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Coastal and Offshore Environmental Inventory

Cape Hatteras to Nantucket Shoals

Complement Volume

Marine Experiment Station
Graduate School of Oceanography

University of Rhode Island
Marine Publication Series

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Publication Note

The two volumes published as "Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals" have been photographed directly from typescript. The purpose has been to publish the work as quickly as possible in order to provide current information to the people who need it. The present volume, like its predecessor, was produced from start to finish in less than one year. Authorship, review and other technical support has been provided by 25-30 people connected with the University of Rhode Island Graduate School of Oceanography and various other departments within the university, the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology.

Many timely manuscripts which are subjected to the costly process of rigid editorial standard and typeset composition become outdated before they come into print. These volumes have been edited, with this consideration foremost, to a satisfactory level of completeness and comprehensibility though minor inconsistencies of editorial detail persist.

Introduction

General Introduction to Complement Volume

The objective of this complement volume was the same as that of the first study, "Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals". Qualified authorities have been assigned to survey the present state of knowledge in certain marine and related science areas not covered in the initial study.

This volume was also funded by contracts between the American Petroleum Institute and the University of Rhode Island and individual authors of the chapters. The Subcommittee on Fish, Wildlife and Conservation of the Environmental Task Force, Committee on Exploration of the American Petroleum Institute organized these studies in meetings with members of the staff and faculty of the Graduate School of Oceanography, University of Rhode Island. Saul B. Saila, Professor of Oceanography and Director, Marine Experiment Station, was the program coordinator. Elaine Y. Pratt served as managing editor.

Chapters in the first volume include the following subject areas: physical oceanography, chemical oceanography, phytoplankton, zooplankton, benthic fauna, fisheries, marine mammals and birds. Contents of the present volume include chapters on coastal vegetation, marine geology, offshore weather and climate and coastal zone utilization. An introductory section includes chapter summaries and an introduction to environmental quality problems. Examples of environmental and organismal changes are given with possible causes to suggest the complex nature of problems related to environmental quality.

Synopses

Coastal Vegetation

The Atlantic Coast from Cape Hatteras to Cape Cod comprises parts of two physiographic provinces. The Coastal Plain (specifically the embayed section) is represented by the coastline northeast to New York, Long Island and Cape Cod. The New England province is represented by the coastline of Connecticut, Rhode Island and a small portion of Massachusetts. Physiographic characteristics of these areas are described.

Three major forest regions have been identified in the study area: the southeastern evergreen forest region south of Chesapeake Bay, the oak - pine forest region from the Chesapeake Bay area to Sandy Hook, New Jersey, and the oak - chestnut forest region covering Long Island and the coast of New England. Characteristics of these regions and their plant communities are discussed as background for a more specific treatment of coastal zone communities.

Major sections of this chapter deal with a discussion of the available information on the natural plant communities, and their dynamics and distribution, as they exist on the fringe of coast which is influenced in some way by saline water. The first section deals primarily with flowering plants which occur on dunes, around lagoons and border the upland regional forest communities. The following section deals with marine benthic macroalgae which inhabit the inter-tidal regions of the coast.

In those areas where the coast consists of sandy beaches, with and without lagoons behind them, the general community pattern is: dune grasses, dune grasses and shrubs, and then shrubs which are bounded either by a lagoon with its associated tidal marsh or by an upland forest. In these areas marine benthic algae are rare and usually found associated with man-made structures such as a break-water, bridge or buoy.

In those areas, where rocky shores occur (primarily in the New England physiographic province and the north shore of Long Island), the general community pattern, going from submerged to upland, is: subtidal algal zone, subtidal fringe algal zone, midtidal algal zone, supratidal fringe algal zone, supratidal algal zone, tide pools, lichens on bare rocks, shrubs, upland forest.

Some attempt has been made to show effects of man on natural plant communities.

Marine Geology

The Middle Atlantic Bight coastline is dominated by large estuaries (most prominent being Delaware Bay and Chesapeake Bay), barrier islands and coastal marshes which form in the quiet estuarine and barrier island lagoon environments. Most barrier islands are actively migrating both along the shore and landward, but in at least some areas a portion of the islands may be relict or partly relict.

The Middle Atlantic continental shelf and slope are characterized by relatively low average gradients, 03' to 07' and 2^{o} to 7^{o}, respectively. Shelf morphology is dominated by sand ridge and swales in the nearshore, transverse channels extending across the shelf, and a series of submerged terraces. The latter two features are relicts of low strands of the sea during Pleistocene glaciations, while many of the sand ridges are modern or are relict features which have been modified by modern processes.

Although the continental slope is less well-studied than the shelf, the morphology appears to be more varied than previously envisioned. Gradients range from less than 1^{o} to near vertical

outcrops. The continental slope is cut by numerous canyons and gullies. These erosional features are prime avenues for the transport of land-derived sediment to the deep sea.

The continental margin began accreting behind a major ridge formed during the initial rifting of the continents, probably during the late Paleozoic. Maximum accumulation has occurred along the Baltimore Canyon Trough - Georges Bank Trough axis, where 8 to 12 km of sediment have been deposited. Continental margin sedimentation during the Mesozoic was primarily upward, but once the ridge was flooded by seaward-moving sediment (during late Mesozoic or early Tertiary) the sedimentation pattern shifted to outbuilding. In southern New England Cenozoic accumulation was primarily on the continental rise, while to the south it resulted in shelf and slope progradation.

Presently the continental margin appears to be tectonically quiet, although there are several trends of earthquake epicenters which would suggest structural trends normal to the shelf. These may be related to slight activity along old fracture zones.

Most of the shelf sediment is composed of relict sand. Modern sediments are accumulating in estuaries and lagoons, the nearshore and on the continental slope, while residual Coastal Plain sediments, reworked by Pleistocene glaciers, characterize Georges Bank and Nantucket Shoals.

The lack of modern sediment accumulation on the Middle Atlantic continental shelf is related to the small quantity of river sediment which presently enters the sea. That which does enter probably re-enters the estuaries and coastal marshes or by-passes the shelf and is deposited on the slope or deep sea. Therefore, although most of the shelf sediment is out of compositional equilibrium, it is apparently in quasi-textural equilibrium with the modern environment.

Offshore Weather and Climate

Regional climatic analyses of the offshore weather and climate in the Middle Atlantic Bight reveal pronounced spatial and temporal variations in the basic elements of air temperature, relative humidity, visibility, sky cover, precipitation, fog, wind direction and wind speed. Extra-tropical storm development and intensification is significant in this area, particularly during the winter half-year. Tropical storms, although not numerous and highly variable in number from year-to-year, have been observed from June to very early November.

The location of the Gulf Stream in the southern section of the study area has profound influence on the weather and climate. Heat-budget assessment demonstrates that most of the heat supplied by this

current is shown to be used in evaporation. Short-period fluctuations in the position of the northern margin of the Gulf Stream are illustrated.

Bay ice is common along the immediate coastal area, especially during February. Iceberg sightings in the offshore area are extremely rare and none have been observed during recent years.

Coastal Zone Utilization

The coastal zone of the Middle Atlantic Bight has already been called upon to accommodate a wide range of uses attendant on human activity, including recreation, industry, transportation, waste disposal, agriculture, commerce and housing. The North Atlantic Region (NAR), which extends beyond the study area to Maine, encompasses all of the Middle Atlantic Bight with the exception of the northern third of North Carolina. This region (NAR) represents about 5 percent of the nation's land area, 65 percent of its people, and 33 percent of its gross national product. The North Atlantic Regional Water Resources Study was used as a primary source of material for this chapter because it encompassed much of the region of interest.

Any consideration of the utilization of the coastal zone should take into account man's past and present interaction with the ecosystems of the coastal zone. To date, man's thinking with reference to coastal zone utilization has involved economic, political, and to a lesser extent, legal considerations, with very little regard for the ecology of the environment. This statement is reinforced by the descriptions of coastal zone use presented in this chapter.

An attempt is made to develop a comprehensive picture of coastal zone utilization in the study area by describing economic, demographic and land-use patterns as well as by specific statistical information by category of use for appropriate sub-regions of the study area.

The picture of coastal zone utilization which results from this analysis clearly suggests that comprehensive coastal zone planning and management is required. This planning and management must be applied at a regional, and not a local or even state level in order to be most effective. These activities should be oriented toward maintaining and improving the usefulness of the coastal zone to man for now and for the future. They include such things as the development of a coherent system of coastal uses, a system of human inputs related to these uses and an input-output framework tying these perspectives together.

Selected Examples of Environmental and Organismal Changes in the Middle Atlantic Region with Possible Causes

Coastal ocean and estuarine areas are dynamic environments. Most of the easily observed changes in these environments take place under abnormal conditions, such as during severe storms. These storms can raise the normal sea level considerably, and storm surges can cause serious flooding of coastal areas. Such storm effects are localized or occasional in their occurrence, but they may cause serious and long-term changes in the coast affected, and changes in important biota may be demonstrated.

Coastal erosion seems to be facilitated by a rising sea level and can often be explained by conditions other than severe storms. In general, coastal erosion frequently occurs when more material than the waves bring into an area is moved along shore. This erosion is especially likely when the source of supply of beach material is cut off by a head-land or breakwater. Sometimes the sea brings more sediment into an area than it removes. Long swells, due to distant storms, are effective in building up wide beaches under some conditions.

Coastal estuaries in temperate regions are subjected to tidal action, fresh water inflow and marked seasonal temperature changes. Estuarine biota must be adapted to the variable inorganic salt content of the estuary as well as to its marked temperature variations.

Odum and Copeland (1969) have classified the coastal systems of the United States into five broad categories which include: (1) naturally-stressed systems of wide latitudinal range; (2) natural tropical systems of high diversity; (3) natural temperate systems with strong seasonal programming; (4) natural arctic systems with ice stress; and (5) emerging new systems connected to man's activities. The following classification of natural temperate ecosystems with seasonal programming is taken from Odum and Copeland (1969).

Name of type	Characteristic energy source or stress
Tide pools	Spray in rocks, winter cold
Bird and mammal islands	Bird and mammal colonies
Land locked seawaters	Little tide, no migrations
Marshes	Lightly tidal regimes and winter cold
Oyster reefs	Current and tide
Worm and clam flats	Waves and current, intermittent flow
Benthic vegetation	Light and current
Oligohaline systems	Salt water shock zone, winter cold
Medium salinity plankton estuary	Mixing intermediate salinities with some stratification
Sheltered and stratified estuary	Geomorphological isolation by sill
Kelp beds	Swells, light and high salinity
Neutral embayment and shore waters	Shelfwaters at shore

A principle which has been stated by Copeland (1970) is that those systems already subjected to energy-requiring stresses are more likely to resist the changes than those (such as tropical systems) adapted to relatively constant environments. He also points out that there is a differential response to various disturbances which is related to the dominant structure of the system.

The Middle Atlantic Bight is affected by changes induced from a variety of causes. Some examples of natural and man-made phenomena which have affected organisms and/or their environment in the coastal and shelf regions of the study area and its vicinity are listed. Many organisms and communities are not stable in their numerical abundance or diversity. Fluctuations in numbers seem to be common. Some are related to man's activities - others apparently are not. The examples suggest a fairly high degree of resilience of many forms to substantial environmental perturbations, and also a relatively rapid recovery rate in several cases. It is also suggested that recovery from catastrophic events of short duration seems more likely and rapid than recovery from the effects of chronic environmental disturbances. Chronic disturbance effects are, however, more difficult to assess.

Changes of Natural Origin

Hurricanes: The effects of one hurricane (Hurricane Agnes) have been recently documented (Anderson, 1973). A brief summary of its effects will illustrate the kinds and degree of environmental and organismal effects that can be expected from hurricanes. The following material is abbreviated from the study prepared by the Chesapeake Bay Research Council cited above. Hurricane floods dumped record amounts of sediments into Chesapeake Bay. These effects are not fully known at

present but were believed significant to sedentary organisms.

The low salinities brought on by the hurricane killed large amounts of oysters. More than one-half of the Potomac River marketable oysters were reported dead. Oyster reproduction apparently failed completely in 1972. The economic loss to Maryland and Virginia for oysters alone was approximately 12 million dollars on an exvessel basis. Many oyster drills were also killed. Low salinities also killed most of Chesapeake Bay's soft-shelled clams, accounting for an estimated 4 million dollar loss. Losses of hard clams in Virginia were high but no economic value has yet been estimated. Finfish apparently suffered little damage, but sport fishing declined due to the displacement of some species from their usual habitats. Wildlife on Chesapeake Bay was apparently little affected.

Temperature change effects: The tilefish Lopholatilus chamaeleonticeps is found near the bottom on the continental shelf edge from Nova Scotia to the vicinity of Delaware. It has a very narrow depth range of about 45-100 fathoms. The thermal range to which this fish is usually exposed is also very narrow - about 47-53°F.

In the early summer of 1882 a severe kill of tilefish occurred, apparently due to a temporary chilling of the water (Bigelow and Schroeder, 1953). An estimated one and one-half billion tilefish were killed at this time. The species was rare for several years but apparently recovered to nearly previous levels in about 15 years. A kill of this magnitude of tilefish has not occurred since this time.

A disappearance of juvenile croaker, Micropogon undulatus, was found to be associated with unusually low water temperatures in nursery areas in lower Chesapeake Bay (Massmann and Pacheco, 1960). The evidence suggested that extreme low temperatures were responsible.

Disease: The haplosporidian Minchinia nelsoni (MSX) is one of the most important parasites of the American oyster Crassostrea virginica. It has a reported range from North Carolina to Connecticut (Sindermann and Rosenfield, 1969). However, it has more recently been reported from Massachusetts waters (Krantz et al., 1972). This organism has caused severe losses to oysters in Delaware Bay and lower Chesapeake Bay as well as in some other areas. In a six week period in April-May 1957 35-85 percent of all planted oysters were wiped out (Galtsoff, 1964). The total extent of oyster losses due to this organism in the Middle Atlantic region are difficult to evaluate due to the somewhat irregular distribution of affected areas and variability in the degree of infection.

A disease of eelgrass (Zostera marina) called wasting disease

diminished standing crops of eelgrass by about 90 percent in the eastern United States and western Europe in 1933 and 1934. Recovery was virtually complete by the early 1940's as indicated by Addy and Aylward (1944). Labyrinthula, a protozoan, is believed to be the major etiological agent of wasting disease. Stauffer (1937) compared animal communities in typical eelgrass areas with areas where eelgrass disappeared. An approximately one-third decrease in characteristic species resulted in the area having no eelgrass. Zostera is an important food for brant and geese as well as being an attachment surface for diverse invertebrates. The ecological significance of the loss of eelgrass in infected areas is not completely known but is believed to be high.

