increases seaward as water becomes more saline. Density in the water column closely parallels the salinity structure; i.e., it is either isopycnic to the bottom or has a shallow mixed layer, except off the bay, where the vertical gradient is sharp from surface to bottom. Instability within the water column may occur.

Dissolved oxygen at the surface generally ranges between 4.7 and 7.6 ml/l, with lowest values occurring off the bay. At bottom on the Continental Shelf, values range between 3.1 and 7.2 ml/l, with lowest values occurring south of Cape Hatteras.

Values of pH range between 7.90 and 8.40 at the surface, and between 8.10 and 8.30 at the bottom. Lowest surface and bottom values occur off Chesapeake Bay.

(2) Offshore--The horizontal surface temperature gradient marking the Gulf Stream is most evident during winter. South of the Gulf Stream, surface temperatures vary only slightly. Vertical temperature structure north of the Gulf Stream generally is characterized by a mixed layer in the upper 100 meters; south of the Gulf Stream the water column is isothermal to depths of at least 500 meters. During winter, the vertical discontinuity at the northern edge of the Gulf Stream is strongest.

Surface salinity ranges between 34.0 o/oo and 36.5 o/oo, with highest values in the southeast. North of the Gulf Stream the water column is characterized by a shallow mixed layer, a weak positive salinity gradient, and a slight salinity maximum at a depth of about 150 meters. South of the Gulf Stream the water column is essentially isohaline to about 500 meters.

Surface density shows relatively little variation, ranging only between about 25.0 and 26.5 σ_t. Vertically, in the northern part of this region, the pycnocline occurs from the surface to about 30 meters before a slow constant increase with depth occurs. In the south isopycnic conditions prevail in the upper 600 meters.

Mean dissolved oxygen at the surface ranges between 5.0 and 5.5 ml/l. The oxygen minimum (3.4 ml/l is present in the northern part of this region at a depth of about 250 meters; in the southern part, the minimum (3.5 ml/l) probably occurs at about 700 meters.

February pH data indicate a surface range of about 8.20 to 8.25, and near-bottom values of about 8.15.

b. Spring

(1) Coastal--During April and May, a transition from winter to near-summer conditions occurs. In April, north of Chesapeake Bay, 9°C water still is present; by May this is replaced by 13° to 15°C. Also, in May warmer water flows out of Chesapeake Bay. By June, temperatures in the coastal region have risen about 5° to 10°C higher than April values. North of Cape Hatteras temperatures tend to decrease from the surface to a depth of about 15 meters (i.e., no mixed layer), then become isothermal; however, near the edge of the Continental Shelf, a shallow mixed layer may occur. South of the cape the water may be isothermal (figs. 15 and 18).

Mean surface salinity generally ranges between 30 o/oo and 33 o/oo, but nearshore values may be lower (about 26 o/oo) south of the bay, and higher (36 o/oo) south of Cape Hatteras. Salinity increases only slightly from the surface to depths between 10 and 25 meters, then remains constant to the bottom, except near Chesapeake Bay where a strong gradient occurs in the upper 10 meters.

Mean surface density ranges from about $20.5\sigma_t$ near the bay to slightly greater than $24.0\ \sigma_t$ south of Cape Hatteras. Vertical density structure resembles salinity structure. In most of this region, density increases slowly with depth; however, near Chesapeake Bay strong density gradients in the upper 10 meters and vertical instability may occur.

In spring, surface dissolved oxygen ranges between about 4.4 and 7.8 ml/l. The lowest value and greatest range of values occur off Chesapeake Bay in April; during May and June, the ranges generally are smaller. Oxygen concentrations at the bottom range between 3.3 and 7.7 ml/l. Lowest bottom values occur south of the bay in June; highest values are found off the bay.

The surface range of pH for this season is about 8.00 to 8.55; at the bottom, values range between 7.80 and 8.55. Lowest values occur near the bay.

(2) Offshore--The Gulf Stream is still noticeably warmer than those waters to the west during April and May, although the difference is not as great as during winter. June conditions approach those of summer, with surface temperatures warming quickly throughout this region. Vertical temperature structure generally is characterized by a mixed layer within the upper 100 meters, except in the northeast, where no mixed layer occurs, and in the southeast, where the water column is isothermal to depths of at least 600 meters.

Mean surface salinity ranges between about 33.0 o/oo and 36.5 o/oo during spring, with highest values in the southeastern part. The horizontal salinity gradient around Cape Hatteras is strongest during this season. Salinity in most of this region increases from the surface to depths of about 100 to 200 meters, then decreases with depth. However, in the southeast the water column is isohaline to depths of about 450 meters.

Mean surface density ranges between 23.0 and $26.5\ \sigma_t$. The water column is characterized by increasing density from the surface to the bottom (i.e., no mixed layer) except in the southeast where the vertical structure is isopycnic to depths of 600 meters. Instability near the surface may occur in the Gulf Stream.

Mean dissolved oxygen at the surface ranges between 4.8 and 5.5 ml/l. The oxygen minimum in the northern part of this region is about 3.3 ml/l at a depth of 250 meters; in the south a minimum of 3.4 ml/l occurs at about 850 meters.

In April, surface pH values range between about 8.40 and 8.50; in May and June values are lower, varying between 8.15 and 8.25. Near-bottom pH values during spring range between 8.05 and 8.25.

c. Summer

(1) Coastal--Mean surface temperatures are highest during August and are several degrees cooler in September in most of this region.

A mixed layer occurs to depths of about 10 meters in much of the region north of Cape Hatteras, except near Chesapeake Bay where there is no mixed layer. South of the cape a mixed layer may not occur (figs. 16 and 18). Upwelling may occur along the coast just north of Cape Hatteras (Wells and Gray, 1960a).

The lowest mean surface salinity (about 23 o/oo) occurs off the bay; but the normal seasonal range for most of this region is between 29 o/oo and 33 o/oo and high values of about 35 o/oo occur south of Cape Hatteras. The horizontal change in salinity near the bay may be as great as 6 o/oo in about 20 kilometers. Except near the bay, the water column is isohaline to depths of about 10 meters; salinity then increases with depth. Near the bay, the vertical salinity gradient is strong from the surface to the bottom, with no mixed layer.

Mean surface density is lowest near the bay ($\sigma_t \approx 16$) and increases seaward. Vertical density structure is characterized by a shallow (10-meter) mixed layer, except near the bay where the outflow of low-salinity water causes a strong vertical gradient. Instability in the water column is most likely to occur near Cape Hatteras.

Dissolved oxygen ranges between 3.6 and 6.0 ml/l at the surface and between 3.6 and 5.5 ml/l near the bottom. Lowest surface and bottom values are near the bay and occur in July.

Surface pH values near Chesapeake Bay range between 7.65 and 8.60; near-bottom values range between 7.10 and 8.55.

(2) Offshore--Surface temperature variation is least during summer, especially in August when there is only about 3°C range throughout this region and thermal boundaries of the Gulf Stream are least distinct. Vertical temperature structure is characterized by a mixed layer in the upper 30 meters, except in the northeast where there is no mixed layer. Generally, temperature decreases steadily below the mixed layer; however, in the northeast a slight increase is noted between 50 and 100 meters.

Mean surface salinity during summer ranges between 33 o/oo and 36 o/oo, and highest values occur in the south. The horizontal surface salinity gradient around Cape Hatteras is weakest during this season. Vertical salinity generally increases from the surface to depths between 50 and 200 meters. In the northeast a minor salinity minimum occurs at 50 meters before salinity increases to a maximum at 150 meters, then decreases below.

Mean surface density ranges between 23 and 24 σ_t. Generally, no mixed layer occurs, and density increases rapidly from the surface to depths between 50 and 150 meters, then gradually increases to the bottom. The strongest vertical density gradients occur during summer.

Mean dissolved oxygen at the surface ranges between 4.5 and 4.9 ml/l. The oxygen minimum in the north is about 3.3 ml/l at a depth of 200 meters; in the south a minimum of 3.5 ml/l occurs at 700 meters.

No pH data are available for this region.

d. Autumn

(1) Coastal--Mean surface temperatures in the coastal region

decrease during autumn. By December, temperatures less than 15°C cover most of the Continental Shelf north of Cape Hatteras; temperatures of about 9°C occur north of 37°N and off Chesapeake Bay. The water column is isothermal in most of this region; however, near the bay, surface temperatures are slightly cooler than those at depth (figs. 17 and 18).

Mean surface salinity varies from about 31 o/oo to 33 o/oo, but near the bay is about 29 o/oo and south of Cape Hatteras probably is as high as 36 o/oo. The water column in most of this region is isohaline, but near the bay there is a strong vertical salinity gradient with increasing values to the bottom.

Mean surface density is lowest off the bay, where salinity is low. The water column is isopycnic except near the bay, where a strong vertical gradient occurs. Instability may occur on the Continental Shelf during autumn.

Surface dissolved oxygen ranges between 3.7 and 8.4 ml/l. Lowest values occur in October north of the bay; highest values occur in December off the bay. Near-bottom oxygen values near the bay range from 3.4 ml/l in October to 8.0 ml/l in December.

The surface pH range near Chesapeake Bay is about 7.40 to 8.50. Near-bottom values range between 7.25 and 8.40.

(2) Offshore--Mean surface temperatures during autumn decrease as a result of seasonal cooling, and the horizontal gradient marking the Gulf Stream is stronger. A shallow mixed layer occurs within the upper 50 meters throughout this region.

Mean surface salinity generally ranges between 33.0 oo/o and 36.5 o/oo, with highest values located in the south. Vertical salinity structure is characterized by increasing values from the surface to depths between 100 and 200 meters, then decreasing values with depth below 200 meters.

Mean surface density ranges between 23 and 25 σ_t. A mixed layer to a depth of about 50 meters occurs only in the south. Elsewhere the pycnocline extends from the surface to at least 100 meters. Vertical density gradients are strongest near the northern edge of the Gulf Stream. Instability may occur near the surface in this region.

Mean surface dissolved oxygen ranges from 5.2 ml/l in the northern part of this region to 4.8 ml/l in the southeast. The oxygen minimum (3.6 ml/l) occurs at a depth of about 300 meters in the north and at about 750 meters south of the Gulf Stream.

No pH data are available for this region.

3. Discussion

a. Effects of seawater properties at the surface--A major influence on the spread and dispersion of a pollutant is the presence of fronts (boundaries or interfaces) which may be caused either by sharp salinity or temperature differences. In this Area frontal regions occur off Chesapeake Bay and near the Gulf Stream.

Although low salinity values are common throughout the coastal region, they are particularly noticeable near Chesapeake Bay where the horizontal change with distance is probably greater than elsewhere on the Continental Shelf. A surface pollutant (e.g., oil) may collect at the seaward interface where a pronounced salinity gradient occurs (Kennedy and Wermund, 1971). Concentration at this interface is most likely during summer when the mean surface salinity gradient is about 6 o/oo in 20 kilometers.

Surface contaminants may also concentrate along the northern boundary of the Gulf Stream. This is primarily a thermal boundary which is strong during late autumn through early spring and is most intense during winter. "Surface float" may tend to collect at zones of convergence (fronts) such as this one (Garber, 1960). The occurrence and relative strength of these fronts may inhibit the spread of surface pollutants and may also influence the direction in which contaminants move. For example, a pollutant introduced in winter in the coastal region north of Cape Hatteras, where the general flow is south, may travel as far as the cape and then be impeded by a strong thermal gradient. This effect is contingent upon the physical characteristics of the pollutant and on local real-time conditions. The presence of pollutants on the surface also may inhibit air-sea interchange of oxygen or deplete surface dissolved oxygen and many pollutants may produce temporary changes in surface pH.

b. Effects of seawater properties in the water column--If pollutants introduced at the sea surface are heavier (more dense) than the surface water they will sink either to a layer of similar density or to the bottom. Those heavy enough to reach bottom quickly generally will not be influenced by density variations of the water column. However, stratification within the water column will affect lighter pollutants. Vertical diffusion is greatest when the water column is homogeneous, i.e., isopycnic. However, if density discontinuities exist, vertical diffusion is inhibited or halted. Mean density structures of the Area are discussed in "Description of seawater properties" section.

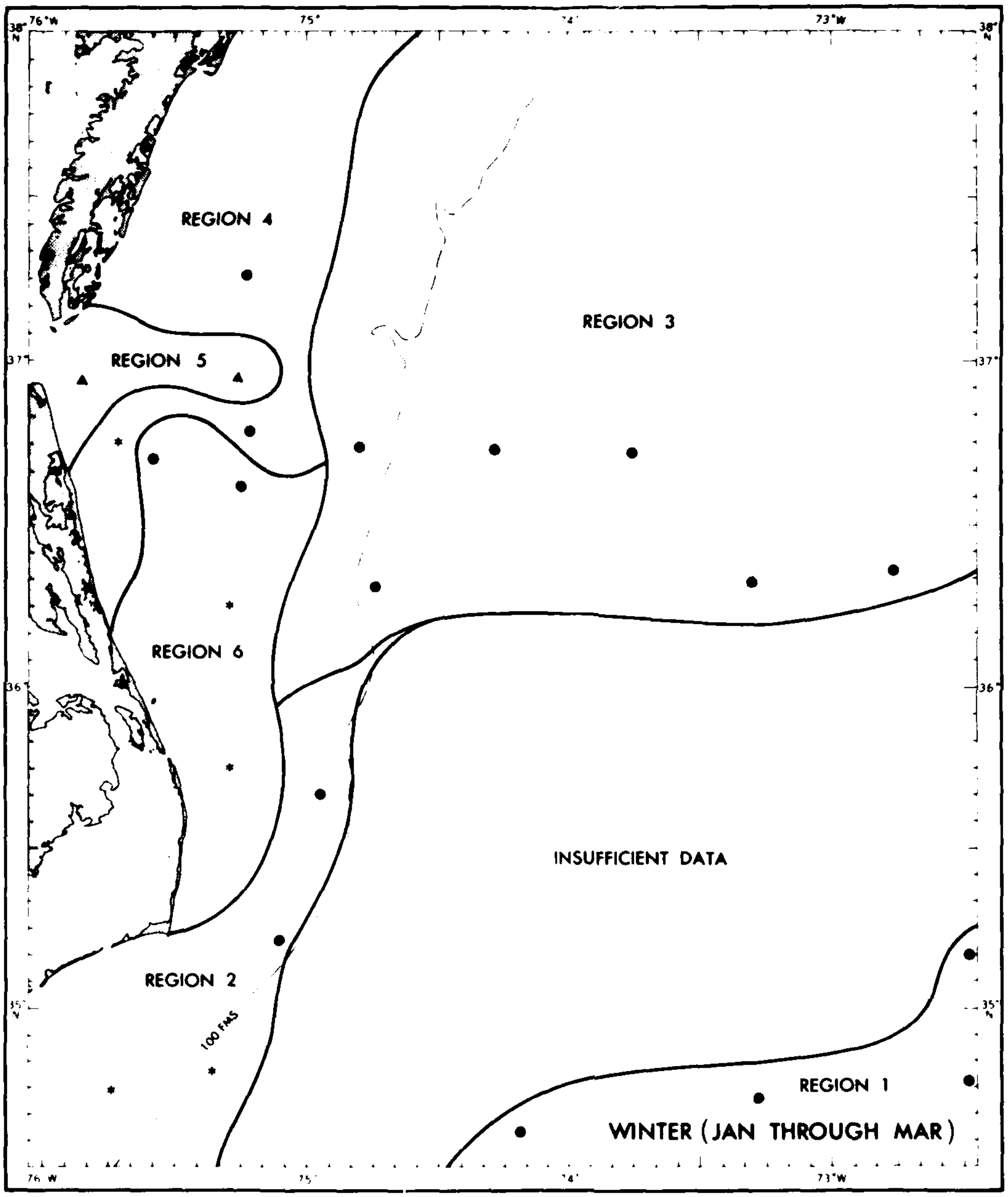
Regions where density stratification may theoretically affect vertical movement of pollutants may be inferred from figure 19, which depicts changes in vertical density for a unit of depth.*

In any region, regardless of season, that displays a strong density gradient, density layers in the upper water column will be shallower than in regions with weaker gradients. Pollutants heavy enough to sink may collect and spread along layers of similar density (false bottom). In regions where strong gradients occur, entrainment of contaminants could be closer to the sea surface than in regions where the gradient is weaker (compare figures 18 and 19, Section 7, September, Stations B and F). Contaminants which collect along these "false bottoms" may also surface elsewhere.

Pollutants introduced below the surface may behave similarly. If the water column is homogeneous, pollutants lighter than the ambient density may easily reach the surface. However, a pollutant premixed to the density at the point of introduction may mix and spread within that density layer and is not likely to reach the surface. The more stable the water column, the less likely is vertical diffusion to occur, although some slow diffusion will occur with time.

---

* Figure 19 is included to supplement the density sections in figure 18, is based on real-time data, and may not reflect average conditions.



REGION LOCATOR CHART

LEGEND

EACH TYPICAL TRACE REPRESENTS THE MOST
VALUES OF TEMPERATURE, SALINITY, AND
METERS (2,000 FEET) OF EACH REGION.
WITHIN AN ENVELOPE ENCLOSING THE
OBSERVATIONS THE NUMBER OF OCEAN
TO DERIVE EACH TRACE IS SHOWN WI
DISTRIBUTION OF STATIONS IS INDICATED

NUMBER OF OBSERVAT

● 1
* 2–5
▲ >5

LEGEND

ACE REPRESENTS THE MOST COMMONLY OCCURRING
PERATURE, SALINITY, AND DENSITY IN THE UPPER 610
FEET) OF EACH REGION. THE MODAL TRACE LIES
VELOPE ENCLOSING THE RANGE OF 100% OF THE
THE NUMBER OF OCEANOGRAPHIC STATIONS USED
CH TRACE IS SHOWN WITH THE TRACE, AND THE
OF STATIONS IS INDICATED FOR 30 QUADRANGLES.

NUMBER OF OBSERVATIONS

- ● 1
- * 2–5
- ▲ >5

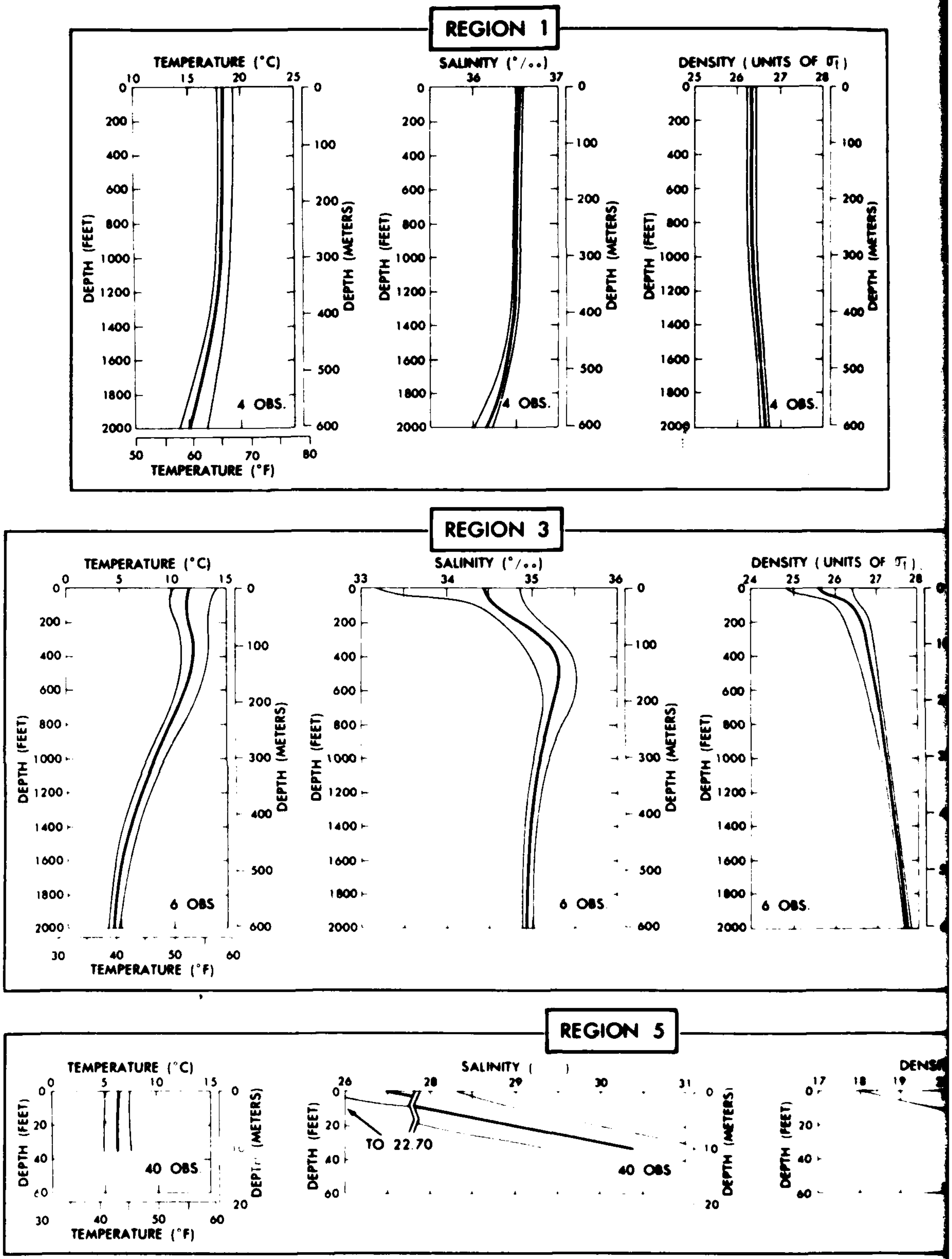
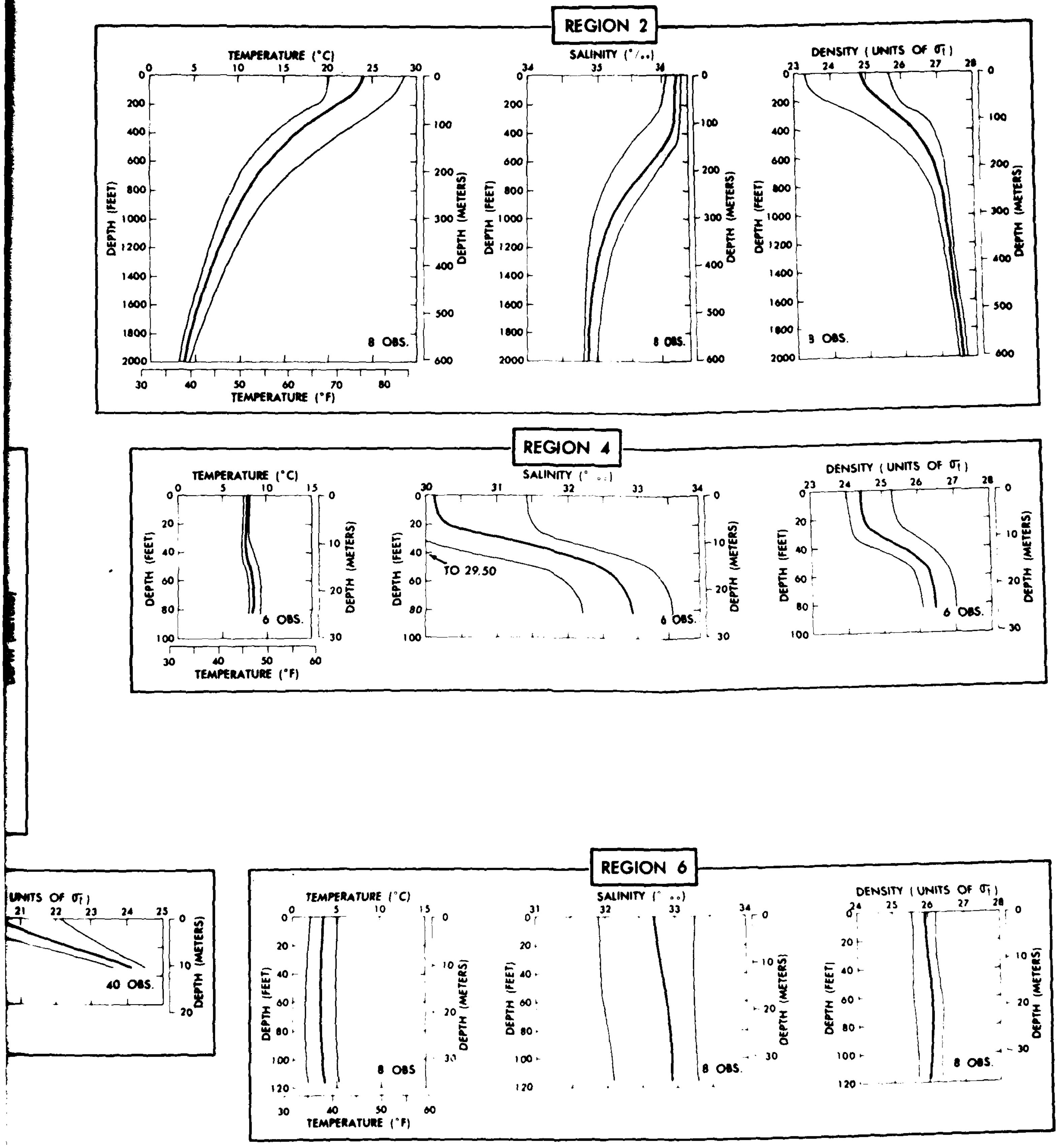
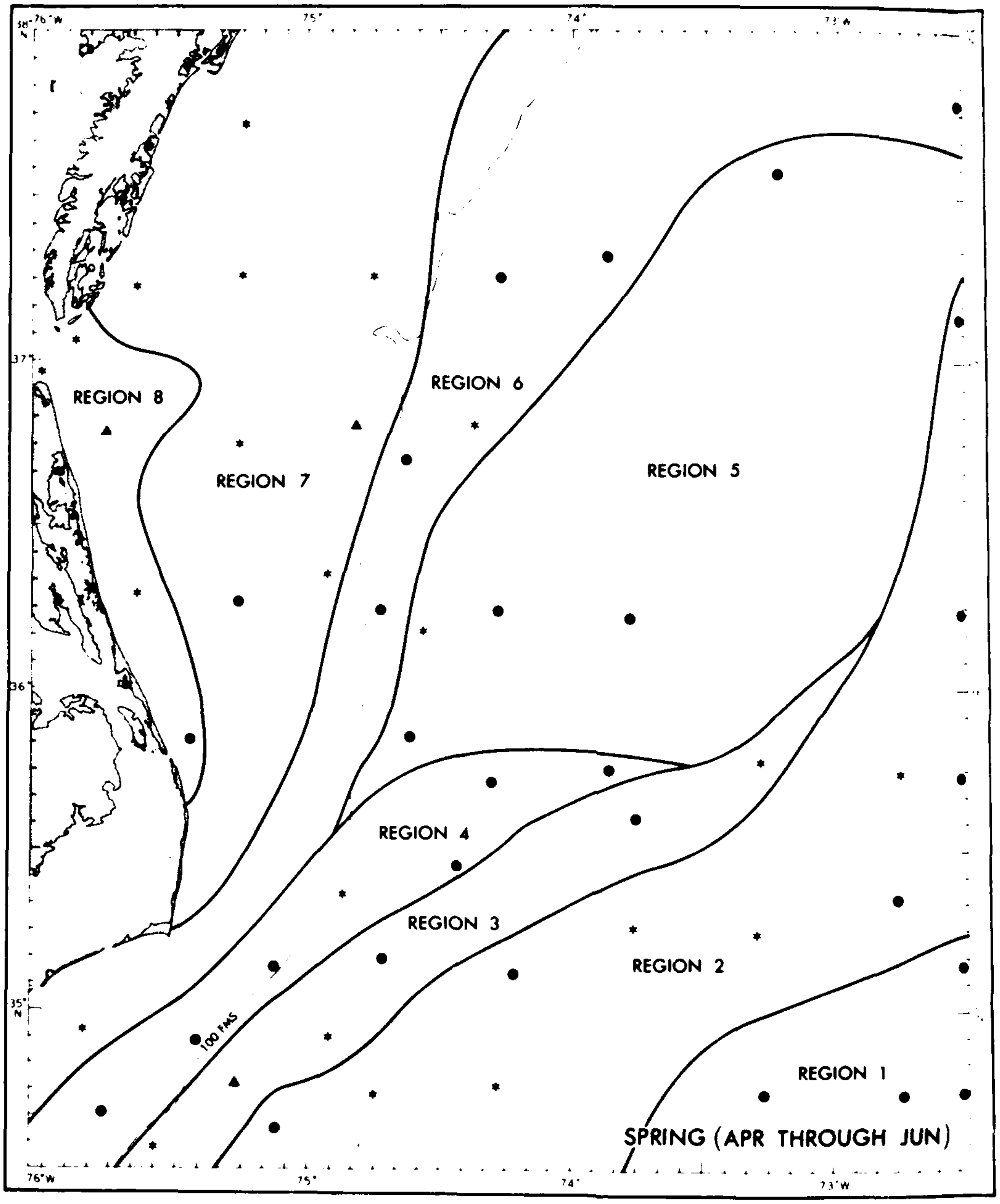


FIGURE 14. TYPICAL TRACES AND RANGE



F TEMPERATURE, SALINITY, AND DENSITY, JANUARY THROUGH MARCH (WINTER)

3



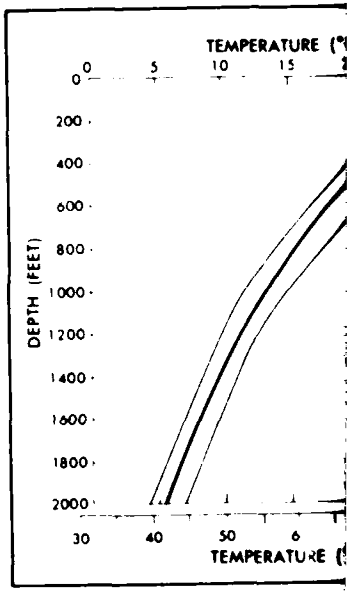
REGION LOCATOR CHART

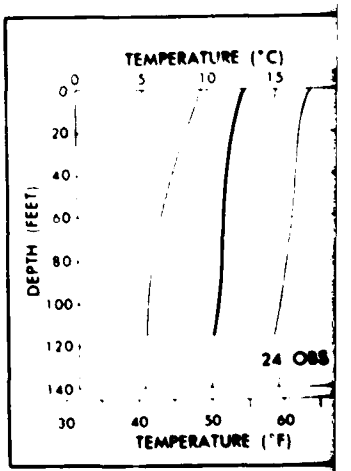
LEGEND

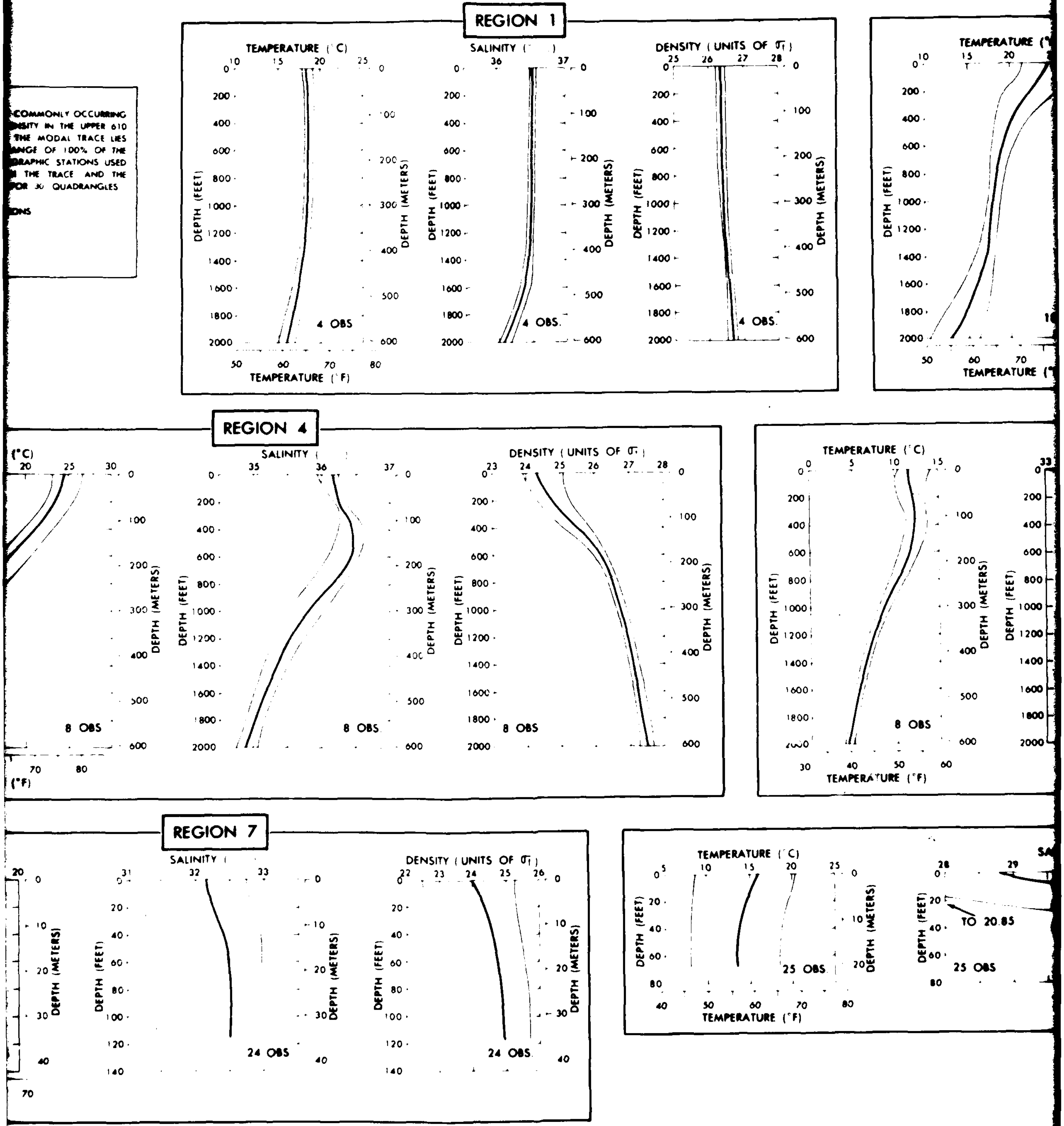
EACH TYPICAL TRACE REPRESENTS THE MOST C
VALUES OF TEMPERATURE, SALINITY, AND DEN
METERS (2,000 FEET) OF EACH REGION TH
WITHIN AN ENVELOPE ENCLOSING THE RAN
OBSERVATIONS THE NUMBER OF OCEANOGR
TO DERIVE EACH TRACE IS SHOWN WITH
DISTRIBUTION OF STATIONS IS INDICATED FO

NUMBER OF OBSERVATION

● 1
* 2–5
▲ >5





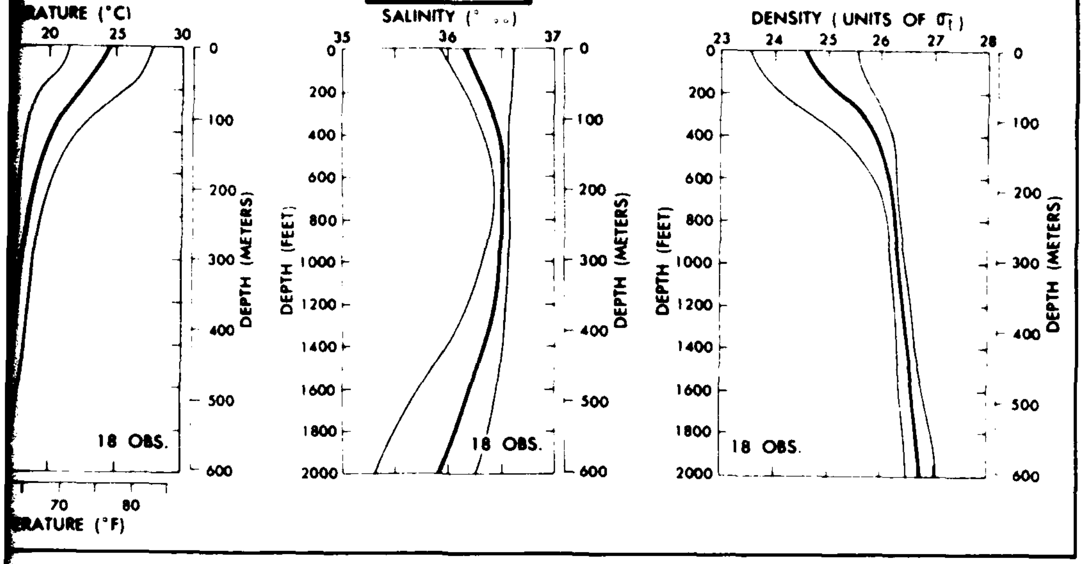


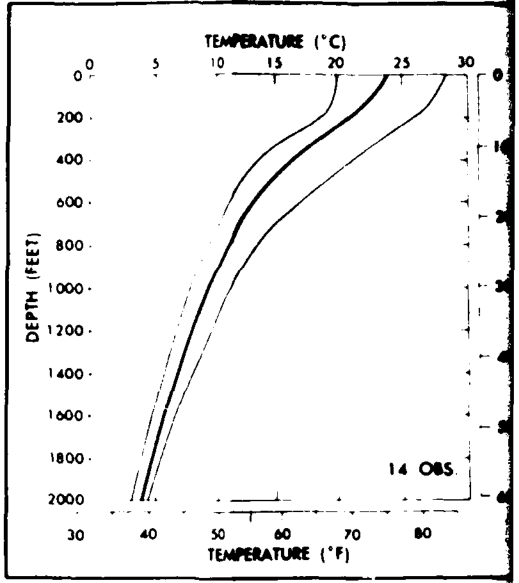
COMMONLY OCCURRING
SITY IN THE UPPER 610
THE MODAL TRACE LIES
NGE OF 100% OF THE
RAPHIC STATIONS USED
THE TRACE AND THE
OR 30 QUADRANGLES

ONS

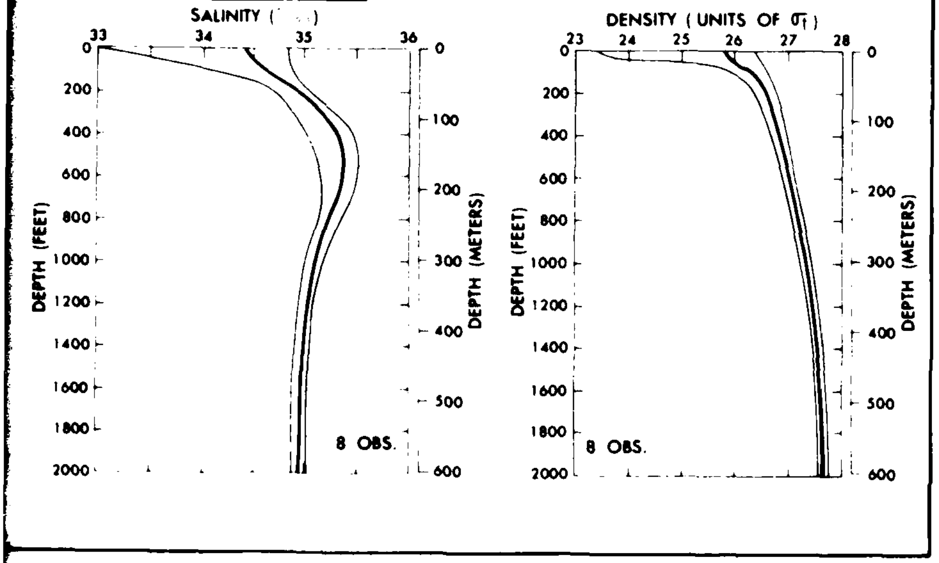
FIGURE 15. TYPICAL TRACES AND

REGION 2

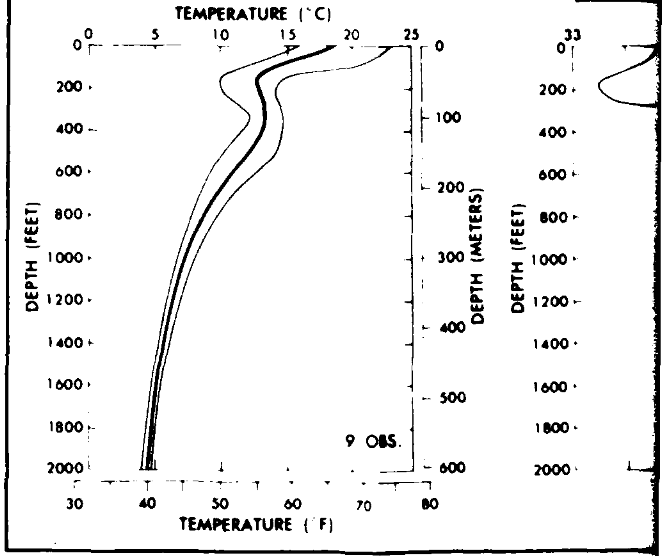




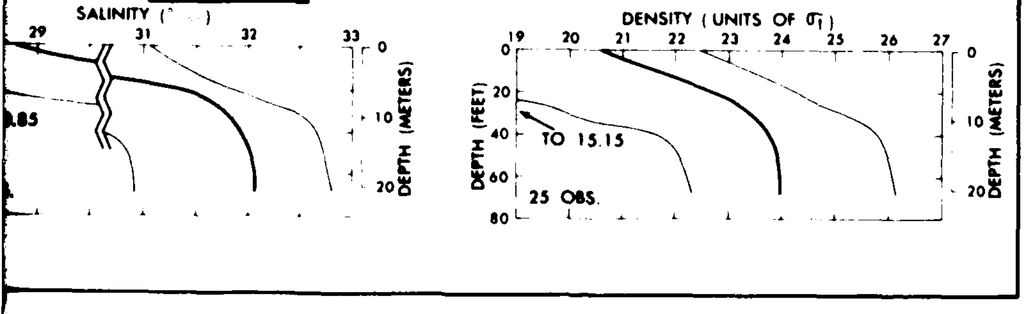
REGION 5



REGI

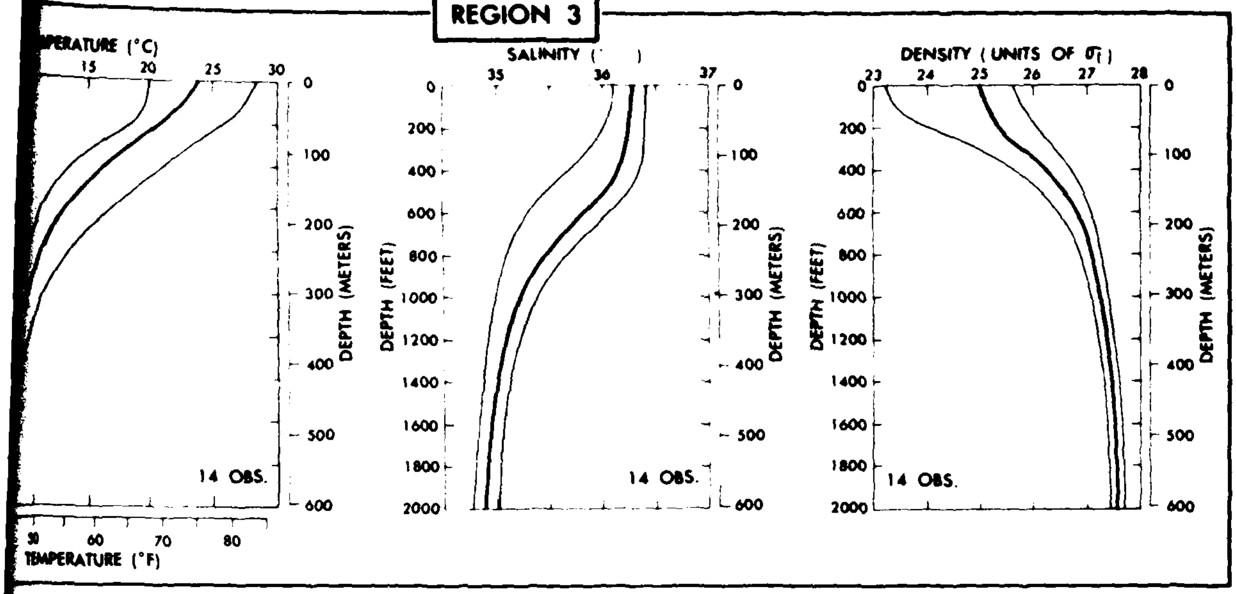


REGION 8

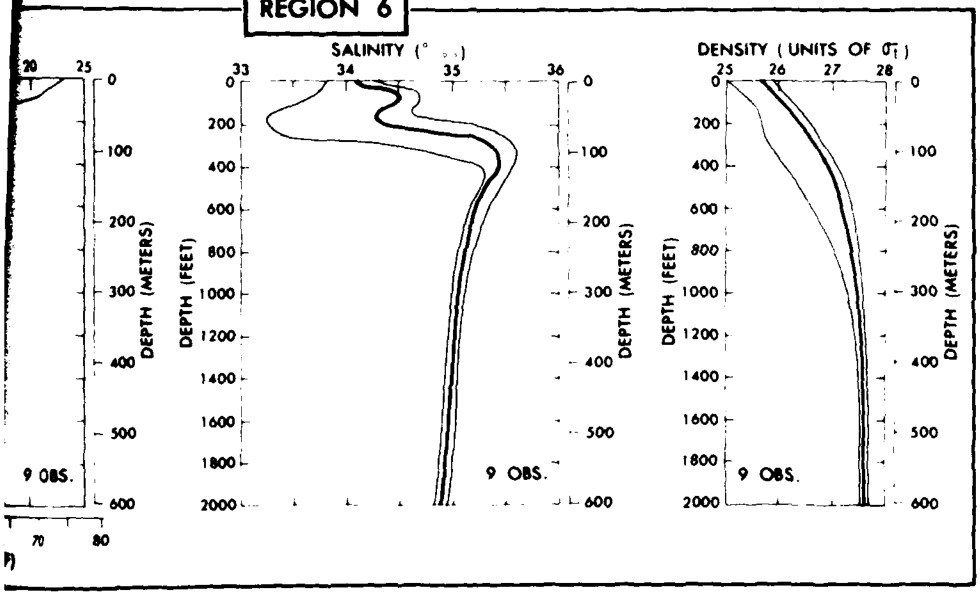


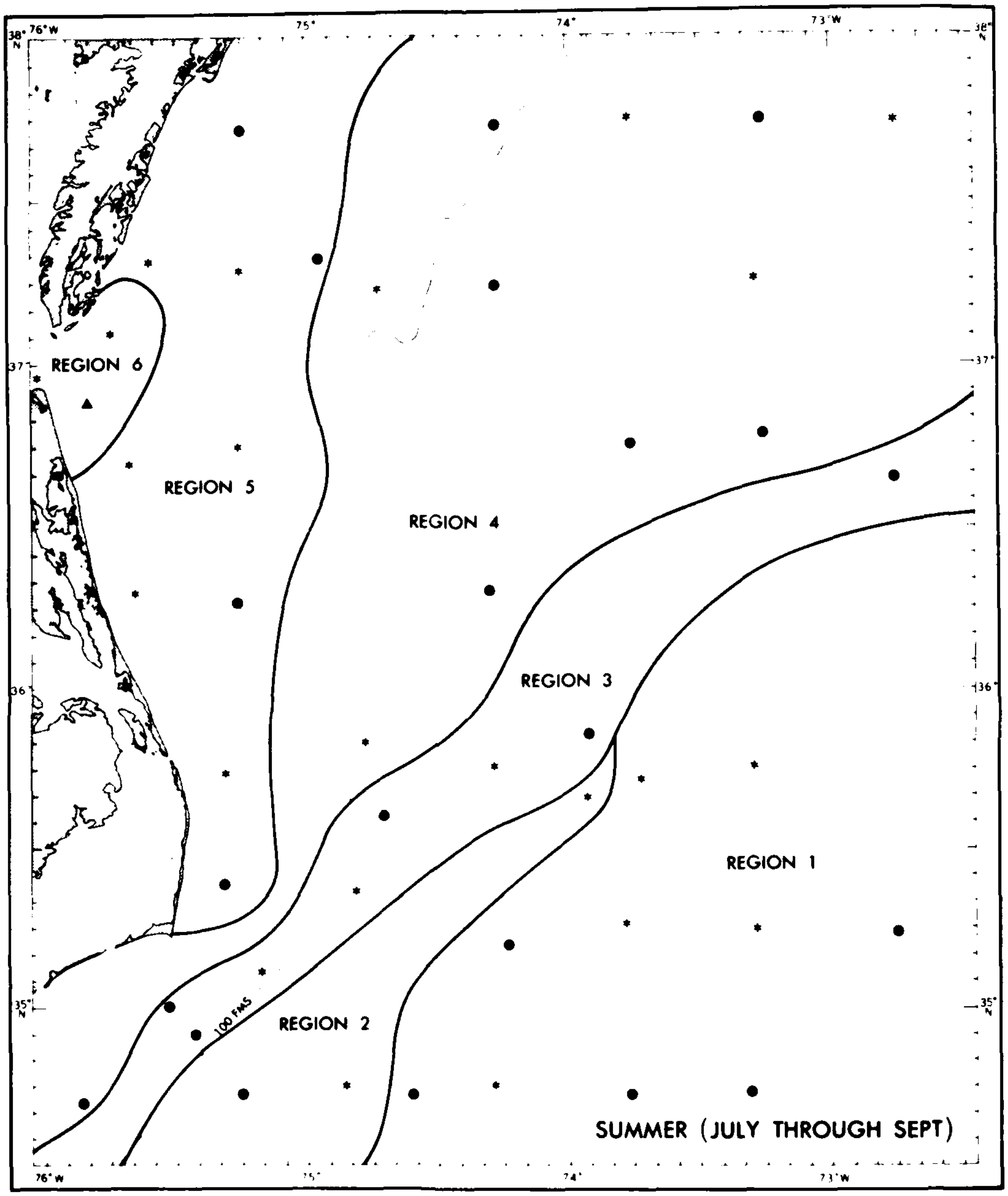
ES AND RANGES OF TEMPERATURE, SALINITY, AND DENSITY, APRIL THROUGH JUNE (SPRING)

REGION 3



REGION 6

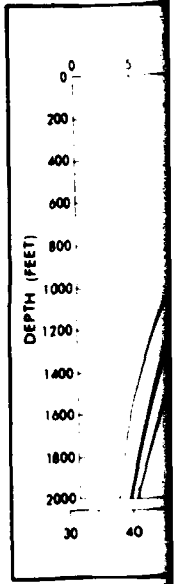


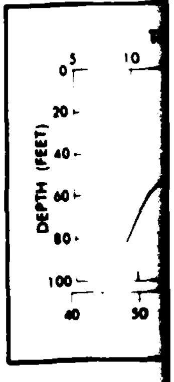


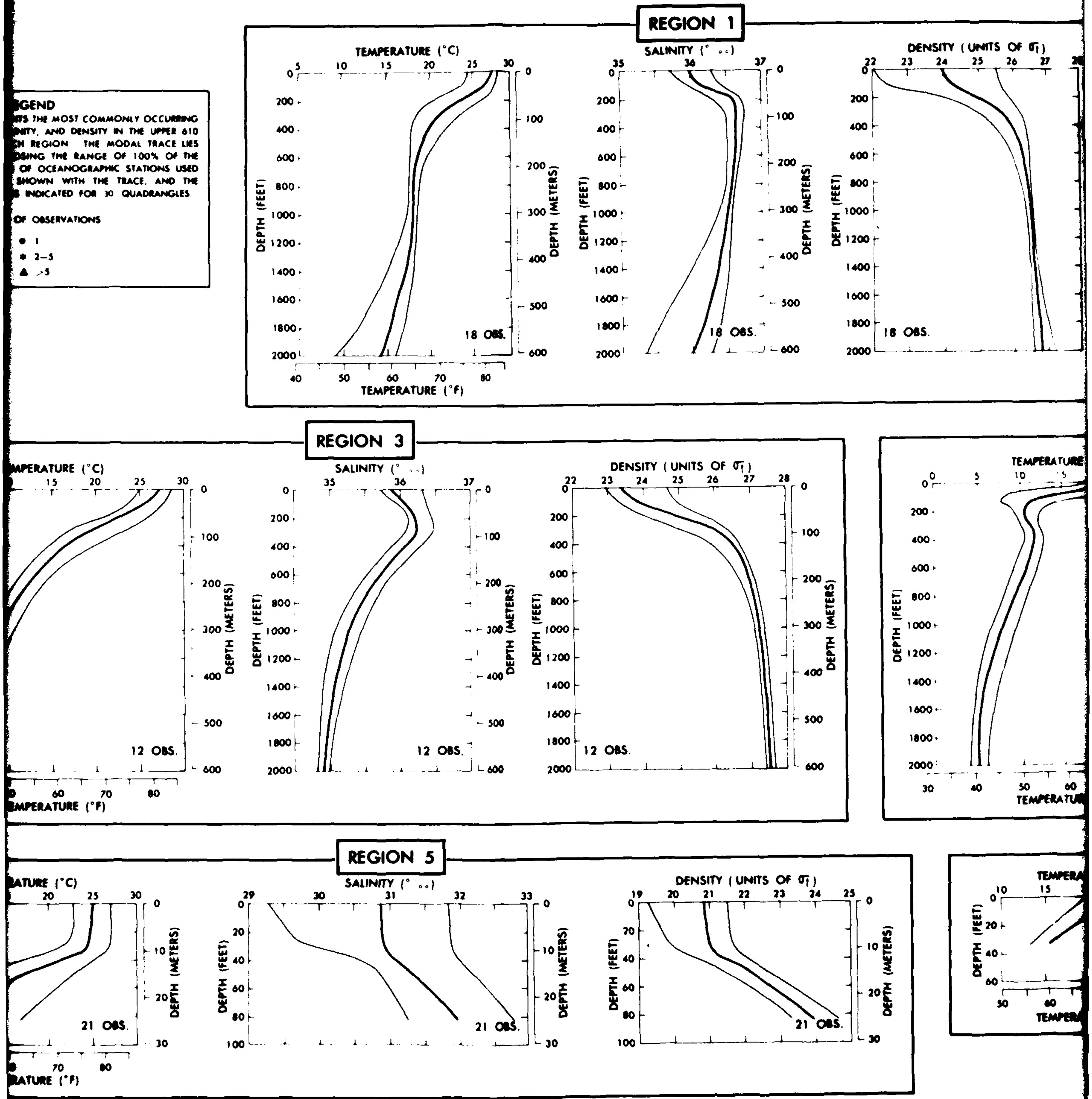
REGION LOCATOR CHART

EACH TYPICAL TRACE REP
VALUES OF TEMPERATURE
METERS (2,000 FEET) O
WITHIN AN ENVELOPE
OBSERVATIONS. THE NU
TO DERIVE EACH TRAC
DISTRIBUTION OF STATI

NU







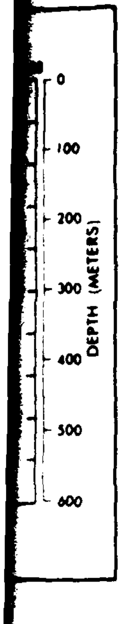
GEND

TS THE MOST COMMONLY OCCURRING
NITY, AND DENSITY IN THE UPPER 610
H REGION THE MODAL TRACE LIES
SING THE RANGE OF 100% OF THE
OF OCEANOGRAPHIC STATIONS USED
SHOWN WITH THE TRACE, AND THE
INDICATED FOR 30 QUADRANGLES.

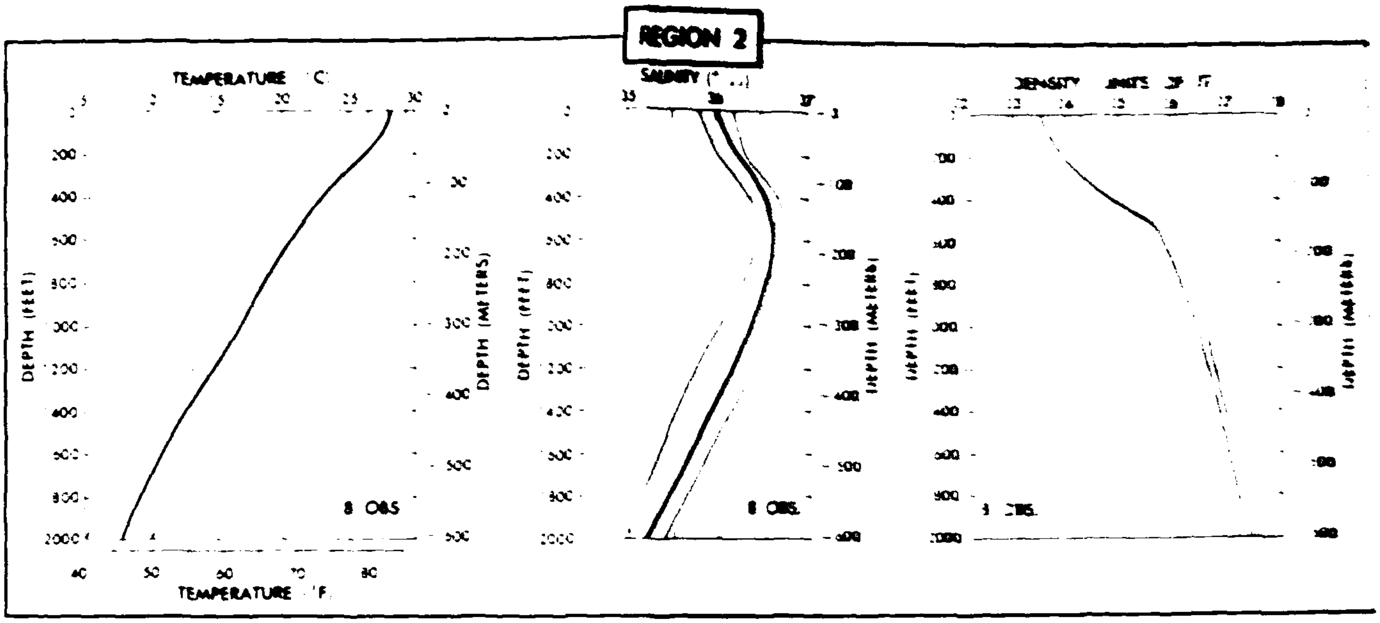
OF OBSERVATIONS

● 1
✱ 2–5
▲ >5

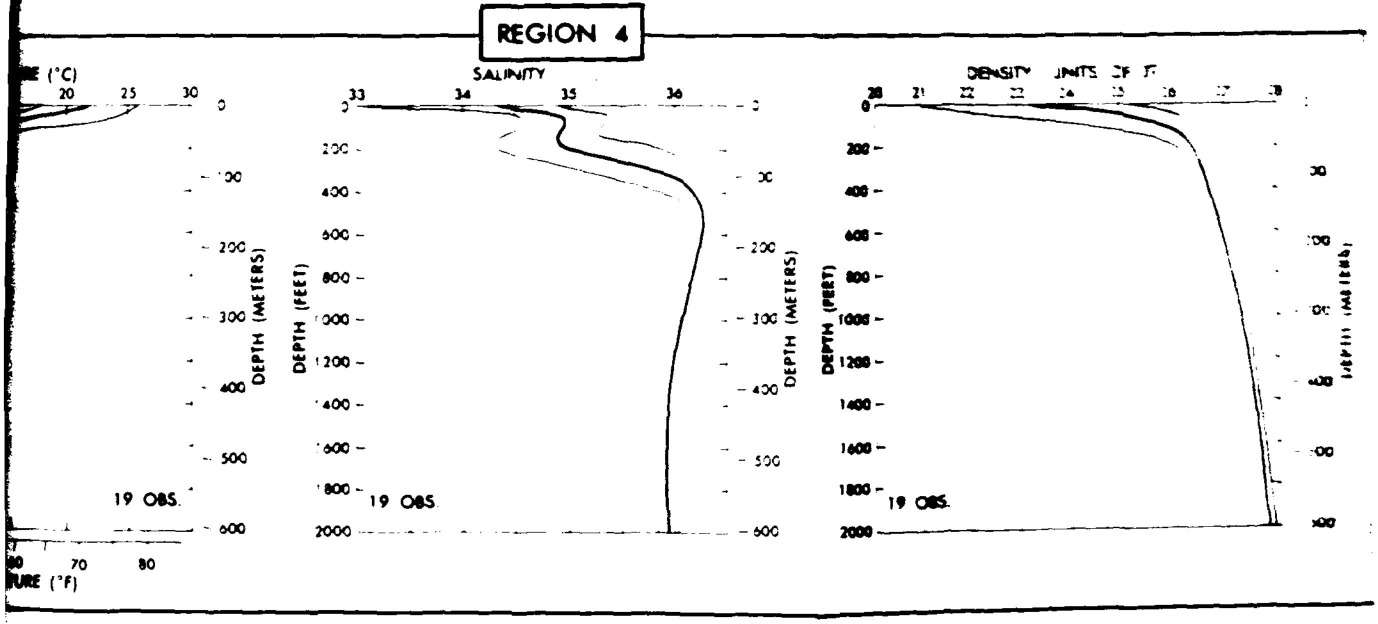
FIGURE 16. TYPICAL TRACES AND RANGES OF TEMPERATURE, SALINITY, A



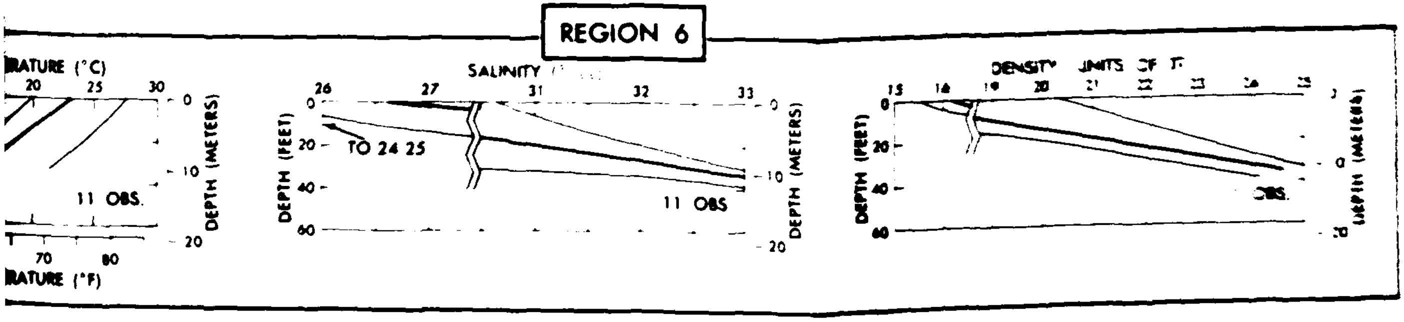
REGION 2



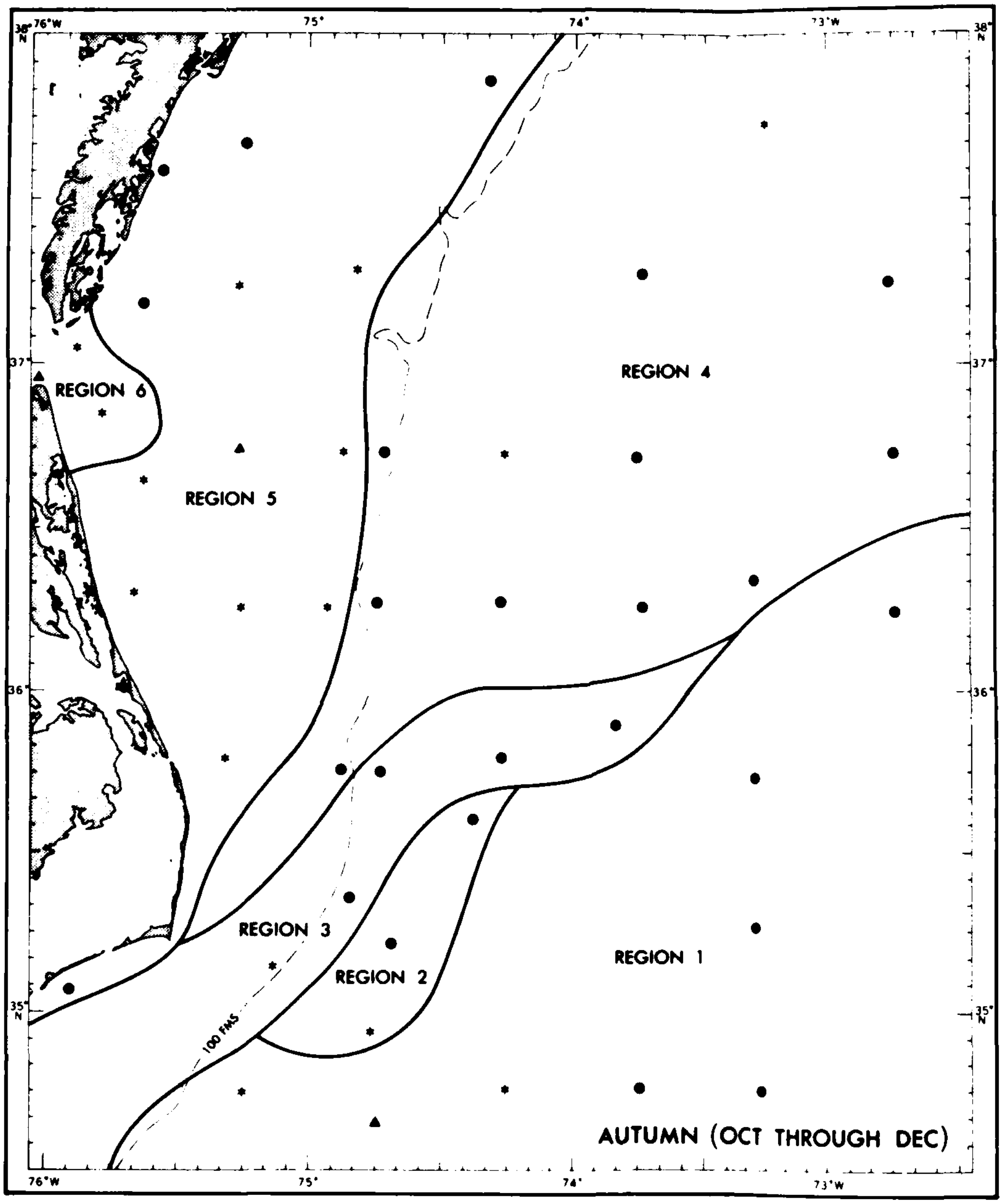
REGION 4



REGION 6



ND DENSITY, JULY THROUGH SEPTEMBER (SUMMER)



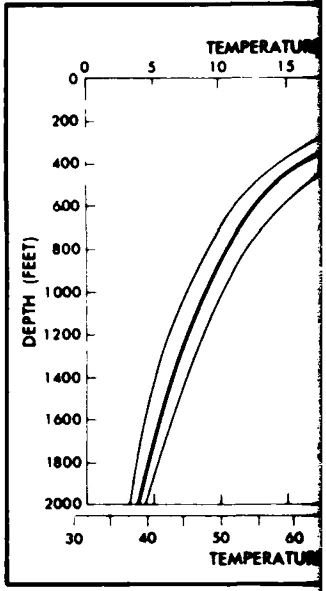
REGION LOCATOR CHART

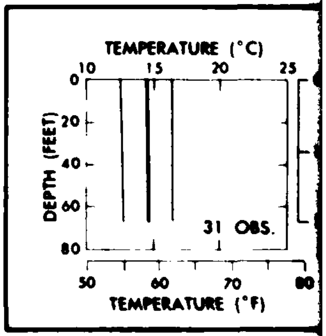
LEGEND

EACH TYPICAL TRACE REPRESENTS THE MO
VALUES OF TEMPERATURE, SALINITY, AND
METERS (2,000 FEET) OF EACH REGIO
WITHIN AN ENVELOPE ENCLOSING TH
OBSERVATIONS THE NUMBER OF OCEA
TO DERIVE EACH TRACE IS SHOWN
DISTRIBUTION OF STATIONS IS INDICAT

NUMBER OF OBSERV

● 1
✱ 2–5
▲ >5





ST COMMONLY OCCURRING
DENSITY IN THE UPPER 610
. THE MODAL TRACE LIES
RANGE OF 100% OF THE
NOGRAPHIC STATIONS USED
WITH THE TRACE, AND THE
FOR 30 QUADRANGLES.

ATIONS

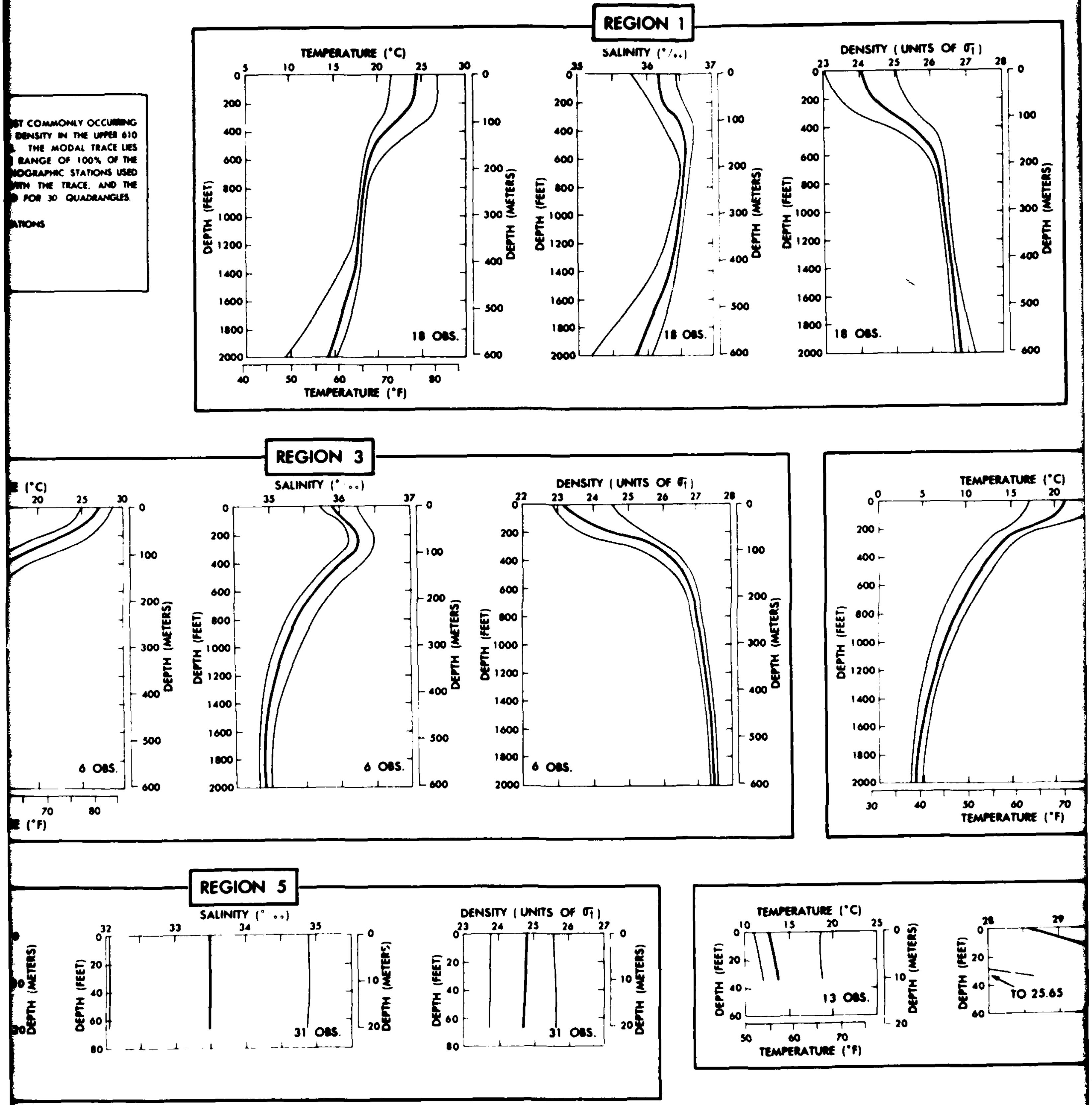
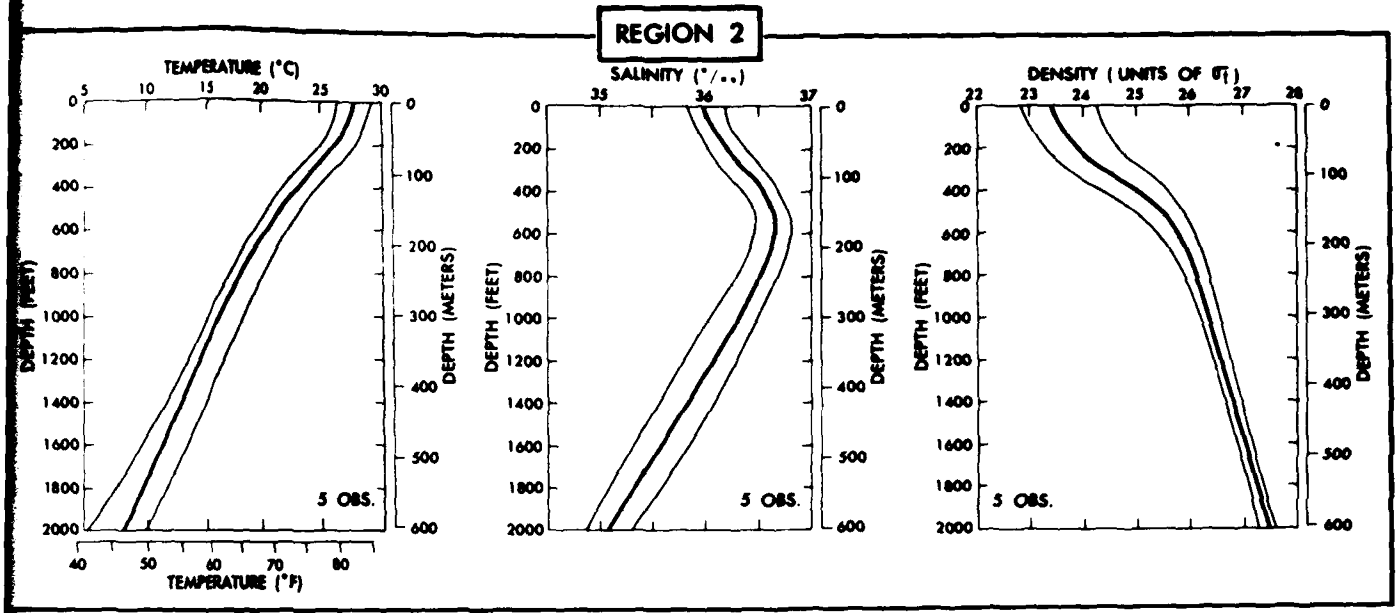
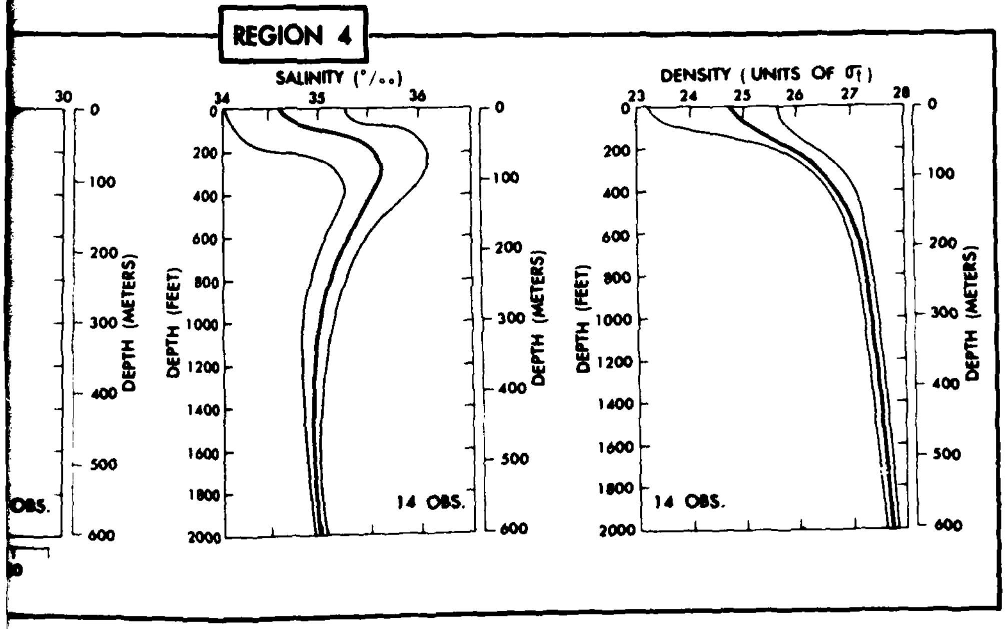
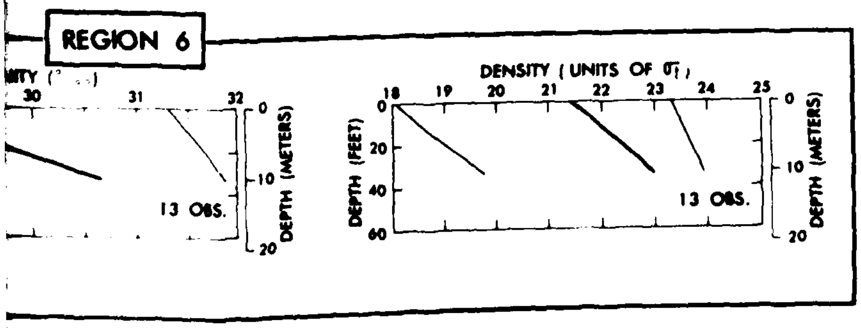


FIGURE 17. TYPICAL TRACES AND RANGES OF TEMPERATURE, SALINITY, AND DENSITY,

2

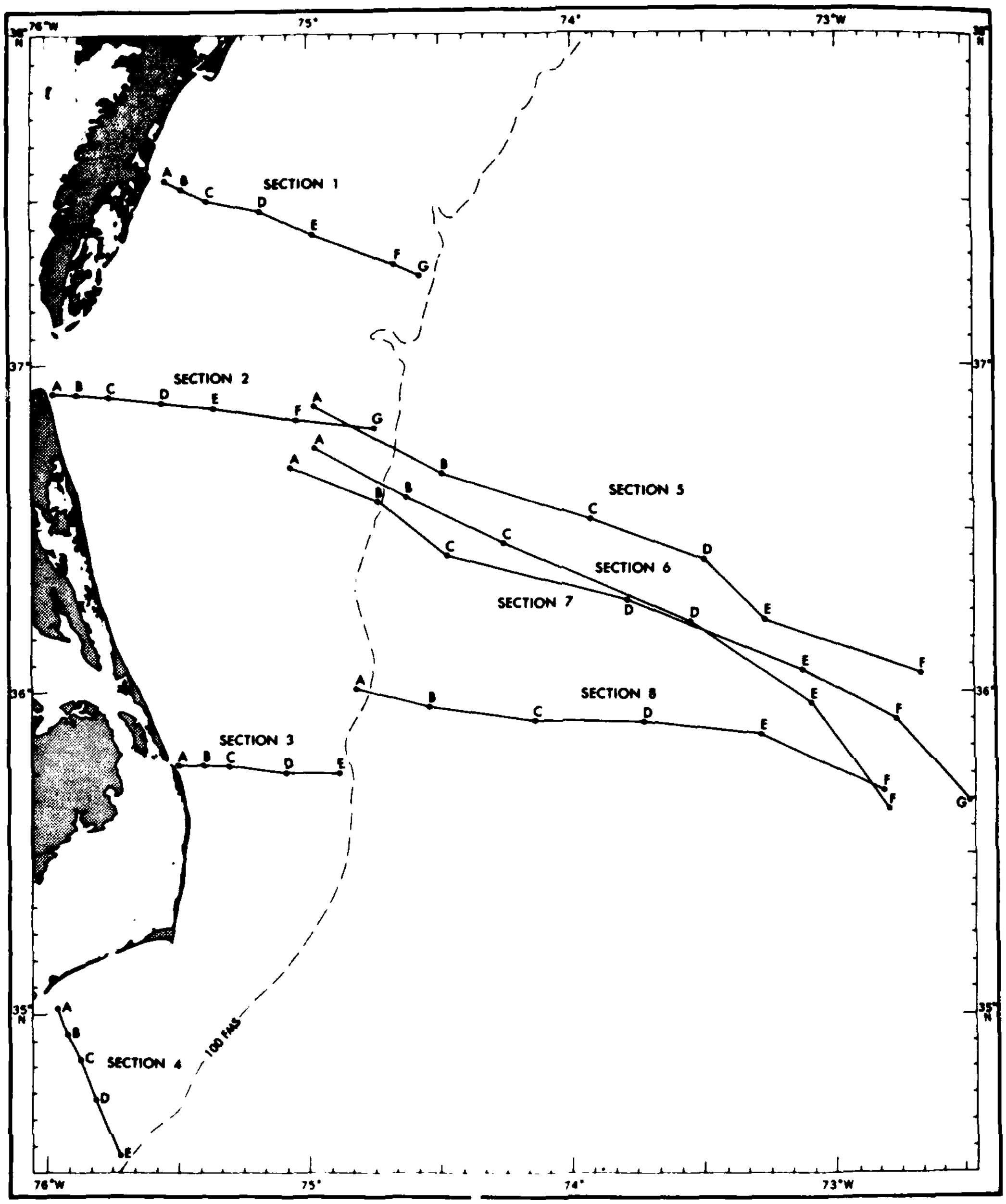




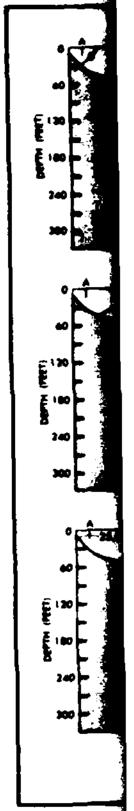


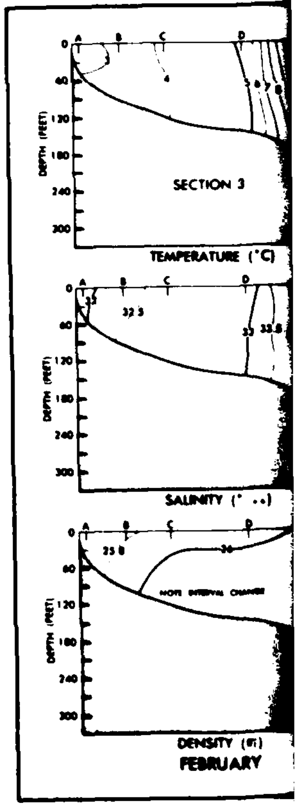
OBER THROUGH DECEMBER (AUTUMN)

3



VERTICAL SECTION LOCATOR CHART





WINTER

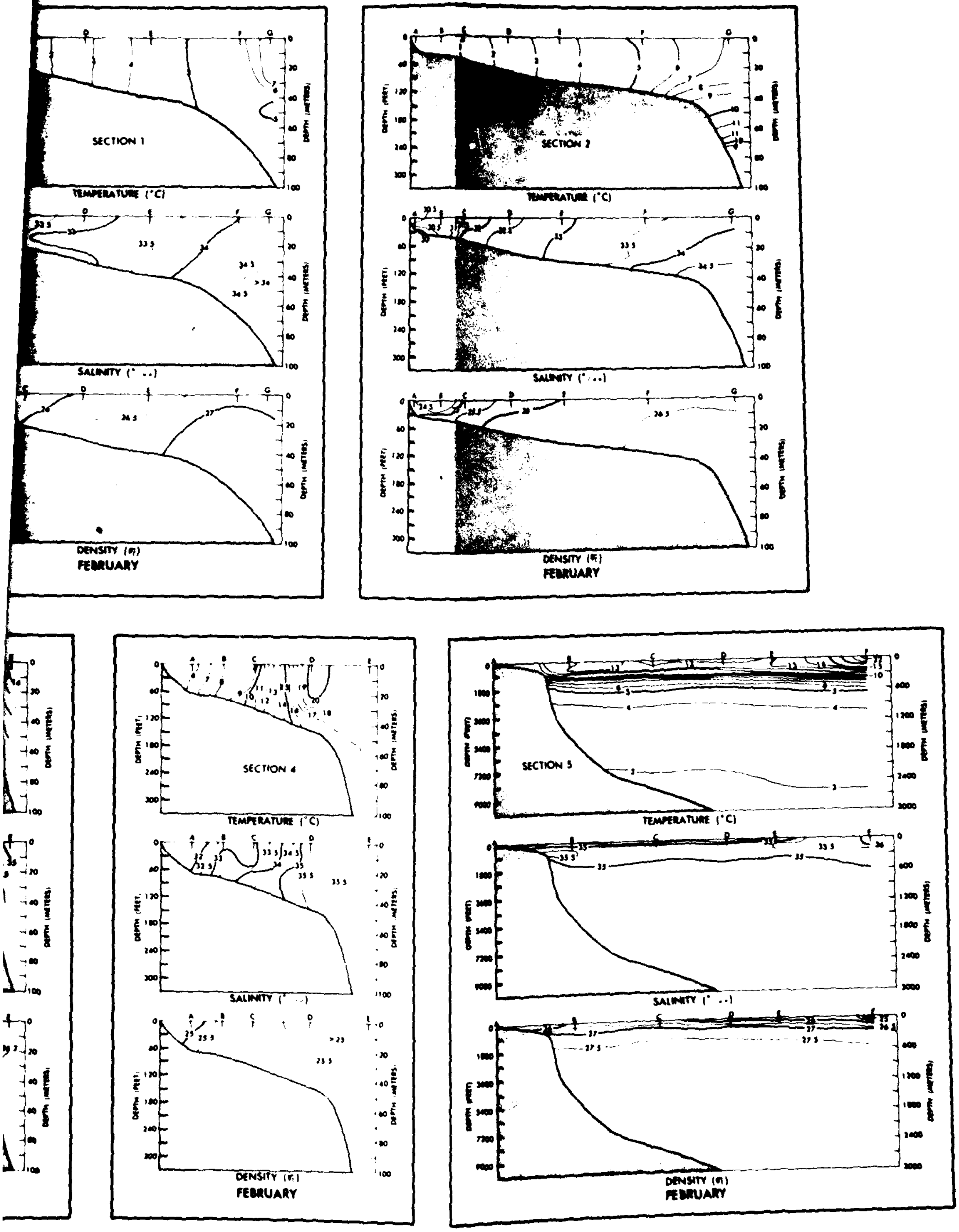
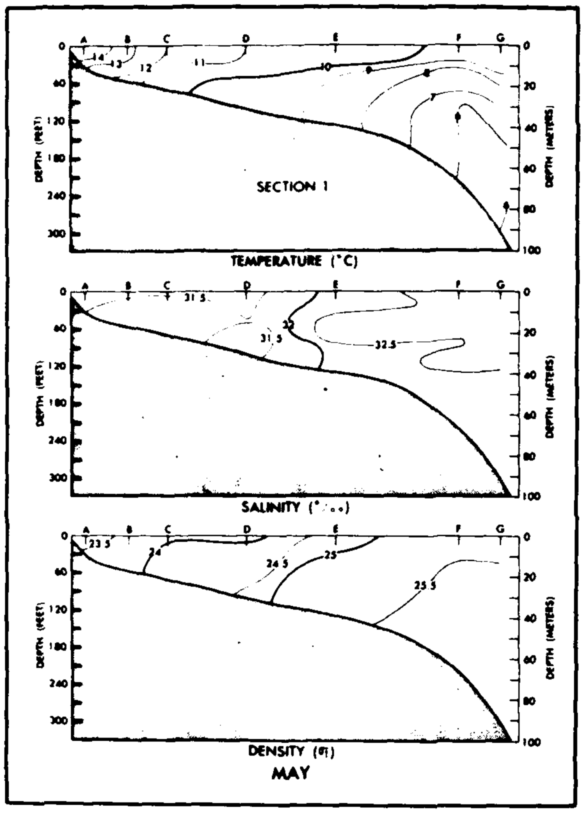
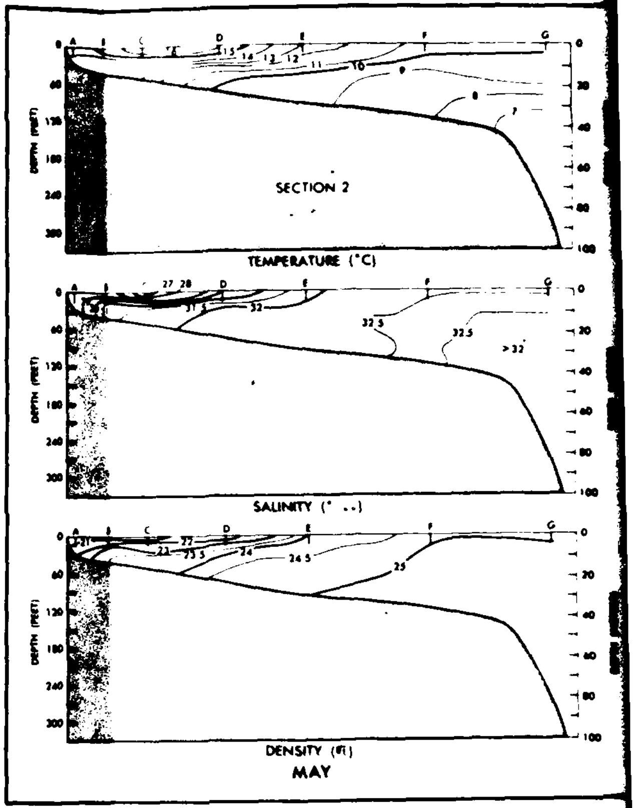


FIGURE 18. VERTICAL SECTIONS OF TEMPERATURE, SALINITY, AND DENSITY

SPRING

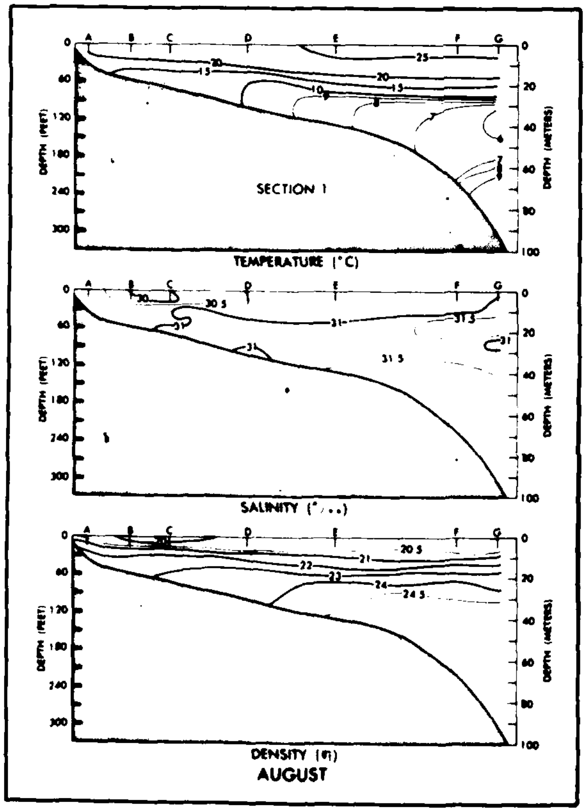


MAY

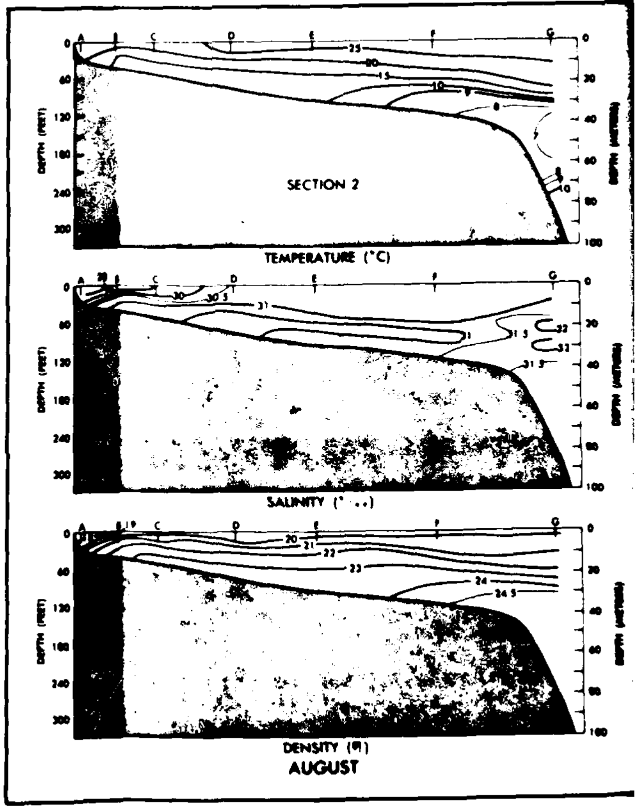


MAY

SUMMER

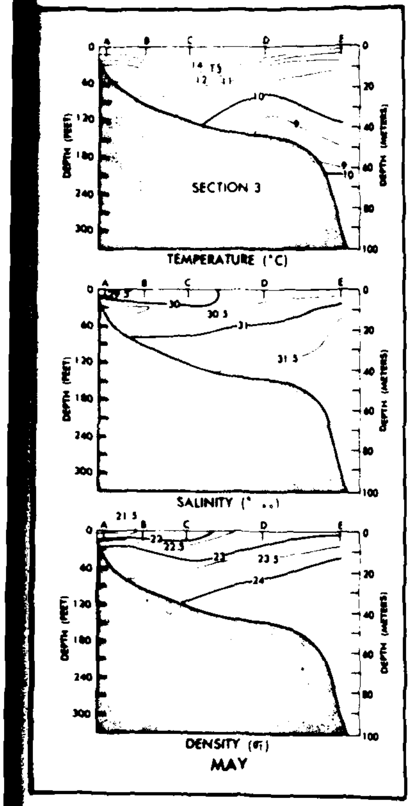


AUGUST

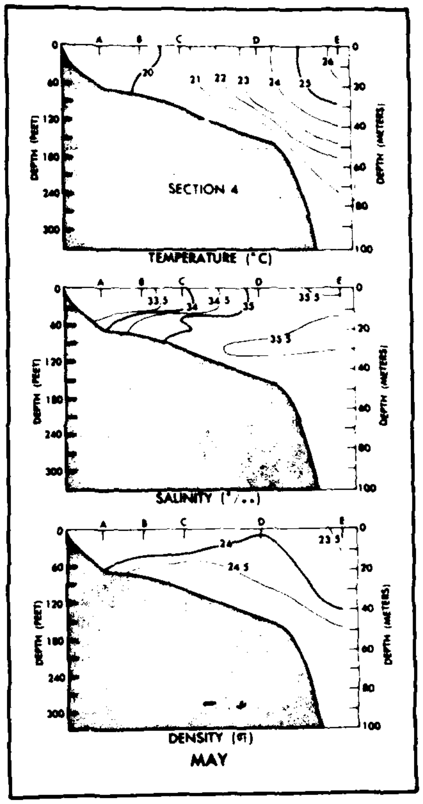


AUGUST

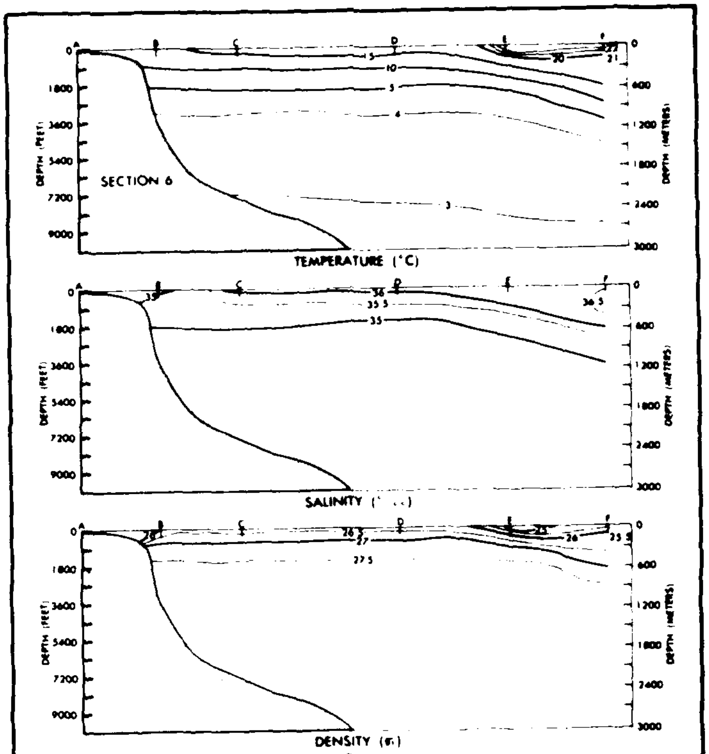
FIGURE 18. VER



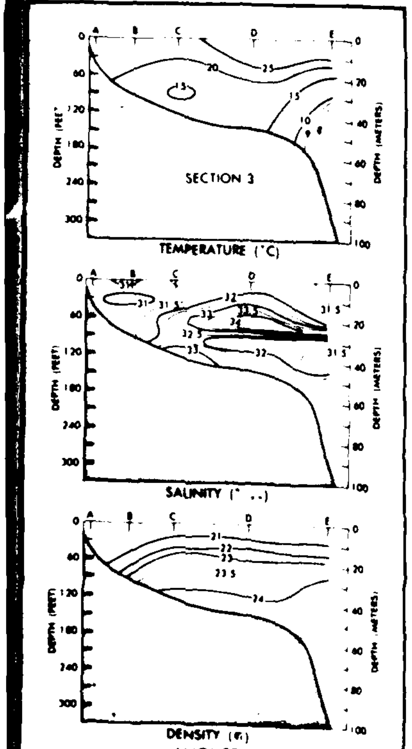
MAY



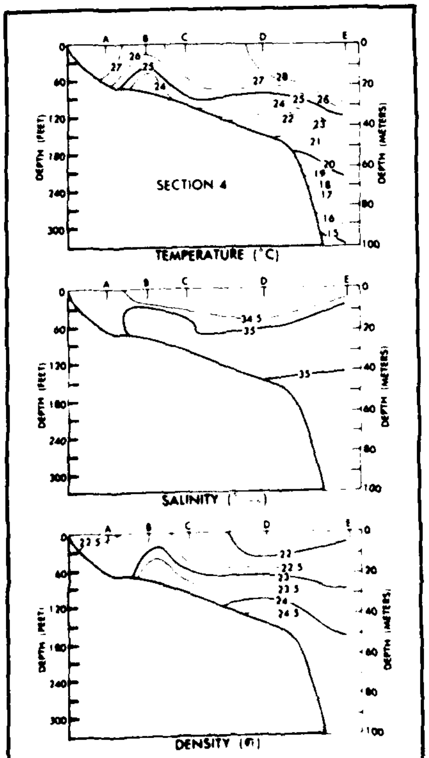
MAY



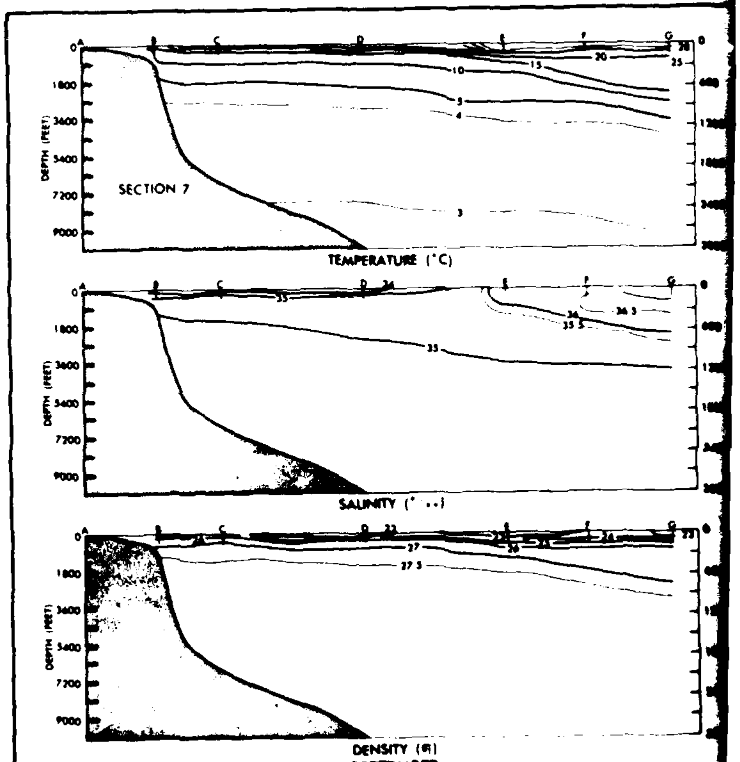
APRIL



AUGUST



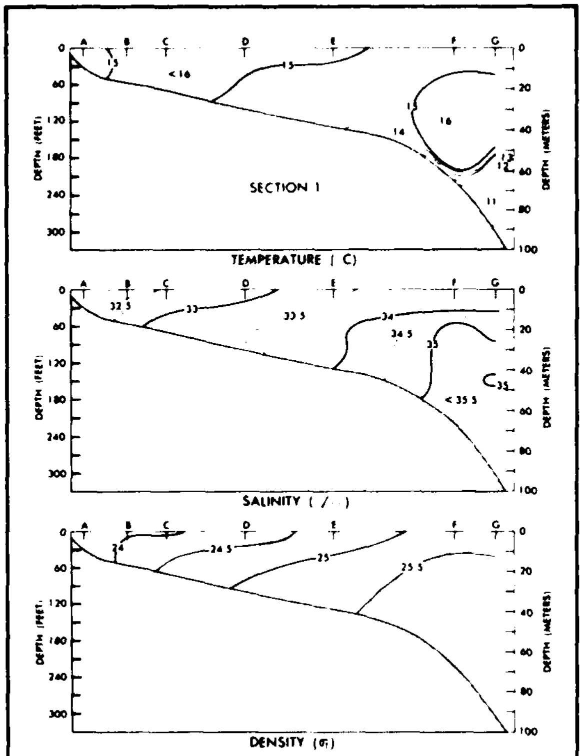
AUGUST



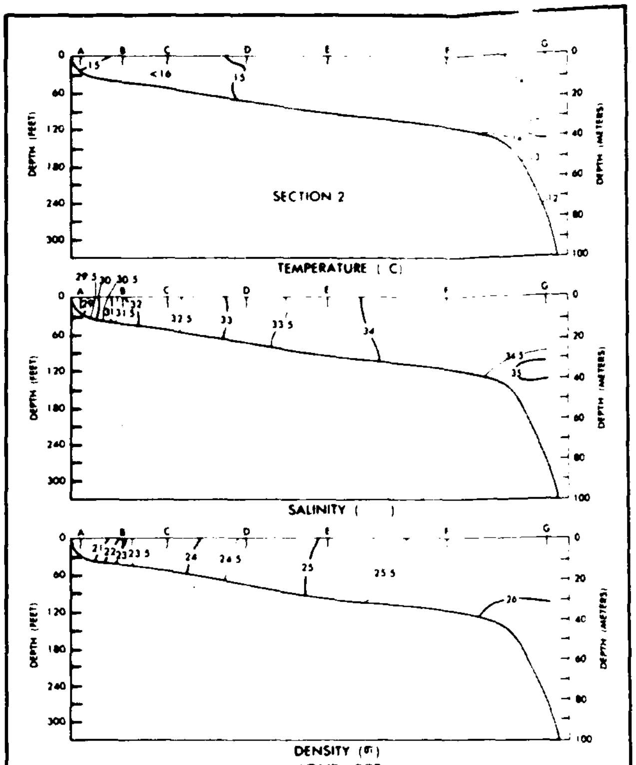
SEPTEMBER

ECTIONS OF TEMPERATURE, SALINITY, AND DENSITY (CON.)