Activities of Man

In addition to natural phenomena causing changes in the quality of the environment in coastal ocean and estuarine areas, discharges, spills and other activities of man alter the environment and affect the stability and diversity of biological communities. Some of these man induced disturbances include dredging and filling, bulkheading, various forms of domestic and industrial pollutants, thermal loading and impoundment. The effects of these disturbances depend on their location, duration and intensity. It is not easy to assign quantitative values to them in spite of the fact that a reasonable amount of effort has already been spent in attempting to do this. In general it is apparent that man, in his quest to manage the coastal ocean and estuarine systems of the Middle Atlantic Bight, must take into account the ecological system, the type of disturbance, the response and its recurrence patterns before this can be accomplished.

American shad: The decline in the catch of American shad Alosa sapidissima since about the turn of the 20th century to approximately one-fourth its previous level has been variously attributed to pollution, overfishing and dams which blocked spawning runs, primarily in the Middle Atlantic Bight. Regardless of which cause is dominant, each has been man-induced, taken together they account for a substantial reduction in the shad catch amounting to approximately 35 million pounds per year. Available evidence suggests that the shad fishery will respond to proper management techniques, which include reintroductions and the provision of suitable access to spawning areas. Cronin (1967) has summarized the effect of dams and barriers on anadromous species.

Pollution: The magnitude of the pollution problem in terms of sources, transformations and effects on the biota and the environment is too extensive to be considered here. The subject's complexity involves knowledge of physical oceanography, biological oceanography, chemical oceanography and several other technical disciplines. The purpose of this brief section is merely to note a few salient aspects of the environment, to relate these to pollution problems, and to list some

information concerning pollution effects on fish and marine invertebrate resources with special emphasis on the Middle Atlantic Bight.

The broad and widely accepted definition of a pollutant is anything added to the marine environment causing a deviation from the mean geochemical composition and being in high enough concentration to adversely affect something man values. This definition is considered acceptable for the purposes at hand.

Pollution can be considered in the marine environment in three distinct phases (shown in Table 1). Phase I includes the source of the pollutant and its point of entry into the environment. Phase II lists some of the possible transportation and transformation characteristics imposed on a pollutant, and Phase III includes potential receivers and the final point of residence of the pollutant. The problem is clearly complex, compounded by the wide range of specific polluting materials and their interactions with each other and the local environment.

A dramatic example of pollution in the middle Atlantic area is the waste disposal activity in New York Bight. This has recently been documented in detail by Johnson (1970). Waste materials come from five major sources: a) ocean disposal of sewage sludge, construction materials, industrial wastes and dredge spoil; b) sewer outfalls; c) discharges of trash, bilge wastes and sewage from vessels; d) land runoff and river discharge; and e) accidental spills on land and sea (Horne, Mahler and Russello, 1971). The average annual dumping of solid wastes between 1944 and 1968 was about 9 million metric tons. Each day approximately 1.3 billion gallons of raw or partially treated sewage flows into rivers and to the Bight from the New York metropolitan area. The results of this amount of waste disposal include the creation of a relatively anoxic and unproductive area in the vicinity of the ocean dumping area near the mouth of the Hudson Channel.

In the New York area the condition of Raritan Bay provides a more specific example of pollution effects. This bay may have been producing 3 to 4 million pounds of oyster meats per year at one time according to McHugh et al. (1972). Oysters have been completely replaced by the more pollution-tolerant hard clam. The hard clam is, however, of little value to man today because it is considered unfit for human consumption in large areas of Raritan Bay due to various forms of contamination.

Ketchum (1970) has pointed out that man's influence is greatest in the estuarine areas, and it is here that marine pollution effects are probably felt the most. The following material corroborates Ketchum's statement. According to recently available fish kill data reported for 1971 (Anon., 1972) this was the first year when more fish (56.4 million) were killed by pollution in estuaries than in fresh

Table 1. Pollution in the Marine Environment

Phase I Sources and Emissions	Phase II Transportation and Transformations	Phase III Threats to Organisms and Environment
River Discharges	Tidal Actions	Survival and
Pipeline Discharges	Dispersion	Growth of Organisms
Dumping by Ship or Barge	Adsorption	Human Health
Dredging and Mining Wastes	Adsorption	Lost Economic Benefits
Accidental Discharges by Ships	Oxidation - Reduction	Lost Aesthetic Quality
Agricultural Run-off	Biodegradation	Reduced Community
Atmospheric Deposits and Discharges	Ocean Currents	Stability and Diversity

or oceanic waters. This represented 77 percent of the total number of fish reported killed in 1971. On a national basis municipal sewage systems were the major source of fish kills during that year. Over a longer time period the five major sources of pollution in rank order of importance have been: industrial operations, municipal operations, agriculture operations, other operations and transportation operations. These are listed in descending order of importance. Regrettably there has been an increasing rate of reported fish kills during the past decade and there is no inducation of a leveling off as yet. A breakdown of estuarine fish kills in the middle Atlantic region was not available from the fish kill study. However, the major estuarine fish kills reported in 1971 were from Florida and Texas bays.

Butler (1973) has concluded that detectable DDT residues have declined in both magnitude and number in several species of estuarine mollusks in recent years. DDT pollution in estuaries, as judged by the magnitude of residues in mollusks, peaked in 1968 and has declined markedly since 1970. Apparently the contribution of particulate DDT from primary sources such as agricultural runoff has declined significantly. Johnson (1968) has provided a fairly comprehensive review to that date of literature related to pesticides in fishes. The effects of pesticides on estuarine and coastal organisms are only incompletely known at present and deserve considerably more continued attention.

It is evident that thermo-electric production in the United States, including the middle Atlantic region, will increase in the future. Both fossil-fueled steam-electric stations and nuclear-fueled power plants are a source of thermal discharges into the estuarine and coastal environment. Instances of fish kills directly or indirectly attributed to heated water discharge have been reported. In addition, the magnitude and significance of impingement losses of organisms on power plant intake screens as well as losses by entrainment of organisms in the condenser discharge water are not yet well known. Further studies concerning these problems are highly desirable.

Hydrocarbons in the marine environment are derived from natural sources, from organisms, from submarine seeps and are introduced through man's activity. The toxicity of various oils and oil products is highly variable, depending upon a number of factors. Crude oil and oil products spilled in nature are altered by evaporation, dissolution and by bacterial and chemical attack.

A coordinated biological and chemical study of the long-term effects and fate of a coastal oil spill in West Falmouth, Massachusetts has been documented. The results of these studies have been summarized by Blumer (1973). This spill involved about 650 tons of #2 fuel oil. In addition to immediate effects of the spill on organisms, there apparently were some long-term effects which were associated with the

incorporation of oil into the sediments and the spread of oil laden sediments. Oil was also reported to be incorporated into certain bivalve mollusks. Additional studies by Dr. Allan Michael of the Marine Biological Laboratory at Woods Hole, Massachusetts are currently underway to determine how severe and long-term these reported effects have been.

In the James River from Richmond to Hopewell, Virginia, fish nursery grounds with diverse food webs have been reduced to more simplified forms (Wass and Wright, 1969). Tsai (1968) has also noted a reduction in fish species diversity below the effluent outfalls of the Patuxent River estuary in Maryland, with an increase in diversity further downstream. Wilhm and Dorris (1968) have noted reductions in benthic invertebrate diversity in streams receiving domestic oil and refinery effluents. Briggs and O'Connor (1971) have indicated a reduction in fish species diversity which was associated with unvegetated sandy areas, presumably related to sand mining.

Environmental modifications (salt marshes): Schmidt (1966) has stated that a total of more than 47,000 acres of marsh between Maine and Delaware were lost for various reasons since 1954. The major losses are due to dredging and filling. It has been recognized for some time that marshes are important contributors to the overall productivity of the nearshore coastal environment. The quantitative effects of this loss in terms of marsh dependent plants and animals is difficult to assess. It has been substantial, however.

In many estuaries the sources of much of the primary production are vascular plants, such as marsh grasses. These plants produce large amounts of tissue which is released into estuaries. This source of food decomposes and contributes to the production of the estuary. The importance of marsh areas as nursery and feeding grounds has been documented by McHugh (1967). According to Niering (1972), of the 800 million pounds of fishery products landed in New England in 1960, 500 million pounds were directly dependent upon tidal marshes.

Environmental modification (estuaries): For many years the lower Susquehanna River was considered the major area for striped bass reproduction in Chesapeake Bay. Available evidence now suggests (Dovel, 1971; Dovel and Edwards, 1971) that there has been a shift in the area of greatest egg abundance and in commercial fishing areas which have apparently resulted from environmental modifications, such as increased pollution and dredging. It has been reported (Anon., 1968) that 42,255 acres of shellfish grounds in Chesapeake Bay have been closed due to domestic sewage pollution. An additional 254,000 acres have been adversely affected for fin fish.

Exotic introductions: The alga Codium fragile was first reported in the northeast coast of the United States at Montauk Point, Long Island, New York by Bouck and Morgan (1957). Codium is a cold water marine

alga which appears to grow best in fall and winter. Codium fragile is presumed of Japanese origin according to Silva (1955). The spread of Codium to other areas in the middle Atlantic region has been relatively rapid. It has been reported from Cape Cod and from Rhode Island by Wood (1962) and more recently from New Jersey by Taylor (1967). Its spread to include much of the northern half of the middle Atlantic is anticipated. The exact mechanism for its transport is not known, but it is believed it could have been transported on the hulls of ships, since it is an attached form of alga. The ecological impact of this alga in areas where it is now found has not been fully assessed. However, it can damage the oyster yields by blanketing beds of oysters, and it has been found attached to living scallop shells, impeding their movements. It has also been observed to cover portions of mussel beds.

Eurasian watermilfoil, Myriophyllum spicatum is widely distributed in Europe, Asia and Africa. According to Cronin (1967) this aquatic plant has become a serious menace in Chesapeake Bay by blocking navigation, preventing boating and swimming, interfering with seafood harvesting, increasing siltation and increasing mosquito habitats. Approximately 100 thousand acres are infested. Eurasian watermilfoil thrives over a salinity range from 0-15 °/oo and apparently survives at depths less than 9 feet. Control involves chemical treatments.

Summation

The above-mentioned examples of changes in the quality of the environment and the communities associated with it clearly emphasize the importance of monitoring efforts in addition to the gathering of baseline information in order to properly assess the effects of specific man-made or natural phenomena. Monitoring, baseline studies and various levels of coastal, oceanic and estuarine research should be supported and accelerated in order to acquire the necessary background information. Of particular relevance are carefully planned and executed experiments designed to answer specific questions in a systematic manner. Only the outcomes of effective research programs will permit the force of intelligent management to bear on man's inevitably increasing role in coastal areas and estuarine processes.

S.B. Saila
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Coastal Vegetation

Vegetation of the Coastal Zone from Cape Hatteras to Cape Cod

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Coastal Vegetation

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General Geographic Features

The Atlantic coast of the United States stretches for 5,565 miles (Huxley, 1962) and frames the physiographic province called the Coastal Plain (Fenneman, 1938; Hunt, 1967). The northernmost part of the Coastal Plain has been designated the embayed section (Figure 9.1) because it is basically a coastline of submergence, with a great many sharply edged

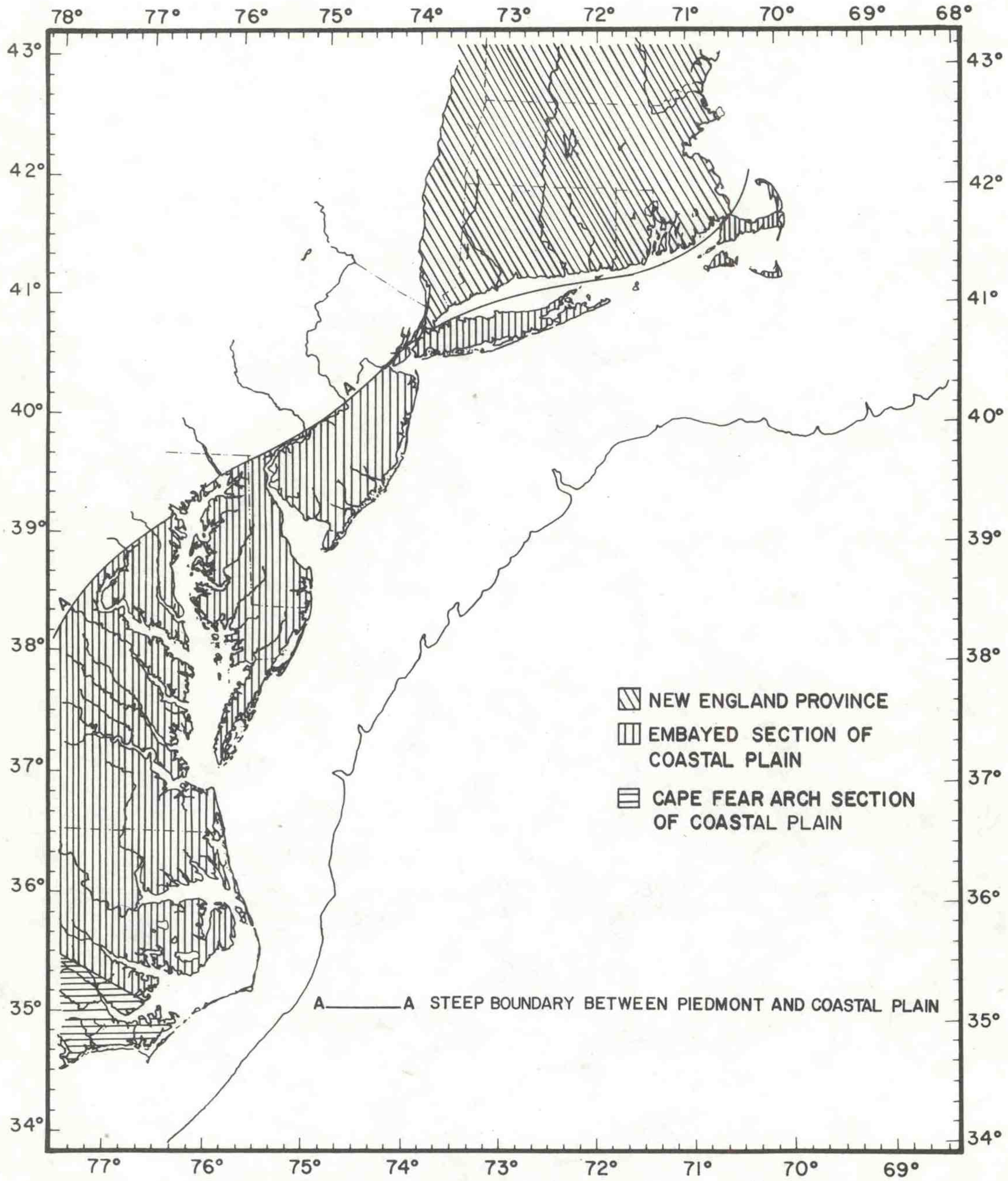


Figure 9.1 Physiographic provinces of the land area adjacent to the Mid-Atlantic Bight.

embayments, sand spits (e.g. Cape Cod, Sandy Hook) and barrier beaches backed by lagoons. Southward from the Carolina capes there are few large bays. Thus, the embayed section which is one of seven sections of the Coastal Plain (Hunt, 1967) extends from the southern edge of Pamlico Sound to Cape Cod and encompasses the approximate boundaries of this study.

The embayed section is so deeply indented by branching bays or estuaries that it is little more than a fringe of peninsulas which narrows northward, disappearing north of Long Island and appearing again from Buzzards Bay to Cape Cod.

Barrier beaches are a prominent part of the topography of this section due to the gentle slope of Atlantic plain.

Northeastward from New York, the sea covers the whole width of the coastal plain formations which are joined with the continental shelf and only the highest parts escape submergence. Long Island, Block Island, Martha's Vineyard, Nantucket Island and Cape Cod are the tops of ridges formed by coastal plain geologic formations and capped by glacial drift. The coastline from Long Island to Buzzards Bay is characteristic of the New England Province rather than the Coastal Plain Province because of this.

The New England Province portion of this coastline has been designated the seaboard lowland section. It is distinguished from the New England upland section, a broad plateau-like region, by its lower altitude and erosional history, but appears to be merely a sloping margin of the upland. The border is approximately 6 to 16 miles wide in Connecticut and western Rhode Island, but as the region grades into the eastern Massachusetts and Cape Cod area, it widens considerably.

The well known bays of the Atlantic coastline are Chesapeake Bay, Delaware Bay, and Narragansett Bay, with Chesapeake Bay being the largest embayment on the Atlantic coast. It is the submerged lower valley of the Susquehanna River and is 195 miles long and 3-30 miles wide. It is separated from the Atlantic Ocean by the Delmarva Peninsula and its mouth is 13 miles wide (between Cape Charles and Cape Henry). On the western side of the bay are the estuaries of the Patapsco (Baltimore's port), the Severn, the Patuxent, the Potomac, the Rappahannock, the York and the James Rivers. On the eastern side are the estuaries of the Elk, Chester, Choptank, Miles, Nanticoke, Northeast, Pocomoke, and Sassafras Rivers, with numerous inlets which lead to many shipping centers. Chief ports in the bay are Newport News, Norfolk, and Portsmouth in Virginia, and Baltimore, Maryland. Many islands along the eastern side shelter Pocomoke and Tangier Sounds (Huxley, 1962).

Delaware Bay is the submerged lower valley of the Delaware River. It is about 52 miles long and about 12 miles wide. Unlike Chesapeake Bay it is fairly even-sided with few inlets. Its major port city is Philadelphia and Delaware Bay is linked to Chesapeake Bay via the Chesapeake and Delaware Canal which connects the Elk River in Maryland with the Delaware River near the upper end of both bays.

Where the Coastal Plain meets the edge of the Piedmont north of the Rappahannock River in Virginia, there is a steep slope or escarpment known as the "fall line." In this area tidal waters extend inland to this fall line. South of the Rappahannock the boundary is not as distinct topographically; that is, there is a gentle rise in the Coastal Plain to the Piedmont plateau and tide waters are not able to extend inland as far as the Piedmont.

Narragansett Bay in Rhode Island is about 30 miles long and 3-12 miles wide. The major rivers which flow into this bay are the Seekonk and Taunton. Its major ports are Providence and Newport. A distinguishing characteristic of this bay is the large islands of Aquidneck, Prudence and Conanicut which cause the existence of three relatively narrow passageways.

Major offshore islands within the study area are situated off the coast of southern New England and are associated with glaciation of the last glacial period. The southern edge of the advancement of the ice sheet is marked by the line of islands from Staten Island to Nantucket. This glaciation is one of the major causes of the differences which exist between the northern and southern portions of the coastal plain.

Long Island (Huxley, 1962) is the largest of these islands, it is about 100 miles long and about 25 miles wide. The heavily populated boroughs of Brooklyn and Queens comprise the extreme western portion; the central and eastern part is more thinly populated. Long Island is relatively low in profile. Two ridges (moraines), which run the length of the island, and bluffs on the north, provide the only relief to its topography. Along the northern coast there are many bays and harbors, mainly in the western section. These are barred from each other by moderately high forested peninsulas (necks). The southern shore is framed along 75 miles of its length by barrier beaches enclosing large sheltered lagoons (e.g., Jamaica, Great South, Moriches, and Shinnicock). The well-known barrier beaches are Coney Island (30,000,000 people per summer), Long Beach, Jones Beach, and Fire Island (40 miles long).

In close proximity to Long Island are Manhattan and Staten Islands. Manhattan is 25 miles long and 12.5 miles wide and completely urbanized. Staten Island which is 14 miles long and 7 miles wide, is mainly a somewhat thinly populated residential area.

The islands off the coast of Rhode Island and Massachusetts (e.g., Block Island, Martha's Vineyard, Nantucket Island and associated smaller islands) are thinly populated residential areas with some fishing ports on each.

General Forest Regions

Three general forest regions extend along the coast from Cape Hatteras to Cape Cod (Figure 9.2): the northern sector of the Southeastern Evergreen Forest Region extends as far as the James River (southern edge of Chesapeake Bay), the oak-pine forest region extends along the coast from the eastern shore of Chesapeake Bay to Sandy Hook, New Jersey, and the oak-chestnut forest region from Sandy Hook, across Long Island and southern New England to Cape Cod (Braun, 1964).

The Southeastern Evergreen Forest Region

This region is essentially confined to the Coastal Plain south of the James River. The vegetation of this region is in part warm temperate-subtropical, in part distinctively coastal plain, and in part temperate deciduous. It is made up of a variety of widely different forest communities. The coniferous, mixed coniferous and deciduous hardwood, and mixed coniferous and broad-leafed evergreen hardwood communities are interrupted here and there by swamps, bogs and prairies.

In this region the Coastal Plain is marked by a series of terraces of Pleistocene age, successively younger toward the coast, now generally considered to be also Pleistocene in age. The upper, older ones are much dissected, but the younger ones are still comparatively smooth.

Interstream areas are flatter and more poorly drained on the younger (outer) terraces, stream bottoms are broader, and slopes limited to the immediate vicinity of bottom. Here the evergreen shrub-bogs ("bays" or "pocosins"), the cypress swamps and cedar bogs, the savannahs and flat woods are extensively developed on the flat interstream areas; and cypress and bottomland hardwood forests occur along the river ways. Sand hills, old dunes associated with ancient shorelines, are favorable for the development of xeric pine communities. Coastal dunes, beaches, tidal estuaries, and lagoons, have their own characteristics favoring distinct vegetation types.

Generally the forest community types of the southeastern evergreen forest region include: *Pinus palustris*[1] forests, *Pinus taeda* forests, *Pinus elliottii* forests, *Pinus-Quercus-Carya* forests, *Taxodium-Nyssa* swamps, and *Quercus virginiana* forests

[1]Scientific names used in this report have been updated wherever possible.

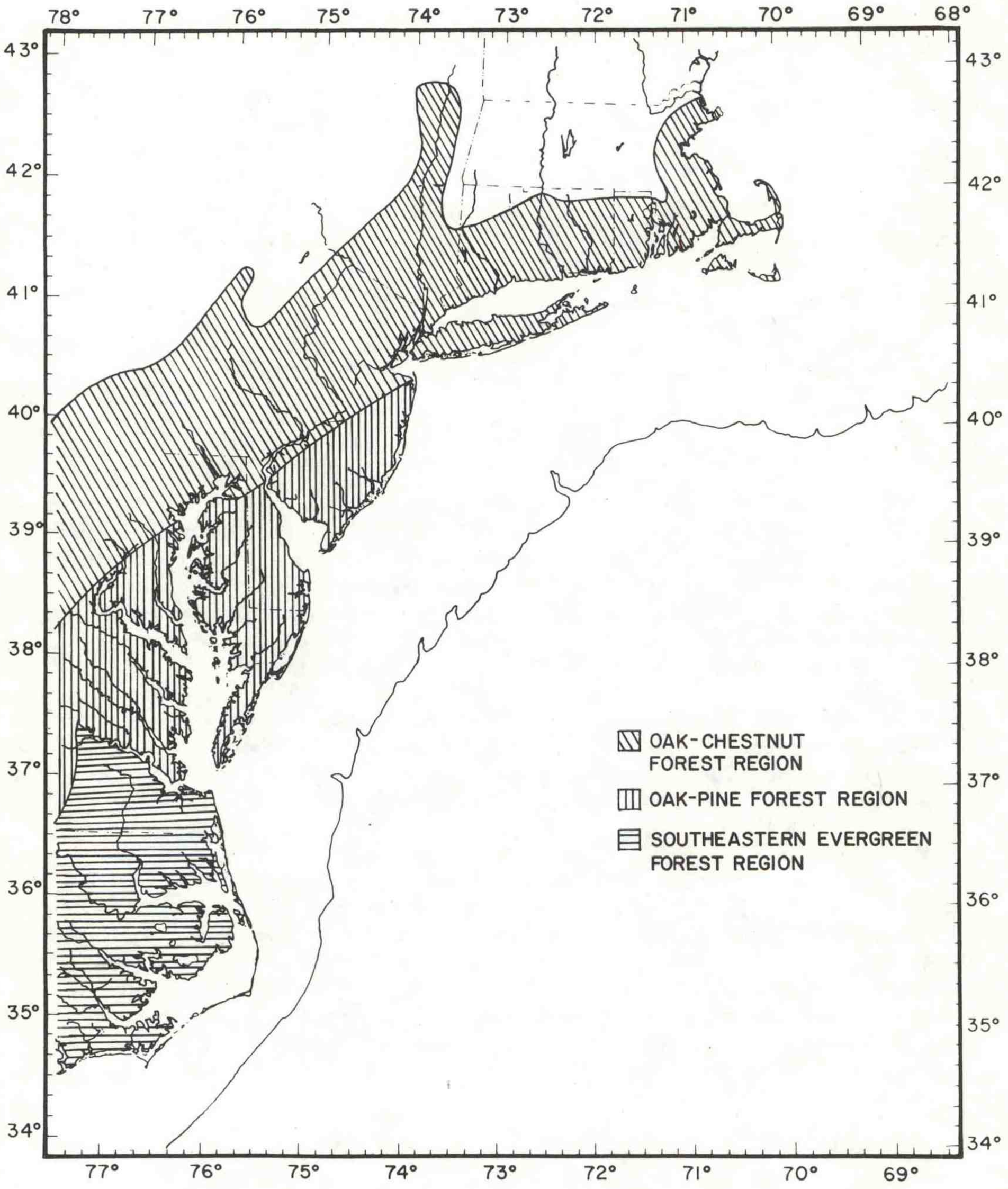


Figure 9.2 General forest regions of the land area adjacent to the Mid-Atlantic Bight.

The pines which dominate this region do so only as a result of extensive and frequent fires (natural in the past, they are now part of man's management of the area). Without periodic fires, oaks, hickories and other hardwoods soon come to dominate any community of the uplands of this region (Wells, 1928; Chapman, 1932; Garren, 1943).

Near the coast are the swamp forests and live oak forests. The most extensive swamps in this region are the Dismal Swamp (Kearney, 1901) and the Pamlico swamps. The characteristic species of the swamp forests along streams in the low flat coastal plain are members of the genus Taxodium and the genus Nyssa.

Evergreen oak forests, in which Quercus virginiana is usually predominant occur in a narrow belt along the South Atlantic and Gulf coasts, in about the same general area as Pinus elliottii forests. Quercus virginiana var. geminata, and Q. myrtifolia - as well as - Pinus elliottii may be constituents of the coastal forests. Like the Pinus elliottii forest, the evergreen oak and oak-pine communities often occupy dunes on coastal islands where successional development may lead to the replacement of pine and pine-oak by evergreen oak. These species on the coastal dunes are tolerant of salt spray (Oosting, 1945; Oosting and Billings, 1942) and the evergreen oak forest is considered to be a "salt spray climax" (Wells, 1939, 1942; Wells and Skunk, 1938).

Quercus virginiana is generally a tree of the coast; it may be found, however, on alluvial soils somewhat more removed from the coast mixed with deciduous species and sometimes Magnolia grandiflora evergreen magnolia (Penfound and Howard, 1940).

The Oak - Pine Forest Region

The region (Figure 9.2) extends as a broad band from southern New Jersey southward to Georgia and then westward to the alluvial lands of Mississippi. Between the James River and the Potomac River, the region extends across the coastal plains of Virginia; north of the Potomac, it is confined to, but not coextensive with the coastal plain. There, the inner part of the Coastal Plain is occupied by the oak-chestnut forest region.

The oak-pine region is transitional between the central deciduous forest and the predominantly evergreen forests of the southeast. The amount of loblolly pine here affords a contrast with the central deciduous forest which has none and with the southeastern evergreen forest region which has many more pines. The boundary between the oak-pine and southeastern evergreen forests is chosen as the James River based upon floristic differences between the two sides. The latter contains a large number of characteristic species of the South Atlantic and Gulf Coastal Plain, whereas, Quercus virginiana and Pinus palustris, common members of the south-

eastern evergreen forest, are decidedly rare north of the James (Braun, 1964).

Pines are more or less temporary in the oak-pine forest region and are ultimately replaced by deciduous trees except on poorer soils or in drier sites. Common pines include Pinus taeda, Pinus echinata, Pinus virginiana and Pinus rigida.

Common deciduous trees of this area are: Quercus alba, Quercus velutina, Quercus stellata, Quercus rubra, Quercus falcata, Carya glabra, Oxydendrum arboreum and Liquidambar styraciflua.

The Chesapeake Bay area is the prominent physiographic feature of the oak-pine forest region. Both upland and lowland forests are well represented in the area, on both the eastern and western shores of Maryland (Shreve, et al., 1910). The upland forests of drained or sloping areas resemble those of the Piedmont farther south. Pinus taeda, in pure stands or mixed with Pinus virginiana or with deciduous trees, is the most abundant tree in secondary forests on abandoned lands. On flat clay uplands, with poor drainage, Liquidambar styraciflua, Quercus phellos, Q. palustris and Nyssa sylvatica mingle with the usually more abundant Quercus alba. Upland swamp forest communities, which are poorly represented or absent in the Piedmont, occur in the oak-pine forest region on both clay and sandy soils. Those on clay are not sharply delimited from mixed pine-deciduous communities of the drier clay uplands; the deciduous species are more abundant and the scrub pine absent. Upland swamp forests in sandy soils may be predominantly coniferous or broad-leaved; the latter are developmentally older. Trees usually present are Quercus phellos, Q. alba, Q. nigra, Q. prinus, Liquidambar styraciflua, Acer rubrum, Nyssa sylvatica, Magnolia virginiana, Ilex opaca, and Cornus florida. Throughout the sandy areas of the uplands, cutting and clearing have greatly increased the amount of pine. Sterrett (1908) states that originally there was very little pine in the "mixed pine and hardwood region" of southern Delaware, and that the same types of forest prevailed as in the hardwood belt of the Coastal Plain to the north.