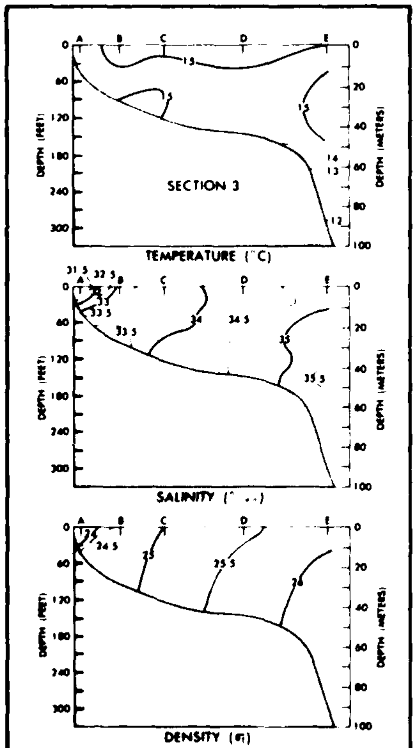
AUTUMN



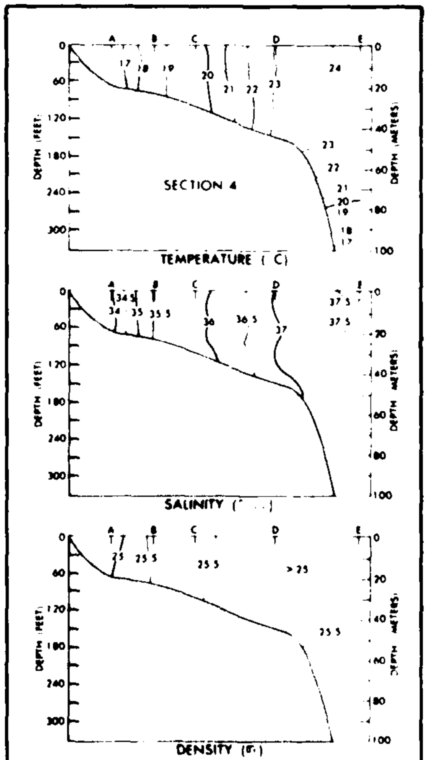
NOVEMBER



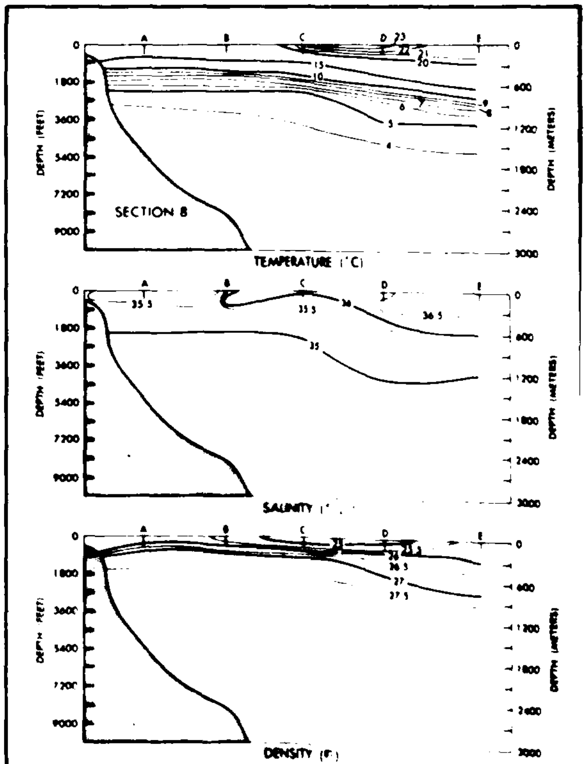
NOVEMBER



NOVEMBER



NOVEMBER



DECEMBER

FIGURE 18. VERTICAL SECTIONS OF TEMPERATURE, SALINITY, AND DENSITY (CON.)

Instability, or decrease in density with depth, may affect dispersion and distribution of contaminants. Instability is observed near the Gulf Stream during April and December, and is probably caused by temporary near-surface temperature inversions. In the coastal region, however, these instabilities are more persistent and occur throughout the water column. Where near-surface instability occurs, contaminants introduced at the surface are more likely to mix within the surface layers and sink more rapidly to the layer of equal density. Near-surface instability is most prominent near the Continental Shelf edge, especially off Cape Hatteras.

Where unstable water is present at middepth, convective mixing occurs, and a pollutant may dissipate more rapidly. Instability on the bottom in the coastal region may produce an unusual distribution of pollutants which are introduced on or reach the bottom; mixing and dispersion of the pollutants may be increased, and distinct layering of pollutants is less likely. Summer is the only season during which bottom instability does not occur in the coastal region.

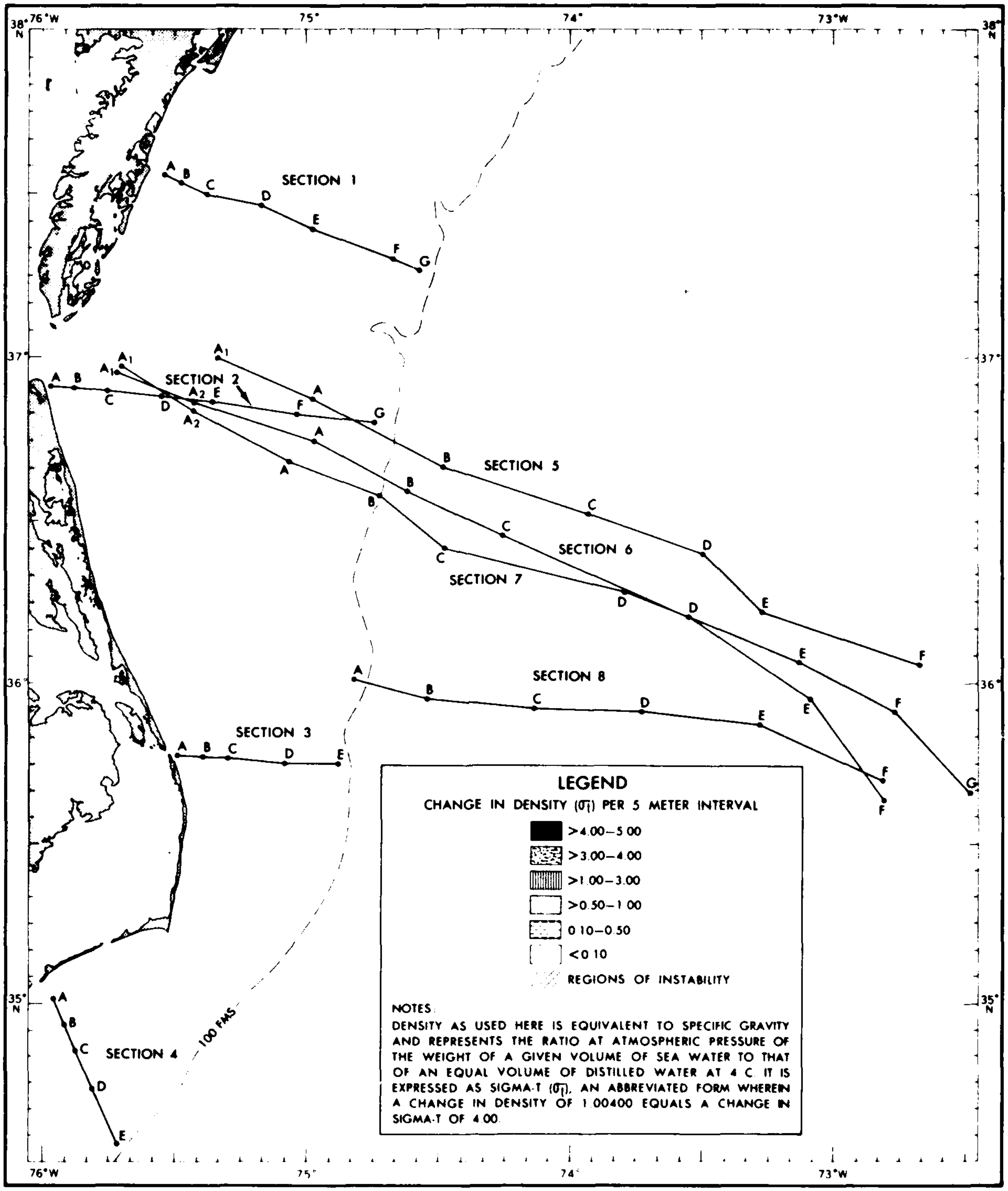
The presence of some pollutants within the water column may deplete ambient oxygen through oxidation processes. It may also cause small changes in pH, although this property is fairly conservative.

4. Data sources

Sea surface temperature presentations are based on all available merchant marine observations taken in the past 100 years as collected at the Environmental Data Service, National Climatic Center, and compiled by this Office by 6-minute quadrangles. Most of the observations tabulated are injection temperatures that may contain inaccuracies (e.g., approximation of readings, faulty thermometers, or heat contamination from ship engines and boilers). However, because the data coverage in the Area is good, these errors are minimized. Monthly variability of sea surface temperatures is based on data taken regularly and recorded in U.S. Coast and Geodetic Survey Publication 31-1 (1968).

Vertical traces of temperature, salinity, density, and oxygen are based on oceanographic station data provided by the National Oceanographic Data Center (NODC) and stations cited in Pollak, 1952. These regional presentations are determined by combining all available data for 30-minute quadrangles by trimonthly periods according to similarity of structure. Data distribution is indicated for each region. Other values (oxygen and pH) presented in the text also are derived from oceanographic stations, although data on these parameters are generally sparse.

Vertical sections 1 through 4 of temperature, salinity, density, and gradients are derived from data taken by the R. V. Dolphin during 1965-66 (Clark, et al. 1969). Vertical sections 5 through 8 are derived from stations taken by R. V. Atlantis during 1932 and retained at NODC.



NOTES:

DENSITY AS USED HERE IS EQUIVALENT TO SPECIFIC GRAVITY AND REPRESENTS THE RATIO AT ATMOSPHERIC PRESSURE OF THE WEIGHT OF A GIVEN VOLUME OF SEA WATER TO THAT OF AN EQUAL VOLUME OF DISTILLED WATER AT 4 C. IT IS EXPRESSED AS SIGMA-T (σ_T), AN ABBREVIATED FORM WHEREIN A CHANGE IN DENSITY OF 1.00400 EQUALS A CHANGE IN SIGMA-T OF 4.00.

FIGURE 19. LOCATOR CHART AND LEGEND FOR VERTICAL SECTIONS OF DENSITY GRADIENTS

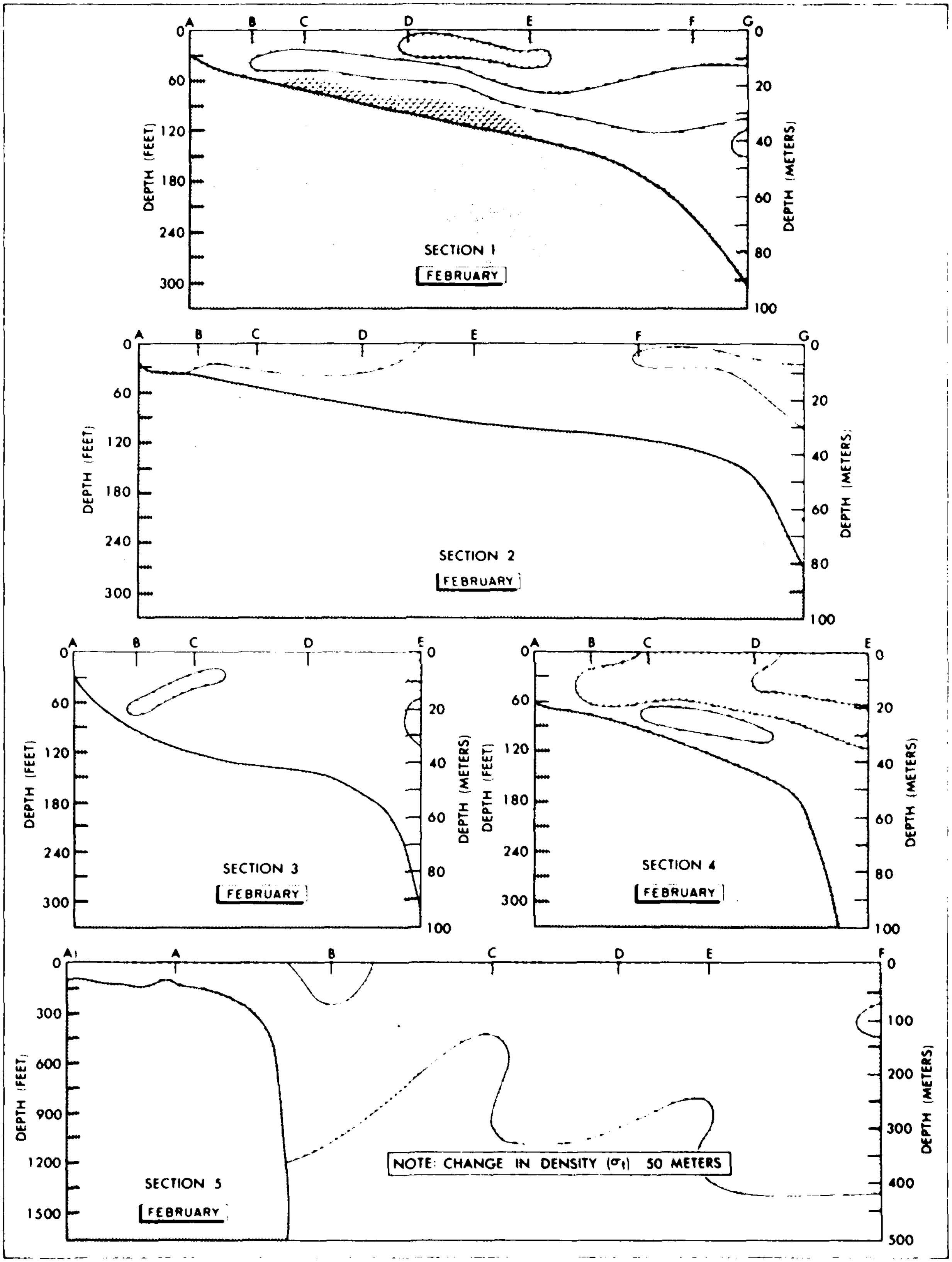


FIGURE 19. VERTICAL SECTION OF DENSITY GRADIENTS (CON.)

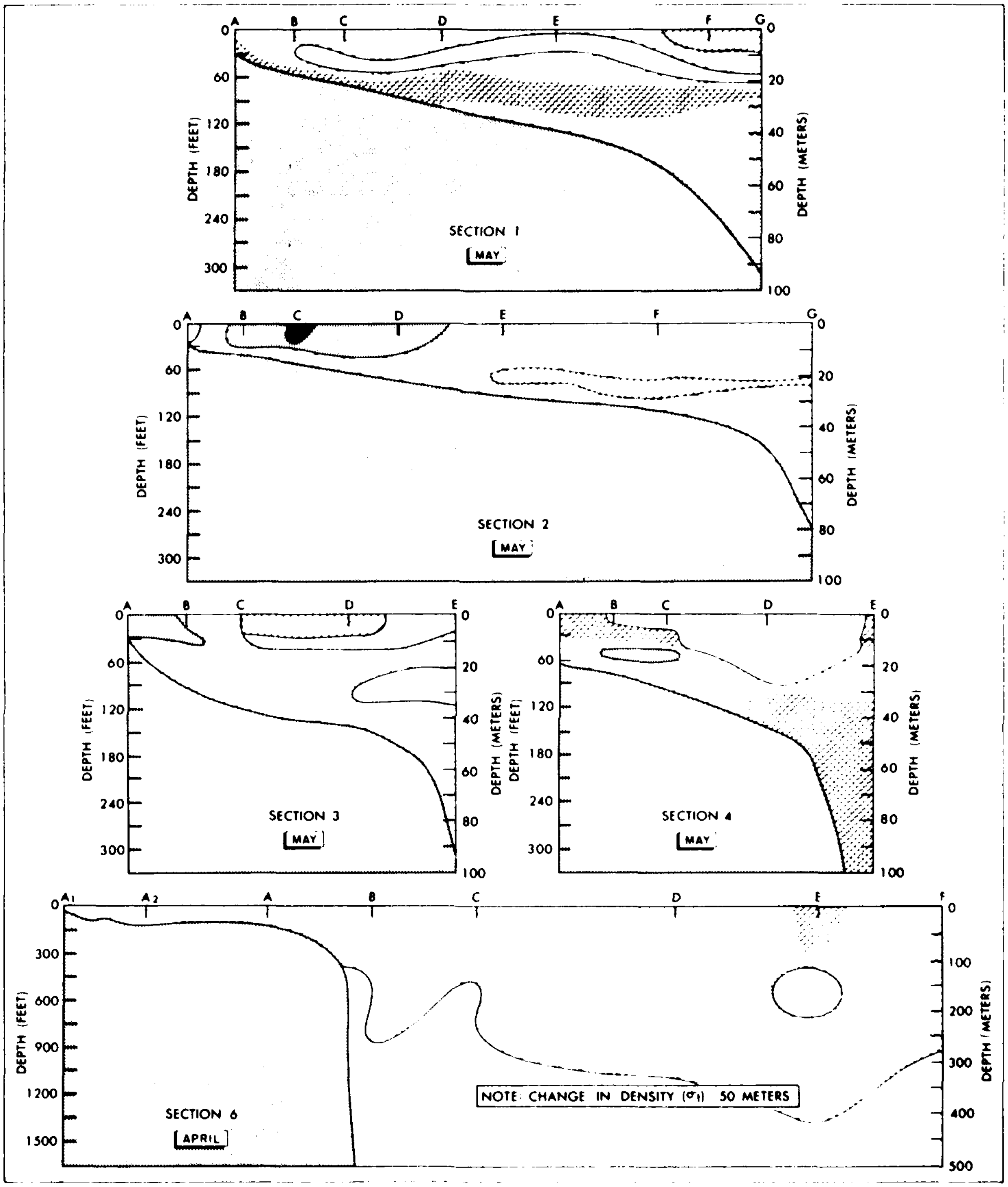


FIGURE 19. VERTICAL SECTION OF DENSITY GRADIENTS (CON.)

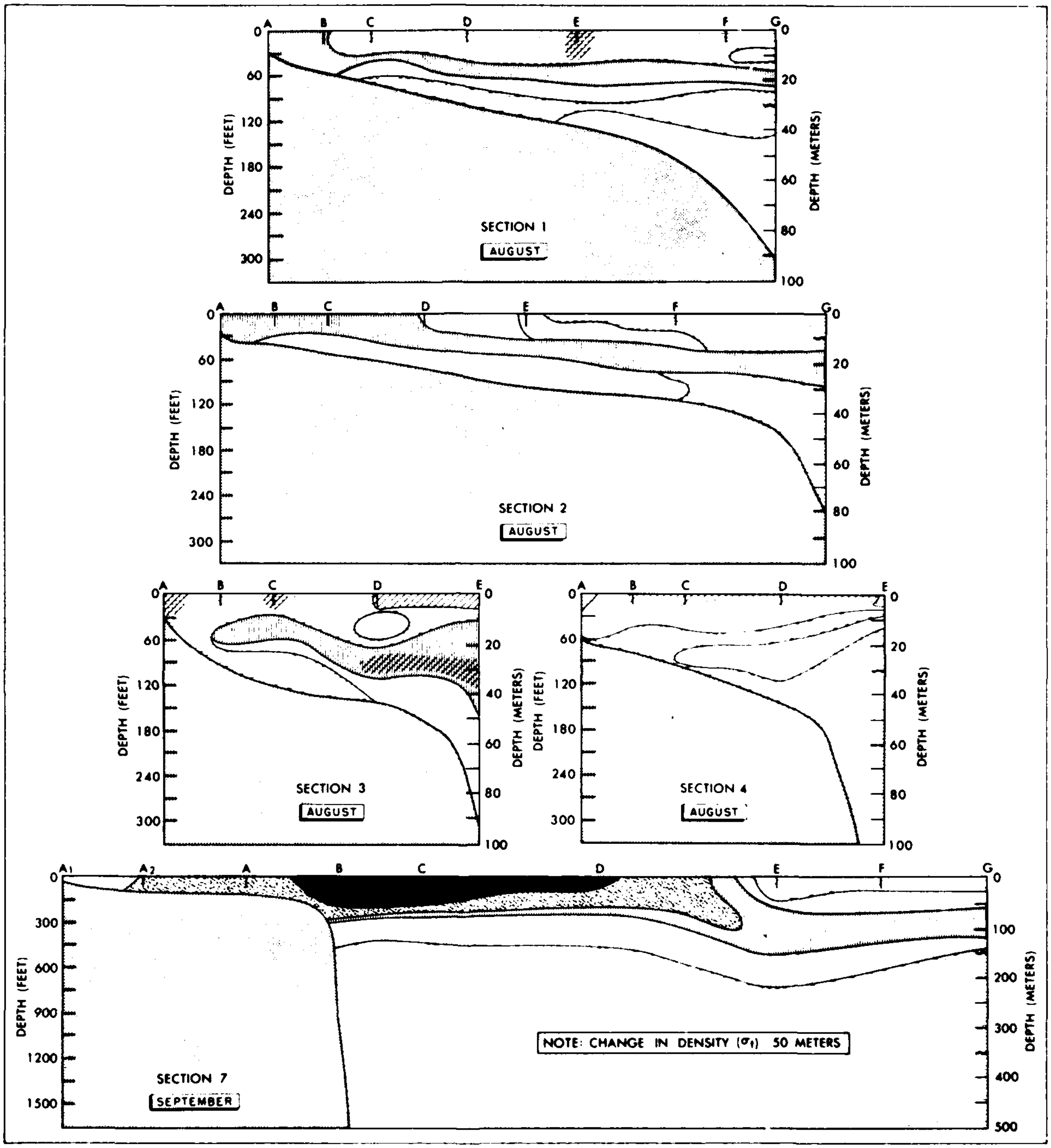


FIGURE 19. VERTICAL SECTION OF DENSITY GRADIENTS (CON.)

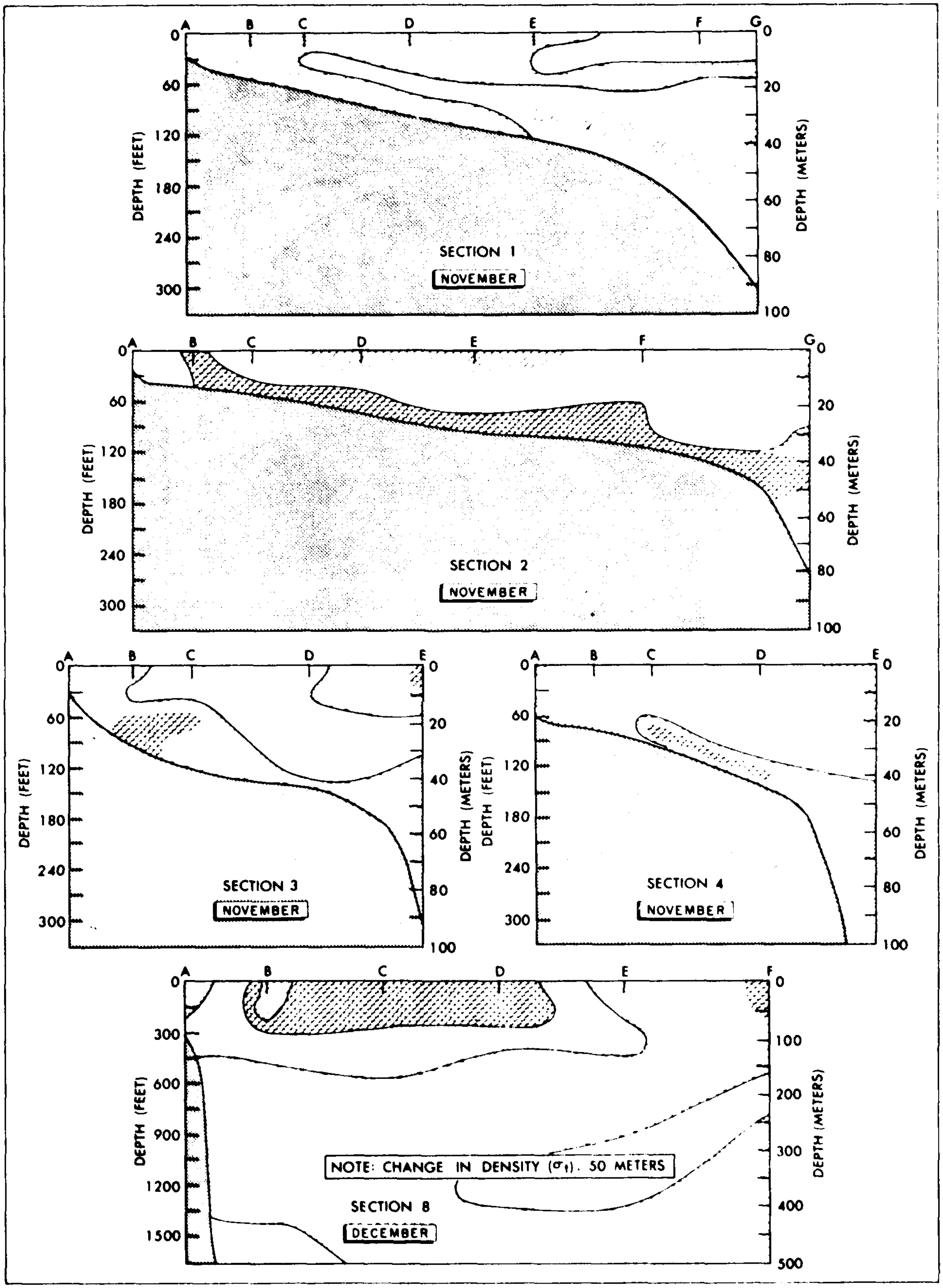


FIGURE 19. VERTICAL SECTION OF DENSITY GRADIENTS (CON.)

D. Marine Geology

1. Introduction

The Continental Shelf is 20 to 65 nautical miles wide in this Area, the 100-fathom isobath closely approximating the shelf break. Sand is the predominant surficial sediment on the shelf and is often found mixed with mud or gravel in localized zones. The grain-size distribution of most shelf and slope sediments is skewed toward fine-grained material. Coarse material is concentrated in nearshore areas and scattered on the shelf. During the autumn, winter, and spring, sediments on the entire shelf are subject to wave erosion and transportation, whereas in summer these processes are less extensive.

North of the Chesapeake Bay entrance, most of the coast is privately owned and commercially undeveloped. To the south, the beaches are owned by federal and nonfederal public agencies and are used for recreational and nonrecreational purposes.

2. Bathymetry

The Continental Shelf is 20 nautical miles wide off the coast of North Carolina, increasing in width to 65 nautical miles off the entrance to Chesapeake Bay (fig. 20). A bathymetric profile A to A' is shown on figure 21. The 100-fathom isobath approximates the shelf break. Seaward of the shelf, the continental slope varies in width from 5 nautical miles in the south to 25 nautical miles in the north. The shelf edge is incised by the Norfolk and Washington Canyons between 37°00' and 37°30'N. Each canyon averages 2 nautical miles in width and 12 nautical miles in length with about 700 fathoms of relief. The 1,100-fathom isobath approximates the base of the continental slope. The continental rise lies seaward of the slope.

3. Bottom materials

The distribution of surficial bottom sediments (fig. 22) is based on approximately 1,800 bottom samples as shown in figure 23 (U.S. Naval Oceanographic Office, unpublished). Five bottom material types, based on the average diameter of the particles, are distinguished:

TYPE	GRAIN SIZE RANGE
Mud	80% of the grains less than 0.062 mm.
Mud-sand	More than 20% of the grains between 0.062 and 2.000 mm, and more than 20% of grains less than 0.062 mm.
Sand	80% of the grains between 0.062 and 2.000 mm.
Gravel	80% of the grains between 2 and 256 mm.
Rock	Boulders larger than 256 mm.

Sediments on the Continental Shelf consist of predominantly arkosic* to subarkosic** fluvial sand. Mud or gravel is often found in combination with sand in localized zones. The shelf sediments were deposited in shallow water

---

* > 25% feldspar

** 5- 25% feldspar

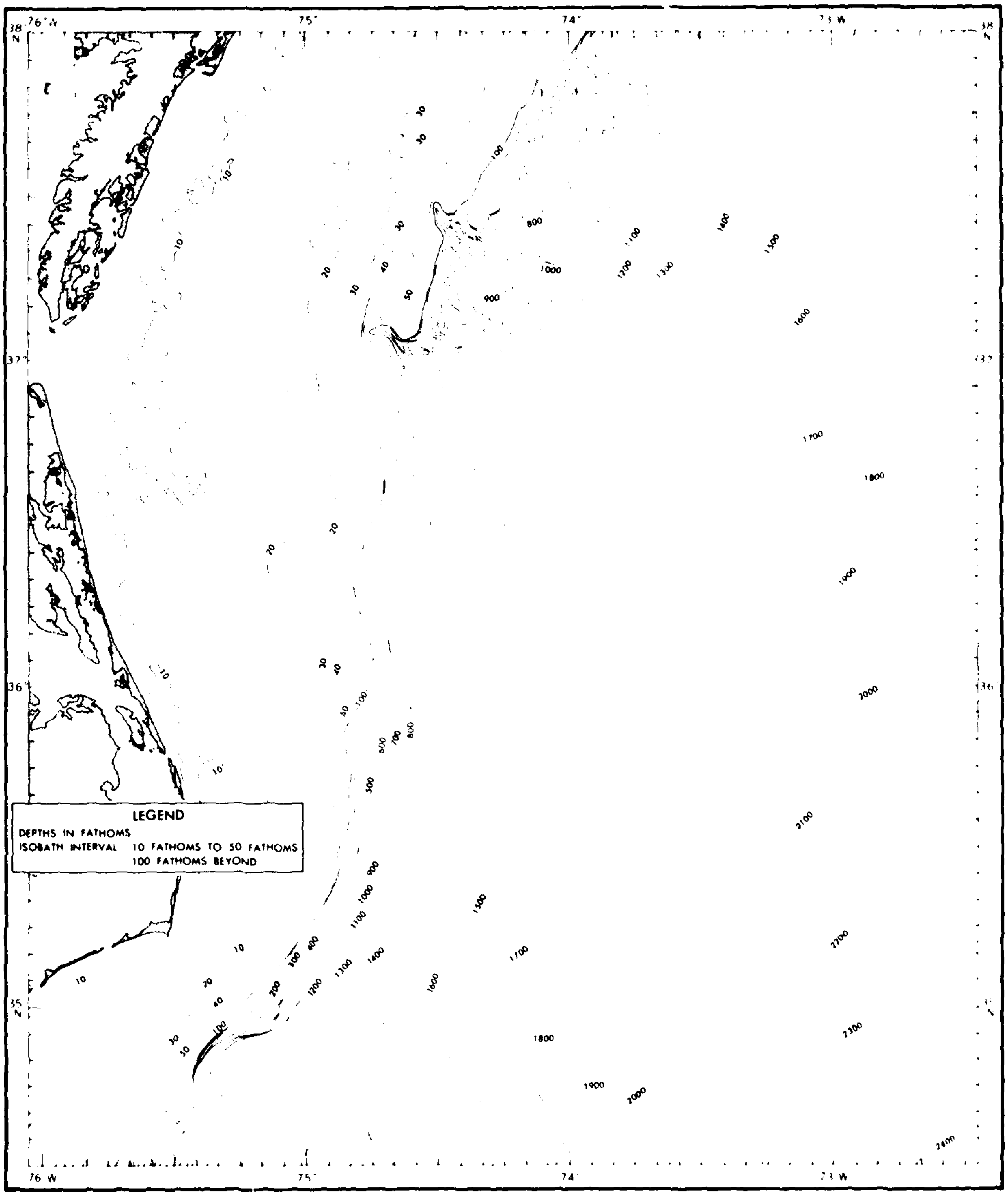


FIGURE 20. BATHYMETRY

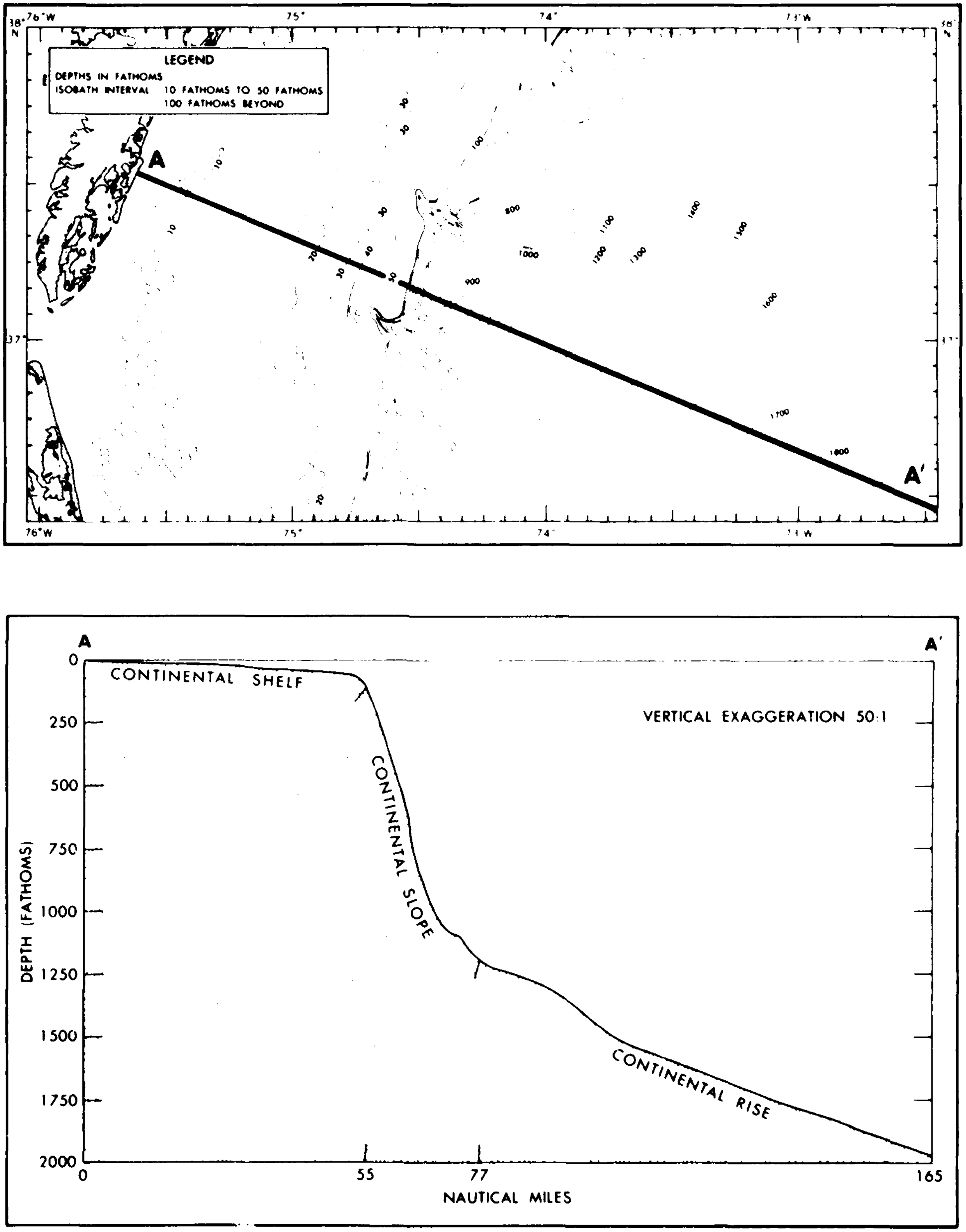


FIGURE 21. BATHYMETRIC PROFILE ALONG A-A'

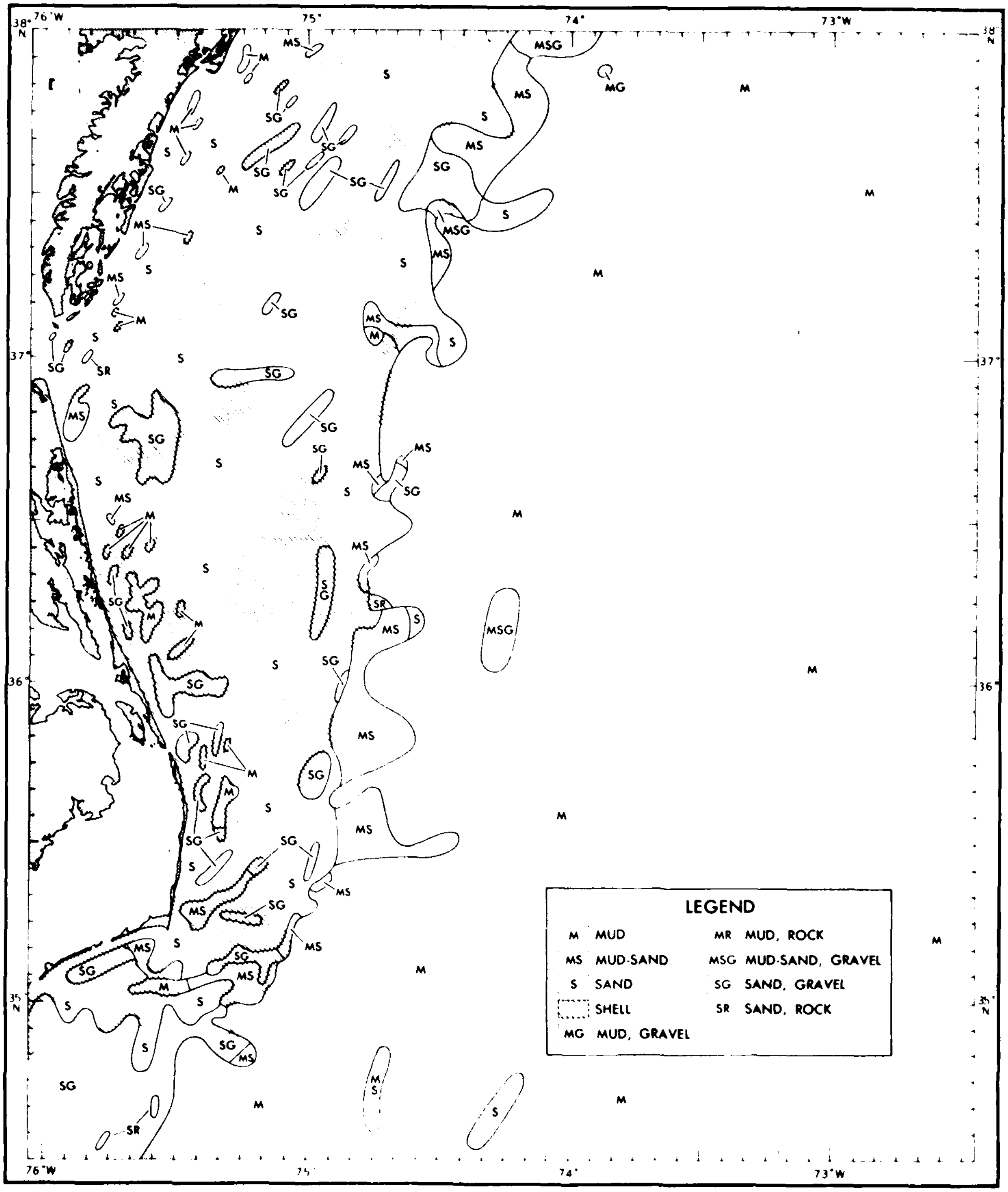


FIGURE 22. BOTTOM SEDIMENTS

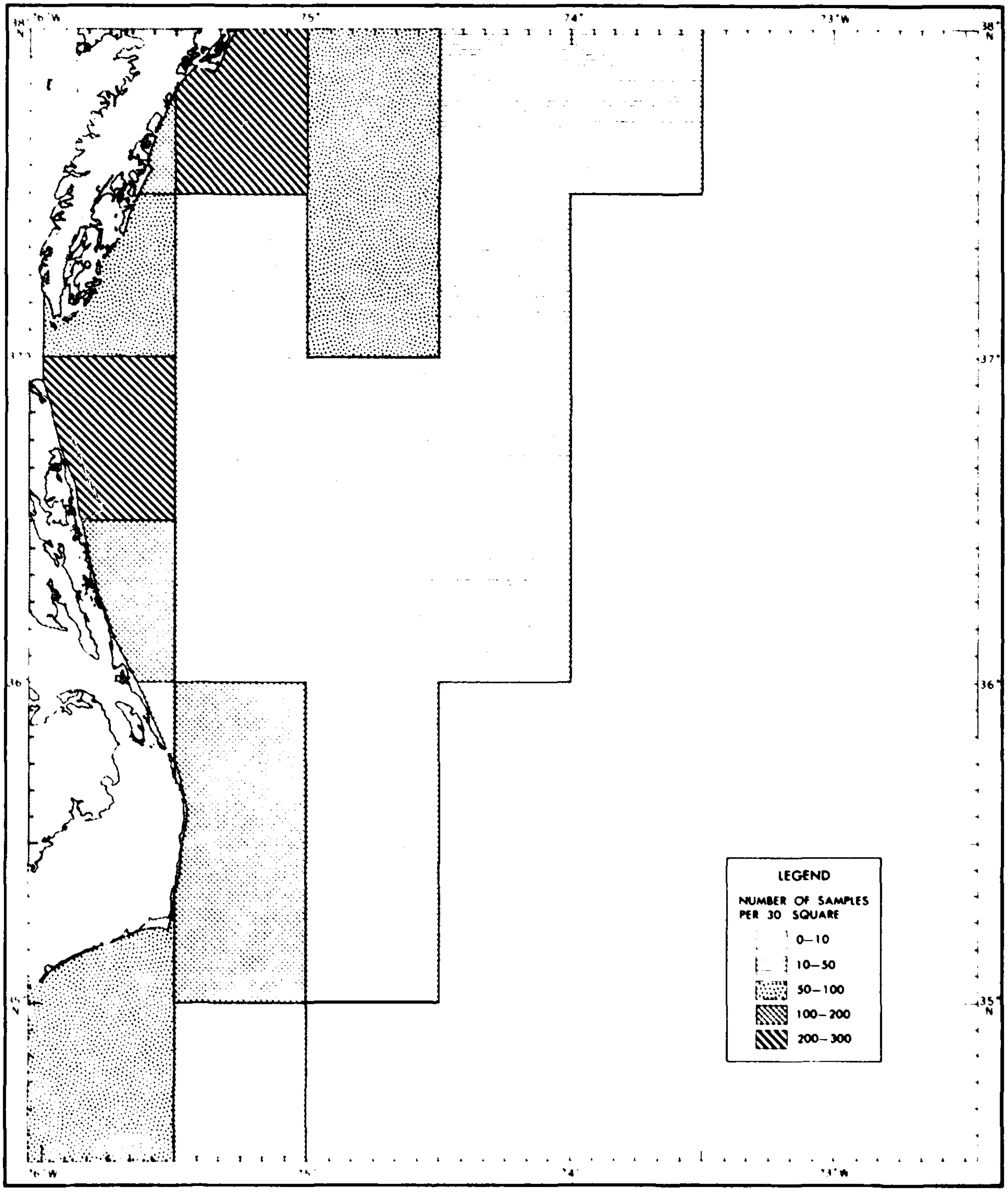


FIGURE 23. BOTTOM SAMPLE DISTRIBUTION

during the last lower stands of Pleistocene (continental glacial epoch) sea level and post-Pleistocene reworking has removed most fine-grained sediment (silt and clay) leaving only fine to coarse sand (fig. 24). The surficial sediments of most of the Continental Shelf and slope have frequency-distribution curves skewed toward finer material (positive) with the exception of the sediments in three extensive nearshore zones which have frequency-distribution curves skewed toward coarser material (negative) (fig. 25).

Modern sediments which consist of mud-size grains are accumulating only in estuaries and on the continental slope. These fine-grained fluvial sediments escape from the estuaries during floods and storms. The fact that most shelf sediments are relict sands indicates that most modern river-derived sediment does not remain on the shelf. It is either recycled back into the estuaries, or it crosses the shelf and is deposited on the continental slope or rise (Milliman, Pilkey and Ross, 1972). Mud is the dominant sediment type on the continental slope and rise.

4. Transport of materials

Sediment transport as a result of forward drift ($\bar{\mu}$) (Appendix B) is generated by wave action and presented in figure 26. Waves act on sediment distribution both by resuspending (reintroducing into water column) and by transporting sediments.

Resuspension of bottom material can occur whenever there is sufficient orbital wave motion (μ_o) (Appendix C) close to the seabed. Once the bottom material is in susupension it can be transported by the forward drift. On the basis of a modification of Sundborg's competency curves (Allen, 1965) (fig. 27), orbital velocities close to the bed must exceed 37 cm/sec, 54 cm/sec, and 60 cm/sec to resuspend medium sand (0.24 mm), fine sand (0.062 mm), and silt (0.052 mm), respectively. In order to transport the material after it is suspended, the forward drift velocity must exceed 37 cm/sec, 2.4 cm/sec, and 1.0 cm/sec, respectively.

These principles are applicable to the construction of a model for predicting the dispersal of dredge spoil deposits over the seabed. For example, during autumn, winter, and spring, the above orbital and forward velocities are frequently equaled or exceeded, and dredge spoil deposited on the shelf would be subject to erosion and transportation. As shown by bottom drifters (Harrison et al., 1967) transportation is predominantly toward the coast. Silt and fine sand can theoretically be resuspended and transported within 10 nautical miles of the shelf break over much of the above period (fig. 26). In summer, wave action on silt and fine sand is confined to within 20 nautical miles of the coast in the southern half of the Area and to within 30 nautical miles of the shelf break in the northern half.

5. Shoreline ownership and usage

Shoreline ownership and usage are shown in figure 28 (U.S. Army Corps of Engineers, vol. 1 & 2, 1971). On the Delmarva Peninsula, most of the coast is privately owned and commercially undeveloped except for that portion of federally owned shoreline used as a wildlife refuge and NASA facility. South of the Chesapeake Bay entrance, along the Virginia coast, shoreline ownership is both federal and nonfederal public, and is used for recreational and nonrecreational purposes. Along the coast of North Carolina the land is for public recreation.

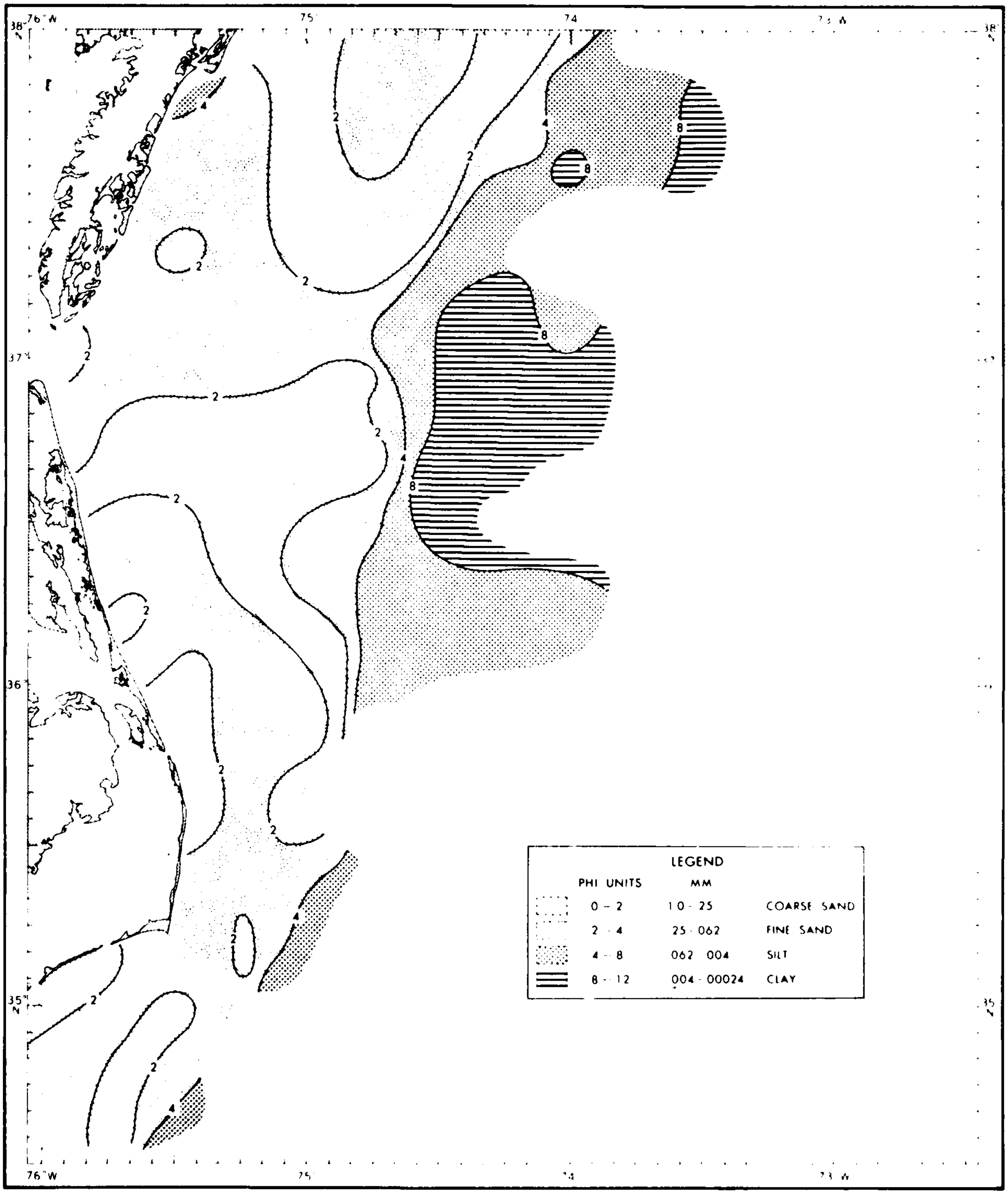


FIGURE 24 SEDIMENT SIZE DISTRIBUTION

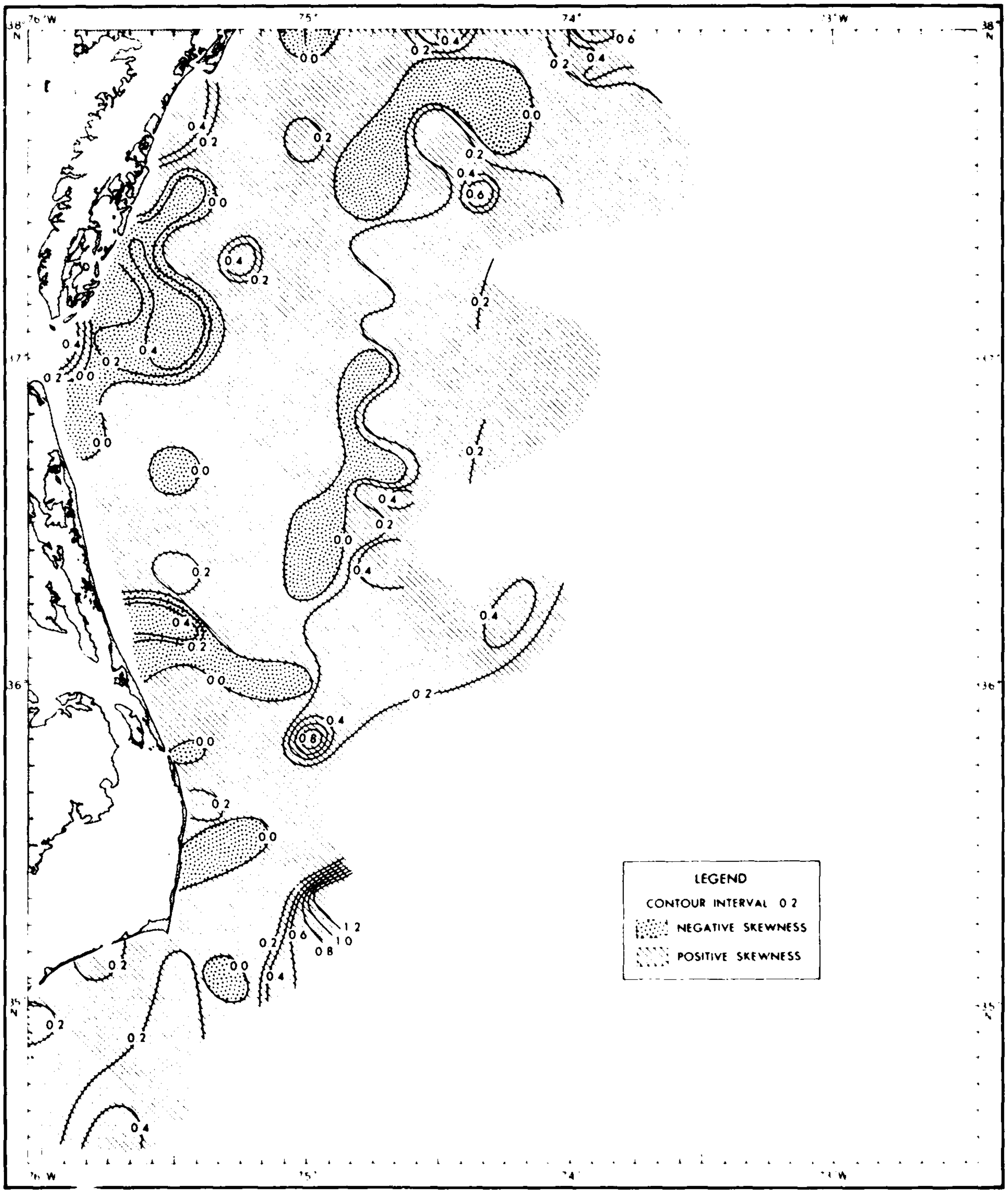
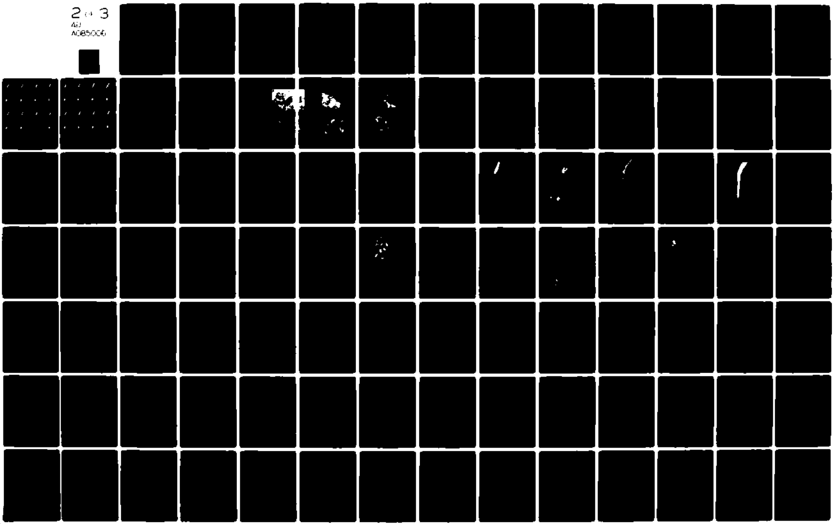
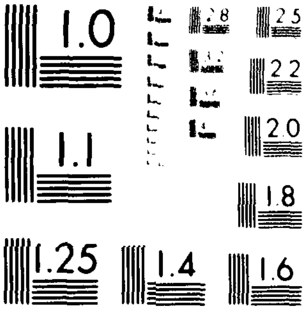


FIGURE 25 SKEWNESS

AD-A085 006 NAVAL OCEANOGRAPHIC OFFICE NSTL STATION MS F/G 8/1
MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFO--ETC(U)
MAY 74 R G BEAUCHAMP
UNCLASSIFIED N00-SP-250 NL

2 of 3
AD
A085006





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

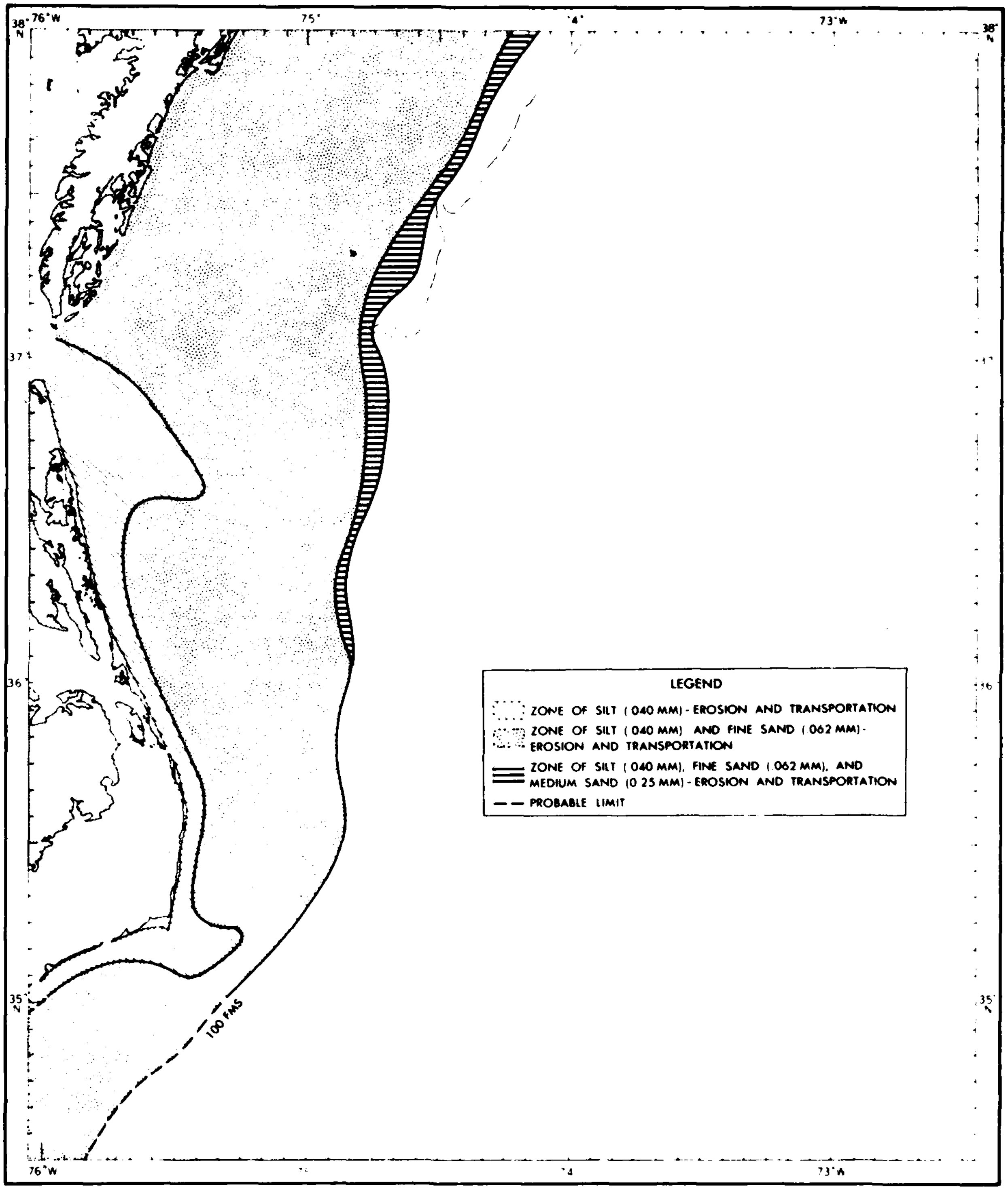
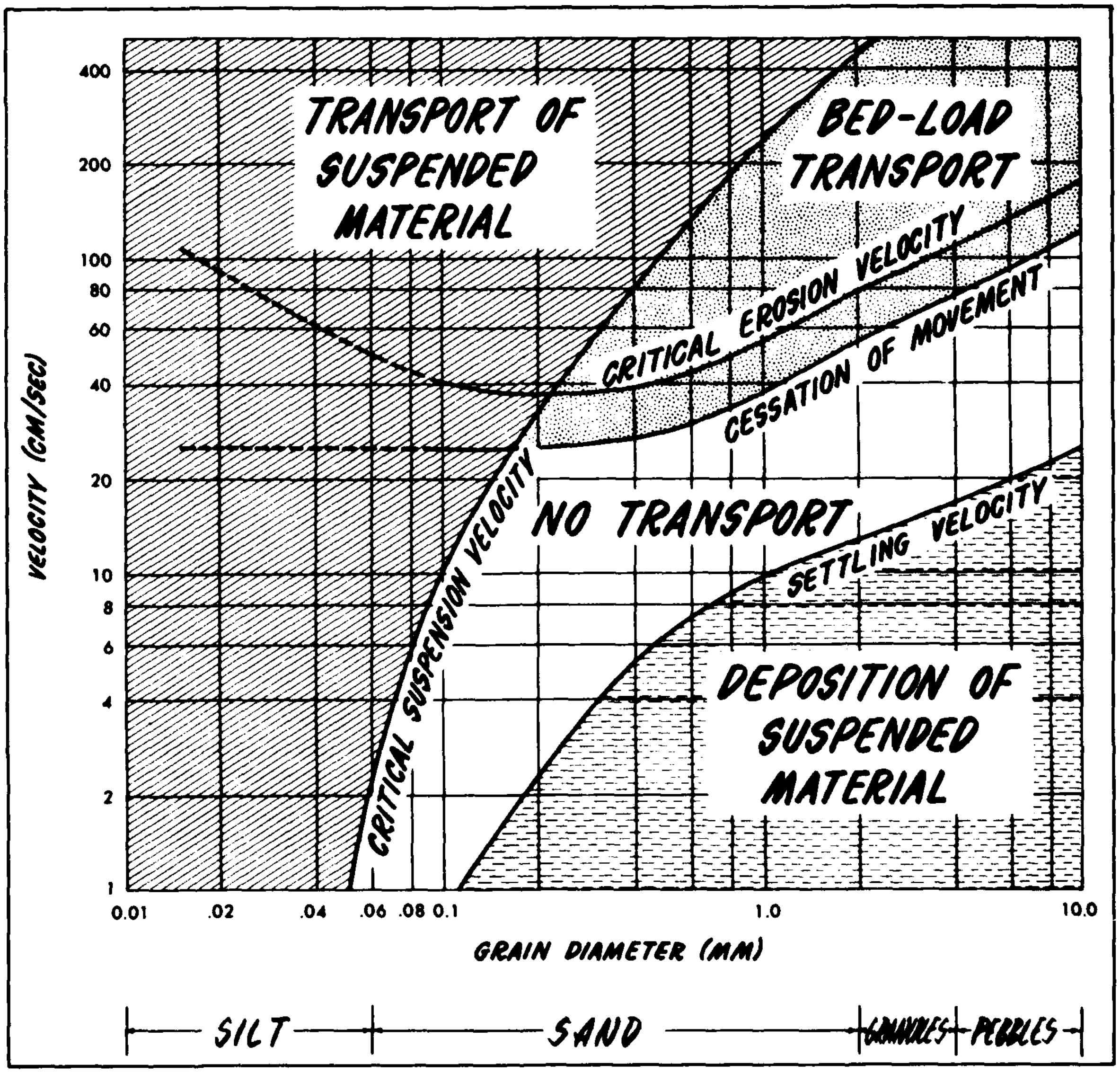


FIGURE 26. ZONES OF SUSPENSION AND TRANSPORT RELATED TO GRAIN SIZE



(AFTER ALLEN, J., 1965)

FIGURE 27. COMPETENCY CURVE

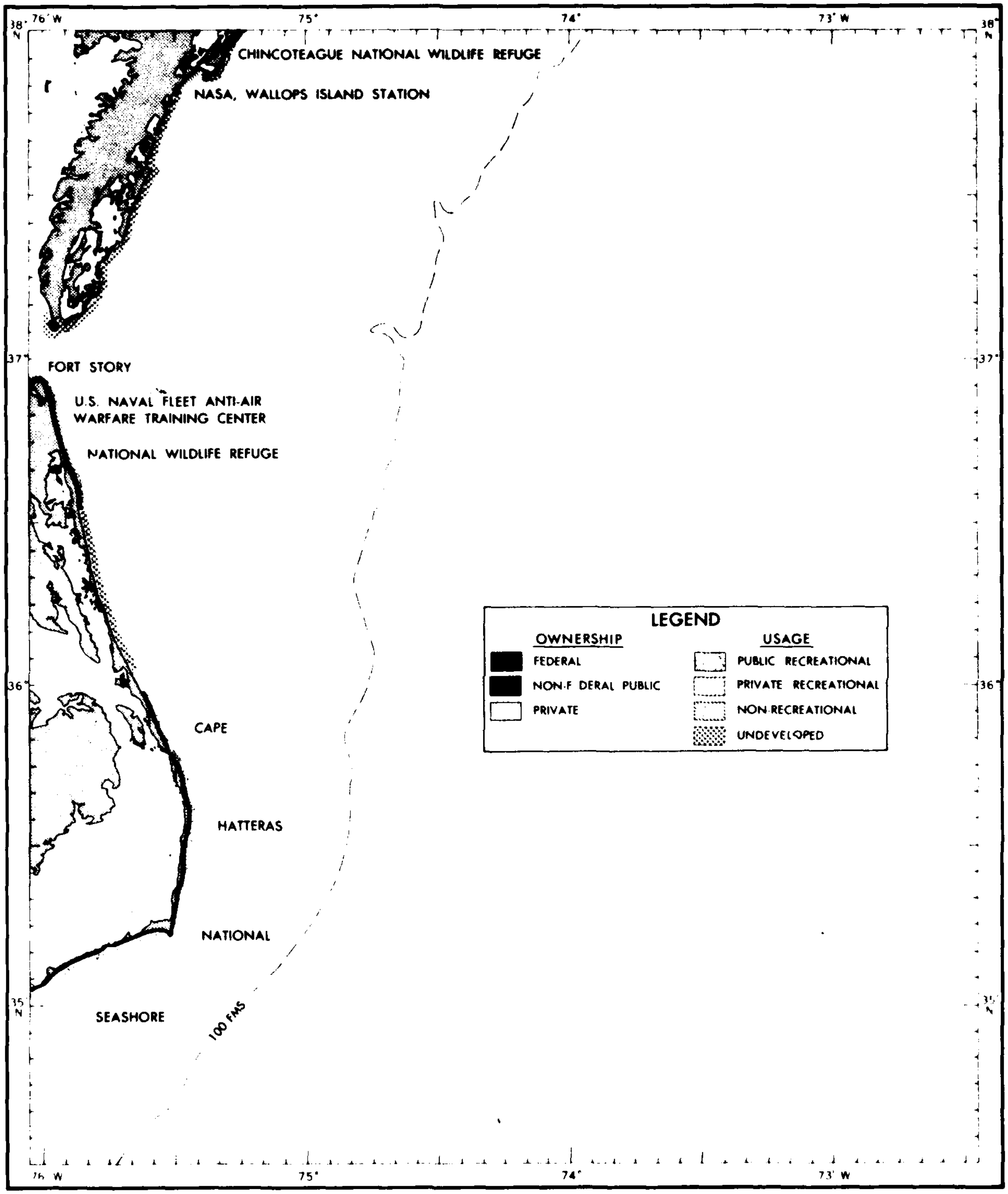


FIGURE 28. SHORELINE OWNERSHIP AND USAGE

E. Marine Biology

1. Plankton distribution

a. Introduction--The plankton biomass present in the Hampton Roads/Norfolk Operating Area comprises numerous species. The waters between Cape Cod and Chesapeake Bay, with the exception of Georges Bank, contain larger volumes of phytoplankton and zooplankton than any other temperate or boreal coastal area on either side of the Atlantic. For example, the volume of production for May averages 800 mg C/m^3*, about twice that of the productive Icelandic Coast (450 mg C/m^3) (St. John, 1958).

The Operating Area has four distinct water regimes (fig. 29) based on temperature, salinity, and nutrients: the entrance to Chesapeake Bay, Continental Shelf (Virginia and North Carolina), Carolina Coastal, and Gulf Stream - Florida Current. However, the boundaries of these regimes fluctuate with seasonal changes. Likewise, the quantities and number of species of plankton also change. The phytoplankton and zooplankton of the bay entrance are tolerant of large ranges in salinity and temperature, as are the many eggs and migrating fish larvae that are spawned in the estuaries of Chesapeake Bay or in the adjoining ocean.

The nutrient-rich Continental Shelf regime extends south from Delaware to between 35°30'N and Cape Hatteras depending on the season. Generally, in cold seasons zooplankton here consists almost entirely of boreal-temperate species. However, in warm periods, a variety of warm-water forms prevails.

Volumes of winter zooplankton along the Carolina coast are only about one-half those in the Continental Shelf regime. The Gulf Stream - Florida Current plankton population is even more sparse, with only meager quantities in any season.

b. Bay entrance--Primary production in this regime is high; daily output is about 500 mg C/m^2** (Moiseev, 1969).

Phytoplankton blooms in the bay entrance in spring and autumn, with population maximums at these times. Diatoms are dominant in the winter, whereas dinoflagellates are more numerous during spring and summer and late autumn. Greater diversity of species appears to spread from the sea toward the inner bay during cold seasons, and seaward from rivers and estuaries during warm seasons. Principal phytoplankton organisms are listed in figure 29. The prominent species are Skeletonema costatum, Chaetoceros affinis, C. compressus, and Cerataulina bergonii.

Influx of low-salinity water from rivers and sharp changes in temperature greatly influence organisms in the bay entrance. Plankton without a tolerance for these variables may not survive. For example, the copepod Centropages typicus enters the bay from the ocean but usually cannot adapt because of low salinity (Deevey, 1960).

The copepod Acartia tonsa is the most abundant zooplankter in Chesapeake Bay. It dominates the zooplankton in all seasons, but reaches its greatest abundance near the bay entrance in spring. Another zooplankter, the chaetognath Sagitta enflata, is most abundant in summer and autumn and has an average density at the bay entrance of 6.2 specimens/m^3.

---

* Milligrams of Carbon per cubic meter.
** Milligrams of Carbon per square meter.

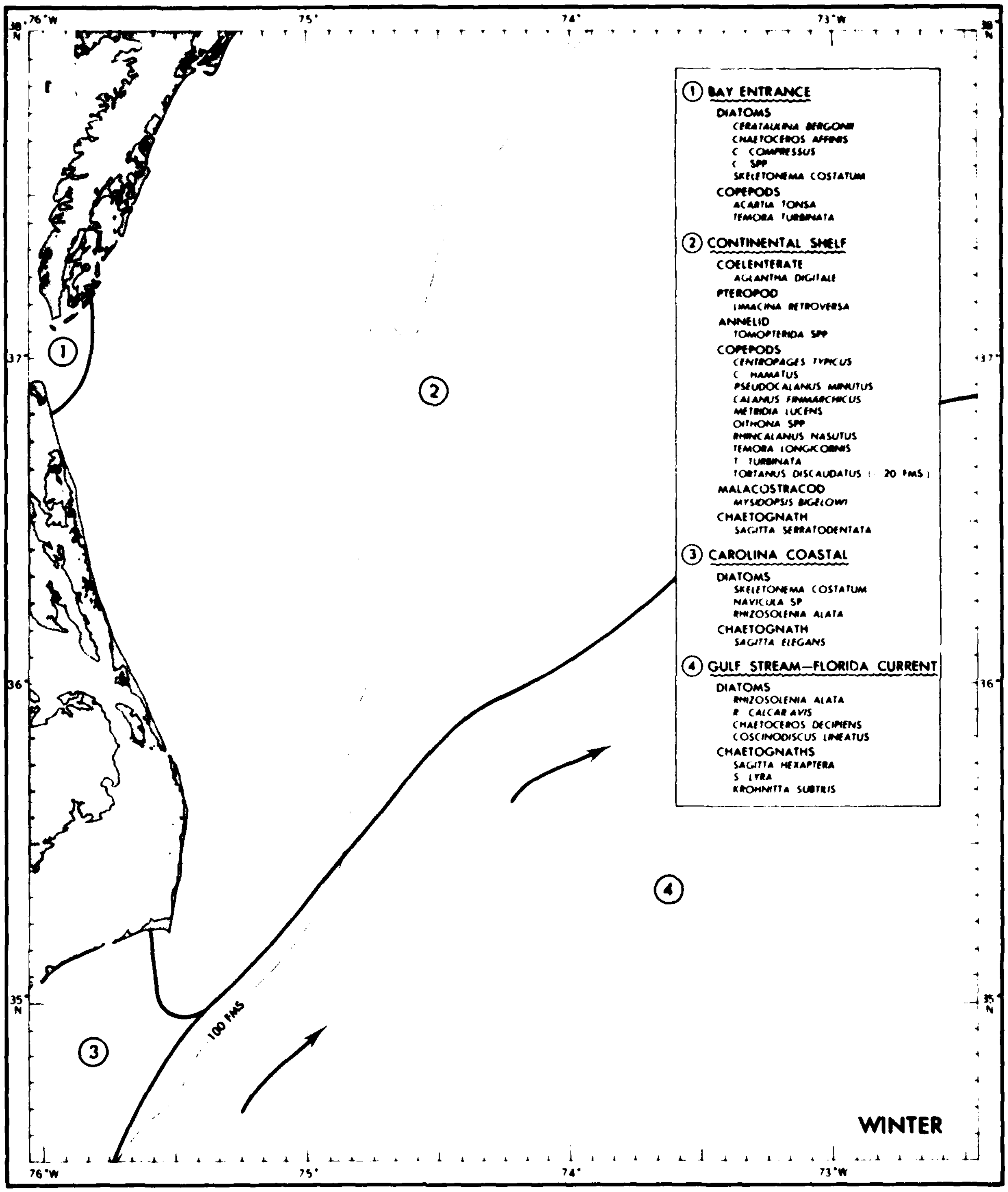


FIGURE 29. PLANKTON SPECIES DISTRIBUTION

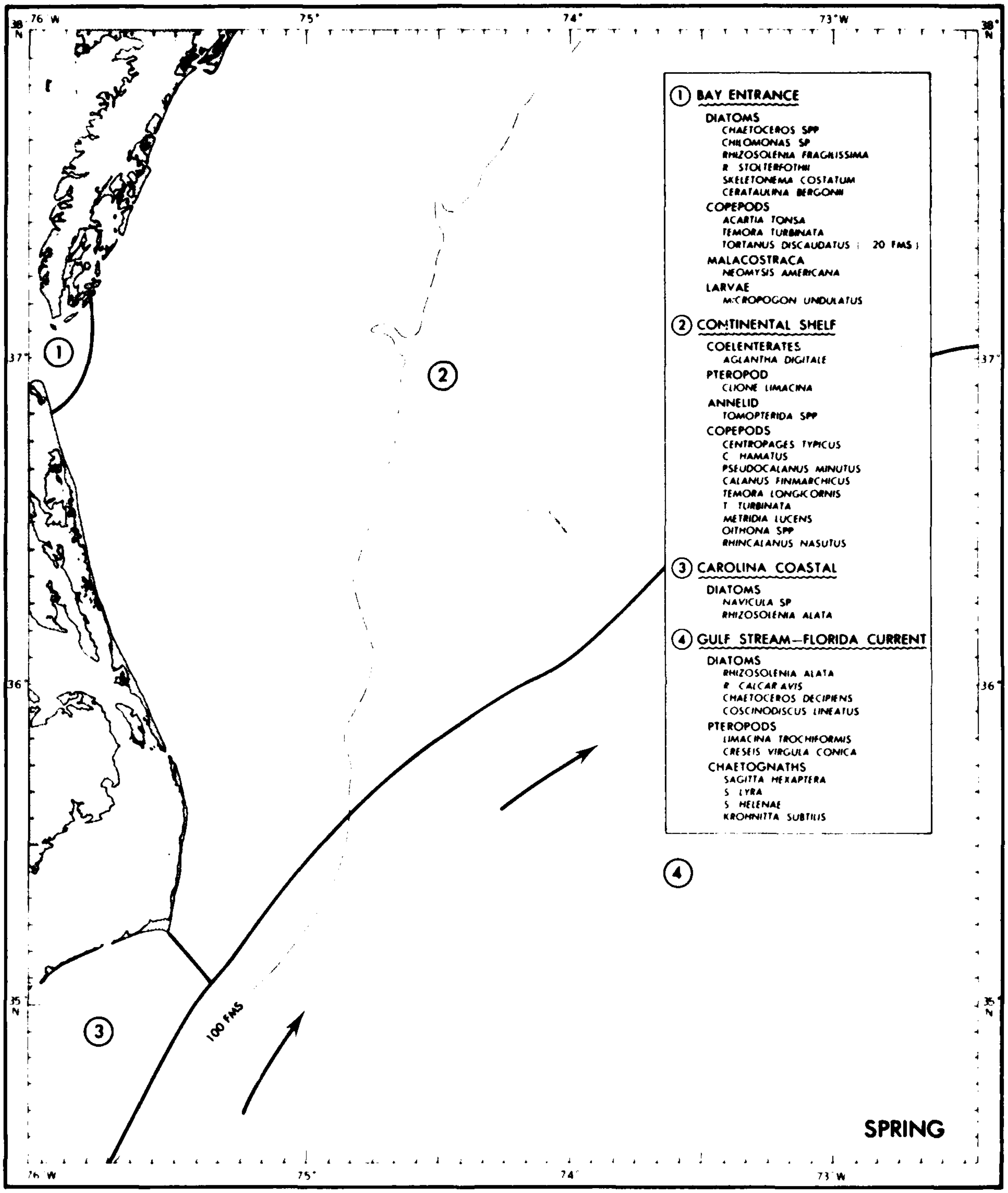


FIGURE 29. PLANKTON SPECIES DISTRIBUTION (CON.)

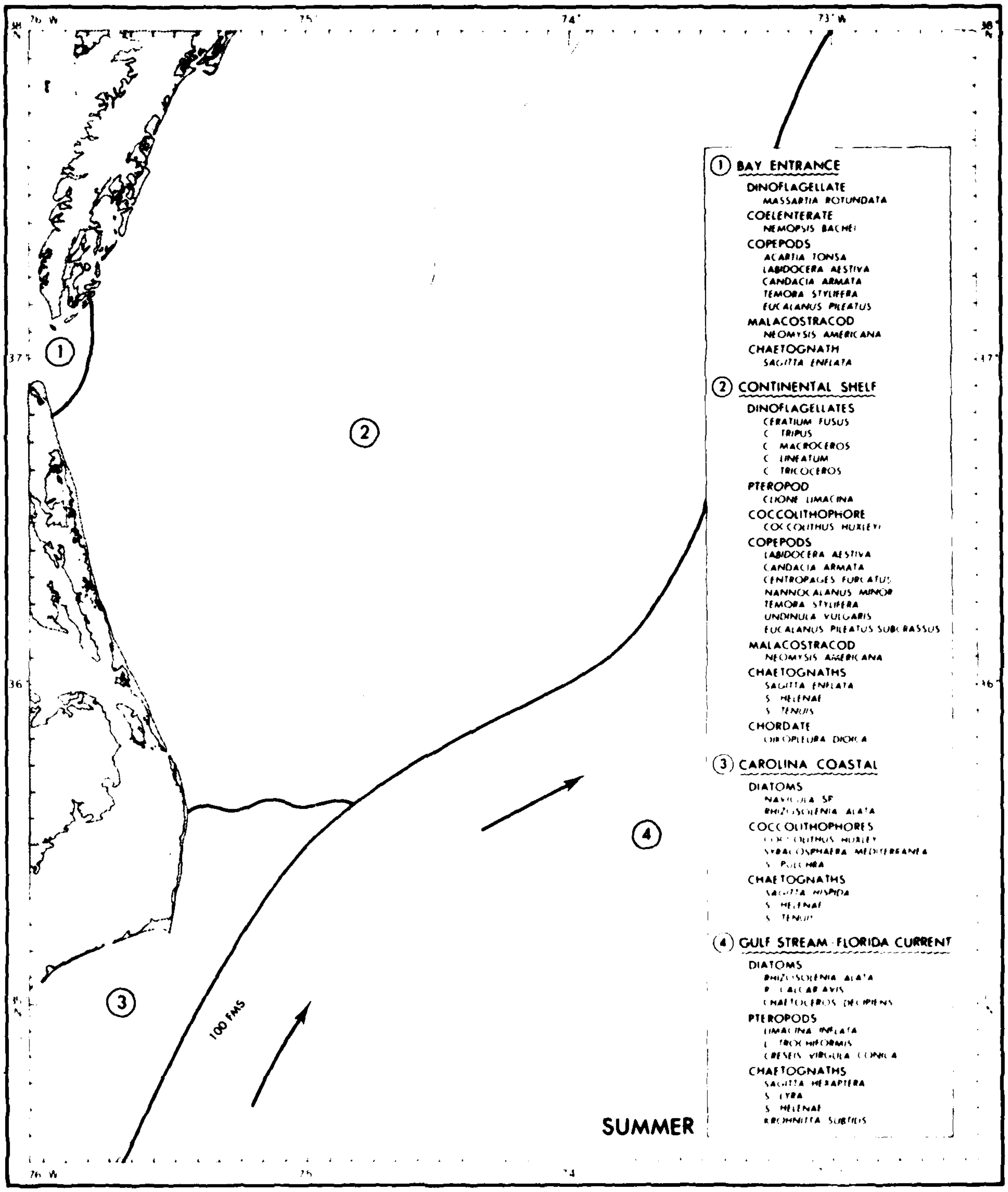


FIGURE 29. PLANKTON SPECIES DISTRIBUTION (CON.)

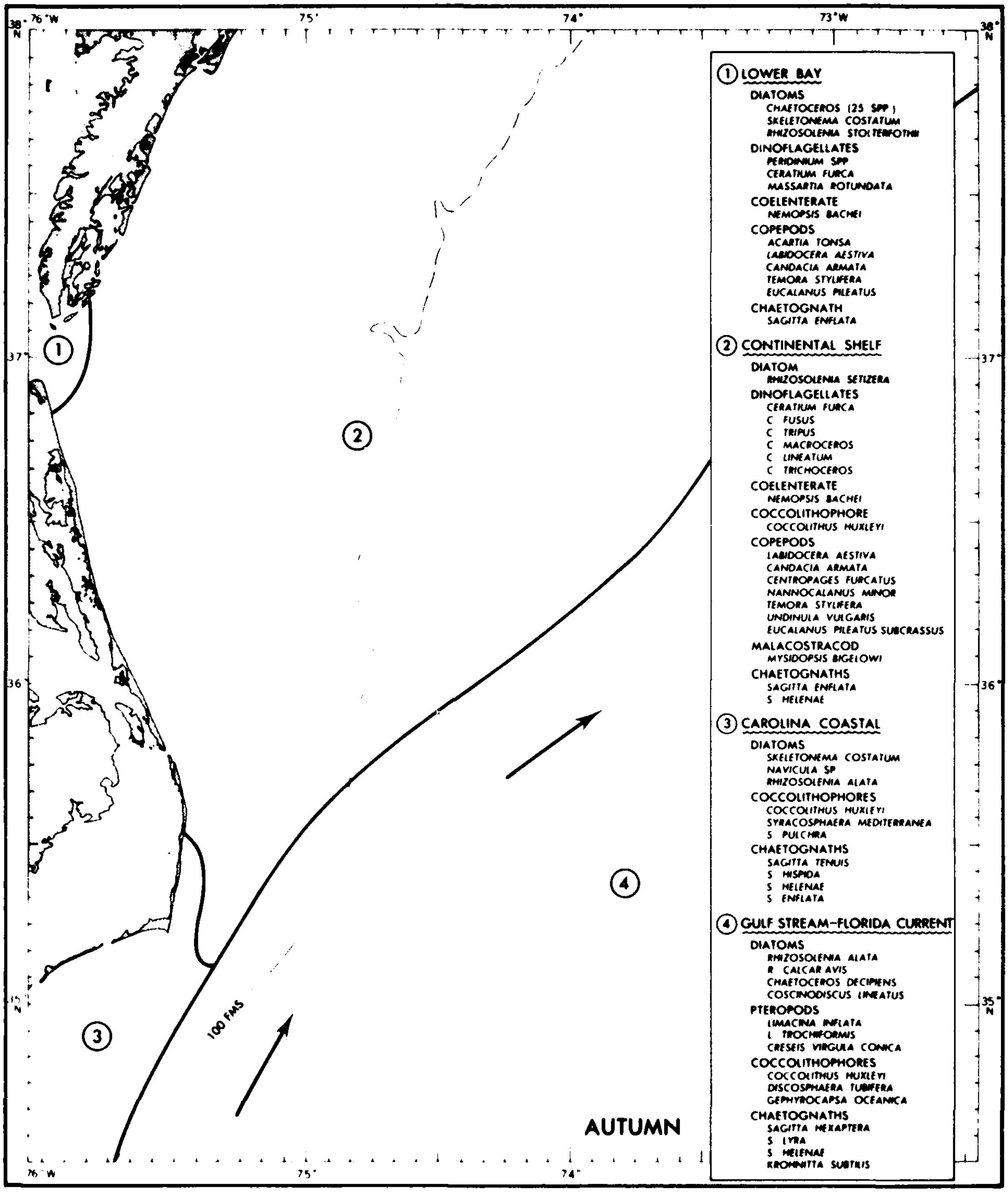


FIGURE 29. PLANKTON SPECIES DISTRIBUTION (CON.)

Close interrelationships occur in this regime between fish and plankton. Fish eggs are part of the plankton biomass; however, the hatched fry feed on the zooplankton. For example, juvenile croaker (Micropogon undulatus) and menhaden (Brevoortia tyrannus) larvae, which move into the lower bay from the open ocean where spawning has occurred, and Atlantic herring (Clupea harengus harengus) and American shad (Alosa sapidissima), which spawn in the bay estuaries with fry passing through the lower bay to the ocean, all feed heavily on zooplankton.

c. Continental Shelf--This is the largest and most complex regime of the study Area. Primary production ranges from 250 to 500 mg C/m^2/day on the continental slope and tapers to a lower level in the Gulf Stream (Moiseev, 1969). This range compares with 400 mg C/m^2/day on the Continental Shelf off New York (Ryther and Yentsch, 1958).

Be, et al. (1971) report high plankton volumes exceeding 100 ml/1000 m^3 north of Cape Hatteras. However, plankton volume may reach 700 to 800 ml/1000 m^3 in summer and 400 ml/1000 m^3 in winter. Van Engel and Eng-Chow (1965) set the displacement volume of the total zooplankton for the period October through July at 9.5 ml/20-minute half-meter net haul.

The environmental parameters of this regime fluctuate widely, thereby affecting the quantities and species of plankton inhabiting these waters during any one season. Temperature appears to be the primary influencing factor, directly limiting the existence of zooplankton in coastal waters during winter months. However, temperature, turbulence, and reduced solar radiation in winter months also act to reduce the production of phytoplankton, the basic food supply of herbivorous zooplankton. With reduction of the phytoplankton standing crop from spring to winter, there is a consequent tendency for reduction of the zooplankton population in winter (fig. 30) (St. John, 1958; Clark, et al., 1969).

Six species of the dinoflagellate Ceratium are abundant in summer and autumn (fig. 31). These warm-temperate or tropical species are members of a community that is most abundant in autumn and especially so in offshore waters, i.e., toward the Gulf Stream.

During the first half of the year, the zooplankton population consists almost entirely of boreal-temperate species, whereas during the second half a variety of warm-water species is present (fig. 31). Four species of copepods, Centropages typicus, Pseudocalanus minutus, Labidocera aestiva, and Eucalanus pileatus-subcrassus, are found in the largest numbers over the broadest areas for the greatest periods of time (fig. 32). C. typicus, unquestionably the dominant form, is present every month in surface waters. It and C. hamatus occur in greatest abundance in winter and spring. Copepods of tropical origin are relatively scarce and occur only in summer and autumn.

Grant (1963a, b) identified Sagitta serratodentata as the most abundant chaetognath over the middle Atlantic shelf during midwinter. Another chaetognath, S. enflata, occurs in offshore waters throughout the year and is concentrated in the summer and autumn.

Other less significant plankton forms include the coelenterate Aglantha digitale and the annelid worms of genus Tomopterid, both occurring from Delaware south to Chesapeake Bay. The tunicate Oikopleura dioica is a warm-water species found on the Continental Shelf off the Bay. The shrimp like mysid Neomysis americana is present throughout the year and is dominant during April through September. It is the most common mysid inhabiting northeastern coastal waters (Wigley and Burns, 1971). Numerous other invertebrates also are represented in the zooplankton population, e.g., the larvae of coelenterates, ctenophores, and tunicates, which abound especially in July through September.

Fish eggs and larvae are prominent additional components of the zooplankton in this regime. The Continental Shelf is the spawning region and migration route to spawning grounds for many species of fish. Generally, fish eggs are present in all seasons except winter, with peak abundance during May through July. A notable exception is the eggs and fry of croaker (Micropogon undulatus), which occur offshore in late summer and through winter and spring. Menhaden (Brevoortia tyrannus) eggs and larvae have been collected to 40 miles offshore during December through March. Fourspot flounder (Hippoglossima oblonga) larvae occur in coastal shelf waters south to North Carolina in depths greater than 20 fathoms (36.6 meters).

d. Carolina coastal--Zooplankton in this regime reaches maximum abundance in summer and autumn and is minimal in winter. However, in contrast to the other regimes, the midwinter minimum of zooplankton volumes is not pronounced. Volumes in January are maintained at 70 percent of the summer average This slight variation in seasonal volumes, expecially near Cape Hatteras, may be attributed to relatively warm winter water temperatures with good solar radiation; hence, the zooplankton population is assured of a moderate standing crop of phytoplankton food supply. The close proximity of the Gulf Stream also supplies shelf waters with reproducing populations of oceanic plankton (St. John, 1958).

The zooplankton volumes in the regime are at maximum concentrations near the midshelf region. Least volumes are in shallow coastal areas and in offshore Gulf Stream - Florida Current water. The zooplankton population in May has a mean volume of 0.29 cc/m^3; in June, 0.28 cc/m^3; and in January, 0.20 cc/m^3 (St. John, 1958). Be, et al. (1971) reported total plankton displacement volume along the Continental Shelf south of Cape Hatteras to be 0.28 cc/m^3.

The winter zooplankton of this regime, compared with that from Cape Cod to Chesapeake Bay, is only about one-half that in the richer waters to the north.

Plankton populations in the shelf area are influenced by other water masses. Occasionally in winter, Virginia coastal water may be transported by storms southwestward around Cape Hatteras. The Virginia coastal calanoid, Centropages typicus, invades the mid-North Carolina Coast along with these cold-water intrusions. The Gulf Stream - Florida Current occasionally penetrates shoreward and carries many oceanic species into coastal waters.

In contrast to the waters to the north, the majority of species south of Cape Hatteras are of tropical origin, e.g., the three chaetognaths Sagitta tenuis, S. helenae, and S. enflata. These species have an average abundance of >3 specimens/m^3 of water (Pierce and Wass, 1962). Copepods in these waters are also mainly warm-water species. Prominent in slope waters is one species of pteropod, Limacina retroversa, with 10 specimens/m^3 of water (Chen and Hillman, 1970).

e. Gulf Stream - Florida Current--The waters of the Gulf Stream have been shown to carry meager quantities of plankton compared to coastal waters. Be, et al. (1971) report 114 mg/m³ wet weight of total plankton for the region of the Gulf Stream - Florida Current between 35° and 37°N.

The following chaetognaths are indicative of Gulf Stream - Florida Current waters, although their abundance is low: *Sagitta hexaptera*, 0.1 to 0.9 specimen/m³; *S. lyra* $<0.1/m^3$; and *Krohnitta subtilis*, $<0.1/m^3$ (Pierce and Wass, 1962).

Other forms present include the pteropods *Limacina inflata*, 5 specimens/m³ of water, and *L. trochiformis* and *Creseis virgula conica*, 3.5/m³ of water (Chen and Hillman, 1970).

However unproductive and undiversified the Gulf Stream - Florida Current may seem in number and quantity of species present, its proximity to the coast results in an increase in water temperature on the shelf in the southern part of the study Area. In the region off Cape Hatteras, considerable mixing of the Gulf Stream - Florida Current and cold waters from the north occurs. Plankton species and quantities, therefore, may vary considerably and be of cold water, boreal-temperate origin or of warm water, temperate-tropical origin.

f. Discussion--With the influx of Chesapeake Bay estuarine water, cold water from northern currents, and warm Gulf Stream water, plus seasonal changes, the Area is a constantly changing and very fertile environment for plankton and higher forms on the food pyramid.

Primary production compares with that of the highest productive areas in the Atlantic Ocean. The largest total plankton concentrations are located primarily in waters of Chesapeake Bay and the Continental Shelf. The Gulf Stream - Florida Current, in comparison, has meager quantities of plankton. Highest plankton counts can be expected in early summer and late autumn over the mid- to outer Continental Shelf. Plankton production is lowest from midwinter to early spring.

Generally, copepods dominate the zooplankton community, with *Acartia tonsa* and *Centropages typicus* being the principal species. The dominant phytoplankton genera are the dinoflagellate *Ceratium* and diatoms *Skeletonema* and *Chaetoceras*. These, plus numerous others as well as eggs, larvae of fishes, and other marine forms, comprise the total plankton population.

2. Benthos

a. Introduction--The marine benthos is those plants and animals that live in, upon, or in close relationship with the ocean bottom. In the shallow lighted zones algae and epifauna (attached animals) that occur upon bottom substrates are commonest, decreasing somewhat in numbers with depth. In deeper water most of the organisms burrow through the bottom sediments or live just beneath the sediment surface (infauna).

b. Community composition

(1) Estuaries--The most characteristic benthic organisms in the estuarine regions of the study area are the algae *Fucus vesiculosus* and

Enteromorpha intestinalis, marsh grass *Spartina alterniflora*, the bryozoan *Biflustra tenuis*, the snail *Littorina irrorata*, the oyster *Crassostrea virginica*, the clam *Mya arenaria*, the barnacle *Balanus improvisus*, and the blue crab *Callinectes sapidus* (fig. 33) (Andrews, 1956; Boesch, 1972; Shaw and Merrill, 1966; Stephenson and Stephenson, 1952; Taylor, 1957; Tenore, 1970; Wulff and Webb, 1969; Zaneveld, 1972).

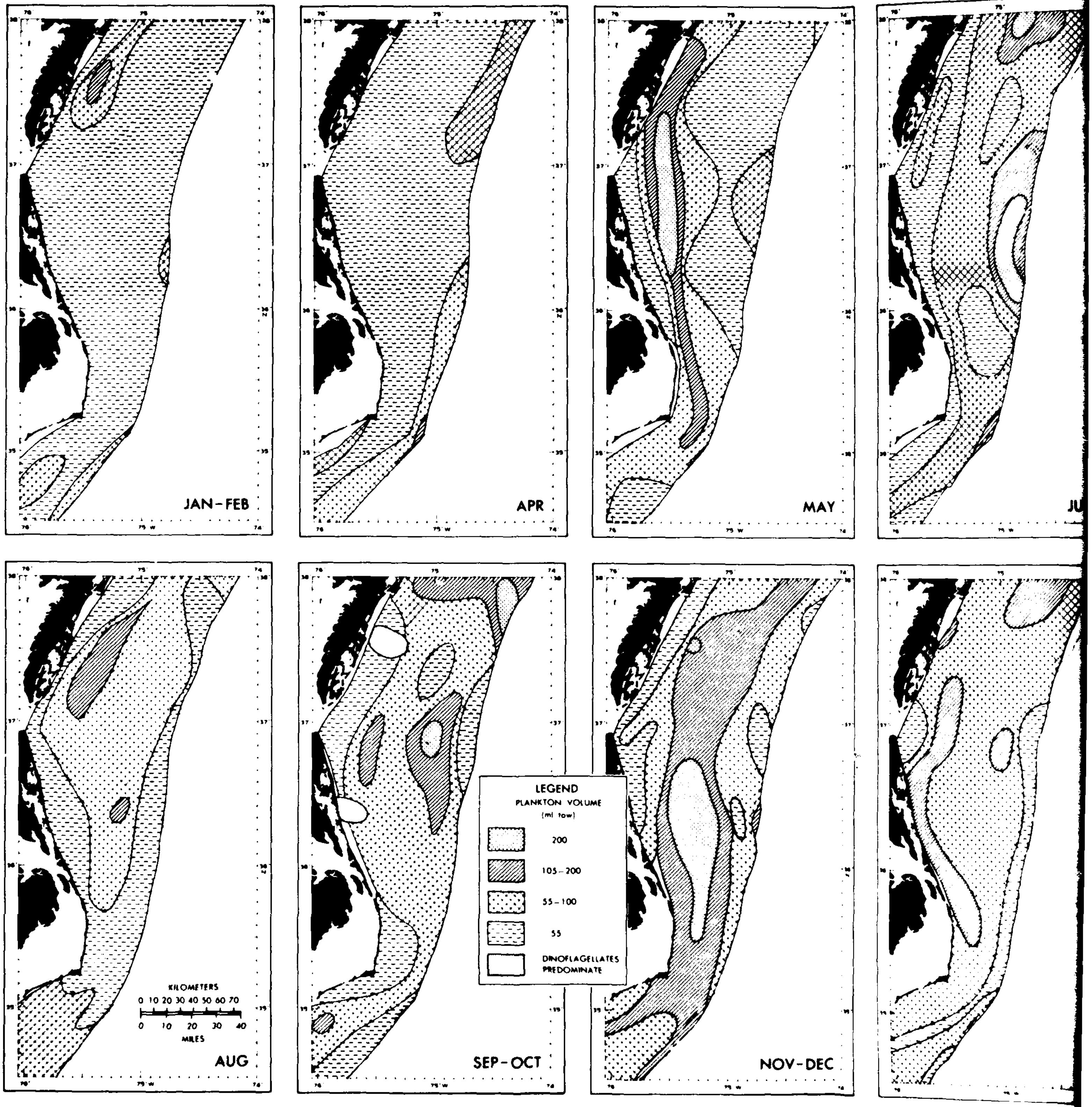
Many of the organisms commonly found in the bays and estuaries are also common in coastal and oceanic waters. Many planktonic forms, commercially important benthic invertebrates, and fishes have been found both in Chesapeake Bay and offshore, or during part of their life cycle move either into or out of Chesapeake Bay in large numbers (Cowles, 1930). The estuaries serve as nursery grounds for many important fishes. Many of the algae observed on coastal intertidal and subtidal surfaces off Delaware also occur in estuaries and bays (Zaneveld, 1972). Large numbers of dislodged terrestrial and marsh plants have been found far offshore where they are considered to be important contributors of organic material to the ecology of deep benthos (Rowe and Menzies, 1969). Many of the fouling organisms found at Hampton Roads are also found at locations offshore (Daugherty, 1961; Shaw and Merrill, 1966).

Large volumes of suspended particulate matter are flushed out of Chesapeake Bay (Schubel and Biggs, 1969), thus becoming available to coastal trophic cycles. Terrestrial dissolved humic substances (gelbstoff) originating from the biodegradation of trees, plants, marsh grasses, and estuarine algae are transported out of the streams and estuaries of the Carolina - Virginia coast (Culliney, 1972). The phenolic and carbohydrate compounds of gelbstoff are used directly and indirectly by coastal organisms and in some areas may be more abundant than those available from phytoplankton (Seiburth and Jensen, 1968, 1969). Thus, it is clear that the estuaries of this Area contribute significantly to the maintenance of the coastal and offshore ecosystems. For further information on the estuaries, readers can refer to a comprehensive review of biological and ecological data collected in Chesapeake Bay, including descriptions and checklists of many benthic groups (McErlean, Kerby and Wass, 1972).

(2) Intertidal zone--The coastal intertidal zone of the Hampton Roads/Norfolk Operating Area is divided into two very distinct types: rocky intertidal, including rock jetties, groins, navigation aids, pilings, and other manmade objects; and sandy intertidal, which includes the extensive sandy beaches of Virginia and North Carolina. The rocky intertidal benthos is dominated by sessile filter-feeding organisms and attached algae usually of microscopic size. The sandy intertidal benthos is dominated by microscopic, interstitial organisms, which are filter feeders, detritus feeders, and scavengers, and relatively few large animals. Attached plants are rare in the sandy intertidal zone. They may appear on the beach after dislodgement.

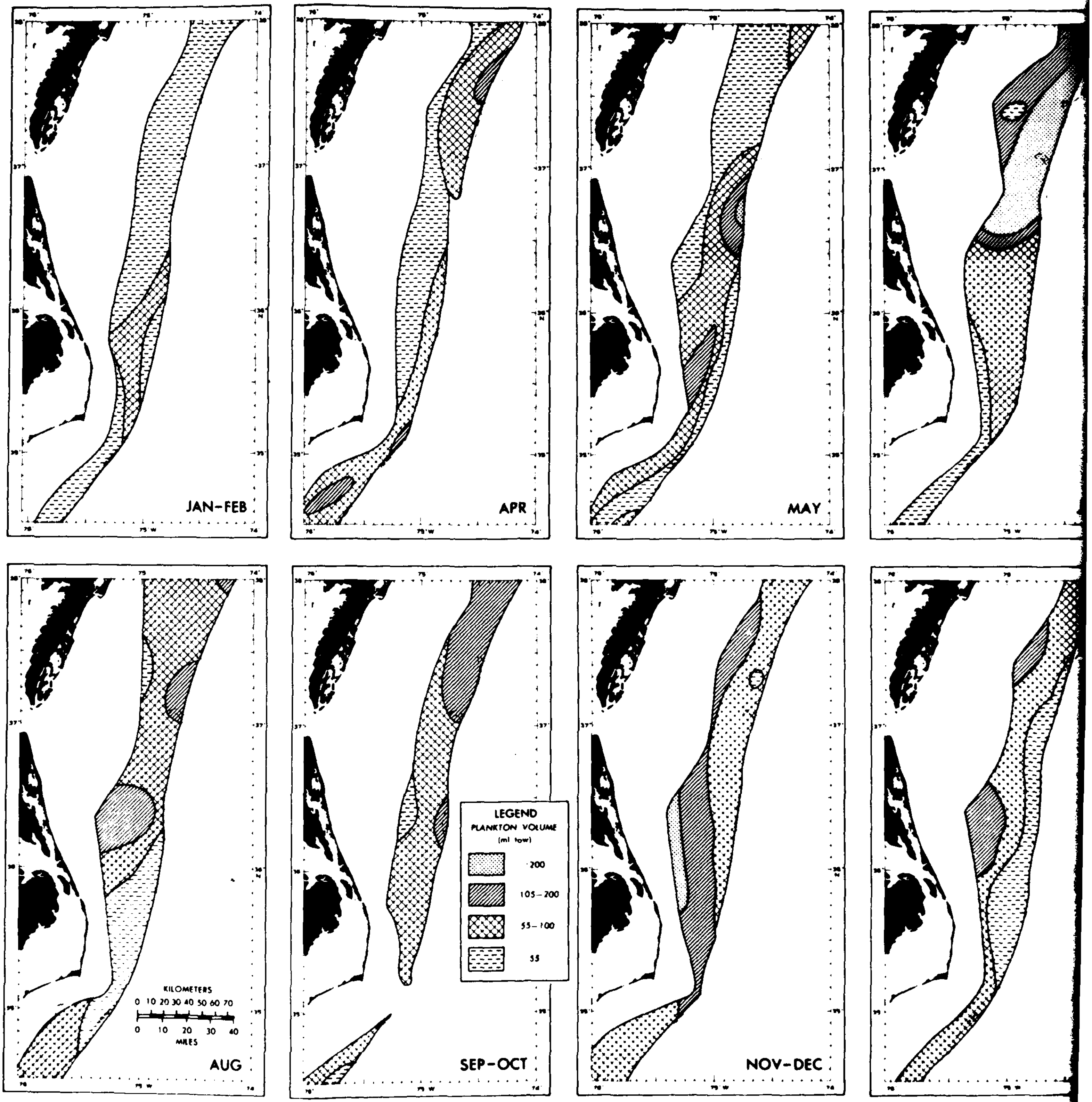
The rocky intertidal zone is typified by distinct horizontal zones of organisms (fig. 33). These zones contain organisms of similar tolerances and preferences for temperature, salinity, desiccation, and extremes of submergence and exposure. Depth zonation is common in benthic communities, but nowhere more distinct and clear cut than in the rocky intertidal zone.

Typically the uppermost zone, which is rarely submerged and receives moisture mostly in the form of spray and wave splashing, is occupied by small molluscs such as snails and by small blue-green and green algae (fig. 33). This zone is usually sparsely populated.



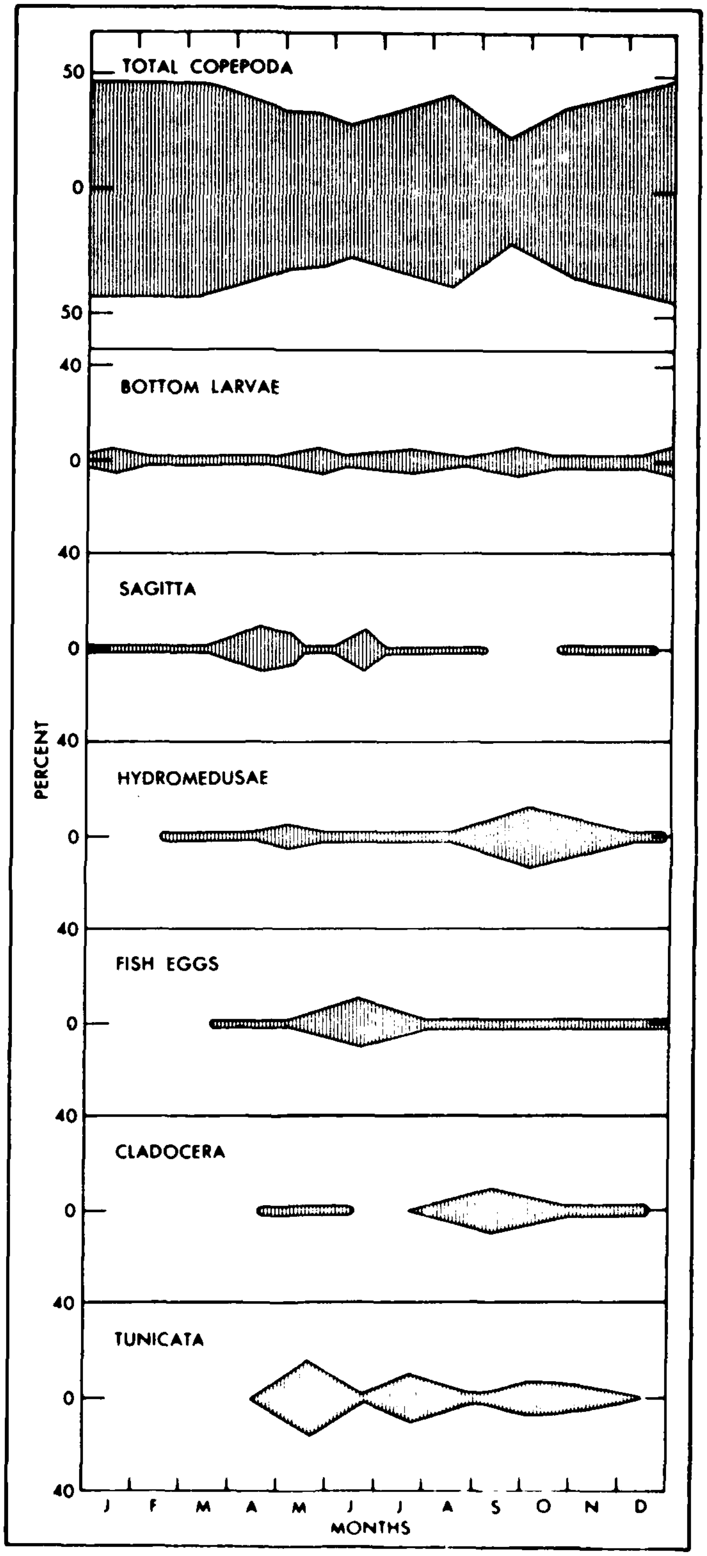
NOTE: DATA COLLECTED FROM DEC 65 TO DEC 66.
(MODIFIED AFTER CLARK ET AL, 1969)

FIGURE 30. PLANKTON VOLUME FOR SHALLOW WATER – CONTINENTAL SHELF (TO 100 FM



NOTE: DATA COLLECTED FROM DEC 65 TO DEC 66.
(MODIFIED AFTER CLARK ET AL, 1969)

FIGURE 31. PLANKTON VOLUME FOR DEEP WATER—CONTINENTAL SHELF EDGE



FROM DEEVEY G B [illegible]

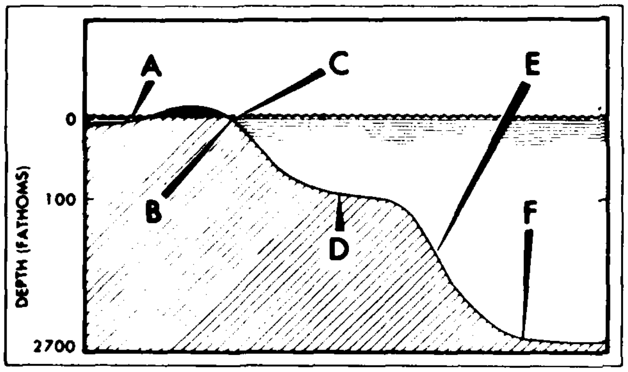
FIGURE 32 PERCENTAGES OF MAJOR GROUPS OF ZOOPLANKTON ON CONTINENTAL SHELF AVERAGE OF 3-YEAR PERIOD

The second deeper zone receives a great amount of breaking wave action and is uncovered by most low tides. It is often dominated by the green algae Ulva lactuca and Enteromorpha intestinalis, the bryozoan Bugula neritina, the snail Littorina littorea, the mussel Mytilus edulis, and the acorn barnacles, Balanus trigonus and B. improvisus (Cowles, 1930; Gosner, 1971; Zaneveld, 1972). Competition for space in this and the other lower zones is keen. Clean surfaces are readily fouled by attaching organisms. As the intertidal community develops and individuals grow, crowding and overgrowth occur, since space, not nutritional requirements, is the limiting factor.

The third deeper zone is influenced greatly by the orbital motion of waves and to some extent by breaking waves, and is submerged during most low tides. This zone is commonly dominated by the brown algae Fucus vesiculosus and Ectocarpus confervoides, the nudibranch Acanthodoris pilosa, the oysters Ostrea equestris and Crassostrea virginica, the barnacle Chthamalus fragilis, the tunicates Styela plicata, and numerous grazing and predatory crabs and fishes (fig. 33) (Cowles, 1930; Gosner, 1971; Marcus, 1961; McDougal, 1943; Shaw and Merrill, 1966; Stephenson and Stephenson, 1952; Wulff and Webb, 1969; Zaneveld, 1972). The lowest tidal zone which is uncovered only during the lowest low tides is commonly occupied by the red algae Gracilaria verrucosa and Ceramium rubrum, the sponge Microciona prolifera, various sertularid and plumularid hydroids, the bryozoans Schizoporella unicornis and Hippoporina americana, and many grazing and predatory crabs and fishes (fig. 33) (Cowles, 1930; Gosner, 1971; McDougal, 1943; Stephenson and Stephenson, 1952; Wulff and Webb, 1969). Below the lowest zone the organisms characteristic of the intertidal zones integrate with those common to littoral depths and gradually disappear with increasing depth.

Few published reports exist on the community composition, ecology, and diversity of sandy beach intertidal zones. The North Carolina sandy beach community is typified by low diversity and low density (Dexter, 1969). Dominants are the bivalve Donax variabilis, small copepods, the haustoriid amphipod Neohaustorius schmitzi, the mole crab Emerita talpoida, the polychaete Scololepis squamata, and the sand dollar Mellita quinquesperforata (fig. 33) (Dexter, 1967, 1969; Pearse, 1942). Most of the organisms such as the amphipods, molluscs, and copepods are suspension or filter feeders. Others such as the crabs, amphipods, and polychaetes are scavengers and detritus feeders (Dexter, 1969). Though vertical zonation exists in the sandy intertidal benthos, it is less distinct than in the rocky communities, the dominant organisms having wider ranges of depth distribution.

(3) Continental Shelf--The sediments of the Continental Shelf are generally sands with occasional mud and gravel beds and submerged rock - coral reefs. Most benthic organisms are adapted to crawl over these fine sediments without sinking or to burrow through or dig into them. The benthic community typically is diverse and abundant. Common groups of animals with examples of each are: scallop (Placopecten magellanicus), clams (Arctica islandica and Mercenaria mercenaria), polychaetes (Hyalinoecia artifex and Pomatoceros caeruleus), crabs (Cancer borealis), sea stars (Asterias forbesi), and demersal fishes (Paralichthys dentatus) (fig. 33).

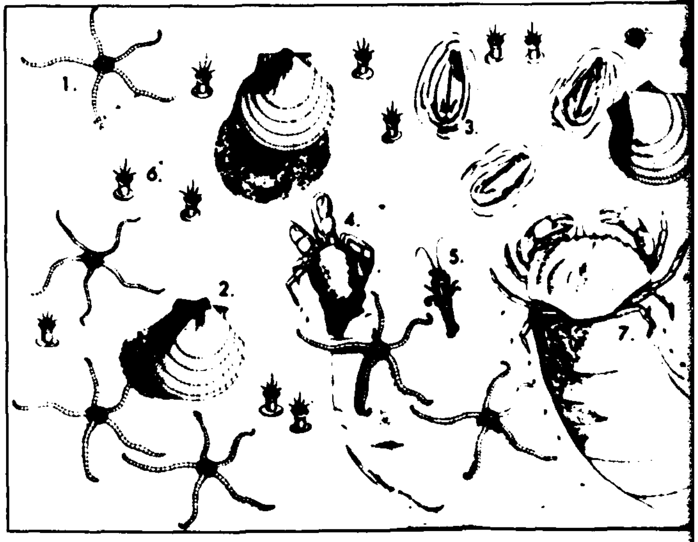


FAUNAL ZONE LOCATIONS

NOTE:
SOME OF THE MORE COMMON ORGANISMS REPRESENTATIVE OF EACH BENTHIC COMMUNITY ARE ILLUSTRATED; NUMEROUS ADDITIONAL SPECIES ALSO OCCUR IN EACH COMMUNITY THROUGHOUT THE AREA.

ESTUARINE

LITTORAL—CONTINENTAL SHELF



A

1. **MARSH GRASS** *(Spartina alterniflora)*
2. **ALGAE** *(Fucus vesiculosus)*
3. **SNAIL** *(Littorina littorea)*
4. **CLAM** *(Mya arenaria)*
5. **CRAB** *(Callinectes sapidus)*
6. **BARNACLE** *(Balanus improvisus)*
7. **OYSTER** *(Crassostrea virginica)*

ROCKY INTERTIDAL

B

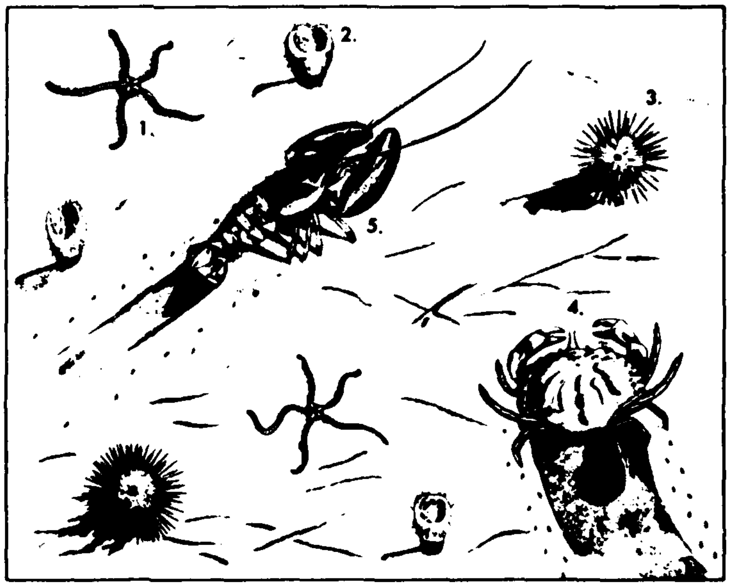
1. **SNAIL** *(Littorina litter*
2. **ALGAE** *(Enteromorph*
3. **ALGAE** *(Ulva lactuc*
4. **BARNACLE** *(Balanus*
5. **MUSSEL** *(Mytilus edu*
6. **ALGAE** *(Fucus vesicul*
7. **OYSTER** *(Crassostrea*
8. **ALGAE** *(Gracilaria v*
9. **NUDIBRANCH** *(Acan*
10. **SPONGE** *(Microcion*
11. **ALGAE** *(Ceramium r*

LF

D

1. **BRITTLE STAR** *(Bathypectinura heros)*
2. **SCALLOP** *(Placopecten magellanicus)*
3. **CLAM** *(Mercenaria mercenaria)*
4. **HERMIT CRAB** *(Catapagurus sharreri)*
5. **SHRIMP** *(Crangon septemspinosa)*
6. **WORM** *(Hyalinoecia artifex)*
7. **CRAB** *(Cancer borealis)*

CONTINENTAL SLOPE



E

1. **BRITTLE STAR** *(Bath*
2. **SPONGE** *(Hyalone*
3. **URCHIN** *(Ophiomu*
4. **CRAB** *(Cancer bore*
5. **LOBSTER** *(Homarus*

FIGURE 33. REPRESENTATIVE ORGANISMS CHARACTERISTIC OF SIX FAUNAL ZON

SANDY INTERTIDAL

B

SNAIL *(Littorina littorea)*
ALGAE *(Enteromorpha intestinalis)*
ALGAE *(Ulva lactuca)*
BARNACLE *(Balanus trigonus)*
MUSSEL *(Mytilus edulis)*
ALGAE *(Fucus vesiculosus)*
OYSTER *(Crassostrea virginica)*
ALGAE *(Gracilaria verrucosa)*
NUDIBRANCH *(Acanthodoris pilosa)*
SPONGE *(Microciona prolifera)*
ALGAE *(Ceramium rubrum)*

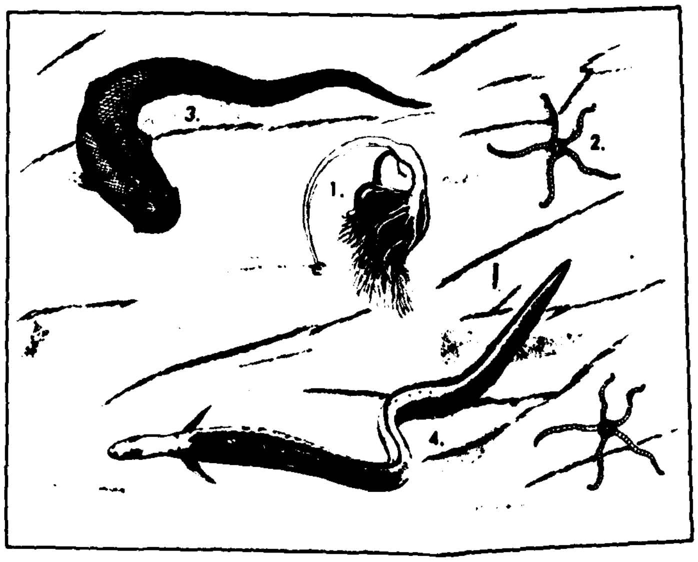
C

1. **AMPHIPOD** *(Neohaustorius schmitzi)*
2. **MOLE CRAB** *(Emerita talpoida)*
3. **GHOST SHRIMP** *(Callianassa major)*
4. **SNAIL** *(Oliva sayana)*
5. **CLAM** *(Donax variabilis)*
6. **QUAHOG** *(Mercenaria mercenaria)*
7. **POLYCHAETE** *(Scolelepis squamata)*
8. **SAND DOLLAR** *(Mellita quinquiesperforata)*

SLOPE BOTTOM—ABYSSAL PLAIN

E

BRITTLE STAR *(Bathypectinura heros)*
SPONGE *(Hyalonema boreale)*
URCHIN *(Ophiomusium lymani)*
CRAB *(Cancer borealis)*
LOBSTER *(Homarus americanus)*



F

1. **SEA PEN** *(Umbellula lindahli)*
2. **BRITTLE STAR** *(Amphiophiura bullata)*
3. **FISH** *(Nematonurus sp.)*
4. **EEL** *(unidentified)*

SIX FAUNAL ZONES

Numerous benthic samples have been gathered by Woods Hole Oceanographic Institution (WHOI) off the east coast of the U.S. (fig. 34). The biological components of the shelf sediments collected by WHOI consisted of a mollusc-dominated infauna, echinoderm-dominated epifauna, and many species of crustaceans and polychaetes (Hathaway, 1971; Milliman, 1972). Somewhat north of the study Area but within a biologically similar environment, benthic animal abundance increases from 6,000 individuals/m² near shore to 13,000 individuals/m² at the shelf edge reaching a minimum of 25 to 100 individuals/m² at 5,000 meters depth. Molluscs, polychaetes, sipunculids, crustaceans, and echinoderms constitute 85 percent to 100 percent of the fauna (Sanders et al., 1965; Sanders and Hessler, 1969). The common molluscan macrobenthos observed by underwater photography off the northeast coast from Maine to Cape Hatteras includes numerous crustaceans, annelids, and echinoderms whose geographic distribution covers adjoining sections of the Middle Atlantic Shelf (Cowles, 1930). Many bivalve molluscs occur in nearshore sediments off Assateague Island, decreasing in numbers offshore (Henderson and Bartsch, 1915). Ocean quahogs (Mercenaria campechiensis) occur in abundance in sandy-shell and sandy-silt sediments off Assateague Island and in smaller numbers in 10m to 30m depths off Maryland, Virginia, and North Carolina (Merrill and Ropes, 1967). The lobster Homarus americanus and the crabs Cancer irroratus, C. borealis, and Munida iris are the most common decapods along the shelf edge from Delaware to North Carolina (Musick and McEachran, 1972).

Several benthic surveys have been conducted in the vicinity of Cape Hatteras, partly because of its significance as a faunal boundary. The sea star Astropecten americanus, rock crabs Cancer borealis and C. irroratus, galatheid shrimp, and sea anenomes were the most common of 211 species collected in depths less than 200m off Cape Hatteras (Cerame-Vivas and Gray, 1966). About 241 species of bryozoans and 5 species of entoprocts were collected in a survey of shelf sediments from Florida to New Jersey (Maturo, 1968). Some 110 species of polychaetous annelids have been found in inshore waters off Cape Hatteras and Pamlico Sound (Wells and Gray, 1964). Some 70 species of marine sponges have been found in the inshore waters of North Carolina (Wells, 1960a). The shallow water (50-500m) meiofauna consists of animals smaller than 0.500 mm dominated by nematodes, numerous copepods, ostracods, foraminiferans, polychaetes, gastrotrichs, and others, while the fauna below 500m is mostly made up of nematodes and foraminiferans (Tietjen, 1971).

Data from the many benthic surveys conducted south of Cape Hatteras generally are applicable only to the waters south of Cape Hatteras because environmental conditions have established a faunal boundary in the cape vicinity. The benthic populations of the shelf edge and upper slope south of Cape Hatteras occur in restricted ribbons or zones parallel with depth contours (Rowe and Menzies, 1969). Coralline algae (Lithothamnion) and corals are common on the shelf and shelf edge south and southeast of Cape Hatteras. Lithothamnion growths often form submerged reefs, which host a diverse and abundant fauna. The upper reef sandy fauna is dominated by the bivalve Glycymeris undata. Hydroids, gorgonians, bryozoans, and echinoids dominate the epifaunal assemblage of the reefs. The lower reefs sandmud assemblage is dominated by the gastropod Polystira florencae and the brachyuran crustacean Acanthocarpus alexandri. The epifauna of these reefs is an important nutritional element of the commercially important demersal fishes of the Carolinas (Menzies, 1966).

Some 112 species of invertebrates attach to calico scallop (Aequipecten gibbus) shells 30 to 40m deep off Core Banks, North Carolina. The barnacles

Balanus amphitrite and *B. calidus* dominate the epifauna of these shells (Wells et al., 1964). More than 240 species of molluscs are coincident with *Aequipecten gibbus* 20 to 30m deep off Cape Lookout (Porter, 1971). Many molluscs, including the scallops, are eaten by the starfish *Astropecten articulatus* (Porter, 1971, 1972). Four commercially important molluscs are common in the vicinity of Cape Hatteras. The Atlantic deep sea scallop *Placopecten magellanicus* occurs north of Cape Hatteras in water deeper than 40m; the bay scallop *Argopecten irradians* occurs in bays, sound, and inlets; and the calico scallop *Argopecten gibbus* is found in 20 to 40m of water off Cape Lookout (Porter, 1971). The southern quahog *Mercenaria campechiensis* is common between Cape Lookout and Beaufort Inlet in 10 to 20m depths (Porter and Chestnut, 1962).

The invertebrate fauna associated with *Oculina* coral heads at Cape Lookout is very diverse (more than 300 species) and abundant. The inshore coral community, which is exposed to heavy surf and orbital motion of waves, is dominated by the boring bivalve *Lithophaga bisulcata*, the oyster *Ostrea equestris*, the sipunculid *Paraspidosiphon parvulus*, the polychaetes *Syllis gracilis* and *Nereis occidentalis*, and tanaid and cirripede crustaceans. Forty kilometers offshore, where environmental conditions are relatively stable, *Oculina* corals are less abundant than inshore, and are accompanied by sponge-octocoral hydroid epifauna. The community associated with the offshore *Oculina* heads is dominated by the anemone *Aiptasia pallida*, the polychaetes *Syllis spongicola* and *S. gracilis*, tanaid crustaceans, the amphipod *Erichthonius sp.*, and the isopod *Jaeropsis coralicola*. The composition of the coral communities changes as the coral heads mature and undergo degradation by the boring bivalve *Lithophaga bisulcata* (McCloskey, 1970).

(4) Continental slope--The literature is sparse on the benthic fauna of the slope between Delaware and Cape Hatteras. Most studies have been conducted by WHOI just north of the Area and by Florida State University and Duke University off Cape Lookout and South Carolina.

The benthic fauna of the northern section of the Area is dominated by polychaetes, crustaceans, bivalves, and sipunculids (Hathaway, 1971; Sanders et al., 1965; Sanders and Hessler, 1969). As many as 365 species occur at a depth of 1,400 m on the slope. The abundance of benthic organisms generally decreases and the community composition changes with increasing depth (Sanders and Hessler, 1969).

South of Cape Hatteras similar generalizations apply to the benthos of the slope, i.e., changing community composition and decreasing abundance with increasing depth (Grassle, 1967). Here, the benthic communities occur in ribbonlike horizontal zones. The upper slope (200-1,000m) population is characterized by the polychaete *Hyalinoecia artifex*, the sea star *Astropecten americanus*, crabs *Cancer borealis* and *Munida valida*, and the hermit crabs *Catapagurus sharreri* and *Parapagurus pilosimanus*. In the deeper (1,000-3,000m) portions of the slope the fauna changes markedly because of the influence of bottom currents flowing southward. At these depths the benthic population is characterized by the polychaete *Hyalinoecia artifex*, the urchin *Phormosoma placenta*, the brittle stars *Ophiomusium lymani*, *Ophiocantha simulans* and *Bathypectinura heros*, and the hermit crab *Parapagurus pilosimanus* (Menzies, 1972; Rowe and Menzies, 1969). The distribution and abundance of these organisms appear to be influenced by temperature fluctuations and sediment size which in turn are related to the movements and proximity of the Gulf Stream (Rowe and Menzies, 1969). Because of the indurated (hardened) type of sediments, the benthic macrofauna of Hatteras Canyon is markedly different from that of nearby shelf and slope areas (Rowe, 1971).

(5) Slope bottom - abyssal plain--Data are not available on abyssal-benthic populations within the Area. However, data collected north and northeast of the Area (Sanders, et al., 1965; Sanders and Hessler, 1969) and southeast of the Area (Rowe and Menzies, 1969; Menzies, 1972) should apply to the fauna that occurs north and south of Cape Hatteras, respectively. The northern abyssal-benthic fauna is typified by a diverse, low-density community dominated by species of polychaetes, crustaceans, bivalves, and sipunculids. Also common are pogonophorans, ophiuroids, anemones, solenogastres, gastropods, scaphopods, and various demersal fishes. The dominance of polychaetes tends to decrease seaward as the importance of crustaceans simultaneously increases (Sanders, et al., 1965).

South of Cape Hatteras the abyssal-benthic macrofauna is typified by the sponge Euplectella suberea, the soft coral Anthomastus glandiforous, the sea pens Pennatula aculeata and Umbellula lindahli, the holothurians Euphronides depressa and Pilopatides gigantea, and the hermit crab Parapagurus pilosimanus (Rowe and Menzies, 1969). This population is similar to the upper abyssal fauna found farther to the south off South Carolina (Menzies, 1972).

c. Abundance and biomass--The abundance and biomass of benthic fauna generally increase from near shore to the shelf edge and decrease from the shelf edge to the abyssal plain. Along the Gay Head, Massachusetts-Bermuda Transect, abundance increases from a maximum of 6,000 organisms/m^2 near shore to a maximum of 23,000/m^2 at the shelf edge, then decreases to 500/m^2 at the bottom of the slope and 25 to 100/m^2 on the abyssal plain under the Sargasso Sea (Sanders and Hessler, 1969). Between depths of 23 and 507m, on the shelf between Cape Cod and Delaware the range of biomass is 2 to 1,057 g/m^2, averaging 156 g/m^2 (Emery et al., 1965). The decrease in abundance in the deep benthos is attributable to a gradual decrease in availability of food originating in the euphotic zone (Sanders and Hessler, 1969).

Available data on intertidal and inshore abundance and biomass of benthos are scarce. Fouling accumulates on exposed surfaces in the mouth of Chesapeake Bay at a maximum rate of 162 g/cm^2/yr (Daugherty, 1961). Oysters occur in concentrations up to 115 per buoy in the mouth of Chesapeake Bay (Shaw and Merrill, 1966). Approximately one larva per 130 cm^2 of surface set on plates exposed for 3 months at Beaufort, N.C. (McDougal, 1943). North Carolina sand beach amphipods occur in an average density of 100 individuals/m^2 (Dexter, 1967).

Six species of shellfish occur in numbers sufficient for commercial exploitation in the area: Mercenaria campechiensis, Arctica islandica, Spisula solidissima, Placopecten magellanicus, Argopecten irradians, and A. gibbus (Merrill and Ropes, 1967; Porter, 1971; Porter and Chestnut, 1962; Wigley and Emery, 1968). Commercially harvestable lobsters and crabs occur in concentrations of up to 30 animals per station at depths of 70 to 270m (Musick and McEachran, 1972).

On the southern continental slope the common polychaete Hyalinoecia artifex and the ophiuroid Ophiomusium lymani have been photographed in concentrations of 15 organisms/m^2 and 10/m^2, respectively. On the continental rise the epifaunal assemblage is composed of scattered sea pens (Umbellula *lindhali*), and in deeper water on the Hatteras abyssal plain a sparse epifaunal population of ophiuroids (*Amphiophiura bullata*) exists (Rowe and Menzies, 1969). An 11.5km-long megatrawl tow south of the Area at 2,300 to 2,500 meters revealed 57 species of animals weighing 22,665 grams (average biomass of $0.8 g/m^2$) (Menzies, 1972).

d. Diversity--Diversity is computed logarithmically or by organism count to demonstrate relative numbers of organisms in biological communities. High diversity in a benthic community indicates that many species of organisms are capable of surviving, thriving, and reproducing in the community and, in turn, that the community is "healthy."

Table I shows numerical faunal diversity for the benthos of the northeast coast of North America. Studies of the shallow, pierside fouling community at Beaufort, North Carolina, showed a numerical diversity of 69 species (McDougal, 1943). Sandy, intertidal communities have somewhat lower diversity (41 species) (Dexter, 1969). Littoral benthic communities on the North Carolina shelf are composed of at least 211 species (Cerame-Vivas and Gray, 1966). Approximately 170 species were collected during a study of a submerged reef south of Cape Lookout (Menzies, 1966). A total of 300 species was reported from reefs off South Carolina and southern North Carolina (Pearse and Williams, 1951). At least 112 species of invertebrates attached to scallop shells off Core Banks, North Carolina, were identified (Wells, et al., 1964). In a later study, however, 241 species of molluscs alone were found associated with North Carolina scallop shells (Porter, 1971). More than 300 species of animals occur in association with coral heads off Cape Lookout (McCloskey, 1970). More than 70 species of invertebrates occur on coquina substrate between Cape Hatteras and Cape Lookout (Wells and Richards, 1962). Thus, the number of species found in the intertidal and littoral benthos is high, the actual number being dependent upon the specific location, type of substrate, and type of method of study.

In deeper water, benthic community diversity remains high, similar to that of a shallow, tropical marine environment such as in the Caribbean (Sanders and Hessler, 1969). Just to the north of the Area 365 species occur at 1,400m, 257 at 2,496m, 208 at 2,864m, 310 at 2,891m, and 196 at 4,680m (Sanders and Hessler, 1969; Hessler and Sanders, 1967). Off Cape Lookout, faunal diversity in slope samples exceeds that of shelf samples (Grassle, 1967). The diversity of benthic foraminifera populations in the western North Atlantic peaks at 35-45m, 100-200m, and below 2,500m, while generally increasing with depth (Buzas and Gibson, 1969).

Benthic logarithmic (H') diversity values have been calculated by Boesch (1972) for stations off the Virginia and North Carolina coast. These show a trend of gradually increasing diversity from the shallow shelf (4-30m) to the outer shelf (100-200m) and to the upper slope (450-600m) (fig. 35). In the mildly polluted waters of Hampton Roads and the oligohaline water of the York River - James River area diversity is the least observed in the study area (fig. 35) (Boesch, 1972). However, less diversity has been observed in the highly polluted waters of Los Angeles, California, harbor.

Several authors have proposed that H' diversity indices can be used as a criterion or measure of water quality and valuable indicators of the influence of pollution on the benthos (Wilhem and Dorris, 1968; Armstrong, et al., 1971; Boesch, 1972). Numerical and H' diversity data calculated for the benthos in this Area and summarized in this report indicate that the

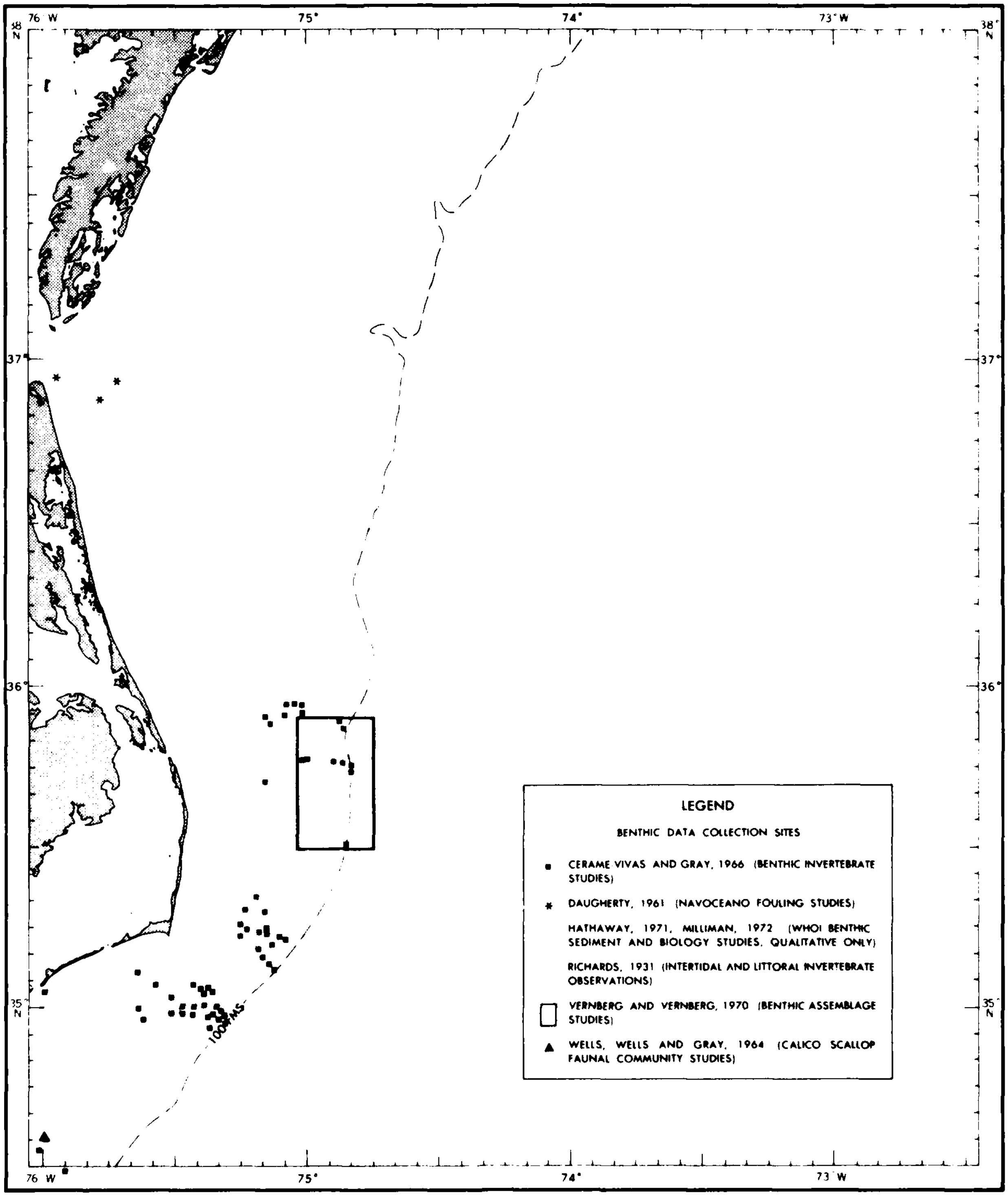


FIGURE 34 BENTHIC DATA COLLECTION SITES

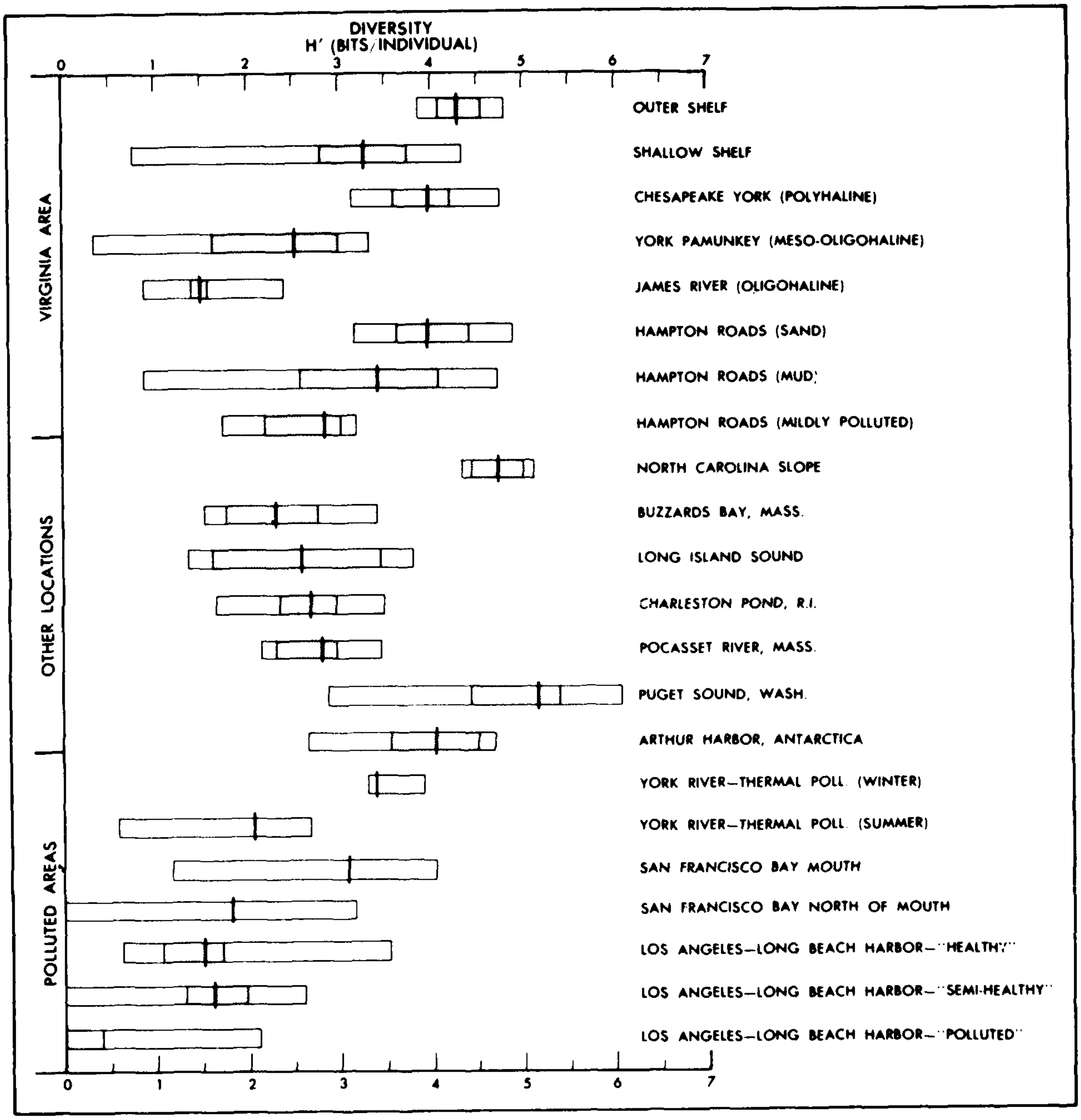
TABLE I. NUMBERS OF SPECIES OF EACH MAJOR PHYLUM FOUND IN FIVE PRINCIPAL ZONES AS ENUMERATED BY VARIOUS AUTHORS

Protozoa	Porifera	Coelenterata	Nemertea	Bryozoa	Annelida	Sipunculida	Mollusca	Arthropoda	Echinodermata	Vertebrata
ESTUARY										
No Data	3(5) 6(10) 23(17)	10(5) 1(9) 7(10)	3(5) 4(9)	23(5) 8(10)	35(5) 38(9) 4(10)	2(5) 2(9)	77(1) 14(5) 29(9) 12(10)	57(5) 25(9) 24(10)	3(9) 3(10)	1(4) 1(5) 3(9) 6(10)
INTERTIDAL (0 to < 2M)										
No Data	8(5) 7(17)	61(5)	11(5)	50(5)	40(5)	1(5)	103(5)	36(5)	8(5)	10(5)
LITTORAL TO SHELF BREAK (2 to < 200M)										
5(19)	2(2) 5(4) 35(5) 1(9) 4(12) 25(13 45(17) 3(19)	21(2) 10(4) 174(5) 2(9) 9(12) 10(13) 14(19)	41(5) 6(9) 2(12) 5(13) 5(19)	17(4) 107(5) 246(8) 4(12) 24(13) 17(19)	4(2) 36(4) 268(5) 39(9) 17(12) 32(13) 16(19) 110(20)	7(5) 2(9) 2(12) 1(13)	61(2) 207(3) 420(5) 57(6) 42(9) 62(12) 38(13) 241(14) 66(15) 74(18) 27(19)	81(2) 43(4) 249(5) 35(9) 48(12) 70(13) 16(19)	41(2) 9(4) 93(5) 3(9) 14(12) 13(13) 2(19)	48(5) 3(12) 78(13) 2(19)
CONTINENTAL SLOPE (200 to < 3000M)										
No Data	6(7) 6(11) 1(16)	16(7) 7(11) 6(16)	4(7)	1(7)	91(7) 2(11) 1(16)	8(7) 1(11)	84(7) 4(11)	167(7) 16(11) 3(16)	20(7) 12(11) 9(16)	5(7) 8(11)
SLOPE BASE/CONTINENTAL RISE (>3000M)										
No Data	2(7) 1(16)	4(7) 2(16)	1(7)	11(7)	47(7)	2(7)	35(7)	84(7) 1(16)	4(7) 3(16)	1(7)

AUTHOR LIST

1. Andrews, 1956
2. Cerame-Vivas and Gray, 1966
3. Coomans, 1962
4. Cowles, 1930
5. Gosner, 1971
6. Henderson and Bartsch, 1915
7. Hessler and Sanders, 1967
8. Maturo, 1968
9. McCloskey, 1970
10. McDougal, 1943
11. Menzies, 1972
12. Menzies, 1966
13. Pearse and Williams, 1951
14. Porter, 1971
15. Porter, 1972
16. Rowe and Menzies, 1969
17. Wells et al., 1960
18. Wells et al., 1964
19. Wells and Gray, 1964

EXAMPLE OF USE: 3 species of Porifera in the Estuary Zone were identified by author No. 5 (Gosner, 1971).



NOTE:
DIVERSITY VALUES (H') FOR MACROBENTHOS OFF VIRGINIA (BOESCH, 1972), THE NORTH CAROLINA CONTINENTAL SLOPE (GRASSLE, 1967), BUZZARDS BAY AND LONG ISLAND SOUND (SANDERS, 1956, 1960), CHARLESTON POND, R.I. (PHELPS, 1964), THE POCASSET RIVER, MASS. (SANDERS, ET AL., 1965), PUGET SOUND (LIE, 1968), ARTHUR HARBOR, ANTARCTICA (LOWERY, 1969), YORK RIVER AT YORKTOWN (WARINNER AND BREHMER, 1966), SAN FRANCISCO BAY (PEARSON ET AL.,1967), AND LOS ANGELES AND LONG BEACH HARBORS (REISH, 1959).

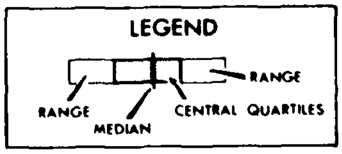


FIGURE 35. DIVERSITY VALUES FOR MACROBENTHOS OFF VIRGINIA AND OTHER AREAS

offshore waters between Delaware and Cape Lookout are "healthy." Diversity values compare favorably with those of other geographic areas, including highly productive temperate regions. Of the regions where diversity has been calculated, it is lowest only in the polluted Hampton Roads and York River - James River regions (fig. 35) (Boesch, 1972).

e. Zoogeographic distribution--Though most animals are restricted by temperature and other regimes, some are cosmopolitan and inhabit numerous zoogeographic provinces. In studies of marine benthos large geographic areas, called faunal provinces, are delineated by sharp temperature boundaries and/or prominent physiographic features of adjacent landmasses.

Cape Hatteras has long been recognized as an important faunal boundary because of the sharp north-south temperature change associated with it and the position of the Gulf Stream relative to it. At Cape Hatteras, the northerly flowing Gulf Stream, with its relatively warm water, comes into dynamic contact with the southerly flowing colder water of the coastal current. Both water masses bend to the east and flow away from the coast (Vernberg and Vernberg, 1970a). The marine area between Cape Cod and Cape Hatteras is often called the Virginian Faunal Province; and the area from Cape Hatteras to Cape Kennedy, Florida, the Carolinian Faunal Province (fig. 36) (Coomans, 1962). The area offshore from North Carolina and beneath the Gulf Stream inhabited by warm-water organisms is called the Tropical Faunal Province (fig. 36) (Cerame-Vivas and Gray, 1966).

Although authorities disagree over delineation and naming the faunal provinces north and south of Cape Hatteras, many of the species that occur north of Cape Hatteras do not occur south of it and vice versa. For example, less than 30 percent of the Carolinian decapod fauna occurs north of Cape Hatteras (Gosner, 1971). Less than 50 percent of the Virginian mollusc fauna ranges south of Cape Hatteras, and 42 percent of the molluscs found at Beaufort occur in the Virginian province (Coomans, 1962). Opisthobranch molluscs are generally widespread in distribution except for tropical west Atlantic species, which are prevented from extending northward by Cape Hatteras (Franz, 1970). Of 74 species of algae collected at Delaware, all are known to occur north of Cape May, New Jersey, and 47 are known to occur south of Cape Hatteras (Table II). Thus, the algae of the Delaware area is temperate-boreal and originate from cold northern waters (Zaneveld, 1972).

In laboratory experiments species of invertebrates of the Cape Hatteras area, with southern affinity, survive higher temperatures than more northerly displaced species. Many of the southern-affinity species could not survive low temperatures that are characteristic of either the water mass north of Cape Hatteras (Virginian) or the waters between the Gulf Stream and the shore (Carolinian) (Vernberg and Vernberg, 1970b).

Of the 107 species of organisms found on a submerged reef southeast of Cape Lookout, 97 (91 percent) have southern distributional affinities, 6 (5 percent) are cosmopolitan, and 4 (4 percent) are typical northern forms (Menzies, et al., 1966). Only 8 of the 211 species found north, south, and east of Cape Hatteras are common to all three faunal provinces (Virginian, Carolinian, and Tropical) (fig. 36). Sixteen percent of the Carolinian species occur offshore in the Tropical province. Ten percent of the Carolinian fauna are found in the Virginian province. Species found in the Virginian province were not found in the Tropical province (fig. 36). Thus, the bottom temperature boundaries, which reach a maximum difference of 15°C in winter, are formidable barriers between these areas (Cerame-Vivas and Gray, 1966).

Though Cape Hatteras is a well-known barrier to the distribution of littoral benthic animals, some overlaps exist in distribution of species north and south of it, as indicated in the percentages given above. Also, some northern and southern species have overlapping thermal limits as determined in laboratory experiments (Vernberg and Vernberg, 1970a & b). Certain organisms of the benthos, such as polychaetes, are eurythermal, and, though they display northern and southern affinities, some species occur in both the Virginian and Carolinian provinces (Wells and Gray, 1964). The intertidal organisms at Beaufort and Cape Lookout have southern affinities, but many of them also occur north of Cape Hatteras or are cosmopolitan, prompting Stephenson and Stephenson (1952) to call the Carolinian province the "Transitional Faunal Province."

The blue mussel Mytilus edulis, which is a typical northern cold-water animal, occasionally is transported in the larval stage southward around Cape Hatteras by storm-generated water currents. Thus, M. edulis, which is killed by 80°F water temperatures, and another northern species Balanus balanoides, occur sporadically during the winter at Beaufort and other Carolinian locations (Wells and Gray, 1960a). These northern-affinity species, however, are transported and survive transport only during the winter when water temperatures are tolerable and die during the summer (Cerame-Vivas and Gray, 1966).

f. Discussion--As indicated by the community composition, distribution, diversity, and abundance data presented above, the benthos of the Hampton Roads/Norfolk Operating Area is a very important part of the marine ecological system. The abundance and biomass of the benthic organisms on the Continental Shelf are high, decreasing gradually down the continental slope. The diversity of the benthic communities at all depths is high, except in polluted inshore waters. Commercially important molluscs and crustaceans are abundant on the shelf. Depth and distribution patterns of the benthic communities are stable and predictable. The influence of the warm Gulf Stream, particularly off Cape Hatteras, increases the productivity and diversity of the benthos of the Area.

In the event of thermal addition, oil spill, toxic dumping, spoils dumping, or other large-scale environmental stress, baseline data on the benthos are sufficient in most parts of the Area, particularly near Cape Hatteras and Chesapeake Bay, to assess damage to or change in the benthic communities with respect to abundance, biomass, community composition, and diversity of the benthic communities. For example, in the vicinity of large or active spoil dumps on the shelf, benthic biomass, abundance, and diversity should decrease and community composition should change as the organisms affected are killed or driven away. Because of the interdependence of the organisms on various trophic levels and depth zones, environmental stress that results in changes to the plankton population will be reflected in subsequent changes in the benthos. Likewise, changes in the filter-feeding benthic population will influence the abundance of predatory sea stars, crabs, fishes, and other animals. Finally, food chains and exchanges and transport of organic matter between depth zones may result in stresses exerted on one part of the ecosystem to be reflected in changes in community composition and abundance in another part.

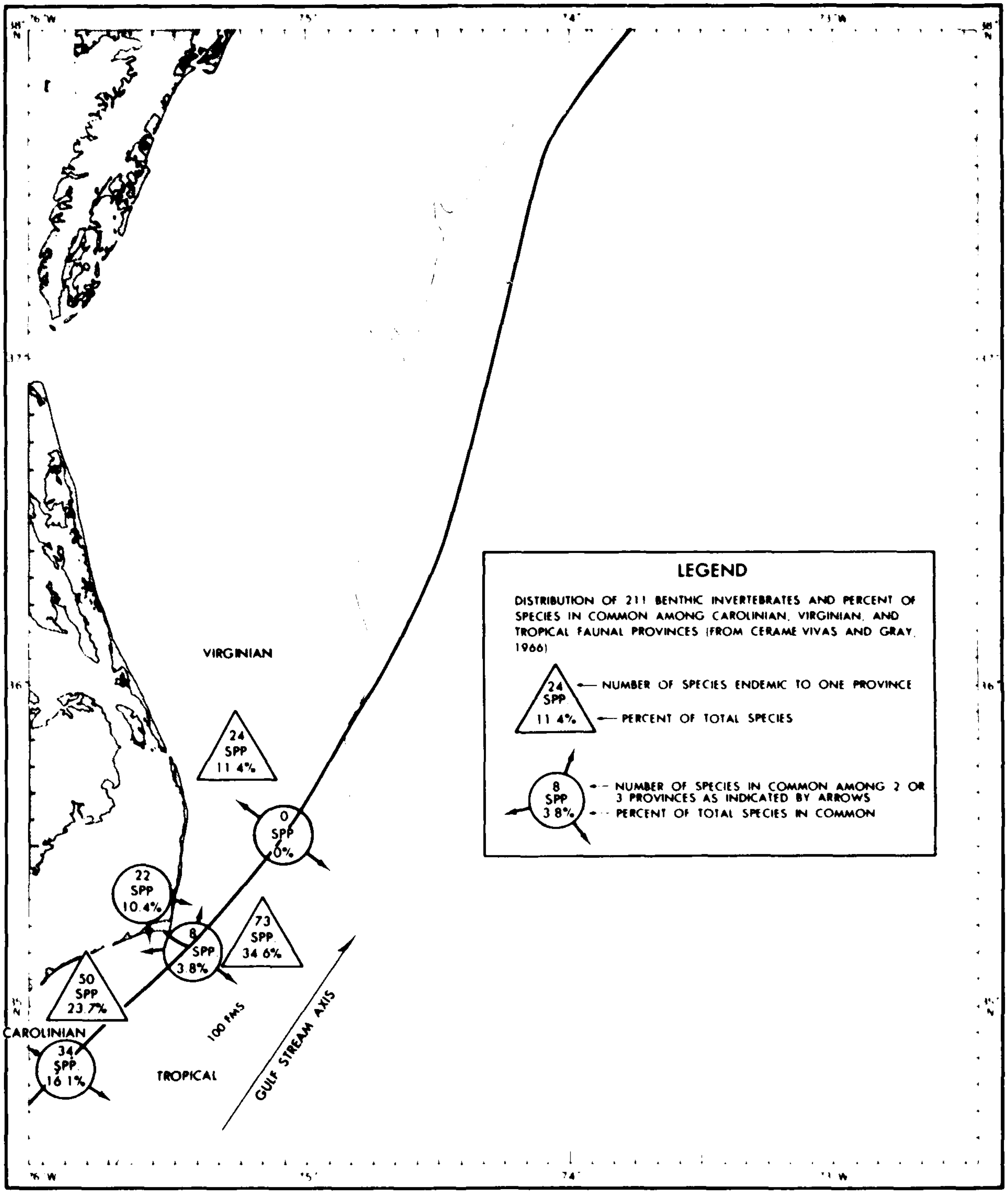


FIGURE 36. DISTRIBUTION OF BENTHIC INVERTEBRATES IN FAUNAL PROVINCES

TABLE II. GEOGRAPHIC DISTRIBUTION AND SEASONAL OCCURRENCE OF PRINCIPAL LITTORAL ALGAE BETWEEN CAPE MAY, NEW JERSEY AND CAPE HATTERAS, NORTH CAROLINA

SPECIES	DISTRIBUTION	MONTHS + PRESENT - ABSENT											
Cyanophyta	States	J	F	M	A	M	J	J	A	S	O	N	D
1. *Entophysalis deusta*	N.J. Del. Md. Va.	-	-	-	+	-	+	+	+	-	-	-	-
2. [illegible]	Del. Md.Va. N.C.	-	+	-	-	-	+	+	+	-	-	-	-
3. [illegible]	Del. Va.	-	-	-	-	-	+	-	+	-	-	-	-
4. [illegible]	Del. Md. Va. N.C.	-	-	-	-	-	+	-	+	-	-	-	-
5. [illegible]	Del. Va.	-	-	-	-	-	+	-	-	+	-	-	-
6. [illegible]	Del. Va.	-	-	-	-	-	+	-	+	-	-	-	-
7. [illegible]	Del. Va.	-	-	-	-	-	+	+	-	-	-	-	-
8. *Microcoleus chthonoplastes*	Del. Md. Va. N.C.	-	-	-	-	-	+	-	+	-	-	-	-
9. *Lyngbya confervoides*	N.J. Del. Md. N.C.	-	-	-	-	-	+	+	+	-	-	-	-
10. *Lyngbya aestuarii*	Del. Md. Va. N.C.	-	-	-	-	-	+	+	-	-	-	-	-
11. *Lyngbya semiplena*	Del. Md. Va. N.C.	-	+	-	-	-	+	+	+	+	-	+	-
Chlorophyta and Xanthophyta		J	F	M	A	M	J	J	A	S	O	N	D
1. [illegible]	Del.	-	-	-	+	-	-	-	-	-	-	+	-
2. [illegible]	Del.	-	-	-	-	-	+	-	-	-	-	-	-
3. [illegible]	Del. Md. Va.	-	-	-	-	-	+	-	-	-	-	-	-
4. [illegible]	Del. Va.	+	+	-	+	-	+	+	-	-	-	+	-
5. [illegible]	Del. Va.	-	-	-	-	-	+	-	-	-	-	-	-
6. [illegible]	N.J. Del. Md. Va.N.C.	-	-	-	+	+	+	+	-	-	-	-	-
7. *Enteromorpha intestinalis*	N.J.Del.Md.Va.N.C.	+	+	+	+	+	+	+	+	+	+	+	-
8. *Enteromorpha linza*	N.J.Del.Md.Va.	+	+	-	-	+	+	+	+	-	-	+	-
9. *Ulva lactuca* var. *latissima*	N.J.Del.Md.Va.N.C.	-	+	-	-	+	+	+	+	+	-	+	-
10. *Ulva lactuca* var. *rigida*	Del. Va. N.C.	-	-	-	+	-	+	-	-	+	-	-	-
11. [illegible]	Del.	-	-	-	+	-	-	-	-	-	-	-	-
12. [illegible]	Del.	-	-	-	+	-	-	-	-	-	-	-	-
13. [illegible]	Del. Md.	-	-	-	-	-	+	+	-	-	-	-	-
14. [illegible]	Del.	-	-	-	-	-	+	-	-	-	-	-	-
15. *Rhizoclonium riparium*	Del. Va.	-	-	-	-	-	-	-	-	+	-	-	-
16. [illegible]	Del. Va.	-	-	-	-	+	-	+	+	-	-	+	-
17. [illegible]	Del. Va. N.C.	-	-	-	-	-	+	+	-	-	-	-	-
18. [illegible]	Del. Va.	-	-	-	-	+	+	+	+	+	+	-	-
19. *Cladophora expansa*	Del. Va.	-	-	-	-	-	+	-	-	-	-	-	-
20. *Bryopsis hypnoides*	Del. Md. Va.	-	-	-	+	-	+	-	-	-	-	-	-
21. *Bryopsis plumosa*	N.J. Del. Md. Va.	-	+	-	+	+	+	+	-	-	-	+	-
22. [illegible]	Del. Va.	+	-	-	-	-	+	-	-	-	-	-	-
Phaeophyta		J	F	M	A	M	J	J	A	S	O	N	D
1. [illegible]	N.J.Del.Md. Va.	+	-	+	-	-	+	+	-	-	-	+	-
2. *Ectocarpus confervoides*	Del. Md. Va. NC.	+	-	-	+	+	+	+	-	-	+	-	-
3. *Ectocarpus fasciculatus*	N.J. Del.	-	-	-	-	-	+	-	-	-	-	-	-
4. *Ectocarpus tomentosus*	Del.	-	-	-	-	-	+	-	-	-	-	-	-
5. [illegible]	Del.	-	-	-	+	-	-	-	-	-	-	-	-
6. *Ralfsia verrucosa*	Del.	-	-	-	-	-	+	-	-	-	-	-	-
7. *Elachistea fucicola*	Del.	-	-	-	-	-	+	-	+	-	-	-	-
8. *Leathesia difformis*	Del. Va. N.C.	-	-	-	-	+	-	-	-	-	-	-	-
9. *Punctaria plantaginea*	Del. Md.	-	-	-	+	-	+	+	-	-	-	-	-
10. *Petalonia fascia*	Del. Md. Va.	-	-	-	-	-	+	+	-	-	-	-	-
11. *Scytosiphon lomentaria*	N.J. Del. Md. Va.	-	-	-	+	-	+	+	-	-	-	-	-
12. *Ascophyllum nodosum*	Del. Md. Va.	-	-	-	-	-	+	+	+	+	+	+	-
13. *Fucus edentatus*	Del. Md. Va.	-	-	-	-	-	-	+	-	-	-	-	-
14. *Fucus spiralis*	Del. Md. Va.	-	-	-	-	-	-	-	+	-	-	-	-
15. *Fucus vesiculosus*	Del. Md. Va. N.C.	-	+	+	+	+	+	+	+	+	+	+	-
16. [illegible]	N.J. Del. Md. Va.	-	-	-	-	-	+	+	-	-	-	+	-
17. [illegible]	Del. Md. Va.	-	-	-	-	-	+	-	-	-	-	-	-
18. [illegible]	Del.	-	-	-	-	-	+	-	-	-	-	-	-
19. [illegible]	Del. Va. N.C.	-	-	-	-	+	-	+	+	+	+	-	-
20. *Sargassum natans*	Del. Md. Va. N.C.	-	-	-	-	-	-	+	+	-	-	+	-
Rhodophyta		J	F	M	A	M	J	J	A	S	O	N	D
1. *Bangia fuscopurpurea*	Del. Md. Va.	-	+	-	+	-	+	+	-	-	-	-	+
2. *Porphyra umbilicalis*	N.J.Del. Md. Va.	+	+	-	+	-	+	+	-	-	+	-	+
3. *Agardhiella tenera*	N.J.Del.Va.N.C.Md.	+	+	+	+	-	+	+	+	+	+	-	-
4. *Hypnea musciformis*	Del. Md. Va.	-	-	-	-	-	-	+	+	-	-	-	-
5. *Gracilaria verrucosa*	N.J.Del.Md.Va.N.C.	+	+	+	+	+	+	+	+	-	+	-	-
6. *Gracilaria foliifera*	N.J.Del.Md.Va.N.C.	-	-	-	-	-	-	-	+	-	-	-	-
7. *Phyllophora membranifolia*	Del.	-	-	-	+	-	-	-	-	-	-	-	-
8. *Chondrus crispus*	Del. Va.	-	-	-	-	-	+	+	-	-	-	-	-
9. [illegible]	N.J. Del. Md. Va.	-	-	-	-	-	+	-	-	-	-	-	-
10. [illegible]	N.J. Del.	-	-	-	+	-	-	-	-	-	-	-	-
11. [illegible]	N.J. Del. Md. Va.	-	-	-	-	-	+	+	+	-	-	-	-
12. *Ceramium strictum*	N.J.Del.Md.Va.N.C.	-	-	-	+	-	+	+	+	-	-	+	-
13. [illegible]	Del. Md. Va.	-	-	-	-	-	-	+	-	-	-	-	-
14. *Ceramium rubrum*	N.J. Del. Md. Va.	+	+	+	+	+	+	+	+	+	-	+	-
15. *Chondria tenuissima*	Del. Md. Va.	-	-	-	-	-	+	+	+	-	-	-	-
16. *Polysiphonia harveyi*	Del. Md. Va. N.C.	-	-	+	-	+	+	+	+	-	-	+	-
17. *Polysiphonia subtilissima*	Del.	-	-	-	-	-	-	-	-	-	-	+	-
18. [illegible]	N.J.Del.Md.Va.N.C.	-	-	-	-	-	+	+	-	-	-	-	-
19. *Polysiphonia denudata*	N.J.Del.Md.Va.N.C.	-	-	-	-	+	+	+	+	+	-	+	-
20. *Polysiphonia nigrescens*	Del.Md.Va. N.C.	-	+	-	-	+	+	+	-	-	-	-	-

(AFTER ZANEVELD, 1972)

3. Fisheries

a. Introduction--The waters of the Hampton Roads/Norfolk Operating Area support a wide variety of valuable fishes and several commercially important species of shellfish. Exploitation by U.S. and foreign fishermen is fairly heavy. A commercial (figs. 37 and 38) fishery for both human consumption and industrial purposes (i.e., catch converted to meal and oil) is active, with most of the catch taken within or along the 100-fathom contour. In addition, a widespread and active sports fishery exists, mainly in protected or nearshore waters.

A key feature of the fish population in the Area is the extent of migratory activities by many of the species. Two basic migratory patterns are discernible, namely, north-south and onshore-offshore. The major species that migrate north-south include menhaden, bluefish, Atlantic mackerel, Spanish mackerel, and striped bass. These migrations are essentially coastal and seldom extend seaward of the Continental Shelf edge. The northward migration usually takes place in spring and the return migration in autumn. Tuna migrate in the offshore waters of the Chesapeake bight.

The onshore-offshore migration pattern is primarily a response to temperature conditions, away from shallow waters as they rapidly cool in autumn and toward them in spring, when temperatures rise and the supply of food organisms also rises. Thus, many of the commercial species included in this migratory pattern, such as flounder, spot, porgy (scup) (which also moves somewhat northwestward in spring and southeastward in autumn), weakfish, croaker, etc., exhibit seasonal catch patterns, i.e., largest catches offshore in winter and nearshore in summer.

In describing the fisheries of the study Area, the significance of the sounds, bays, and estuarine regions forming its shoreward fringe should not be overlooked. Some of the major ocean species spawn in these shallower, less saline waters; others feed there extensively, taking advantage of the enhanced productivity created by nutrients from land runoff. Especially vital to the life cycles of many of the ocean species is the value of the fringing shore waters as protected nursery grounds where their young can feed and grow, free from oceanic turbulence (fig. 39). Most of the shellfish resources also depend on the quieter, more productive inshore waters for their well being. Brief reviews of the commercial, industrial, and sports fisheries of the Area are given below.

b. Commercial fisheries

(1) Offshore--The waters seaward of the 15-fathom curve are exploited in this fishery. Heaviest fishing occurs near the indentations along the 100-fathom curve during the period October through May. Using the otter trawl, U.S. vessels of 50 feet or more in length catch up to 200,000 pounds of fish per trip of 2 to 6 days. The catch is mixed in this bottom fishery; major species include porgy, fluke, butterfish, harvestfish, and sea bass. Shellfish taken offshore by dredges include surf clams and sea scallops (fig. 40). An offshore lobster population is also currently being exploited by U.S. fishermen.

Using somewhat modified methods such as midwater trawls and high-opening otter trawls, foreign fishermen exploit Continental Shelf waters of the study Area, seeking mainly herring and mackerel. In 1971, 201 Soviet and

28 other eastern European large stern and side trawlers fished in the Area mainly during the period January through April (fig. 41). Other species such as sea robin, hakes, and butterfish are sometimes taken; some of these may be processed for industrial use. An estimated 91.1 million pounds worth $3.6 million were taken in this foreign fishery in 1971 (U.S. Dept. Comm., 1972). The Japanese also fish in the deeper waters of the Area, especially in autumn, for tuna and swordfish. Their 1971 catch of these species, obtained by 11 longline vessels, was 462,000 lb., worth $143,000 (U.S. Dept. Comm., 1972). U.S. longliners are also beginning to exploit offshore tuna concentrations, and purse seines have also been used with variable results.

(2) Nearshore--Most of the U.S. fishing vessels fishing in the area are small or medium-sized craft. They make daily trips during their main season of May through November, staying largely within the 15-fathom curve. The principal gear of the nearshore bottom fishery is the otter trawl, which takes fluke, weakfish, porgy (scup), croaker, butterfish, harvestfish, and sea bass. Bottom-dwelling shellfish such as clams and scallops are taken in nearshore waters by a variety of scraping and grabbing gear (see below), which also frequently take finfish species. Other gear operated on the bottom include sea bass pots and the shrimp trawl (modified otter trawl in North Carolina).

The purse seine is the principal upper water gear in nearshore commercial fishing operations. It is used in the menhaden fishery. Sometimes spotter airplanes help to locate the fish. Drift gill nets catch other migrating pelagic fishes, such as striped bass, in nearshore waters.

Chesapeake Bay catches are often regarded as a separate component in the fisheries of this Area. Fishing gear used in the bay are also typical of those used from other shorelines along the Area; these miscellaneous gear include set gill and pound nets, haul seines, fyke or hoop nets, small pots and traps, and various drag and grabbing gear. The importance of bay and estuarine waters in the life cycles of many ocean species has already been mentioned. The value of the bay catch far exceeds that of the ocean for Maryland and Virginia (see Tables III to VI).

c. Industrial fisheries--Between 40 and 50 percent of all fishery products landed in the United States are reduced for industrial use. Two major industrial fisheries are conducted by U.S. fishermen in the study Area. The menhaden purse-seine fishery catches enormous numbers of this schooling, pelagic, migratory fish (see Tables III to VI). Numerous thread herring are also taken incidentally with menhaden during the fall fishery off North Carolina. The meal made from menhaden is used as a supplement in livestock feeds, while the oil serves in a variety of commercial products. The menhaden resource has been marked by large fluctuations in abundance. Figure 42 shows the distribution of the major industrial fish species.

The trawl fishery incident to its regular operation takes a wide variety of edible and nonedible bottom fishes, most of which (91 percent) are used for meal (poultry feed). The 1965 catch in Maryland was 12.5 million pounds, mainly from summer trawling on inshore Atlantic grounds. Two million pounds of Virginia's 4.5-million-pound catch were from pound nets in lower Chesapeake Bay. Half of North Carolina's 8-million-pound industrial trawl catch came from Pamlico Sound and coastal waters. Thirty-two reduction plants operated in the Area in 1969, whose products had a value of $9,956,048 (U.S. Dept. Comm., 1972).