Lowland forests vary in physiognomy and composition in relation to degree of overflow and permanence of abundant water. Both hardwood swamps and cypress swamps may be distinguished. The lowland hardwood forest communities frequently contain an admixture of Pinus taeda and sometimes Chamaecyparis thyoides. Liquidambar styraciflua is almost everywhere the most abundant species; Acer rubrum, Quercus phellos, Q. palustris and Nyssa sylvatica are the usual associates, and in areas seldom reached by high water, Liriodendron tulipifera and Fagus grandifolia may occur. The cypress swamps, or "river swamps" (Shreve et al., 1910) occupy lands adjacent to but upstream from the brackish marshes.

Cypress swamps are at their northern limit in the oak-pine forest region. They are northern outliers of a community more typical of the southeast. The Pocomoke River Swamp, toward the southern end of the eastern shore of Maryland, and the well-known Dismal Swamp of North Carolina are characteristic of this type of forest. They are dominated by Taxodium distichum, Nyssa sylvatica var. biflora, and Acer rubrum. Nearly pure stands of Chamaecyparis thyoides occur near the upland borders of the cypress swamp where the soil is peaty; in less peaty areas, the lowland hardwood forest forms a transition to the upland forest. Here are oaks, chiefly Quercus nigra, Q. phellos, Q. michauxii, Q. alba, with which are associated Liriodendron tulipifera, Betula nigra, Fagus grandifolia and occasional trees of the upland forest (Beaven and Oosting, 1939).

Pine barrens occupy the greater part of the coastal plain of New Jersey. Topographically, this is an area of low relief through which flow sluggish streams in shallow valleys. The soils are sandy, in places gravelly, and generally strongly podzolized (i.e., the upper soil has been strongly leached). It is separated from the coast by a band of tidal marsh and coastal strand and dunes, behind which is a broken strip of oak woods four to five miles in width (Braun, 1964). Principle species include Pinus rigida, Quercus stellata, Q. marilandica and Q. ilicifolia.

The Oak - Chestnut Forest Region

In the coastal zone, only one section of this forest region occurs and that is the glaciated section (Figure 9.2). The southern boundary of this section is the southern boundary of the area known to foresters as "central hardwoods" or as "sprout hardwoods", because of the abundance of reproduction by this method. The section thus extends a short distance south of the glacial boundary in New Jersey and eastern Pennsylvania. It extends northward in the Hudson River Valley to the vicinity of Albany, and eastward across southern New England.

The limits of this section bear little relation to physiographic boundaries except on the west. The section includes parts of four physiographic provinces: Coastal Plain (Long Island and extreme southeastern Massachusetts and the older Cretaceous surface in New Jersey); Piedmont (extreme eastern Pennsylvania and northern New Jersey); Ridge and Valley Province (the Hudson-Champlain section from Pennsylvania to north of the Mohawk River); New England Province (southern part of New England upland, including New Jersey and Hudson highlands, and the southern end of seaboard lowland in Massachusetts and Rhode Island). The one unifying feature in the physiographic history of the greater part of the section is glaciation. Most of the area was covered by ice of the Wisconsin stage; smaller areas to the south of the Wisconsin terminal moraine in Pennsylvania and New Jersey were reached by Illinoian or by Jerseyan glaciation. The southern boundary of this vegetation section is fairly coincident with the southern limits of these early ice advances (Braun, 1964).

The forests of the glaciated section of the oak-chestnut region are mostly secondary communities. In appearance these are usually even-aged stands, in which some 25-30 species may be represented. The trees are mainly of sprout origin, the sprouts having originated after clean-cutting or fires, occasional trees from seed are included in the stands (Schwarz, 1907; Frothingham, 1912). The ability to sprout appears to be retained indefinitely; hence sprout woods may be one, two, or even three times removed from the old-growth stand from which they originated.

A number of unlike primary forest types (other than local, edaphic, and developmental communities) occur in the glaciated section: oak forests, oak-hickory forests, oak-chestnut forests, mixed mesophytic forests, and Tsuga canadensis-hardwoods forests. The Pinus rigida or pine-oak forest type of the sand plains is an edaphic community originally fairly extensive. The forest communities of undrained depressions, swamps of alluvial flats are developmental communities due to local edaphic conditions. Some of these, because of the persistence of the habitat, may sometimes be thought of as physiographic types (Bromley, 1935).

In the oak or oak-hickory forest types, Quercus alba is the most characteristic and usually most abundant species. This is a somewhat xeric forest type and has as associates Quercus velutina, Carya ovata, and Acer rubrum (Nichols, 1913, 1914; Raup, 1941).

Quercus prinus, Q. velutina and Q. rubra communities, or combinations of these, represent the former oak-chestnut forest type. Nowhere in this section is Castanea dentata (chestnut) presently a dominant or characteristic tree canopy species since it was decimated by the Chestnut Blight of the early 1900's.

Edaphic climax communities and developmental forest communities of Connecticut were discussed by Nichols in a series of papers (1913-20); communities of uplands, lowlands (including lakes and bogs), stream valleys and seacoast areas are included.

Chamaecyparis thyoides is the dominant tree of certain of these swamps or bogs. These occur from Massachusetts southward, and are well represented in Connecticut and on Long Island (Nichols, 1915; Bromley, 1935; Taylor, 1916).

Deciduous swamp forests occupy many of the glacially formed depressions; Acer rubrum, Ulmus americana, Quercus palustris, Q. Alba Nyssa sylvatica,and sometimes Liquidambar styraciflua are the principal species. These occur in mixed and almost pure stands, and sometimes in combinations with Chamaecyparis thyoides (Braun, 1964).

Pinus rigida is the dominant tree on sand plains of Connecticut, Rhode Island, and southeastern Massachusetts; and in the Hudson-Mohawk pine barrens between Albany and Schenectady.

A few rather unusual types of woodland (or groves) occur in the coastal belt of this section. A maple-holly forest covers the oldest dunes on Sandy Hook. This is a woodland of strikingly mesophytic aspect, made up of large trees of Ilex opaca, and Acer rubrum, together with occasional Juniperus virginiana, Prunus serotina and Celtis occidentalis, and a tangled understory overrun with vines (Chrysler, 1930). It is interpreted as a sand dune or salt spray climax leading from beach grass to shrubs to Juniperus virginiana and finally to Ilex opaca. A forest community in which I. opaca is a constituent also occurs near the east end of Long Island; here Fagus grandifolia and Acer rubrum are the principal species (Taylor, 1923) and on Fire Island. Diospyros virginiana forms a grove at Lighthouse Point near New Haven (Hawes and Hawley, 1909; Nichols, 1913). This is the northern outpost for this species. On the Elizabeth Islands of Massachusetts, pure stands of beech occur. "These trees grow nowhere very tall, averaging perhaps 30 to 40 feet and their low, flat, leafy crowns meet overhead, forming a thick roof through which a subdued light filters." (Fogg, 1930). Usually, however, a number of other species occur with the beech: Quercus alba, Q. velutina, Ostrya virginiana, Sassafras albidum, Acer rubrum, Nyssa sylvatica and Hamamelis virginiana.

TABLE 1. List of forest tree species, with their common names mentioned in the section on general forest regions.

Acer rubrum	red maple
Betula nigra	river birch
Castanea dentata	Chestnut
Carya glabra	pignut hickory
C. ovata	shagbark hickory
Celtis occidentalis	hackberry
Cornus florida	Flowering dogwood
Chamaecyparis thyoides	white cedar
Diospyros virginiana	persimmon
Fagus grandifolia	beech
Hamamelis virginiana	witch-hazel
Ilex opaca	American holly
Juniperus virginiana	red cedar
Liquidambar styraciflua	sweet gum
Liriodendron tulipifera	tulip-tree
Magnolia grandiflora	southern magnolia, evergreen magnolia
M. virginiana	sweet bay
Nyssa sylvatica	black gum, sour gum, tupelo
Ostrya virginiana	hop hornbeam
Oxydendrum arboreum	sourwood
Prunus serotina	wild black cherry
Quercus alba	white oak
Q. falcata	southern red oak
Q. ilicifolia	bear oak, scrub-black oak
Q. marilandica	black-jack oak
Q. michauxii	cow oak, swamp chestnut oak
Q. nigra	water oak
Q. palustris	pin oak, spanish oak
Q. phellos	willow oak
Q. prinus	chestnut oak
Q. rubra	red oak
Q. stellata	post oak
Q. velutina	black oak
Q. virginiana	live oak, evergreen oak
Pinus eschinata	short leaf pine
P. elliottii	slash pine
P. palustris	longleaf pine
P. rigida	pitch pine
P. taeda	loblolly pine
P. virginiana	Virginia pine
Sassafras albidum	sassafras
Taxodium distichum	bald cypress
Tsuga canadensis	hemlock
Ulmus americana	white elm

Coastal Zone Land-Plant Geography

North Carolina

Along most of the North Carolina coast from the Virginia border to just south of Cape Lookout, there extends a series of barrier islands called the Outer Banks (Figure 9.3) Behind the barrier islands lie large lagoons (Albemarle Sound, Pamlico Sound and associated smaller sounds), containing small islands, and the mainland shore.

The Outer Banks and islands within the lagoons have principally two vegetation types as cover, the dry dune communities and the tidal marsh communities. On the islands, the development and complexity of these two types depends, in large part, upon island size and the amount of human manipulation and exploitation.

Due to man's presence and to stabilization projects on the islands, two systems of geography and vegetation have developed. The unmodified islands (1), are best exemplified by the Core Banks. The stabilized islands (2), are exemplified by most of the islands from Ocracoke northward (Dolan et al., 1973) which have been modified by man for developmental purposes.

1. Unmodified Islands

The islands which have not been modified for stabilization purposes (Figure 9.4a) are characterized by having a wide (100-200m) beach on the ocean side of islands, behind which is a zone of low irregular dunes which are broken here and there by overwash breaches. The major plant species inhabiting these dune regions are Spartina patens and Uniola paniculata (see Table 5 for a list of species common to the coastal zone with these common names. In addition, on the natural dunes from Portsmouth Island south, just above the high-tide line Cakile edentula, Croton punctatus and Physalis maritima from a distinctive band of vegetation which is lacking on the manipulated dunes northward from Portsmouth (Burk, 1962).

Behind the foredunes are a series of overwash surfaces left by storms with elevation generally diminishing away from the dune and toward the sound. Plant distribution depends upon the elevation and degree of protection which is afforded a particular micro habitat. Generally vegetation density increases with distance from the crest of the foredune. In this region an herbaceous community and a shrub community are found, shrubs being in the more protected parts of the islands.

Besides Spartina patens and Uniola paniculata, the herbaceous community behind the dune includes the grasses: Andropogon scoparius var.

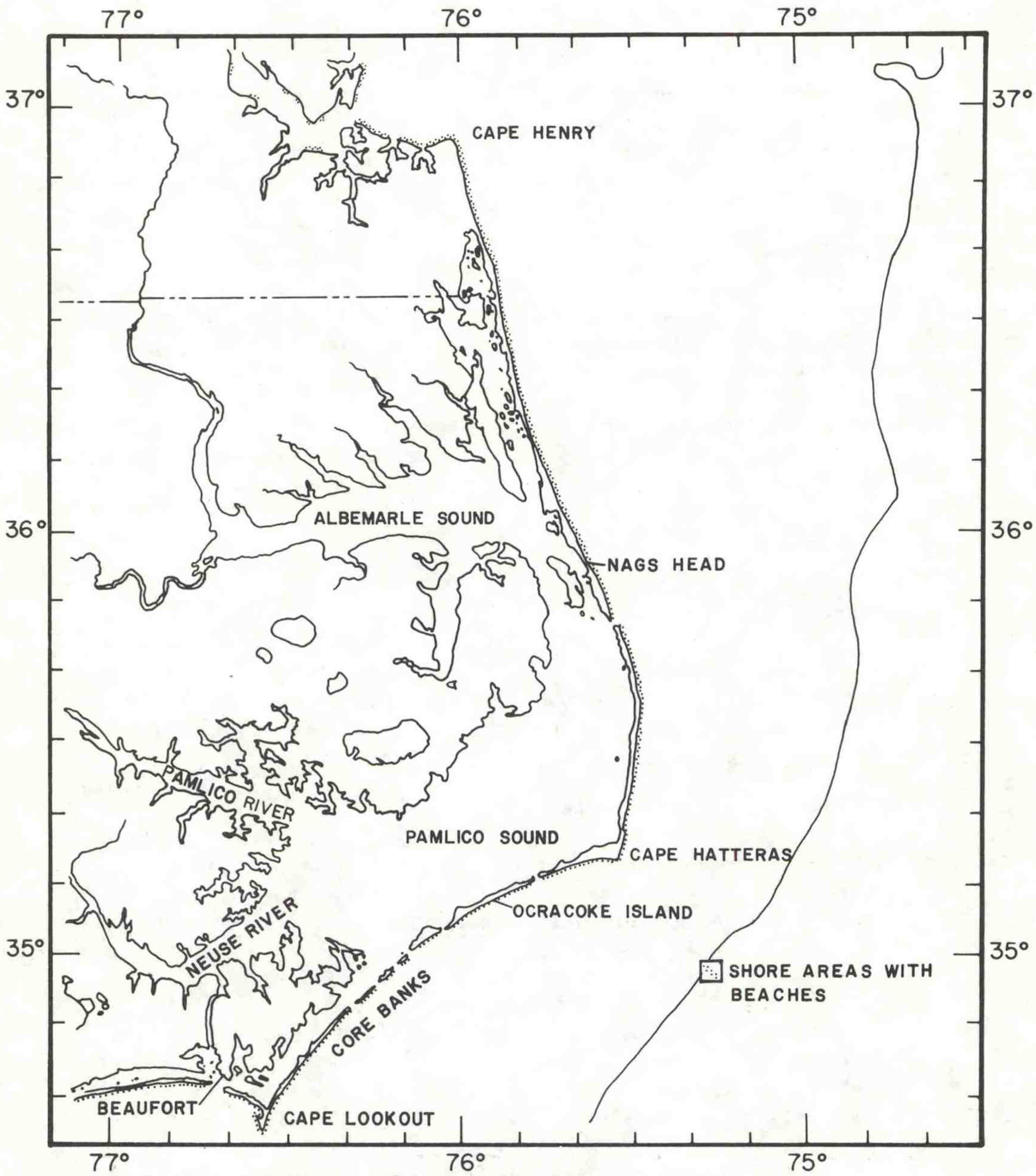


Figure 9.3 Coastal areas of North Carolina.

littoralis, Cenchrus spp., Eragrostis spectabilis, Muhlenbergia capillaris, and Triplasis purpurea and the forbs: Euphorbia polygonifolia, Oenothera humifusa, Hydrocotyle umbellata and Solidago sempervirens.