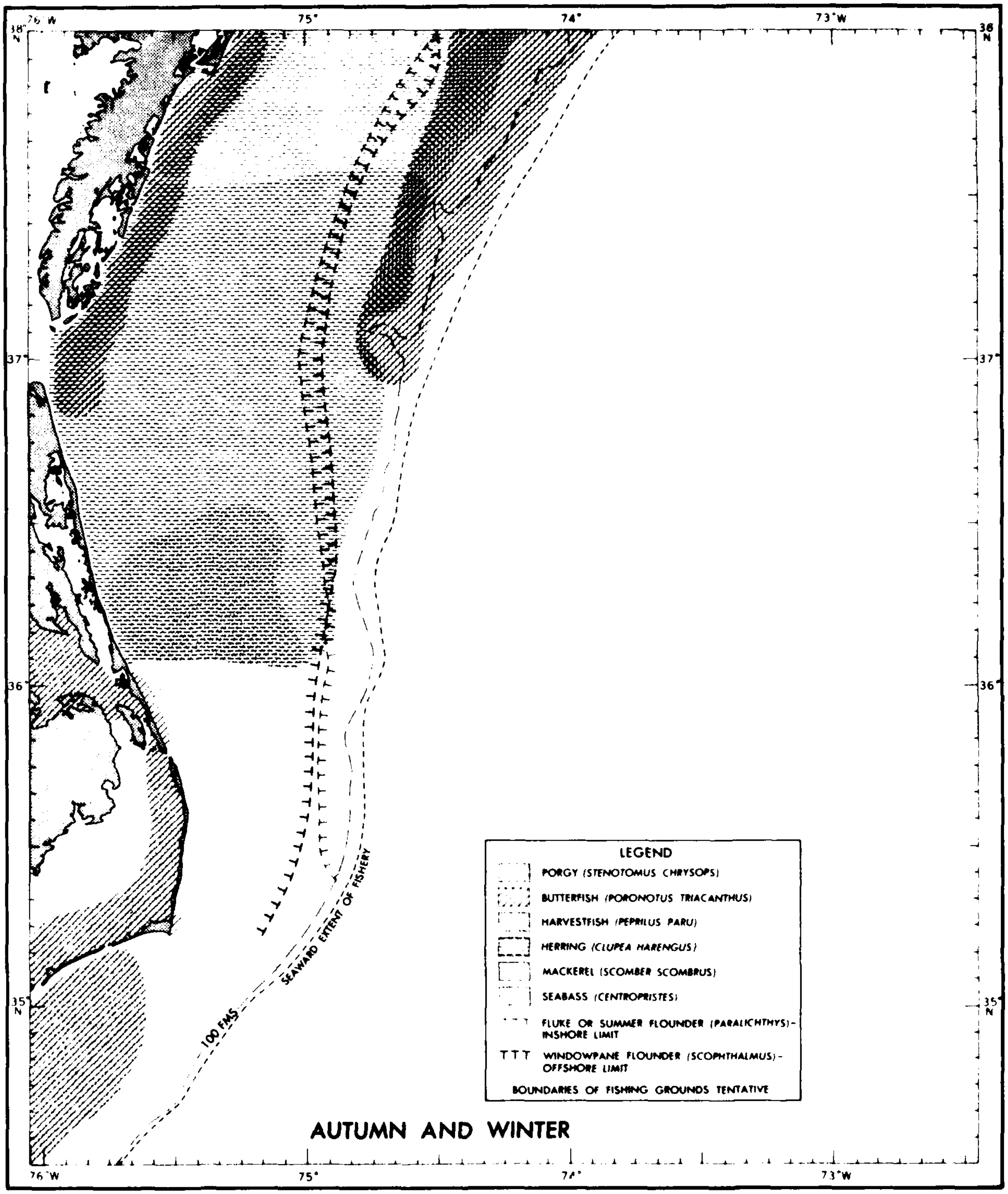


FIGURE 37 DISTRIBUTION OF DEMERSAL FISHERIES

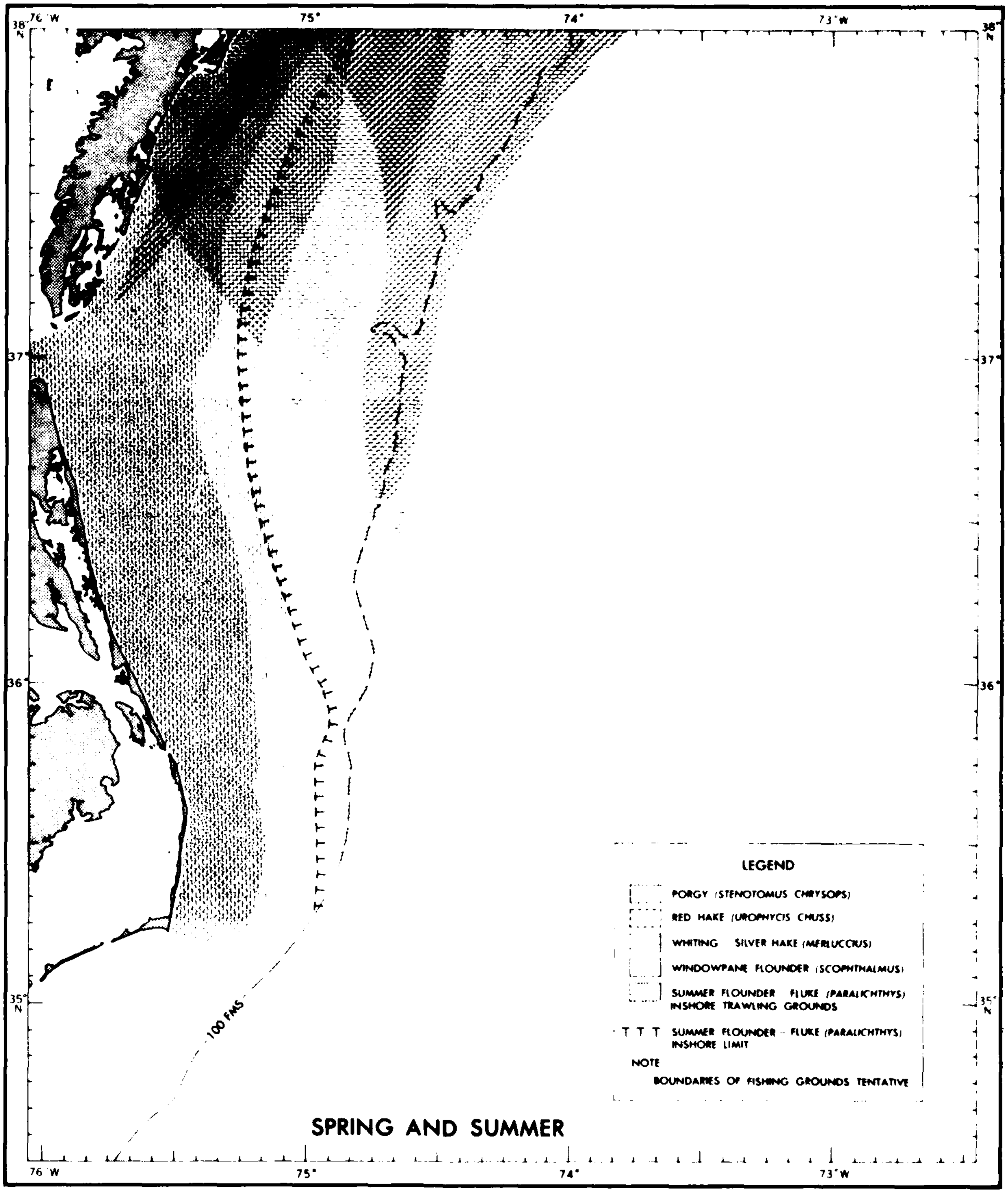


FIGURE 37 DISTRIBUTION OF DEMERSAL FISHERIES (CON)

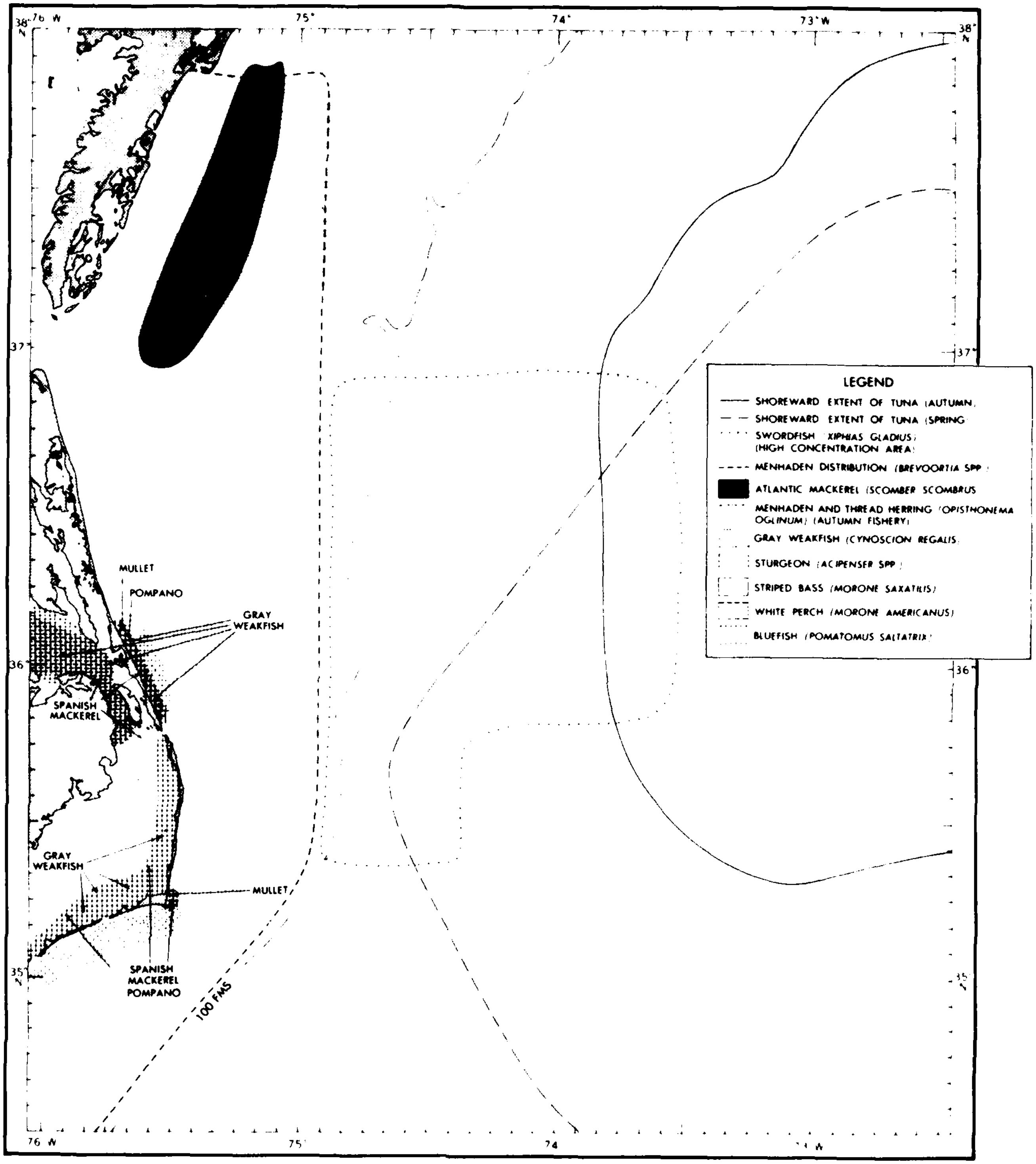
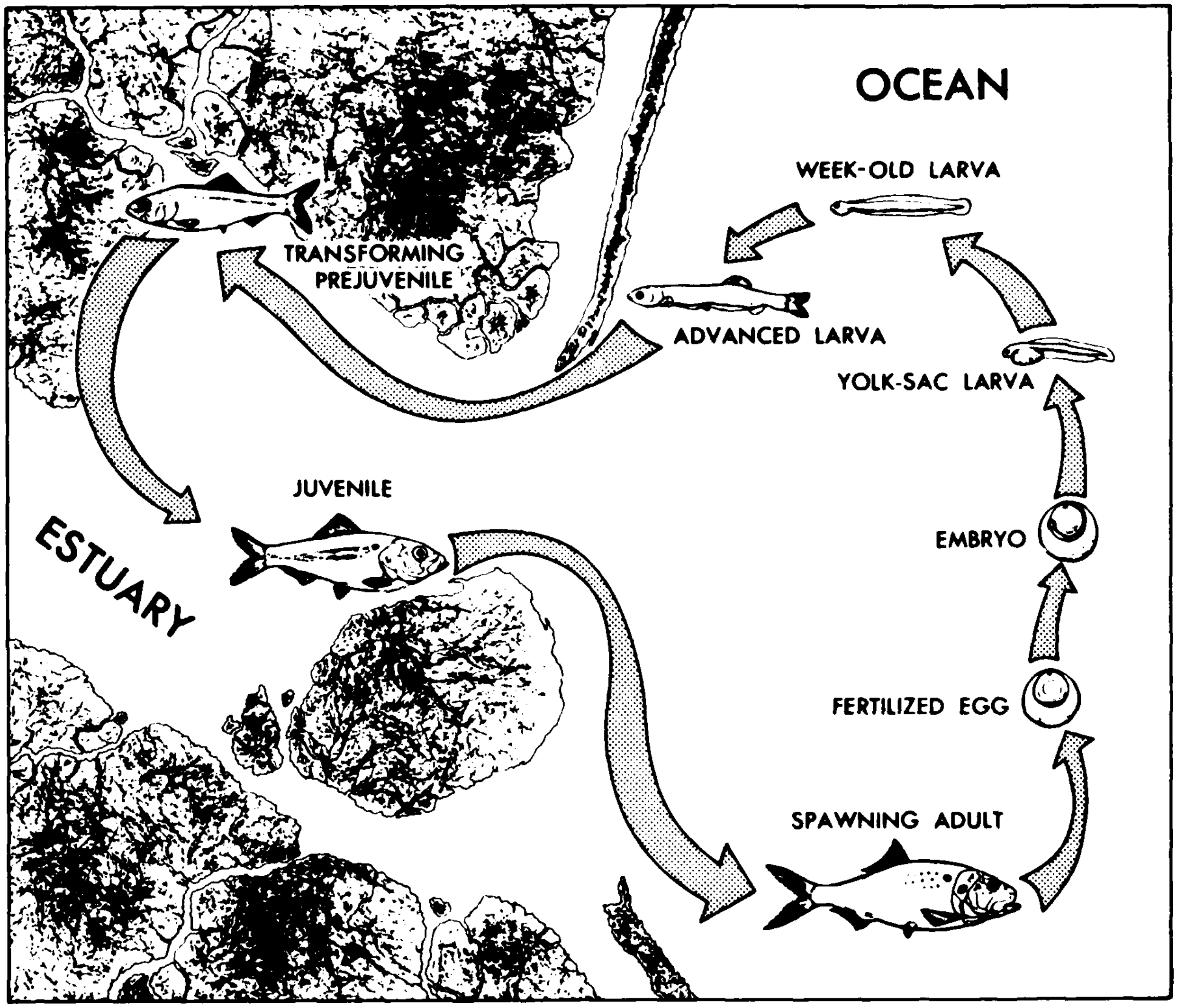


FIGURE 38 DISTRIBUTION OF PELAGIC FISHERIES



(FROM SHAPIRO, S., 1971)

FIGURE 39. SCHEMATIC OF FISH LIFE HISTORY

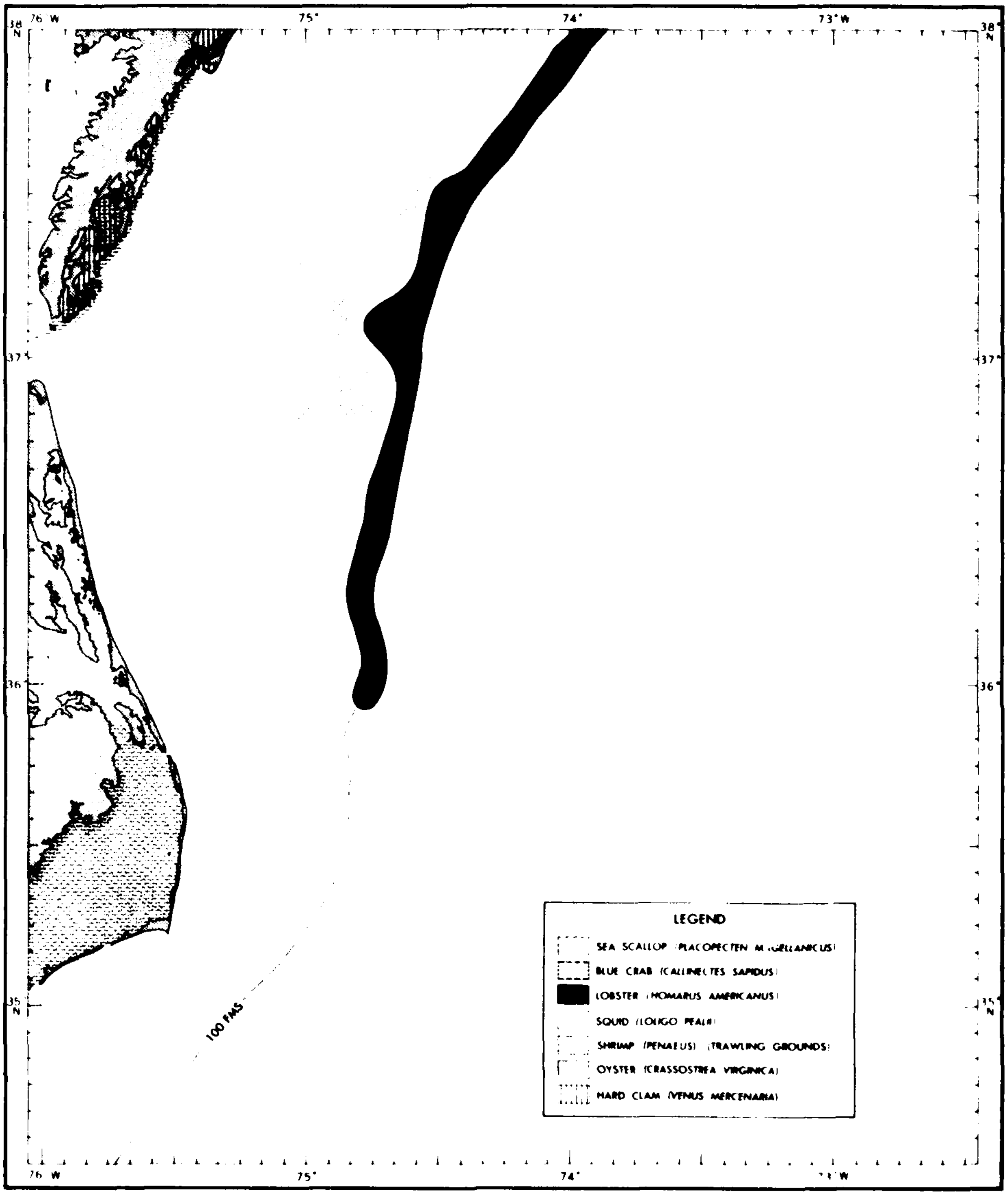
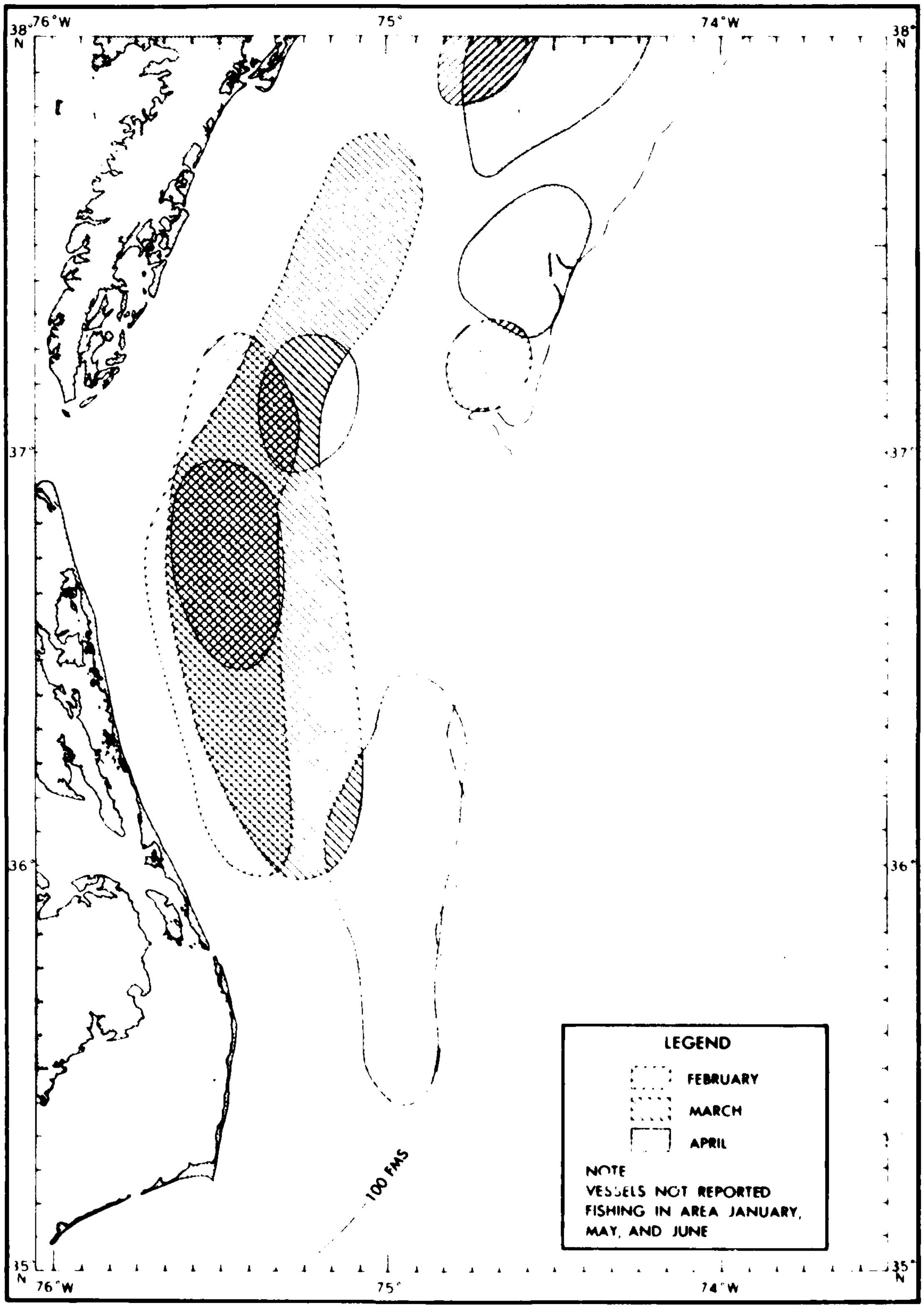


FIGURE 40. DISTRIBUTION OF SHELLFISH



(AFTER U.S. DEPT OF COMMERCE, 1972)

FIGURE 41 DISTRIBUTION OF FOREIGN FLEETS

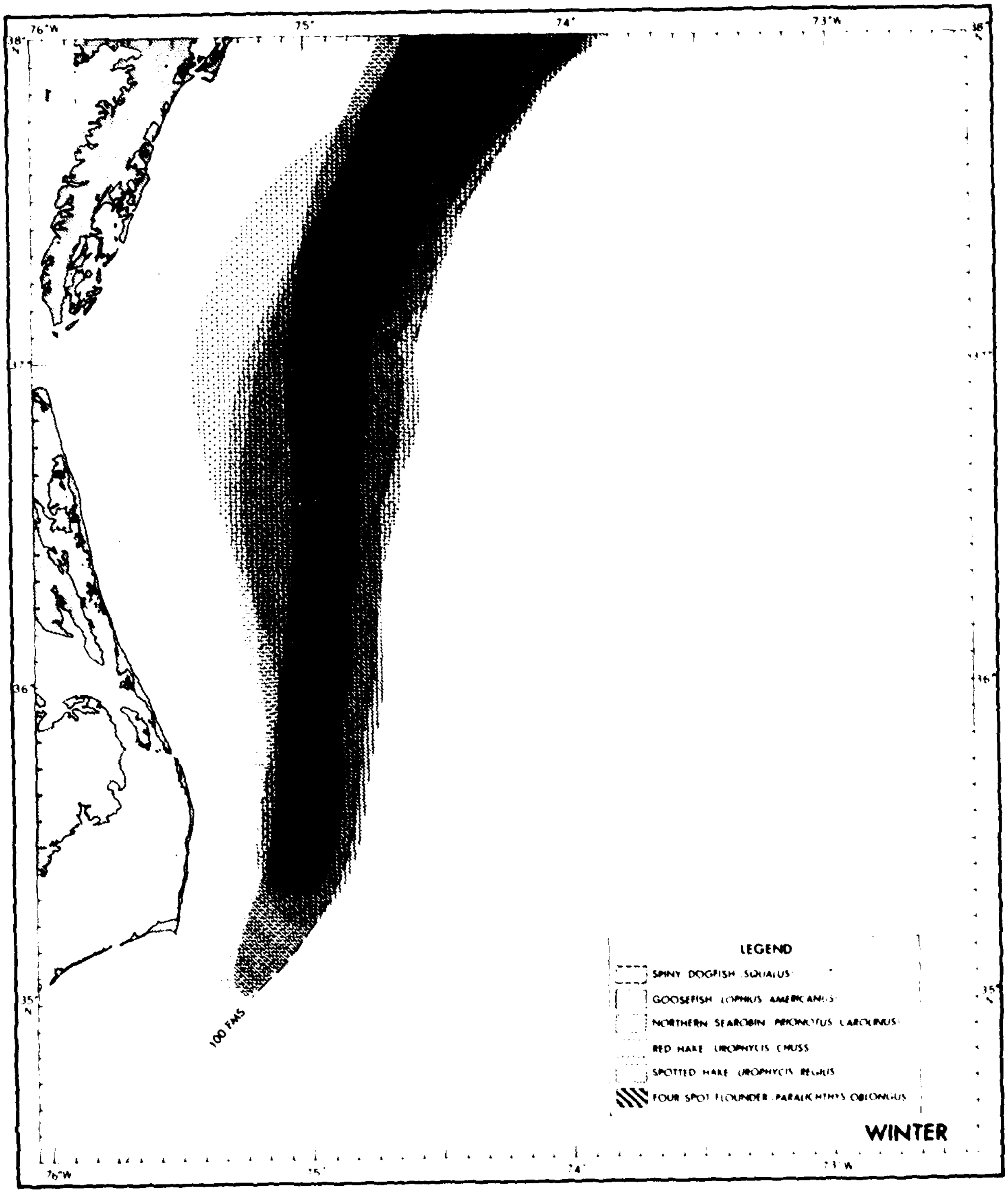


FIGURE 42 INDUSTRIAL FISHERIES

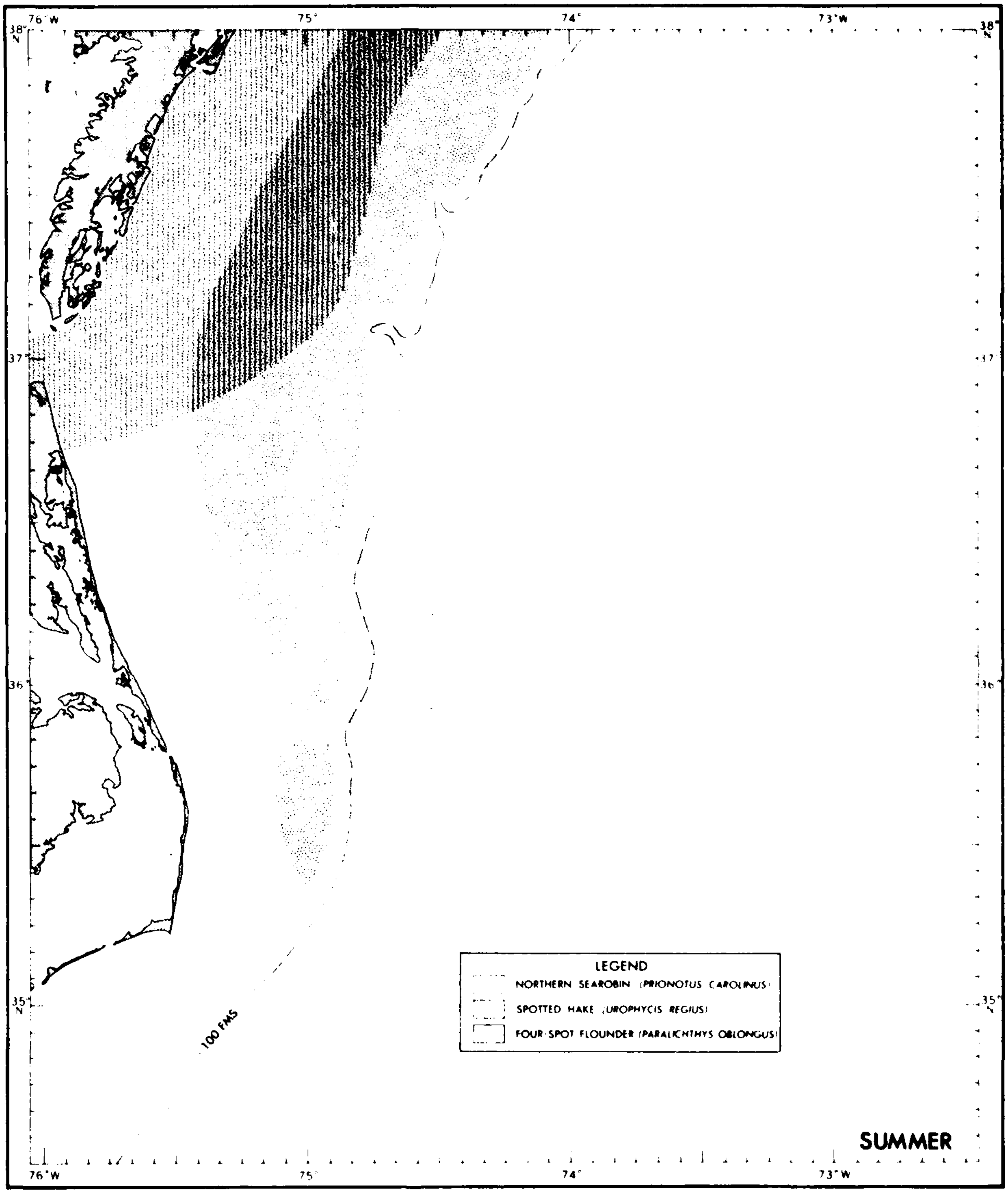


FIGURE 42 INDUSTRIAL FISHERIES (CON.)

TABLE III. COMMERCIAL FISHERIES CATCH—MARYLAND OCEAN WATERS

Species-Annual Catch over $50,000	1969 QUANTITY, #	1969 VALUE, $	1970 QUANTITY, #	1970 VALUE, $	1971 QUANTITY, #	1971 VALUE, $
Flounders	200,500	68,355	384,700	93,041	308,911	102,074
Sea Bass	147,000	35,412	202,300	60,744	127,908[1]	41,305[1]
Sea Trout (gray weakfish)	165,600	14,149	279,600	24,084	344,103	24,500
Striped Bass	211,900	45,150	290,000	57,550	113,874	43,099
Crabs, blue (hard, soft, & peeler)	163,700	24,755	323,400	19,640	251,600	29,685
Lobsters	26,500	23,957	[illegible]	20,465	28,088	28,[illegible]
Clams:						
hard	759,800	442,071	521,500	287,295	352,986	[illegible]
surf	7,126,901	891,619	13,661,200	1,474,777	7,294 459	914,199
Conchs	99,500	[illegible]	[illegible]	64,390	60,678	9,658
Oysters	127,200	418,[illegible]	[illegible]	309,[illegible]	157,600	295,500
TOTAL including miscellaneous species	9,631,900	2,004,310	16,410,900	2,434,566	9,158,814	1,673,852

\# Pounds

[1] Excluding December

NOTE: Fish and crab quantities in round or live weights; clams, conchs, and oysters in total meats; scallops in edible meats.

NOTE NUMBERS FOR EACH SPECIES DO NOT ADD TO TOTALS

TABLE IV. COMMERCIAL FISHERIES CATCH—CHESAPEAKE BAY, INCLUDING TRIBUTARIES

Species-Annual Catch over $50,000	1969 QUANTITY, #	1969 VALUE, $	1970 QUANTITY, #	1970 VALUE, $	1971[1] QUANTITY, #	1971[1] VALUE, $
Alewives	13,903,500	677,339	21,110,400	444,199	8,839,167	215,213
Bluefish	N.A.	N.A.	[illegible]	[illegible]	414,981	[illegible]
Catfish & Bullheads (freshwater)	[illegible]	202,624	[illegible]	[illegible]	N.A.	N.A.
Eel	[illegible]	[illegible]	1,492,901	[illegible]	474,858	[illegible]
Menhaden	[illegible]	[illegible]	[illegible]	[illegible]	16,[illegible][2]	[illegible]
Sea Trout (gray weakfish)	[illegible]	84,998	[illegible]	[illegible]	[illegible]	[illegible]
Shad	3,535,200	290,184	5,134,400	420,928	1,069,878	111,009
Spot	[illegible]	[illegible]	[illegible]	[illegible]	407,464	[illegible]
Striped Bass	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Swellfish	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
White Perch	2,481,500	423,801	[illegible]	[illegible]	[illegible]	[illegible]
Crabs	[illegible]	6,947,960	[illegible]	[illegible]	[illegible]	[illegible]
Clams: hard	[illegible]	[illegible]	467,800	[illegible]	[illegible]	[illegible]
soft	7,909,500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oysters (spring & fall)	21,930,600	13,578,43[illegible]	[illegible]	14,[illegible],449	[illegible]	[illegible]
TOTAL, including miscellaneous species of which several are freshwater	288,927,200	30,317,6[illegible]	541,827,400	42,968,[illegible]	[illegible]	[illegible]

\# Pounds

[1] 1971 species figures for Chesapeake Bay and its Maryland tributaries only; to calculate totals for the main and other tributaries add [illegible] pounds and $6,661,235.

[2] Menhaden data taken by purse seines not available for 1971.

N.A. = Data not available

NOTE: Fish and crab quantities in round or live weights; clams and oysters in total meats.

NOTE NUMBERS FOR EACH SPECIES DO NOT ADD TO TOTALS

(NATIONAL MARINE FISHERIES SERVICE, 1969 AND PRELIMINARY DATA FOR 1970 AND 1971)

TABLE V. COMMERCIAL FISHERIES CATCH - VIRGINIA OCEAN WATERS

Species Annual Catch over $50,000	1969		1970		1971	
	QUANTITY, #	VALUE, $	QUANTITY, #	VALUE, $	QUANTITY, #	VALUE, $
Butterfish	[illegible]	[illegible]	[illegible]	[illegible]	454,943	69,386
Flounders	[illegible]	486,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Menhaden¹	[illegible]	[illegible]	[illegible]	947,614	N.A.	N.A.
Porgy (Scup)	2,806,[illegible]	[illegible]	[illegible]	[illegible]	1,910,963	[illegible]
Sea Bass	[illegible]	[illegible]	[illegible]	306,588	[illegible]	114,518
Spot	N.A.	N.A.	[illegible]	[illegible]	N.A.	N.A.
Striped Bass	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weakfish	[illegible]	[illegible]	N.A.	N.A.	N.A.	N.A.
Crabs	N.A.	N.A.	[illegible]	[illegible]	[illegible]	[illegible]
Lobsters	[illegible]	[illegible]	[illegible]	148,882	[illegible]	200,[illegible]
Clams - hard soft	N.A. N.A.	N.A. N.A.	[illegible] [illegible]	[illegible] [illegible]	[illegible] 4,506,622	668,185 526,715
Oysters	N.A.	N.A.	[illegible]	486,089	810,621	548,069
Scallops, Sea	[illegible]	1,474,434	[illegible]	994,957	[illegible]	801,933
TOTAL, including miscellaneous species	[illegible]	[illegible]	[illegible]	5,140,783	[illegible]	[illegible],908,190

Pounds

¹Menhaden data taken by purse seines not available for 1971.

N.A. = Data not available

NOTE: Fish, lobster, and crab quantities in round or live weight; clams and oysters in total meats; scallops in edible meats.

NOTE NUMBERS FOR EACH SPECIES DO NOT ADD TO TOTALS

TABLE VI. COMMERCIAL FISHERIES CATCH - NORTH CAROLINA OCEAN WATERS

Species-Annual Catch over $50,000	1969		1970		1971	
	QUANTITY, #	VALUE, $	QUANTITY, #	VALUE, $	QUANTITY, #	VALUE, $
Alewives	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bluefish	[illegible]	[illegible]	N.A.	N.A.	[illegible]	[illegible]
Croaker	[illegible]	[illegible]	N.A.	N.A.	[illegible]	[illegible]
Flounders	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Herring, Thread	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Kingfish	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Menhaden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mullet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sea Bass	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sea Trout (Gray & Spotted)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shad	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spot	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Striped Bass	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Crabs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clams - hard	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oysters	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scallops - Bay Calico	[illegible]	[illegible]	[illegible] [illegible]	[illegible] 498,482	[illegible] [illegible]	[illegible] [illegible]
TOTAL including miscellaneous species [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Pounds

N.A. = Data not available

NOTE: Fish and crab quantities in round or live weights; clams, oysters, and scallops in total meats.

NOTE NUMBERS FOR EACH SPECIES DO NOT ADD TO TOTALS

(NATIONAL MARINE FISHERIES SERVICE, 1969 AND PRELIMINARY DATA FOR 1970 AND 1971)

Industrial trawl catches could be greatly increased by shifting the location of major fishing effort to offshore grounds. Around the 100-fathom contour alone a summer bottom trawl fishery could yield about 150 million pounds, comprised mainly of three hake species, sea robin, and fourspot flounder (Heald, 1970) (fig. 43). Soviet-bloc fishermen are beginning to exploit this resource and already have done so heavily to the north. The Continental Shelf between Delaware Bay and Cape Hatteras is estimated to be capable of sustaining a total annual catch of 800 million pounds, of which half would be spiny dogfish and sharks (Heald, 1970).

The National Marine Fisheries Service does not publish species breakdowns of industrial fish catches, but the major constituents are believed to include, during the winter, goosefish, four skate species, two flounder species, the spiny dogfish, sea robin, and hake (especially red hake) species mentioned above and in figure 42. Principal summer catches include two skate species, spotted hake, and sea robin. The results of a study conducted on the 1964 industrial catch by the North Carolina Division of Commercial and Sport Fisheries (Brown and McCoy, 1969) is shown in Table VII.

d. Marine sport fisheries--Marine sport fishing is a large and important recreational activity in the Area. An estimated 1,250,000 people participate in the sport yearly and spend in excess of $183 million per year for equipment, transportation, and fees (Bureau of Sport Fisheries and Wildlife, 1970).

Sport fishing is conducted from charter and head boats (27 percent of catch), small private boats (54 percent), shore (14 percent), and piers (5 percent) throughout the Area. Currently there are approximately 275 charter and head boats registered in the Area. Larger sport fishing boats fish offshore mainly for billfish, tuna, striped bass, and bluefish in the northern part, and king mackerel, spanish mackerel, and bluefish in the southern part of the Area. Small boats troll and bottom-fish for a wide variety of species. Fishing from piers and from the shore is principally for channel bass, striped bass, bluefish, sea trout, flounder, and sea mullet.

In 1970, the estuarine and marine sport fishing catch was predominantly composed of spot, puffers, mackerel, bluefish, and striped bass. These five species made up 65 percent of the total Middle Atlantic sport fishing catch of 110,600,000 fish.

Although sport fishing takes place all year, the most active period for most fishermen is from May through October. Off North Carolina it usually runs from April through November.

Figures 44 to 49 (Alexandria Drafting Co., 1972a, b) illustrate the sport fishing grounds. These grounds are usually associated with shoaling areas and wrecks. Appendix D provides data on the biology and fishery of the major species.

4. Inventory and possible effects of contaminants

a. Introduction--It is difficult to predict the possible harmful consequences to the biota from the presence of any pollutants singly or in combination. The President's Council on Environmental Quality recently concluded that too little is known of the biological effects of toxic substances to be able to qualify their total effect upon any single species (Council on

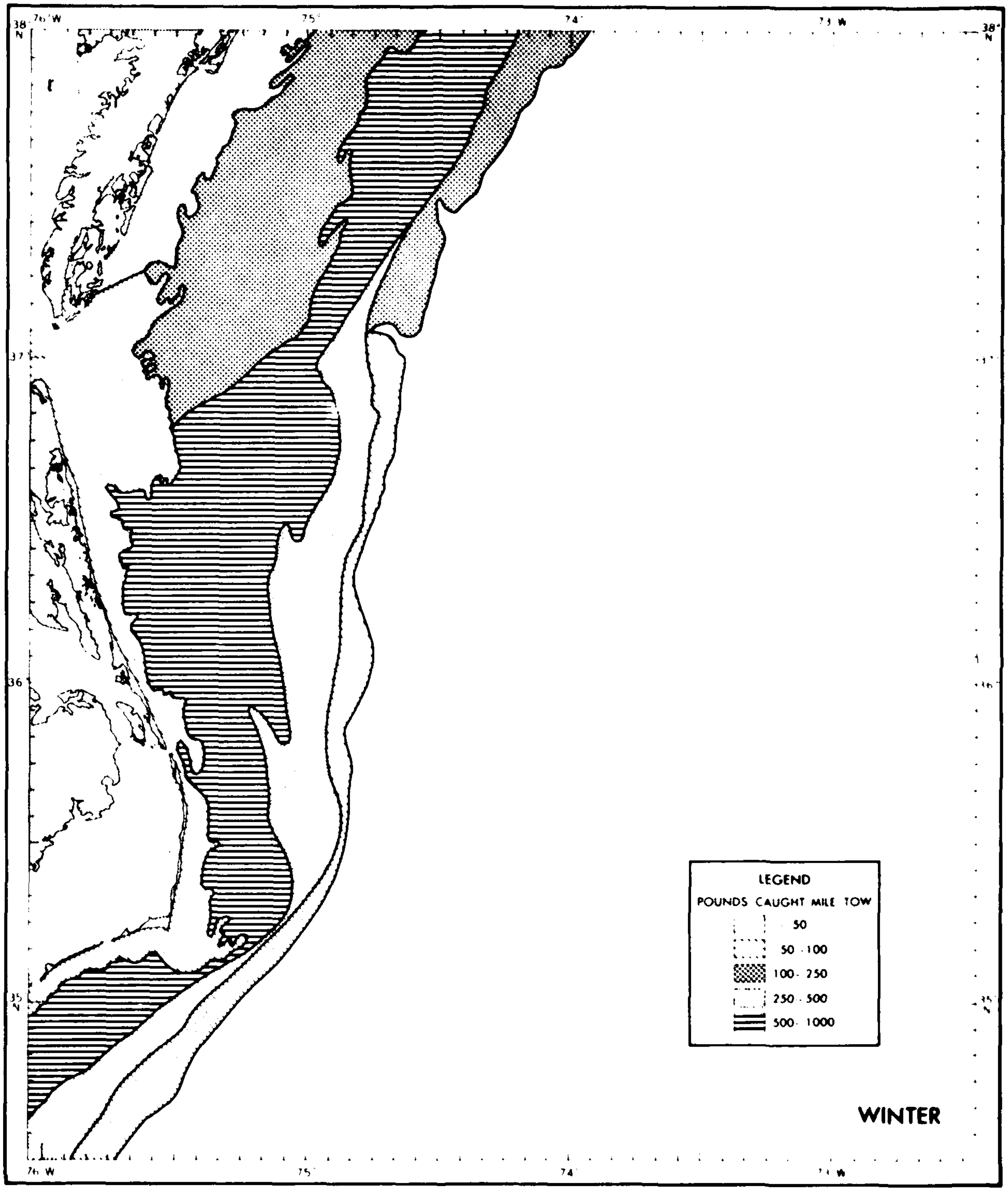


FIGURE 43. BIOMASS (FISHERIES) POTENTIAL

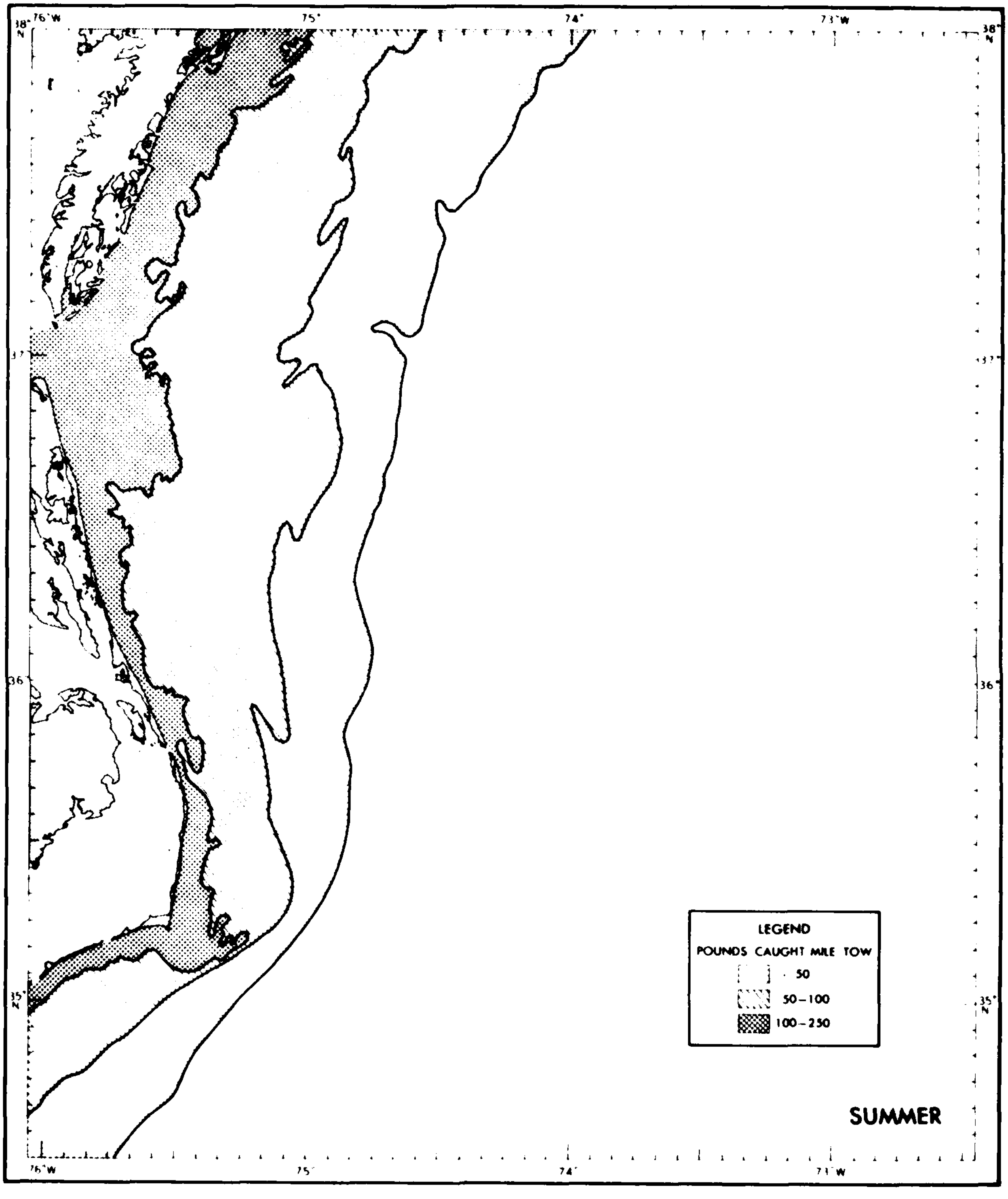


FIGURE 43 BIOMASS (FISHERIES) POTENTIAL (CON.)

TABLE VII. INDUSTRIAL FISHERIES OF NORTH CAROLINA

SPECIES		Quality*	Method of Capture	% Composition by number		% Composition by weight		Time of Predominant Capture
Common Name	Scientific Name			1962	1964	1962	1964	
Croaker	*Micropogon undulatus*	E	TLP	40.6 (0.8)	30.1	42.6 1.0	30.3	May-Jan
Spot	*Leiostomus xanthurus*	E	TLP	19.0 (4.5)	17.0	17.4 (2.0)	16.2	Jan-Nov
Butterfish	*Poronotus triacanthus*	E	T	9.1	19.6	7.5	10.2	Jan-Apr, Oct-Nov
Gray Trout	*Cynoscion regalis*	E	T	2.9	6.4	3.1	11.3	Nov-Jan, Mar-Apr
Long Spine Porgy	*Stenotomus caprinus*	N	T	6.0	4.3	5.0	3.2	Jun-Oct
Hogfish	*Orthopristis chrysopterus*	E	TLP	4.4 (3.1)	1.0	4.3 (2.7)	2.0	Jan
Pinfish	*Lagodon rhomboides*	N	TLP	3.0 (39.9)	1.1	1.9 (30.2)	1.2	Mar-Nov
Sand-perch	*Bairdiella chrysura*	E	TLP	1.3 (1.3)	2.0	1.9 (1.1)	3.0	Dec-Mar
Puffer	*Sphaeroides maculatus*	E	T	-	0.8		1.7	Apr
Clear-nose Skate	*Raja eglanteria*	N	T	0.1	0.2	1.3	1.6	Feb
Filefish	*Monacanthus hispidus*	N	T		0.5		1.2	Sep-Oct
Rock Sea Bass	*Centropristes philadelphicus*	E	T		0.7		1.1	Feb
Menhaden	*Brevoortia tyrannus*	N	LP	(33.3)		(42.9)		N D
Thread Herring	*Opisthonema oglinum*	N	LP	(8.0)		(6.0)		N D

(Brown, J. & E. McCoy, 1969)

*E - Edible - possible use as fish protein concentrate

N - Nonedible

T - Trawl

L - Long haul

P - Pound net

( ) - Long haul, pound net

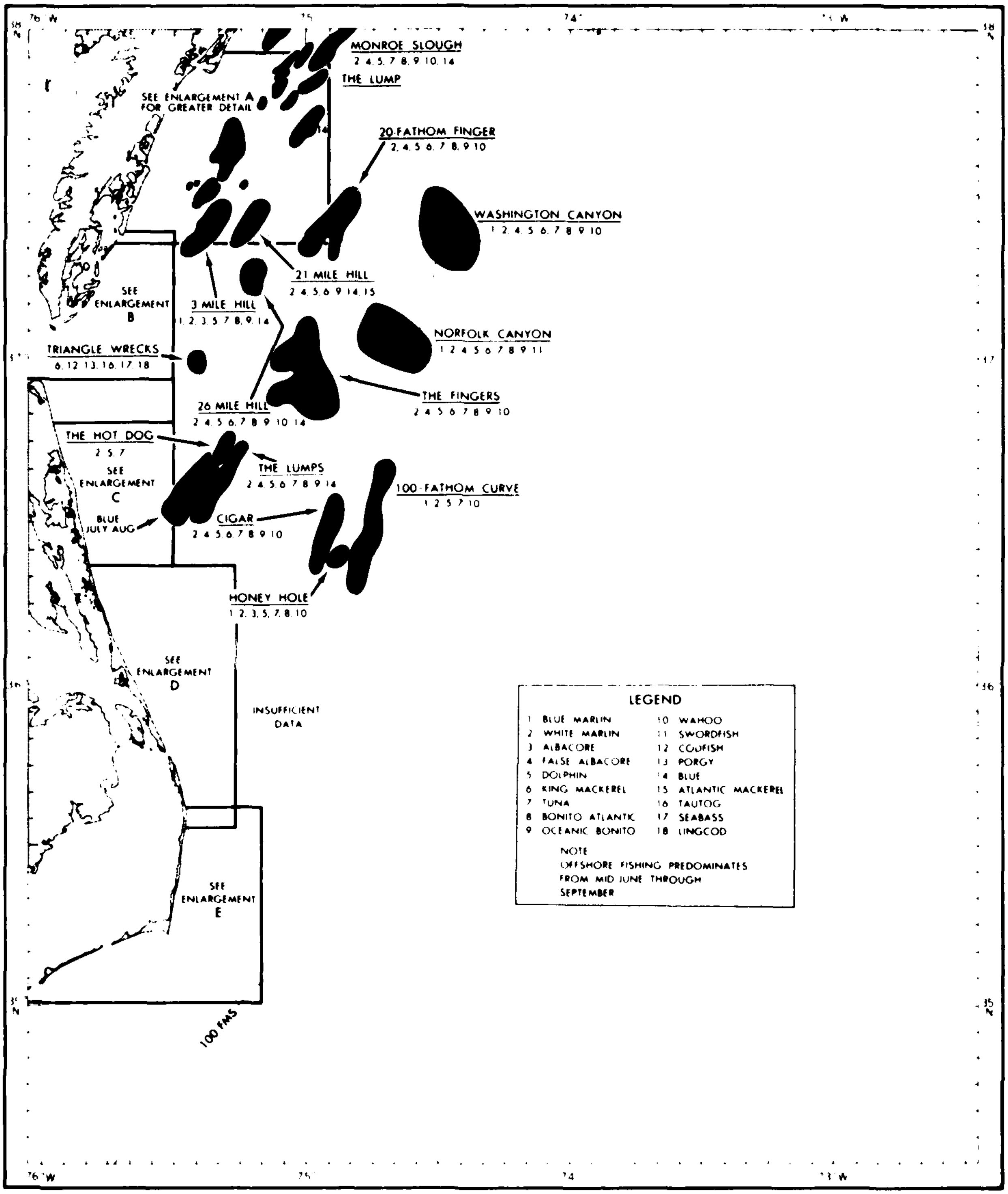
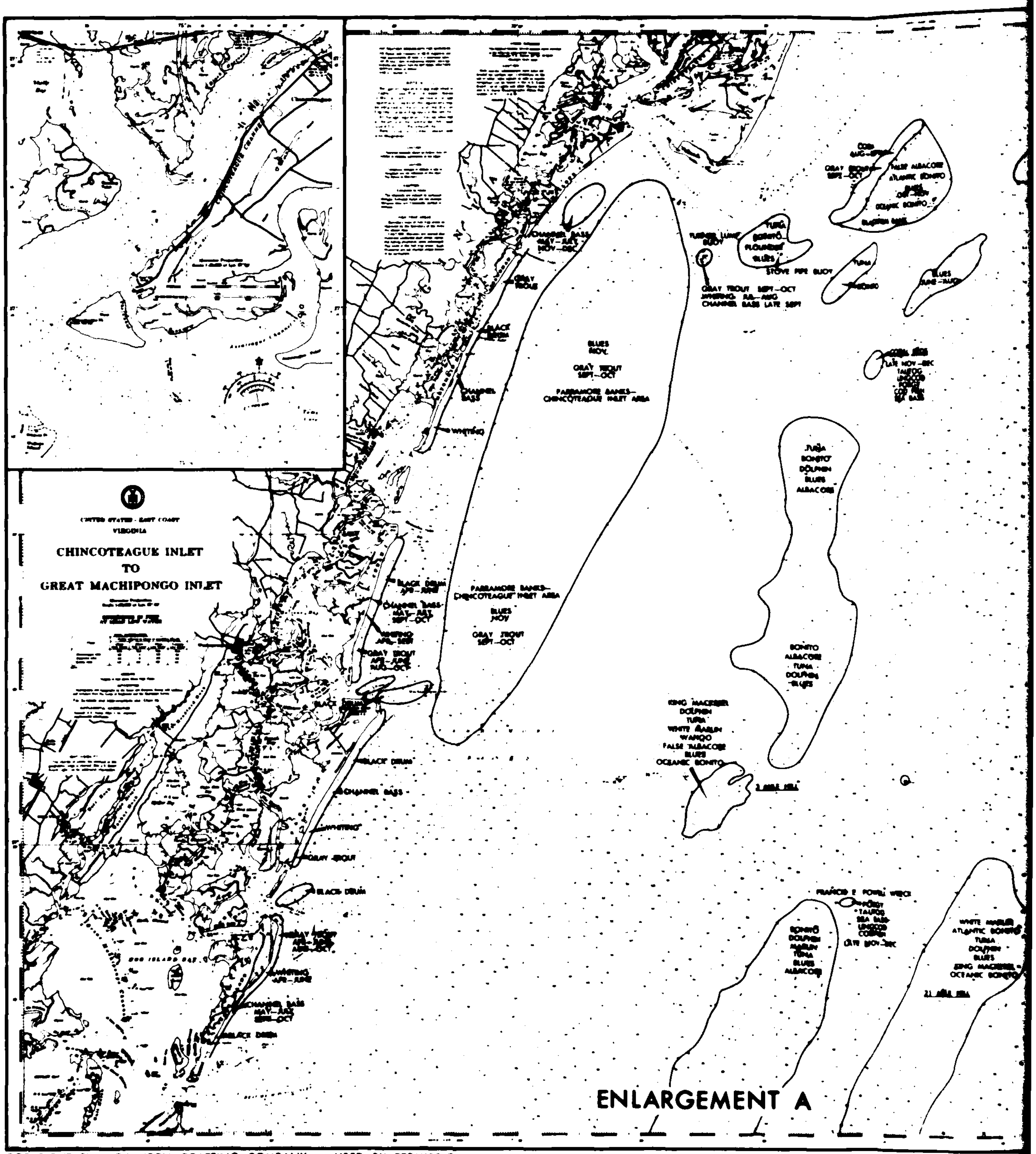
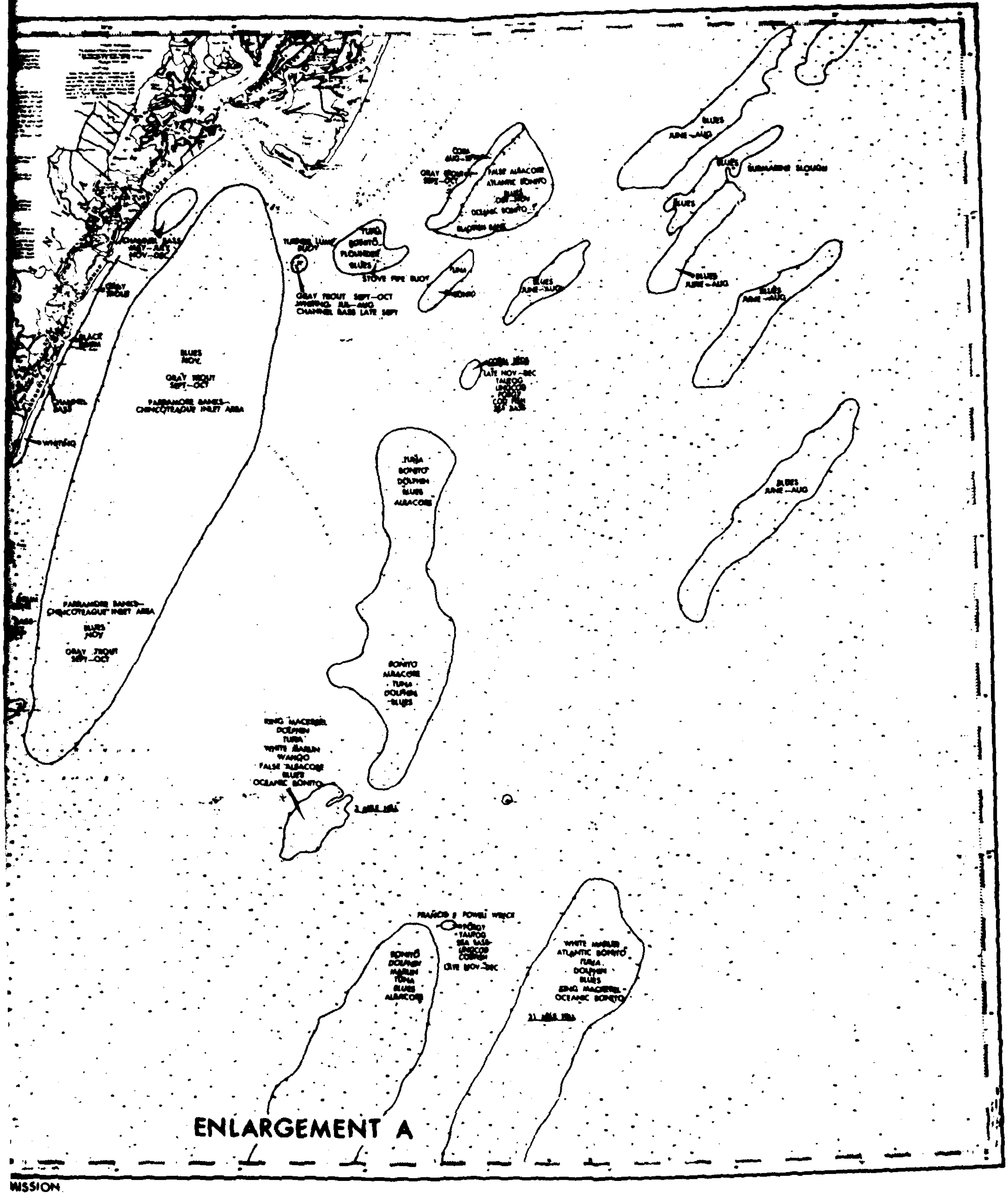


FIGURE 44. OFFSHORE SPORT FISHERIES



COPYRIGHT BY ALEXANDRIA DRAFTING COMPANY. USED BY PERMISSION.

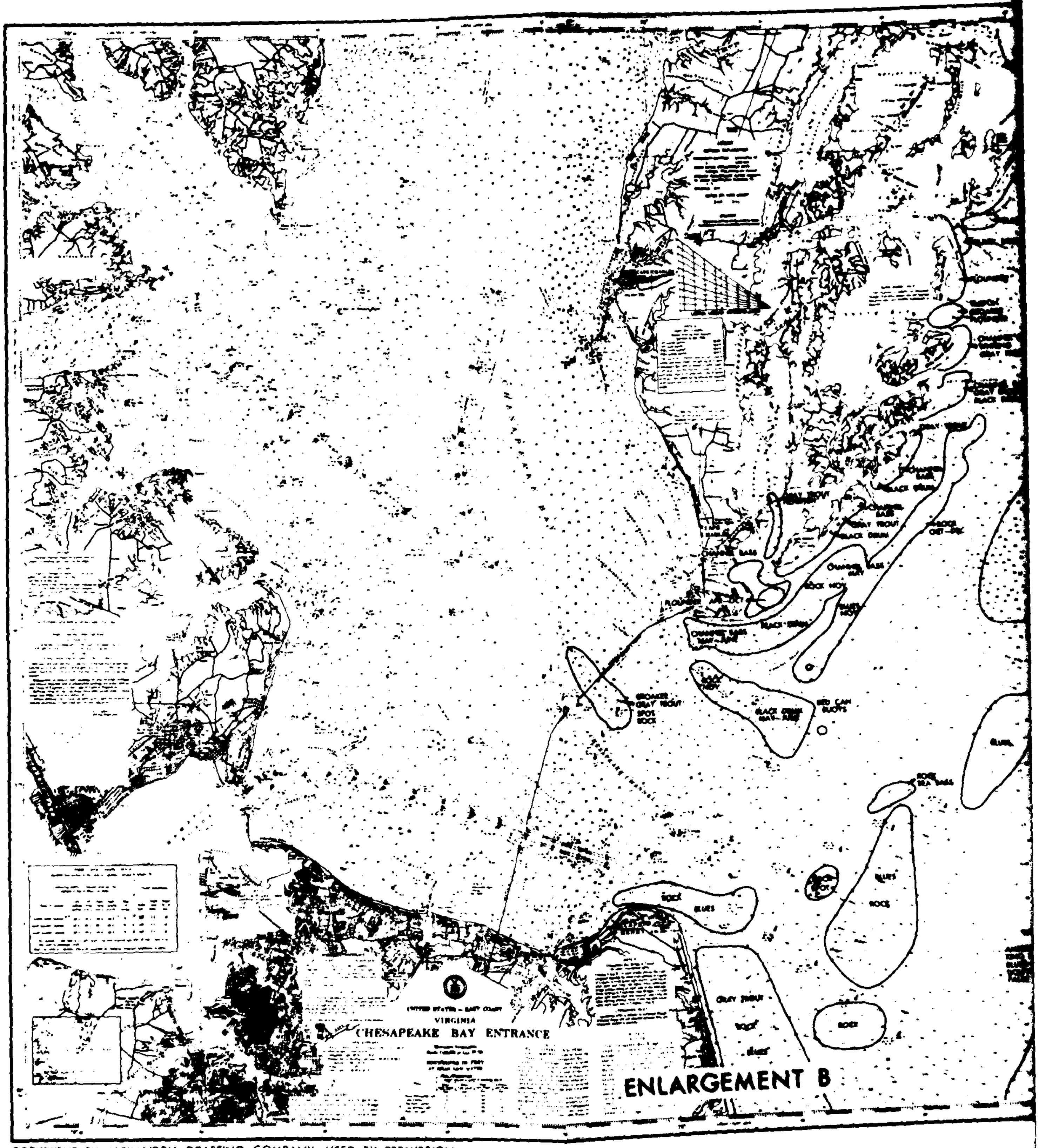
FIGURE 45. CHINCOTEAGUE INLET TO GREAT MACHIPONGO INLET



MISSION

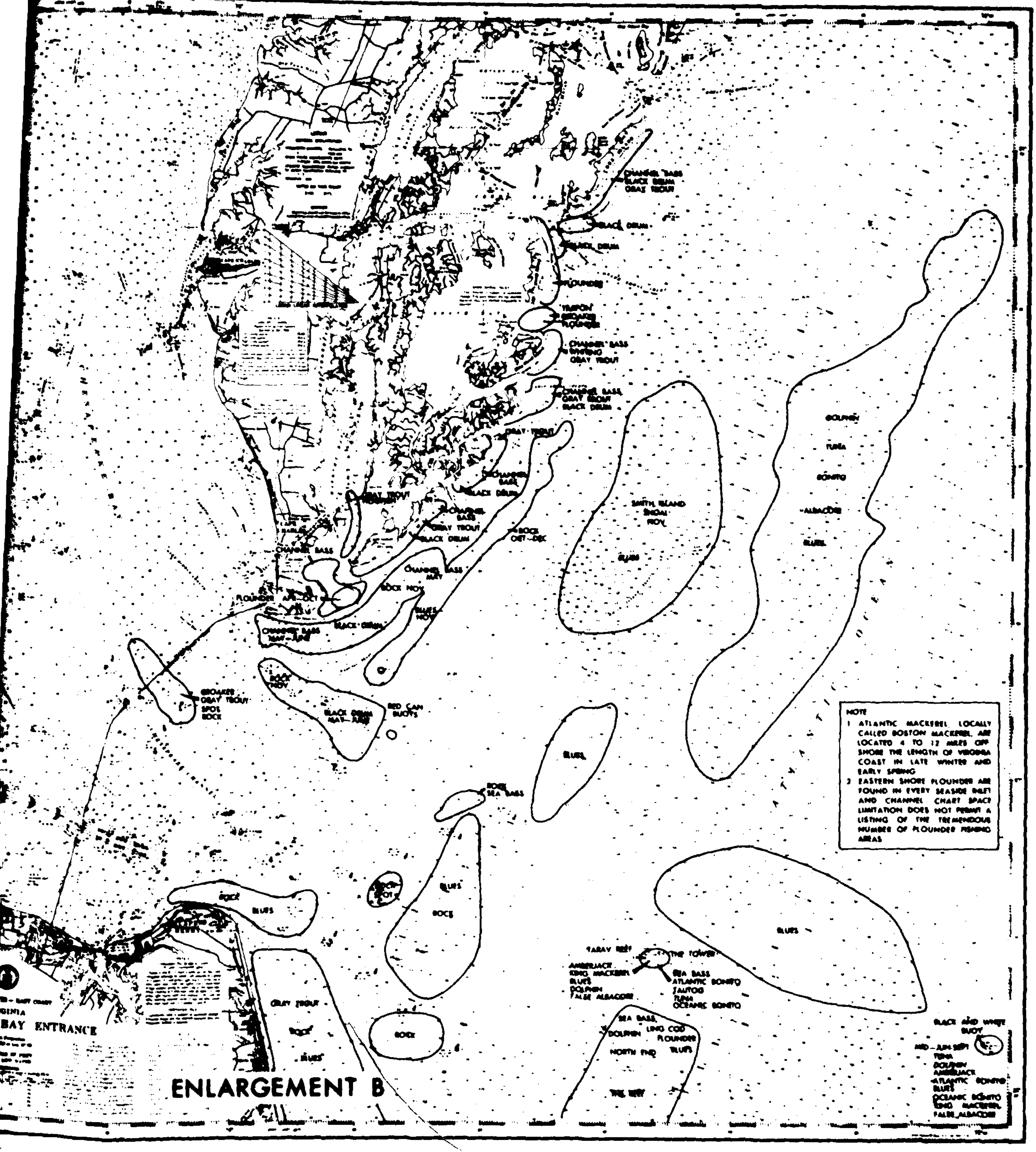
FIGURE 45. CHINCOTEAGUE INLET TO GREAT MACHIPONGO INLET

LITY PRACTICABLE



COPYRIGHT BY ALEXANDRIA DRAFTING COMPANY. USED BY PERMISSION

FIGURE 46. CHESAPEAKE BAY ENTRANCE



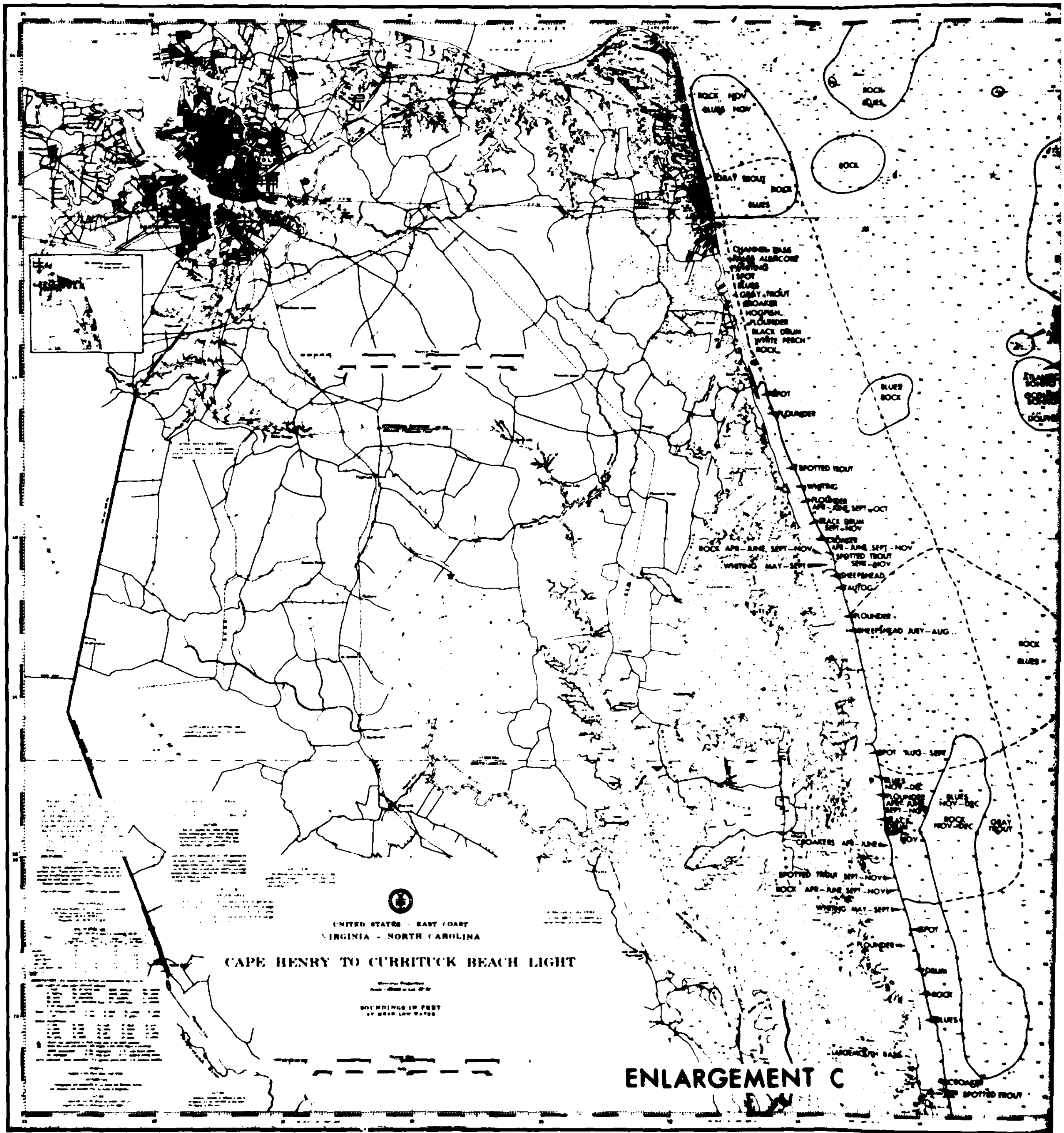
NOTE

1 ATLANTIC MACKEREL LOCALLY CALLED BOSTON MACKEREL ARE LOCATED 4 TO 12 MILES OFF-SHORE THE LENGTH OF VIRGINIA COAST IN LATE WINTER AND EARLY SPRING

2 EASTERN SHORE FLOUNDER ARE FOUND IN EVERY SEASIDE INLET AND CHANNEL CHART SPACE LIMITATION DOES NOT PERMIT A LISTING OF THE TREMENDOUS NUMBER OF FLOUNDER FISHING AREAS

FIGURE 46. CHESAPEAKE BAY ENTRANCE

CABLE



COPYRIGHT BY ALEXANDRIA DRAFTING COMPANY. USED BY PERMISSION.

FIGURE 47. CAPE HENRY TO CURRITUCK BEACH LIGHT

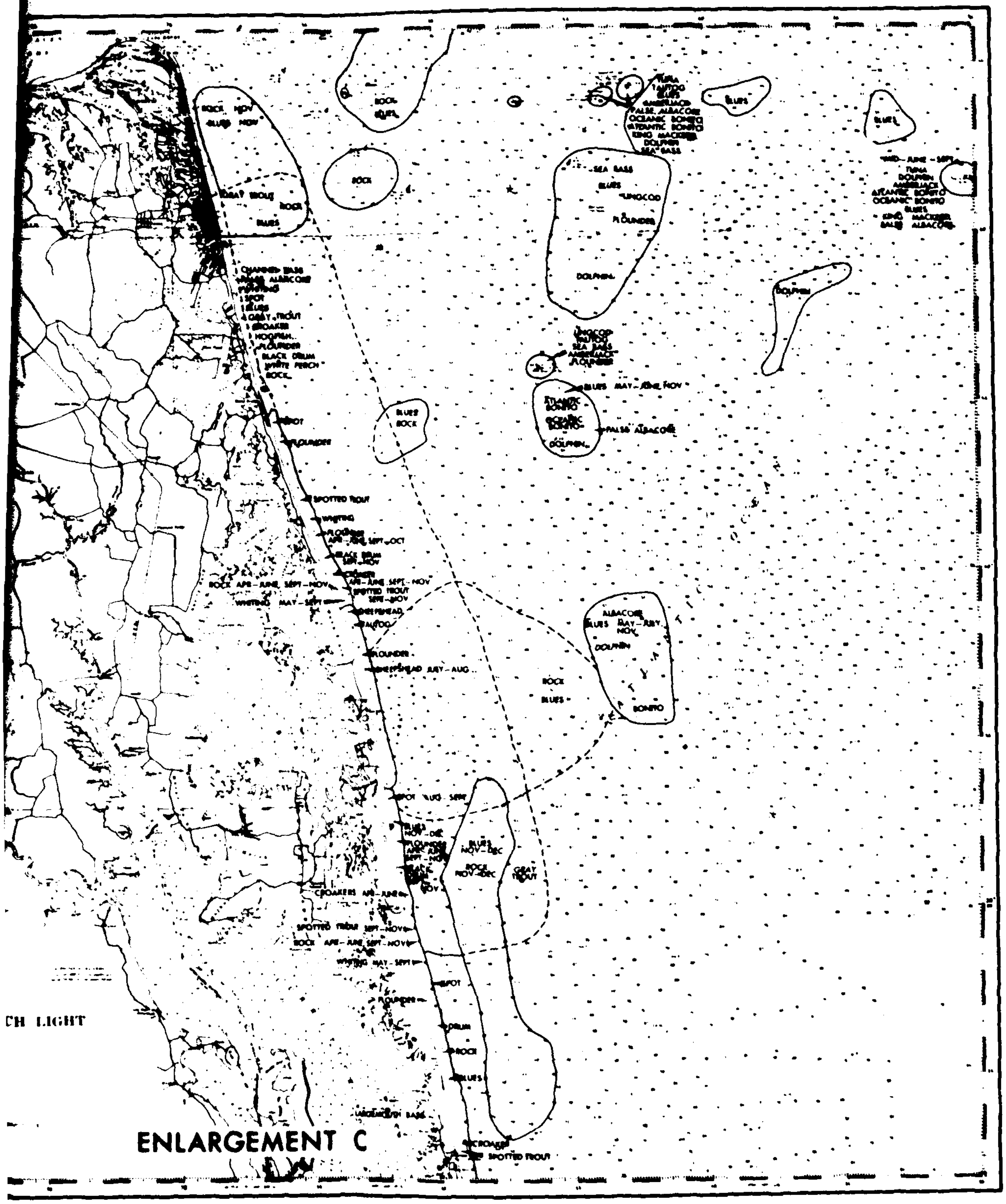
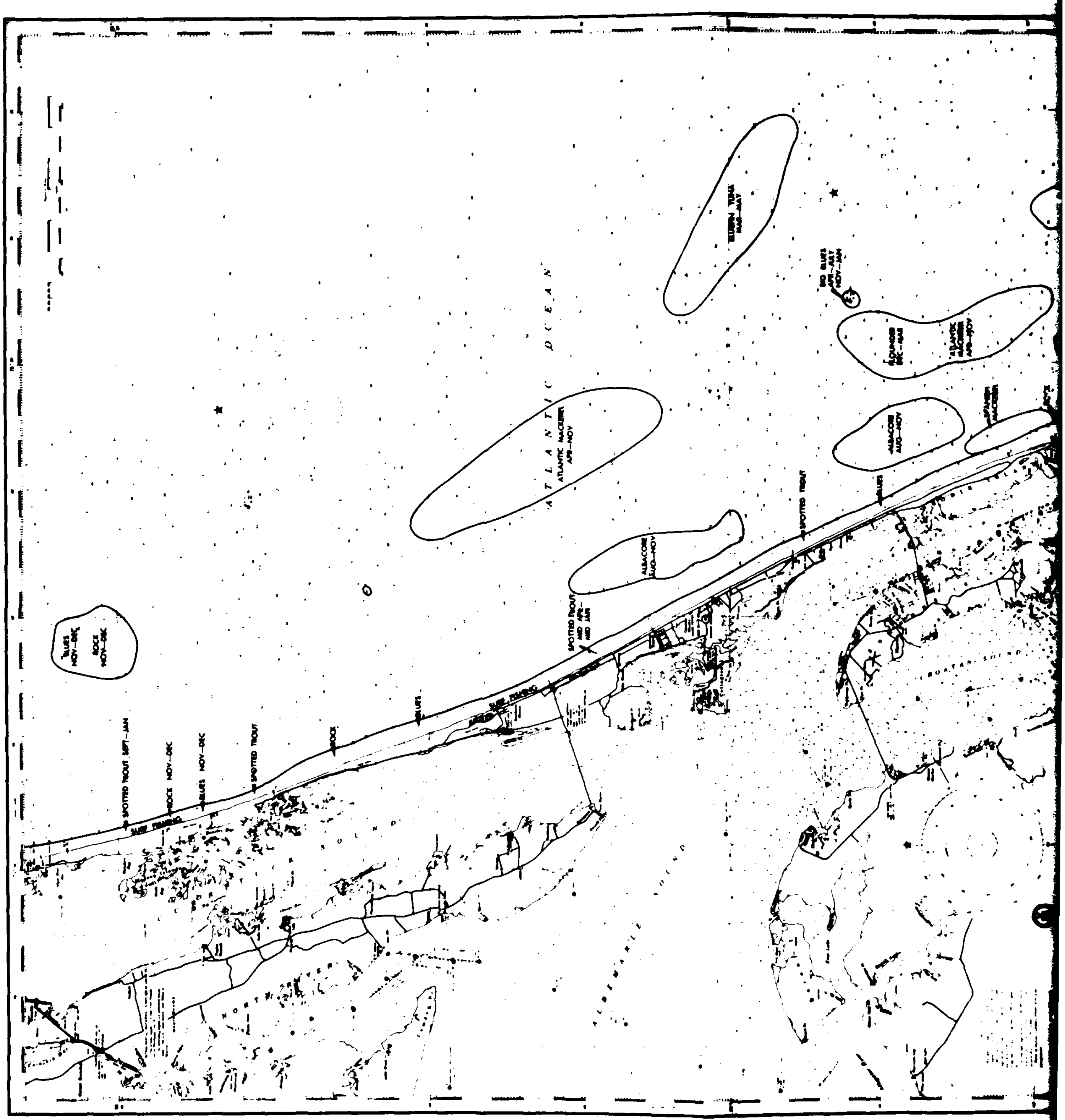
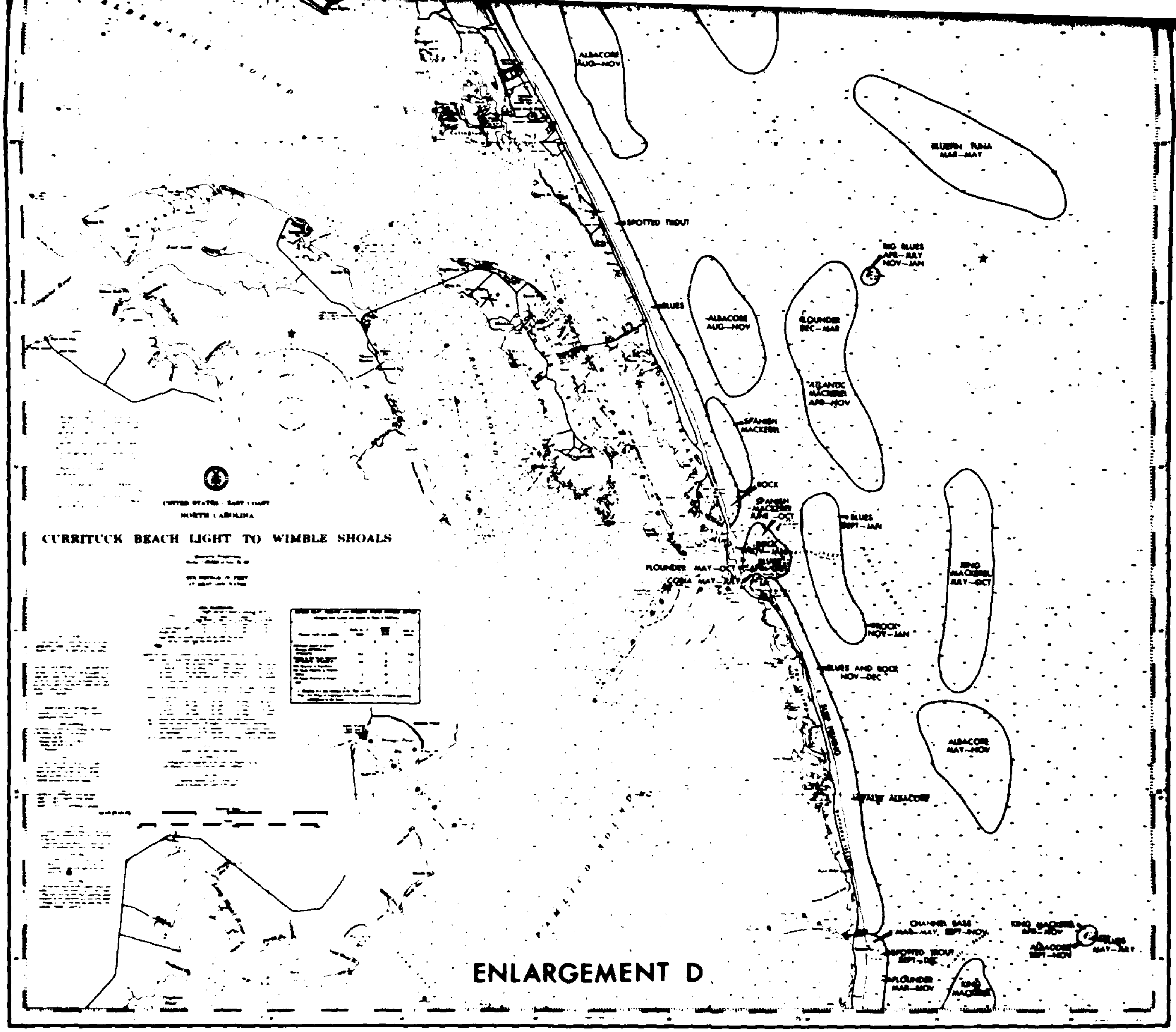


FIGURE 47 CAPE HENRY TO CURRITUCK BEACH LIGHT


SPOTTED TROUT SEPT–JAN
ROCK NOV–DEC
BLUES NOV–DEC
SPOTTED TROUT
SURF FISHING
ROCK
BLUES
SURF FISHING
SPOTTED TROUT MID APR–MID JAN
BLUES NOV–DEC
ROCK NOV–DEC
ALBACORE AUG–NOV
ATLANTIC MACKEREL APR–NOV
ATLANTIC OCEAN
SPOTTED TROUT
BLUES
BLUEFIN TUNA MAR–MAY
BIG BLUES APR–JULY NOV–JAN
BLOWFISH DEC–MAR
ATLANTIC MACKEREL APR–NOV
ALBACORE AUG–NOV
SPANISH MACKEREL
ALBEMARLE SOUND
NORTH RIVER



COPYRIGHT BY ALEXANDRIA DRAFTING COMPANY USED BY PERMISSION

FIGURE 48 CURRITUCK BEACH LIGHT TO WIMBLE SHOALS

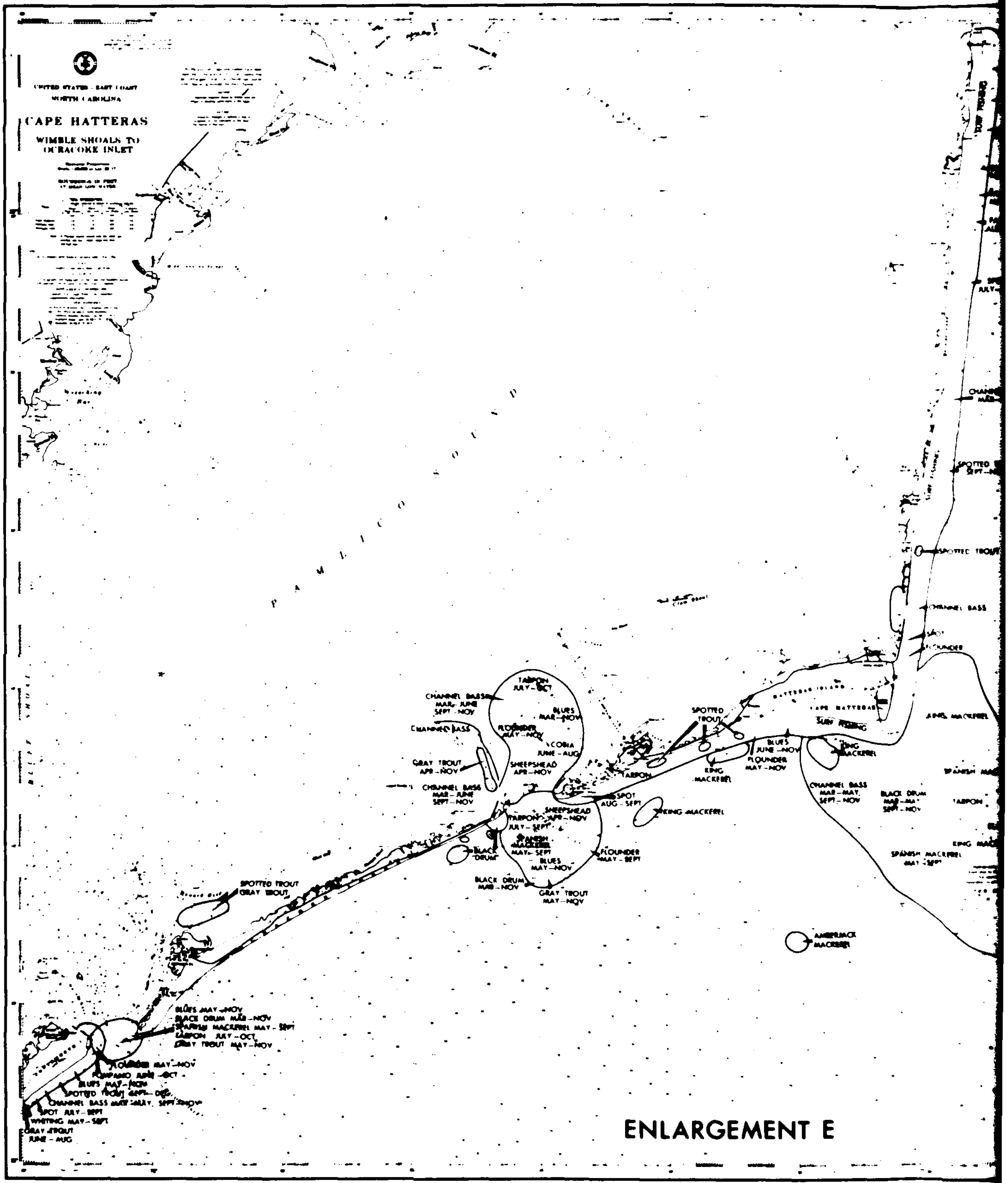
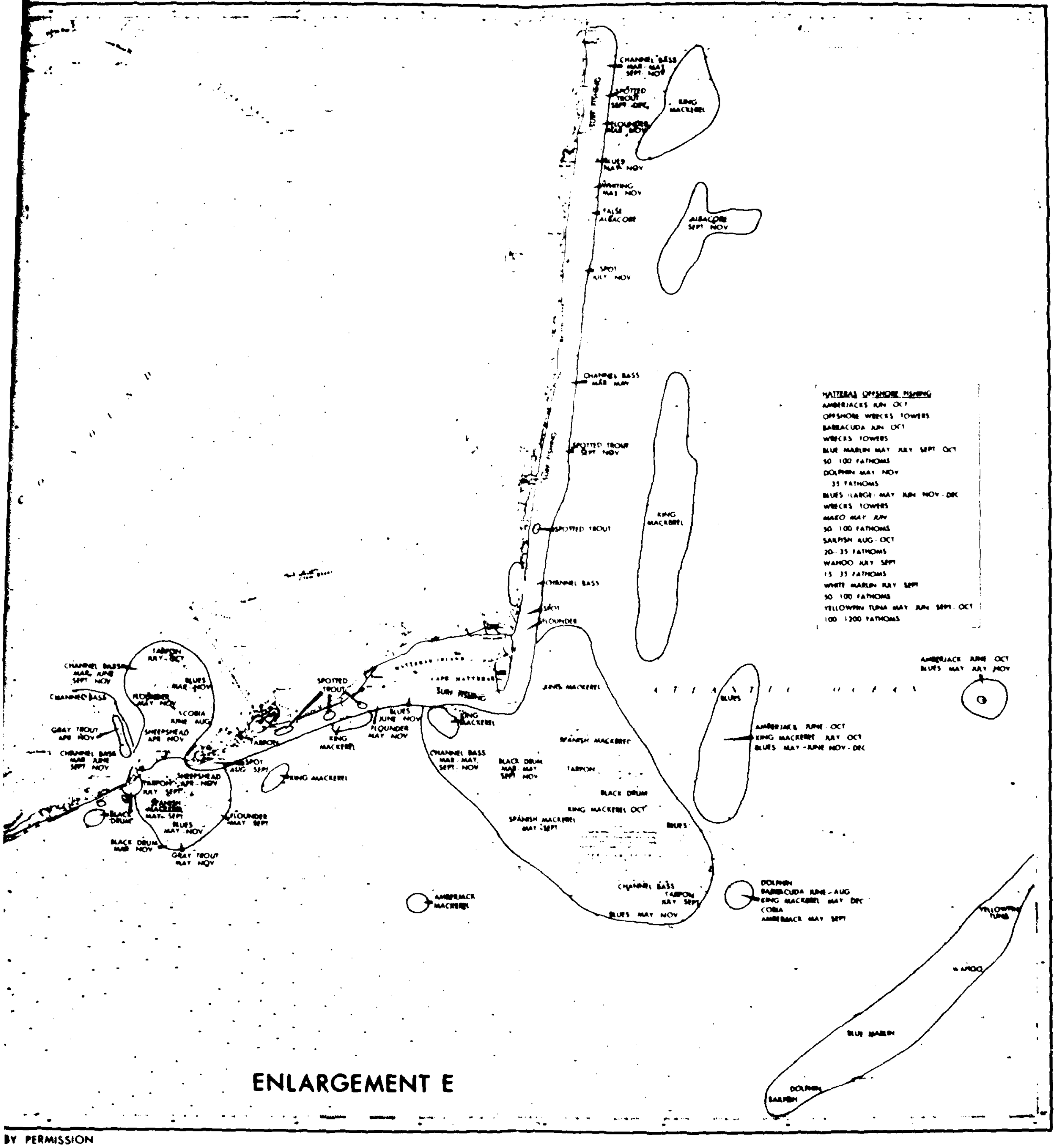


FIGURE 49. CAPE HATTERAS



BY PERMISSION

FIGURE 49. CAPE HATTERAS

Environmental Quality, 1971). This is especially true for marine species, as most past research has concentrated upon terrestrial and freshwater organisms.

The introduction of a contaminant into the ocean may effect either synergistic or antagonistic relations. Species' tolerances for contaminants and stresses differ and may vary with age, sex, and health. Eggs, larvae, and juveniles of aquatic organisms generally are more susceptible to pollution than the adults. Also, the different life stages of invertebrates and vertebrates occupy different locations in the water column and exhibit different mobilities, both of which affect their possible contact with a contaminant. The organisms at different life stages also require different food organisms. Therefore, their survival is dependent not only upon their own tolerance during developmental stages, but also upon the tolerance of the different food organisms to pollutants.

b. Oil--Ships are the principal source of oil pollutants. When tankers discharge oil cargoes, they ballast the discharged tanks with sea water. Dry cargo and passenger ships also ballast their double-bottom fuel tanks with seawater. When the water ballast is discharged into the sea it carries with it part of the oil remaining in the tanks. The amount of oil discharged by a single ship is generally small but the total for the world naval and merchant fleets is a very significant quantity.

Pollution by crude (unrefined) petroleum is enhanced by the tendency of such oils to form emulsions with salt water. These emulsions often originate when oil in its natural state is found trapped with salt water. Some of the oil and water form an emulsion as a result of turbulence from pumping operations and are loaded aboard tankers. A part of the emulsion, along with oil sludge, settles to the bottom of the cargo tanks. Some of the sludge and emulsion remains after the cargo has been discharged and mixes with seawater ballast when hot seawater is used to wash the empty tanks. This procedure produces more water-oil emulsion which is discharged into the sea.

The oil-water residue in a tanker after its cargo has been discharged contains recoverable oil equal to about 0.3 percent of the cargo. About one-third of the cargo capacity is filled with seawater ballast after discharge of cargo. Cleaning the ballast tanks before ballasting would recover about one-third of the oil recoverable by cleaning all the tanks, or 0.1 percent of the cargo. However, discharging ballast from uncleaned tanks would put about half of the oil in the ballast tanks into the sea (about 0.05 percent of the cargo). The pollution potential of vessels in the crude oil trade is more than three times that of vessels which carry clean (refined) petroleum. The estimated worldwide losses from tank cleaning and deballasting of tankers in 1963 were 2.5 million barrels of crude oil and 0.8 million barrels of refined products. From these values should be subtracted an amount for oils recovered aboard and discharged ashore.

Most petroleum products transported via tanker through this Area in 1970 originated in Gulf Coast ports and were northbound to the Port of New York (640 million barrels), Delaware Bay (440 million barrels), and Chesapeake Bay (190 million barrels). The tankers followed the 100-fathom contour south of 37°30'N. Oil from Caribbean ports comprises about 20 percent of the total, and the tankers usually enter the Area east of 73°30'W and north of 36°N when bound for refineries north of 38°N.

Maximum channel depths of 46 feet limit transiting tanker size to about

60,000 deadweight tons (DWT). Less than 40 percent of the transiting vessels had drafts that exceeded loaded World War II vintage T-2 tankers (30-foot draft, 16,765 DWT). More than 45 percent of the tankers were relatively small, with drafts of 18 feet or less.

Although the bulk of the tanker traffic follows the routes shown in figure 50, the vessels are not limited to these lanes and tankers are often found outside them. The coastal shipping combined with the traffic entering and leaving lower Chesapeake Bay make the Area one of the most heavily traveled sealanes in the world with a high potential for oil pollution by deballasting, tank cleaning, or catastrophic accident (U.S. Coast Guard reported one 20,000-gallon spill caused by ship collision during the 1970-71 period).

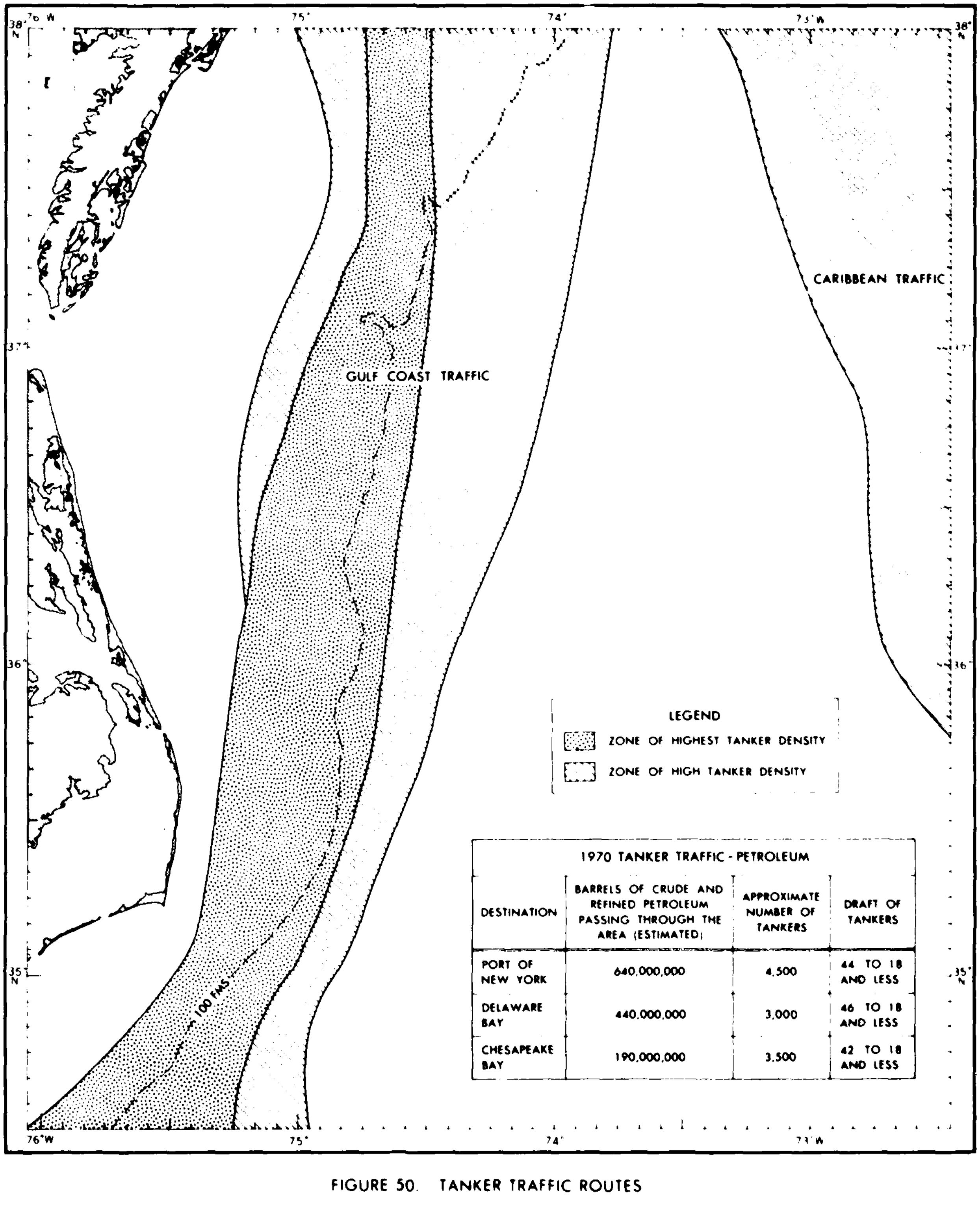
Many commercially important fish species have planktonic eggs and larvae in the surface layers of the ocean where they may be exposed to oil. Crude oil kills cod eggs and causes fish eggs to hatch prematurely. It affects nutrition in fish by blocking the taste receptors or by mimicking chemical messengers that predators use to locate their prey. Respiration in fish is affected by physical clogging of the gills, precipitation of certain metals on branchial epithelium, and action of certain hydrocarbons on the branchial cells, all of which may lead to lethargy and possible death (Hufford, 1971).

The majority of shallow-shelf, bottom invertebrates at practically all latitudes have pelagic larvae that form an important component of the neritic plankton (Mileikousky, 1970). Brief exposures of zooplankton and planktonic stages of benthic organisms to diesel oil in concentrations of about 1.0 ml/l resulted in accelerated mortality rates (Hufford, 1971). Oil also taints the flesh of fish and molluscs and may make them unmarketable. Studies have shown that hydrocarbons assimilated by a marine organism are stored in its lipid pool and may become a part of the entire food chain. Some crude oil fractions are suspected carcinogens; also, the nonhydrocarbon fraction contains heavy metals (see Section F4(h)) which may be a hazard to man as well as the marine biota.