In those areas that are protected for long periods from overwash, thickets of Baccharis halmifolia, Myrica cerifera and Iva frutescens develop. On old dunes, or areas protected by dunes, the shrub thickets are much more fully developed and contain Ilex vomitoria, Juniperus virginiana and Quercus virginiana. The stems of the shrubs grow close together in a tangled mass and often vines of various species are found growing in and over these shrubs including Parthenocissus quinquefolia, Rhus radicans, Lonicera sempervirens, Smilax spp. and Vitis spp. (Burk, 1962).

Generally, then, on these relatively unmodified islands, there are found extensive beaches, low foredunes and increasingly thicker and taller vegetation with increasing distance from the foredune. Two other frequently occurring but localized situations should be mentioned. At times a rear dune forms which has vegetation on its crest like that of the foredune, but the protection of this second dune will allow the development of a maritime woodland dominated by Juniperus virginiana and Quercus virginiana (Oosting and Billings, 1942; Dolan et al., 1973). The other situation is the formation of ponds between dunes. In these areas the dominant plants tend to be Eleocharis spp., Juncus spp., Scirpus spp, Fimbristylis spp, Cladium jamaicensis, and Spartina cynosuroides (Burk, 1962).

2. Stabilized Islands

The islands that have been stabilized through human intervention take on a somewhat different appearance than those not so modified (Figure 9.4b). The beach area in most cases of "stabilization" has been reduced to less than 50 m and in some areas has all but disappeared, (Dolan et al., 1973). Behind this beach is a stabilized dune which is much higher in profile than on the unmodified islands. This leads to a loss of certain foredune species as reported above and also leads to a reduction in the amount of overwash to the back side of the island. The majority of these manipulated dunes are today dominated by Ammophila breviligulata. Although it is at its southern limit here, A. breviligulata has ideal sand stabilization properties and is therefore propagated in nursery beds and transplanted onto areas to be stabilized, and then maintained in luxuriant condition through fertilization. Uniola paniculata is also found on these foredunes but in much less abundance because it does not lend itself as well to large scale propagation and management.

These high artificial foredunes provide greater protection from sea storms, and the shrubs described above grow very readily and may produce large, impenetrable thickets. The National Park Service has initiated programs of irradication in some areas because of the extensiveness and growth of these shrub communities.

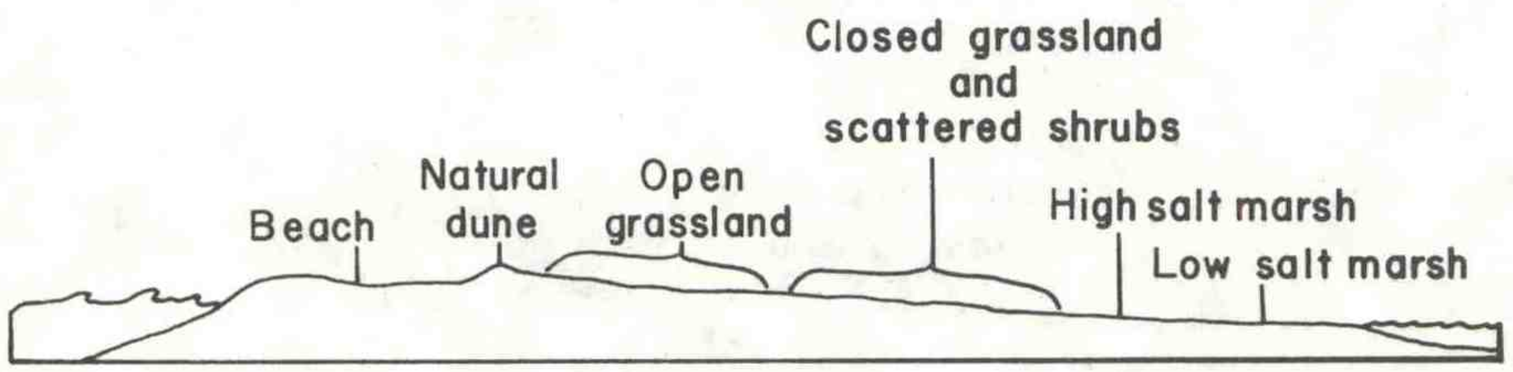


Figure 9.4a Cross section of a natural barrier beach (after Dolan et al., 1973).

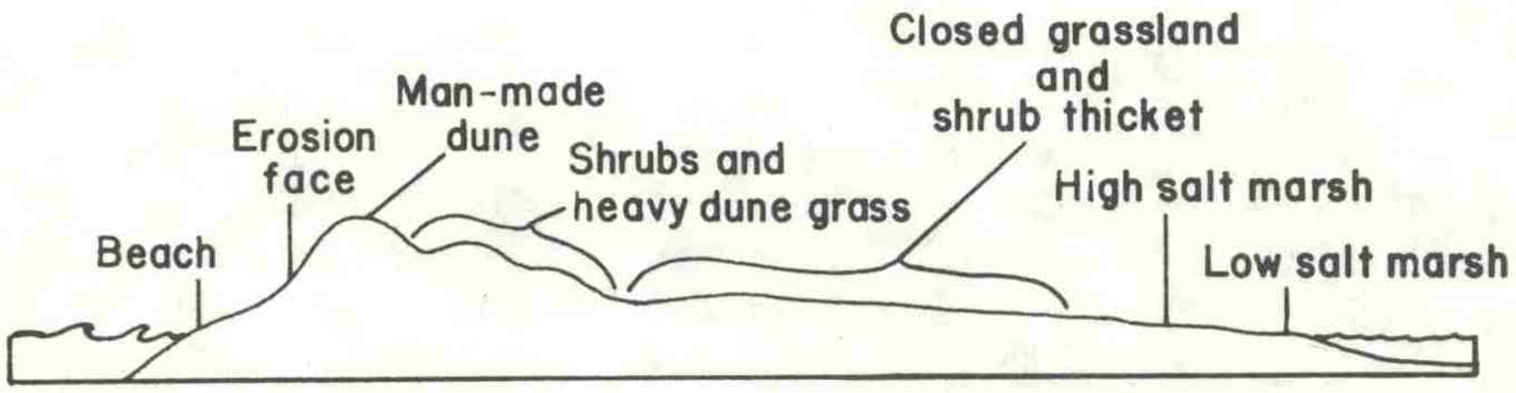


Figure 9.4b Cross section of a manipulated, stabilized barrier beach (after Dolan et al., 1973).

Tidal marshes occur on the landward sides of the barrier beaches, as a fringe to the small islands in the sound, and commonly along the mainland shore. The tides within the sounds, while present, are very uneven in their effects. Regular tidal pulses occur only in those areas adjacent to the inlets. The marshes, in response to this type of tidal activity show a mosaic pattern involving salt water marsh and fresh water marsh (Wells, 1928). Spartina alterniflora forms large stands in areas of high salinity, while Spartina patens tends to dominate areas of intermediate salinity and Juncus roemerianus dominates areas of low salinity on the tidal marshes (Burk, 1962; Adams, 1963).

These three most prominent tidal marsh species generally occur in adjacent colonies which at times may be very nearly pure stands and at other times rather mixed communities. Burk (1962) lists 34 species which may be associated with these on the tidal marsh. Nearby fresh water marshes are equally as complex, with 48 species (Burk, 1962), the dominant ones being Typha spp., Juncus spp, and Scirpus spp.

The mainland shore of the lagoons is low with many river marshes and swamps. The Pamlico River extending from Washington, North Carolina to Pamlico Sound (about 65 miles) is one fo the major rivers in this area. This estuary is wide and shallow with large expanses of Ruppia spp. and Potamogeton spp. beds in wide sandy areas along the shore. Wells (1928) describes this aquatic community as having ten species which are frequent, including Potamogeton spp., Nymphaea odorata, Callitriche heterophylla, and Zostera marina.

This coastal region has a vegetation mosaic (depending upon substrate, elevation and salinity) of tidal marsh communities, freshwater submerged communities, and freshwater marsh communities. Inland from these vegetation types are swamp forests and upland forests which were discussed in the general vegetation section.

Virginia to Delaware

Most of the coastal zone of Virginia, Maryland and Delaware occurs around Chesapeake and Delaware Bays, only a small amount of coastline is actually exposed to the Atlantic Ocean (Figure 9.5). Barrier islands protect much of the coast of Virginia and Maryland, but are not so well-developed in Delaware. In all three states, however, bays and lagoons extend far inland and these are usually surrounded by swamps, broken up by low-lying islands, and often connected by slowly flowing streams (Snow, 1902, 1913).

The predominant plant of the dunes north of Chesapeake Bay is Ammophila breviligulata; Uniola paniculata, a southern species, having

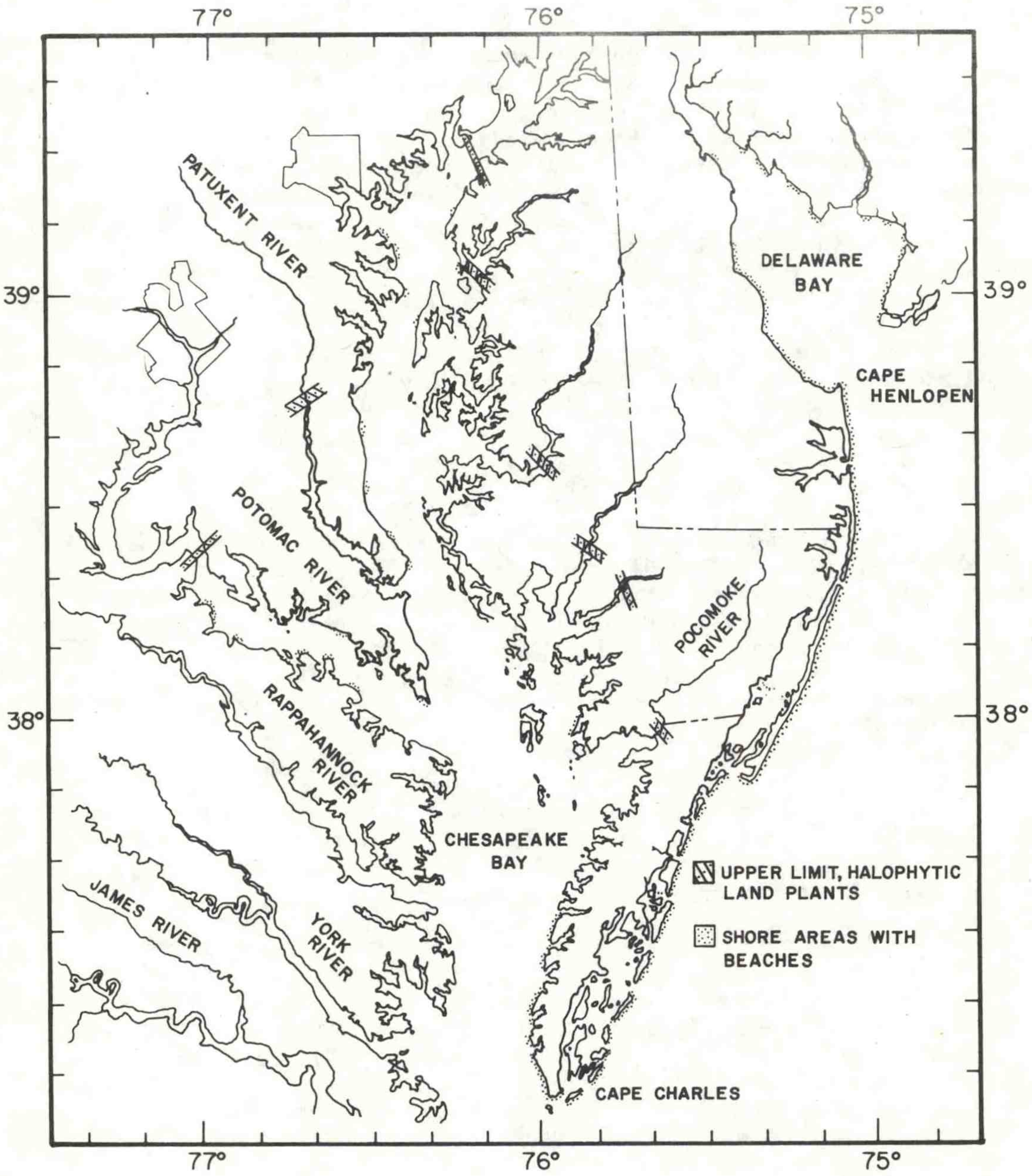


Figure 9.5 Coastal areas of Virginia, Maryland and Delaware.

been replaced almost totally. Associates of A. breviligulata in this region of the coastline include Hudsonia tomentosa, a northern species common north of Chesapeake Bay, Cakile edentula, Oenothera humifusa, Xanthium canadense, Salsola kali, Euphorbia polygonifolia, Polygonum glaucum, Panicum amarum, and Cenchrus spp. (Snow, 1902; Shreve et al., 1910).

Behind the herbaceous dune communities there exists a shrub community composed of such species as Lechea minor, Baptisia tinctoria, Myrica cerifera, Baccharis halimifolia, Rhus copallina, and Diospyros virginiana. In those areas best protected from tides and frequent storms a woodland community exists which generally includes Juniperus virginiana, Pinus rigida, Quercus falcata, Q. stellata, Diospyros virginiana and Celtis spp.

A marsh community is found on the landward sides of any barrier islands; around most bays, lagoons, and ponds; and lining the rivers. Since the shoreline of Chesapeake Bay and Delaware Bay is extensive, the amount of marshland is also extensive. The transition from tidal marshes to freshwater marshes can be seen along the open waters of the bays, and in passing up any of the rivers emptying into the bays. Because of the gentleness of the general slope of the land, the transition from tidal to freshwater marsh is very gradual and in most instances difficult to define.

Shreve et al., (1910) give an example of the type of plant community separation one would expect to find in traveling up one of the longer rivers of the eastern shore of Chesapeake Bay: (1) salt marsh abutting directly upon the upland forest, (2) tidal marsh backed by fresh water marsh, (3) fresh water marsh abutting the upland, (4) fresh-water marsh backed by stream swamp, (5) river swamp abutting the upland forest.

Narrow fringe marshes along the estuaries are composed simply of a zone of Spartina alterniflora with its few associated plants. Broader tidal marshes may have three zones with the zone nearest the salt water always being S. alterniflora, with which may be associated Salicornia spp., Spergularia marina, and Aster tenuifolius. Behind this is usually a zone of Spartina patens and lastly a zone of either Spartina patens and/or Distichlis spicata, accompanied by Aster tenuifolius, Aster subulatus, Juncus gerardi, and Gerardia maritima. At times there may also be grass-depressions in the marsh (pannes) which are bare or support Salicornia spp. (Shreve et al., 1910).

The freshwater marshes are floristically rich with Typha spp., Scirpus spp.,bulrushes, Carex spp.,Vernonia noveboracensis, Hibiscus moscheutos, Impatiens capensis, and Helenium autumnale. The swamp forest of the region is the typical Taxodium-Nyssa swamp which is discussed in the general vegetation section above.

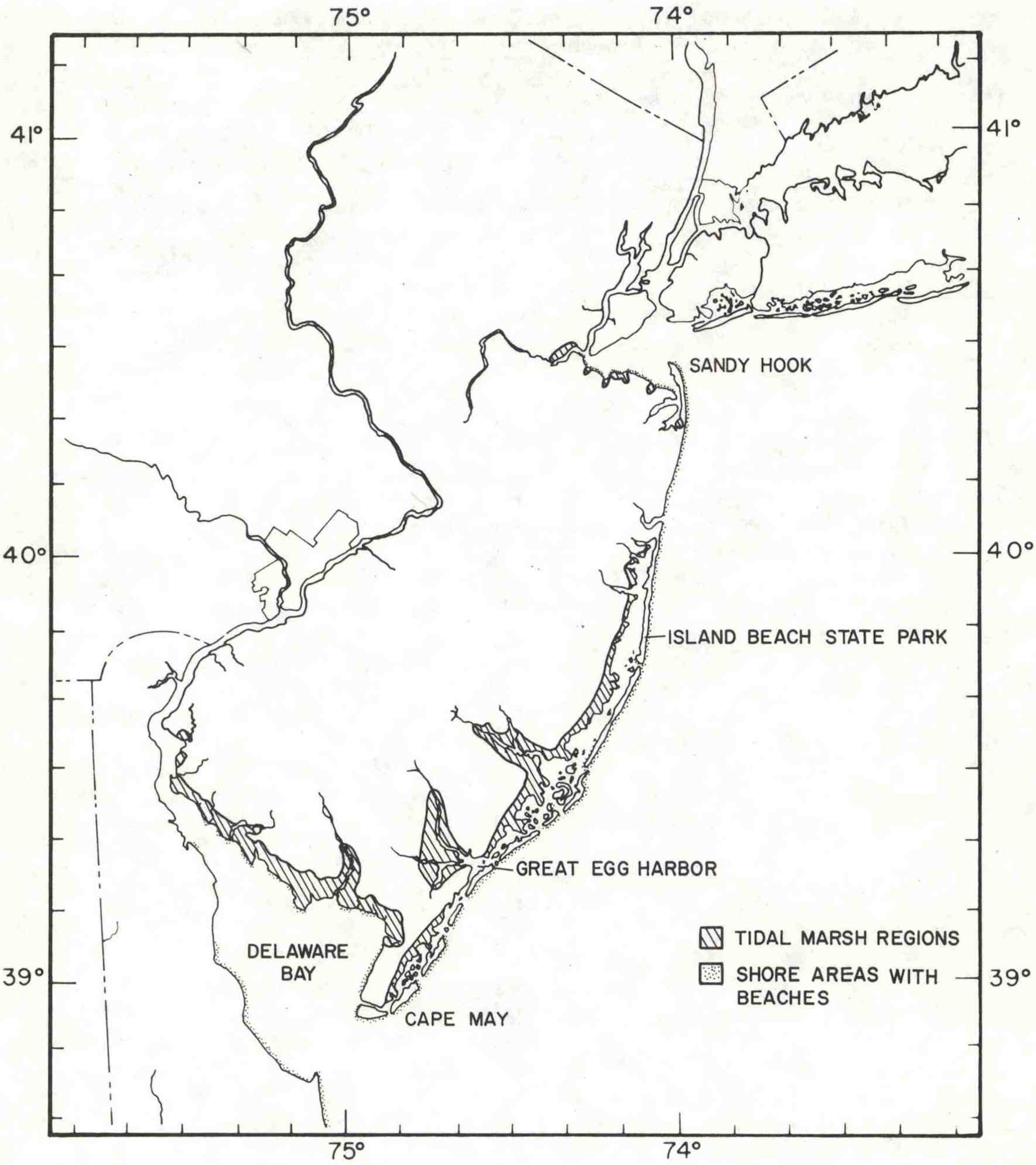


Figure 9.6 Coastal areas of New Jersey.

New Jersey

Harshberger (1900) has given a cursory description of the vegetation of the New Jersey barrier beaches (Figure 9.6). He lists the vegetation types as follows: beach formation, dune formation, thicket formation, marsh-dune formation, salt marsh formation, bay dune formation, bay beach formation and bay water formation.

The most abundant plant of the middle beach is Cakile edentula: its associates include Arenaria peploides, Salsola kali, Euphorbia polygonifolia, Cenchrus spp. Oenothera humifusa is found in the community of the upper beaches south of Great Egg Harbor (southern New Jersey is its northern limit). Other species which occur in this upper beach community are Gerardia maritima, Solidago sempervirons and Strophostyles helvola.

On the crest and lee side of dunes, the dominant plant is Ammophila breviligulata. The two most common associates of A. breviligulata in this community, which has a relatively low number of species, are Lathyrus japonicus and Solidago sempervirons. Just behind the grass community is a shrub community of Myrica cerifera, Baccharis halimifolia, Rhus copallina, Panicum virgatum and Strophostyles helvola.

What Harshberger (1900) calls a "dune complex" exists behind the foredunes which are described above. This complex, evident in most areas along the length of the New Jersey coast, develops on dune sides, valleys and hollows. Hudsonia tomentosa is a low growing dominant of this complex with herbs, Strophostyles helvola, Scirpus spp., Panicum virgatum, Gerardia maritima, Vaccinium spp., Rosa spp. and Rhus radicans; trees, Juniperus virginiana, Pinus rigida, Ilex opaca, Quercus phellos, and Q. ilicifolia.

A marsh community exists between dunes, where depressions intercept ground water. In such areas Ptilimnium capillaceum, Polygonum hydropiperoides, Hypericum spp., Teucrium canadense, Juncus spp., Panicum spp., and Spiranthes cernua are commonly found.

In areas of the barrier islands protected from wind and sea, thickets of shrubs and trees develop. In New Jersey the species commonly occurring in such thickets include: Juniperus virginiana (which sometimes forms a thicket by itself), Ilex opaca, Iva frutescens, Pinus, rigida, Rhus copallina, Diospyros virginiana, Vitis spp., Rhus radicans, and Prunus maritima.

On the lagoon side of the barrier islands of New Jersey, Harshberger (1900) found beaches, salt marshes and submerged salt-water communities.

Beaches on the bay side of the islands were found to be caused by westerly winds piling sand along the bay front. These beaches have a vegetative cover similar to the oceanside beaches. Where sand does not pile up in this manner, there usually exists a salt marsh community. Salt marsh plants of New Jersey include the three characteristic species of the Atlantic marshes (Spartina alterniflora, Spartina patens, and Juncus gerardi) as well as Limonium carolinianum, Salicornia spp., Spergularia marina, Juncus scirpoides, Distichlis spicata, and Sabatia stellaris. In shallow areas of the lagoons the submerged aquatics are Ruppia maritima and Zostera marina.

Martin (1959) in an intensive study of the most northern of the New Jersey barrier islands lists and maps 46 different communities (Table 2). Although this study was much more detailed than that by Harshberger, it draws the same general conclusions; except that the Phragmites communis community is shown by Martin to be important on the lagoon side of the island in the general mosaic of tidal marshes, brackish marshes and freshwater marshes. Table 3 gives a description of the major community types and their habitat ranges in Island Beach State Park.

Sandy Hook has been described as having 5 general community types (Chrysler, 1930). The tidal marshes occur on the inner or western side of the peninsula and are characterized by Spartina alterniflora, Suaeda maritima, Salicornia spp, and Limonium carolinianum. The middle beach areas support a vegetation composed of Spartina patens, Cakile edentula, Euphorbia polygonifolia, Salsola kali and Solidago sempervirons. The upper beach and young dune areas are characterized by having Ammophila breviligulata, Lathyras japonicus, Solidago sempervirons and Xanthium echinatum; Strophostyles helvola is unable to compete well here as it does further south.

The thickets and woodlands were the last two types to be described by Chrysler (1930). The shrub thickets occur on the middle, rolling portion of the peninsula and are characterized by Myrica cerifera with associates being Prunus maritima, Rhus copallina, Rhus radicans, Rosa spp. and Juniperus virginiana. Phragmites communis dominates wet areas Hudsonia tomentosa is dominant in more or less barren, sandy areas. On the oldest dunes, extending to the west and north of the shrub thickets, is a woodland of Acer rubrum, Ilex opaca, Juniperus virginiana, Prunus serotina and Celtis spp.

New York - Connecticut

The plant associations of central Long Island have been detailed by Conard (1935). The salt marsh areas which he described contained seven communities dominated by: (1) Spartina alterniflora, (2) Sali-

TABLE 2. Types of communities existing in Island Beach State Park, New Jersey (after Martin, 1959).

Herbaceous communities

1. Ammophila communities
2. Hudsonia communities
3. Phragmite communities
4. Fresh marsh communities
5. Brackish marsh communities
6. Tidal marsh communities
7. Vaccinium bog communities

Low thickets

8. Low thickets
9. Low xeric thickets
10. Low dune thickets
11. Low mesic thickets
12. Smilax thickets
13. Low marsh thickets
14. Low Baccharis thickets

High thickets

15. High thickets
16. High xeric thickets
17. High dune thickets
18. High mesic thickets
19. High Juniperus thickets
20. High Juniperus-Pinus thickets
21. High marsh thickets
22. High Juniperus-marsh thickets
23. Baccharis-Juniperus thickets

Herb

24. Ammophila - low T.M. (Thicket Mixtures)
25. Hudsonia - low T.M.
26. Hudsonia - high T.M.
27. Hudsonia - low dune T.M.
28. Hudsonia - high dune T.M.
29. Ammophila-Hudsonia - low T.M.
30. Phragmites - low shrub mixtures
31. Phragmites-Baccharis T.M.
32. Phragmites-Baccharis-Juniperus T.M.
33. Spartina-Baccharis-Juniperus savanna
34. Spartina-Baccharis savanna
35. Fresh marsh - marsh T.M.
36. Ammophila-Baccharis - marsh T.M.
37. Brackish marsh - marsh T.M.
38. Brackish marsh - Baccharis T.M.
39. Spartina - Iva savanna

Transitional Thickets

40. High to low mesic thickets
41. High to low xeric thickets
42. High to low dune thickets

Woodland

43. *Juniperus* woodland
44. *Pinus* woodland
45. *Juniperus*-*Pinus* woodland
46. Swampy *Juniperus* woodland

TABLE 3. The interrelation of topography and community types on Island Beach State Park, New Jersey (after Martin, 1959)

Community Types	Primary dunes		Secondary dunes			Bayshore	
	Foredunes	Backdunes	Foredunes	Hollows	Backdunes	Inner	Outer
Ammophila	———						
Hudsonia		———			———		
Fresh marsh				———		———	
Salt marsh							———
Low xeric thicket	———		———		———		
Low mesic thicket		———		———		———	
Spartina-Iva savanna							———
High mesic thicket				———			
Spartina-Boccharis-Juniperus savanna						———	
Juniperus woodland				———			
Pinus woodland				———			

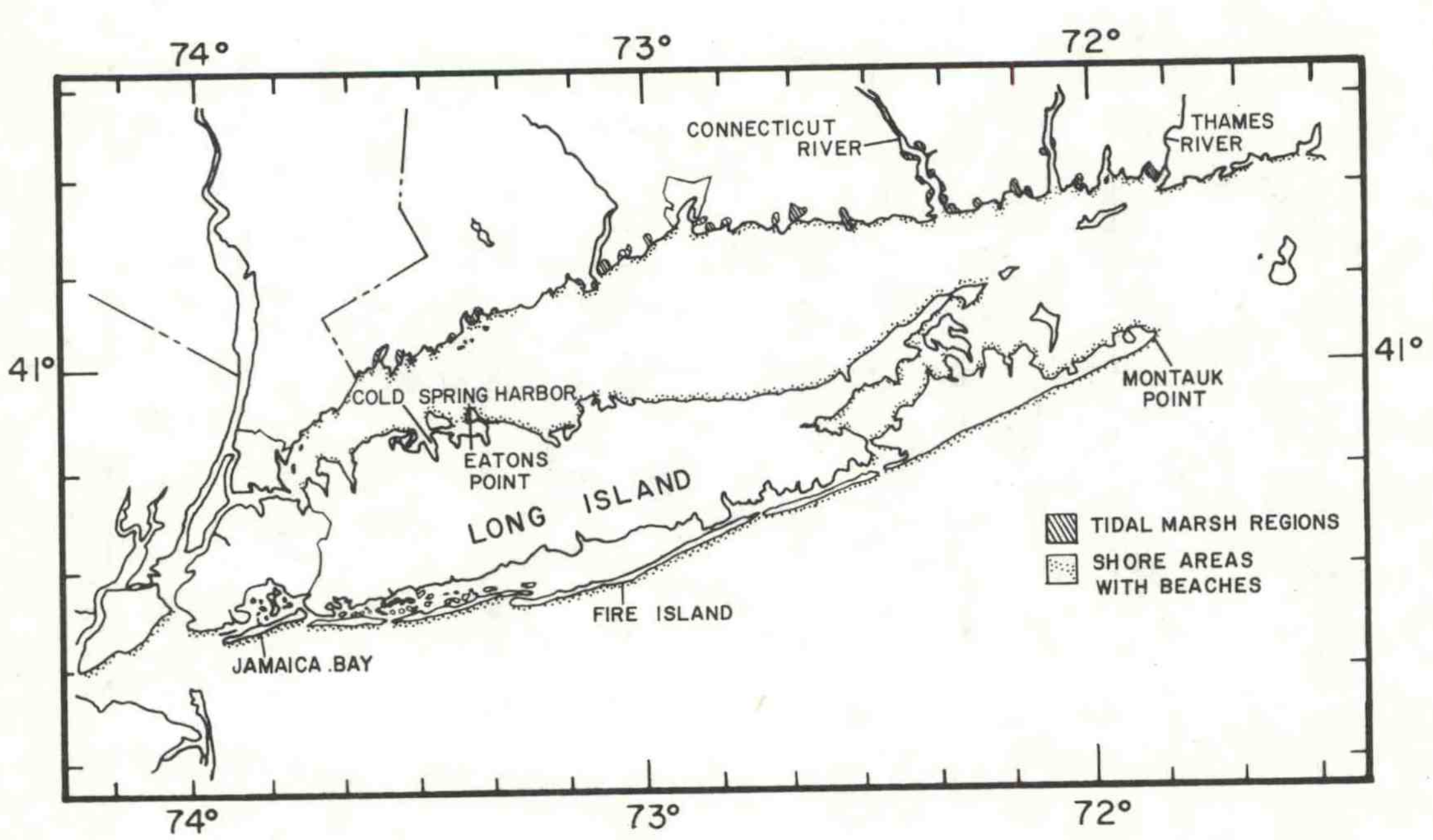


Figure 9.7 Coastal areas of New York and Connecticut.

cornia virginica, (3) Distichlis spicata, (4) Spartina patens, (5) Spergularia marina and Plantago juncoides, (6) Sueda maritima, and (7) Scirpus americanus.