Surface oil slicks have been found to be effective concentrations of dissolved organics and inorganics. Oil slicks have indicated the presence of pesticides, which were undetectable in the surrounding water, and they even be agents of pesticide transport. Biological activity also is very intense in the water immediately under slicks. These findings indicate that oil spills may have major deleterious consequences on the marine environment beyond their intrinsic pollutant effects.

c. Industrial wastes--This is a very general term applied to a wide range of chemical materials that provide an excellent opportunity for synergistic and antagonistic interactions that affect the overall toxicity of the effluent (Wilber, 1969). Of all categories of wastes disposed of at sea, industrial wastes rank second behind dredge spoil in terms of tonnage and costs (Smith and Brown, 1971).

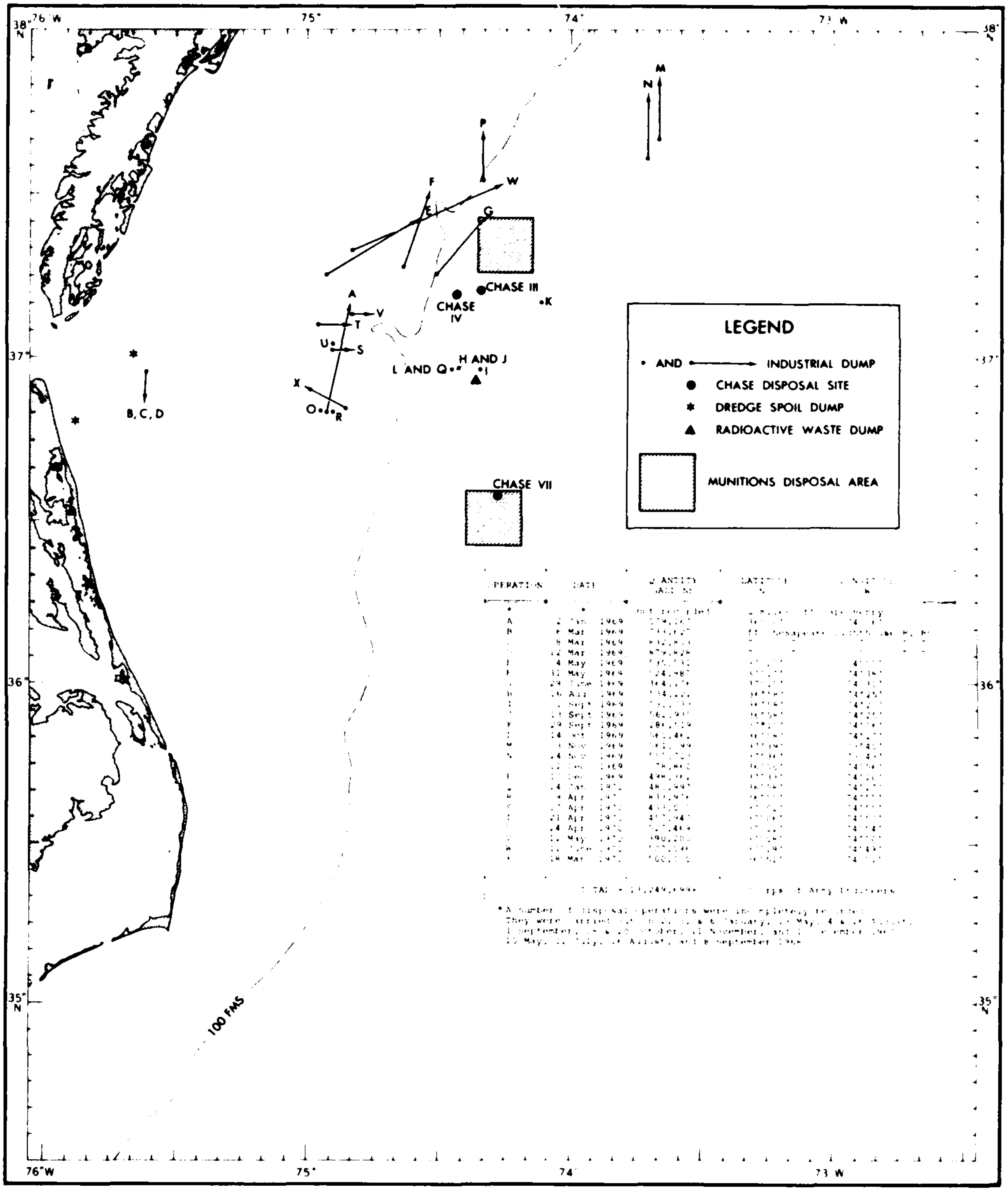
The only sea disposal of industrial wastes in this Area has been the operations at E. I. DuPont de Nemours and Company of Wilmington, Delaware. They were authorized in September 1966 by the U.S. Army Corps of Engineers, District #5, to transport waste from their Seafort, Delaware plant to a general area defined as 50 nm east of Cape Henry for ocean disposal (fig. 51). To date, they have disposed of more than 13 million gallons of liquid wastes (see table in figure 51) described as calcium sulfate diluted with an organic solution. The dumping locations utilized so far coincide with known commercial shell,



1970 TANKER TRAFFIC - PETROLEUM

DESTINATION	BARRELS OF CRUDE AND REFINED PETROLEUM PASSING THROUGH THE AREA (ESTIMATED)	APPROXIMATE NUMBER OF TANKERS	DRAFT OF TANKERS
PORT OF NEW YORK	640,000,000	4,500	44 TO 18 AND LESS
DELAWARE BAY	440,000,000	3,000	46 TO 18 AND LESS
CHESAPEAKE BAY	190,000,000	3,500	42 TO 18 AND LESS

FIGURE 50. TANKER TRAFFIC ROUTES



OPERATION	DATE	QUANTITY (GALLONS)	LATITUDE N	LONGITUDE W
*	*	not recorded	[illegible]	[illegible]
A	2 Jan 1969	[illegible]	[illegible]	[illegible]
B	6 Mar 1969	[illegible]	[illegible] Chesapeake [illegible]	[illegible]
[illegible]	8 Mar 1969	[illegible]	[illegible]	[illegible]
[illegible]	12 Mar 1969	[illegible]	[illegible]	[illegible]
[illegible]	4 May 1969	[illegible]	[illegible]	[illegible]
F	31 May 1969	[illegible]	[illegible]	[illegible]
[illegible]	29 June 1969	[illegible]	[illegible]	[illegible]
[illegible]	16 Aug 1969	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Sept 1969	[illegible]	[illegible]	[illegible]
[illegible]	13 Sept 1969	[illegible]	[illegible]	[illegible]
K	29 Sept 1969	281,519	[illegible]	[illegible]
[illegible]	14 Oct 1969	[illegible]	[illegible]	[illegible]
M	3 Nov 1969	[illegible]	[illegible]	[illegible]
N	24 Nov 1969	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Dec 1969	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Dec 1969	[illegible]	[illegible]	[illegible]
[illegible]	14 Jan 1970	[illegible]	[illegible]	[illegible]
R	4 Apr 1970	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Apr 1970	[illegible]	[illegible]	[illegible]
[illegible]	21 Apr 1970	[illegible]	[illegible]	[illegible]
[illegible]	24 Apr 1970	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] May 1970	490,20[illegible]	[illegible]	[illegible]
W	[illegible] June 1970	[illegible]	[illegible]	[illegible]
[illegible]	18 Mar 1970	[illegible]	[illegible]	[illegible]

TOTAL = 13,249,69[illegible] [illegible] Corps of Army Engineers

*A number of disposal operations were incompletely recorded. They were carried out on [illegible] January, [illegible] May, 4 & [illegible] August, 1 September, [illegible] & 20 October, [illegible] November, and [illegible] December 1969 [illegible] May, [illegible] July, [illegible] August, and 8 September 1968.

FIGURE 51. DISPOSAL AREAS

demersal, and pelagic fisheries. Toxicity studies for this particular waste were performed by the DuPont Company to establish the 24- and 48-hour TL_ms* for bluegill sunfish, a fresh-water species, in a fraction of the mixture of wastes (correspondence by Falk, 1967). Further studies and toxicity tests involving marine organisms are needed to help assess the environmental impact of these dumping operations.

d. Dredge spoil--Dredge spoil consists of sediments (alluvial sand, silt, and clay) and municipal or industrial waste sludges dredged to improve and maintain navigation channels. The Army Corps of Engineers does most of its dredging with seagoing hopper dredges and dumps the spoil in open coastal waters, generally not more than 3 to 4 miles from the dredging site (Smith and Brown, 1971). Figure 51 identifies the two dredge spoil disposal sites located in this Area, one of which is currently being utilized. Their histories are summarized in Table VIII.

TABLE VIII. DREDGE SPOIL DISPOSAL

DATE	CUBIC YARDAGE
37°00'N, 75°40'W	
1 January to 27 August 1966	4,416,512
27 November 1966 to 1 March 1967; 7 March to 28 March 1967	546,264
21 June to 10 December 1967	4,173,016
	TOTAL 9,135,792
36°48'N, 75°54'W	
10 December 1967 to 25 February 1968	1,042,000
3 March to 16 May 1968	1,977,161
30 July to 17 December 1968	2,435,964
3 May to 1 July 1969	587,750
1 October 1969 to 5 May 1970	4,768,713
30 June to 31 July 1970	314,710
27 November 1970 to 6 January 1971	467,728
30 June to 5 September 1972	1,114,611
	TOTAL 12,708,637

NOTE: All spoils, composed of sand, silt, clay, and shell, were dredged from Thimble Shoal Channel.

(U S ARMY CORPS OF ENGINEERS, NORFOLK DISTRICT)

---

* median tolerance limit

Biota in the environs of a dredge spoil disposal site may be harmed by the rapid sediment build up and turbidity associated with these operations (Smith and Brown, 1971). Both disposal sites are in commercial fishing areas. The fisheries include fluke, window pane flounder, porgy, herring, mackerel, spotted hake, northern sea robin, and spiny dogfish. See "Fisheries" section for additional data on fisheries in the region of disposal sites.

e. Munitions dumping--From 1952 to 1964 the Navy routinely dumped small volumes of unserviceable, obsolete, and overage munitions products in several disposal areas, two of which are located in this Area (fig. 51). From 1964 to 1970 the Navy disposed of munitions on a much larger scale by sinking 19 stripped-down surplus World War II cargo ships, loaded with up to 10,000 tons each of unwanted cargo, in ocean sites off the east and west coasts of the U.S. This latter disposal program at first was referred to as Operation CHASE ("Cut Holes And Sink 'Em") (U.S. Navy report, 1972) and later was changed to the Deep Water Dump Program (DWD).

There are several small disposal areas and three CHASE disposal sites located in the Area (fig. 51). All three of the CHASE vessels sunk in the study Area detonated during sinking (Table IX). The previously cited report by the U.S. Navy (1972) concludes that:

> "Explosive munitions dumped in the deep ocean will affect the environment to some degree. The specific effects are in part related to the kinds and quantity of ordnance, and more importantly to whether or not detonation occurs during the scuttling process. A DWD operation in which detonation of the cargo occurs will result in three separate environmental influences: 1) a detonation generated shock wave, 2) detonation of gaseous and particulate products, and 3) a residue of scattered debris on the seafloor. The two former environmental influences are relatively short term and transient, whereas the latter influence is of long duration. If detonation of the cargo does not take place, the presence of the hulk and cargo on the seafloor is the only environmental influence."

Consequently, a moratorium has been placed upon the disposal of munitions at sea, and other means of disposal are being thoroughly investigated.

f. Sewage, refuse, and garbage--At-sea disposal of sewage sludge and refuse is a practice of many municipalities and naval facilities in the United States (Smith and Brown, 1971).

TABLE IX. CHASE DISPOSAL OPERATIONS

DATE	TOTAL CARGO * NET EXPLOSIVES ** (SHORT TONS)	LATITUDE	LONGITUDE
15 July 1965	4040 * 512.19 **	37°11.8'N	74°21.1'W
16 Sept 1965	8715 408.2	37°11'N	74°26'W
29 July 1966	6033 442	36°34.3'N	74°16.9'W

Domestic sewage is a complex liquid waste that may receive varying degrees of treatment before discharge and has already created public health hazards in the Chesapeake Bay area (Wilbur, 1969). Although sewage outfalls are not documented for this Area, the bay would be the major receiving basin for municipal wastes. These materials eventually flush from the bay into the nearshore waters, where their ultimate fate is uncertain. Overboard discharge of biodegradable wastes is the only disposal method used by most naval and commercial vessels in transit, and is prohibited within 12 miles of shore.

A Navy evaluation of the probable environmental impact of dumping untreated sanitary sewage and wet garbage into the open ocean tentatively concluded that proper disposal practices should render the effluent environmentally compatible (Oceanographer of the Navy, 1971). However, the viability and virulence of human pathogens in the effluent is unknown and alternate methods of paper waste disposal, especially of dunnage and publication wastes, require investigation. The investigators disapproved of discharge of wastes in estuarine and nearshore waters where biodegradation mechanisms may already be overtaxed.

g. Radioactive wastes--Artifical radioactive materials have entered the marine environment through atmospheric tests of nuclear weapons, ocean disposal of low-level radiation packaged solid wastes, and discharges from nuclear power plants and vessels. Marine organisms may selectively assimilate and retain these waste materials, often concentrating them to many times their ambient level in the process (National Academy of Sciences/National Research Council, 1971), and affect their dispersal through biological transport. These interactions should be of paramount concern, for many marine organisms are current or potential food organisms for man and provide a return path for these unwanted materials.

A radioactive waste disposal site located within this area at 36°56'N, 74°23'W (fig. 51) received 84,423 millicuries of radioactive wastes contained in concrete encased steel drums, from 1949 to 1967 (Table X). A 1962 National Academy of Sciences/National Research Council report discusses the probabilities of container breachment through collision between drums at repeatedly used dump sites, and depth criteria for their safe disposal. Smith and Brown (1971) indicate the extent and some results of resurvey operations at radioactive ocean disposal sites. These studies, together with a 1972 National Academy of Sciences review of radiation standards, indicate that a serious reconsideration of ocean disposal for these wastes is in order.

h. Heavy metals--Metals enter the marine ecosystem from many sources. They occur as salts in effluents from mines, metal-processing factories, chemical industries, oil wells, dredge spoils, etc. (Wilbur, 1969). They also are used in marine fouling paints as fouling inhibitors. The highly toxic heavy metals are generally insoluble, reaching saturation at about 10 ppm, and are believed to act largely on the gill surfaces of marine animals. Portmann (1970) determined the 48-hour LC_{50}* of six heavy metals for four marine organisms.

Recent experiments by Connor, Wilson, and Portmann emphasize the danger of continued addition of heavy metals to restricted waters. Connor (1972) and Portmann (1968) pointed up the greater relative toxicity of mercury, copper, and zinc to the larvae of one species each of oyster, shrimp, crab, and lobster than to their adult stages. Connor determined that the 48-hour LC_{50} of

---

*Concentration lethal to 50% of population within 48-hour period.

metals to the most sensitive of these larvae is approximately 100 times their accepted representative values in seawater. Wilson and Connor (1971) also showed that the LC_{50} of mercury for adult Crangon crangon (a test species of shrimp used both by Connor and Portmann) exposed for 1,000 hours was less than 1/100 of that determined for 48 hours. This 1,000-hour LC_{50} of mercury approaches the mercury concentration found in the sea. If these lethal concentrations hold for larvae of Crangon and other species the threat to these species is already serious.

TABLE X RADIOACTIVE WASTE DISPOSAL SITE 36 56 N 74 23 W

DATE	RADIO-ACTIVITY (MILLICURIES)	DATE	RADIO-ACTIVITY (MILLICURIES)
7 49	200	5 59*	5,000 + 3,850 = 8,850
3 50	250	11 59	4,872
12 50	500	[illegible] 60	3,743
3 51	200	6 60	3
3 52	500	11 60	7,013
5 53	700	[illegible] 61	8,207
6 54	500	7 61	1,125
10 54	200	6 62	1,900
8 55	500	8 62	2,320
5 56*	280 + 400 680	[illegible] 63	2,300
5 57	500	8 64	3,050
5 58	700	7 65	4,310
9 58	800	7 67	30,500
* Two Disposal Operations Conducted During One Month		TOTAL	84,423

AFTER ATOMIC ENERGY COMMISSION WASHINGTON D C

The normal representative value for the concentration of mercury in sea water is 0.03 ppb, with a probable residence time of 42,000 years. Approximately 10,000 tons of mercury are put into the oceans annually; half from normal weathering of rocks, and half from industrial and agricultural use of mercury compounds (Keckes and Miettinen, 1970). However, this metallic or inorganic form of mercury is not concentrated biologically. Organic methyl mercury is the form most absorbable, retainable, and toxic to living organisms (Miettinen, et al., 1970). Bacteria and viruses are the fixing mechanisms for this form of mercury.

Experiments to determine heavy metal toxicity on embryos of the hard shell clam, M. mercenaria, a fishery resource in this Area, found mercury and silver to be the most toxic of five metals tested (National Marine Fisheries Service, 1972). Other studies show that vertebrates as well as invertebrates are sensitive to mercury compounds, and that mercury ions primarily affect the epithelium of the skin and gills in fish. Keckes and Miettinen (1970) describe the biological effects of mercury in the marine environment and the symptoms of acute mercury poisoning in fish. There is growing evidence of genetic and developmental effects from mercury compounds. In the United States and Canada commercial fish with a mercury content of 0.5 ppm wet weight would be labeled contaminated (Food and Agricultural Organization of the United Nations, 1971).

Lead is a trace element used so extensively by our society that the amount entering the oceans annually from the atmosphere through washout of aerosols originating from leaded automobiles fuels is similar to the amount introduced from rivers. The use of so much lead has raised the average lead concentrations of the mixed layer of the Northern Hemisphere oceans by a factor of about five. Lead concentration profiles in the oceans are highly variable (0.07 to 0.4 g Pb/l) in young surface waters, increase with proximity to industrialized coasts, and remain uniformly low in ancient deep water (0.02 g Pb/l) (Food and Agricultural Organization of the United Nations, 1971). Lead in surface waters taken up by organisms passes up the food chain. The effects of high lead levels upon marine organisms are unknown, but lead is known to inhibit enzymes, impair cell metabolism, and damage the central nervous system.

Cadmium also has various deleterious effects upon aquatic organisms. Cadmium salts are found in effluents from electroplating plants, pigment works, lead mines, and other sources that may discharge into Area estuarine waters. Its average concentration in offshore marine waters is 0.02 to 0.17 ppm.

i. Halogenated hydrocarbons--The halogentated hydrocarbons are synthetic chemicals used extensively in industry and agriculture. Their chemical stability and mobility have caused a significant fraction of the total production to enter the marine environment via storm or sewage outfalls and dumping. Very few analyses of seawater for these compounds have been made, and there are no accepted representative values for their concentration. The organo-chlorine pesticides, such as DDT and its metabolites, and the polychlorinated biphenyls (PCB's) have received the most attention. PCB's are very similar in chemical structure to DDT and standard analytical methods do not easily differentiate between them. PCB's are generally more persistent and less toxic than the organo-chlorine pesticides, but have similar effects on the biota and share their ability to concentrate in the tissues of some marine organisms.

Although there is a definite relationship between the levels of organo-chlorine pollutants in water and in marine animals, these substances do not always concentrate through the food chain in the usual manner. While marine mammals and sea birds concentrate these substances through the food chain, marine fishes do not exhibit higher organo-chlorine pesticide concentrations at higher trophic levels as a direct result of their predatory role. In addition, no relationship has been found between fish size and level of organo-chlorine pesticide concentration. In fact, pesticide levels in fish increase with size only as fat content increases. Some fish species in the area, e.g. the menhaden, have high fat content (Food and Agricultural Organization of the United Nations, 1971).

The possible biological effects of these materials upon marine organisms include inhibition of the productivity of phytoplankton populations, death or immobilization of crustaceans, fishes, and molluscs, death of eggs and larvae of bivalve molluscs; deleterious changes in tissue composition of molluscs and teleosts; disruption of the schooling and feeding behavior of boney fishes; and interference with ovary development. It has been suggested that marine species, unlike some fresh-water and terrestrial groups which may acquire resistance to pesticides, may be sensitized during exposure to sublethal pesticide concentration (Eisler, 1969).

F. Marine Ecosystem Components and Processes

According to Odum (1970) "the marine ecosystem consists of any unit including all of the organisms (i.e., the community) in a given area interacting with the physical environment, so that a flow of energy leads to a clearly defined trophic structure, biotic diversity, and material cycles (i.e., exchange of materials between living and non-living parts) within the system." A discussion of the effects of pollution and other stresses upon the ecosystem or parts of the ecosystem must include all the known biotic and abiotic components and processes involved. The following discusses the components of the marine food webs with some specific examples from the Hampton Roads/Norfolk Operating Area, the presence of abiotic processes and pollution stresses, and the possible results of these processes and stresses in changing productivity, community diversity, ecosystem stability, and evolutionary adaptability.

1. Ecological components and food web dynamics

Some of the components and processes of the marine ecosystem are shown in figure 52.

a. Inorganic nutrients--Many inorganic elements and compounds are essential for growth of plants and phytoplankton and, therefore, necessary to the marine ecosystem. Phosphorus and nitrogen are the most important nutrients. Other constituents such as silica, copper, manganese, and iron are less important or are required by fewer organisms.

Phosphorus, mostly in the form of phosphates (PO_4), varies in concentration according to season, geographic location, and depth. In inshore waters, where mixing and regeneration of nutrients take place to some extent year round, phosphate distribution is relatively uniform throughout the water column. In the mouth of Chesapeake Bay, phosphate content ranges between 0.10 to 0.40 g-atom/liter year round at all depths. Along the coastlines the concentration is 0.08 to 0.30 g-atom/l at the surface and increases steadily toward 0.50 to 0.65 g-atom/l at the bottom. In waters over the Continental Shelf the concentration is 0.01 to 0.39 g-atom/l at the surface, increases to a maximum of 1.66 g-atoms/l at 380 meters, then decreases slightly toward the bottom wherever the depth of the water exceeds 380 meters. Over the continental slope the concentration is 0.06 to 0.32 g-atom/l at the surface, increases to a maximum of 1.83 g-atoms/l at 400 meters, then decreases to 0.61 to 1.34 g-atoms/l at the bottom.

Nitrogen, mostly in the form of nitrates (NO_3), and silicates (SiO_3) are utilized by autotrophs in the Area, but fewer data are available on abundance and distribution of these compounds. Throughout the Area, nitrate content ranges between 0.1 and 1.3 g-atom/l at the surface, increases to a maximum of 20 to 35 g-atoms/l at depths of 200 to 450 meters, then decreases slightly toward the bottom. Silicate content varies between 1.0 and 14.0 g-atoms/l at the surface, increases to a maximum of 5 to 27 g-atoms/l at 200 to 450 meters, then decreases slightly with increasing depth below 450 meters.

Inorganic nutrients are generated locally by bacterial decomposition of dead plants and animals. The Gulf Stream and the southern extension of the Labrador Current transport nutrients to oceanic and neritic waters from the south and north, respectively.

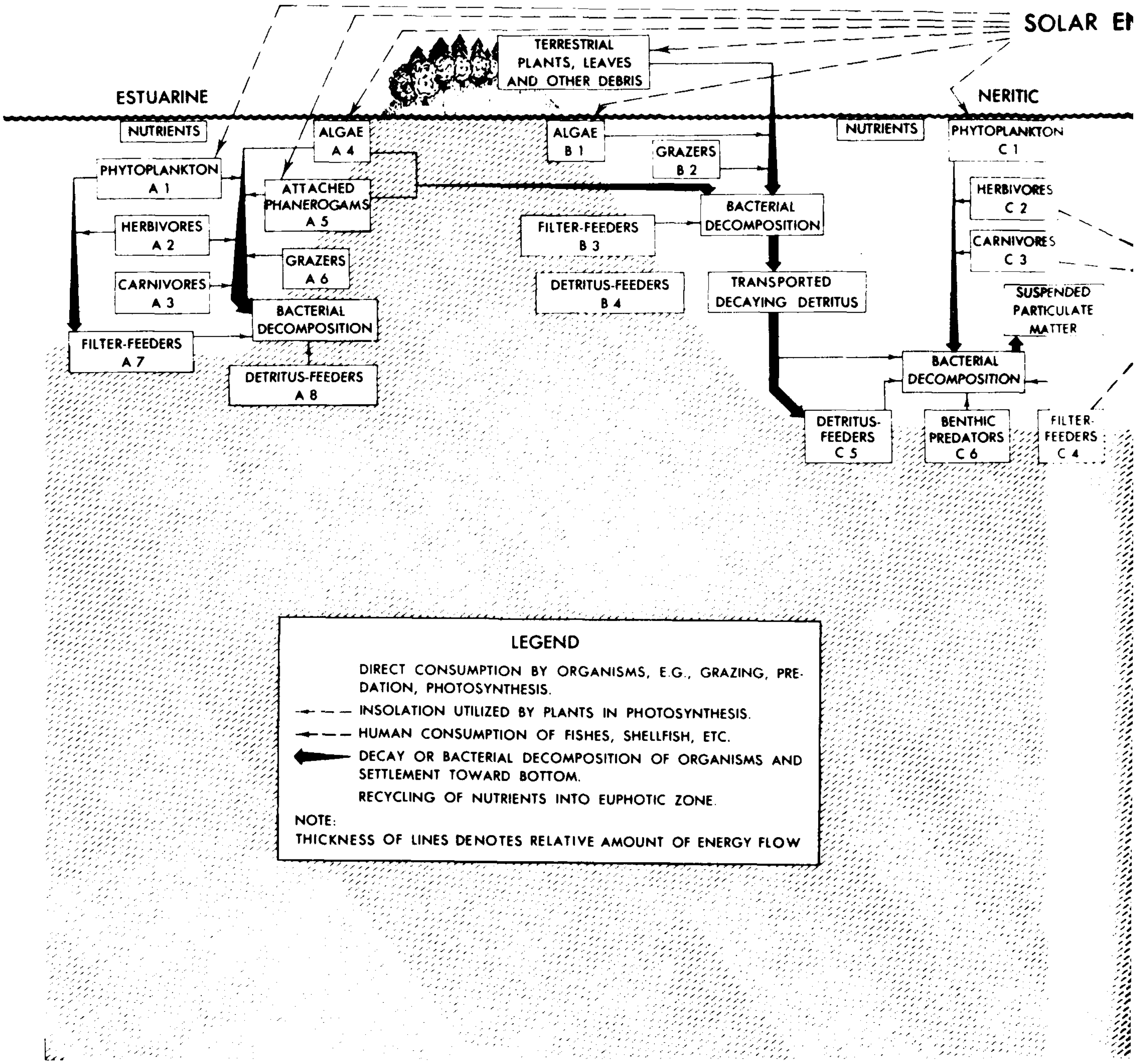
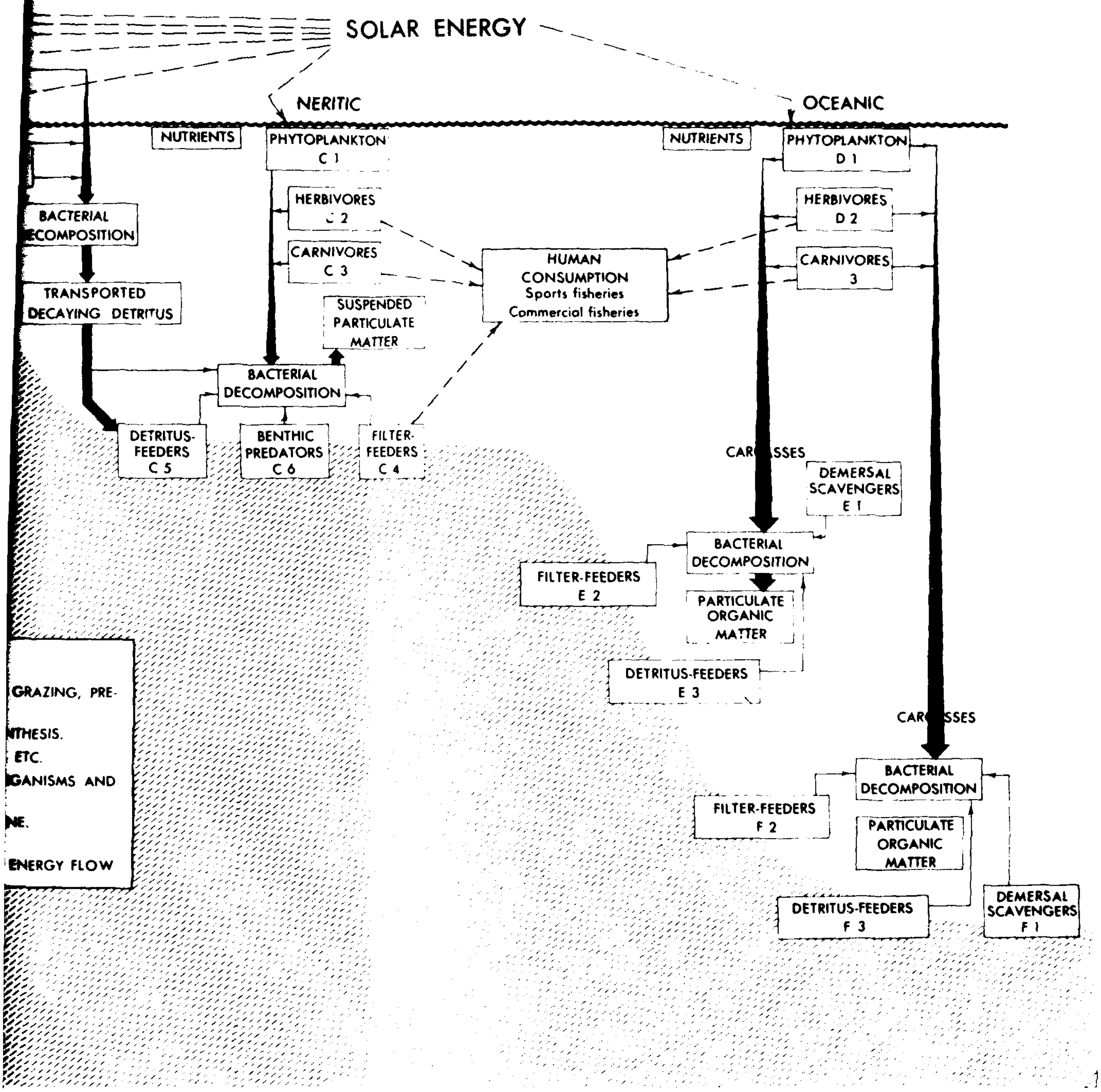


FIGURE 52 FOOD WEB AND ENERGY FLOW SUMMATION AND ORGANIC EXCHANGE BETWEEN MAJOR DEPTH ZONES (



GANIC EXCHANGE BETWEEN MAJOR DEPTH ZONES (Organisms representative of each major level are listed in APPENDIX E.)

Several patterns in the distribution of phosphate, nitrate, and silicate concentrations are evident in the Area. At any location in the Area, the absolute maximum values occur at midwater depths (200 to 450 meters) and tend to increase with increasing distance offshore because of the greater amount of deep water available for regeneration. In the shallow areas off the mouth of Chesapeake Bay and along the coast nutrient distribution is relatively homogeneous. Lowest levels of PO_4, NO_3, and SiO_3 occur during the spring and autumn months, probably as a result of phytoplankton blooms.

There are no data on the specific nutrient values which limit photosynthesis and reproduction among phytoplankton species in the Area. However, available nutrient data indicate that during the spring months nutrient availability may be low enough to limit primary production in the Area. Experimental data show that nitrogen and phosphorus may be depleted by spring phytoplankton blooms to an extent that they critically limit algal growth (Yentsch, 1963; Ryther and Dunstan, 1971; Corner and Davies, 1971). Scarcity of other elements such as iron and manganese, may also limit open ocean populations (Yentsch, 1963). Thus, in spring and fall additions of nutrients to surface waters, either by mixing with nutrient rich deep water or by artificial (human) means, can increase primary productivity if other essential factors, such as sunlight, are available.

b. Organic compounds--Particulate and dissolved organic matter are produced and consumed or absorbed by the plants and animals of the marine ecosystem. Particulate matter includes plants (phytoplankton and detached vegetation), zooplankton, bacteria, and detritus (Fox, 1957). In deep water it occurs in relatively uniform amounts throughout the oceans, but its concentration in the euphotic zone varies greatly according to local rates of primary production (Menzel and Ryther, 1970; Finenko and Zaika, 1970). The small amount of particulate matter that reaches deep sediments is used by benthic animals, and the benthic biomass generally varies directly with euphotic production (Riley, 1972).

Over the continental slope north of Cape Hatteras suspended matter is common throughout the water column. Flocculent material is common at the surface, but the highest concentrations of total suspended matter have been observed at depths of 277 to 614 meters and near the bottom (707 meters), varying directly with plankton and nekton concentrations (Milliman, et al., 1967).

Over the continental slope slightly south of Cape Hatteras maximal particulate carbon occurs at 4 meters (887 μg Carbon/l) and decreases to a minimum of 107 μg C/l at 500 meters. Just east of the Gulf Stream on the extreme western edge of the Sargasso Sea particulate carbon is lower: 243 μg C/l at 6 meters decreasing to a minimum of 39 μg C/l at 500 meters (Hobbie, et al., 1972). In the Sargasso Sea total particulate carbon, living or dead, is 10 to 140 μg C/l at the surface decreasing to a constant 18 μg C/l below 900 meters (Riley, 1972). The inactive part of particulate organic matter comprises about 50 percent of the total quantity in the euphotic zone (Finenko and Zaika, 1970).

Particulate carbon is transported to the Area as well as produced in situ. Large quantities of turtle grass (Thallasia testudinata) transported northward by the Gulf Stream from the Caribbean/Florida area sink to great depths on the continental slope and continental rise off the Carolinas. The largest concentrations of turtle grass (up to 1 blade/6.35 m) occur in November. Turtle grass deposited in these amounts may constitute an important source of organic enrichment in the deep sea (Menzies and Rowe, 1969; Menzies, et al., 1967). *Sargassum natans*, a pelagic offshore plant, sinks in large quantities and adds organic carbon to the ocean bottom, both as detrital plant material and through its associated fauna of bryozoans. Ophiuroids have been observed ingesting this plant material (Schoener and Rowe, 1970). Large amounts of living and detrital suspended particles (seston), which include considerable percentages of combustible organic matter, are transported seaward from Chesapeake Bay and deposited in deep water (Schubel and Biggs, 1969), mostly on the continental slope.

Dissolved organic compounds originating from excretion or extracellular loss by phytoplankton, excretion by animals, bacterial decomposition, and transported humic substances (gelbstoff) contribute a smaller amount to the total organic content of sea water. High levels of dissolved organics may accumulate at or near the surface but small amounts occur at depth (Menzel and Ryther, 1970). Humic matter formed by terrestrial plants and littoral algae is an important source of organic material in seawater and marine sediments (Sieburth and Jensen, 1968, 1969; Sieburth, 1969; Nissenbaum and Kaplan, 1972; Riley, 1972). Marine humic acids also are formed in neritic waters from degradation products of plankton (Nissenbaum and Kaplan, 1972). Dissolved organic substances may be more important than phytoplankton in the nutrition of small filter-feeding organisms (Sieburth and Jensen, 1969).

A cloudy mass of suspended matter (nepheloid layer) observed near the bottom on the continental slope and rise may be an important source of sedimentation and organic enrichment of deep sediments (Ewing and Thorndike, 1965).

c. Autotrophs--The autotrophs, or primary producers, include the phytoplankton and attached plants (mostly algae) and are of upmost importance in the ecosystem because they represent the first link in the primary food chain between inorganic and organic substances (fig. 52). All other marine organisms depend directly or indirectly upon this primary production. The autotrophs generally occur in the lighted (euphotic) zone of the sea, where they produce carbohydrates, proteins, and lipids via photosynthesis.

Primary production rates for attached algae in the Area are not available. In view of the relatively restricted distribution of attached algae (see "Benthos" section) and small amount of coast favorable to the attachment of algae, the percent total carbon fixed by them is probably small and significant only in the shallowest inshore waters. In the salt marshes, however, cord grass (*Spartina alterniflora*) is a major source of both food and recycled phosphorus via biodegradation of its resultant detritus (Reimold, 1972; Teal, 1962).

Plankton abundance and productivity are relatively high throughout this Area, varying somewhat in absolute numbers seasonally and spatially (see "Plankton" section). Total plankton volume over the shelf north of Cape Hatteras is 400 ml/1,000 m^3 during the winter and 700 to 800 ml/1,000 m^3 during the summer (Be, 1969). North of Cape Hatteras over the slope phytoplankton biomasses of 110 μg C/l at 4 meters, 168 μg C/l at 10 meters, and 3 μg C/l at 100 meters were recorded. At another station just east of the Gulf Stream, in the western edge of the Sargasso Sea, a maximum phytoplankton biomass of 19 μg C/l at 6 meters and minimum of 0.3 μg C/l at 200 meters were recorded (Hobbie, et al., 1972). Thus, phytoplankton are abundant, except far offshore in the Sargasso Sea.

Productivity ranges from 250 to 500 mg C/m^2/day over the shelf and exceeds 500 mg C/m^2/day in Chesapeake Bay (Moiseev, 1969), which is very high when compared with the mean production value for worldwide shallow coastal waters, which is 100 $g/m^2/yr$ or 282 $mg/m^2/day$ (Ryther, 1969). Primary production directly influences the population size and production of pelagic and benthic organisms (Raymont, 1963; Ryther, 1969; Rowe, 1969). Areas where primary production is high often are associated with high zooplankton production and high benthic biomass (Ryther, 1969; Rowe, 1971). As described in the "Plankton," "Benthos," and "Fisheries" sections, standing crop biomass values for these groups in the Area are high.

d. Herbivores--A large variety of animals feed directly upon marine phytoplankton and vegetation (fig. 52). These include filter feeders, which may be sessile, buried, planktonic or nektonic, and crawling or swimming grazers. Various protozoans, copepods, mysids, euphausiids, pteropods, appendicularians, larval forms, other small plankters, menhaden, and other small fishes feed heavily on phytoplankton crops and thereby directly affect their population size (Raymont, 1963; Reintjes, 1969). In turn, the population size and successful breeding of these zooplankters depend upon the phytoplankton. As described in the "Plankton" section, the volume of zooplankton in the Hampton Roads/Norfolk Operating Area is relatively great.

Sessile invertebrates filter phytoplankton out of the seawater (see "Benthos" section) and are most common in estuarine and littoral waters. Molluscs (e.g., clams, oysters, scallops, shipworms), crustaceans (e.g., barnacles, mole crabs, amphipods), sipunculids, annelids (tubeworms), bryozoans, tunicates, sponges, corals, and hydroids are the most abundant sessile filter-feeders (fig. 52) (Cowles, 1930; Dexter, 1969; McCloskey, 1970; Pearse, 1942; Pearse and Williams, 1951; Raymont, 1963). In the deep sea few animals are filter-feeders; most are deposit-feeders (Sanders and Hessler, 1969).

Attached plants form the predominant source of food for several species of grazing gastropods and supplement the diet of some crustaceans and fishes in the shallow littoral and estuarine waters of the Area. Grazers feed directly upon living plants, keep the amount of attached vegetation relatively stable, and provide open spaces for attachment of larval invertebrates and algae.

Thus, herbivores are important in the dynamics of the marine ecosystem. They often represent the trophic link between the photosynthetic primary producers and commercially valuable animals, or, as with the menhaden, are themselves commercially harvested. Herbivores also keep phytoplankton and attached vegetation populations at stable levels, thus precluding possible eutrophication and dominance by a single species to the exclusion of others.

e. Carnivores--Most fishes, including many commercially harvested species, mammals, jellyfish (scyphozoans), siphonophores, squids, octopi, and sea birds are pelagic or neritic carnivores and often constitute the highest trophic level of many marine food chains (fig. 52). Some of the larger crustaceans, salps, molluscs, and annelids are also carnivorous. Chaetognaths prey on calanoid copepods and other herbivores (Cowles, 1930; Grant, 1963a, b). Fishes such as shad, mackerel, menhaden, sea trout, and sea herring prey on great quantities of the mysid Neomysis americana (Cowles, 1930; Hopkins, 1965). Bluefish prey on young menhaden in coastal waters (Grant, 1962a). Striped bass feed voraciously upon other fishes and crustaceans (Nichols, 1967). Squaloid sharks are known to eat other sharks, fish such as hake, and crabs (Musick and McEachran, 1969).

On the Continental Shelf and slope the most important carnivores probably are the demersal fishes, echinoderms, errant polychaetes, anemones, crabs, and gastropods. Demersal flounders, hakes, and other fishes, search along the bottom for small bivalves, crustaceans, annelids, and other invertebrates. The sea star (Asterias forbesi), which is abundant throughout most subtidal areas, probably feeds on crustaceans and bivalves, such as clams, oysters, mussels, and quahogs. The sea star (Astropecten articulatus) preys upon at least 74 species of molluscs, including commercially valuable young scallops and quahogs (Porter, 1972). Scallops are also preyed upon by carnivores such as crabs and large gastropods (Emery, 1968). A small number of deep-sea nematodes and other meiobenthos are predators (Tietjen, 1971).

Except for blue crabs (Callinectes sapidus), which occasionally prey upon mole crabs (Emerita talpoida), carnivores are relatively rare in sandy beach areas (Pearse, 1942). In rocky intertidal and estuarine areas carnivores are also uncommon; infrequent starfish prey upon bivalves and barnacles; errant polychaetes prey upon small crustaceans and other invertebrates, some crabs capture living as well as dead invertebrates and fish; boring whelks attack oysters and other bivalves; and small fishes feed on hydroids, crustaceans, and annelids.

Thus, the carnivores of the ecosystem provide the important link between the plant-consuming herbivores and either the highest marine trophic levels or man. The carnivores ultimately concentrate any toxins or other contaminants which have been ingested, accumulated, concentrated, and transferred through numerous individual food chains and thereby present a potential health hazard if consumed by humans.

f. Saprotrophs--The distribution, abundance, and activity of marine bacteria and their biodegradation role in the marine ecosystem have been well documented (ZoBell, 1946; Raymont, 1963; Menzel and Ryther, 1970; Jannasch, et al., 1971; Hobbie, et al., 1972; Oceanographer of the Navy, 1971; Russell-Hunter, 1970). Bacteria, fungi, and some protozoa break down the complex compounds of the remains of all the autotrophs, herbivores, carnivores, and detritus feeders, absorb some of the decomposition products, and release into the water inorganic substances usable by autotrophs (fig. 52). They also release, into the sediments and water, particulate and dissolved organic matter usable by detritus-feeders and filter-feeders. Lignicolous marine fungi occur off North Carolina (Johnson, 1958).

Bacterial decomposition of dead pelagic organisms takes place while they sink, while that of benthic organisms takes place on the bottom. Most biodegradation occurs before the pelagic debris sinks below the upper water layers in which the greatest concentrations of organisms are found; thus, the cycling of most inorganic and organic matter is restricted to relatively near-surface water layers. Plant and animal detritus which sinks into deep water is decomposed slowly by bacteria, but decomposition is supplemented by the scavenging activity of crustaceans, fishes, annelids, and echinoderms. The relatively small amount of organic matter that reaches the deep water layers and sediments is often too deep to be available to euphotic organisms through oceanographic processes such as upwelling and turbulence.

Pelagic consumer organisms release fecal pellets, mostly in the upper, lighted water layers. Decomposition of this fecal material and that of such common benthic organisms as the crustacean (Callianassa major) produce considerable reusable nitrogen and phosphorus (Raymont, 1963; Frankenberg, et al., 1967). Modern man has recently contributed large volumes of sewage and overboard degradable wastes which provide additional resources of nutrients following bacterial and macrosaprophytic activity (Oceanographer of the Navy, 1971).

g. Detritus-feeders and demersal scavengers--Intertidal and littoral organisms filter great quantites of water to capture phytoplankton, particulate organic detritus and bacteria (see "Benthos" section). Small zooplankton depend upon suspended particulate matter as well as phytoplankton for food. Certain species of sandy beach copepods, isopods, amphipods, polychaetes, and molluscs, either filter particulate detritus out of the water or process sand nonselectively for food. Some amphibious and shoreline crabs, isopods, amphipods, birds, and terrestrial mammals and insects live on the remains of stranded marine plants and/or their associated faunas (Pearse, 1942; Dexter, 1969).

Benthic organisms that crawl over or burrow through upper sediment layers ingest and process the sediments for organic matter which has drifted down from the euphotic zone or has been formed in place. On the Continental Shelf shrimps, polychaetes, sipunculids, nematodes, ophiuroids, and other species of echinoderms, annelids, and arthropods are detritus-feeders (fig. 52). Certain filter-feeding benthic and pelagic animals also ingest particulate organic matter suspended in the water.

Benthic organisms are largely dependent upon the rain of dead plants and animals from the euphotic zone. The amount of material reaching the bottom decreases with increasing depth because of the increased length of exposure to pelagic biodegradation during sinking. Therefore, the deep-sea benthic biomass is much smaller than in surface or shallow waters (Sanders and Hessler, 1969). The number of detritus-feeders generally exceeds the numbers of other feeding types in the deep-sea benthos (Sanders and Hessler, 1969; Tietjen, 1971). The most common and most diverse groups of deep-sea detritus-feeding macrobenthic organisms are the polychaetes, tanaids, isopods, amphipods, pelecypods, holothuroids, sipunculids, and oligochaetes (Sanders and Hessler, 1969). The majority of deep-sea nematodes are detritus-feeders, feeding upon the remains of euphotic plankton, in situ bacteria, and transported material such as marsh grass and turtle grass (Tietjen, 1971).

Demersal or deep-sea macrurids and other fishes known to be scavengers, readily devour fish carcasses and other large organic debris which settles toward the bottom (Oceanographer of the Navy, 1971). Some animals such as hake, flounders, and crabs, which are detritus-feeders or supplement their diet with scavenging or detritus-feeding, are consumed by man or by commercially harvested marine animals. Thus, animals that feed on detrital matter represent an important link in the marine ecosystem between bacterial decomposition and predation by ecologically and/or economically important animals.

h. Discussion--The preceding section has described some of the biotic components of the ecosystem and some of the processes that link these components. Food chain relationships in the Area are based mainly upon the autotrophic primary production of phytoplankton and attached plants. The inorganic nutrients necessary for primary production are generated locally in shallow water layers. Some nutrients are also transported into the Area from continental runoff via the estuaries, from warm southern waters via the Gulf Stream, and from cool northern waters via an extension of the Labrador Current. Herbivores which feed on the autotrophs include copepods, pteropods, sessile filter-feeders, and benthic grazers. They are preyed upon by carnivores such as fishes, euphausiids, chaetognaths, and starfish, which may, in turn, be eaten by secondary carnivores such as mammals, fishes, and octopods. Mechanical and bacterial decomposition of dead organisms provides dissolved and particulate organic matter for consumption by filter-feeders and detritus-feeders and regenerates inorganic nutrients for use by autotrophs again. These data on trophic relationships and inorganic and organic cycling explain how introduced pollutants, contaminants, and toxins are assimilated, concentrated, and passed from ocean water through various food chains and possibly to humans.

Available energy declines with each step in the food chain as a result of energy expenditures incurred during locomotion, reproduction, and metabolic and other activities. For example, many autotrophs are eaten by fewer herbivores which support fewer carnivores, etc. (Odum, 1970). Conversely, ingested materials such as pesticides, heavy metals, and radionuclides which accumulate in somatic tissues often undergo "biological magnification" with each step in the food chain (Odum, 1970). Between photosynthetic organisms and man there are often five trophic levels or magnifications in oceanic waters; there are often three in coastal waters because many of the autotrophs and herbivores are large enough to be consumed directly by large copepods and euphausiid zooplankters (Ryther, 1969).

Though the trophic dynamics of the marine ecosystem are largely determined by biological factors in a diverse and productive marine area such as the Hampton Roads/Norfolk Operating Area, certain abiotic and hydrographic parameters also influence the level of primary production and all resultant ecological processes. Some of these abiotic processes and some of the effects of pollutants on marine organisms will be discussed below.

2. Abiotic processes

a. Introduction--Abiotic processes affect the distribution and abundance of the ecological components of the ecosystem, the distribution and toxicity of pollutants, and degree of exposure of marine organisms to the pollutants. Information on waves, water currents, temperature, salinity, oxygen content, pH, density, and sediments is presented in the "Physical processes," "Seawater properties," and "Marine geology" sections.

Some observational and experimental data have been published which link some of these abiotic parameters with ecological components. However, most of these studies were conducted either in fresh water or in seawater outside the Operating Area. Consequently, the following discussion describes some of the probable effects of interactions of abiotic processes on pollutants and the ecosystem according to the basic behavioral and physiological characteristics of marine organisms, applicable laboratory data on the effects of pollutants upon marine organisms, and the physical, chemical, and geological characteristics of the Operating Area.

b. Processes which affect distribution of pollutants

(1) Water currents--A discussion of the surface and subsurface current regimes for the Area was presented in the "Currents" section. These currents transport and disperse any introduced pollutants. Materials that float or remain near the surface will be transported faster than those

that sink toward the bottom, since water current velocities generally decrease with depth.

Active dredge spoil sites off the mouth of Chesapeake Bay are subject to bottom drift currents which flow into the bay. During the winter, total bottom drift includes a current which flows northwesterly over an active spoil site, around Cape Henry into the bay. The greatest erosion, entrainment, and transport of shelf sediments occur during the fall, winter, and spring. Thus, some dredge spoils dumped off the mouth of the bay will be transported into it along the bottom, particularly during these seasons. Also, spoils dumped in the summer which reach the bottom may be eroded and transported into the bay. The turbulent action of storms and floods may erode and resuspend the material again, and surface currents may move it out of the bay and deposit it on the slope.

The industrial, radioactive, and explosive dump sites located on the shelf and slope between 75° and 74°W (see "Inventory and possible effects of contaminants" section and fig. 51) lie in a southerly and southeasterly current regime. Dumped and spilled materials at these sites may be transported either southward toward Cape Hatteras or southeastward toward the Gulf Stream. Eventual mixing with Gulf Stream waters may result ultimately in transport offshore out of the Area. Dump sites located in the Gulf Stream or east of 74°W will be affected by easterly and northeasterly currents, which may move dumped materials offshore out of the Area. During movement in the Area, contaminants may enter the food chain to be ultimately concentrated in animals of high trophic levels.

Based on the direction and velocity of the prevailing currents (see "Currents" section), disposal of pollutants nearshore either north of or within the Operating Area, will endanger the coastal area to the south. It is unlikely that materials dumped on the shelf or slope north of Cape Hatteras will be transported south of Cape Hatteras in appreciable amounts; thus, their effects on the organisms of the Carolinian Faunal Province are limited. Materials dumped south of Cape Hatteras can be transported by the Gulf Stream from the Carolinian Faunal Province toward the northeast out of the Operating Area, as occurred during the September 1972 oil spill.

(2) Temperature--As described in the section, "Seawater properties," sharp temperature gradients often result in the formation of a front (boundary or interface) which can affect the dispersion of surface contaminants. The northern boundary of the Gulf Stream acts as a temperature front. Pollutants dumped or spilled near shore north of Cape Hatteras can be transported southward until impeded by the thermal front of the Gulf Stream. These materials may accumulate along this boundary, slowly mix with Gulf Stream water, and move northeasterly out of the Area.

Water temperature varies sharply with the seasons, being highest in the summer. The metabolic rates of producer and consumer organisms vary directly with water temperature. Therefore, introduced toxic materials such as heavy metals and pesticides will be assimilated, concentrated, and transferred through the food web most rapidly during the summer months, more slowly in the fall and spring, and slowest in the winter.

(3) Salinity--Though low salinity values are common throughout the coastal region a sharp salinity gradient exists off Chesapeake Bay. Surface pollutants such as oil can collect at the seaward interface of this

gradient, particularly during the summer when the gradient is sharpest.

(4) Density--As described in the section, "Seawater properties," relative homogeneity of the density structure of the water column directly affects the depth to which some materials sink. It is possible that some introduced contaminants may accumulate or remain in suspension because of discontinuity layers within the euphotic zone and thus increase the degree of exposure to autotrophic organisms. Introduced materials may disperse from their point of origin along these discontinuity layers to other regions.

Density is influenced by temperature and salinity and determines relative stability within the water column. A stable water column tends to reduce surface-to-bottom mixing. Unstable water increases mixing, dispersion, and homogeneity of introduced pollutants. Unstable conditions exist near the Gulf Stream during April and December and in the coastal regions (see "Seawater properties"). In periods of instability, bottom contaminants can be transported upward into the euphotic zone and subsequently assimilated by the organisms of the food web.

c. Processes which affect the biota

(1) Water currents--Water currents bring necessary nutrients and oxygen to marine organisms and carry away secretions and excretions. They move vast numbers of planktonic organisms thereby determining the location and abundance of herbivores and carnivores (including commercially valuable fishes).

Water currents also disperse and transport pollutants to which marine organisms are exposed. For example, oil, pesticides, heavy metals, industrial wastes, dredge spoils, and radioactive materials introduced in the nearshore waters off Maryland, Delaware, and New Jersey will be transported southwestward along the Delmarva Peninsula, and Virginia and North Carolina coasts endangering the biota of these areas. Material sinking near the entrance of Chesapeake Bay may be swept by bottom currents into the bay. In this way, commercial fisheries, shellfish beds, and recreational areas are susceptible to pollutants introduced miles away. Crude oil spilled off Cape Hatteras in September 1972 was transported northeasterly by the Gulf Stream (see "Currents" section) out of the Area and the coast was unaffected. Pelagic tuna and other offshore fishes may be subjected to pollutants introduced in nearshore waters.

The region where surface, subsurface, and bottom currents would probably least affect introduced pollutants is from 38°00'N, 73°30'W to 38°00'N, 72°30'W, from 36°30'N, 74°00'W to 37°00'N, 72°30'W. In this region, depths are great and the relatively slow water currents produce a net northeast drift out of the Area.

(2) Sediment grain size--As described in the section "Marine Geology," most of the shelf is covered with sandy sediments and most of the slope with finer grain muds. Suspended material flushed out of Chesapeake Bay passes over the shelf before settling on the slope. The grain size of the shelf sediments is conducive to a molluscan-echinoderm dominated benthic fauna; the finer size sediments of the deep slope areas support a rich polychaete-dominated infaunal population. Changes in sediment grain size may change the composition of benthic communities and influence the relative rate of absorption of oil or other coating materials by sediment particles, resulting in increased availability of these contaminants to sediment-processing detritus feeders.

(3) Temperature--As discussed in the section "Benthos," Cape Hatteras represents a strong temperature and faunal boundary. The temperature gradient of the northern boundary of the Gulf Stream causes the formation of an interface and restricts the distribution of surface materials including pollutants and marine organisms. Temperature changes may affect pre-existing distributional characteristics of these pollutants and organisms.

(4) Oxygen--Oxygen content is relatively high throughout the Area (see "Seawater properties" section). An oxygen minimum layer occurs at depths of 200 to 300 meters in the north and 700 to 800 meters in the southern part of the Area. Minimum values of 3.3 to 3.6 ml/l probably do not limit biological activity. However, the presence of some pollutants, (including biodegradable wastes), in the water column may sufficiently deplete ambient oxygen through oxidation processes to create an anoxic condition, particularly at the level of the minimum layer.

(5) pH--Hydrogen ion concentration ranges from 7.10 to 8.60 throughout the Operating Area. These values are well within the range of tolerance of most marine organisms. Most animals can survive in water with pH values of 4.0 to 11.0. However, pH tolerances vary with each species. Additions of highly acidic or highly basic materials may create physiological stresses upon some organisms, especially if a pH stress accompanies some other stress. Basic conditions increase the precipitation of heavy metals and thereby possibly increase the exposure of benthic animals to these metals. The buffering action of the carbonic acid-bicarbonate-carbonate system tends to maintain seawater within a relatively constant range of pH. Therefore, it usually minimizes the effects of dumping acidic and basic wastes. In addition to buffering, normal biochemical activity of photosynthesis tends to increase pH, while that of respiration and saprophytic decomposition tends to lower pH.

3. Interactions of biotic and abiotic processes

a. Influence of stresses on productivity--Dumping of dredge spoils and other activities that increase the turbidity of surface water layers lower productivity by reducing the penetration of sunlight into the water and by interfering with filter-feeding activities of benthic and planktonic animals. Pesticides such as DDT and halogenated hydrocarbons reduce the rates of phytoplankton photosynthesis (Wurster, 1968), reducing productivity and possibly passing the toxic substance through the trophic chain to higher organisms.

The effects of most pollution incidents probably are small in relation to environmental variations. These variations often are cyclic, but the effects of pollutants are often linear and cumulative. The superimposition of a small but constant change upon the natural cycles can have major long-term (10 to 20 years) effects upon productivity or ecosystem composition (Glover et al., 1970). Sublethal pollution may interact with normal natural stresses (e.g., temperature, salinity, insolation cycles) creating overall effects out of proportion to the component effects. For example, productivity will be reduced more if dredge spoils are dumped at a time when the water is turbid than when it is clear.

The total range of productivity in the oceans approximates that of the land (Golley, 1972). Primary productivity throughout the Hampton Roads/Norfolk Area is relatively high (Moiseev, 1969). Absolute population and productivity levels vary seasonally, annually, and over longer term periods.

Productivity also varies with respect to the rate of transfer of nutrients into the euphotic zone, which in turn depends upon the rate of vertical circulation and the available stock of nutrients in deep water. Rate of transfer is slow in deep offshore waters because of weak vertical circulation, and generally increases with decreasing water depth (Riley, 1972).

The net organic production of an individual organism is a function of the food assimilated minus metabolic losses and respiration. Organic energy is unavoidably lost to the food chain at each successive trophic level through: metabolic processes; hunting and capturing food; food not used as a result of death, sedimentation, or emigration from the area; and excretion of dissolved organic matter by plants and animals (Ryther, 1969).

The relative richness of an unstressed ecosystem and its components depends largely upon physical factors such as solar radiation, vertical circulation, nutrient concentrations, water depth, and bottom sediment type. Also, numerous biological interrelationships and processes determine the response of the ecosystem structure to the physical environment.

Secondary and tertiary productivities among the nekton and benthos often vary directly with the amount of food energy produced by and transferred from the autotrophs to higher trophic levels (Raymont, 1963; Rowe, 1971; Ryther, 1969). Since total productivity depends directly upon the numbers or biomass of autotrophs, any stresses that eliminate these organisms or cause a loss in their production efficiency will decrease the productivity of the entire ecosystem. Decreases in primary productivity in the euphotic zone will result, after a time lag, in decreases in the number of fish, mammals, and invertebrates. Therefore, populations which are not themselves exposed to pollution may be affected by a decrease in productivity in a distant part of the food chain.

b. Influence of stresses on community diversity and stability

(1) The relationship of diversity to stability--The term diversity describes and measures species richness or numbers of species in a particular area. "Stability" refers to environmental stability, which implies a range of parameters of the environment, or structural stability, which implies a maintenance of a relatively steady state within a community. Most ecologists agree that diversity and stability are positively correlated (Boesch, 1972; Grassle, 1967; Johnson, 1970; Sanders, 1969; Sanders and Hessler, 1969; Slobodkin and Sanders, 1969).

Some autotrophs, herbivores, carnivores, detritus-feeders, and saprophytes will die or emigrate as a result of acute oil spills, dredge spoil dumps, toxic spills, and chronic long-term additions of pesticides, toxic materials, or oil. Loss of these organisms, particularly of grazing herbivores or predators, will change community composition, and decrease species diversity and structural stability. For example, loss of sea stars which prey upon bivalves, barnacles, and other invertebrates in the intertidal and littoral zones would lower the stability of the benthic communities they inhabit.

As discussed in the "Benthos" section, macrobenthic diversity studies show that diversity and structural stability are high on the Continental Shelf and slope in the Area. In the mouth of Chesapeake Bay at Hampton Roads, however, environmental stresses have apparently eliminated some species and therefore already depressed the community diversity (Boesch, 1972).

Further loss of species and decreased stability will occur if critical environmental factors are changed severely or unpredictably. Changes in sediment grain size, pH, salinity, turbidity, temperature, and productivity levels may cause either subtle or dramatic changes in species composition, population size, reproductive success, and community stability throughout the entire ecosystem or in parts of it.

(2) Roles of predation and competition in maintaining high diversity--Predation and competition for limited resources maintain and increase community diversity and structural stability. Predation is mostly restricted to the upper trophic levels, while competition of all sorts occurs throughout the trophic chain. Both are factors in determining stability within an entire community or ecosystem.

Predation maintains high diversity by precluding a takeover of an environment by one species, by keeping space open for a new recruitment by all competing species, and by eliminating monopolization of the major environmental prerequisites by one species (Spight, 1967; Paine, 1966). In rocky intertidal areas, for example, starfish preying upon mussels and barnacles keep physical space (the prime resource) open for settlement by the planktonic larvae of numerous competing species (Paine, 1966). Predators having several species of prey available can persist when one of the prey species becomes scarce. High-level predators possibly contribute more to community stability than the lower level predators (Saila and Parrish, 1972).

Competitive activity between species (interspecific) and between members of the same species (intraspecific) regulates population size, species diversity, and the evolutionary processes of species and communities. Either by exploitation or by interference, competition encourages speciation and therefore diversity (Miller, 1969). Exploitation occurs when two or more individuals or species have free access to a limiting resource, and the outcome of competition is determined by their relative abilities to use the resource efficiently. Exploitation involves little or no spatial or physical interaction between the competitors. Interference involves the ability of one competitor to prevent the access of another competitor to a required resource (Miller, 1969).

Elimination of competing species allows their competitors relatively free access to required resources and space, and therefore tends to encourage the development of a community dominated by large numbers of a few species. If these few species become increasingly abundant during increasing stresses, chances for a new recruitment by incursions of competing species decrease. Simultaneously, the genetic adaptability and the capability of the dominants to survive abiotic perturbations decrease, and diversity and stability further decrease as an abiotic, highly polluted environment is approached.

(3) Biologically accomodated and physically controlled communities--The analyses of benthic samples by H. L. Sanders have resulted in the stability-time hypothesis which states:

> "Where physiological stresses have been historically low, biologically accommodated communities have evolved. As the gradient of physiological stress increases, resulting from increasing physical fluctuations or by increasingly unfavorable physical conditions regardless of fluctuations, the nature of the community

gradually changes from a predominantly biologically accomodated to a predominantly physically controlled community. Finally, when the stress conditions become greater than the adaptive abilities of the organisms, an abiotic condition is reached. The numbers of species present diminish continuously along the stress gradient" (Sanders, 1968).

Faunal diversity is high in biologically accommodated communities such as pelagic ocean and deep benthic areas. The environment is spatially uniform, unstressed by pollutants, predictable, and stable, or undergoes small predictable seasonal cycles. Complex patterns of energy flow exist through the trophic levels, and a constant and sufficient supply of nutrients is available. Such factors as high geometric, chemical, and plant diversity, multiple predator-prey linkages, and narrow behavioral specializations resulting in spatial and temporal separation of populations all permit larger numbers of populations of different species to coexist (Slobodkin and Sanders, 1969).

In physically controlled communities such as estuaries and polluted harbors, faunal diversity is low and only a few of "indicator" species are able to persist. Environmental conditions fluctuate widely and unpredictably both spatially and temporally, exposing the organisms to severe physiological stresses (Slobodkin and Sanders, 1969). Low-diversity areas are often characterized by polluted conditions, species with wide ecological niches, simple patterns of energy flow through the trophic levels, and either severe predictable cycles in physical parameters, or infrequent unpredictable influxes of undesirable materials or water conditions.

Estuaries are important nursery grounds for valuable pelagic and neritic fishes and as sources of inorganic nutrients and organic matter. Since environmental conditions vary throughout the estuaries and undergo short-term, severe fluctuations, the characteristic low diversity and stability of the estuaries leave them extemely sensitive to additional stresses resulting from human activities.

Species diversity is lower in environments with irregular fluctuations of physical properties than in situations characterized by regular and predictable fluctuations of the same magnitude. Species diversity is also lower where large fluctuations in physical parameters cause severe physiological stresses and lower the probability of survival and reproduction success. Species normally found in biologically accommodated communities are not able to invade or persist in a physically controlled environment, since they are not sufficiently tolerant of environmental changes. The possibility of evolutionary development of specific adaptive mechanisms to lessen the effect of stresses decreases with decreasing predictability of environmental variations. When irregular changes such as pollution stresses do occur in a biologically accommodated, predictable environment, the result is likely to be genetic changes leading to speciation (Slobodkin and Sanders, 1969).

Species inhabiting unpredictable environments show different tolerances and sensitivities to environmental changes during different life history stages. The most sensitive age is often very young, which makes year-class failures likely. A long enough series of year-class failures leads to extinction (Slobodkin and Sanders, 1969).

Thus, the expected repercussions of the formation of an unpredictable, severe environment include decreased probability of speciation, possible local extinction, and decreased possibility of recruitment of new species from adjacent predictable, stable areas. The net result is a tendency toward fewer species and lower structural stability in an environmentally unstable ecosystem.

c. Present and potential role of man in the ecosystem--Human activities in the Hampton Roads/Norfolk Operating Area have included an extensive amount of shipping, including naval operations and oil transport in and out of Chesapeake Bay. Pelagic and benthic fisheries have been exploited by sport and commercial fishermen from Delaware, Maryland, Virginia, and North Carolina. Private, public, and federally controlled seashore areas have been exploited, developed, and used for recreational purposes. Municipal sewage has been piped into estuarine and coastal waters. Areas off the mouth of Chesapeake Bay have been used for dumping dredge spoils. On the Continental Shelf and slope, industrial wastes, radioactive materials, and obsolete explosive ordnance have been dumped.

Some data are available on the physical, chemical, geological, and biological characteristics of the Area; the most pertinent of these data are included in this report. Data on the location, depth, and dates of usage of active and disused dump sites and the chemical and physical nature of materials dumped are sparse and difficult to obtain.

Obviously, all future introductions of foreign materials into this environment with its basic capabilities for a healthy stability should be carefully planned and researched.

The environmental impact of human activities in the Area can be predicted only in general terms. Limited data on the cause-effect relationship of specific pollutants and the ecosystem or its parts prevent detailed analysis. Hypothetical situations in which human activities deleteriously affect the marine ecosystem have been discussed and suggestions made for countering or minimizing them.

BIBLIOGRAPHY

Alexandria Drafting Co. *Salt water sport fishing and boating*, Alexandria, Va. 1971.

Alexandria Drafting Co. *Salt water sport fishing and boating in North Carolina*, Alexandria, Va. 56p., 1972a.

Alexandria Drafting Co. *Salt water sport fishing and boating in Virginia*, Alexandria, Va. 70p., 1972b.

Allen, J. R. L. A review of the origin and characteristics of Recent alluvial sediments, *Sedimentology*, 5, pp. 89-191, 1965.

Anderson, W. W. Fishes taken during shrimp trawling along the south Atlantic coast of the United States, *Contrib. 92*, Bureau of Commercial Fisheries, Biological Lab., Brunswick, Ga., 1963.

Andrews, J. D. Annotated checklist of mollusks of Chesapeake Bay, Virginia Fisheries Lab., Gloucester Pt., Va., Unpublished manuscript, 10p., 1956.

Armstrong, H. E. Development of a gross toxicity criterion in San Francisco Bay, *Proc. 5th. Int. Cong. Water Pollution Research, III, 1/15*, 1971.

Aziz, K. M. S. and H. J. Humm. Additions to the algal flora of Beaufort, N.C. and vicinity, *J. Elisha Mitchell Scientific Soc.*, *78*, pp. 55-63, 1963.

Bagnold, R. A. Beach and nearshore processes, in *Mechanics of Marine Sedimentation*, Part I, edited by M. N. Hill, pp. 507-528. Interscience, New York, 963p., 1963.

Barger, W. R. and W. D. Garrett. Modification of the air-sea interface by artificial sea slicks, *NRL Rep. 6762*, 16p., Naval Research Laboratory, Washington, D.C., 1968.

Be, A. W. H., J. M. Forns, and O. A. Roels. Plankton abundance in the North Atlantic Ocean, in *Fertility of the Sea*, 1, edited by J. D. Costlow, Jr., pp. 17-50, Symposium on Fertility of the Sea, São Paulo, Brazil, 1969. N.Y.: Gordon and Breach Science Publishers, 308p., 1971.

Bodine, F. R. Storm surge on the open coast. Fundamentals and simplified prediction, *Tech. Memo. 35*, U.S. Coastal Engineering Research Center, Washington, D.C., 55p., 1971.

Boesch, D. F. Species diversity of marine macrobenthos in the Virginia **area**, *Chesapeake Science*, *13*, pp. 206-211, 1972.

Boisvert, W. E. Major currents in the north and south Atlantic Oceans between 64°N and 60°S, *Tech. Rep. 193*, 104p., U.S. Naval Oceanographic Office, Washington, D.C., 1967.

Borgstrom, G. *Atlantic Ocean fisheries*. Fishing News (Books) Ltd., London, 312p., 1961.

Breder, M. *Field book of marine fishes of the Atlantic coast from Labrador to Texas*, G. P. Putnam's Sons, New York, 332p., 1948.

Breder, M. and D. E. Rosen. *Modes of reproduction in fishes*, American Museum of Natural History, New York, 941p., 1966.

Bretschneider, C. L. Hurricane surge predictions for Chesapeake Bay, *Misc. Paper 3-59*, 53p., U.S. Army Corps of Engineers, Beach Erosion Board, Washington, D.C., 1959.

Bretschneider, C. L. *The Ash Wednesday east coast storm. March 5-8, 1962. A hindcast of events, causes, and effects*, National Engineering Science Co., Washington, D.C., 17p., 1964.

Brown, J. and E. McCoy. A review of the North Carolina scrap fishery, *Inform. Ser. 1*, 12p., North Carolina Dept. of Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1969.

Bureau of Sport Fisheries and Wildlife, National Survey of Fishing and Hunting, *Research Pub. 95*, 108p., Washington, D.C., 1970.

Burns, D. A. A standard vector deviation rose program for current data, *IMR 0-22-65*, 19p., U.S. Naval Oceanographic Office, Washington, D.C., Unpublished manuscript, 1965.

Buzas, M. A. and T. G. Gibson. Species diversity, benthonic foraminifera in western North Atlantic, *Science*, *163*, pp. 72-75, 1969.

Carriker, M. R. Biology and propagation of young hard clams, *Mercenaria mercenaria*, *J. Elisha Mitchell Scientific Soc.*, *72*, pp. 57-60, 1956.

Cerame-Vivas, M. J. and I. E. Gray. New decapod crustacean records for the coast of North Carolina, *Crustaceana*, *5*, pp. 157-159, 1963.

Cerame-Vivas, M. J. and I. E. Gray. The distributional pattern of benthic invertebrates of the continental shelf off North Carolina, *Ecology*, *47*, pp. 260-270, 1966.

Chen, C. and N. S. Hillman. Shell-bearing pteropods as indicators of water mass off Cape Hatteras, North Carolina, *Bull. Marine Sciences*, *20*, 350p., 1970.

Clark, J., W. G. Smith, A. W. Kendall, Jr., and M. P. Fahay. Studies of estuarine dependence of Atlantic coastal fishes. Northern section, Cape Cod to Cape Lookout, *Data Rep. I*, *Tech. Paper 28*, 132p., Bureau of Sport Fisheries and Wildlife, Washington, D.C., 1969.

Clendenning, K. A. and W. J. North. Effects of wastes on the giant kelp, *Macrocystis pyrifera*, in *Proc. First Internat'l. Conf. on Waste Disposal in the Marine Environment*, pp. 82-91, edited by E. A. Pearson, Pergamon Press, New York, 569p., 1960.

Connor, P. M. Acute toxicity of heavy metals to some marine larvae, *Marine Pollution Bull.*, *3*, pp. 190-192, 1972.

Coomans, H. E. The marine mollusk fauna of the Virginia area as a basis for defining zoogeographical provinces, *Beaufortia*, *9*, pp. 83-104, 1962.

Cooperman, A. I., and H. E. Rosendal. Great Atlantic coast storm, 1962, *Mariner's Weather Log*, *6*, pp. 79-85, 1962.

Corner, E. D. S. and A. G. Davies. Plankton as a factor in the nitrogen and phosphorus cycles in the sea, in Advances in Marine Biology, 9, pp. 102-204, edited by F. S. Russel and M. Yonge, Academic Press, New York, 1971.

Council on Environmental Quality. Ocean dumping, a national policy, Government Printing Office, Washington, D.C., 54p., 1970.

Council on Environmental Quality. Toxic substances, Government Printing Office, Washington, D.C., 25p., 1971.

Cowles, R. P. A biological study of the offshore waters of Chesapeake Bay, Bull. Bureau of Fisheries Doc. 1091, pp. 277-373, 1930.

Cry, G. S. Tropical cyclones of the North Atlantic Ocean. Tech. Paper 55, U.S. Weather Bureau, Washington, D.C., 148p., 1965.

Culliney, J. L. Natural control of settlement and metamorphosis of shipworms, Proc. Third Int. Congress of Marine Fouling and Corrosion, in press, 1972.

Darbyshire, M., and L. Draper. Forecasting wind-generated sea waves, Engineering, 195, pp. 482-484, 1963.

Daugherty, F. M., Jr. Marine biological fouling in the approaches to Chesapeake Bay, Tech. Rep. TR-96, 40p., U.S. Naval Oceanographic Off., Washington, D.C., 1961.

Davis, C. C. The effects of pollutants on the reproduction of marine organisms, in Technical Conference on Marine Pollution and Its Effects on Living Resources and Fishing, (Rome, 9-18 Dec 1970) R-2, 13p., United Nations Food and Agricultural Organization, Rome, 1971.

Davis, J. Exploration for schooling fishes in the middle Atlantic Bight, Virginia Institute of Marine Sciences, Gloucester Pt., Va., Unpublished, 14p., 1969.

Davis, J. Exploring for schooling pelagic fishes in middle Atlantic Bight, Contribution 337, 2p., Virginia Institute of Marine Sciences, Gloucester Pt., Va., 1970.

Davis, J. and E. B. Joseph, Southern record of Sebastes marinus, ocean perch, Chesapeake Science, 5, p. 212, 1964.

Davis, J., J. A. Musick, and E. B. Joseph. Seasonal availability and distribution of benthic fishes of Chesapeake Bight, Summary of Project 3-5-D Commercial Fisheries Research and Development Act, Virginia Institute Marine Sciences, Gloucester Pt., Va., 27p., 1969.

Deevey, G. B. The zooplankton of the surface waters of the Delaware Bay region, Bull. Bingham Oceanographic Collection, 17, pp. 15-41, 1960.

Deuel, D. and J. R. Clark. The 1965 salt-water angling survey, Research Pub. 67, 51p., Bureau of Sport Fisheries and Wildlife, 1968.

Dexter, D. E. Distribution and niche diversity of haustoriid amphipods in North Carolina, Chesapeake Science, 8, pp. 187-198, 1967.

Dexter, D. E. Structure of an intertidal sandy-beach community in North Carolina, Chesapeake Science, 10, pp. 93-98, 1969.

Eisler, R. Pesticide induced stress profiles, E012, 9p., in United Nations Food and Agricultural Organization, New York, 1969.

Eisler, R. Cadmium poisoning in Fundulus leteroclitus (Pisces: Cyprindontidae) and other marine organisms, Fisheries Research Board of Canada, 28, pp. 1225-1234, 1971.

Ekman, V. W. On the influence of the earth's rotation on ocean currents, Ark. F. Mat., Astron. och Fysik, 2, pp. 1-53, 1905.

Emery, K. O., A. S. Merrill, and J. V. Trumbull. Geology and biology of the sea floor as deduced from simultaneous photographs and samples, Limnology and Oceanography, 10, pp. 1-21, 1965.

Emery, K. O. Positions of empty pelecypod valves on the continental shelf, J. Sedimentary Petrology, 38, pp. 1264-1269, 1968.

Engle, R. H. Sublethal chronic effects of DDT and lindane on glycolytic and gluconeogenic enzymes of the quahog, Mercenaria mercenaria, E-13, 7p., United Nations Food and Agricultural Organization, 1970.

Ewing, M. and E. M. Thorndike. Suspended matter in deep ocean water, Science, 147, pp. 1291-1294, 1965.

Fahy, W. Report of trash fish study in North Carolina in 1962, Special Sciences Rep. 5, 20p., North Carolina Dept. of Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1965a.

Fahy, W. Report of trash fish study in North Carolina in 1964, Special Sciences Rep. 7, 13p., North Carolina Dept. of Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1965b.

Fahy, W. An evaluation of North Carolina salt water fisheries, Part I North Carolina Sport Fishery 1962, Special Sciences Rep. 4, 32p., North Carolina Dept. of Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1965c.

Fahy, W. Species composition of the North Carolina industrial fishery, Commercial Fishery Rev., 28, pp. 1-8, U.S. Fish and Wildlife Service, 1966.

Falk, L. L., E. I. Dupont de Nemours and Company. Correspondence with Mr. E. K. Jackson, A. C. E. Distribution 5, 1967.

Finenko, Z. Z. and V. E. Zaika. Particulate organic matter and its role in the productivity of the sea. In Marine Food Chains, pp. 32-44, edited by J. H. Steele, Univ. California Press, Berkeley, Calif., 552p., 1970.

Fisher, A., Jr. Environmental guide to the Virginia capes operating area, Special Pub. SP-211, 58p., U.S. Naval Oceanographic Office, Washington, D.C., 1973.

Food and Agricultural Organization of the United Nations, Report of the seminar on methods of detection, measurement, and monitoring of pollutants in the marine environment. Supplement to the Report of the Technical Conference on Marine Pollution and its Effect on Living Resources and Fishing (Rome, 9-18 Dec 1970), Fisheries Rep. 99, Suppl. 1, 123p., Rome, 1971.

Fox, D. L. Particulate organic detritus, in Treatise on Marine Ecology and Paleoecology, pp. 383-390, edited by J. W. Hedgpeth, Geol. Soc. Amer. Memoir 67, 1, 1957.

Frankenberg, D., S. L. Coles, and R. E. Johannes. The potential trophic significance of Callianassa major fecal pellets, Limnology and Oceanography, 12, pp. 113-120, 1967.

Franz, D. R. Zoogeography of northwest Atlantic opisthobranch molluscs, Marine Biology, 7, pp. 171-180, 1970.

Fuglister, F. C. Gulf Stream, Trans. Amer. Geophys. Union, 44, pp. 498-500, 1963.

Garber, W. F. Receiving water analysis, in Proc. First Int. Conf. on Waste Disposal in the Marine Environment, pp. 372-403, Pergamon Press, New York, 1960.

Gillette, R. Radiation standards: The last word or at least a definitive one, Science, 178, pp. 966-967, 1012, 1972.

Glover, R. S., G. A. Robinson, and J. M. Colebrook. Plankton in the North Atlantic-an example of the problems of analyzing variability in the environment. United Nations Food and Agricultural Organization, Technical Conference on Marine Pollution and its Effects on Living Resources and Fishing, (Rome, 9-18 Dec 1970), pp. 1-12, 1970.

Godwin, W. F., M. W. Street and T. R. Rickman. History and status of North Carolina's marine fisheries, North Carolina Information Ser 2, 81p., North Carolina Dept. of Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1971.

Golley, F. B. Energy flux in ecosystems, in Ecosystem Structure and Function, Proc. 31st Annual Biology Colloquium, pp. 69-90, 1972, edited by J. A. Wiens, Oregon State Univ. Press, Corvallis, Ore., 1972.

Gosner, K. L. Guide to identification of marine and estuarine invertebrates, Interscience, New York, 693p., 1971.

Graham, H. E., and D. E. Nunn. Meteorological considerations pertinent to standard project hurricane, Atlantic and Gulf Coasts of the United States, National Hurricane Research Project Rep. 33, 76p., U.S. Weather Bureau, Washington, D.C., 1959.

Grant, G. C. Atlantic menhaden larvae in Virginia coastal waters, Chesapeake Science, 3, pp. 42-43, 1962a.

Grant, G. C. Predation of bluefish on young Atlantic menhaden in Indian River, Delaware, Chesapeake Science, 3, pp. 45-57, 1962b.

Grant, G. C. Chaetognatha from inshore coastal waters off Delaware, and northward extension of the known range of *Sagitta tenuis*, *Chesapeake Science*, *4*, 38p., 1963a.

Grant, G. C. Investigations of the inner continental shelf waters off lower Chesapeake Bay, Part IV. Descriptions of the Chaetognatha and key to their identification, *Chesapeake Science*, *4*, 107p., 1963b.

Grassle, J. G. *Influence of environmental variation on species diversity in benthic communities of the continental shelf and slope*, Ph.D. Thesis, Duke Univ., Durham, N.C., 213p., 1967.

Gray, I. E. Sea stars of North Carolina, *U.S. Fish and Wildlife Service*, *Fishery Bull.*, *67*, pp. 127-163, 1968.

Harris, D. L. An interim hurricane storm surge forecasting guide, *National Hurricane Research Project Rep. 32*, 23p., U.S. Weather Bureau, Washington, D.C., 1959.

Harris, D. L. Characteristics of the hurricane storm surge, *Tech. Paper 48*, 139p., U.S. Weather Bureau, Washington, D.C., 1963.

Harrison, W., J. J. Norcross, N. A. Pore, and E. M. Stanley. Inferred surface and bottom drift, June 1963 through October 1964, Circulation of shelf waters off the Chesapeake Bight, *ESSA Professional Paper 3*, Part 2, pp. 11-42, Environmental Sciences Services Administration, Washington, D.C., 1967.

Hartman, O. The marine annelids of North Carolina, *Duke Univ. Marine Station Bull. 3*, pp. 1-53, 1945.

Hathaway, J. C., ed. Data file continental margin program, Atlantic coast of the U.S., Samples collected and analyzed data, 2, *WHOI Ref. 71-15*, 490p., Woods Hole Oceanographic Institution, Woods Hole, Mass., 1971.

Hayne, D. W. Marine sport fishing by North Carolina residents, *Special Science Rep. 14*, 37p., North Carolina Dept. Conservation and Development, Division of Commercial and Sports Fisheries, Raleigh, N.C., 1968.

Heald, E. J. Fishery resources atlas, New York to Florida, vol. 1, *Sea Grant Tech. Bull. 3*, 22p., Sea Grant Program (Estuarine and Coastal Studies), Univ. Miami, 1970.

Hellerman, S. Updated estimate of the wind stress on the world ocean, *Monthly Weather Review*, *95*, pp. 607-626, 1967.

Henderson, J. T. and P. Bartsch. Littoral marine mollusks of Chincoteague Island, Virginia, *Proc. U.S. National Museum*, *47*, pp. 411-421, 1915.

Hessler, R. R. and H. L. Sanders, Faunal diversity in the deep sea, *Deep-Sea Research*, *14*, pp. 65-78, 1967.

Hill, M. N., ed., *The Sea*, vol. 3: The earth beneath the sea, Interscience, New York, 963p., 1963.

Hobbie, J. E., O. Holm-Hansen, T. T. Packard, L. R. Pomeroy, R. W. Sheldon, J. P. Thomas, and W. J. Wiebe. A study of the distribution and activity of microorganisms in ocean water, *Limnology and Oceanography*, *17*, pp. 544-555, 1972.

Hopkins, S. H. Distribution of species of *Ciona* (boring sponges) on the eastern shore of Virginia in relation to salinity, *Chesapeake Science*, *3*, pp. 121-124, 1962.

Hopkins, T. L. Mysid shrimp abundance in surface waters of Indian River Inlet, Delaware, *Chesapeake Science*, *6*, pp. 86-91, 1965.

Hufford, G. L. *The biological response to oil in the marine environment, a review*, U.S. Coast Guard, Office of Research and Development, Washington, D.C., 23p., 1971.

Humm, H. J. The seaweed resources of North Carolina, in Taylor, H. F., Survey of marine fisheries of North Carolina, pp. 231-250, Part II, *Biology and Natural History of the Economic Species*, Univ. North Carolina, Univ. N. Car. Press, Chapel Hill, N.C., 1951.

James, R. W. Ocean thermal structure forecasting, ASWEPS Manual, vol. 5, U.S. Naval Oceanographic Office, *Special Pub. SP-105*, Washington, D.C., 217p., 1966.

Jannasch, H. W., K. Eimkjellen, C. O. Wirsen, and A. Farman Jarmaian. Microbial degradation of organic matter in the deep sea, *Science*, *171*, pp. 672-675, 1971.

Jelesnianski, C. P. SPLASH (Special Program to List Amplitudes of Surges from Hurricanes), I. Landfall storms, *Tech. Memo. NWS TDL-46*, 52p., National Oceanic and Atmospheric Administration, Washington, D.C., 1972.

Johnson, R. G. Variations in diversity within benthic marine communities, *American Naturalist*, *104*, pp. 285-300, 1970.

Johnson, T. W., Jr. Some lignicolous marine fungi from the North Carolina coast, *J. Elisha Mitchell Scientific Soc.*, *74*, pp. 42-48, 1958.

Keckes, S. and J. K. Miettinen, Mercury as a marine pollutant, *R-26*, 34p., United Nations Food and Agricultural Organization, Rome, 1970.

Kennedy, J. M. and E. G. Wermund. The behavior of oil on water derived from airborne infrared and microwave radiometric measurements, in *Proc. Joint Conference on Prevention and Control of Oil Spills*, pp. 469-477, 1971.

Kipper, J. M., Jr., and E. J. Joseph. A study of wave persistence for selected locations in the North Atlantic Ocean, North Sea, and Baltic Sea, *Tech. Rep. 149*, 69p., U.S. Naval Oceanographic Office, Washington, D.C., 1963.

Lie, U. A quantitative study of benthic infauna in Puget Sound, Washington, U.S.A., in 1963-1964, *Fiskidir. Skr. Ser. Harunders*, *14*, pp. 229-556, 1968.

Lowery, J. K. *The soft bottom macrobenthic community of Arthur Harbor, Antarctica*, M. A. Thesis, College of William and Mary, Williamsburg, Va., 56p., 1969.

Maloney, W. E. A study of the types, seasons of attachment, and growth of fouling organisms in the approaches to Norfolk, Virginia. *Tech. Rep. 47*, 25p., U.S. Naval Oceanographic Office, Washington, D.C., 1958.

Marcus, E. Opisthobranchia from North Carolina, *J. Elisha Mitchell Scientific Soc.*, *77*, pp. 141-151, 1961.

Matthews, W. H., F. E. Smith, and E. D. Goldberg, eds. *Man's impact on terrestrial and oceanic ecosystems*, Massachusetts Institute of Technology Press, Cambridge, 540p., 1971.

Maturo, F. J. S., Jr. The distributional pattern of the Bryozoa of the east coast of the U.S. exclusive of New England, *Atti. Soc. Ital. Sci. Natur.*, *Milano*, *108*, pp. 261-284, 1968.

McCaul, W. E. Rhynchocoela: Nemerteans from marine and estuarine waters of Virginia, *J. Elisha Mitchell Scientific Soc.*, *79*, pp. 111-124, 1963.

McCloskey, L. R. The dynamics of the community associated with a marine scleractinian coral, *International Rev. Gesamten Hydrobiology*, *55*, pp. 13-82, 1970.

McDougal, K. D. Sessile marine invertebrates of Beaufort, North Carolina. *Ecological Monographs*, *13*, oo, 322-374, Duke University Press, Durham, N.C., 1943.

McErlean, A. J., C. Kerby, and M. L. Wass, eds. Biota of the Chesapeake Bay, *Chesapeake Science*, *13*, *Supplement*, 197p., 1972.

Menzel, D. W. and J. H. Ryther, Distribution and cycling of organic matter in the oceans, in *Organic Matter in Natural Waters*, pp. 31-54, edited by D. W. Hood, 1970.

Menzies, R. J. *Effects of deep-water dumping (conventional munitions) on deep-sea benthic biota, DWD site 9*, unpublished manuscript submitted to U.S. Naval Oceanographic Off., Washington, D.C., 1972.

Menzies, R. J. and G. T. Rowe. The distribution and significance of detrital turtle grass, *Thallassia testudinata*, on the deep-sea, *International Rev. Gesamten Hydrobiology*, *54*, pp. 217-222, 1969.

Menzies, R. J. A submerged reef off North Carolina, *International Rev. Gesamten Hydrobiology*, *51*, pp. 393-431, 1966.

Menzies, R. J., J. S. Zaneveld, and R. M. Pratt. Transported turtle grass as a source of organic enrichment of abyssal sediments off North Carolina, *Deep-sea Research*, *14*, pp. 111-112, 1967.

Merrill, A. S. and J. W. Ropes. Distribution of southern quahogs of the middle Atlantic coast, *Commercial Fisheries Rev.*, *29*, pp. 62-64, 1967.

Miettinen, J. K. Mercury as a hydrospheric pollutant. II. Biological half-time of methyl mercury in four Mediterranean species: A fish, a crab, and two molluscs, *E-90*, 8p., United Nations Food and Agricultural Organization, Rome, 1970.

Meleikousky, S. A. The influence of pollution on pelagic larvae of bottom invertebrates in marine nearshore and estuarine waters, *Marine Biology*, *6*, pp. 350-356, 1970.

Miller, R. S. Competition and species diversity, in *Diversity and Stability in Ecological Systems*, *22*, pp. 63-70, Brookhaven Symposia in Biology, 1969.

Milliman, J. D. Atlantic continental shelf and slope of the U.S.--Petrology of the sand fraction of sediments, northern New Jersey to southern Florida, *Prof. Paper*, *529-J*, pp. 1-40, U.S. Geological Survey, Washington, D.C., 1972.

Milliman, J. D., O. H. Pilkey, and D. A. Ross. Sediments of the continental margin off the eastern United States, *Geol. Soc. Amer. Bull.*, *83*, pp. 1315-1333, 1972.

Milliman, J. D. Alvin dives on the continental margin off the southeastern United States, *Tech. Rep. Mp/67-80*, 18p., Woods Hole Oceanographic Institution, Woods Hole, Mass., 1967.

Mitrovic, V. V. Sublethal effects of pollutants on fish, *R-30*, 10p., United Nations Food and Agricultural Organization, Rome, 1970.

Moiseev, P. A. *The living resources of the world ocean*, Moscow, 334p., 1969.

Musick, J. A. and J. D. McEachran. The squaloid shark *Echinorhinus brucus* off Virginia, *Copeia*, *1*, pp. 205-206, 1969.

Musick, J. A. and J. D. McEachran. Autumn and winter occurrence of decapod crustaceans in Chesapeake Bight, U.S.A., *Crustaceana*, *22*, pp. 190-200, 1972.

Musick, J. A., J. Davis, and J. D. McEachran. *Distribution and abundance of lobsters and sea scallops in Chesapeake Bight*, Virginia Institute Marine Sciences, Gloucester Pt., Virginia, 15p., 1969.

National Academy of Sciences/National Research Council. Disposal of low level radioactive waste into Pacific coastal waters, *NAS-NRC Pub. 985*, 87p., Washington, D.C., 1962.

National Academy of Sciences/National Research Council. *Panel on radioactivity in the marine environment. Radioactivity in the marine environment*, Washington, D.C., 272p., 1971.

National Marine Fisheries Service. *Fishery statistics of the United States*, 1969, U.S. Government Printing Off., Washington, D.C., 474p., 1972.

Neumann, G. and W. J. Pierson, Jr. *Principles of physical oceanography*, Prentice-Hall, Englewood Cliffs, N.J., 545p., 1966.

Nichols, P. R. *Marine resources of the Atlantic coast. Striped bass*, U.S. Dept. of Interior, Bureau of Commercial Fisheries, Washington, D.C., 3p., 1967.

Nickerson, J. W. Storm-surge forecasting, Norfolk, Va., *NAVWEARSCHFAC*, *TP-10.71*, 44p., Naval Weather Research Facility, 1971.

Nissenbaum, A. and I. R. Kaplan. Chemical and isotopic evidence for the *in situ* origin of marine humic substances, *Limnology and Oceanography*, *17*, pp. 570-582, 1972.

North Carolina Department of Conservation and Development. An evaluation of North Carolina salt water fisheries Part I. North Carolina Sport Fisheries 1962, *Special Science Rep. 4*, 32p., Division of Commercial and Sport Fisheries, 1965.

Oceanographer of the Navy. Environmental effects of overboard discharge of biodegradable wastes in the open ocean. Washington, D.C., 151p., 1971.

Odum, E. P. Ecosystem theory in relation to man, in Ecosystem Structure and Function, Proc. 31st Annual Biology Coloquium, pp. 11-24, edited by J. A. Wiens, Oregon State Univ. Press, Corvallis, Ore., 1970.

Paine, R. T. Food web complexity and species diversity, American Naturalist, 100, pp. 65-75, 1966.

Pearse, A. S., and L. G. Williams. The biota of the reefs off the Carolinas, J. Elisha Mitchell Scientific Soc. 67, pp. 133-161, 1951.

Pearse, A. S. Ecology of sand beaches at Beaufort, North Carolina, Ecological Monographs, 12, pp. 135-190, Duke Univ. Press, Durham, N.C., 1942.

Pearson, E. A., P. N. Storrs and R. R. Selleck. Some physical parameters and their significance in marine waste disposal, in Pollution and Marine Ecology, pp. 297-315, edited by T. A. Olson and F. J. Burgess, Interscience, New York, 1967.

Phelps, D. K. Functional relationships of benthos in a coastal lagoon, Ph.D. Thesis, University Rhode Island, Kingston, 146p., 1964.

Pierce, E. L. and N. L. Wass. Chaetognatha from the Florida current and coastal waters of the southeast Atlantic states, Bull., Marine Science of the Gulf and Caribbean, 12, 403p., 1962.

Pollak, M. J. Inshore survey program, Interim Reports IX, , XI, XV. Refs. 52-9, 52-10, 52-13, 52-20, various pages, Johns Hopkins University, Chesapeake Bay Institute, Baltimore, Md., 1952.

Porter, H. J. North Carolina scallop fishery - a bonanza to shell collectors, North Carolina Shell Club Bull. 6, pp. 24-25, 1971.

Porter, H. J. Mollusks coincident with North Carolina's calico scallop fishery, Bull. American Malacology Union, Feb., pp. 32-33, 1972.

Porter, H. J., and A. Chestnut. The offshore clam fishery of North Carolina, Proc. National Shellfish Association, 51, pp. 67-73, 1962.

Portmann, J. E. Progress report on a programme of insecticide analysis and toxicity testing in relation to the marine environment, Helgoland Wiss. Meeresunters, 17, pp. 247-256, Hamburg, 1968.

Portmann, J. E. Toxicity-testing with particular reference to oil-removing materials and heavy metals, E-33, United Nations Food and Agricultural Organization, Rome, 1970.

Portmann, J. E. A discussion of the results of acute toxicity test with marine organisms, using a standard method, E-31, 13p., United Nations Food and Agricultural Organization, Rome 1970.

Pritchard, D. W. Statistical studies of ocean currents, Unpublished, 1947.

Raymont, J. E. G. *Plankton and productivity in the oceans*, Pergamon Press, Oxford, England, 651p., 1963.

Raymont, J. E. G., and J. Shields. Toxicity of copper and chromium in the marine environment, American Public Health Association, in *Recommended Procedures for the Bacteriological Examination of Sea Water and Shellfish*, pp. 275-290, American Public Health Assoc., 1962.

Reimold, R. J. The movement of phosphorus through the salt marsh cord grass *Spartina alterniflora* Loisel, *Limnology and Oceanography*, *17*, pp. 606-611, 1972.

Reintjes, J. W. Synopsis of biological data on the Atlantic menhade, *Brevoortia tyrannus*, *Circular*, *320*, pp. 1-30, U.S. Fish and Wildlife Service, Washington, D.C., 1969.

Reish, D. J. An ecological study of pollution in Los Angeles-Long Beach Harbors, California, *Occasional Paper 22*, 119p., Allan Hancock Found., Univ. Southern California Press, Los Angeles, Calif., 1959.

Richards, H. Notes on the marine invertebrates of the Virginia Capes, *Ecology*, *12*, pp. 443-444, 1931.

Riley, G. A. Patterns of production in marine ecosystems, in Ecosystems Structure and Function, *Proc. 31st Annual Biology Colloquium*, pp. 91-112, edited by J. A. Wiens, Oregon State Univ. Press, Covallis, Ore., 1972.

Rowe, G. T. Benthic biomass and surface productivity, in *Fertility of the Sea*, *2*, pp. 441-454, edited by J. D. Costlow, Jr., [Symposium on Fertility of the Sea, Sao Paulo, Brazil, 1969], Gordon and Breach Science Publishers, New York, pp. 309-622, 1971.

Rowe, G. T. Observations on bottom currents and epibenthic populations in Hatteras Submarine Canyon, *Deep-Sea Research*, *18*, pp. 569-581, 1971.

Rowe, G. T., and R. J. Menzies. Zonation of large benthic invertebrates in the deep-sea off the Carolinas, *Deep-Sea Research*, *16*, pp. 531-537, 1969.

Russell-Hunter, W. D. *Aquatic productivity*, The Macmillan Co., London, 306p., 1970.

Ryther, J. H. Photosynthesis and fish production in the sea, *Science*, *166*, pp. 72-76, 1969.

Ryther, J. H., and W. M. Dunstan. Nitrogen, phosphorus, and eutrophication in the coastal marine environment, *Science*, *171*, pp. 1008-1013, 1971.

Ryther, J. H., and C. H. Yentsch. Primary production of continental shelf waters off New York, *Limnology and Oceanography*, 3, pp. 327-334, 1958.

Saila, S. B., and J. D. Parrish. Exploitation effects upon interspecific relationships in marine ecosystems, *Fishery Bull.* *70*, pp. 383-393, 1972.

Saila, S. B. Dredge spoil disposal in Rhode Island Sound. *Marine Tech. 2*, 48p., Univ. Rhode Island, Kingston, R.I., 1972.

Sanders, H. L. Oceanography of Long Island Sound, 1952-1954. X. Biology of marine bottom communities, Bull. Bingham Oceanogr. Coll. 15, pp. 345-414, 1956.

Sanders, H. L. Benthic studies in Buzzards Bay, III. The structure of the soft-bottom community, Limnology and Oceanography, 5, pp. 138-153, 1960.

Sanders, H. L. Marine benthic diversity: a comparative study. American Naturalist, 12, pp. 243-282, 1968.

Sanders, H. L. Benthic marine diversity and the stability-time hypothesis, in Diversity and Stability in Ecological Systems, 22, pp. 77-81, Brookhaven Symposia in Biology, 1969.

Sanders, H. L., and R. R. Hessler. Ecology of the deep-sea benthos, Science, 163, pp. 1419-1424, 1969.

Sanders, H. L., P. C. Mangelsdorf, Jr., and G. R. Hampson. Salinity and faunal distribution in the Pocasset River, Massachusetts, Limnology and Oceanography, supplement to v. 10, pp. R216-R229, 1965.

Sanders, H. L., R. R. Hessler, and G. R. Hampson. An introduction to the study of deep-sea benthic faunal assemblages along the Gay Head - Bermuda transect. Deep-Sea Research, 12, pp. 845-867, 1965.

Schoener, A. and G. T. Rowe. Pelagic Sargassum and its presence among the deep-sea benthos, Deep-Sea Research, 17, pp. 923-925, 1970.

Schubel, J. R., and R. B. Biggs. Distribution of seston in upper Chesapeake Bay, Chesapeake Science, 10, pp. 18-23, 1969.

Scripps Institution of Oceanography. The field of mean wind stress over the North Pacific Ocean, Oceanographic Rep. 14, 12p., Univ. California, La Jolla, Calif., 1948.

Seiburth, J. M. Studies on algal substances in the sea. III. The production of extracellular organic matter by littoral marine algae, J. Experimental Marine Biology and Ecology, 3, pp. 290-309, 1969.

Seiburth, J. M., and A. Jensen. Studies on algal substances in the sea, I. Gelbstoff (humic material) in terrestrial and marine waters, J. Experimental Marine Biology and Ecology, 2, pp. 174-189, 1968.

Seiburth, J. M., and A. Jensen. Studies on algal substances in the sea, II. The formation of gelbstoff (humic material) by exudates of Phaeophyta, J. Experimental Marine Biology and Ecology, 3, pp. 275-289, 1969.

Shapiro, S. Our changing fisheries, Government Printing Off., Washington, D.C., 534p., 1971.

Shaw, W. N., and A. S. Merrill. Setting and growth of the American oyster, Crassostrea virginica, on navigation buoys in the lower Chesapeake Bay, Proc. National Shellfish Assoc. 56, pp. 67-72, 1966.

Sieling, F. W. Mass mortality of the starfish, Asterias forbesi, on the Atlantic coast of Maryland, Chesapeake Science, 1, pp. 73-74, 1960.

Slobodkin, L. B., and H. L. Sanders. On the contribution of environmental predictability to species diversity, in *Diversity and Stability in Ecological Systems*, *22*, pp. 82-95, Brookhaven Symposia in Biology, 1969.

Smith, D. D., and R. P. Brown. Ocean disposal of barge-delivered liquid and solid wastes from U.S. coastal cities, *SW-19c*, 119p., U.S. Environmental Protection Agency, Solid Waste Management Office, Washington, D.C., 1971.

Spight, T. M. Species diversity: a comment on the role of the predator, *American Naturalist*, *101*, pp. 466-474, 1967.

Spinner, G. P. The wildlife wetlands and shellfish areas of the Atlantic Coastal Zone, *American Geographic Soc. of New York*, *Folio 18*, 4p., 1969.

Stephenson, T. A., and A. Stephenson. Life between tidemarks in North America, II. Northern Florida and the Carolinas, *J. Ecology*, *40*, pp. 1-49, 1952.

St. John, P. A volumetric study of zooplankton distribution in the Cape Hatteras area, *Limnology and Oceanography*, *3*, pp. 387-397, 1958.

Taylor, W. R. Marine algae of the northeastern coast of North America, *Sci. Ser. 13* (*2nd ed.*), 509p., Univ. Michigan Press, Ann Arbor, Mich., 1957.

Teal, J. M. Energy flow in a salt marsh ecosystem of Georgia, *Ecology*, *43*, pp. 614-624, 1962.

Tenore, K. R. The macrobenthos of the Pamlico River estuary, North Carolina, *Rep. 40*, 113p., Water Resources Research Institute, Univ. North Carolina, Chapel Hill, N.C., 1970.

Thom, H. C. S. Asymptotic extreme-value distributions of wave heights in the open ocean, *J. Marine Research*, *29*, pp. 19-27, 1971.

Thorade, H. Die Geschwindigkeit von triftstromungen und die Ekman'sche theory, *Annales des Hydrographie and Maritimen Meteorologie*, *42*, p. 379, 1914.

Tietjen, J. H. Ecology and distribution of deep sea meiobenthos off North Carolina, *Deep-Sea Research*, *18*, pp. 941-957, 1971.

U.S. Army Coastal Engineering Research Center. Shore protection planning and design, *Tech. Rep. 4*, 401p., Corps of Engineers, Wash., D.C., 3rd ed., 1966.

U.S. Army Corps of Engineers. *National shoreline study, regional inventory report, North Atlantic Region*, *I*, 120p., Washington, D.C., 1971.

U.S. Army Corps of Engineers. *National shoreline study, regional inventory report, North Atlantic Region*, *II*, Washington, D.C., 1971.

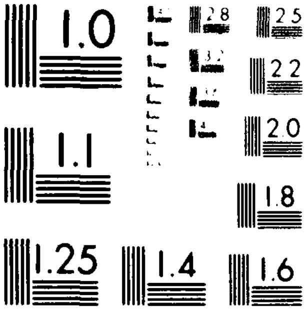
U.S. Coast and Geodetic Survey. Surface water temperature and density Atlantic coast - North and South America, *Pub. 31-1*, 102p., U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., 1968.

U.S. Department of Commerce. *Annual summary of activities, southeast region*, NMFS, NOAA, *Atlantic States Marine Fisheries Commission 1971-72*, Washington, D.C., 28p., 1972.

AD-A085 006 NAVAL OCEANOGRAPHIC OFFICE NSTL STATION MS F/G 8/1
MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFO--ETC(U)
MAY 74 R G BEAUCHAMP
UNCLASSIFIED N00-SP-250 NL

3 of 3
AD
A085006

END
DATE
FILMED
7-80
DTIC


1.0
2.8
2.5
3.2
2.2
2.0
1.1
1.8
1.25
1.4
1.6

[illegible]

[illegible]

U.S. Department of Commerce. *Report of foreign fishing off U.S. coasts*, (published monthly), 1971-1972, National Marine Fisheries Service, Washington, D.C.

U.S. Department of Commerce. *Virginia, Maryland, North Carolina - landings, National Oceanic and Atmospheric Administration Current Fisheries Statistics*, Various numbers, Washington, D.C., 1971-1972.

U.S. National Climatic Center, Wind, wind wave (sea) and swell wave data summarized by 1° latitude - longitude quadrangles from tape data family - 11 (surface marine observations, 1800-1968), National Oceanic and Atmospheric Administration, Unpublished, Asheville, N.C.

U.S. National Oceanographic Data Center. Oceanographic station data for Marsden square 116, U.S. Naval Oceanographic Office, Unpublished, Washington, D.C.

U.S. National Ocean Survey. National Oceanic and Atmospheric Administration, Surface and subsurface current data at various locations within the study area, National Oceanic and Atmospheric Administration, Unpublished, Washington, D.C.

U.S. National Ocean Survey. *Tidal current tables, Atlantic coast of North America*, Washington, D.C., 1973.

U.S. Naval Oceanographic Office. Oceanographic atlas of the North Atlantic Ocean, Section I. Tides and Currents, *Pub. 700*, U.S. Naval Oceanographic Office, Washington, D.C., 93p., 1965.

U.S. Naval Oceanographic Office. Surface current data for Marsden square 116. U.S. Naval Oceanographic Office, Washington, D.C., Unpublished.

U.S. Naval Oceanographic Office. Bottom sediment data for Marsden square 116. U.S. Naval Oceanographic, Washington, D.C., Unpublished.

U.S. Navy Report. *Environmental condition report for numbered deep water munitions dump sites*, Department of the Navy, Washington, D.C., 129p., 1972.

Van Engel, W. A. and Tan Eng-Chow. Investigations of inner continental shelf waters off lower Chesapeake Bay, Part IV. The Copepods, *Chesapeake Science*, *6*, pp. 183-189, 1965.

Vernberg, F. J. and W. B. Vernberg. Lethal limits and the zoogeography of the faunal assemblages of coastal Carolina water, *Marine Biology*, *6*, pp. 26-32, 1970a.

Vernberg, W. B. and F. J. Vernberg. Metabolic diversity in oceanic animals, *Marine Biology*, *6*, pp. 33-42, 1970b.

Warinner, J. E. and M. L. Brehmer. The effects of thermal effluents on marine organisms, *Air Water Pollution International J.*, *10*, pp. 277-289, 1966.

Wass, M. L. Check list of the marine invertebrates of Virginia, Institute of Marine Science, *Special Science Rep. 24*, pp. 1-56, Virginia Institute of Marine Science, Gloucester Pt., Va., 1963.

Wells, H. W. Maryland records of the gastropod, Littorina littorea, with a discussion of factors controlling its southern distribution, Chesapeake Science, 6, pp. 38-42, 1965.

Wells, H. W. Marine sponges of North Carolina, J. Elisha Mitchell Scientific Soc., 76, pp. 200-245, 1960.

Wells, H. W., and I. E. Gray. Summer upwelling off the northeast coast of North Carolina, Limnology and Oceanography, 5, pp. 108-109, 1960a.

Wells, H. W., and I. E. Gray. The seasonal occurrence of Mytilus edulis on the Carolina coast as a result of transport around Cape Hatteras, Marine Biological Lab., Woods Hole, Mass., Biological Bull., 119, pp. 550-559, 1960b.

Wells, H. W., and I. E. Gray. Polychaetous annelids of the Cape Hatteras area, J. Elisha Mitchell Scientific Soc., 80, pp. 70-78, 1964.

Wells, H. W., and H. G. Richards. Invertebrate fauna of coquina from the Cape Hatteras region, J. Paleontology, 36, pp. 586-591, 1962.

Wells, H. W., M. J. Wells, and I. E. Gray. On the southern limit of Balanus balanoides in the western Atlantic, Ecology, 41, pp. 578-580, 1960.

Wells, H. W., M. J. Wells, and I. E. Gray. The calico scallop community in North Carolina, Bull. Marine Science Gulf and Caribbean, 14, pp. 561-593, 1964.

Wigley, R. L. and B. R. Burns. Mysid abundance in the western North Atlantic Ocean, Fishery Bull., 69, p. 717, 1971.

Wigley, R. L. and K. O. Emery. Submarine photos of commercial shellfish off northeastern U.S., Commercial Fisheries Rev., 30, pp. 43-49, 1968.

Wilber, C. G. The biological aspects of water pollution, C. C. Thomas, Springfield, Ill., 269p., 1969.

Wilhem, J. L. and T. C. Dorris. Biological parameters for water quality criteria, Biological Science, 18, pp. 447-481, 1968.

Williams, A. B. Marine decapod crustaceans of the Carolinas, U.S. Fish and Wildlife Service, Fishery Bull. 65, pp. 1-293, 1965.

Wilson, K. W. and P. M. Connor. The use of continuous flow apparatus in the study of longer term toxicity of heavy metals, International Council for the Exploration of the Sea, 8, 4p., 1971.

Wulff, B. L., E. M. J. Wulff, B. H. Robison, J. K. Lowery, and H. J. Humm. Summer marine algae of the jetty at Ocean City, Maryland, Chesapeake Science, 9, pp. 56-60, 1968.

Wulff, B. L. and K. L. Webb. Intertidal zonation of marine algae at Gloucester Point, Virginia, Chesapeake Science, 10, pp. 29-35, 1969.

Wurster, C. F. DDT reduces photosynthesis by marine phytoplankton, Science 159, pp. 1474-1475, 1968.

Yentsch, C. S. Primary production, in Oceanography and Marine Biology, an Annual Review, 1, pp. 157-175, edited by H. Barnes, George Allen and Unwin Publ., London, 1963.

Yergen, W. E. A statistical rose program, Special Pub. SP-64, U.S. Naval Oceanographic Office, Washington, D.C., 17p., 1962.

Zaneveld, J. S. The benthic marine algae of Delaware, U.S.A., Chesapeake Science, 13, pp. 120-138, 1972.

Zaneveld, J. S. The marine algae of the American coast between Cape May, New Jersey, and Cape Hatteras, North Carolina, I. The Cyanophyta. Botanica Marina, 9, pp. 101-128, 1966.

Zaneveld, J. S. and W. D. Barnes. Reproductive periodicities of some benthic algae in lower Chesapeake Bay, Chesapeake Science, 6, pp. 17-32, 1965.

ZoBell, C. E. Marine microbiology, Chronica Botanica Co. Publ., Waltham, Mass., 240p., 1946.

APPENDIX A.

PHYSICAL DATA

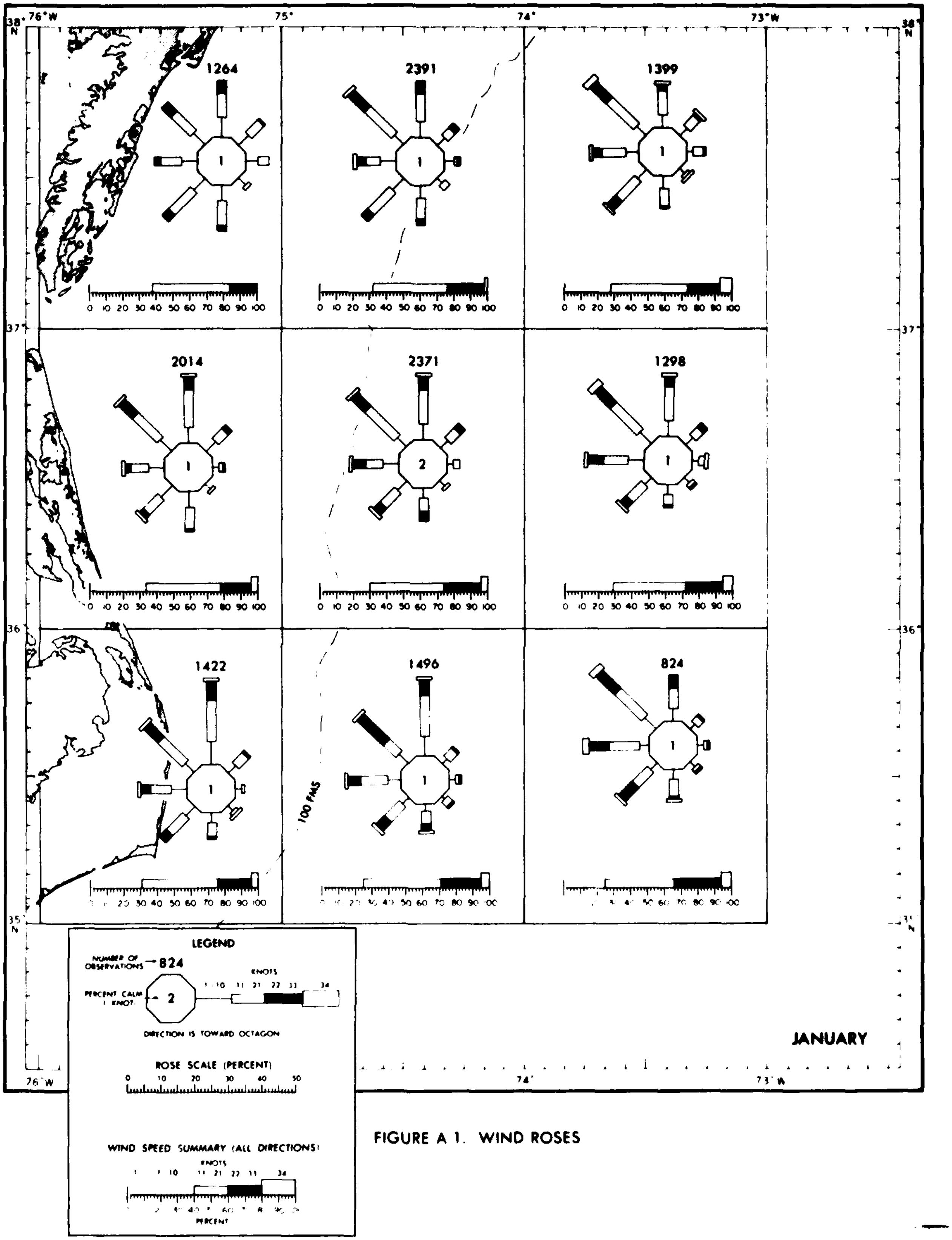


FIGURE A 1. WIND ROSES

PRECEDING PAGE BLANK-NOT FILMED

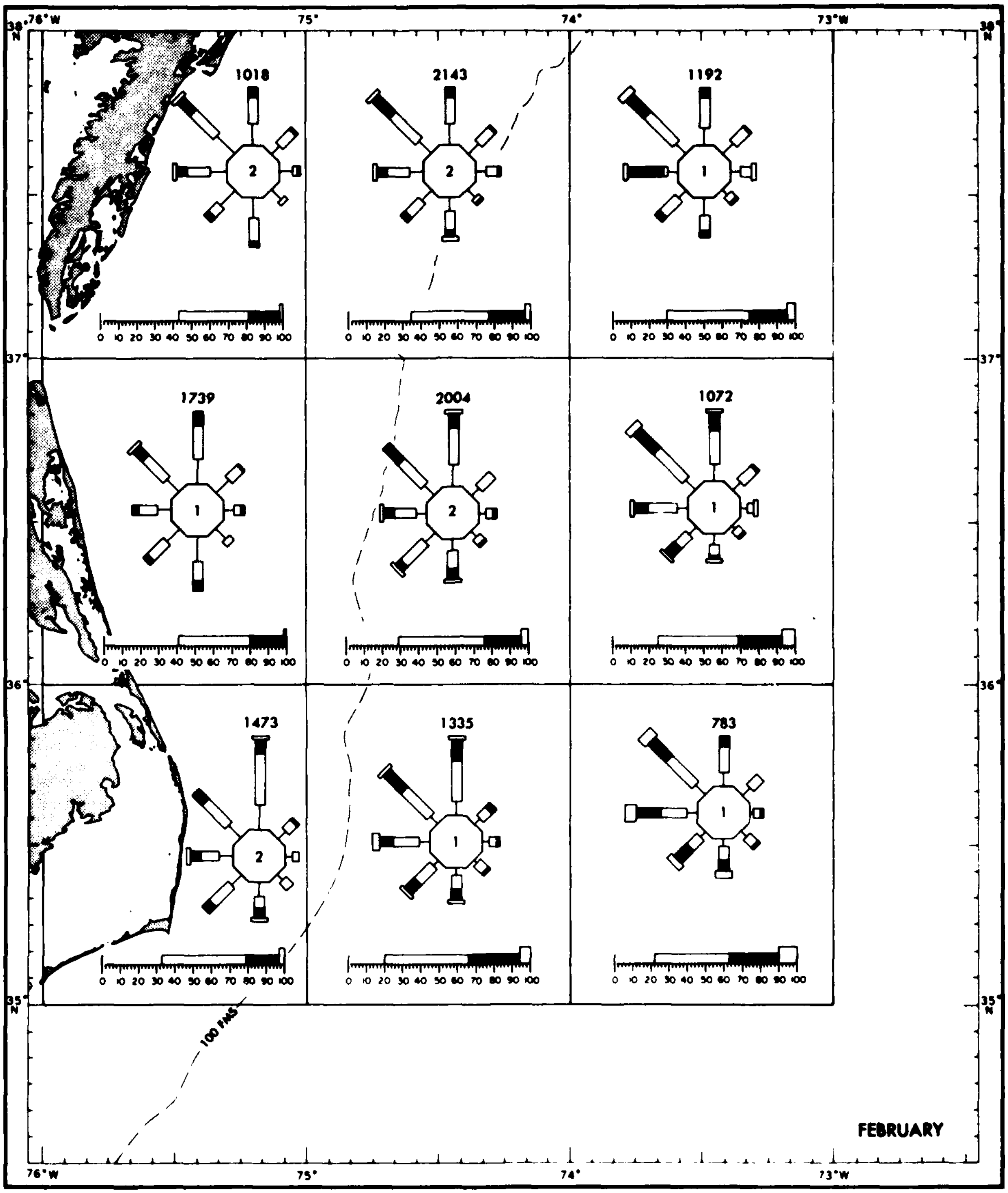


FIGURE A 1. WIND ROSES (CON.)

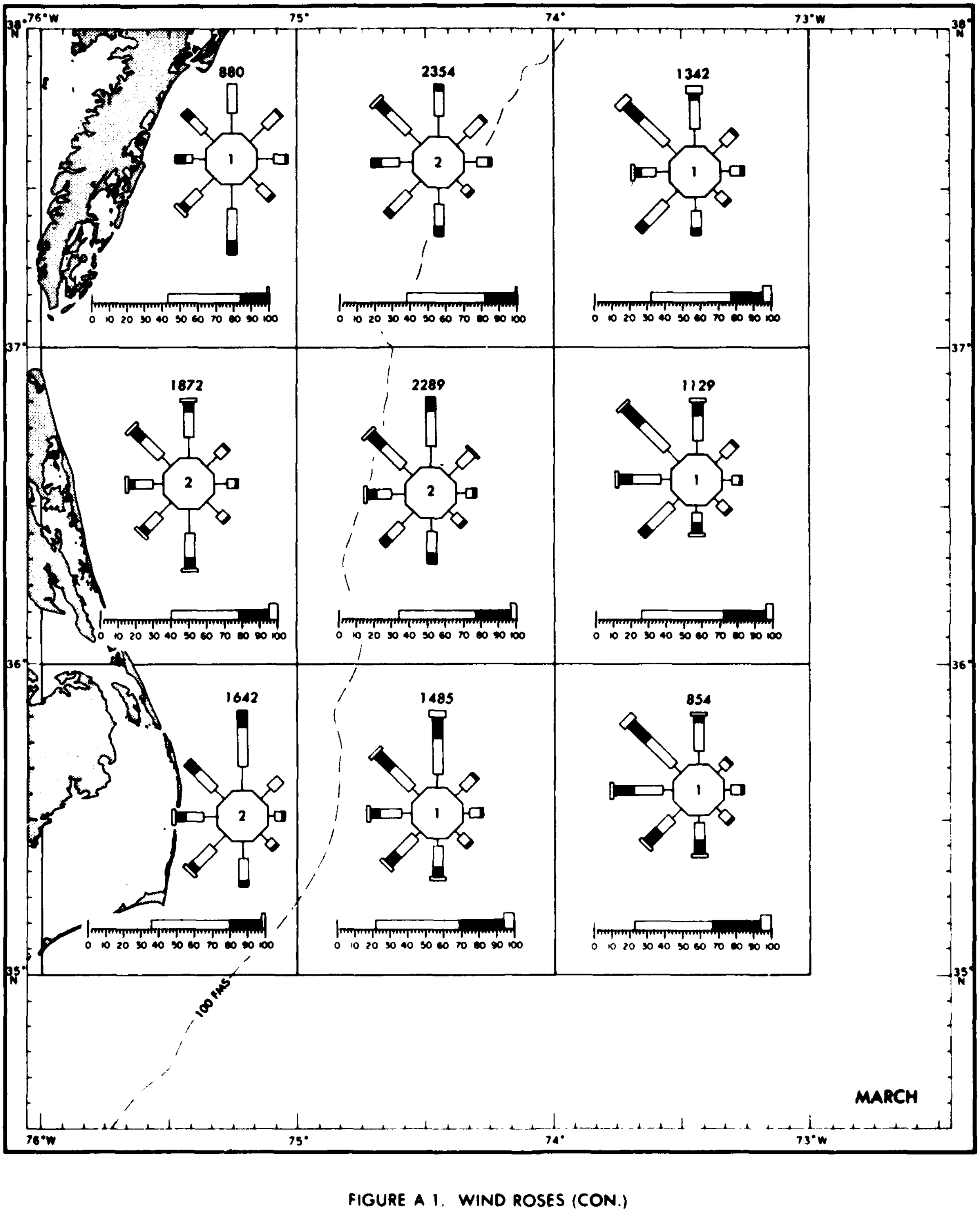


FIGURE A 1. WIND ROSES (CON.)

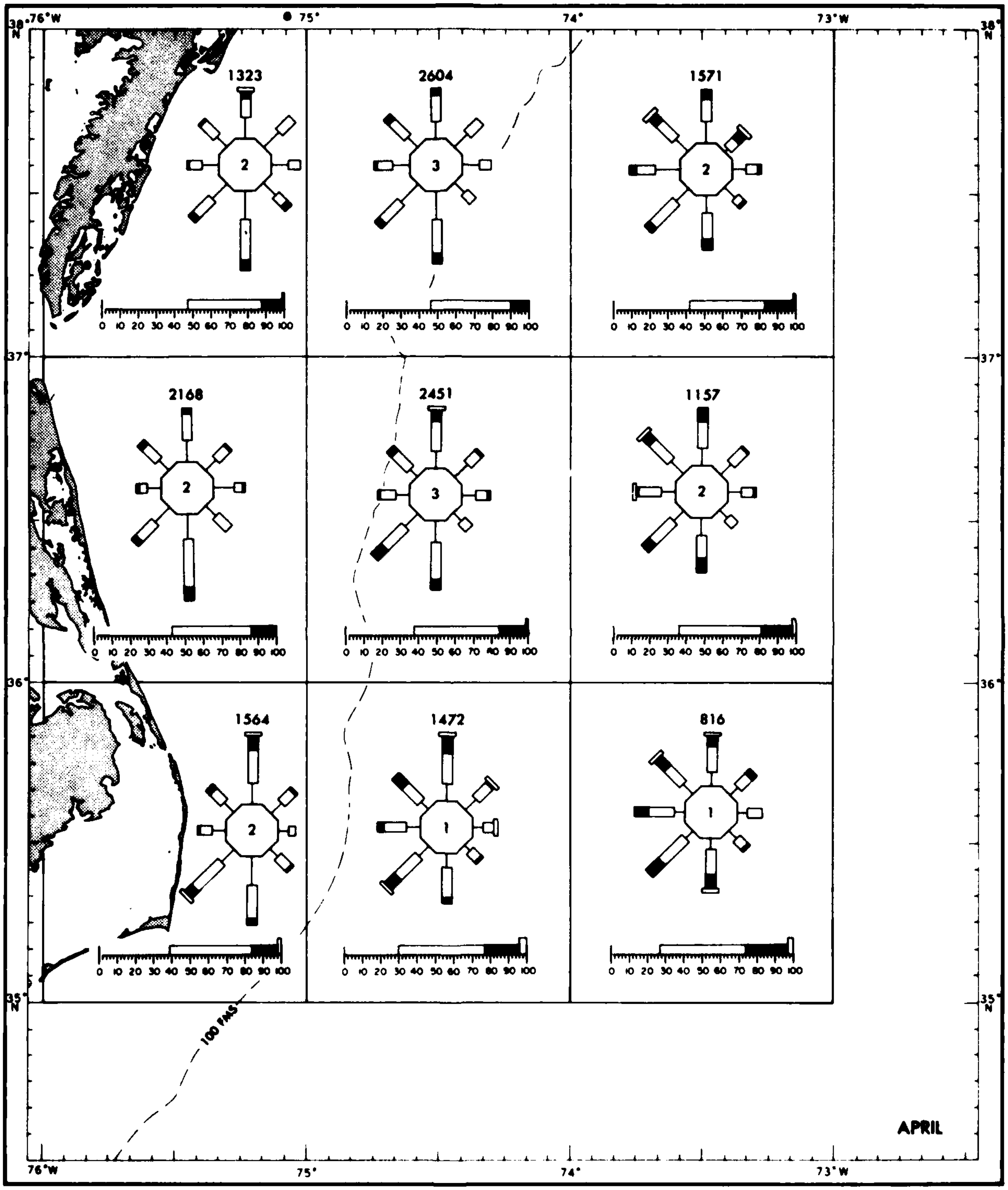


FIGURE A 1. WIND ROSES (CON.)

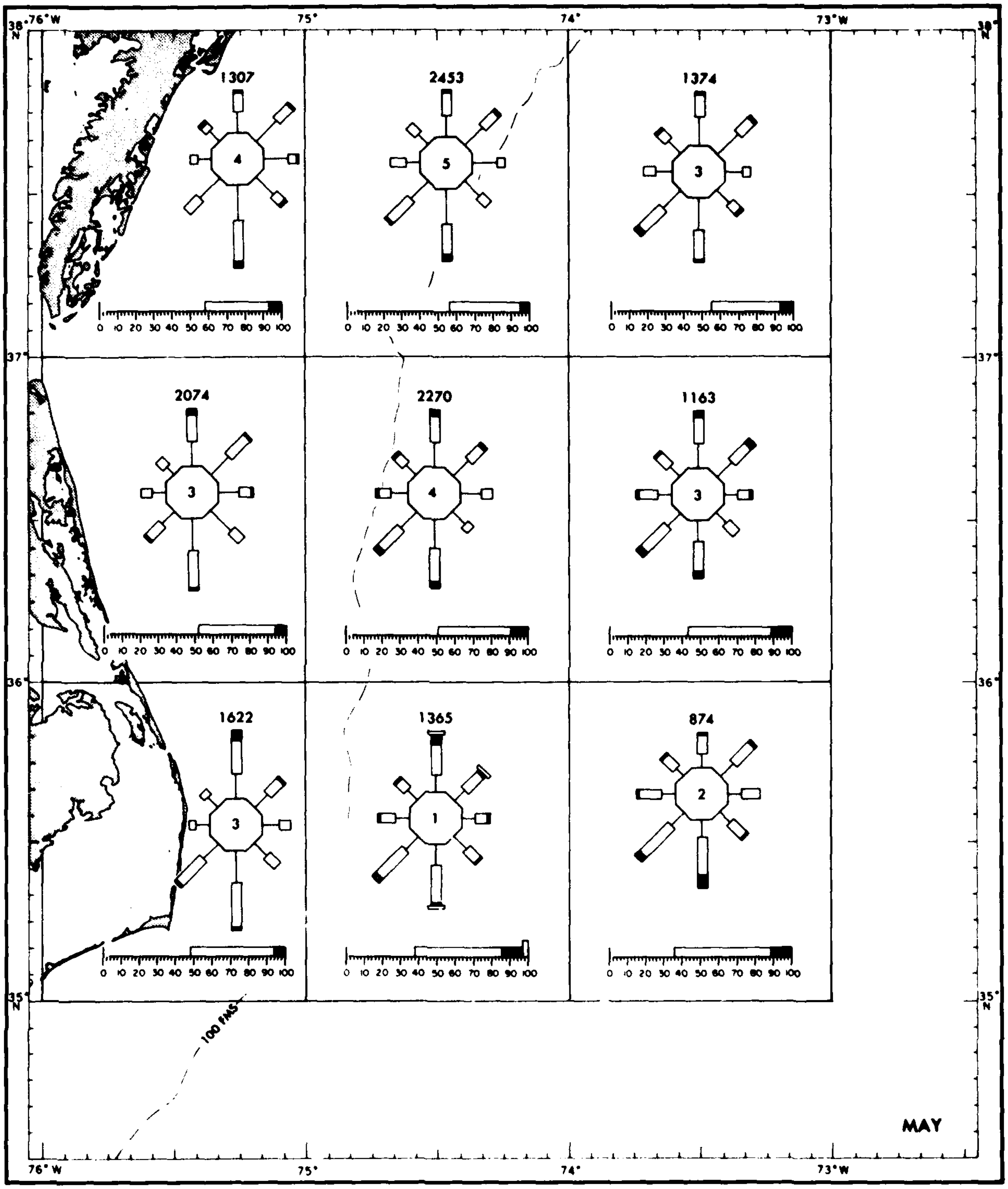


FIGURE A 1. WIND ROSES (CON.)

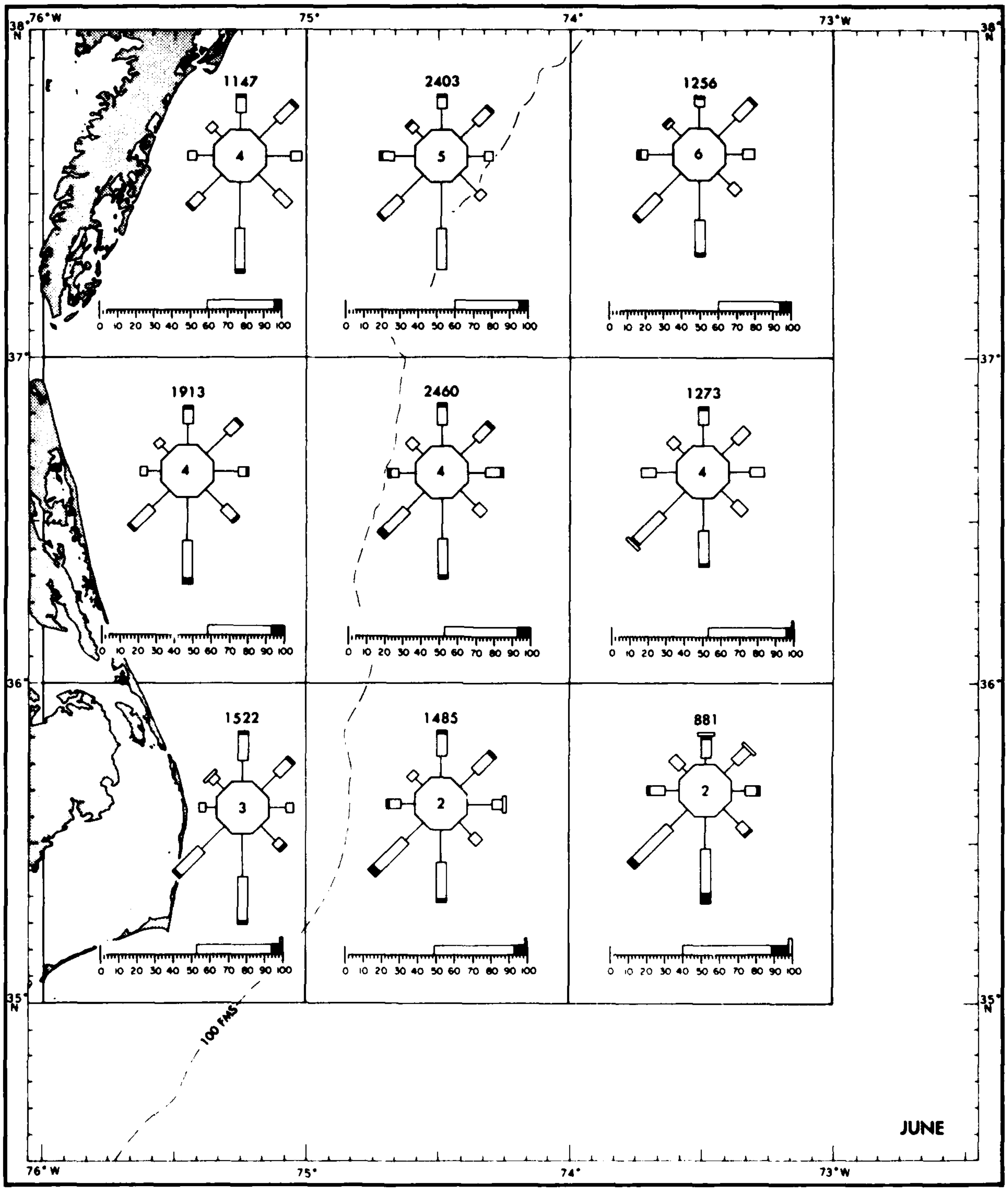


FIGURE A 1. WIND ROSES (CON.)

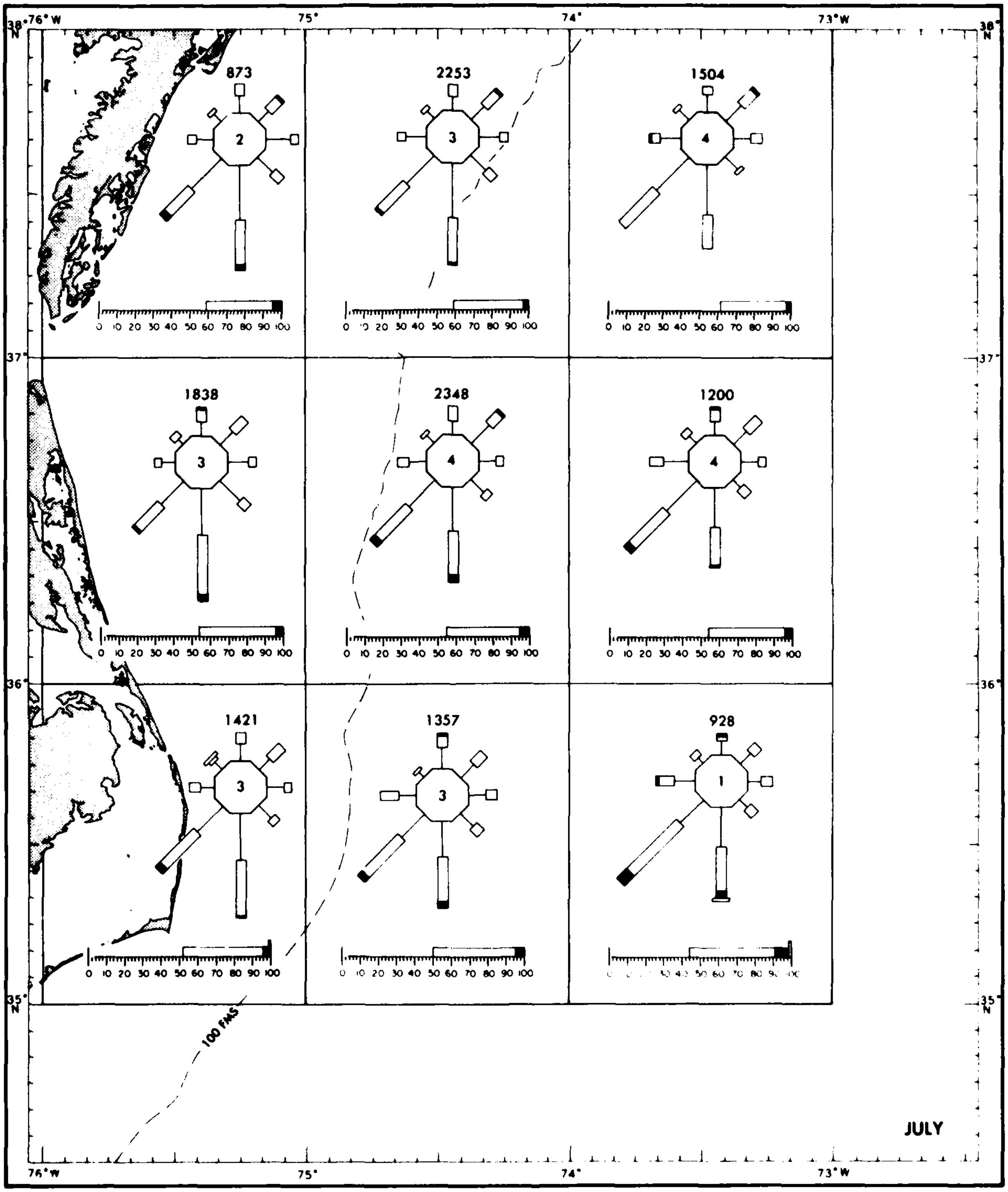


FIGURE A 1. WIND ROSES (CON.)

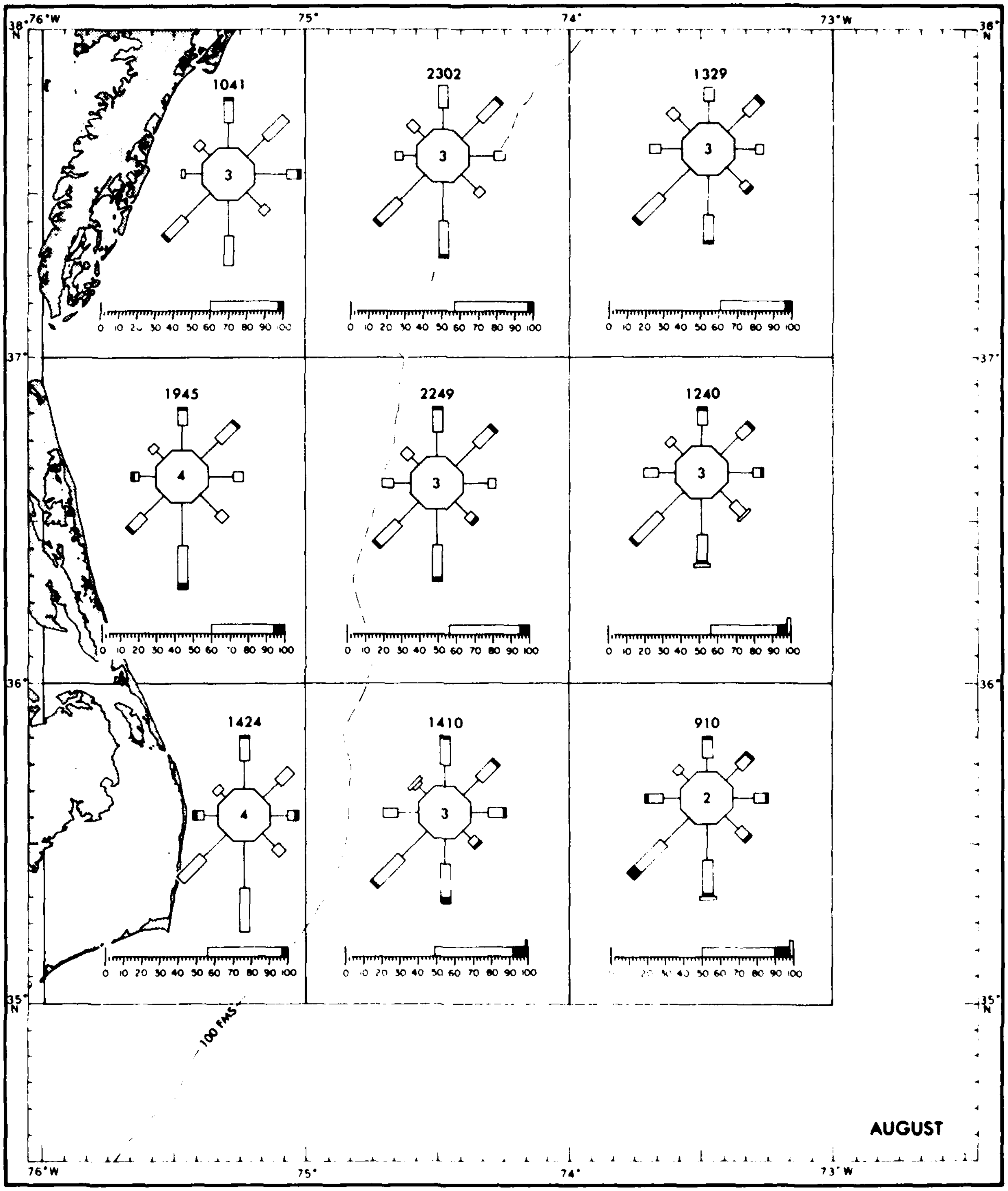


FIGURE A 1. WIND ROSES (CON.)

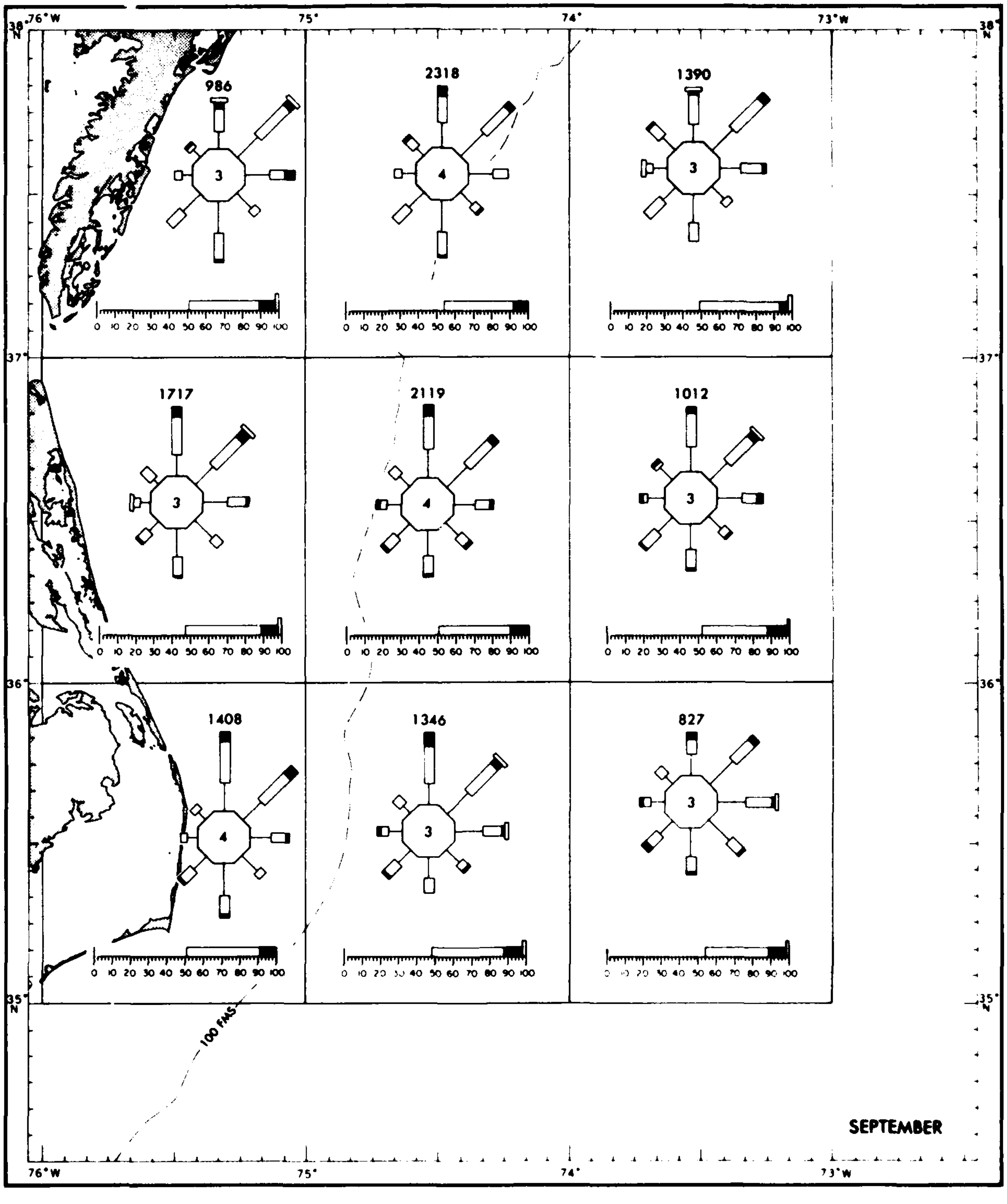


FIGURE A 1. WIND ROSES (CON.)

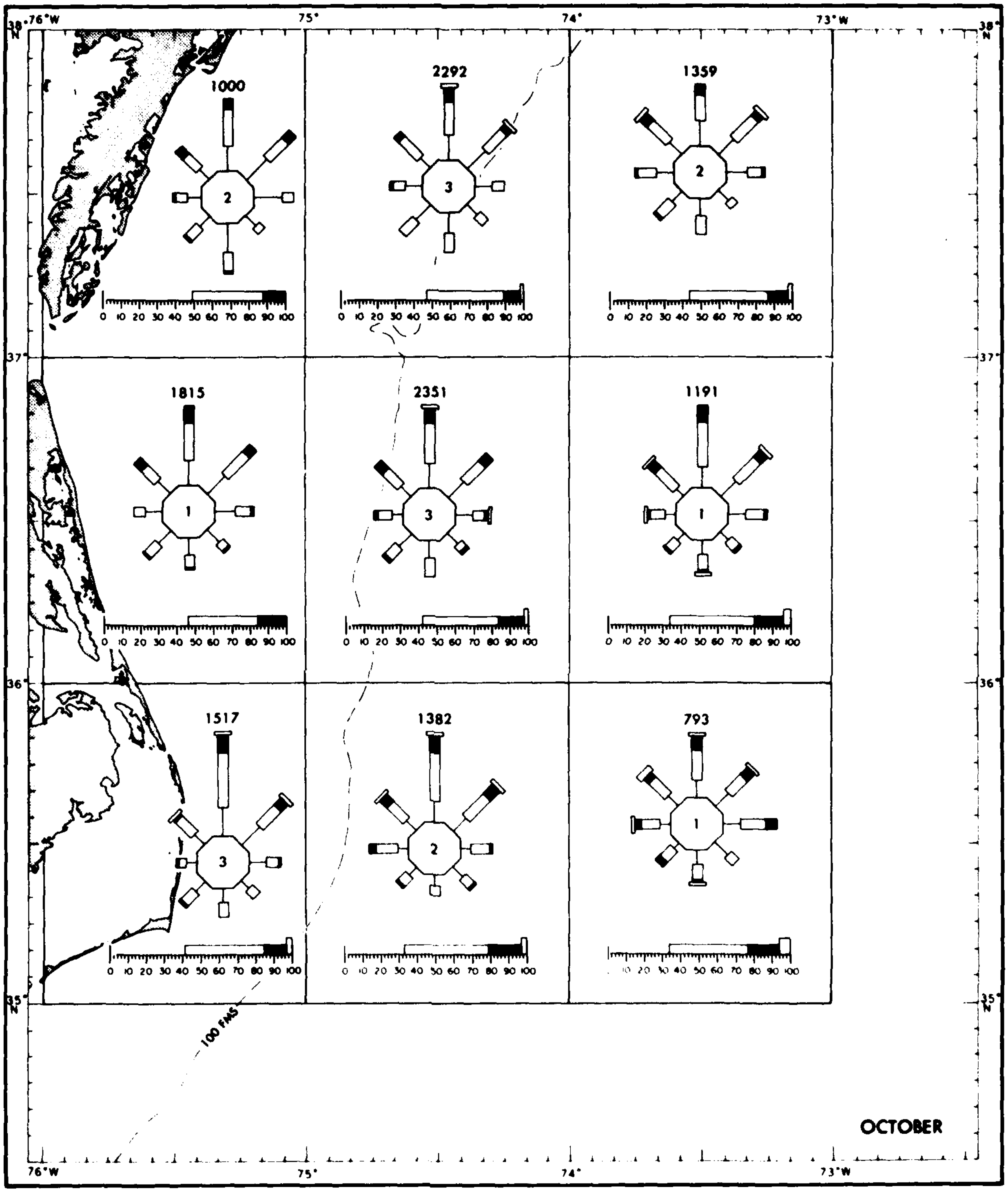


FIGURE A 1. WIND ROSES (CON.)

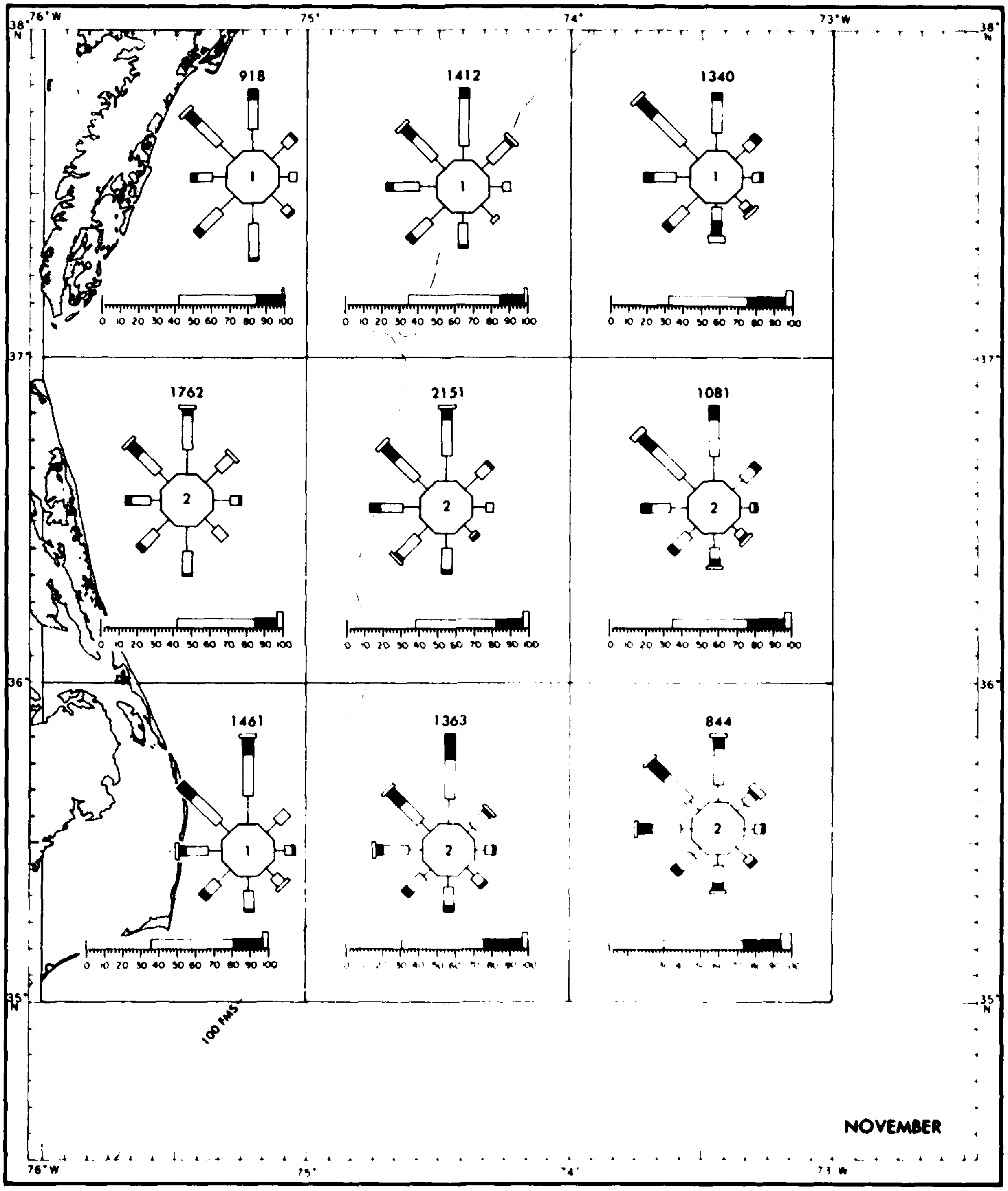


FIGURE A 1 WIND ROSES (CON.)

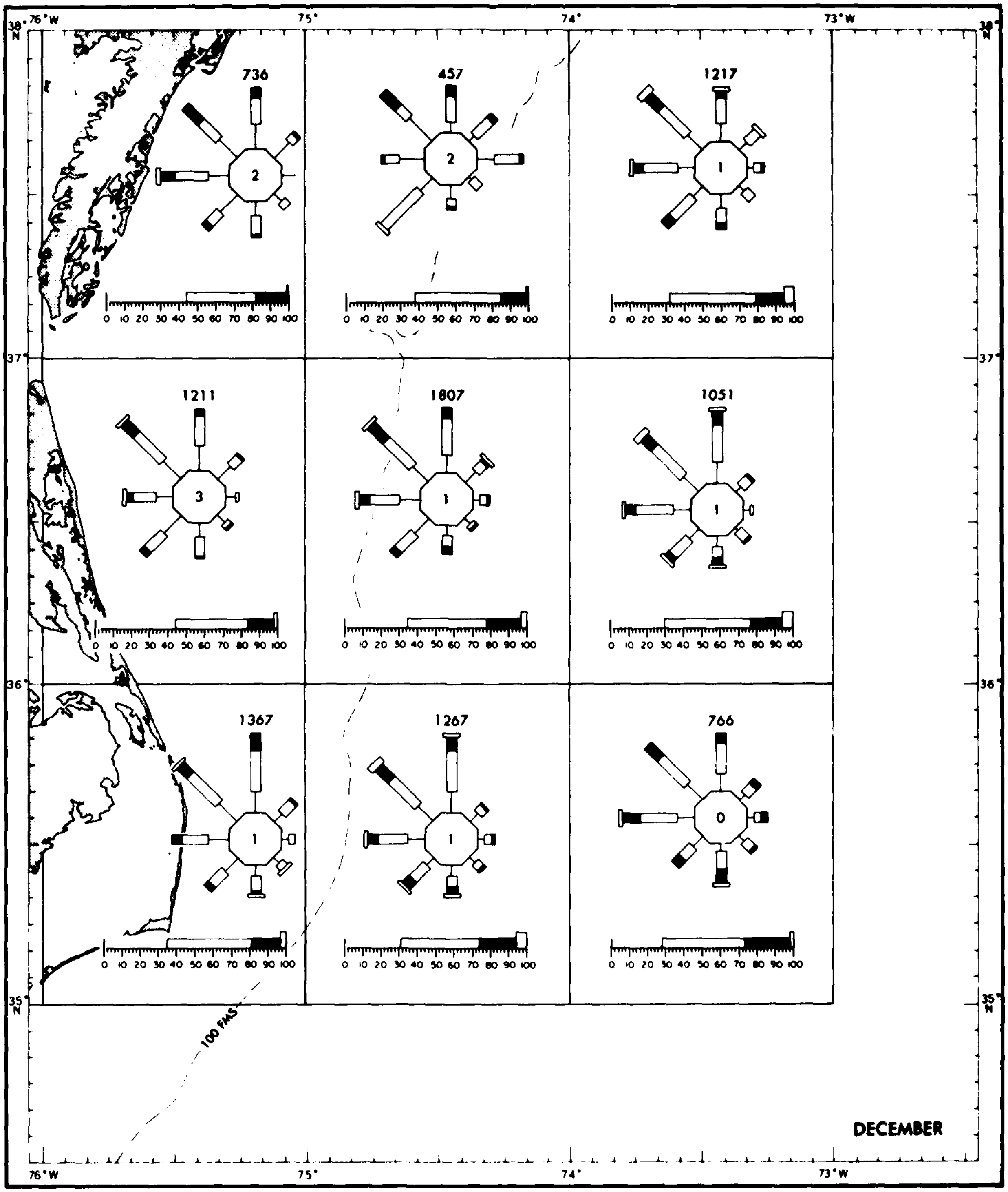


FIGURE A 1. WIND ROSES (CON.)

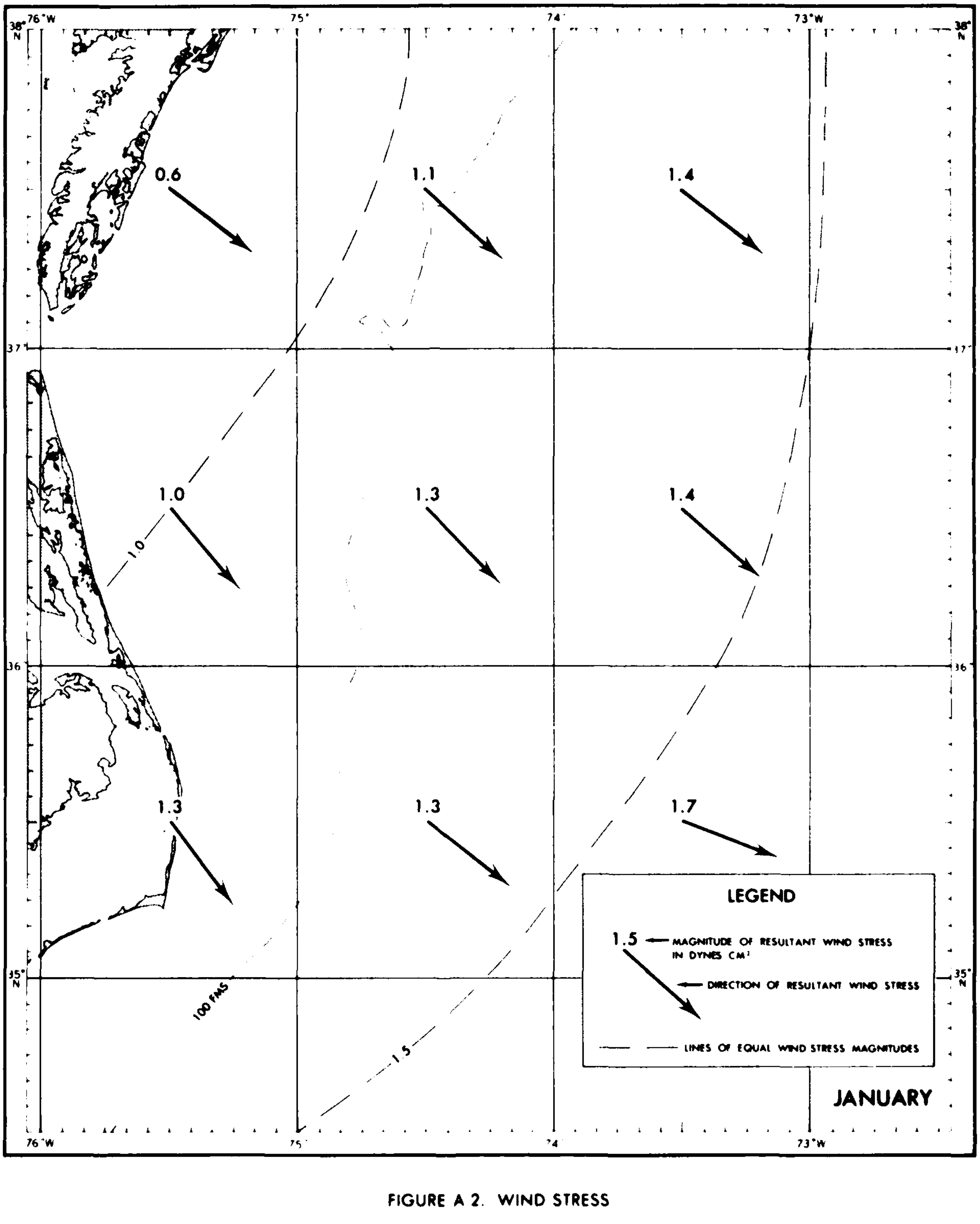


FIGURE A 2. WIND STRESS

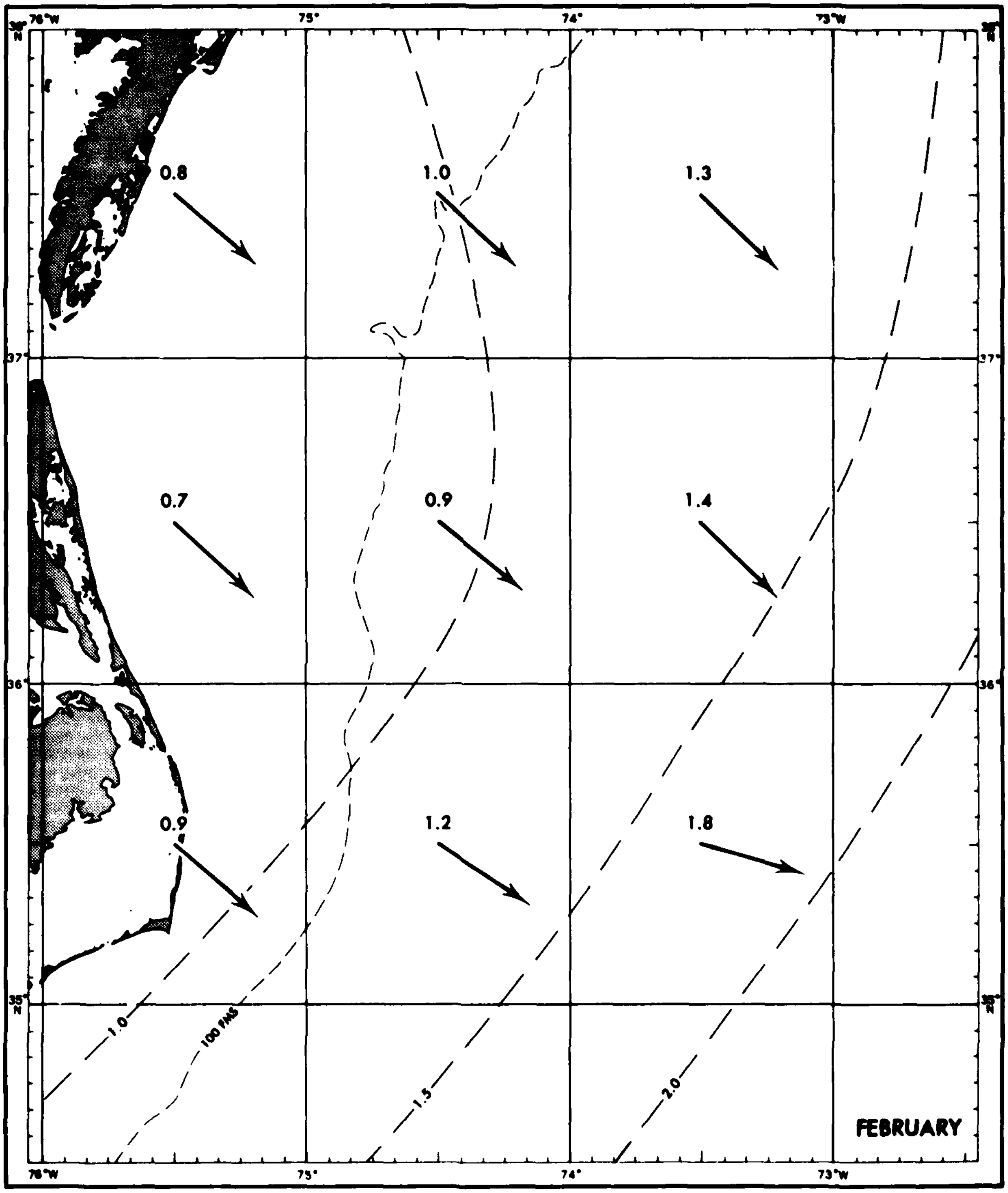


FIGURE A 2. WIND STRESS (CON.)

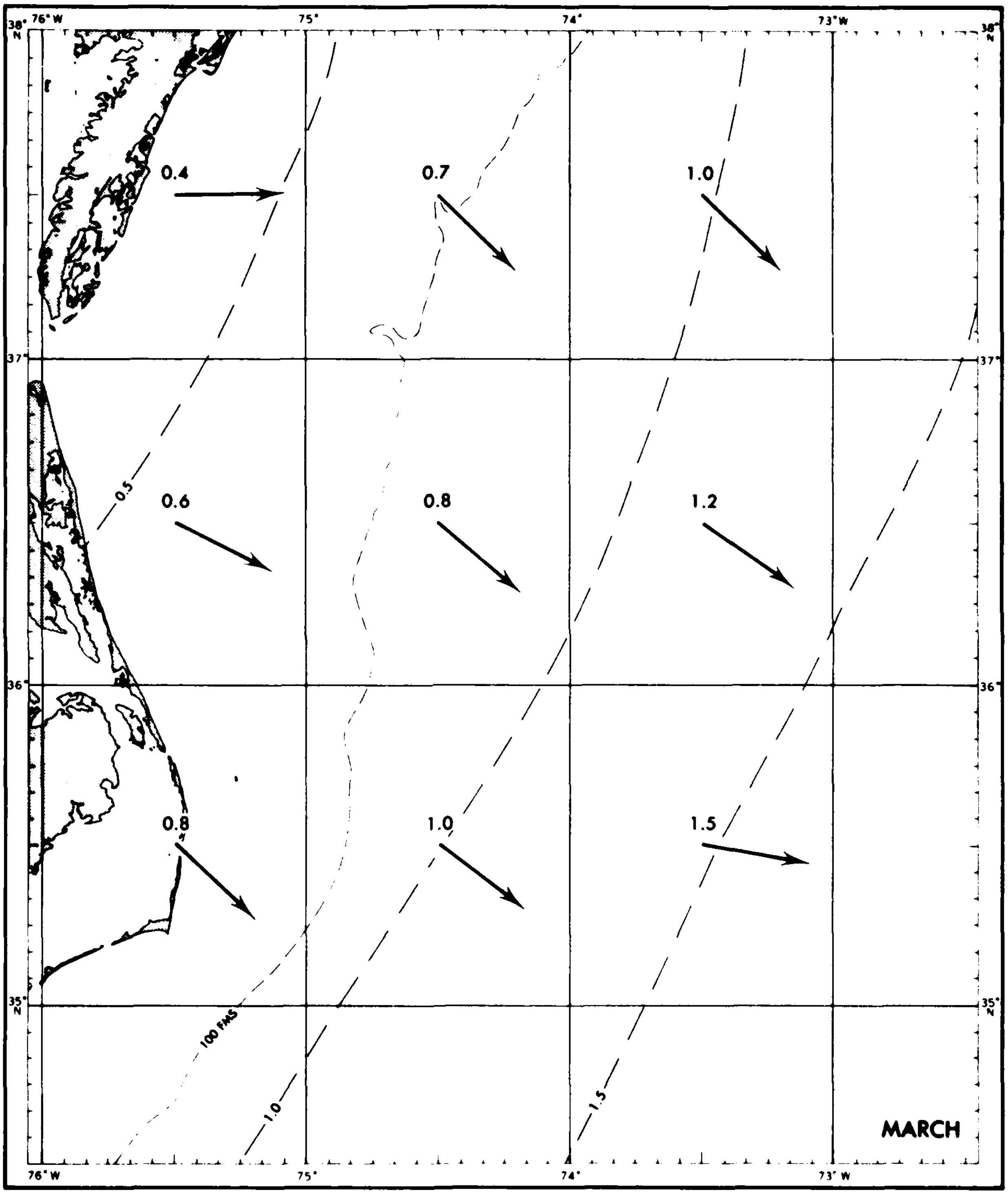


FIGURE A 2. WIND STRESS (CON.)

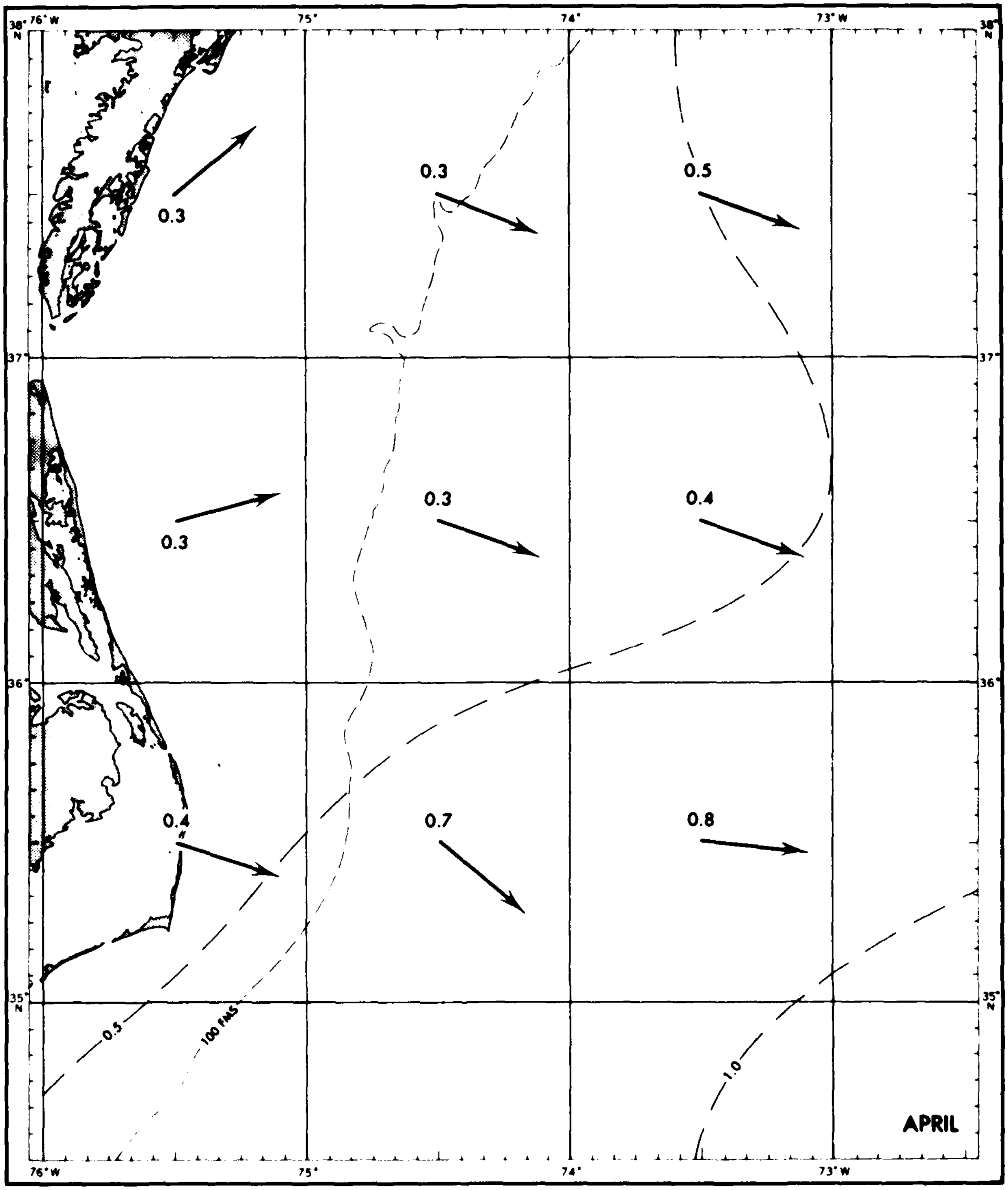


FIGURE A 2. WIND STRESS (CON.)

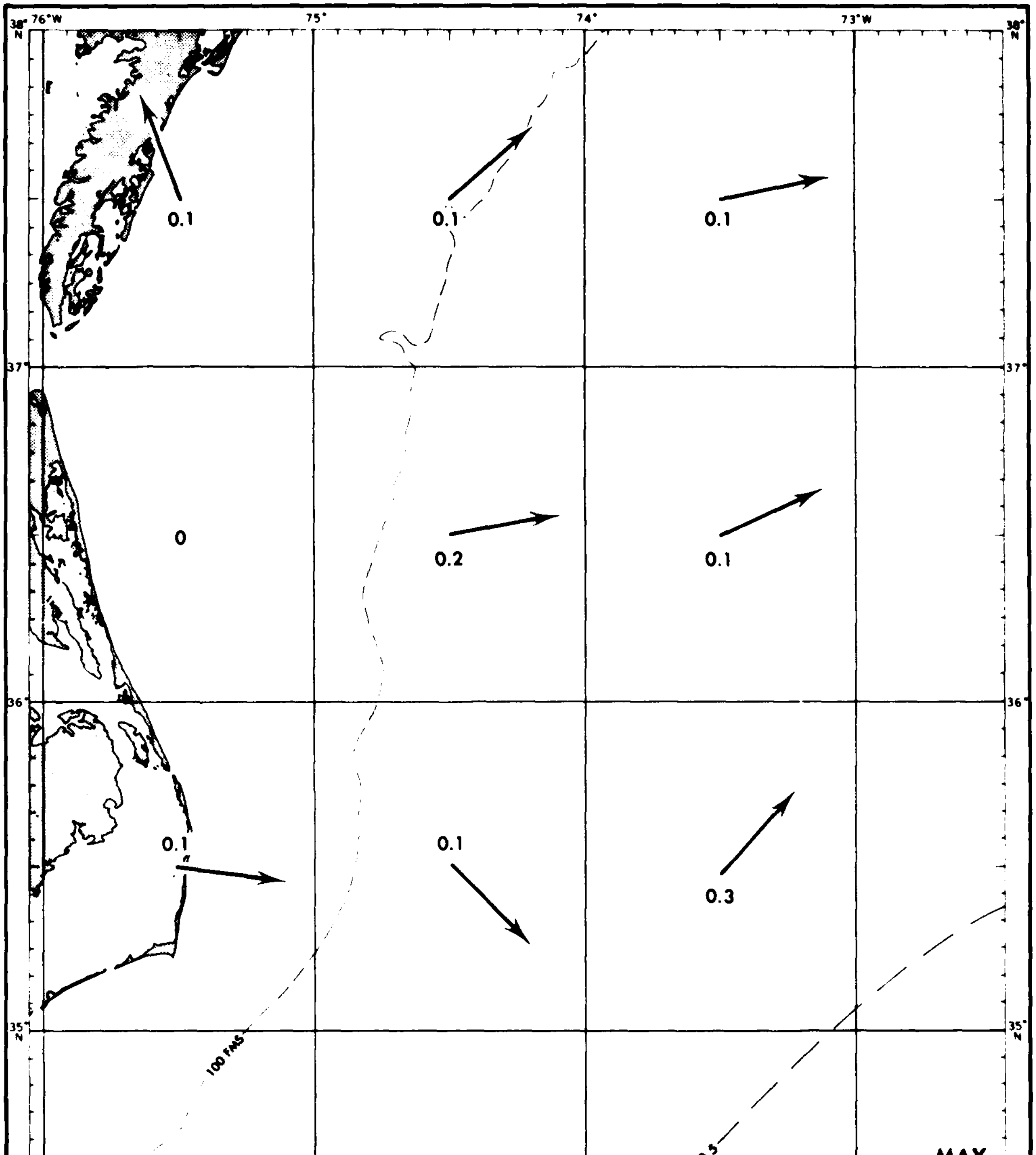


FIGURE A 2. WIND STRESS (CON.)

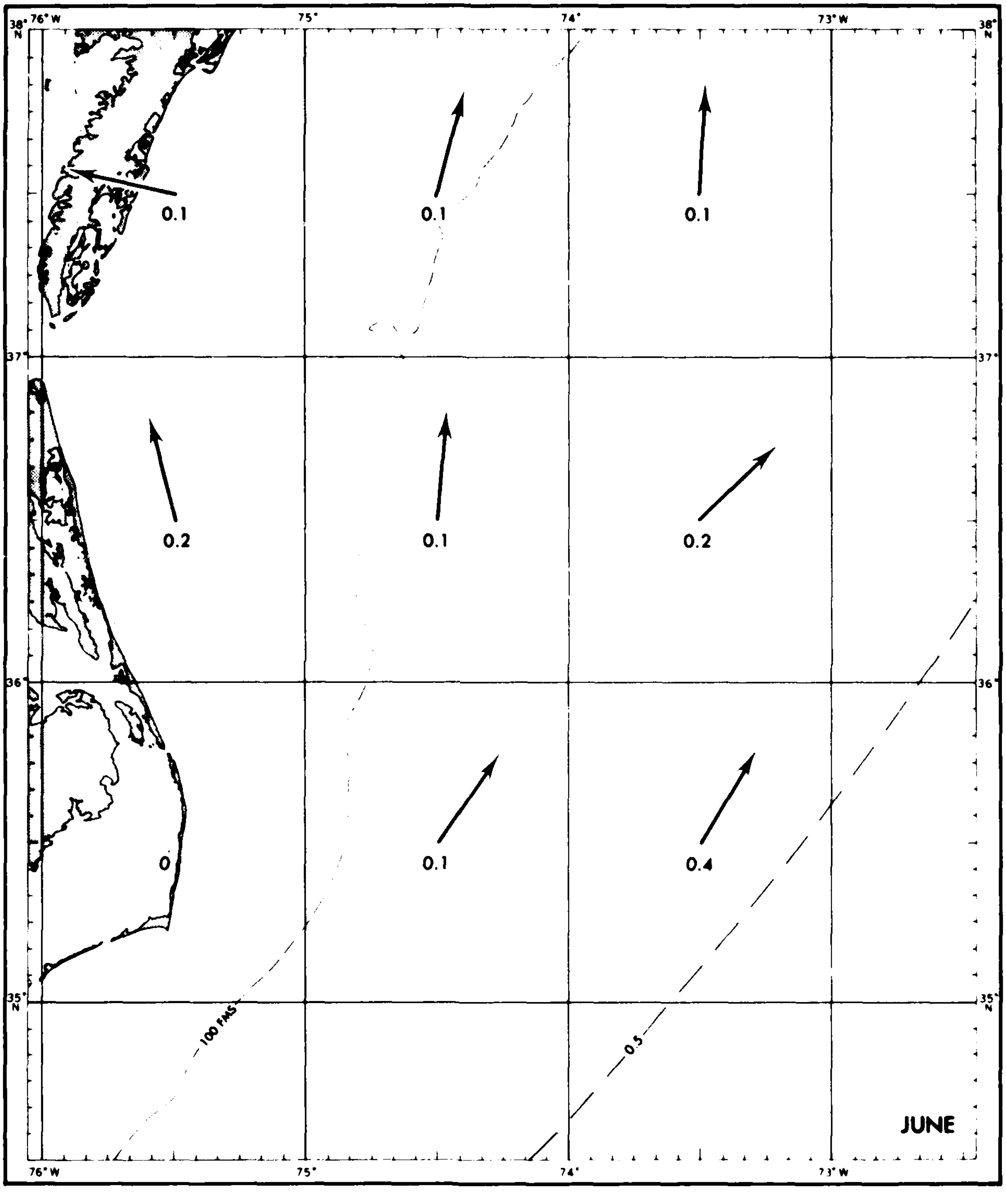


FIGURE A 2. WIND STRESS (CON.)

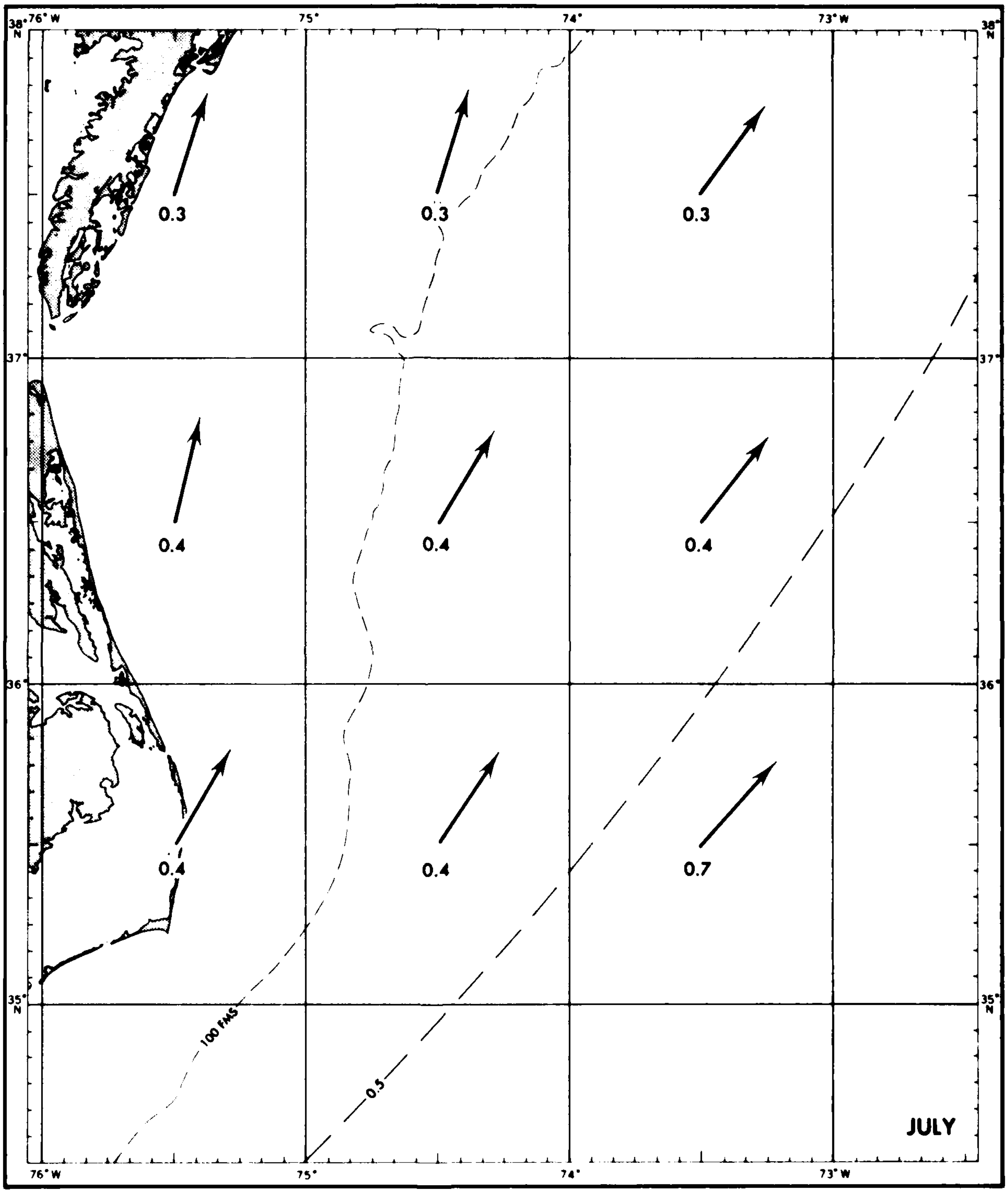


FIGURE A 2. WIND STRESS (CON.)

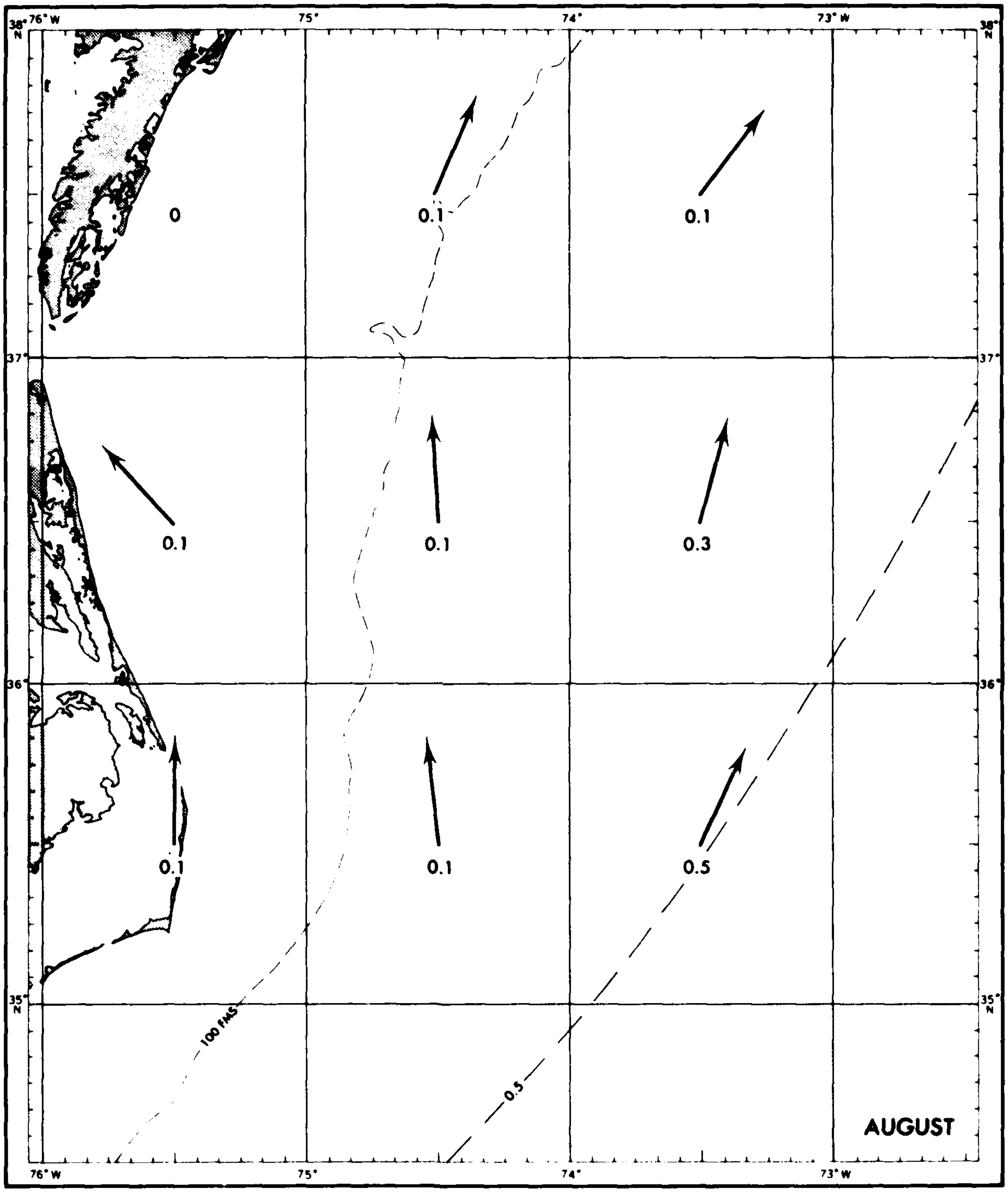


FIGURE A 2. WIND STRESS (CON.)