Spartina alterniflora forms a dense meadow of tall, stout grass. It is the marginal emergent vegetation on muddy shores where the soil is twice a day covered with salt or brackish water. Often it is the only flowering plant covering extensive areas. On very broad salt marshes with gentle slopes, Salsola kali forms dense, almost exclusive stands, usually behind the Spartina patens zone. Also behind the marginal fringe of Spartina alterniflora are areas of Distichlis spicata and Spartina patens mixed with Juncus gerardi. On denuded spots in the upper portions of the marsh, Spergularia marina and Plantago juncoides form a community because they can quickly occupy a disturbed area. High on the marsh where there is some influence of fresh water, Scirpus americanus occurs as a transition to the upland vegetation.

The beach communities described by Conard (1935) include common zonations of the northern Atlantic coast; a fringe widely scattered Cakile edentula plants and then the extensive community of Ammophila breviligulata with Solidago sempervirons.

Behind the Ammophila are areas covered with low growing Hudsonia tomentosa and/or shrubs including Prunus maritima, Myrica cerifera, Juniperus virginiana, Vaccinium spp., Iva frutescens, and Pinus rigida. In areas where there is standing fresh or brackish water there often occurs a stand of Phragmites communis among the shrubs.

The south side of Long Island, exposed to the Atlantic Ocean is much like New Jersey in its vegetative characteristics. The north side of the island is much more like that of the Connecticut coast (Figure 9.7). Here the land slopes very sharply to Long Island Sound. Beach areas are small in contrast to the beaches of the extensive barrier islands of the south, and much of the coastline is rocky, with well developed algal zonations (discussed later), and a narrow fringe of shrubs fronting the deciduous forest. These areas are generally not well studied and need a good deal more work. However, these areas have been subjected to extensive residential and industrial development so much alteration of natural vegetation has already occurred.

The narrow beaches of Connecticut, where the vegetation is allowed to develop, are topped with beach grass and give way quickly to a shrub and deciduous forest community of the oak-chestnut region type as described in the second section of this chapter.

Since there are no well-developed barrier islands on the coast of Connecticut or on the northern shores of Long Island, salt marshes are

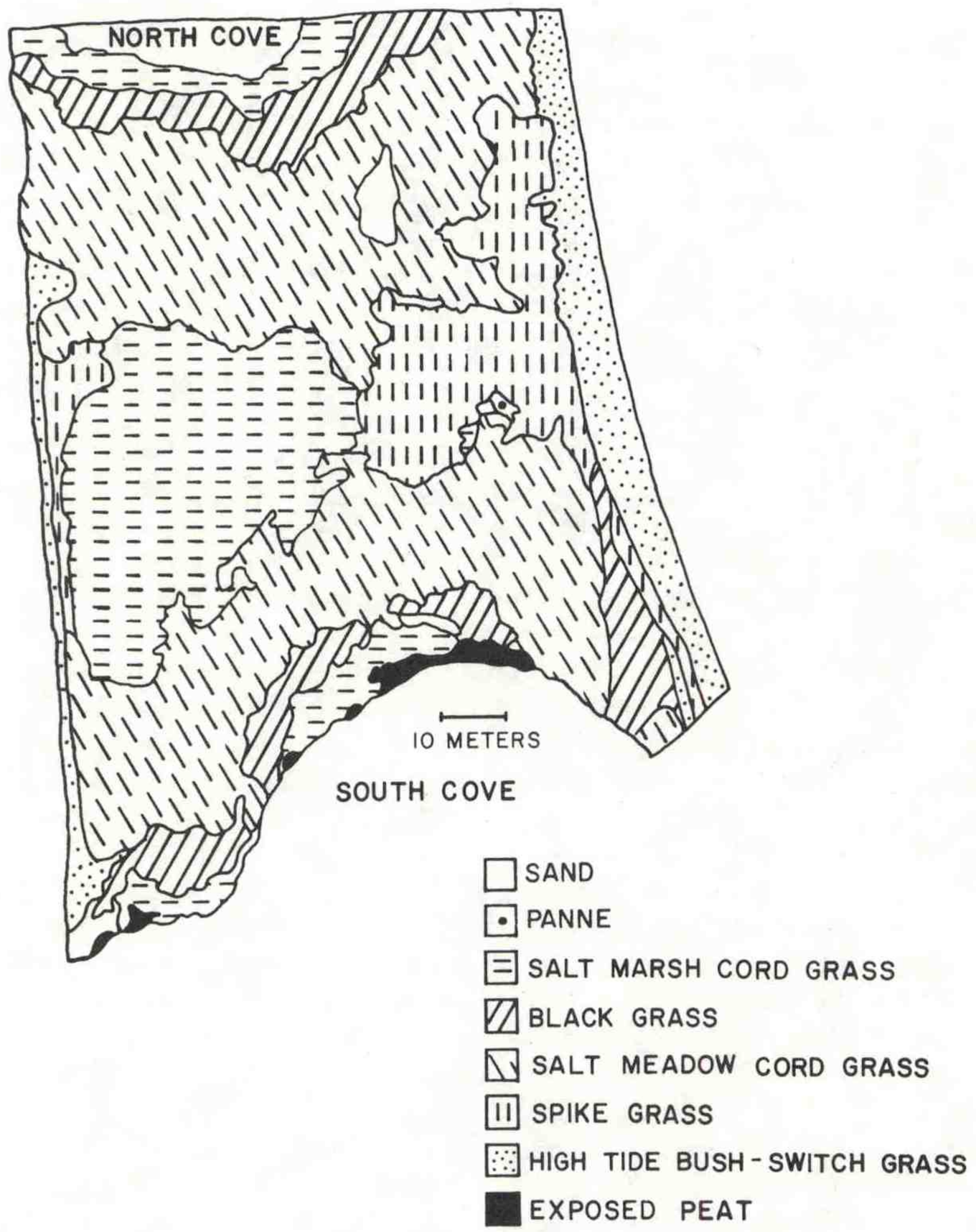


Figure 9.8 Zonation of the vegetation on the Mamacoke marsh, Thames River, Connecticut (after Niering, 1961).

mostly confined to estuarine situations, and the larger marshes are all found along or associated with rivers entering the sound (Table 4). Niering (1961) has reported on one such marsh on the Thames River (Figure 9.8). This marsh is structured with a zone of Spartina alterniflora bordering the water and Distichlis spicata and Spartina patens occupying areas landward from S. alterniflora; Juncus gerardi was found to occur only in localized situations. Other common species of these marshes include Limonium carolinianum, Gerardia maritima, Aster subulatus, Plantago juncoides, Salsola kali and Solidago sempervirons. Where the marsh meets the upland and salinity is low, Panicum virgatum, Baccharis halimifolia, Iva frutescens and Hibiscus palustris commonly grow. In less salty estuarine marshes of tidal rivers and streams, Typha, Phragmites, and Scirpus abound (Hill and Shearin, 1970).

The tidal marshes on the extreme eastern border of Connecticut were described by Miller and Egler (1950) as having a general sequence of upland forest, to upland shrub border, to upper border with Panicum virgatum, to Juncus gerardi upper slope, to Spartina patens lower slope, to Spartina alterniflora lower border, to the bay; a sequence not unlike that others have reported.

Rhode Island and Massachusetts

The coastline of Rhode Island and southern Massachusetts is a mixture of rocky coasts, beaches, and beaches with saline ponds (lagoons) behind them (Figure 9.9). Palmatier's (1973) report describes the dynamics of the barrier beach and lagoon system in Rhode Island. He reports finding a sample of beach grass in which the annual growth pattern of the grass measured against the dune layers indicate that the dune has grown in height rather consistently about seven inches a year, about 28 inches in four years. At the same beach site as the grass was found, a layer of cobbles and pebbles at 11 inches and at 23 inches below the surface indicated a severe storm and overwash in 1968 and again in 1970.

The normal progression of the beaches and salt marshes of the area is for them to move landward with the rising sea levels. The foredunes of barrier beaches are now found to stand on peat from tidal marshes which were flooded by the rising sea level. Swamp cedar stumps were found under tidal marsh peat in the Pettaquamscutt River area of Rhode Island indicating the existence of a fresh water swamp forest prior to tidal marsh development. When laying the transatlantic cable disturbed the sea floor off the coast of Rhode Island, blocks of peat in excess of one cubic foot were washed ashore, indicating the presence of tidal marsh peat on the sea bottom (Chapman, 1938; Palmatier, 1973).

The three dominant plants of Rhode Island and Massachusetts salt marshes are Spartina alterniflora, Spartina patens, and Juncus gerardi;

TABLE 4. Vertical distribution of the more common land plants of Cold Spring Harbor (after Johnson and York, 1915)

Tide levels 12 feet	Vegetation Belts	Supra-Littoral Beach of Spit			Supra-Littoral Marsh		
		Species	Range		Species	Range	
		m Ammophila breviligulata	8.3 to	12	m Scirpus americanus	6.5 to	12
		d Cakile edentula	8.5	11.5	Dryopteris thelypteris	8.5	12
		d Solidago sempervirens	8	11.5	m Juncus gerardi	7.3	8.8
		d Lathyrus maritimus	10	11	m Spartina patens	6.5	8.7
		d Euphorbia polygonifolia	8.5	12	m Eleocharis olivacea	8.3	12
11 feet		d Salsola kali	8.5	12	m Scirpus robustus	6.8	8.7
		d Xanthium echinatum	10	11.5	d Solidago sempervirens	6.5	12
		d Aster tenuifolius	9	11	d Iva frutescens	7.5	8.5
		d Atriplex arenaria	6.5	8.7	d Aster subulatus	7.3	9
10 feet	Supra-Littoral Belt. 8 to 12 feet (Storm Beach and Supra-Littoral Marsh.)	d Rhus radicans	9	12	d Hibiscus moscheutos	8	12
		d Rhus glabra	11	12	d Gerardia maritima	8	8.7
		d Polygonum scandens	9	12	m Distichlis spicata	6.5	8.5
		d Ailanthus glandulosa	9	12	d Lysimachia terrestris	9	?
		d Verbascum thapsus	9	12	d Asclepias incarnata	8.3	12
		m Agropyron repens	8.3	12	m Agropyron repens	8.7	12
		d Galium claytoni	8	12	Solaginella apus	9	12
9 feet		d Oenothera biennis	11	12	Palavacinnia lyellii	9	12
		d Robinia pseudoacacia	9	12			
		d Salix sp.	11.8	12			
		d Polygonella articulata	10	12			
8 feet							
		m Spartina patens	6.5	8.7	d Atriplex patula hastata	6	8.5
		d Suaeda maritima	6.5	8	d Limonium carolinianum	7.3	8.3
		d Salicornia europaea	6.5	7.5	d Plantago juncoides	6.3	8.3
	Upper Littoral Belt. 6.5 to 8 feet. (On all shores.)	m Juncus gerardi	7.3	8.8	m Scirpus nanus	6.3	8
		m Scirpus americanus	6.5	12	m Triglochin maritima	6.3	7.5
7 feet		m Scirpus robustus	6.8	8.7	m Typha angustifolia	7.8	12
		m Distichlis spicata	6.5	8.5			
		d Salicornia ambigua	6	7.5			
6.5 feet		d Spergularia marina	7	8			
6 feet		m Spartina alterniflora				1.5 to	6.5
		d Lilaeopsis lineata				5.5 to	6.5

5 feet

Mid-littoral Belt.
1.5 to 6.5 feet
Mid-littoral Marsh and
Mid-littoral Rockweed
Association

3 feet

2 feet

1.5 feet

0 foot - M.L.W.

m Zostera marina..... -3 to 1.5

m Ruppia maritima..... 0

Bottom Vegetation.
-5 to +1.5 feet
(Lower Littoral and Sup-
littoral Belts.)

-1 foot

-2 feet

-3 feet

*The two numbers given under "range" indicate the levels (above mean low water) between which the species usually grows. The species are given in each belt in the order of prevalence.

The small letter before the name of each species shows to the eye, in glancing down the column, the phylogenetic relationship of the forms of each belt. Thus: d - Dicotyledoneae, and m = Monocotyledoneae.

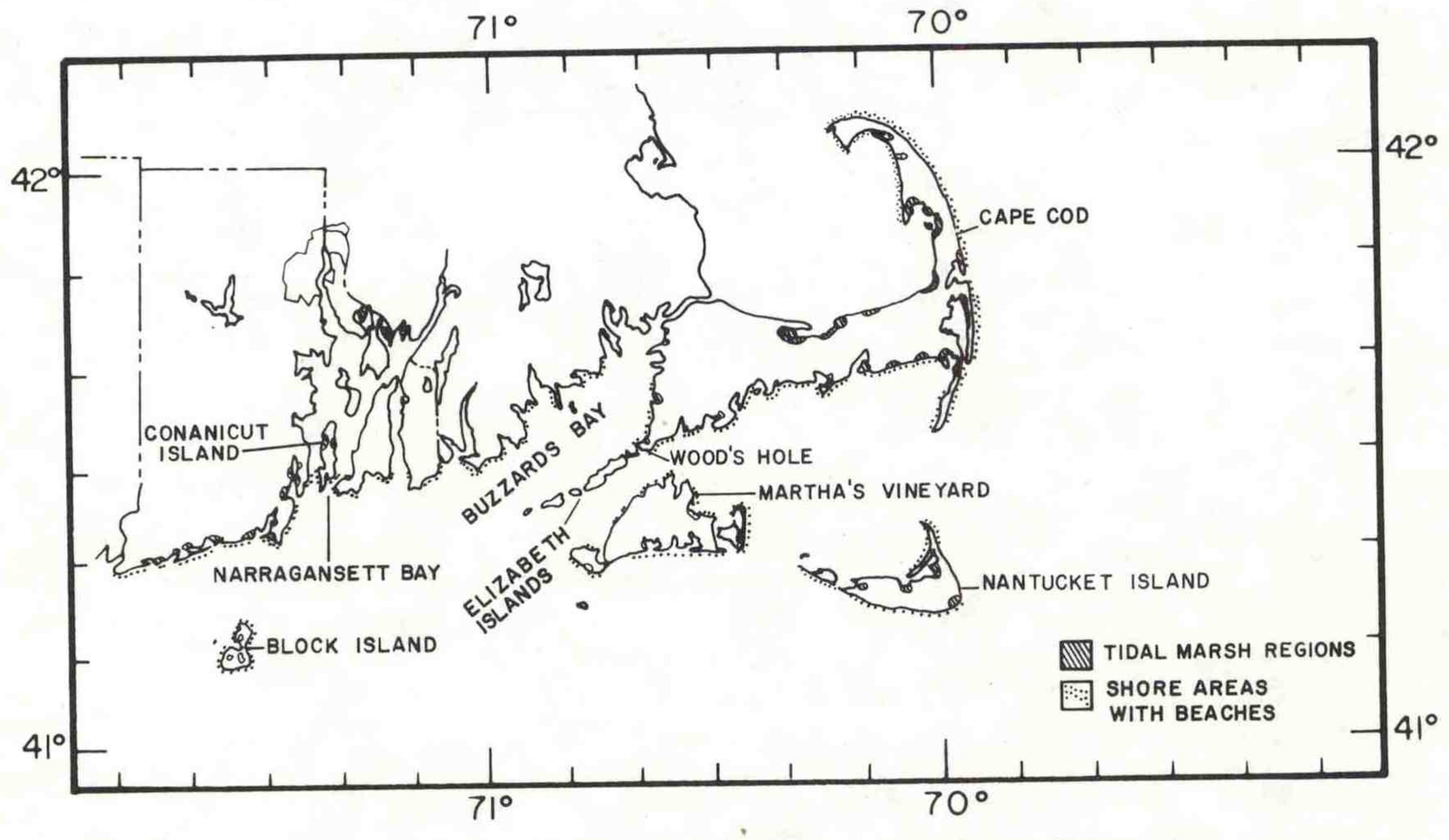


Figure 9.9 Coastal areas of Rhode Island and southern Massachusetts.

all form extensive pure stands on the marsh (Hill and Shearin, 1970; Redfield, 1972). If a marsh is extending toward sandy areas, the border is marked by the presence of Iva frutescens on the saline side and Panicum virgatum on the freshwater side of the border. If, however, the marsh is expanding into an area where ground water is abundant, then the border is marked by the presence of Spartina pectinata, a number of species of Scirpus and often Phragmites communis (Palmatier, 1973).