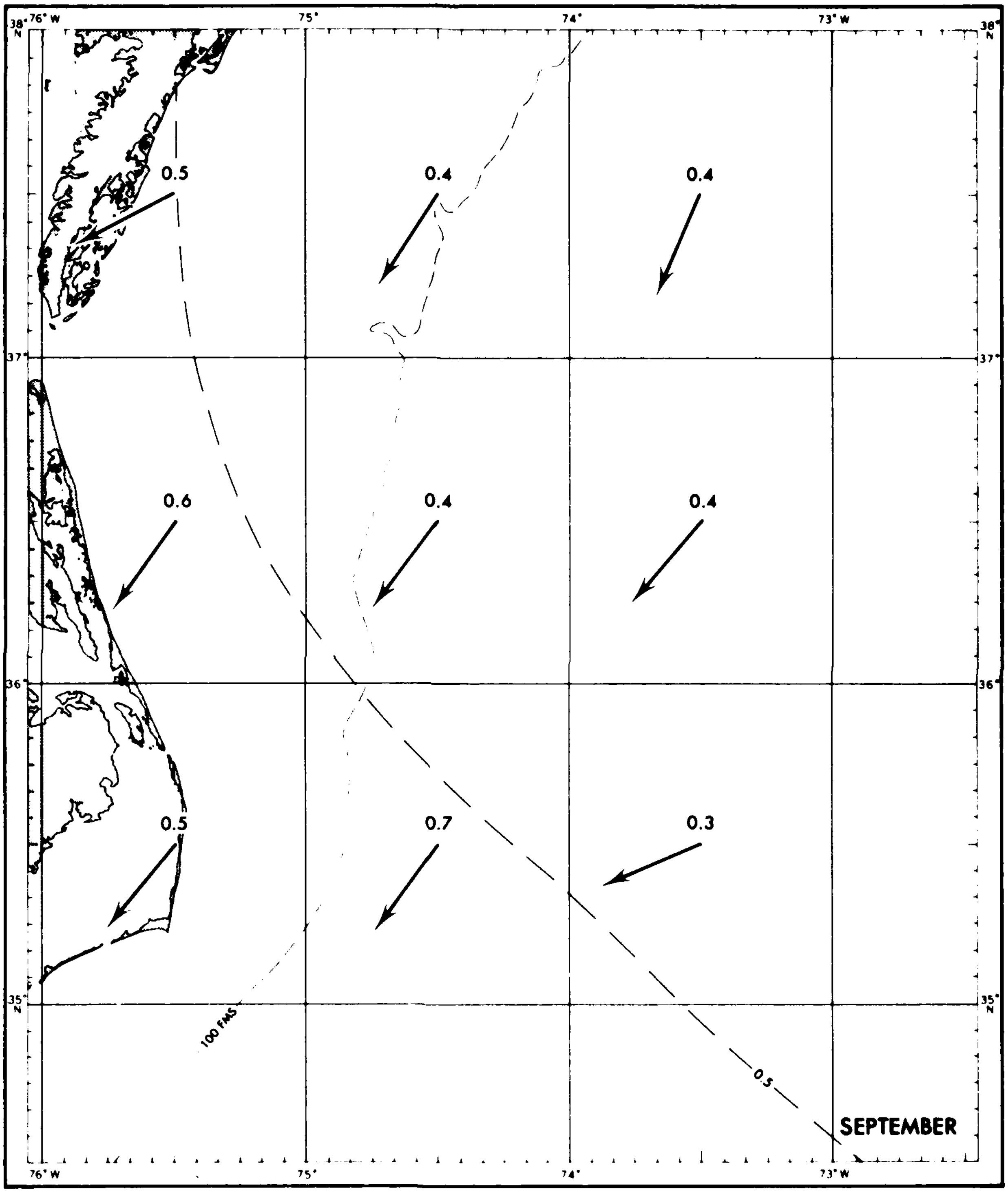


FIGURE A 2. WIND STRESS (CON.)

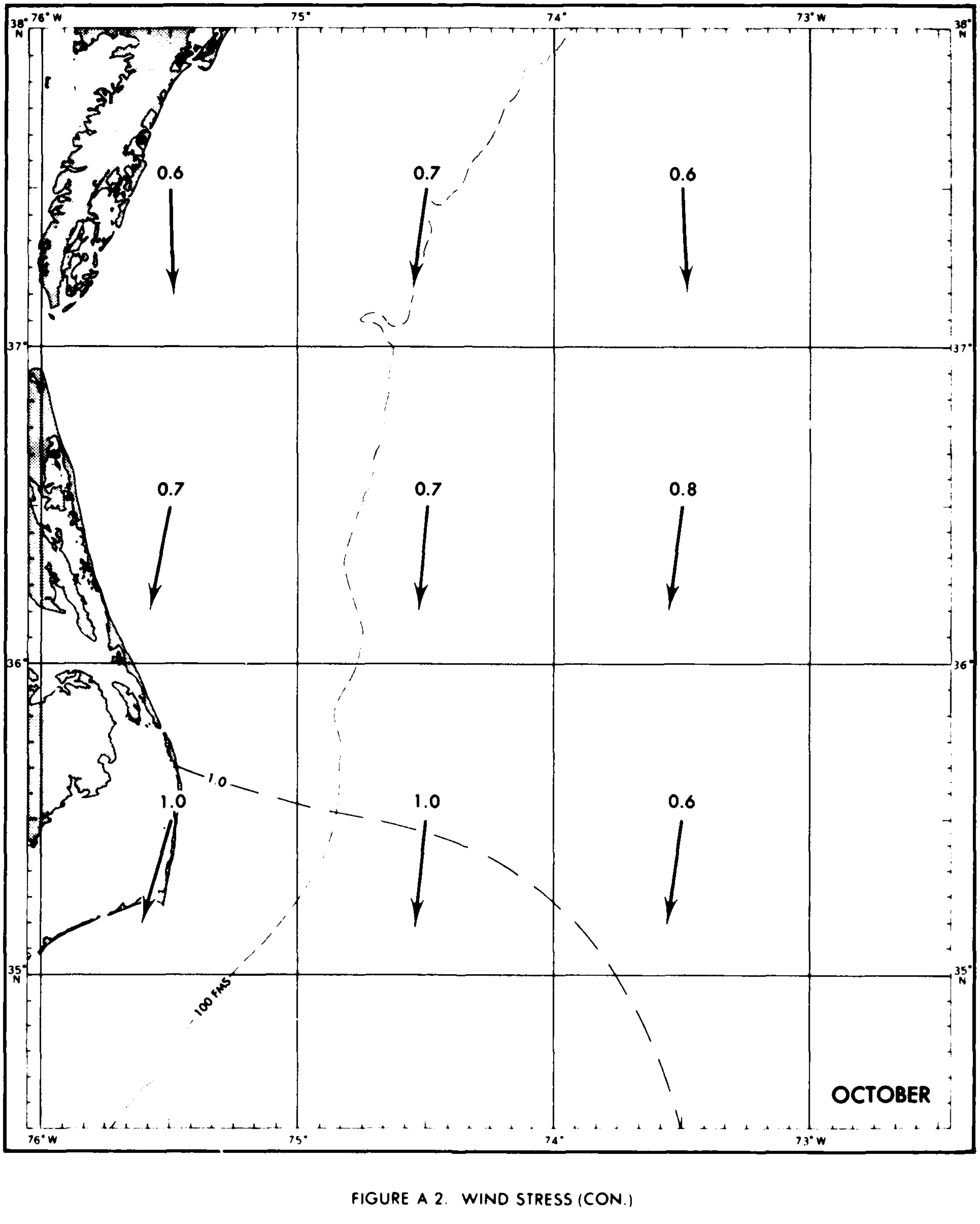


FIGURE A 2. WIND STRESS (CON.)

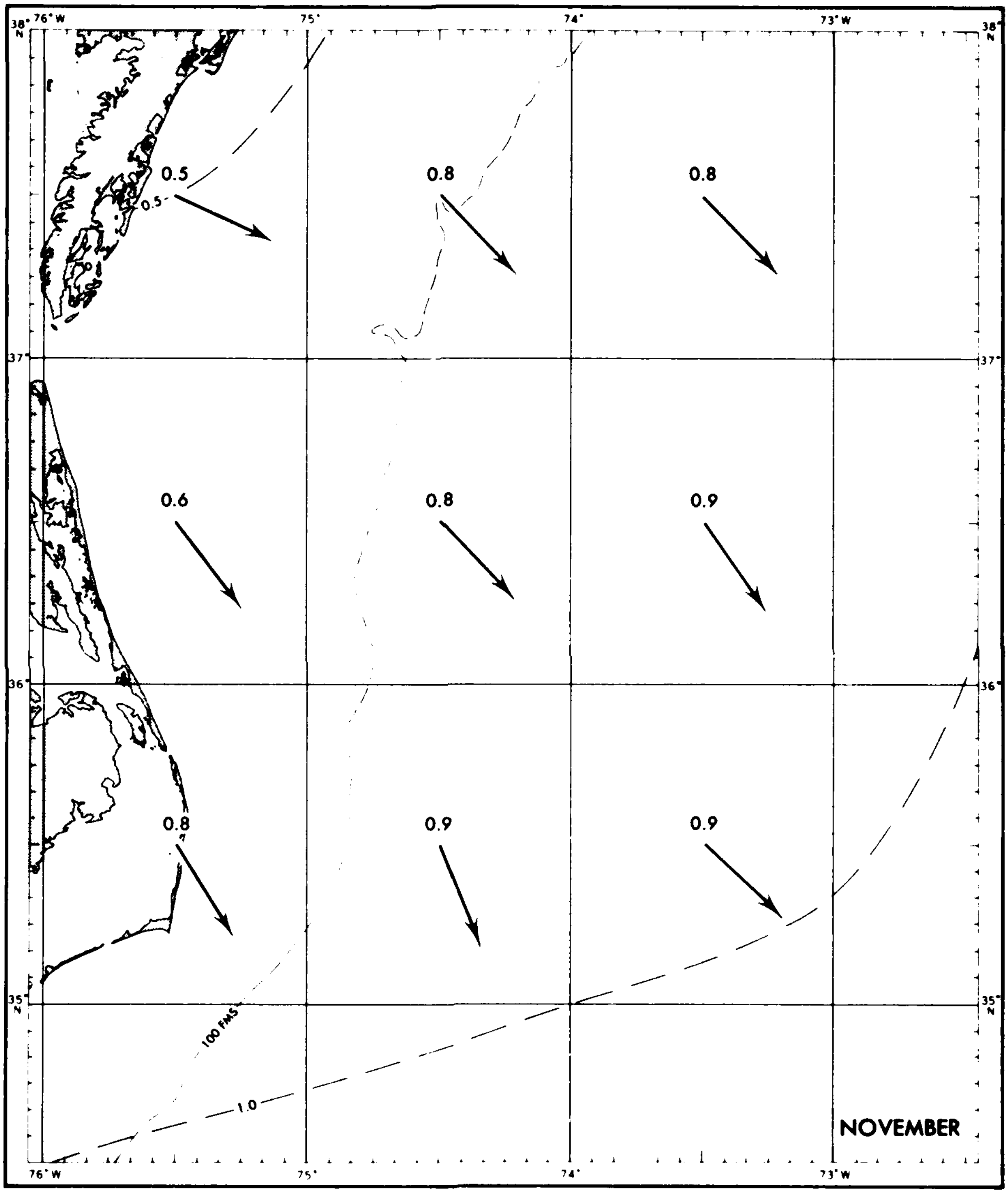


FIGURE A 2. WIND STRESS (CON.)

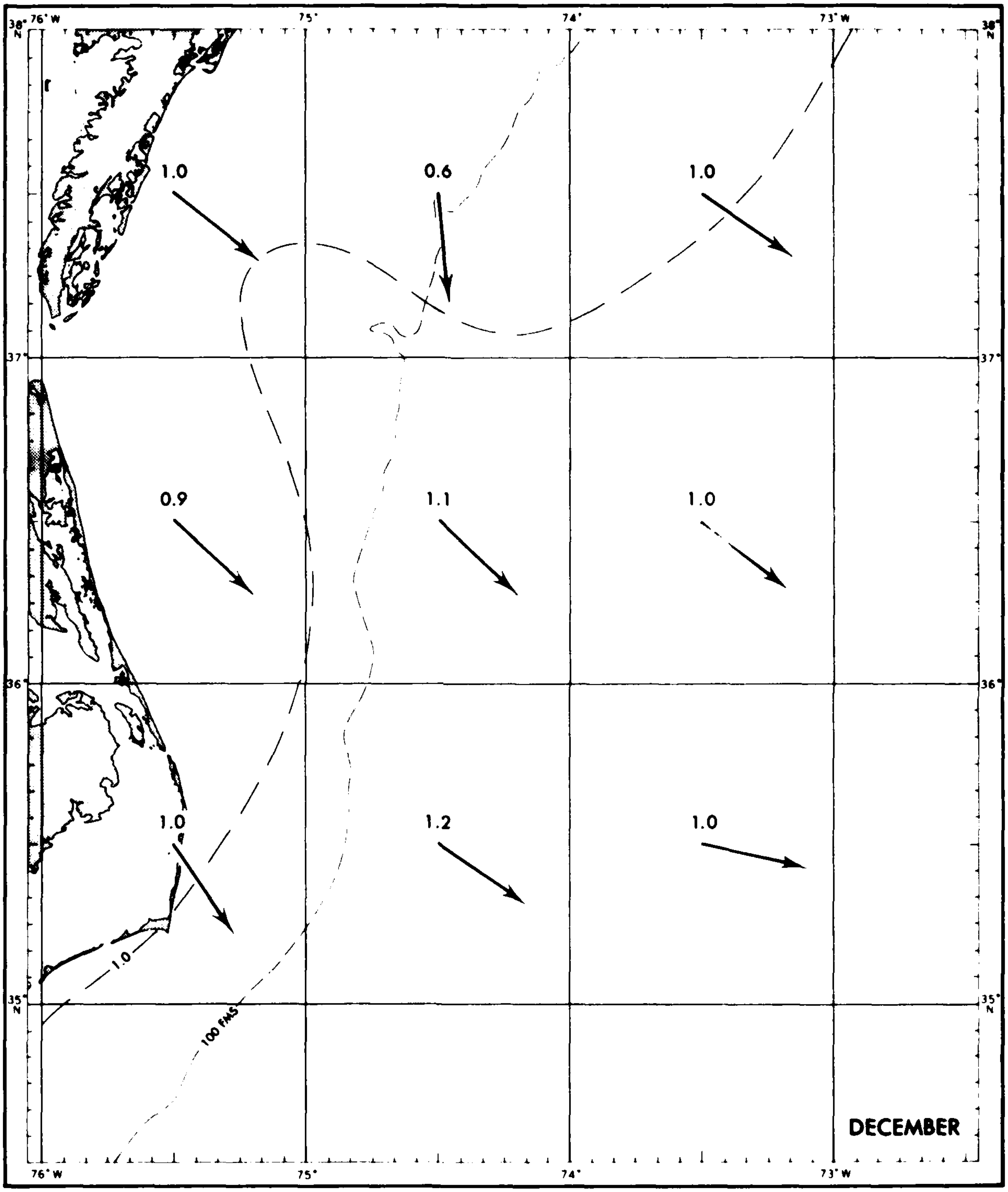


FIGURE A 2. WIND STRESS (CON.)

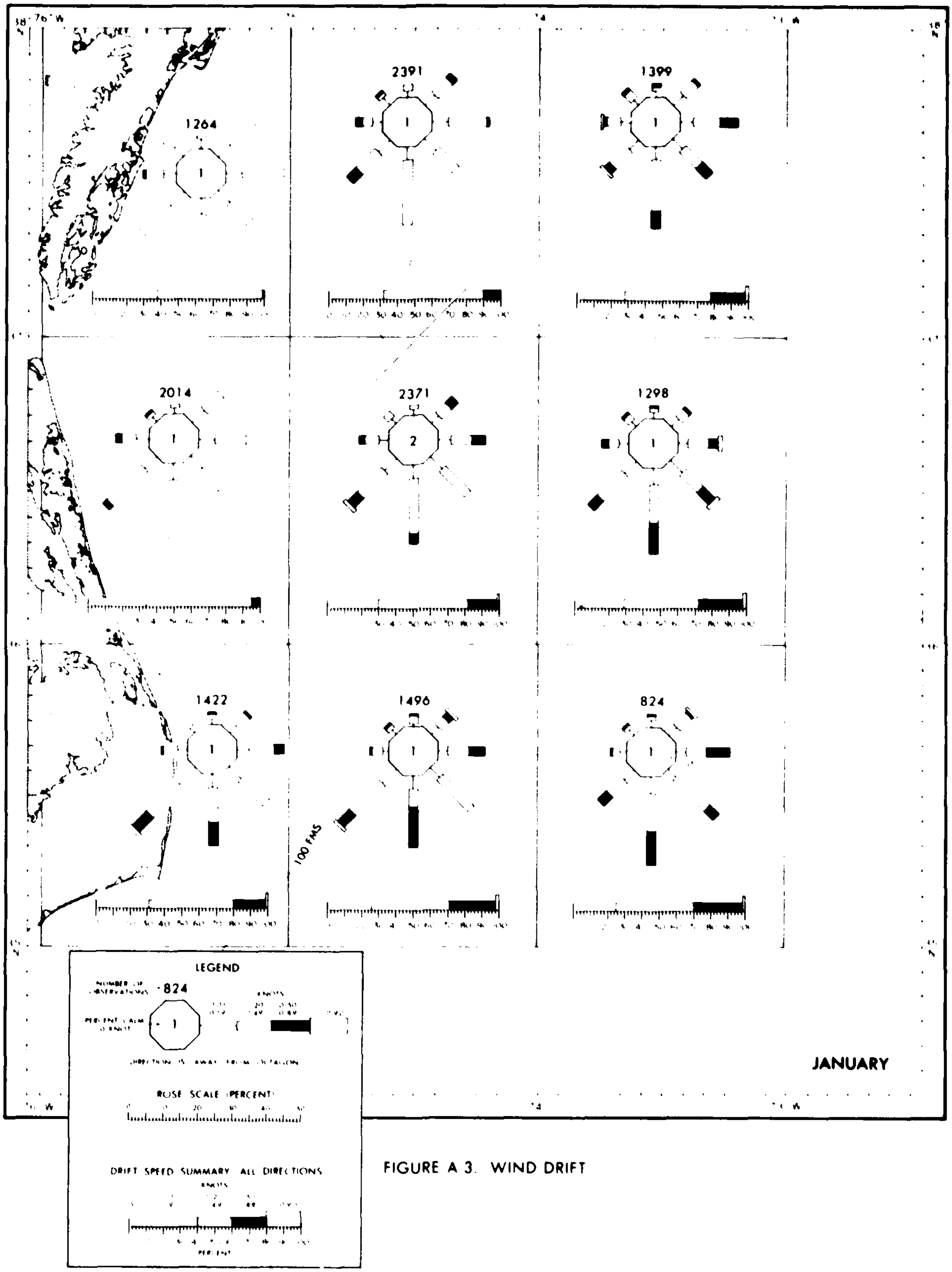


FIGURE A 3. WIND DRIFT

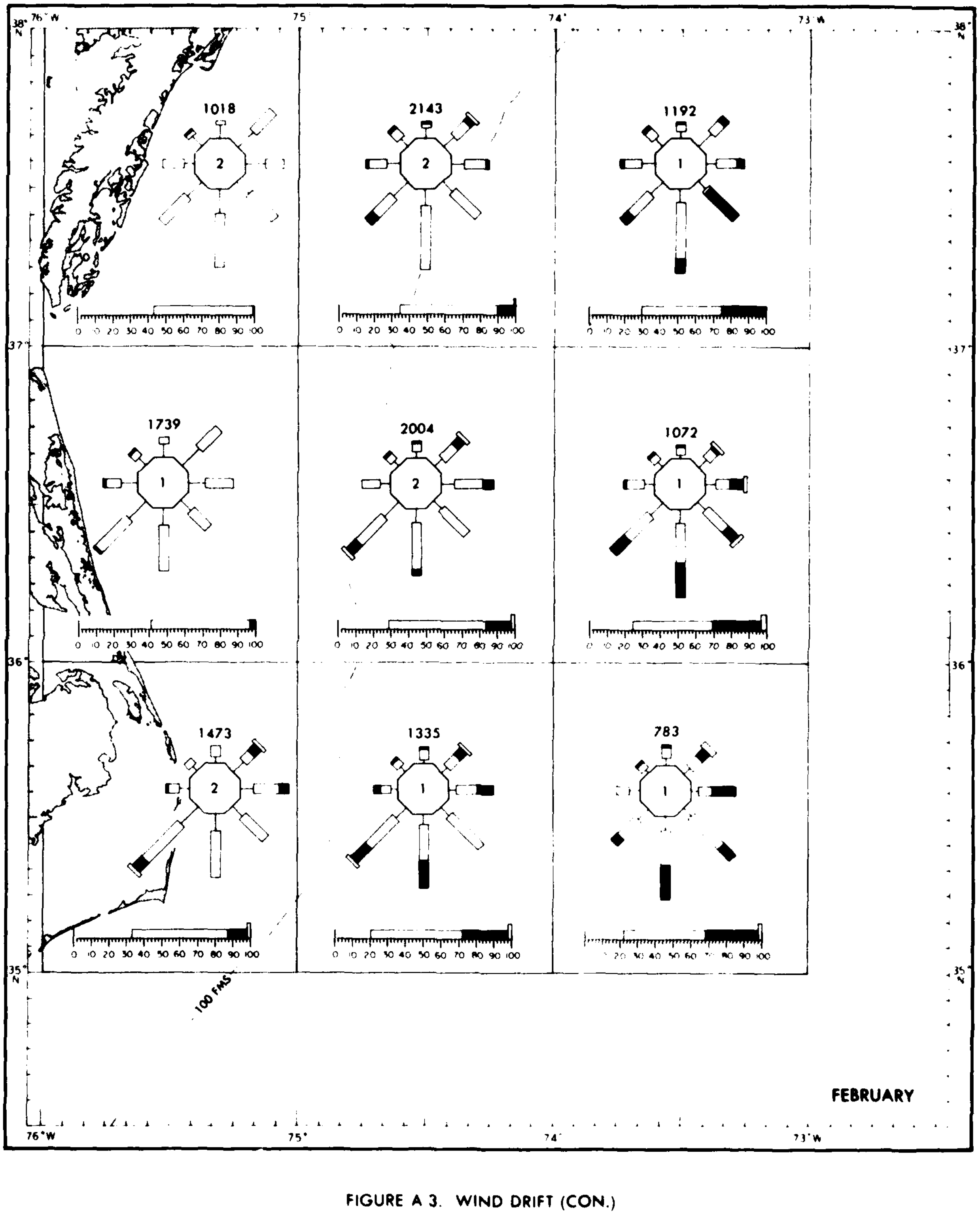


FIGURE A 3. WIND DRIFT (CON.)

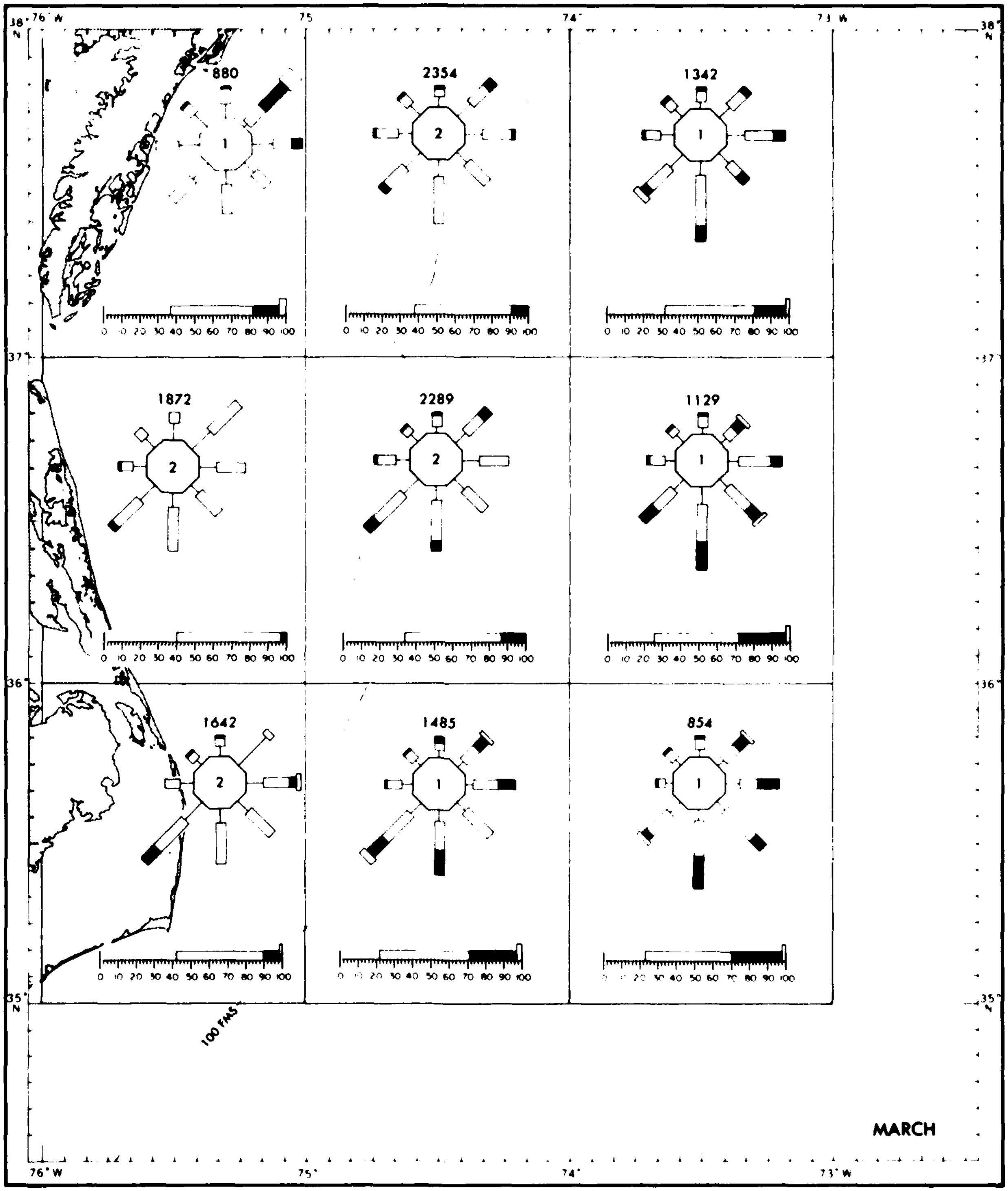


FIGURE A 3. WIND DRIFT (CON.)

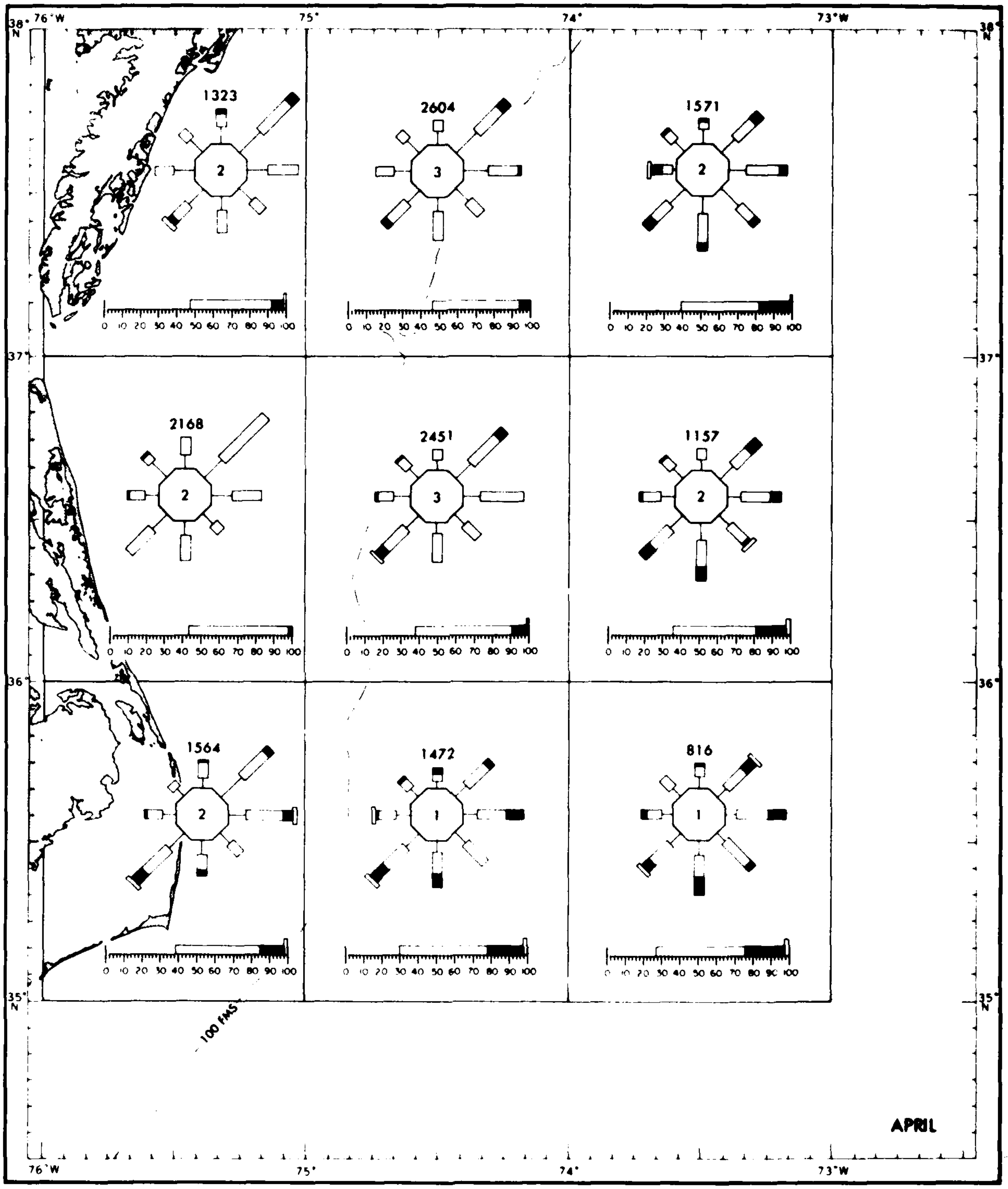


FIGURE A 3. WIND DRIFT (CON.)

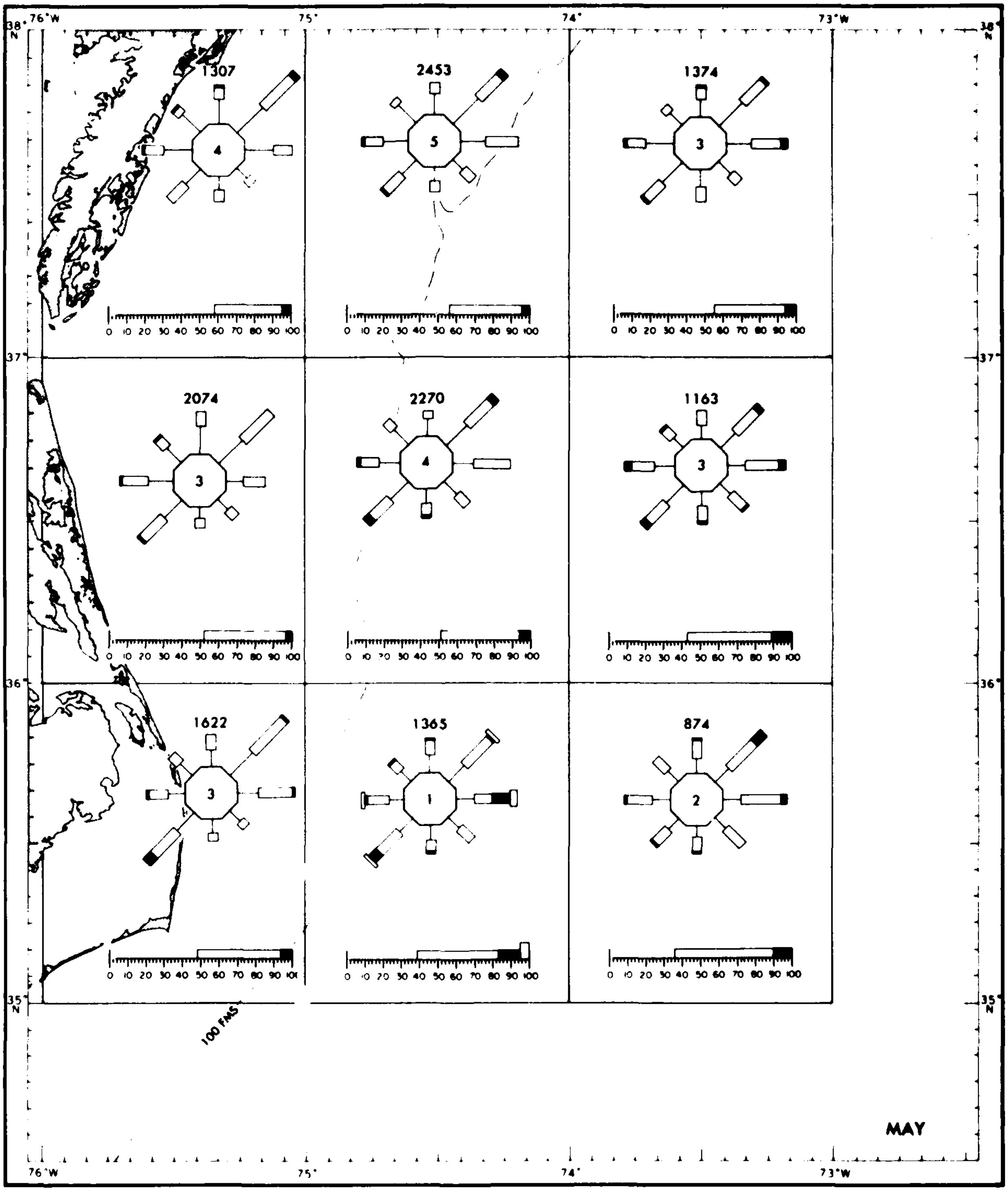


FIGURE A 3. WIND DRIFT (CON.)

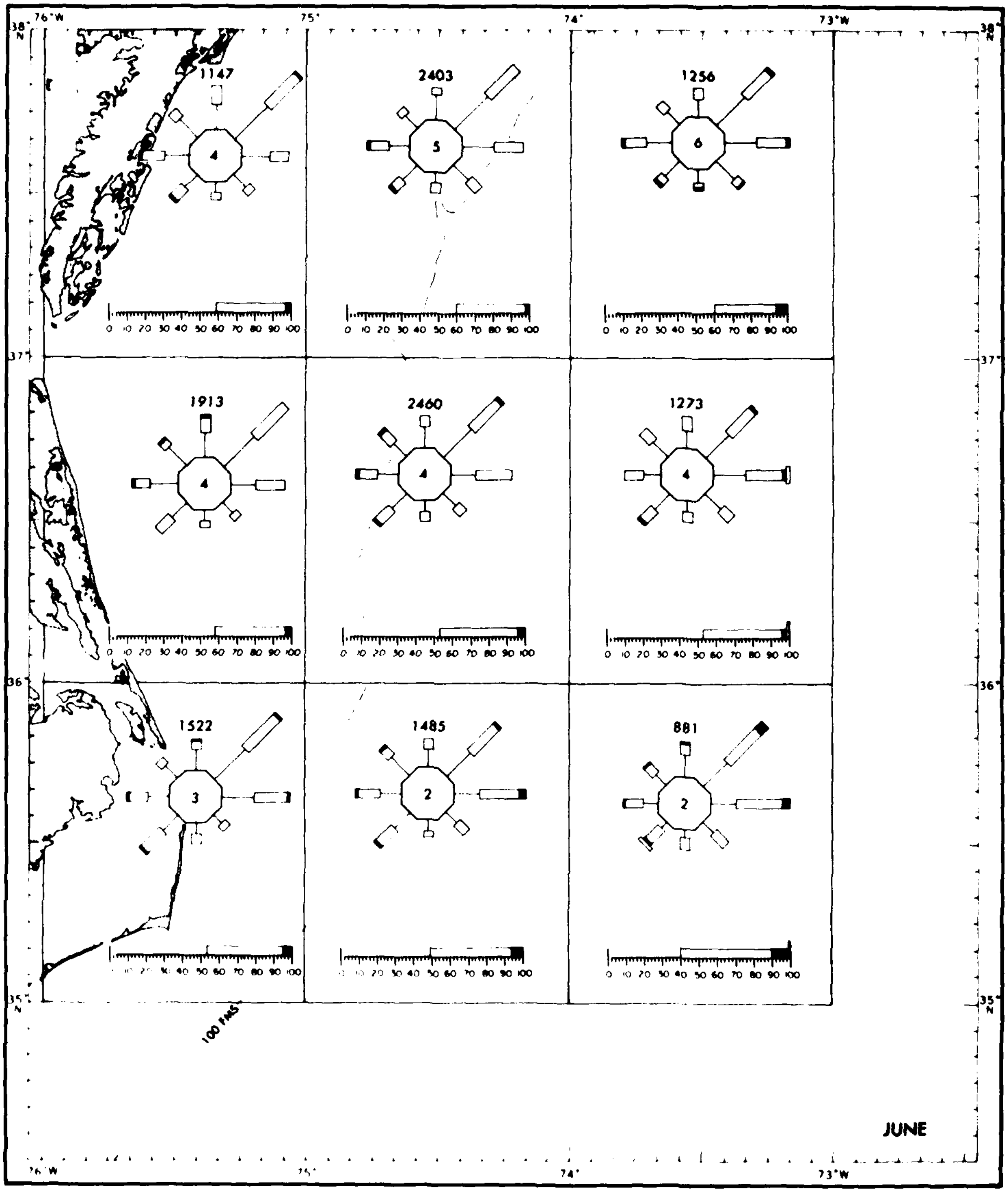


FIGURE A 3. WIND DRIFT (CON.)

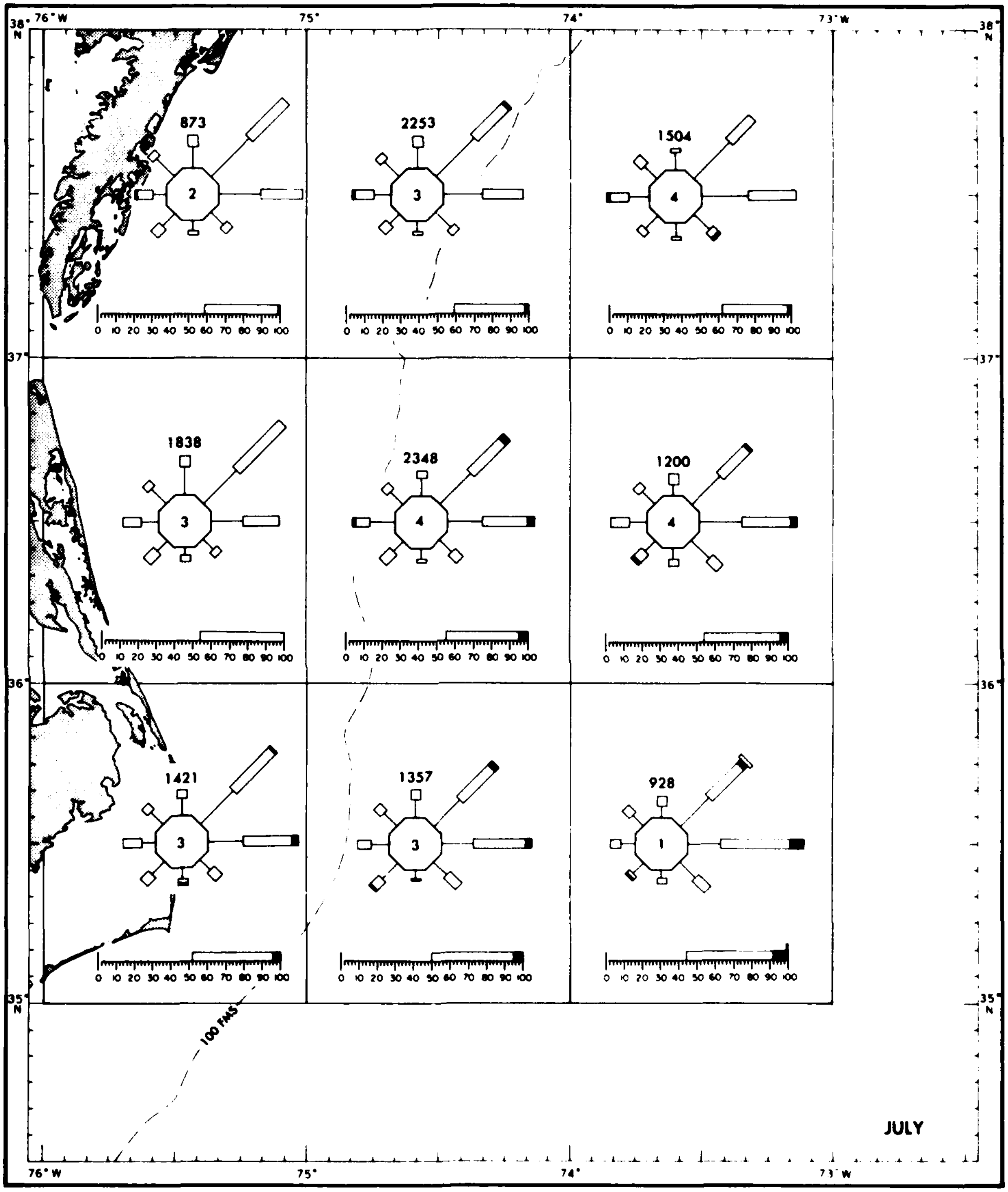


FIGURE A 3. WIND DRIFT (CON.)

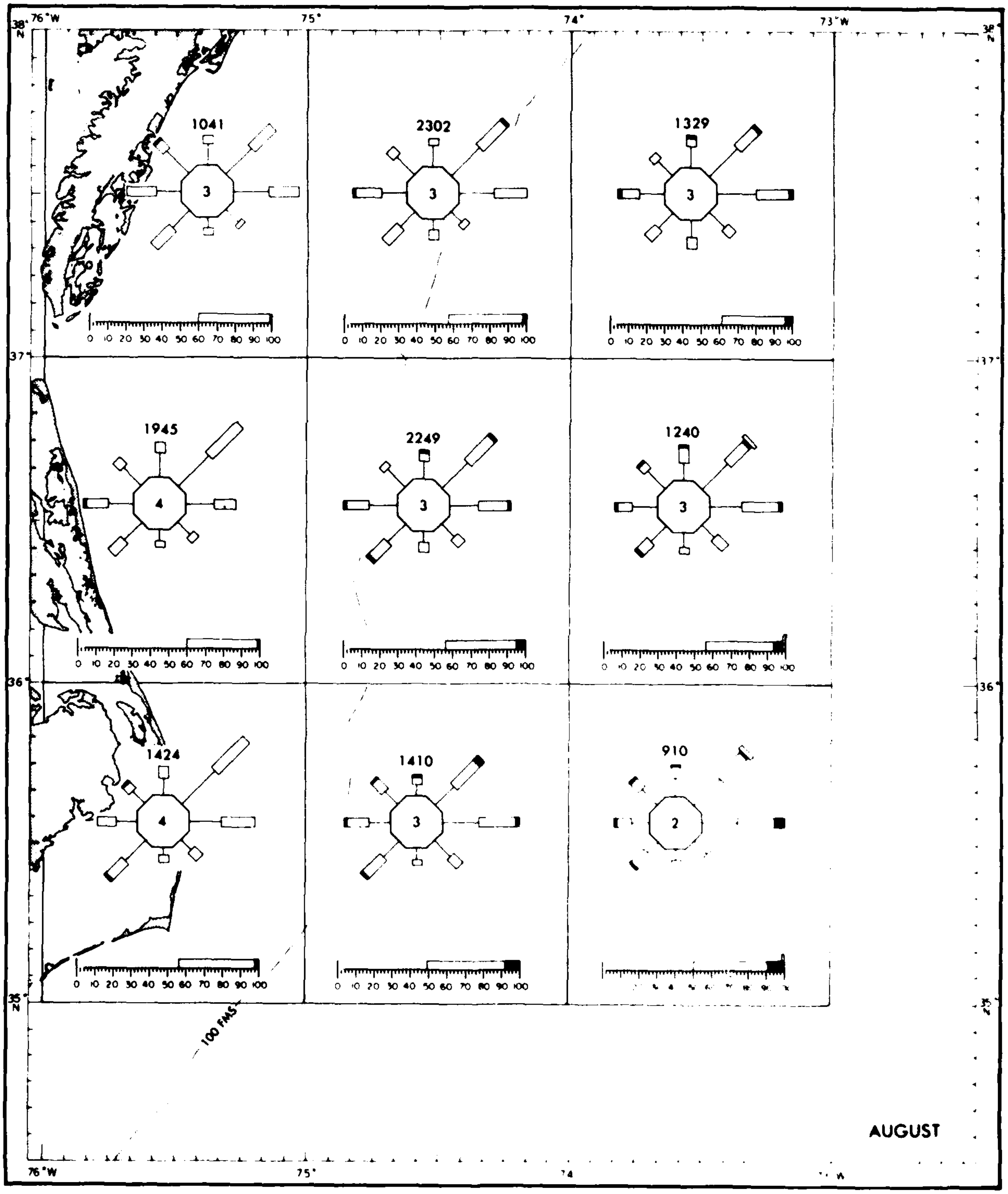


FIGURE A 3. WIND DRIFT (CON.)

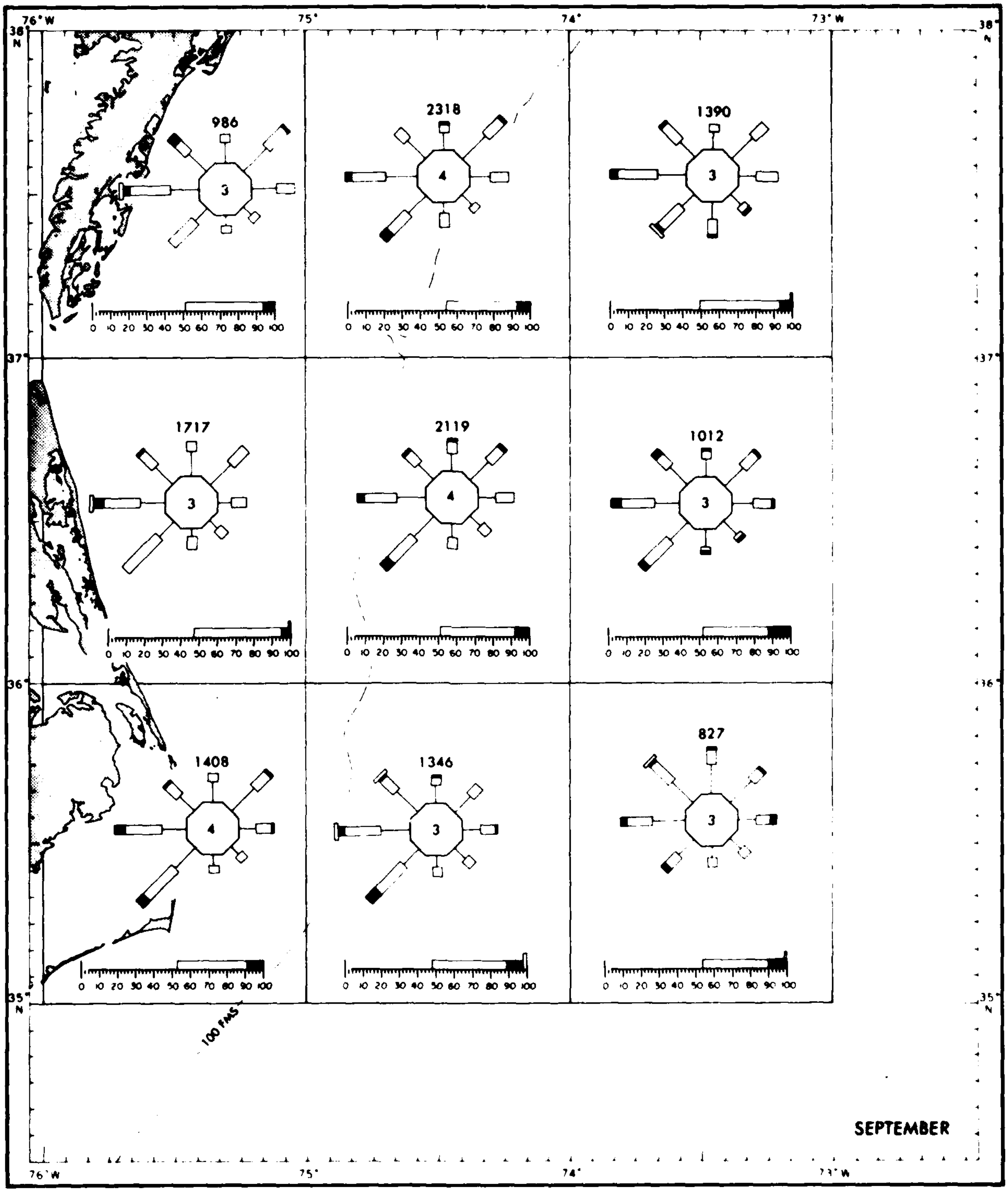


FIGURE A 3. WIND DRIFT (CON.)

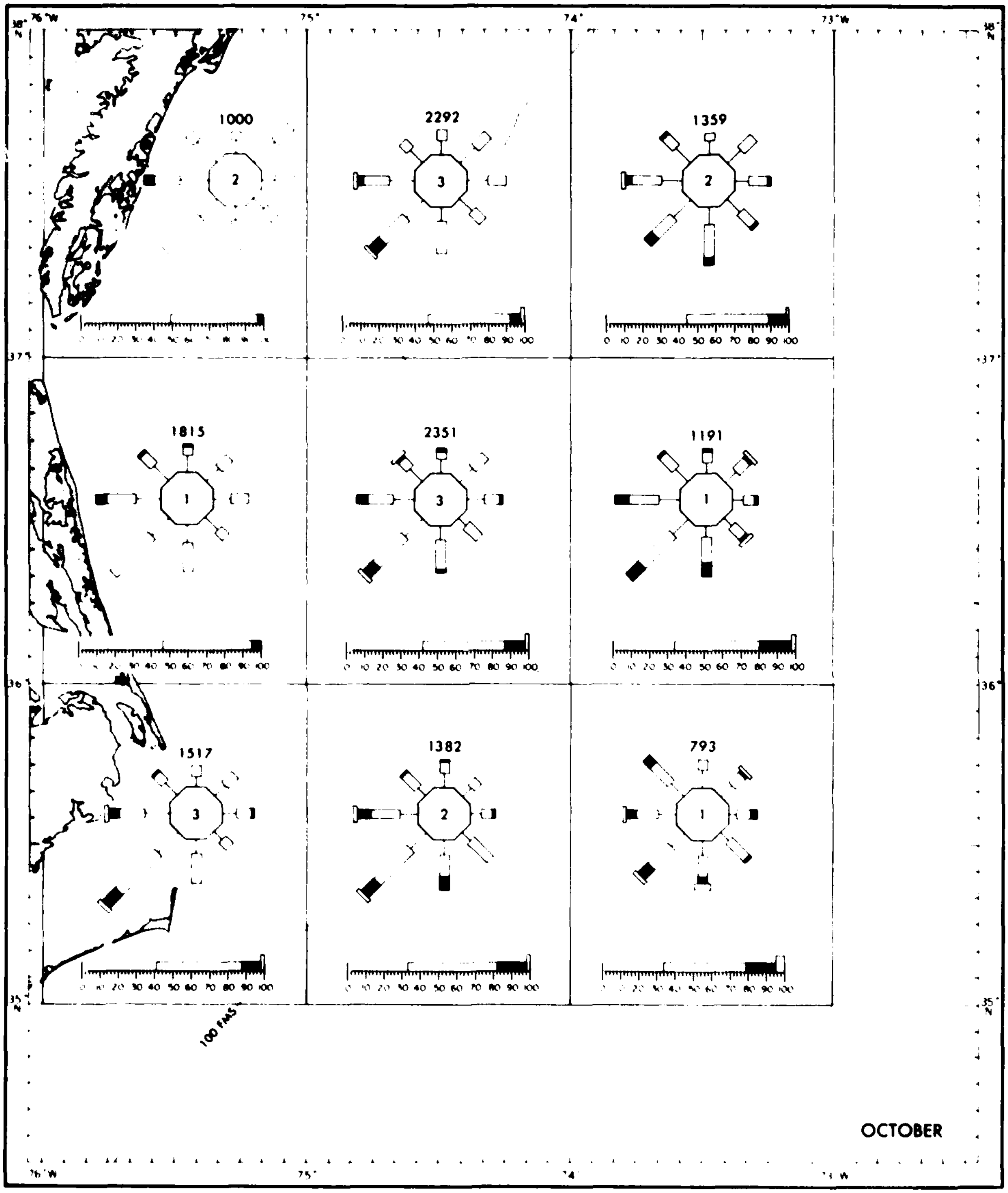


FIGURE A 3. WIND DRIFT (CON.)

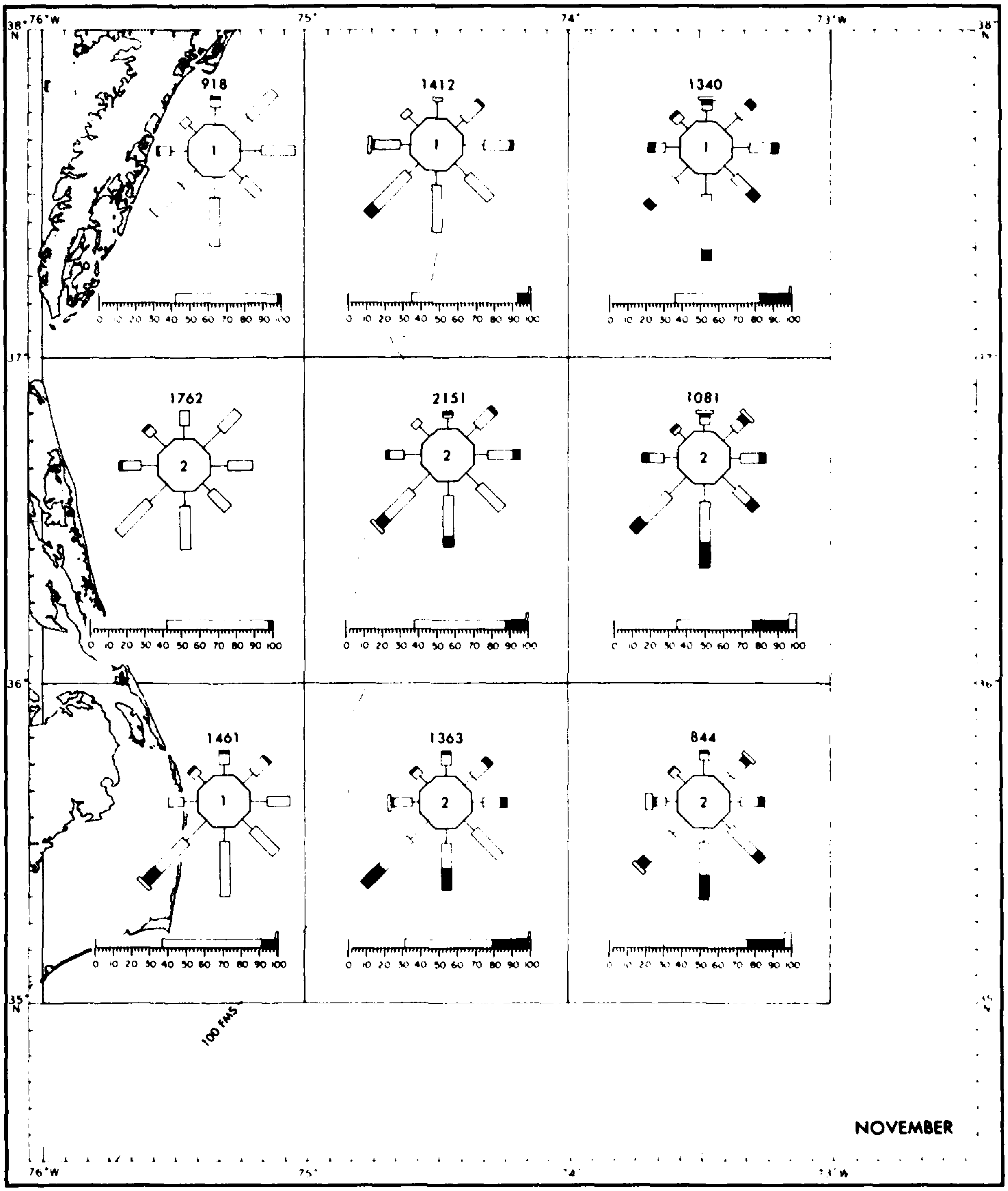


FIGURE A 3. WIND DRIFT (CON.)

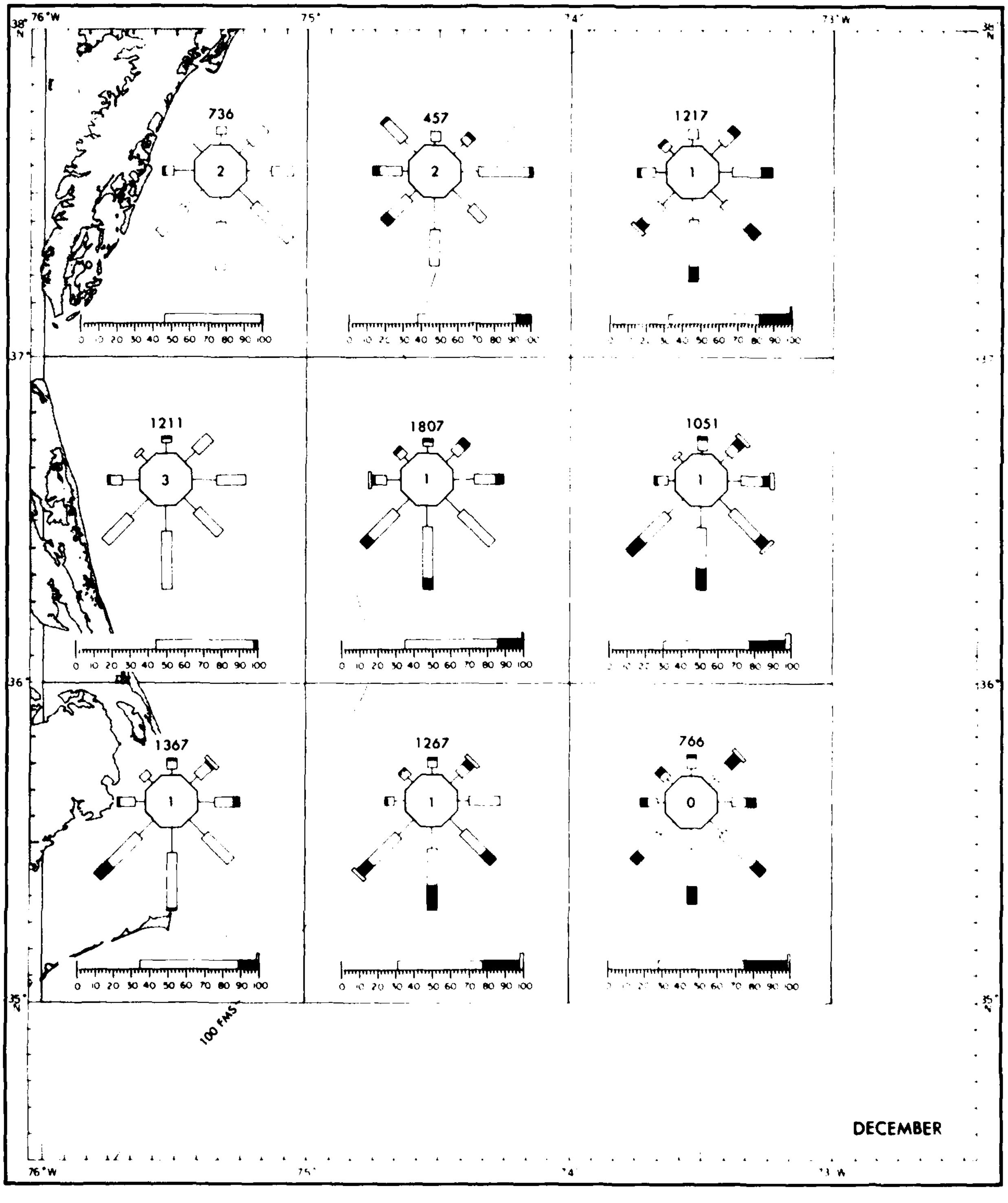


FIGURE A 3. WIND DRIFT (CON.)

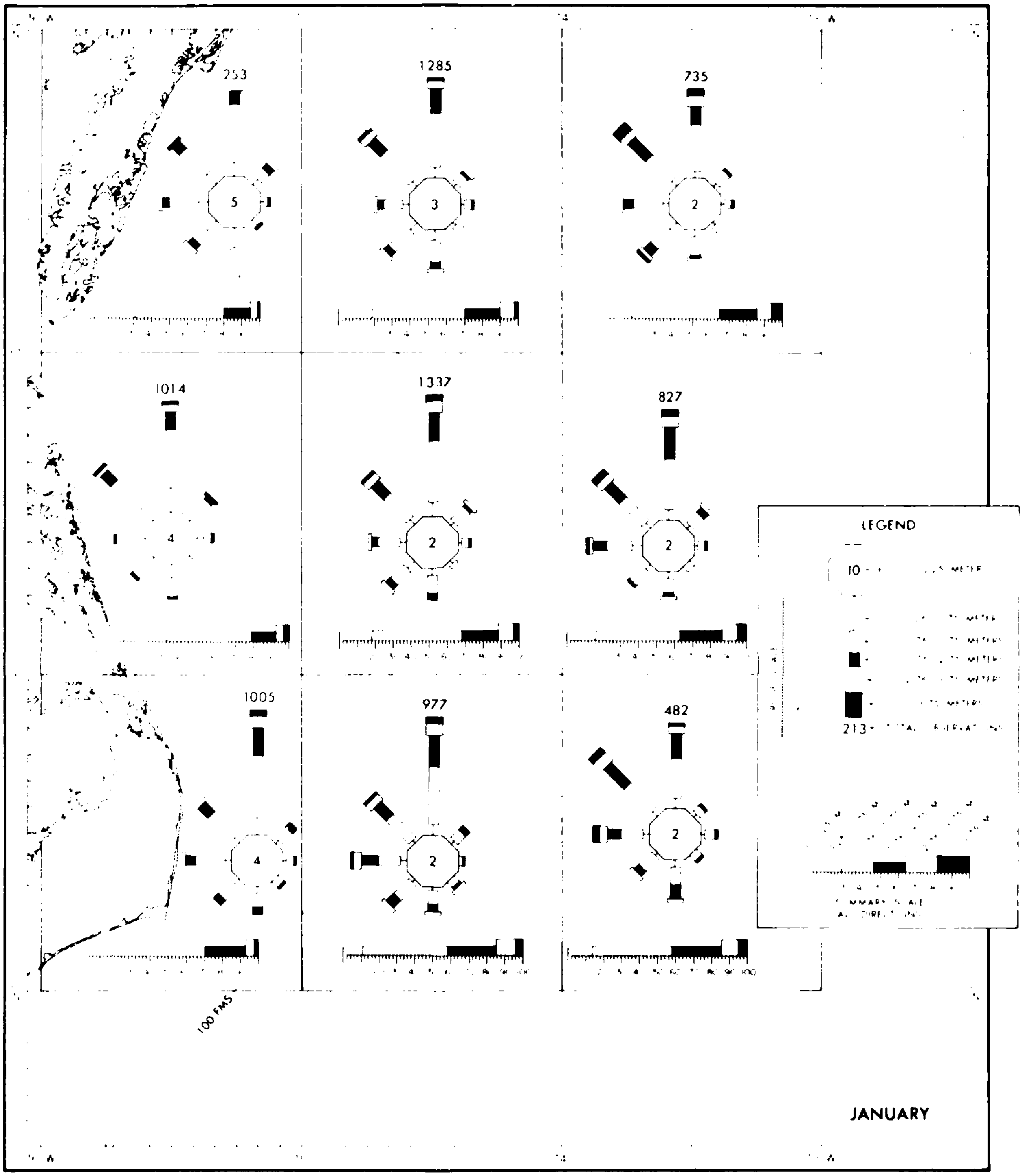


FIGURE A 4 WAVE ROSES

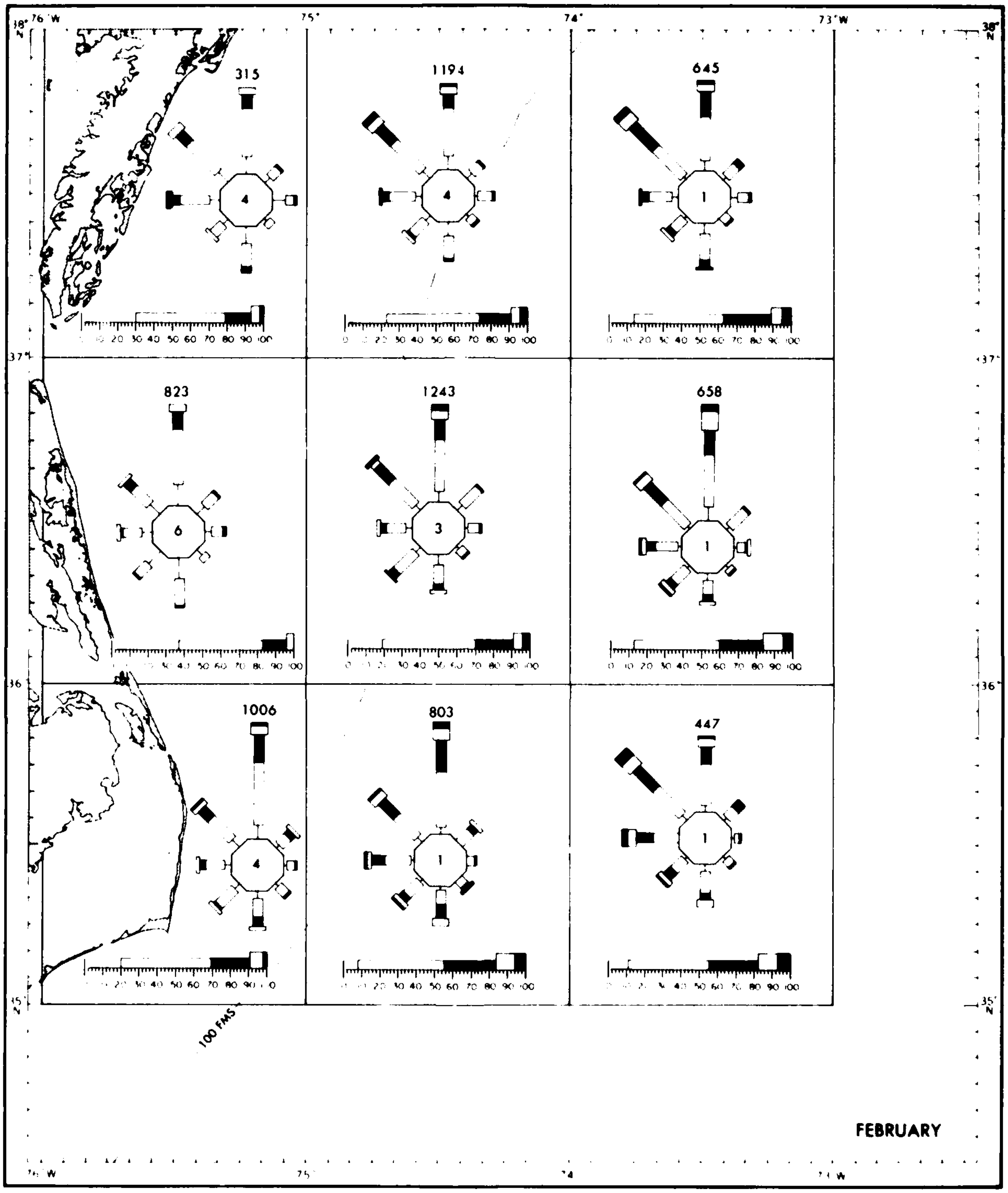


FIGURE A 4. WAVE ROSES (CON.)

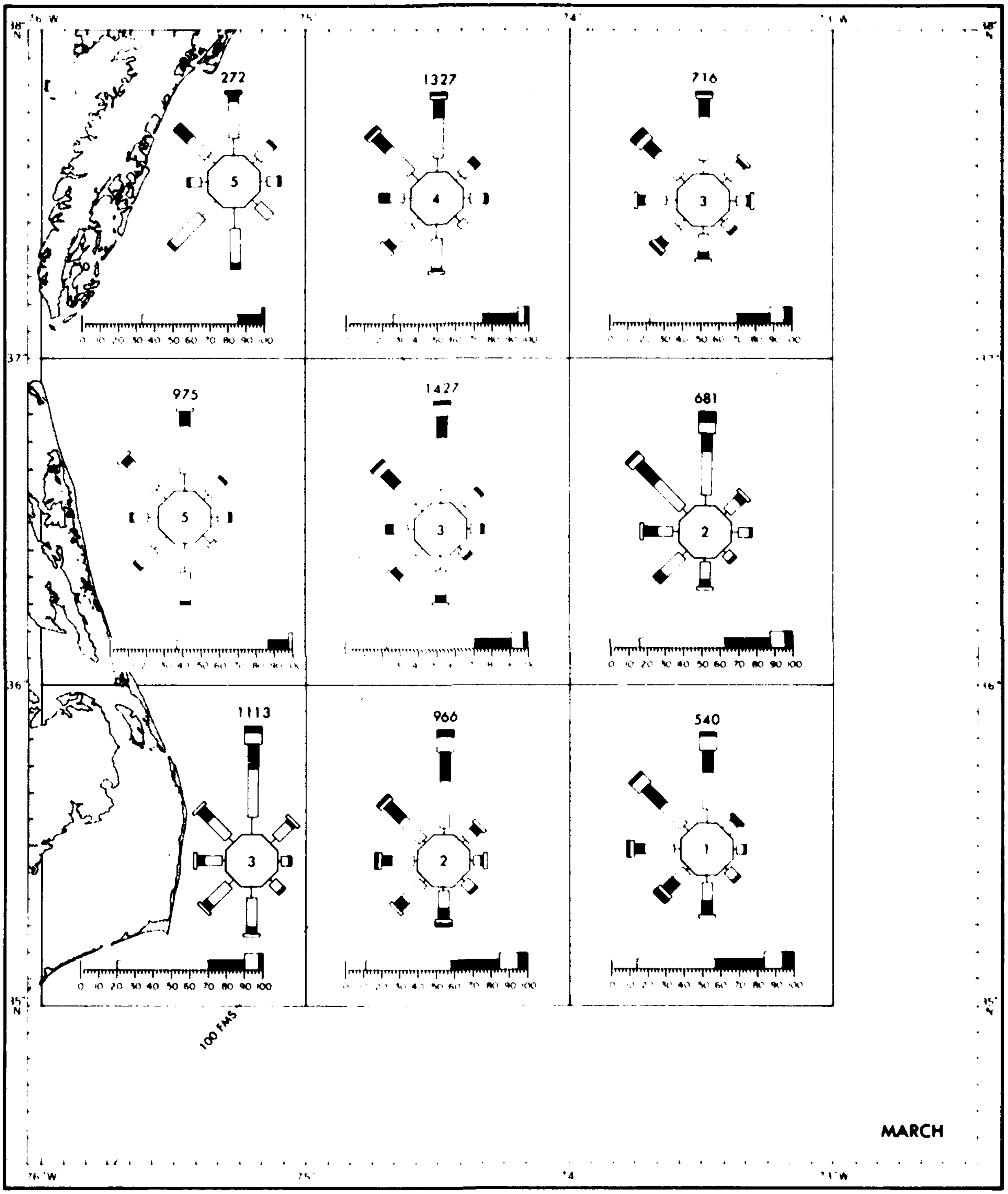


FIGURE A 4 WAVE ROSES (CON)

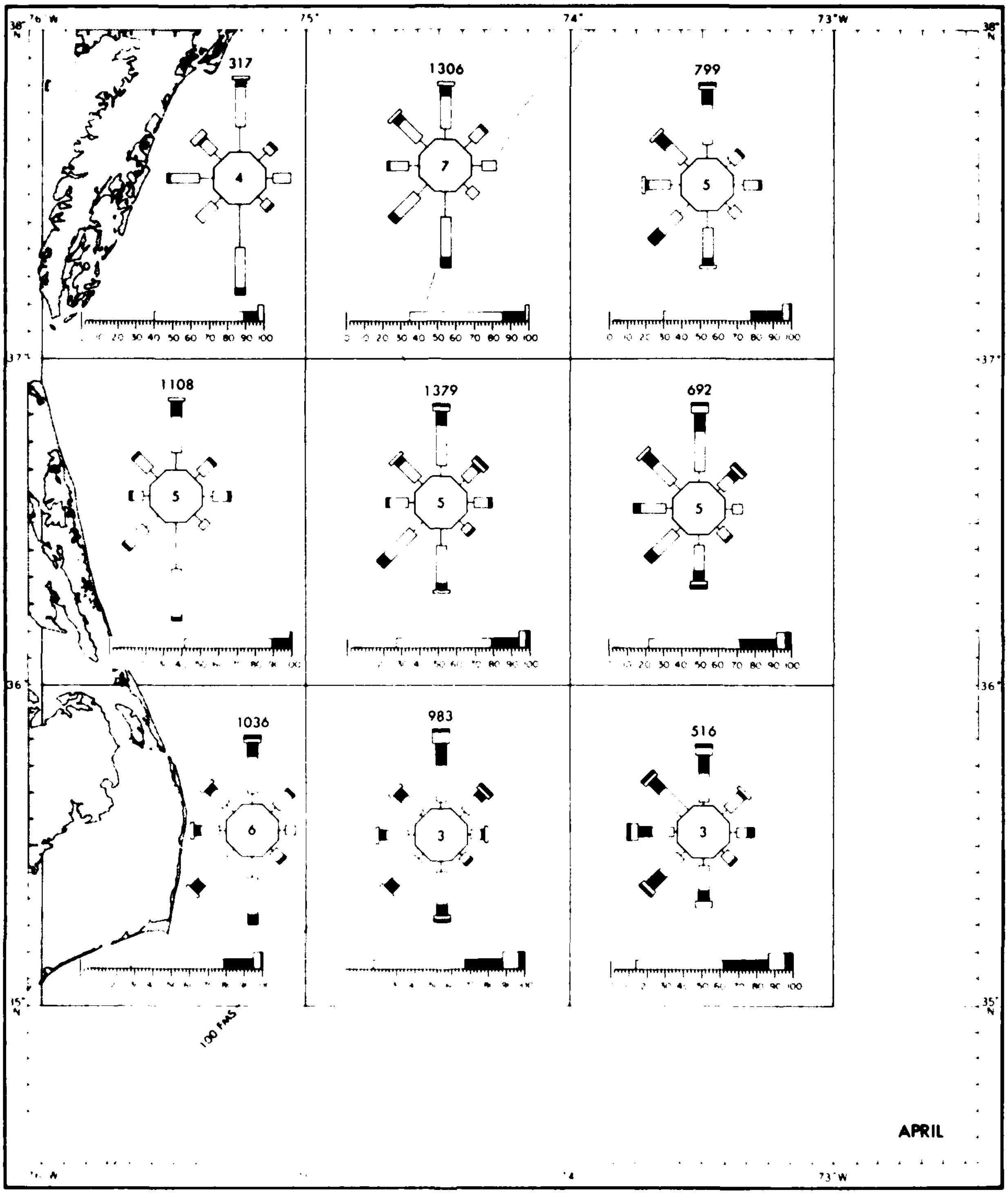


FIGURE A 4 WAVE ROSES (CON)

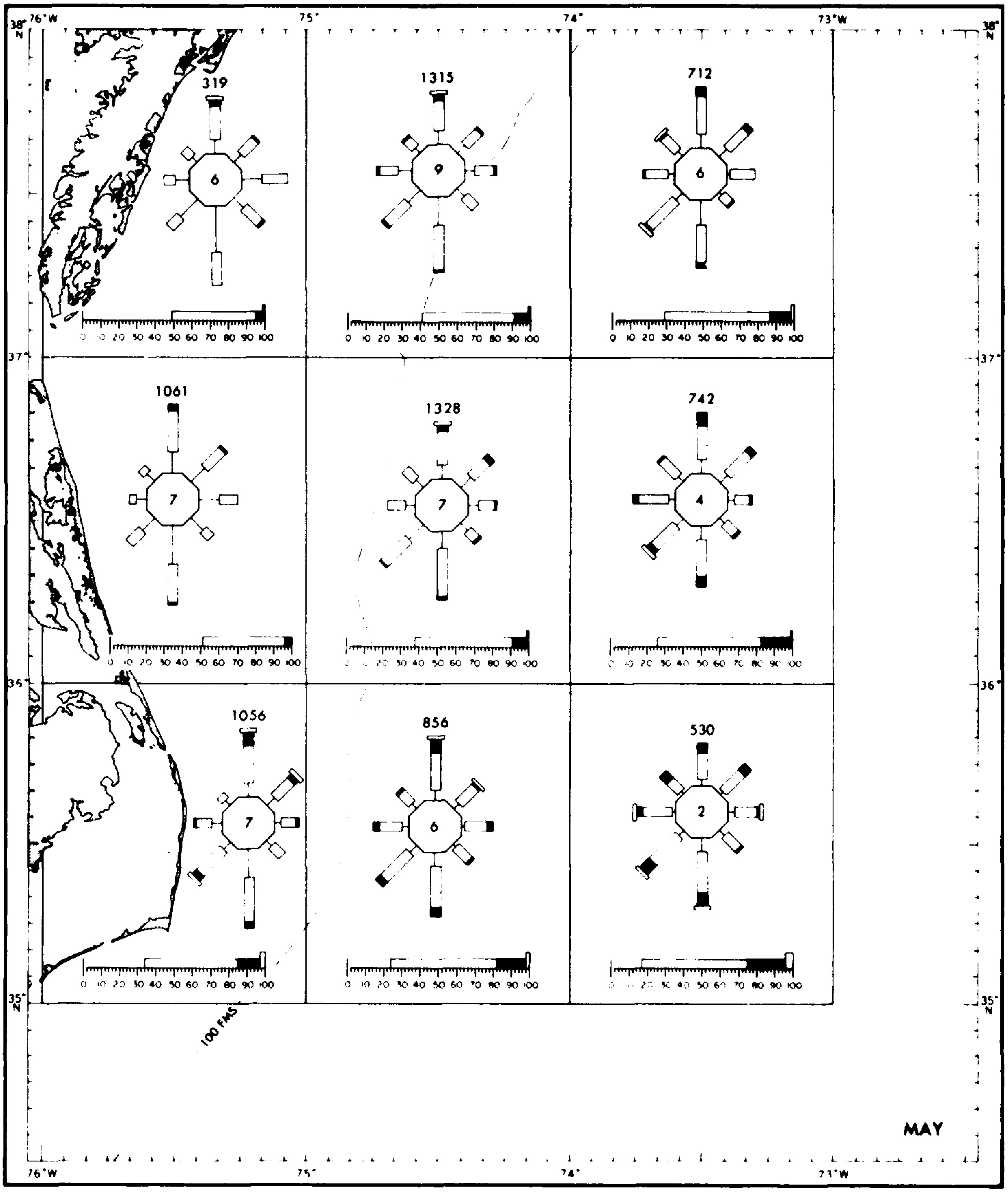


FIGURE A 4. WAVE ROSES (CON.)

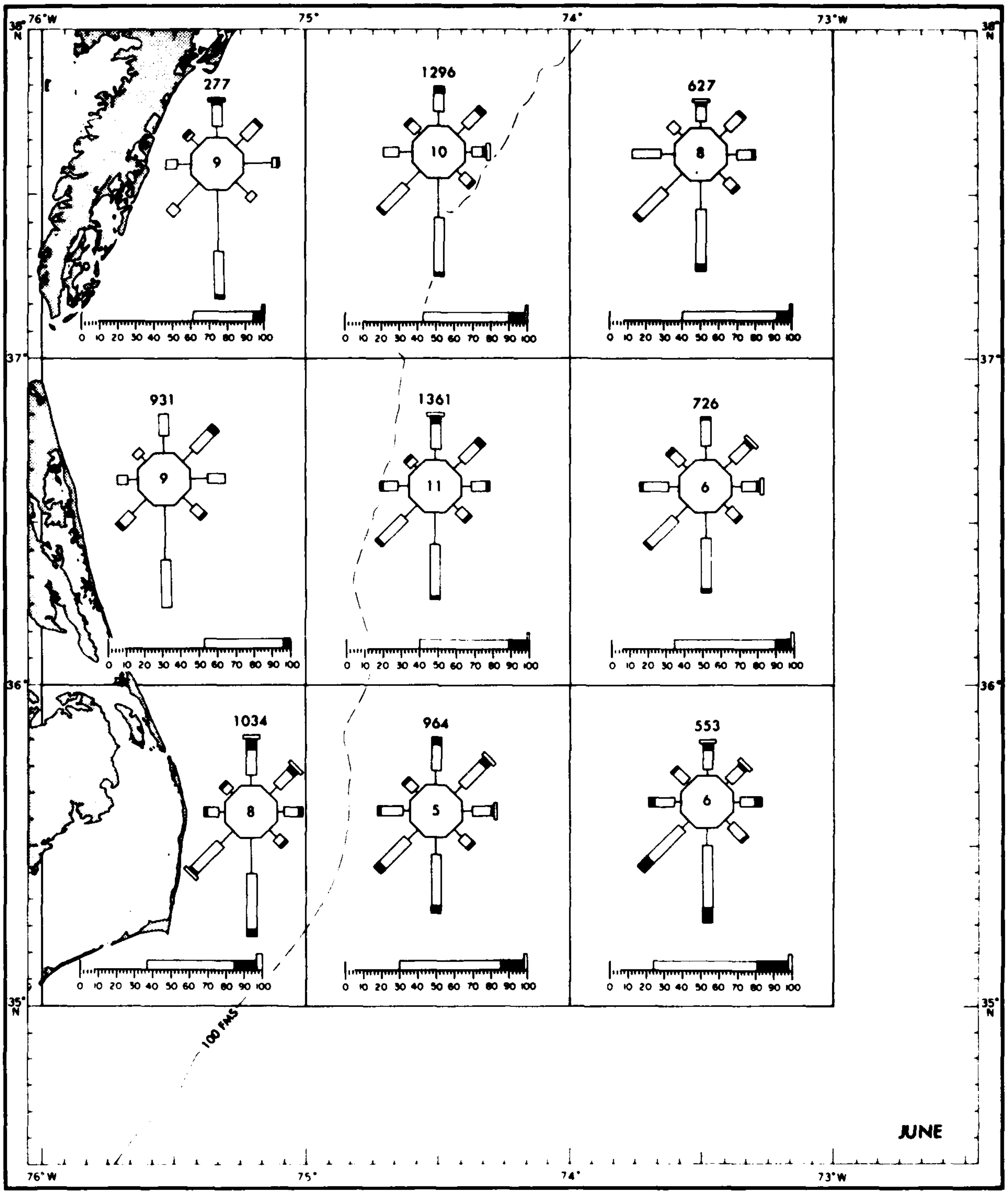


FIGURE A 4 WAVE ROSES (CON.)

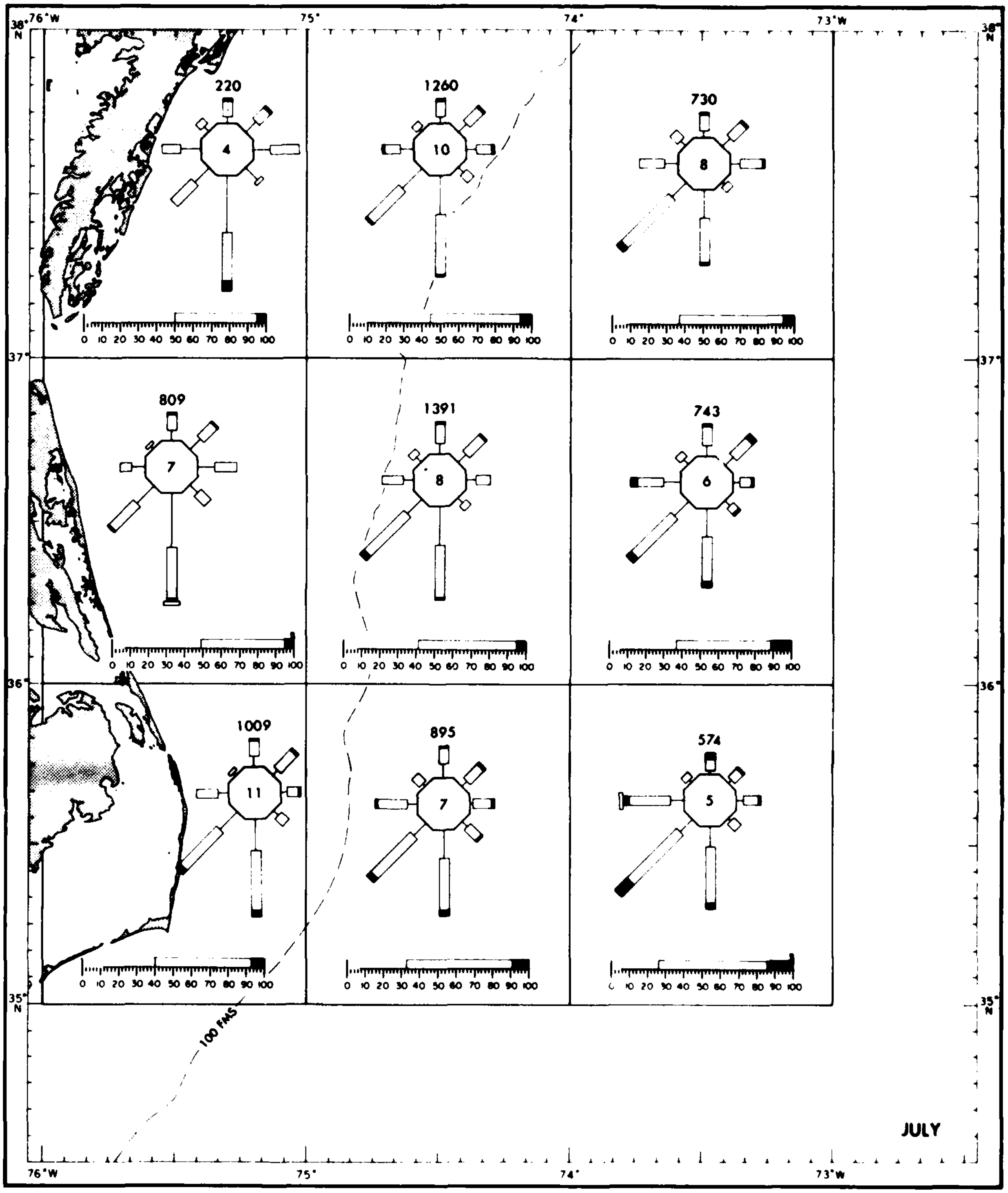


FIGURE A 4. WAVE ROSES (CON.)

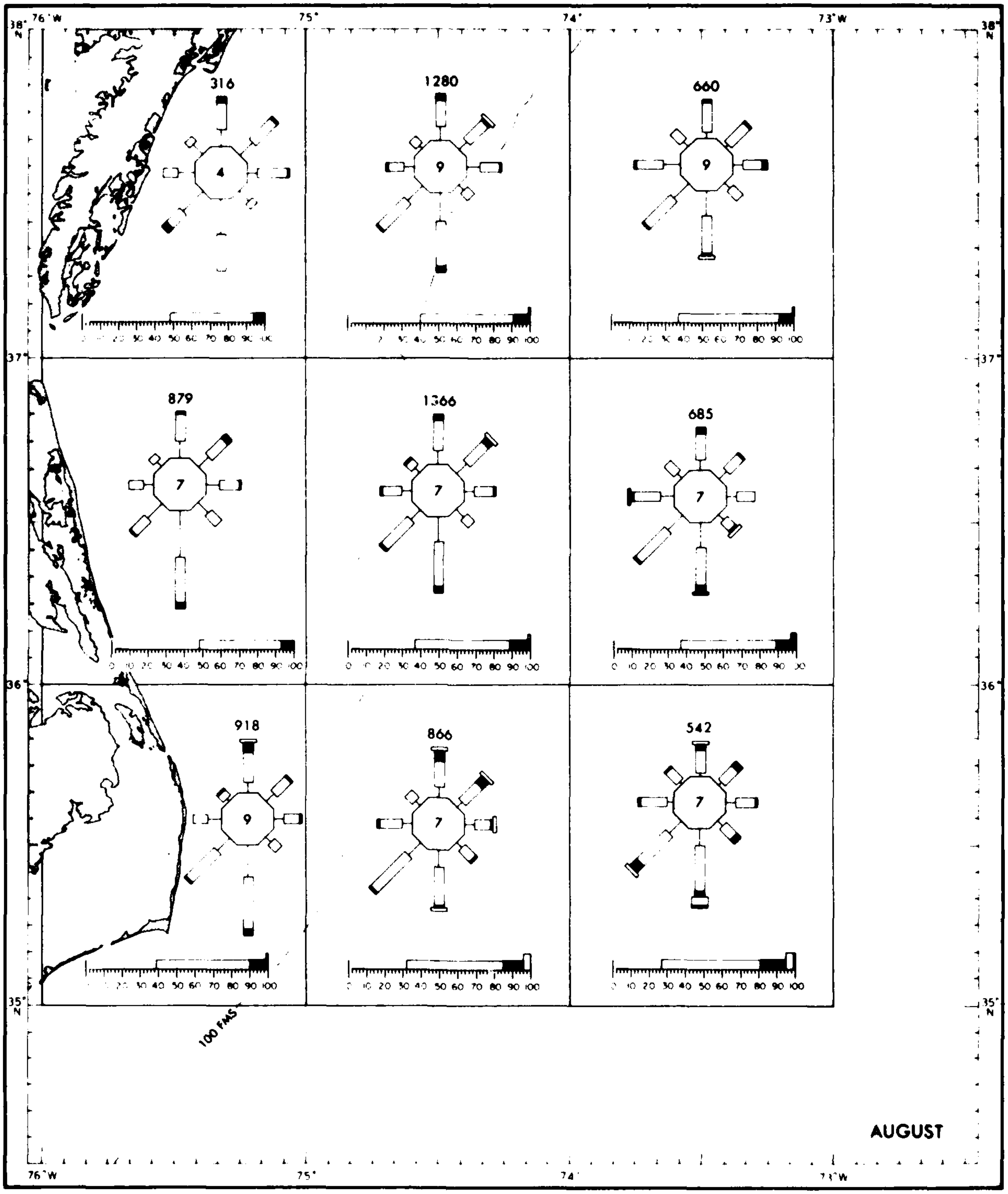


FIGURE A 4. WAVE ROSES (CON.)

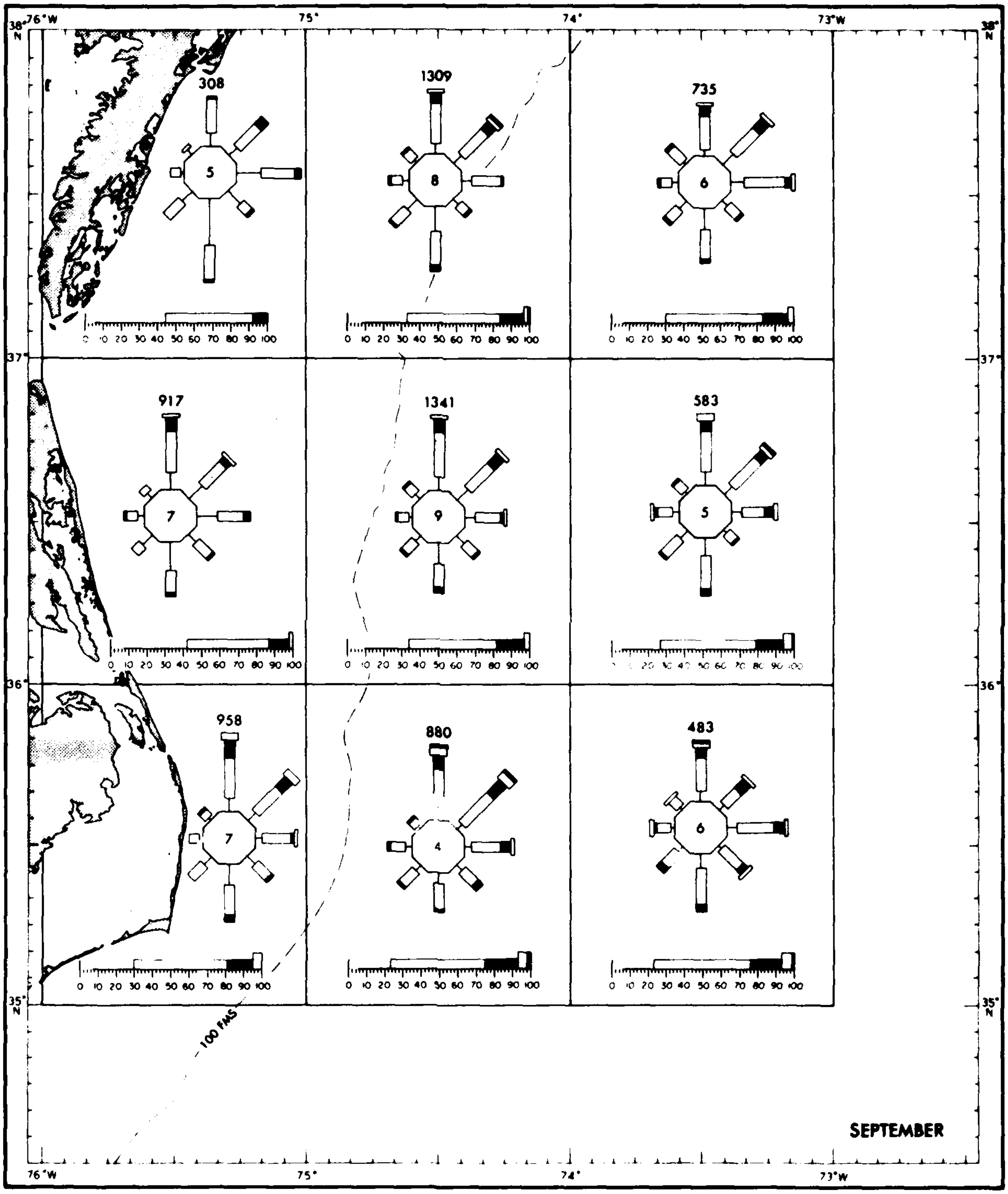


FIGURE A 4. WAVE ROSES (CON.)

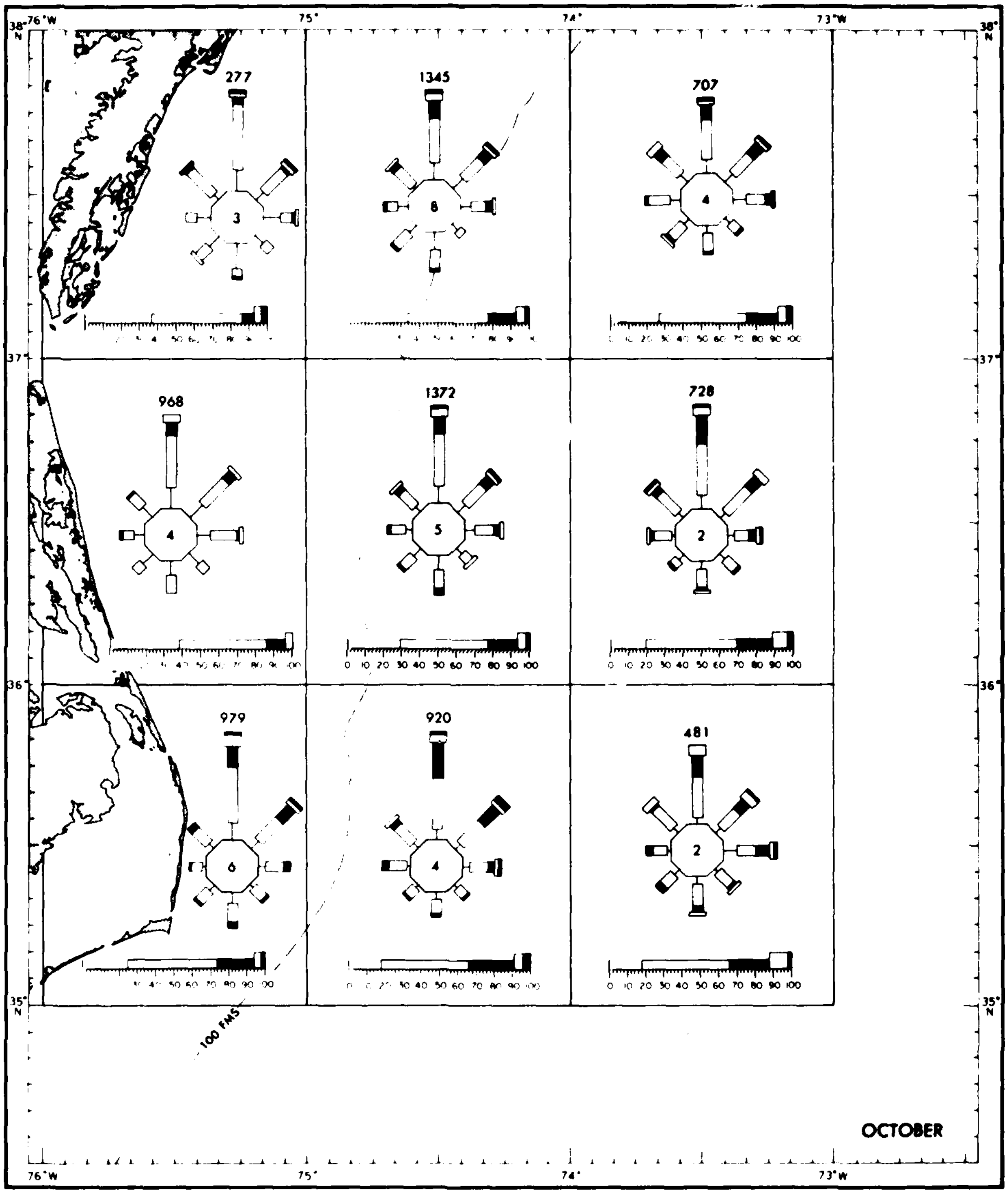


FIGURE A 4. WAVE ROSES (CON.)

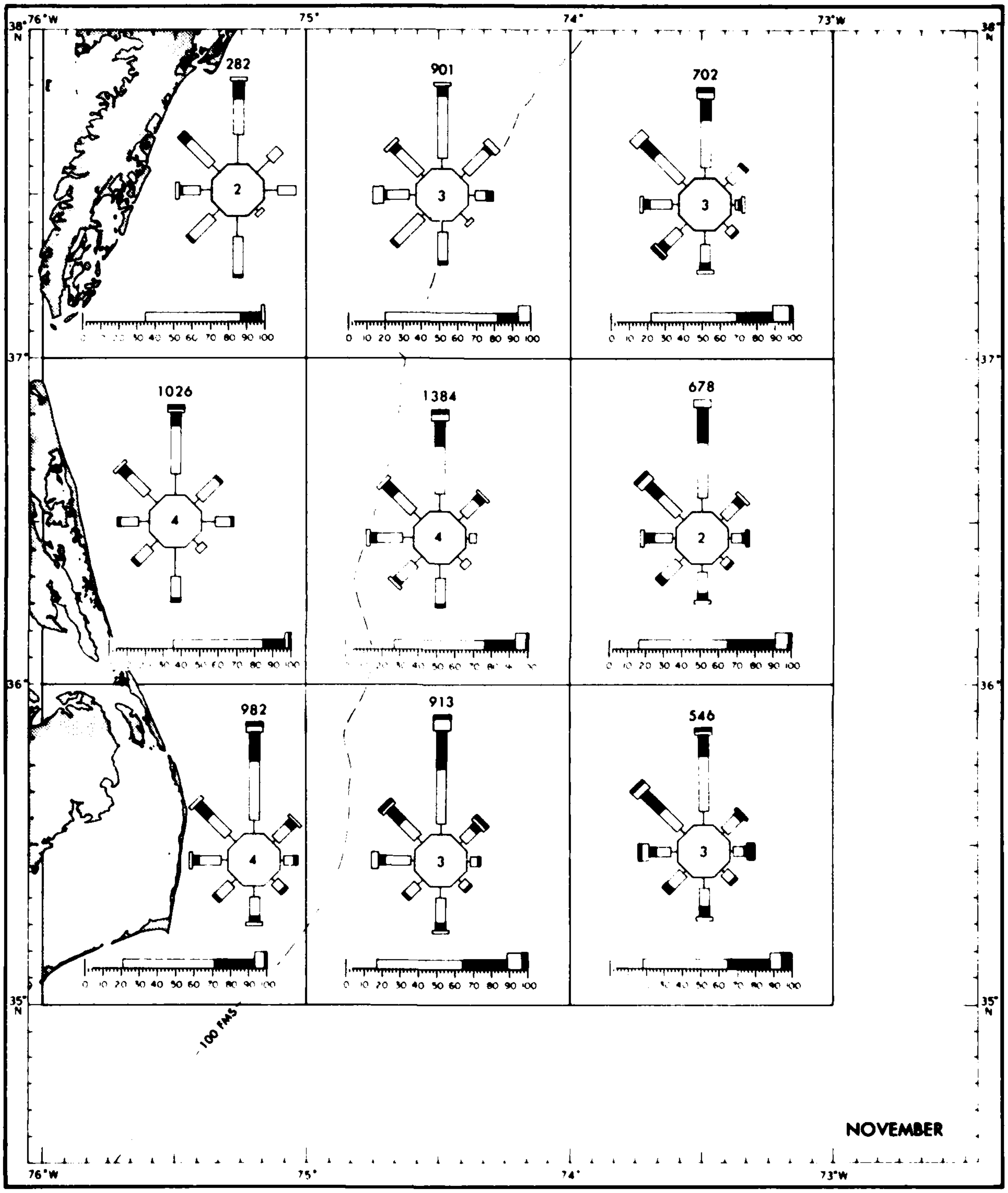


FIGURE A 4. WAVE ROSES (CON)

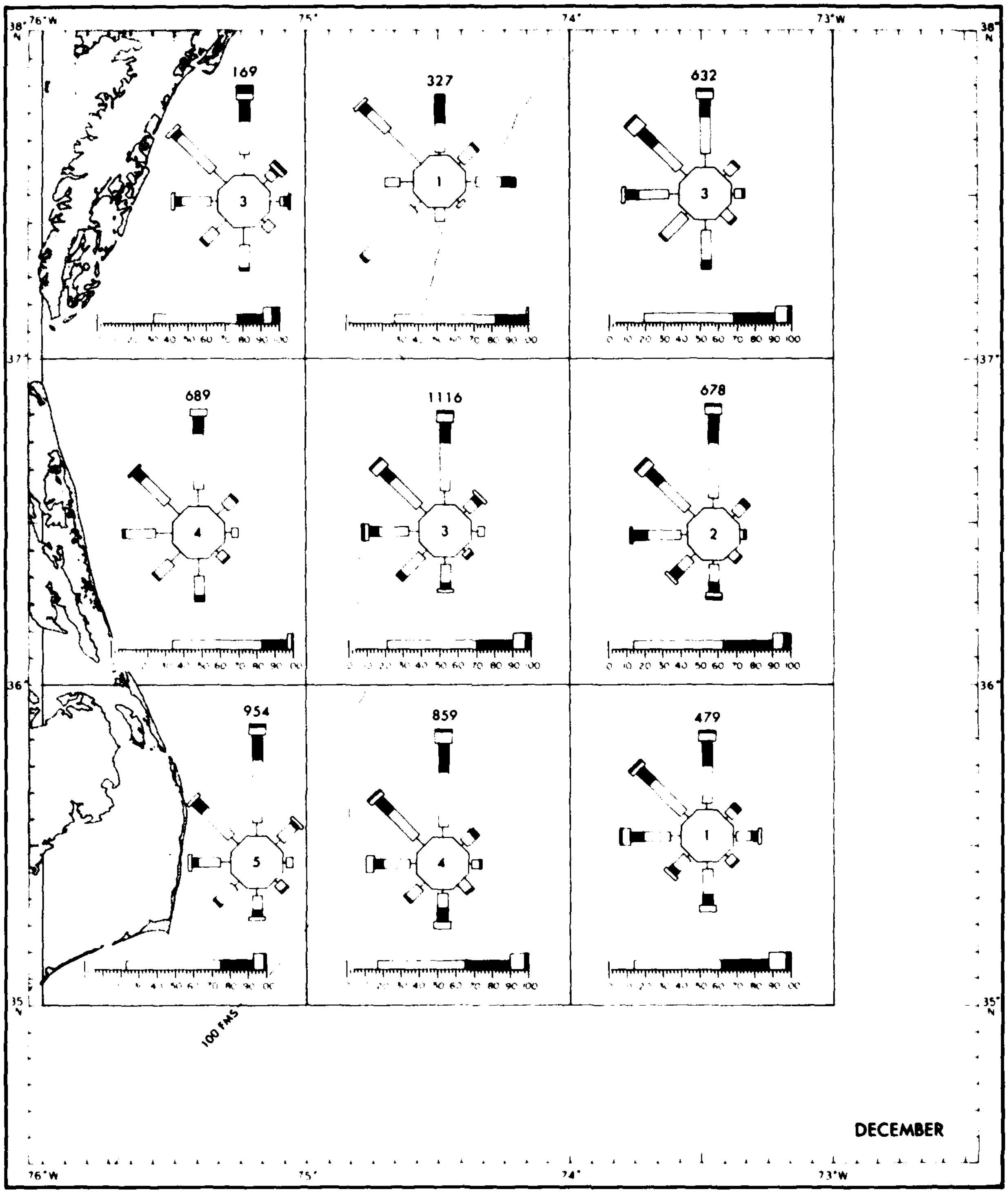


FIGURE A 4. WAVE ROSES (CON.)

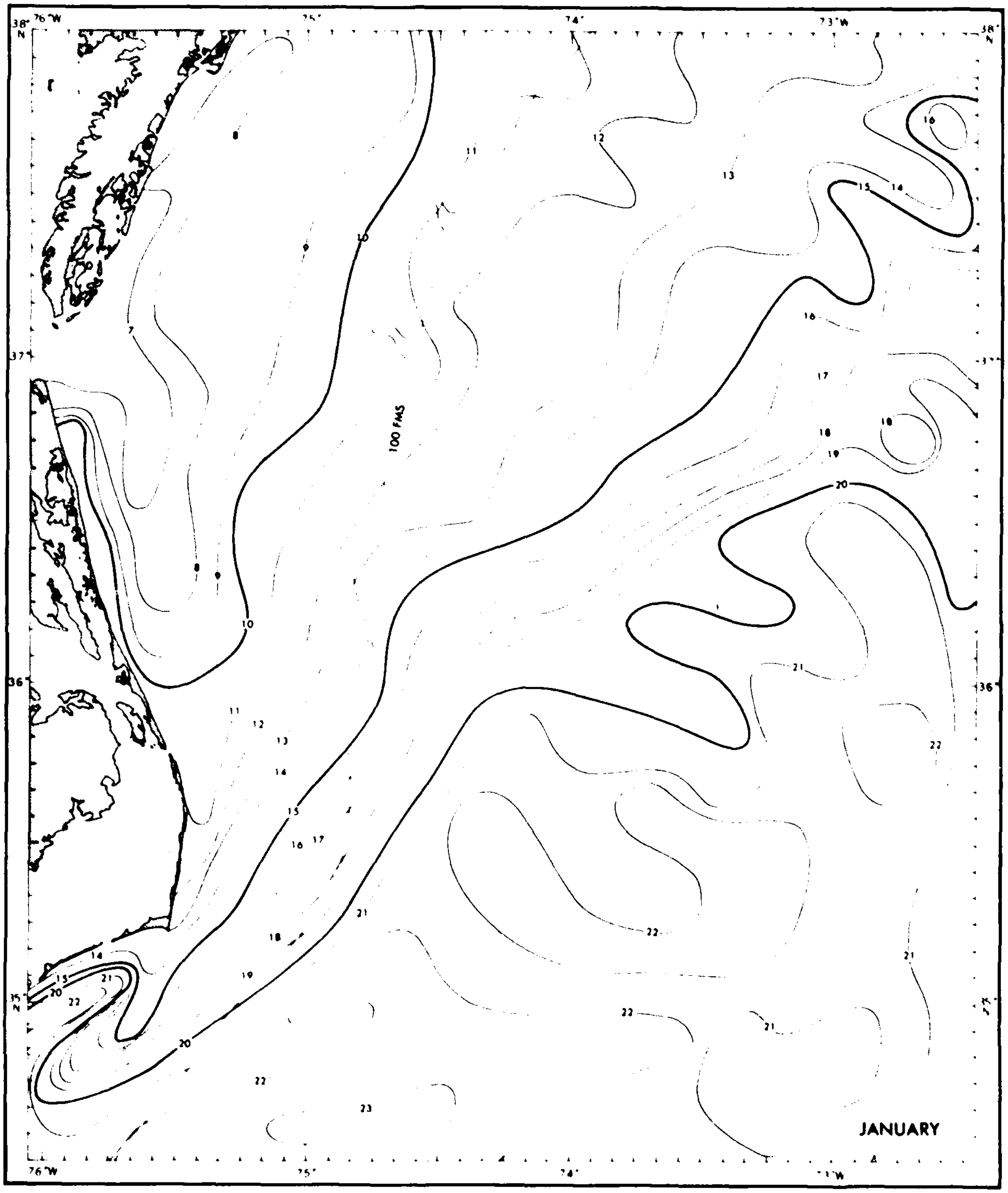


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C)

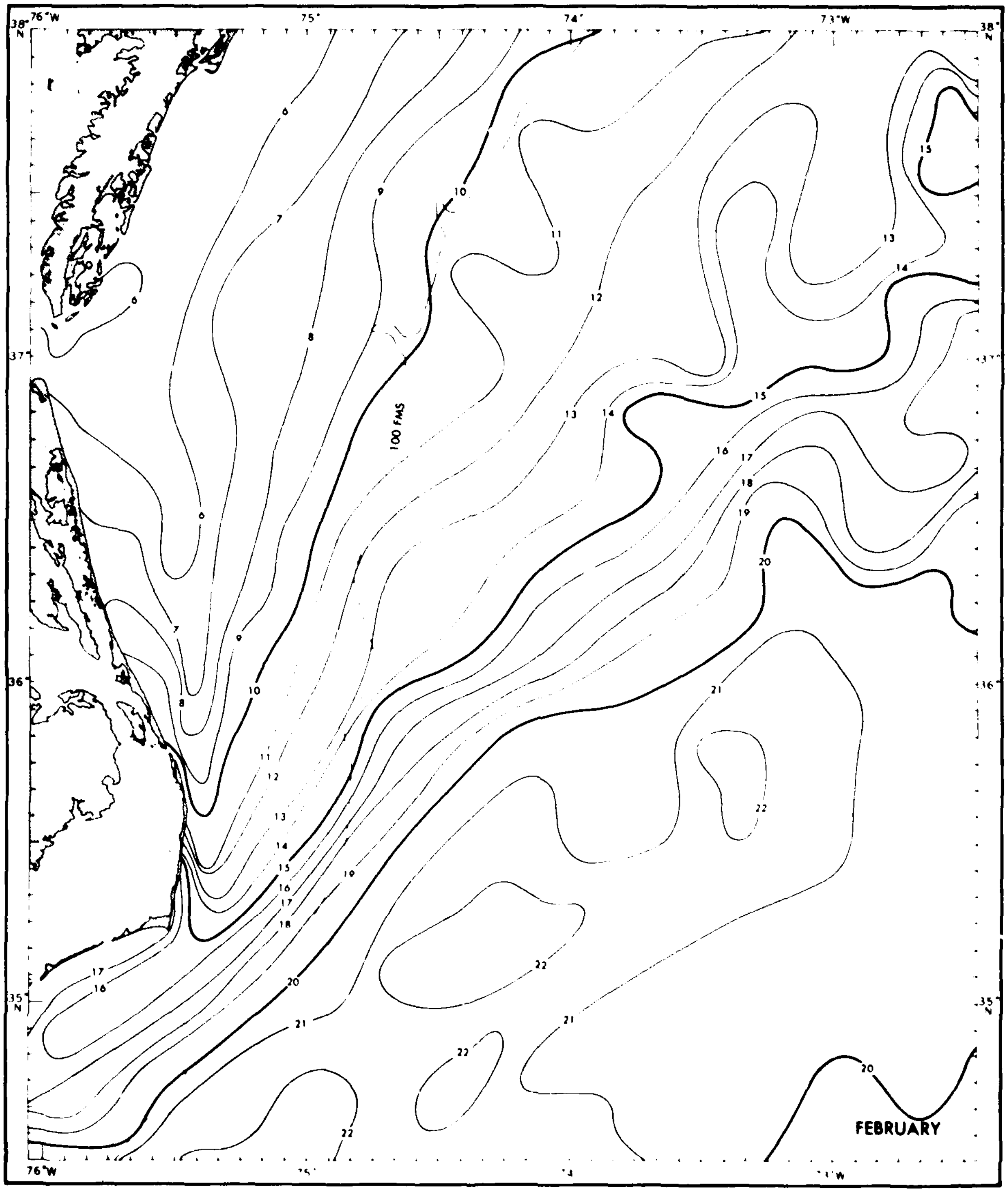


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

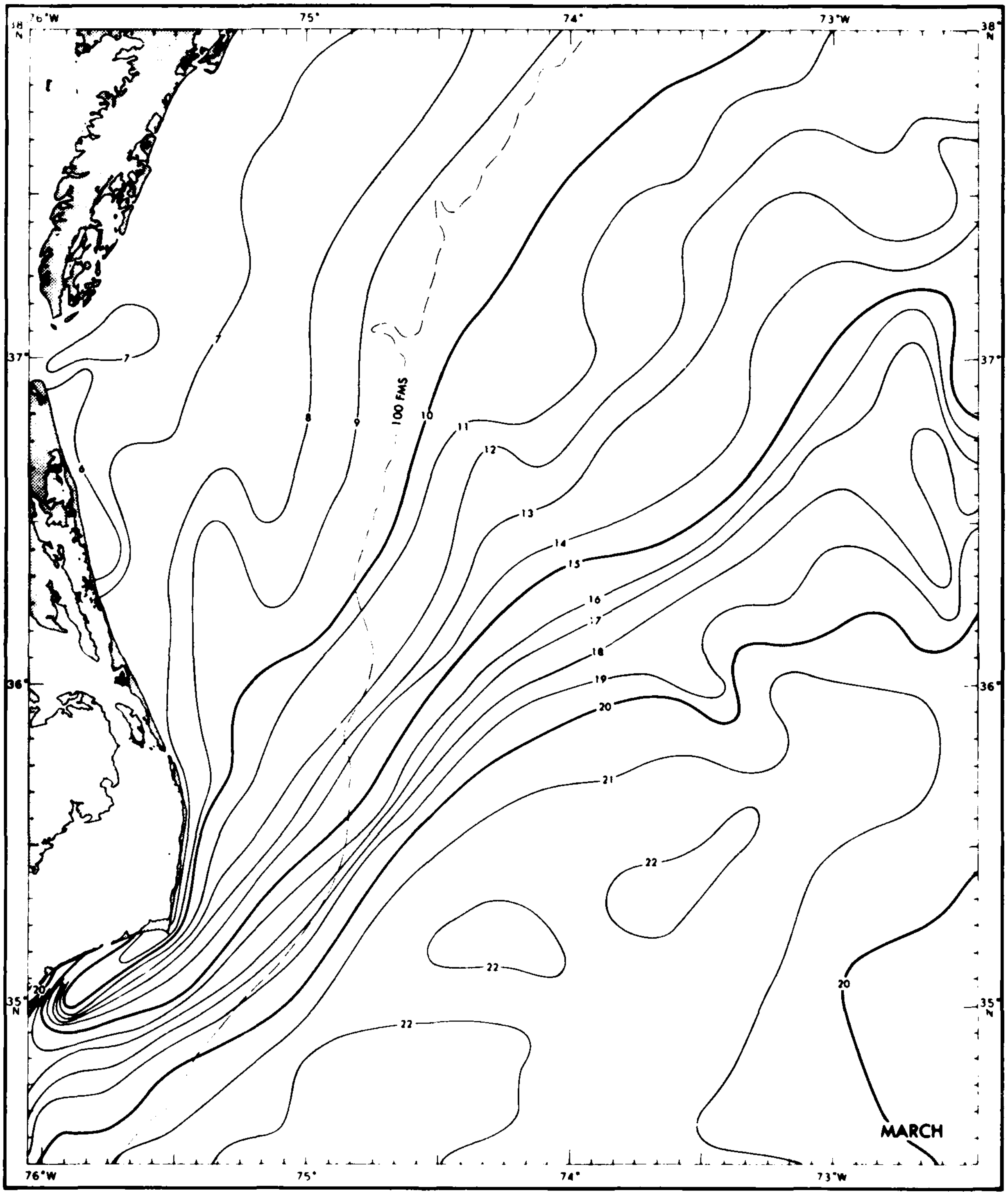


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

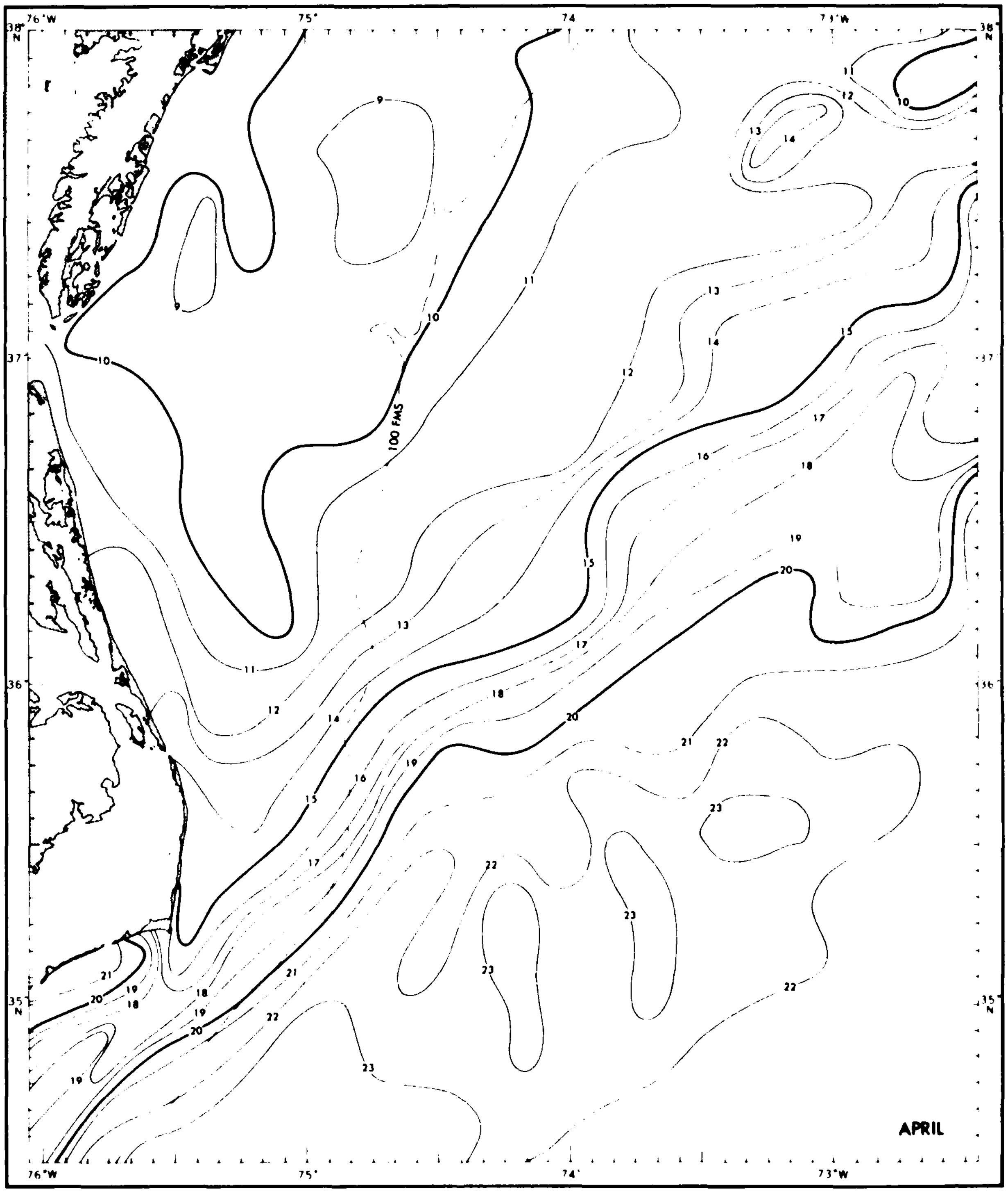


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

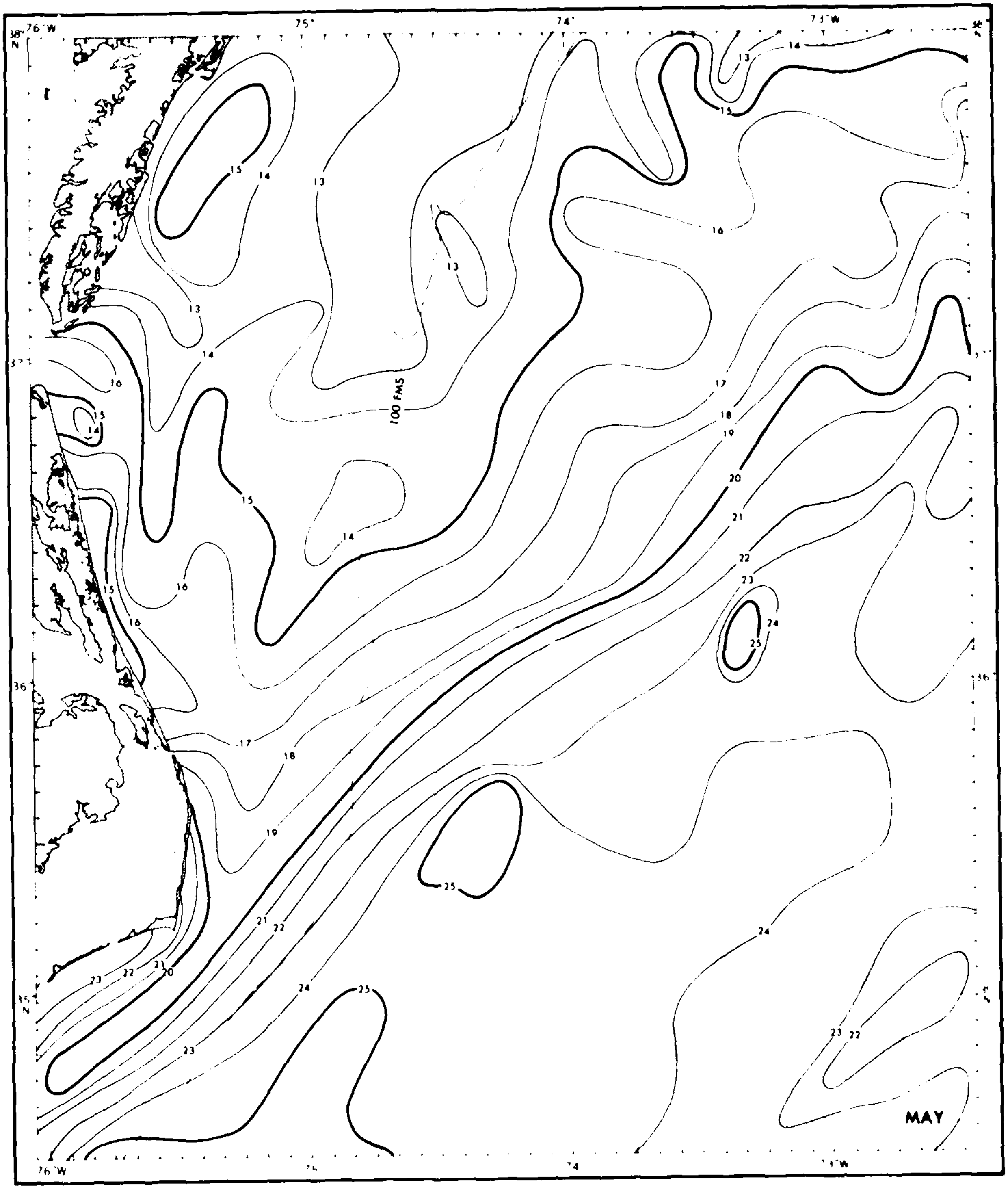


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

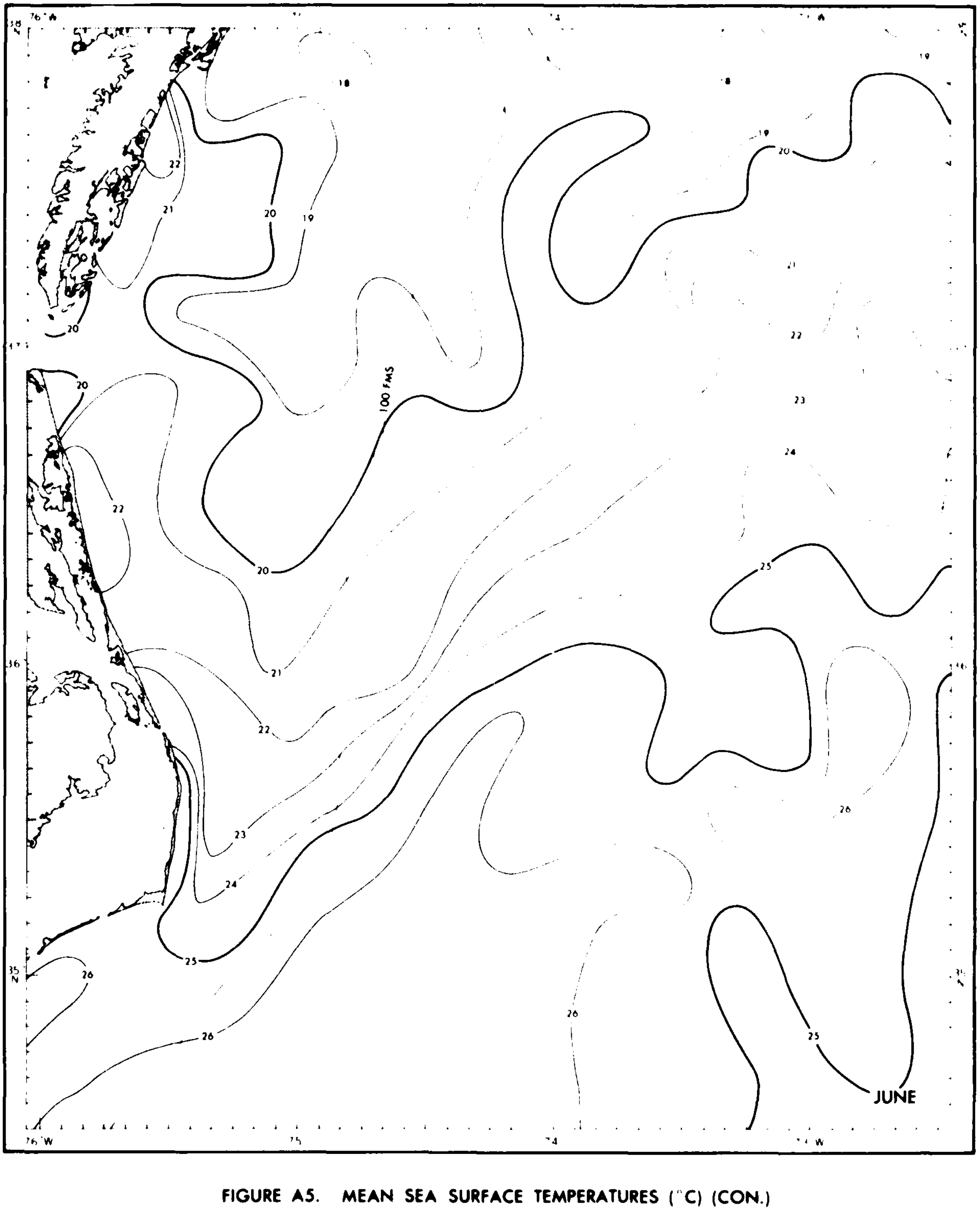


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

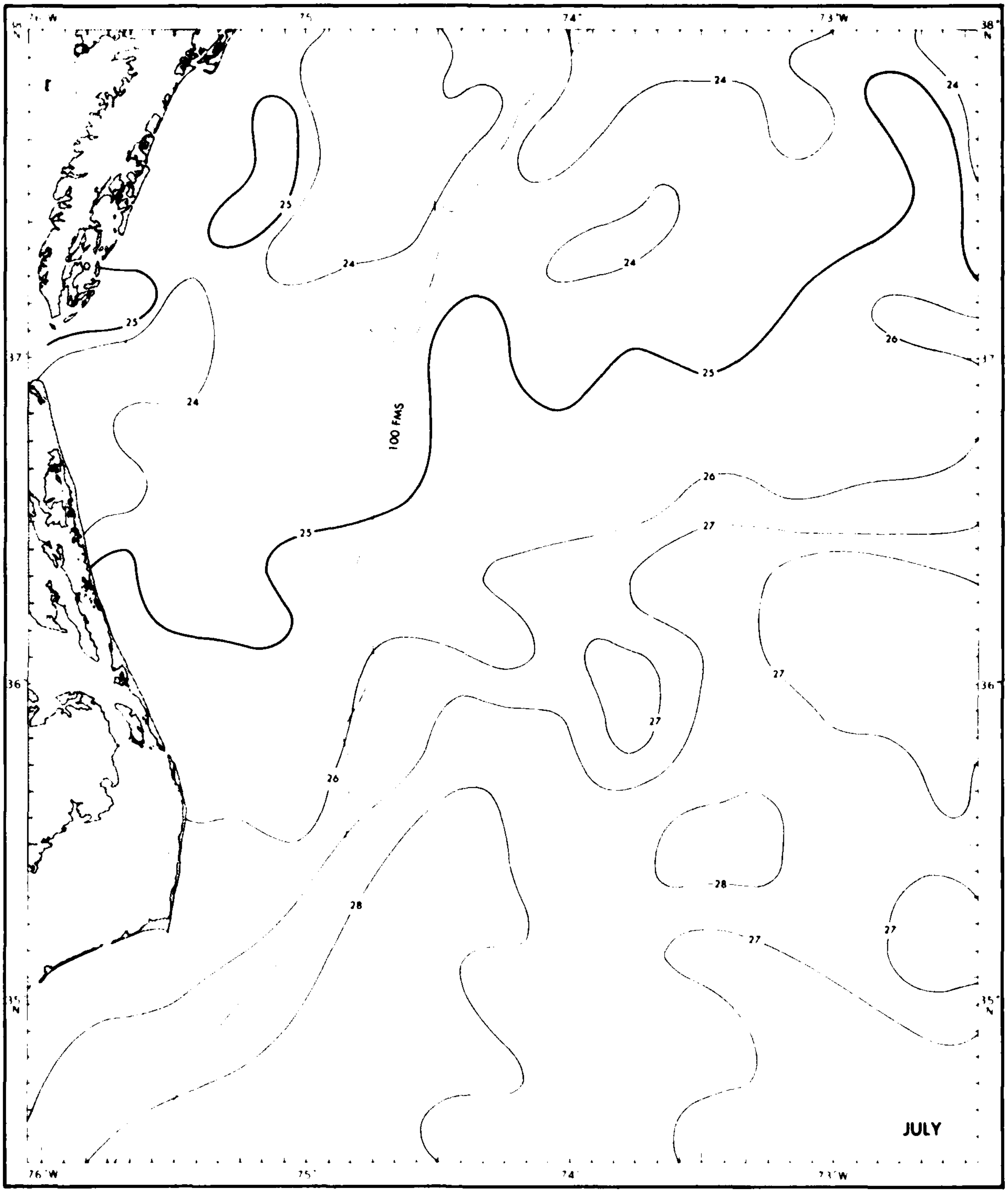


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

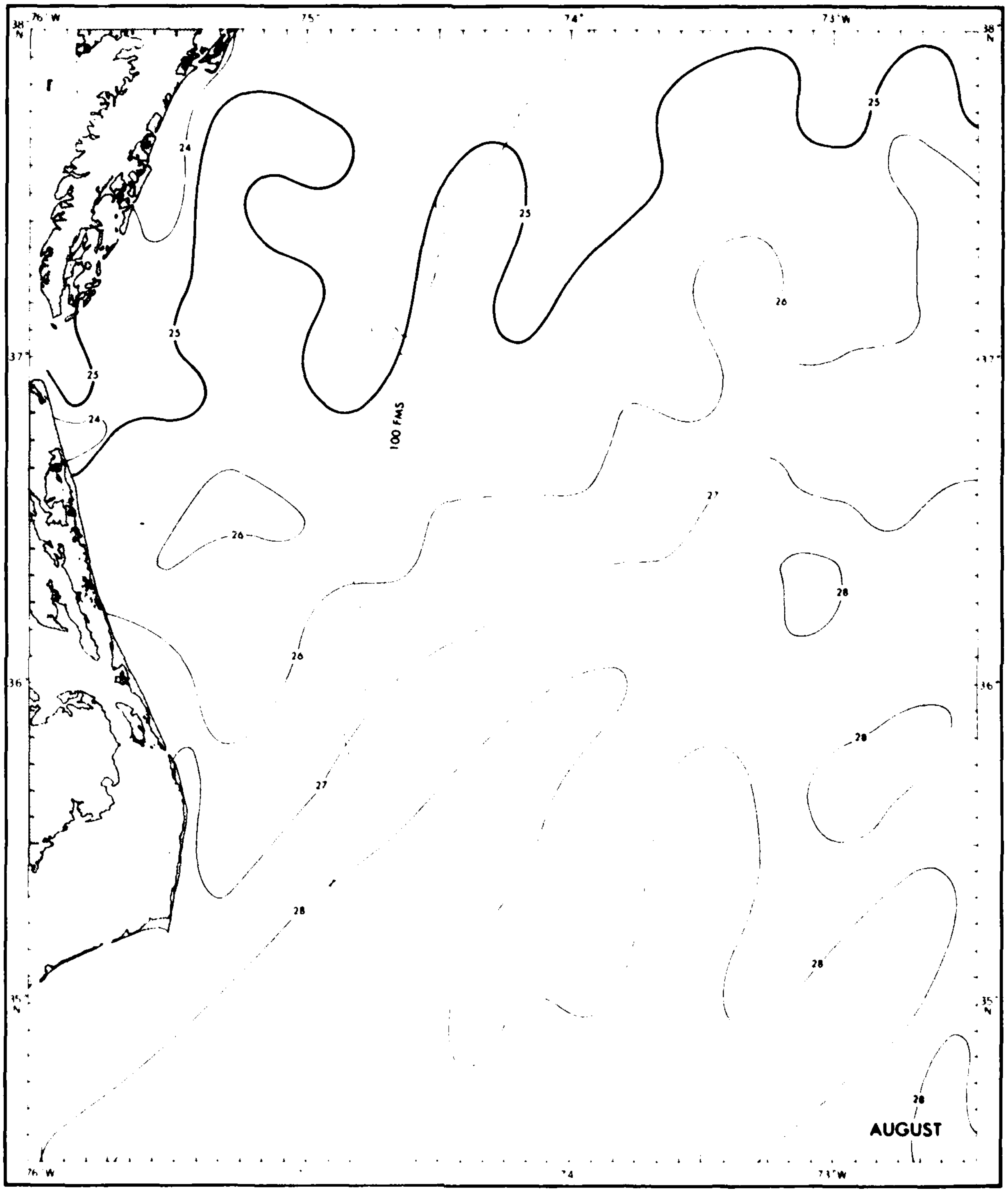


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

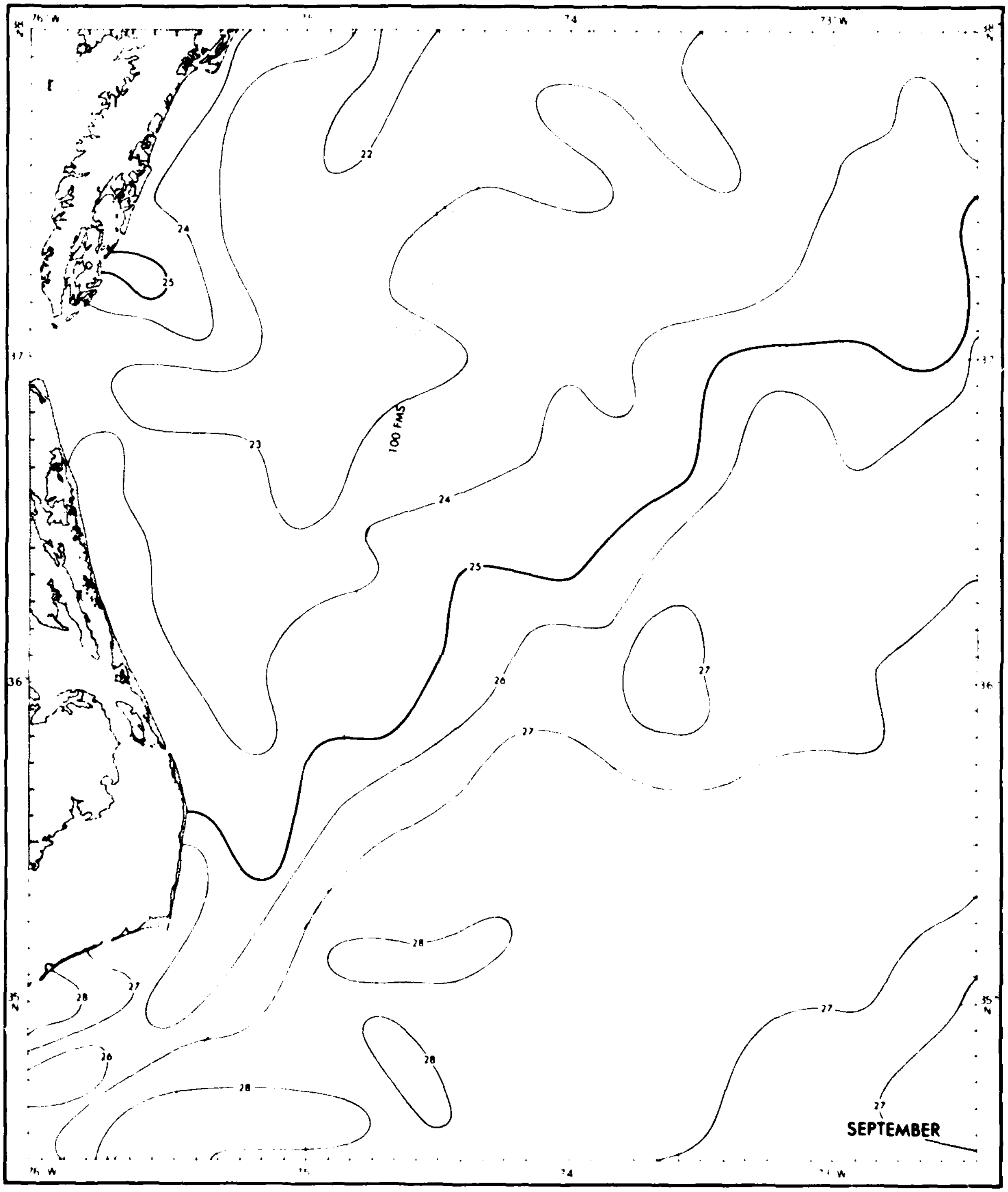


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

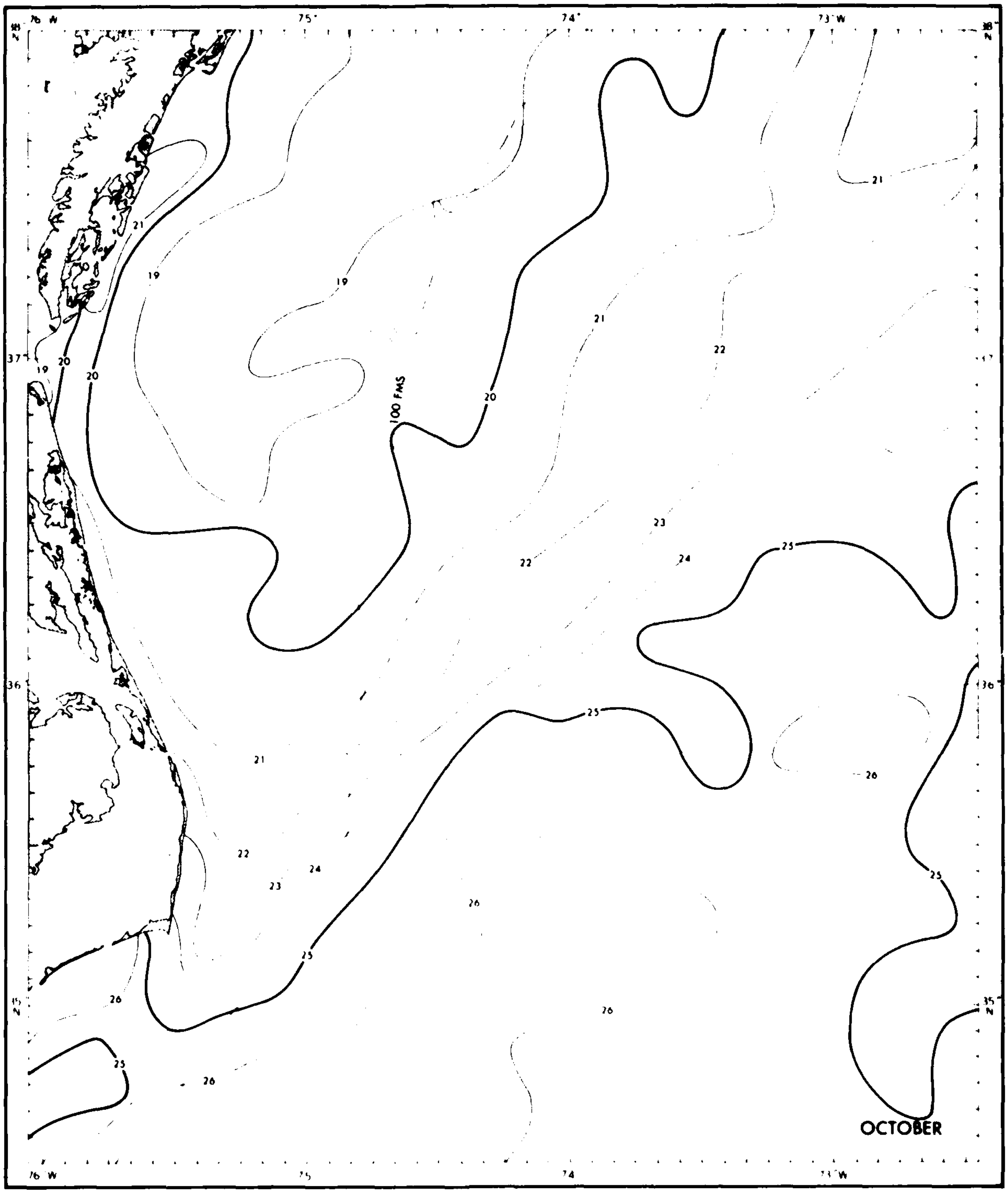


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

FIGURE A5. MEAN SEA SURFACE TEMPERATURES (C) (CON.)

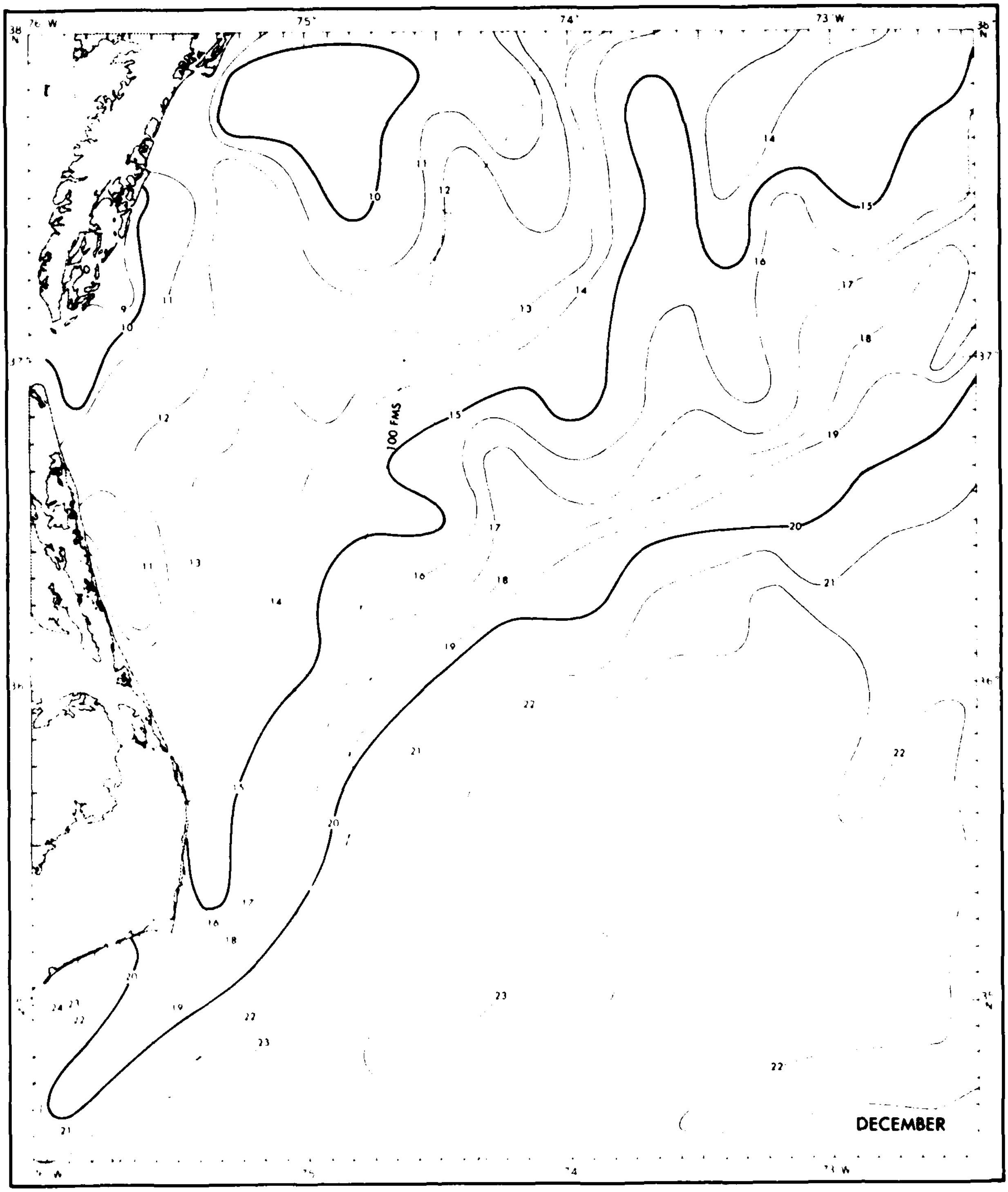


FIGURE A5. MEAN SEA SURFACE TEMPERATURES (°C) (CON.)

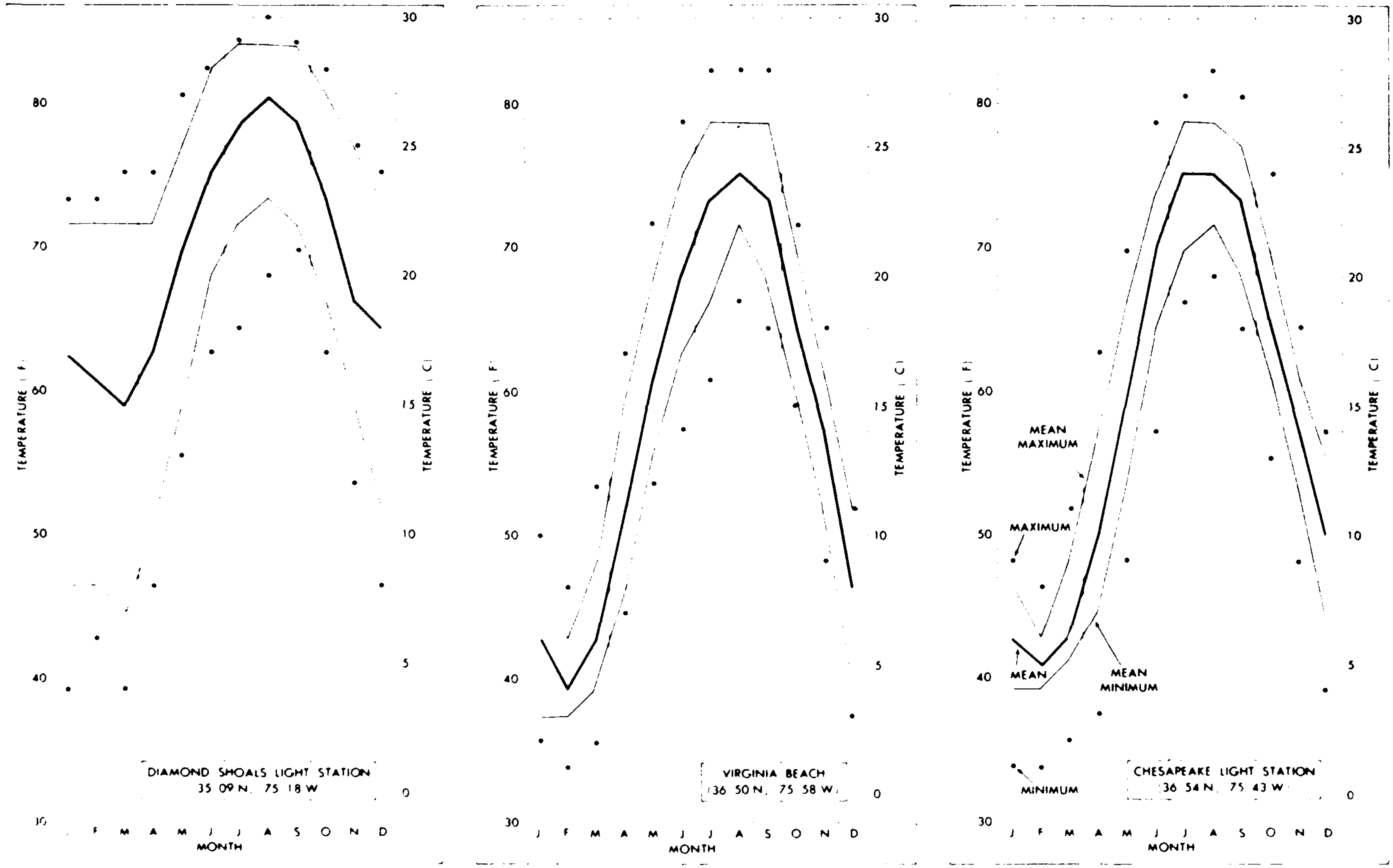


FIGURE A 6 MONTHLY VARIABILITY OF SEA SURFACE TEMPERATURES

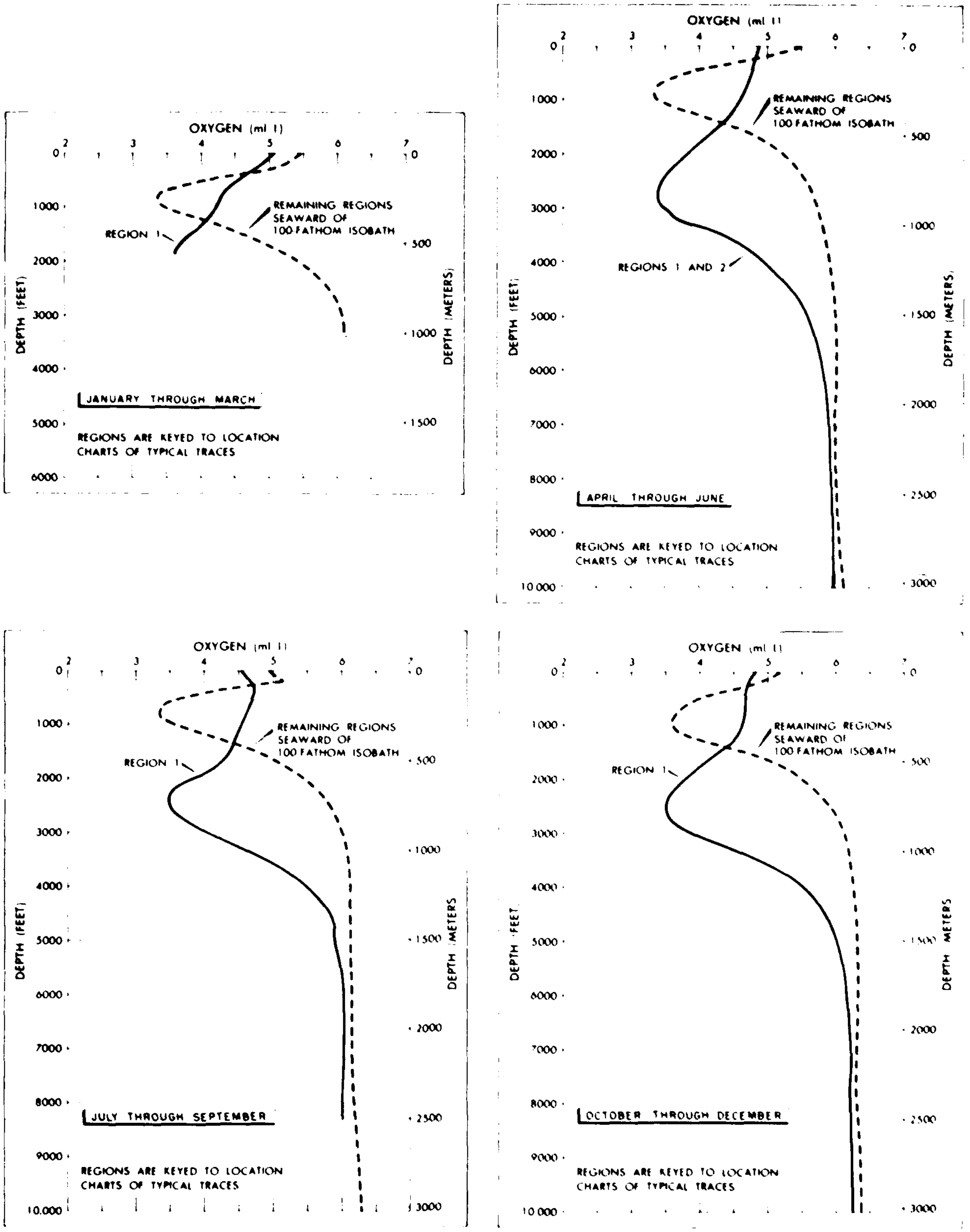


FIGURE A 7 MEAN OXYGEN TRACES

APPENDIX B.

METHOD FOR DETERMINING BOTTOM DRIFT

The orbital velocity of waves close to the seabed can be expressed as (Bagnold, 1963):

$$\mu_o = \frac{\pi H}{T} \Big/ \operatorname{Sinh} \frac{2\pi h}{L} \qquad (1)$$

Where μ_o = orbital velocity, cm sec^{-1}
H = wave height, cm
h = water depth, cm
L = wavelength, cm
T = period, seconds

Similarly, the forward drift velocity near the bottom is given by:

$$\bar{\mu} = \frac{5}{4} \frac{\mu_o^2}{C} \qquad (2)$$

Where $\bar{\mu}$ = forward drift velocity, cm sec^{-1}
C = wave velocity, cm sec^{-1}

Although wave heights, periods, lengths, and velocities are continuous functions of time, μ_o and $\bar{\mu}$ were calculated from finite values of these variables. This approximation results from the need to categorize the original observations into a workable code.

The wave data used in the calculations (U.S. National Climatic Center, 1971) are presented according to the following format:

Code	Equivalent Periods in Sec	Equivalent Height Range in Meters
1	≤ 5	1/2
2	6.7	1 - 1 1/2
3	8.9	2 - 2 1/2
4	10,11	3 - 3 1/2
5	12,13	4 - 4 1/2
6	14,15	5 - 6
7	16,17	6 1/2 - 7 1/2
8	18,19	8 - 9
9	< 20	≥ 9 1/2

The ranges of height, H, were further converted to midpoint values as follows:

1/2 to 0.5
1-1 1/2 to 1.25
2-2 1/2 to 2.25
3-3 1/2 to 3.25
4-4 1/2 to 4.25
5 - 6 to 5.50
6 1/2 - 7 1/2 to 7.00
8 - 9 to 8.50
≥ 9 1/2 to 10.00

Similarly, the ranges of period, T, were converted to the following midpoint values:

6,7 to 6.5
8,9 to 8.5
10,11 to 10.5
12,13 to 12.5
14,15 to 14.5
16,17 to 16.5
18,19 to 18.5

Orbital velocities were calculated for the following depths, h:

100 fathoms, i.e., 183 meters
50 fathoms, i.e., 91 meters
40 fathoms, i.e., 73 meters
30 fathoms, i.e., 55 meters
20 fathoms, i.e., 37 meters
10 fathoms, i.e., 18 meters

The relation sinh $\frac{2\pi h}{L}$ was determined from the published tables (U.S. Army Coastal Engineering Research Center, 1966), the wavelength L having been modified to take into account the movement of deepwater waves into shallow regions. This modified wavelength is L_O. The wave velocity, C, was derived from the expression:

$$C = C_O \tanh \frac{2\pi h}{L} = \frac{L_O}{T} \tanh \frac{2\pi h}{L}$$

Where C_O = deep-water wave velocity

The values of tanh $\frac{2\pi h}{L}$ were also established from the above source.

The resulting values of μ_o and $\bar{\mu}$, as calculated from Equations (1) and (2), are listed in Appendix C. The frequency of occurrence of these velocities at a specific location can next be ascertained from the historical wave distribution. Only those waves which feel bottom are considered. Thus, all the observed waves crossing the 100-fathom isobath, only 3 percent may be feeling the bottom. These are the waves which are used in calculating μ_o and $\bar{\mu}$ along that particular isobath. If these waves have a period of 20.5 seconds and a height of 10 meters, they will affect the bottom with a 49.8 cm $\sec^{-1}$ orbital velocity and a 1.0 cm $\sec^{-1}$ drift velocity. In essence, an orbital velocity of 49.8 cm $\sec^{-1}$ and a drift velocity of 1.0 cm $\sec^{-1}$ resulting from waves having the above characteristics are measured 3 percent of the time near the bottom. Waves of other periods and heights will contribute to a spectrum of orbital and drift velocities.

The frequency of occurrence of various velocities, as determined from all available surface wave data, is given in Appendix C for each of the four seasons.

APPENDIX C.

TABLE OF ORBITAL AND DRIFT VELOCITIES

d = 100 fathoms

ORBITAL VELOCITY (cm/sec)

	T(sec)		
Wave Height H(m)	20.5	18.5	16.5
0.50	2.5	1.9	1.2
1.25	6.2	4.7	3.1
2.25	11.2	8.5	5.6
3.25	16.2	12.3	8.1
4.25	21.2	16.1	10.6
5.50	27.4	20.8	13.7
7.00	34.8	26.5	17.4
8.50	42.3	32.1	21.2
10.00	49.8	37.8	24.9

DRIFT VELOCITY (cm/sec)

	T(sec)		
Wave Height H(m)	20.5	18.5	16.5
0.50	0.0	0.0	0.0
1.25	0.0	0.0	0.0
2.25	0.1	0.0	0.0
3.25	0.1	0.1	0.0
4.25	0.2	0.1	0.1
5.50	0.3	0.2	0.1
7.00	0.5	0.3	0.1
8.50	0.7	0.5	0.2
10.00	1.0	0.6	0.3

d = 50 fathoms

ORBITAL VELOCITY (cm/sec)

	T(sec)				
Wave Height H(m)	20.5	18.5	16.5	14.5	12.5
0.50	5.8	5.3	4.5	3.6	2.3
1.25	14.5	13.2	11.3	8.9	5.8
2.25	26.0	23.7	20.4	16.0	10.5
3.25	37.6	34.2	29.4	23.1	15.2
4.25	49.1	44.7	38.5	30.3	19.9
5.50	63.6	57.9	49.8	39.2	25.7
7.00	80.9	73.6	63.4	49.8	32.7
8.50	98.3	89.5	77.0	60.5	39.7
10.00	115.6	105.2	90.6	71.2	46.8

DRIFT VELOCITY (cm/sec)

	T(sec)				
Wave Height H(m)	20.5	18.5	16.5	14.5	12.5
0.50	0.0	0.0	0.0	0.0	0.0
1.25	0.1	0.1	0.1	0.0	0.0
2.25	0.3	0.3	0.2	0.1	0.1
3.25	0.7	0.6	0.5	0.3	0.2
4.25	1.2	1.0	0.8	0.5	0.3
5.50	2.0	1.7	1.3	0.9	0.4
7.00	3.2	2.8	2.2	1.4	0.7
8.50	4.7	4.1	3.2	2.1	1.0
10.00	6.5	5.6	4.4	2.9	1.4

d = 40 fathoms

ORBITAL VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5
0.50	7.0	6.5	5.8	4.9	3.6	2.0
1.25	17.5	16.2	14.7	12.2	9.1	5.1
2.25	31.7	29.2	26.2	22.0	16.3	9.2
3.25	45.6	42.2	37.9	31.8	23.6	13.3
4.25	59.6	55.2	49.5	41.5	30.9	17.4
5.50	77.1	71.4	64.1	53.7	39.9	22.5
7.00	98.1	90.9	81.6	68.4	50.8	28.6
8.50	119.2	110.4	99.1	83.1	61.7	34.7
10.00	140.2	129.8	116.5	97.7	72.6	40.9

DRIFT VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5
0.50	0.0	0.0	0.0	0.0	0.0	0.0
1.25	0.2	0.1	0.1	0.1	0.1	0.0
2.25	0.5	0.5	0.4	0.3	0.2	0.1
3.25	1.1	1.0	0.8	0.6	0.4	0.1
4.25	1.9	1.7	1.4	1.0	0.6	0.2
5.50	3.2	2.8	2.3	1.8	1.1	0.4
7.00	5.1	4.5	3.8	2.8	1.7	0.6
8.50	7.5	6.6	5.6	4.2	2.5	0.9
10.00	10.4	9.2	7.7	5.8	3.5	1.3

d = 30 fathoms

ORBITAL VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5	8.5
0.50	8.7	8.2	7.7	6.8	5.6	3.8	1.7
1.25	21.7	20.6	19.2	17.0	14.0	9.5	4.3
2.25	39.0	37.1	34.6	30.6	25.2	17.2	7.7
3.25	56.4	53.5	49.9	44.2	36.4	24.8	11.1
4.25	73.7	70.0	65.2	57.8	47.6	32.7	14.6
5.50	95.4	90.7	84.5	74.8	61.6	42.0	18.9
7.00	121.4	115.4	107.5	95.2	78.4	53.4	24.0
8.50	147.4	140.1	130.5	115.6	95.2	64.9	29.2
10.00	173.4	164.8	153.6	136.0	112.0	76.4	34.3

DRIFT VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5	8.5
0.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.25	0.3	0.3	0.2	0.2	0.2	0.1	0.0
2.25	0.9	0.8	0.7	0.6	0.6	0.2	0.1
3.25	1.9	1.7	1.6	1.3	1.2	0.5	0.1
4.25	3.2	3.0	2.7	2.2	2.0	0.8	0.2
5.50	5.4	5.0	4.4	3.6	3.3	1.4	0.3
7.00	8.7	8.0	7.2	5.9	5.4	2.3	0.5
8.50	12.8	11.9	10.6	8.7	7.9	3.3	0.8
10.00	17.7	16.4	14.7	12.1	11.0	4.6	1.1

d = 20 fathoms

ORBITAL VELOCITY (cm/sec)

T(sec)

		20.5	18.5	16.5	14.5	12.5	10.5	8.5
Wave Height H(m)	0.50	11.4	11.0	10.5	9.8	8.7	7.1	4.5
	1.25	28.5	27.5	26.3	24.4	21.8	17.7	11.3
	2.25	57.3	49.5	47.3	44.0	39.2	31.8	20.4
	3.25	74.0	71.6	68.3	63.5	56.6	46.0	29.4
	4.25	96.8	93.6	89.2	83.0	74.0	60.1	38.5
	5.50	125.3	121.1	115.5	107.5	95.8	77.8	49.8
	7.00	159.5	154.1	147.0	136.8	122.0	99.0	63.3
	8.50	193.7	187.2	178.5	166.1	148.1	120.3	76.9
	10.00	227.9	220.2	210.0	195.4	174.3	141.5	90.5

DRIFT VELOCITY (cm/sec)

T(sec)

		20.5	18.5	16.5	14.5	12.5	10.5	8.5
Wave Height H(m)	0.50	0.1	0.1	0.1	0.1	0.1	0.0	0.0
	1.25	0.6	0.5	0.5	0.4	0.4	0.3	0.1
	2.25	1.8	1.7	1.6	1.4	1.2	0.9	0.4
	3.25	3.8	3.6	3.4	3.0	2.5	1.8	0.8
	4.25	6.6	6.2	5.8	5.1	4.2	3.1	1.4
	5.50	11.0	10.4	9.6	8.6	7.2	5.1	2.4
	7.00	17.8	16.9	15.6	13.9	11.6	8.3	3.9
	8.50	26.2	24.9	23.0	20.5	17.1	12.2	5.7
	10.00	36.2	34.4	31.9	28.4	23.7	16.9	7.9

d = 10 fathoms

ORBITAL VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5	8.5	6.5
0.50	17.6	17.1	16.9	16.3	15.5	14.3	12.3	8.1
1.25	43.9	42.6	42.2	40.7	38.9	35.8	20.7	20.3
2.25	79.0	76.7	76.0	73.3	69.9	64.5	55.2	36.6
3.25	114.1	110.8	109.8	105.9	101.0	93.1	79.7	52.9
4.25	149.1	144.0	143.5	138.4	132.0	121.7	104.2	69.1
5.50	193.0	187.6	183.8	179.2	170.9	157.5	134.9	89.4
7.00	245.6	238.7	236.4	228.0	217.5	200.5	171.7	113.8
8.50	298.4	289.9	287.2	276.9	264.2	243.5	208.5	138.3
10.00	351.0	341.0	337.8	325.8	310.8	286.4	345.3	162.6

DRIFT VELOCITY (cm/sec)

T(sec)

Wave Height H(m)	20.5	18.5	16.5	14.5	12.5	10.5	8.5	6.5
0.50	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.1
1.25	1.9	1.8	1.8	1.7	1.5	1.4	1.1	0.5
2.25	6.1	5.7	5.7	5.4	5.0	4.4	3.4	1.7
3.25	12.7	11.9	11.9	11.2	10.4	9.1	7.2	3.6
4.25	21.7	20.4	20.4	19.1	17.8	15.6	12.3	6.2
5.50	36.4	34.2	34.1	32.0	29.8	26.2	20.6	10.4
7.00	58.9	55.4	44.2	51.8	48.2	42.4	33.3	16.9
8.50	86.9	81.7	81.4	76.5	71.1	62.6	49.1	24.9
10.00	120.3	113.0	112.7	105.8	98.3	86.6	68.0	34.4

APPENDIX D.

SYNOPSIS OF BIOLOGICAL DATA ON COMMERCIALLY IMPORTANT SPECIES OF FISH AND INVERTEBRATES

SPECIES	HABITAT	MOVEMENTS	BIOLOGY	FISHERY	MISCELLANEOUS
VERTEBRATES:					
Bluefish (*Pomatomus saltatrix*)	Pelagic, schooling.	Population base apparently to the south. Moves north in spring, south in autumn. Some fish exit to north, others remain in region throughout summer.	Spawns during spring and early summer, probably just offshore in northern part of area.	Bulk of landings during May through November. Outer Banks fishermen use seines and gill nets. Also sought by sports fishermen.	
Butterfish (*Poprilus triacanthus*) and Harvestfish (*P. paru*)	Demersal.	Migrates relatively short distances, toward shallow waters in spring, deeper waters in autumn.	Spawns in June and July. Eggs are pelagic and hatch in less than 2 days at 72°F. Young remain near Portuguese man-of-war or other large medusae.	Taken by pound nets and seines in sounds and bays, by trawlers offshore.	Young often killed and wasted by shrimp trawlers.
Croaker (*Micropogon undulatus*)	Demersal, sometimes in schools during warm weather.	Winters in offshore waters in southern part of area and migrates northward toward coastal and estuarine waters in spring. Reverse direction during autumn.	Spawns during fall offshore. Young remain in estuarine waters during first year, then migrate offshore with adults in autumn.	Caught with pound nets and gill nets in estuarine waters, haul seines in coastal waters, and by trawlers on offshore grounds. Best catches during October through May.	Fishery undergoing steady decline in catch. Young caught in industrial catch.
Fluke and Flounders (*Paralichthys dentatus, P. lethostigma scophthalmus aquosus*)	Demersal.	Adult fish leave coastal bays & inshore waters in fall and spend winter at depths of 20-85 fathoms. Return to shallower waters in spring.	*P. dentatus*. Probably spawns offshore in late fall or winter. *S. aquosus* spawns inshore in spring & early summer. Eggs are pelagic and hatch in about 8 days at temperatures around 53°F.	Taken by trawlers offshore in winter and near shore all year, with highest catches during summer. Haul seines used along coast. Taken in inside waters by pound nets, haul seines, shrimp trawls and gigs.	
Whiting (*Merluccius bilinearis*) Red hake (*Urophycis chuss*) Spotted hake (*U. regius*)	Demersal and midwater.	Whiting found during winter along the 100-fathom contour. Move toward shallower waters in spring, return to deeper waters in fall.	Whiting spawns inshore during the summer. Eggs hatch in about 48 hours. Red hake is also a summer spawner, and spotted hake spawns in winter.	Russians fishing for Whiting during winter. Red hake trawled for during summer near shore and for industrial use offshore during winter. Spotted hake is a component of industrial fish catch.	
Sea herring (*Clupea harengus*)	Pelagic, schooling.	Not definitely known.	Spawns in deeper waters offshore in fall. Demersal eggs hatch in about 22 days at 45°F.	Taken during late winter and spring in rivers and estuaries by pound nets, haul seines and gill nets.	Underexploited by U.S. fishermen. Communist fishermen catch large numbers offshore.

PRECEDING PAGE BLANK-NOT FILMED

SPECIES	HABITAT	MOVEMENTS	BIOLOGY	FISHERY	MISCELLANEOUS
Alewives ***(Alosa pseudoharengus A. aestivalis)***	Pelagic, schooling.	Young spends first summer in rivers and migrates seaward in autumn. Adults enter rivers in spring to spawn, return to sea immediately and migrate northward toward Gulf of Maine. Returns to offshore river areas in fall.	Spawns in rivers from April through June when water reaches 50-60°F. Eggs hatch in about 6 days. ***(A. pseudoharengus) A. aestivalis*** spawns in brackish water of 70°F. Eggs hatch in about 50 hours. Young enter estuaries until autumn, then migrate offshore.	As above.	
Shad ***(Alosa sapidissima A. mediocris)***	Pelagic, schooling	As above.	Spawns in late spring in rivers and streams. Eggs hatch in 7 days at 60°F. ***(A. sapidissima) A. mediocris*** appears to be entirely marine. No data on spawning.	As above	Pollution and overfishing have reduced this fishery
Kingfish ***(Menticirrhus saxatilis)***	Pelagic.	Few data available on movements.	Spawns in summer. Pelagic eggs hatch in about 2 days at 68°F.	Caught commercially by trawlers, haul seines, pound nets and gill nets. Largest catch during winter & early spring. Sought by sports fishermen from shore & piers.	Fishery has been declining in recent years
Menhaden ***(Brevoortia tyrannus)***	Pelagic, schooling.	Migrates northward along coast in spring, southward during autumn.	Spawns at sea & in larger estuarine areas from May to October. Eggs hatch in two days at 72°F. Larvae move into estuaries and remain 6-8 months. In September or October most return to sea.	Fishing is by purse seine for this once valuable industrial species. After several years of declining catches to north, fishery now centers off North Carolina from Nov-Jan. Smaller catches in Chesapeake Bay and ocean waters to north from May through October.	
Porgy or scup ***(Stenotomus chrysops)***	Demersal.	Winters mainly in offshore waters in southern part of area. Migrates northwestward in spring toward shallower water. Reverses direction in autumn.	Spawns in late spring during third year of life. Eggs hatch in about 40 hours at 72°F	Taken by trawls in winter offshore of Maryland & Virginia. Fishery moves inshore in summer. Trawling off North Carolina in spring. Pound nets & sports fishermen also take a percentage of the catch	Fishery has been declining slightly.
Sea bass ***(Centropristes striatus)***	Demersal	No data available on movements	Spawns from May to July offshore. Eggs are nonadhesive and buoyant. Young inhabit shallow bays.	Taken in deep waters during winter by trawling and to a lesser extent by fish pots	Fishery declining recently

SPECIES	HABITAT	MOVEMENTS	BIOLOGY	FISHERY	MISCELLANEOUS
Mullet (*Mugil cephalus M. curema*)	Mostly pelagic	Moves offshore for spawning	Spawns offshore in late summer Larvae move inshore to mature	Caught throughout year with haul seines gill nets and pound nets highest landings during September and October off North Carolina	
Spanish mackerel (*Scomberomorus maculatus*)	Pelagic, schooling	Concentrates off east coast of Florida in winter, in late March and April begins to expand northward along Atlantic coast reaching New York waters by July Return migration begins in September and October	Spawning occurs off middle Atlantic coast in late spring and early summer Eggs are pelagic and hatch in about 25 hours at 77°F	Taken by haul seines from Atlantic beaches and in Pamlico Sound Remainder taken by pound nets and gill nets in Albemarle Sound Also caught by sports fishermen	
Atlantic mackerel (*Scomber scombrus*)	Pelagic, sometimes schooling	Migrates inshore in spring and offshore in autumn	Similar to above	Taken by gill nets 12 to 15 miles off Chincoteague Cape Charles region Some are taken by other trawls and a few in lower Chesapeake Bay pound nets	
Spot (*Leiostomus xanthurus*)	Mostly demersal	Offshore October through March Moves inshore in spring and remains there through summer	Spawns offshore from December through March Locations of eggs and larvae are unknown	Taken by haul seines trawls and gill nets with highest catches during late summer and autumn Much caught by sport fishermen	
Striped bass (*Morone saxatilis*)	Mostly pelagic	Congregates in deep pools in Chesapeake Bay and North Carolina sounds during winter Ascends rivers to spawn during March through July then to deeper nearshore waters to feed summer & autumn Some fish make northward migrations along coast in spring & summer to New England returning in autumn	Spawns during May in fresh or mildly brackish water Water must be active to keep eggs afloat Eggs hatch in 3 days at 58°F	Taken by gill nets pound nets & haul seines Trawling conducted near Outer Banks Peak landings Nov through April in North Carolina & March & April in Md & Va Heavily fished by sport fishermen	
Tuna, Yellowfin (*Thunnus albacares*) Bluefin (*T. thynnus*)	Pelagic schooling	Stocks appear during late winter, migrate north eastward in spring, southward through and out of area in fall	Spawns south of area Little else known of oceanic biology	Growing U S fishery east of Cape Hatteras Fishing is by longlines Japanese also exploiting this resource	
Swordfish (*Xiphias gladius*)	Pelagic	Not known	Spawns from February to April well offshore and possibly south of the area	Little U S exploitation at present due to high mercury tissue content	

SPECIES	HABITAT	MOVEMENTS	BIOLOGY	FISHERY	MISCELLANEOUS
Swellfish or puffer (***Sphaeroides maculatus***)	Demersal, buries in sandy bottoms	Little studied, some movement toward shallow waters in spring and back to deeper waters in autumn	Spawns inshore in early summer. Eggs hatch in about 4-5 days	Fished in Chesapeake Bay by pots, pound nets and haul seines. Also in shallow coastal waters by seines and otter trawls	
Weakfish (***Cynoscion regalis***) Spotted seatrout (***Cynoscion nebulosus***)	Pelagic	Adult fish move toward inshore waters in March and April. In May they move to deeper waters apparently to spawn but then increase in abundance again in shallower water from June through August. In fall they move offshore to slightly deeper waters	Spawns may to September. Eggs free floating and hatch in about 36 hours	Taken with pound nets from lower Chesapeake Bay and by trawl just south of Cape Hatteras during the winter. Gill nets and seines are also used	
INVERTEBRATES					
Clams Hard (***Venus mercenaria***) Soft (***Mya arenaria***) Surf (***Spisula solidissima***)	Benthic	N A	Clams spawn from late spring to early summer. Within one to two weeks the swimming larvae settle and attach to bottom, later to become buried. Clams grow most rapidly during their first two years	Taken by hand and with forks, hoes, tongs, rakes, and escalator dredges in shallow waters, and by hydraulic dredges in deeper waters	
Blue crab (***Callinectes sapidus***)	Benthic	See biology	Spawns in summer in lower Chesapeake Bay. Young move up the bay and various estuaries until winter. The following spring migration continues and mating occurs in brackish water. Females & some males then move back down the bay	Hard crabs are taken commercially with pots and trot lines during spring through fall. Amateurs frequently use dip nets, a gear also used along with scrapes and fyke nets to catch soft crabs. Dredges & trawls used in winter in deeper waters	Spring and summer molting or shedding of old exoskeletons to allow increased growth of new ones, results in much sought after soft crab form
Lobster (***Homarus americanus***)	Benthic	Some migration toward shallower waters during spring and summer, reversed in autumn	Little known on biology of offshore populations. Shallow water lobsters mate in the summer. Females retain sperm and produce eggs the following summer with hatching occurring a year later	Some taken by pots, most by otter trawls on offshore grounds	

N A   Not Applicable

SPECIES	HABITAT	MOVEMENTS	BIOLOGY	FISHERY	MISCELLANEOUS
Oyster (***Crassostrea virginica***)	Benthic larvae pelagic	N A	Spawn in early summer Larvae spat are free swimming or drifters for about two weeks then settle & cement to a firm object on bottom Reach market size in two to five years depending on latitude water temperatures and length of growing season	Taken in shallow brackish waters with tongs and with dredges the latter gear sometimes towed by skipjack sailboats	Industry plagued with predators such as drills and disease MSX Production has declined in recent years
Scallops Bay (***Pecten spp.***) Sea (***Placopecten magellanicus***) Calico (***Pecten gibbus***)	Benthic	N A	Bay scallop spawns during summer only once as one year olds Little is known of biology of other scallops	Taken by hand rakes scoop nets and chiefly by dredge Extensive calico scallop resource recently found in deep waters of southern part of area and farther south	
Shrimp White (***Penaeus setiferus***) Brown (***Penaeus aztecus***)	Benthic pelagic when migrating	Some large white shrimp migrate toward central Florida in fall returning northward in spring	Spawn in outside waters near coast from spring to autumn Larvae are swept by tides and currents into estuaries and marshland nursery grounds The growing young gradually move out to deeper waters	Trawlers working Pamlico Sound and coastal grounds south of Cape Hatteras obtain the bulk of the catch	

N A Not Applicable

APPENDIX E.

ORGANISMS REPRESENTATIVE OF EACH MAJOR TROPHIC LEVEL IN THE HAMPTON ROADS/NORFOLK OPERATING AREA

ESTUARINE

A1 Phytoplankton

diatoms *Chaetoceros decipiens*
C. didymus
C. affinis
C. eibenii
C. rostratus
C. densus
C. peruvianus
C. compressus
Skeletonema costatum
Rhizosolenia fragillissima
R. stolterfothii
Cerataulina bergonii
dinoflagellates *Peridinium triquetrum*
Peridinium depressum
Ceratium furca
Massartia rotundata

A2 Herbivorous plankton

copepods *Acartia tonsa*
Centropages typicus
Eurytemora hirundoides
Sparacalanus parvus
Pseudodiaptomus coronatus
Temora longicornis
Corycaeus americanus
crab zoea
mysid *Neomysis americana*
amphipod *Gammarus fasciatus*

A3 Carnivores

medusae *Nemopsis bachei*
Blackfordia virginica
Crysaora quinquecirrha
ctenophore *Mnemiopsis leidyi*
chaetognaths *Sagitta elegans*
Sagitta enflata
larvae of fish *Micropogon undulatus*
Anchoa mitchilli
alewife *Alosa pseudoharengus*
striped bass *Morone saxatilus*
blue fish *Pomatomus saltratrix*

A4 Algae

blue-green *Calothrix crustacea*
greens *Ulva lactuca*
Codium decorticatum
Enteromorpha intestinalis
browns *Fucus vesiculosus*
Sargassum filipendula
Ectocarpus tomentosus

reds *Gracilaria confervoides*
Hypnea musciformis
Gelidium crinale
Chondria tenuissima
Polysiphonia harveyi

A5 Attached phanerogams (grasses, reeds, weeds, etc.)
Spartina alterniflora
Spartina patens
Thallassia testudinum
Juncus roemarianus
Distichlis specata
Zizania aquatica
Polygonum spp.
Nuphar advena

A6 Grazers
snails *Nassarius obsoletus*
Littorina irrorata
Melampus bidentatus
Detracia floridana
mullet *Mugil cephalus*
mummichog *Fundulus heteroclitus*

A7 Filter-feeders
barnacle *Balanus improvisus*
hydroid *Sertularia* sp.
jingle shell *Anomia simplex*
tunicate *Molgula manhattensis*
oyster *Crassostrea virginica*
mussel *Mytilus edulis*
bryozoan *Biflustra tenuis*
clams *Mya arenaria*
Macoma balthica
scallop *Argopecten irradians*

A8 Detritus-feeders
blue crab *Callinectes sapidus*
nemertean *Zygonemertes virescens*
polychaetes *Lepidonotus squamatus*
Harmothoe aculeata
Nereis limbata
Arabella opalina
amphipod *Corophium cylindricum*
shrimp *Crago septemspinosus*
seastar *Asterias forbesi*

INTERTIDAL

B1 Algae
blue-green *Lyngbya semiplena*
greens *Entreromorpha intestinalis*
Ulva lactuca
Cladophora flexuosa
Bryopsis plumosa
browns *Ectocarpus confervoides*
Ascophyllum nodosum
Fucus vesiculosus
Sargassum natans
reds *Porphyra umbilicalis*
Gracilaria verrucosa
Ceramium strictum
Polysiphonia subtillissima

B2 Grazers
snail *Littorina littorea*
nudibranchs *Hermaea dendritica*
Acanthodoris pilosa
Aeolidia papillosa
crab *Libinia emarginata*

B3 Filter-feeders
sponge *Microciona prolifera*
barnacle *Balanus trigonus*
mussel *Mytilus edulis*
mussel *Lithophaga bisulcata*
bryozoan *Bugula neritina*
tubeworm *Hydroides hexagonus*
tunicate *Styela plicata*
oyster *Ostrea equestris*
mole crab *Emerita talpoida*

B4 Detritus-feeders
sipunculid *Parasipidosiphon parvulus*
nemerteans *Zygeupholia rubens*
Cerebratulus lacteus
amphipod *Gammarus* spp.
polychaetes *Glycera americana*
Syllis gracilis
Nereis occidentalis
blue crab *Callinectes sapidus*

NERITIC

C1 Phytoplankton

diatoms *Skeletonema costatum*
Chaetoceros affinis
Chaetoceros compressus
Cerataulina bergonii
Chilomonas sp.
Cryptomonas sp.
Rhizosolenia alata
flagellates *Massartia rotundata*
Peridinium triquetrum
Gyrodinium aureum
Gymnodinium sp.
Pyramimonas sp.
coccolithophores *Coccolithus huxleyi*
Gephyrocapsa oceanica

C2 Herbivores

pteropods *Limacina retroversa*
Limacina inflata
Limacina trochiformis
Creseis virgula conica
copepods *Centropages typicus*
Paracalanus parvus
Pseudocalanus minutus
Labidocera aestiva
Eucalanus pileatus-subcrassus
numerous *invertebrate larvae*

C3 Carnivores

chaetognaths *Sagitta serratodentata*
Sagitta elegans
Sagitta hispida
squid *Loligo pealii*
ctenophore *Pleurobrachia pileus*
Beroe ovata
herring *Clupea harengus*
menhaden *Brevoortia tyrannus*

LITTORAL

C4 Filter-feeders
scallops *Placopecten magellanicus*
Argopecten irradians
Argopecten gibbus
clam *Arctica islandica*
barnacle *Balanus amphitrite*
tubeworms *Pomatoceros caeruleus*
Sabellaria floridensis
southern quahog *Mercenaria campechiensis*
northern quahog *Mercenaria mercenaria*
quill worm *Hyalinoecia artifex*
surf clam *Spisula solidissima*

C5 Detritus-feeders
crabs *Cancer irroratus*, *C. borealis*, *Munida valida*
gastropod *Polystira* sp.
hermit crabs *Catapagurus sharreri*, *Pagurus annulipes*
shrimp *Crangon septemspinosa*
snail *Nassarius trivittatus*
shrimps *Penaeus setiferus*, *P. aztecus*
lobster *Homarus americanus*

flounder *Paralichthys dentatus*
horseshoe crab *Limulus polyphemus*

C6 Predators
seastars *Asterias forbesi*
Astropecten americanus
Astropecten articulatus
porgy *Stenotomus chrysops*
butterfish *Poronotus triacanthus*
crab *Cancer borealis*
whiting *Menticirrhus americanus*
tautog *Tautoga onitis*

OCEANIC

D1 Phytoplankton

coccolithophores _Coccolithus huxleyi_
Cyclococcolithus leptoporus
Katodinium rotundatum

D2 Herbivores

pteropods _Limacina inflata_
Limacina trochiformis
Creseis virgula conica
chaetognaths _Sagitta hexaptera_
Sagitta lyra
Sagitta helenae
Krohnitta subtilis

D3 Carnivores

tuna _Thunnus thynnus_
sailfish _Istiophorus americanus_
marlin _Makaira nigricans_
dolphin _Coryphaena hippurus_
mackerel _Scomberomorus maculatus_
sunfish _Mola mola_
medusae _Cyanea_ spp.
several myctophids, including _Ceratoscopelus materensis_

CONTINENTAL SLOPE

E1 Demersal scavengers

eel, *Nematonurus* sp.
hake *Merluccius bilinearis*
cusk *Brosme brosme*
white hake *Urophycis tenuis*
sea robin *Prionotus carolinus*

E2 Filter-feeders

sponge *Hyalonema boreale*
sea pen *Pennatula aculeata*
sponge *Euplectella suberea*
coral *Anthomastus grandiflorus*
coral *Flabellum goodei*
cucumber *Pseudostichopus villosus*

E3 Detritus-feeders

quill worm *Hyalinoecia artifex*
hermit crab *Parapagurus pilosimanus*
echinoids *Phormosoma placenta*
Plexechinus hirsutus
ophiuroids *Bathypectinura heros*
Ophiomusium lymani
Ophiocantha simulans

SLOPE BASE/ABYSSAL PLAIN

F1 Demersal scavengers

several groups of fishes Macrurids
Morids
Brotulids
Zoarcids
Liparids
Rajids, etc.
cephalopods

F2 Filter-feeders

sponge *Euplectella suberea*
soft coral *Anthomastus grandiflorus*
sea pen *Umbellula lindahli*
holothuroids *Euphronides depressa*
Pseudostichopus villosus
Pelopatides gigantea

F3 Detritus-feeders

decapods *Nematocarcinus ensiferus*
Munnidopsis spp.
Glyphocrangon aculeatus
Parapagurus pilosimanus
ophiuroids *Amphiophiura bullata*
Bathypectinura heros
Ophiomusium lymani
Ophiocantha simulans
echinoids *Phormosoma placenta*
Plexechinus hirsutus
asteroid *Benthopecten spinosus*

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (6) NOO SP-250	2. GOVT ACCESSION NO. AD-A085006	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MARINE ENVIRONMENTAL PLANNING GUIDE FOR THE HAMPTON ROADS/NORFOLK OPERATING AREA.		5. TYPE OF REPORT & PERIOD COVERED (9) Final rept. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Robert G. Beauchamp Editor		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Oceanographic Office Washington, D.C. 20373		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Oceanographic Office	(11)	12. REPORT DATE May 1974 13. NUMBER OF PAGES 272
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	(12) 274	15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(14) NOO-SP-250

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hampton Roads/Norfolk Operating Area
Oceanography - Physical, Biological, Geological
Pollution
Dredge Spoil Dispersion
Bottom Transport

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Surface materials in the Hampton Roads/Norfolk Naval Operating Area will be moved offshore into the Gulf Stream by wind-induced surface flow during 10 months of the year. This flow is reversed during September and October and carries these materials toward the coast - more rapidly as distance to shore decreases

A model using an ellipse technique predicts dispersion directions of surface or suspended material in the Area. The ellipses

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20.
are closely related to the surface currents and are elongated in the direction of prevailing flow.

A second model, to predict the dispersion of dredge spoil or other deposits over the seabed, is postulated. Orbital and forward drift velocities are sufficient during autumn, winter, and spring to erode and transport sediment, such as dredge spoil, on the Continental Shelf. Bottom transport in the Area is predominantly toward the coast regardless of the season. Surface subsurface, and bottom currents probably will least affect introduced pollutants seaward of the Continental Shelf and north of 36°30'N. Any stresses that reduce the biomass of autotrophs or cause a loss in their production efficiency will decrease the productivity of the entire ecosystem.