Mostly freshwater lagoons lie behind the barrier beaches. These are usually bordered with salt marsh species which commonly include the following (Wright, et al., 1949).

Submerged and floating plants:

1. Potamogeton spp.
2. Ruppia maritima
3. Zostera marina
4. Najas spp.
5. Chara spp.
6. Lemna spp.

Emergent plants:

1. Polygonum spp.
2. Triglochin spp.
3. Echinochloa spp.
4. Scirpus spp.
5. Spartina alterniflora
6. Salicornia spp.

Although not well studied, the beach vegetation shows a pattern similar to that found elsewhere on the coast with Ammophila breviligulata being the primary stabilizer of dunes. The landward sides of dunes or borders for rocky shores support a shrub community with commonly occurring Rosa rugosa, Myrica pensylvanica, Prunus maritima, Alnus spp, Baccharis halimifolia, and Iva frutescens. Behind this shrub zone lies the forested region common to these states.

Summary and Comments

Most of the Atlantic coastline is fronted by beaches, many backed with ponds or lagoons, some having uplands behind them. The most complex and dynamic areas are those where the systems include barrier beaches with some ponds behind them. In all cases thusfar reported along the coast, the general tendency is for these barrier beaches to be moving toward the land and, therefore, the natural vegetation moves with the change. The normal progression of communities in sandy beach areas is: Ammophila breviligulata or Uniola paniculata as the dune stabilizer, and open grass - shrub community behind the dune, a shrub community where protec-

tion avails, salt marsh bordering the lagoon on both the beach side and the landward side, and then the upland forest.

Natural storms on the Atlantic, particularly in winter, cause a great deal of perturbation in this beach-lagoon system. Often sand and water are washed over the foredunes, uprooting and covering plants; at times whole sections of beach are blown completely out or open areas are closed in with new beach. Plant communities have adapted to growing under these conditions and species are distributed in relation to their ability to withstand increased amounts of salinity, windiness (salt spray), and standing water, both salt and fresh. Seneca's (1969, 1972) experimentation has dealt with the ability of coastal plants to tolerate increasing salinities. Working with four grasses of the North Carolina coast, he determined that the tolerance to salt for both germination and growth was best in Spartina patens, Panicum amarulum was the next in his series, then Uniola paniculata, and Ammophila breviligulata was the least tolerant of the four.

Salt spray has also been shown to be an important factor in determining distribution of various species of herbs and shrubs on the beach area (Oosting, 1945, Wells and Skunk, 1938).

When this system is artificially stabilized by the use of sea walls or higher than normal foredunes, the natural communities respond by those species which need protection becoming more prevalent, even to the point of at times becoming a nuisance. In some areas, particularly in coastal New Jersey, where development of homes and cottages has completely covered the area behind the beach, natural vegetation is sparse and occurs only as scattered plants between the houses and lawns.

The salt marshes behind the dunes or along rivers are fairly uniform in composition along the Atlantic coast with most of the area of any one marsh being covered by three dominating species, Spartina alterniflora, Spartina patens and Juncus gerardi. Many associated species exist which are more or less abundant depending upon the condition of the three major grasses (Palmatier, 1973). If growing conditions are good for the above three, they usually exclude other plants; however, if growing conditions become unfavorable for these three, other species usually increase proportionately.

Salt marshes have been shown to provide a number of important functions for the overall coastal zone system, these include the marsh being a buffer zone and producing food for both shore and offshore organisms (Teal and Teal, 1969; Wass and Wright, 1969; Hull, 1970). It is also true that great numbers of acres of tidal marshland have been filled in and/or destroyed for the development of homesites, marinas, etc. Since marsh areas are generally good breeding grounds for mosquitos, ditching has been a common way of reducing their breeding habitat by

removing the standing water from any pockets which might exist. Britton, Walden and Buttrich (1915) studied a ditched marsh to determine what changes took place in the vegetative cover. They found that a wet, undrained marsh usually had large bare areas interspersed among Spartina patens, Salsola kali, and Limonium carolinianum. After draining the marshes, these plants are largely replaced by Spartina patens, Distichlis spicata, and Juncus gerardi which also take over the bare areas. Their experiments showed that changes take place rapidly following drainage, from a "poor" wet marsh to a drier marsh dominated by the more "valuable" hay grasses.

Another change which man has brought about in tidal marsh areas is impoundment for improvement of wildlife habitats. MacNamara (1949) reports on one such area where a Spartina marsh was impounded, flooded with fresh water for a year and then allowed to dry down after which a fluctuating system of wet-dry periods was tried to determine what would be the most effective means of management. The plant species were changed to those normally inhabiting fresh water marsh or marsh fringe areas. By keeping the impoundment fairly dry, the duck-food supply was increased and thereby increased the duck and water fowl populations. By filling the impoundment with 8 inches of freshwater and holding it, the area was more favorable for muskrat.

More recently, workers have been attempting to find ways to stabilize dredge spoil areas and to increase tidal marsh acreage. Working with Spartina alterniflora, Woodhouse, Seneca and Broome (1970) found that the establishment of new marsh on some spoil areas is feasible with complete cover to be expected in two growing seasons and that the species could be established either by seeds or transplants.

Tidal marshes, as reported above, do appear to be moving landward all along the Atlantic coast and are, at least in certain areas, being covered on one side by dunes while they encroach upon the upland on the other side (Palmatier, 1973).

Those areas, principally of northern Long Island and Connecticut, where rocky shores are prominent seem to be much more naturally stable. Here benthic macroalgae are the dominant species of the intertidal regions (discussed in the following section) and shrubs are found generally on the tops of the rocky cliffs. Grasses, which are so important to marsh and dune areas, have lost their dominance in this type of habitat. It appears that human developmental pressures are less here also since the topography is much less suited to human endeavors than are marshes and dunes.

TABLE 5. List of species common to the coastal zone, with their common names.

HERBS

Ammophila breviligulata	beach grass
Andropogon scoparius	beard grass
Arenaria peploides	seabeach sandwort
Aster subulatus	marsh aster
A. tenuifolius	slender-leaved aster
Baptisia tinctoria	wild indigo
Callitriche heterophylla	water-chick weed
Cakile edentula	sea rocket
Carex spp.	sedge
Cenchrus spp.	sandbur
Cladium jamaicensis	saw grass
Croton punctatus	croton
Distichlis spicata	spike-grass
Eleocharis spp.	spike-rush
Eragrostis spectabilis	tumble grass
Euphorbia polygonifolia	seaside spruge
Gerardia maritima	gerardia
Helenium autumnale	sneezeweed
Hibiscus moscheutos	swamp rose mallow
H. palustris	marsh mallow
Hudsonia tomentosa	beach heather, wolly hudsonia
Hydrocotyle umbellata	water-pennywort
Hypericum mutilum	St. John's-wort
Impatiens capensis	touch-me-not
Juncus gerardi	black grass
J. spp.	rush
Lathyrus japonicus	beach pea
Lechea minor	pinweed
Limonium carolinianum	sea lavender
Muhlenbergia capillaris	hairgrass
Nymphaea odorata	pond lily
Oenothera humifusa	seabeach evening primrose
Panicum amarum	panic grass
P. virgatum	switch grass
Phragmites communis	reed, tall reed
Physalis maritima	ground cherry
Plantago juncoides	seaside plantain
Polygonum glaucum	seabeach knot weed
P. hydropiperoides	wild water-pepper
Potamogeton spp.	pond weed
Ptilmnium capillaceum	mock bishops'-weed

HERBS

Ruppia maritima	ditch-grass
Sabatia stellaris	sea-pink
Salicornia spp.	glasswort
Salsola kali	salt wort
Scirpus spp.	bulrush
Solidago sempervirens	seaside goldenrod
Spartina alterniflora	salt-marsh cordgrass
S. cynosuroides	salt-reed cordgrass
S. patens	salt-meadow cordgrass
S. pectinata	tall cordgrass
Spergularia marina	sand spurrey
Spiranthes cernua	common ladies-tresses
Strophostyles helvola	wild bean
Suaeda maritima	sea-blite
Teucrium canadensis	germander
Triglochin spp.	arrow grass
Triplasis purpurea	triplasis
Typha spp.	cattail
Uniola paniculata	sea oats
Vernonia noveboracensis	iron weed
Xanthium echinatum	sea burdock
X. spp.	cocklebur
Zostera marina	eel grass

SHRUBS

Baccharis halimifolia	sea myrtle
Ilex vomitoria	yaupon
Iva frustescens	marsh elder
Lonicera sempervirens	honeysuckle
Myrica cerifera	wax myrtle
M. pensylvanica	bayberry
Parthenocissus quinquefolia	Virginia creeper
Prunus maritima	beach plum
Rhus copallina	shining sumac
R. radicans	poison ivy
Rosa rugosa	rugose rose
R. spp.	wild rose
Smilax spp.	greenbriar
Vaccinium spp.	blueberry
Vitis spp.	wild grape

TREES

Alnus spp.	alder
Celtis spp.	hackberry

TREES

Diospyros virginiana	persimmon
Ilex opaca	American holly
Juniperus virginiana	red cedar
Pinus rigida	pitch pine
Quercus falcata	Spanish oak
Q. ilicifolia	bear oak, scrub oak
Q. phellos	willow oak
Q. stellata	post oak
Q. virginiana	live oak, evergreen oak

Marine Benthic Algae

North Carolina - Cape Hatteras

The area with its barrier beaches, sounds, inlets, and mainland coast, offers a variety of sandy or muddy banks, beaches, and offshore reefs, but so far as could be ascertained, there is no natural intertidal rock. There are, however, shore reefs of intertidal peat which may become weathered into shapes similar to those of rocky reefs as well as a number of artificial rocky breakwaters that support a typical marine algal population.

Blumquist and Humm (1946) report peat reefs as a habitat rich in algal forms. On the outer fringes of the peat, erosion by wave action has formed varying irregular depressions and left a mixture of sand and enough dark brown organic material to give a brown to blackish color. This material forms a unique substrate for the growth of marine algae known locally as "black rock". On the basis of the environmental factors of atmospheric exposure, wave action, and salinity, this "black rock" shore may be divided into two reasonably distinct zones.

The upper zone is above the mid-tide level and thus is exposed and free from wave action the majority of the time. In addition, it may be somewhat brackish during low tides due to freshwater seepage from the banks above. The algae found in this zone consist mostly of Cyanophyta such as Entophysalis granulosa, Microcoleus chthonoplastes, Spirulina subsalsa, Lyngbya semiplena and others. The lower zone extending from mid-tide level to below low-tide level, is characterized by constant wave action. The algae found in this zone consist of some summer forms such as Pylaiella littoralis, Sphacelaria furcigera, E. Ectocarpus sp., Entermorpha prolifera, and E. plumosa, Cladophora spp.; and such winter forms as Ectocarpus siliculosus, E. confervoides, and Polysiphonia nigrescens.

Stephenson and Stephenson (1952) report that breakwaters near Beaufort, N.C., present a fairly clean intertidal rocky environment that supports a typical marine intertidal population.

Zonation

A. Supratidal

The Black (Calothrix) Zone is composed of Entophysalis deusta, Calothrix pulvinata, a species of Plectonema, and probably a number of others. The discoloration in the zone may be yellowish gray rather thar black. The blackening occurs above the Chthamalus (barnacle) or white zone, but overlaps it.

B. Intertidal subdivided into three zones; white, oyster, and muddy (after Stephenson and Stephenson, 1952).

1. White zone. Chthamalus fragilis forms a distinct whitish zone between the black zone and the oysters. This barnacle zone is invaded by Porphyra leucosticta from the zone below. Small yellowish brown plants of the Porphyra may extend to the top of the zone.

2. Oyster zone. Crassostrea virginica is a prevalent mid-intertidal species which characterizes the zone but the alga Porphyra leucosticta, in the adult form, reaches its best development here. The Porphyra may be absent toward the end of May. Gelidium, a short moss-like alga occurs on oyster and mussel shells. During April and May the most conspicuous algae are Ulva and Enteromorpha which form a bright green blanket. However, they are not generally characteristic of this zone and while occurring even in the white zone on occasion they are more usually most abundant in the muddy zone. The species usually present are Ulva lactuca, Entermorpha linza, E. prolifera and E. clathrata. Geographically, one of the most interesting features of the district is the presence of Fucus vesiculosus, occurring from the top of the oyster zone to about the bottom of the muddy zone. According to Hoyt (1920), the southern limit is Beaufort, N.C., on the Atlantic coast.

3. Muddy zone. Below the oyster zone lies a marked belt of mud covered rocks which look bare on first glance. The algae of this zone consist of Cladophora, Codium decorticatum, Bryopsis hypnoides, species of Polysiphonia, Gelidium crinale, Gigartina acicularis, Punctaria latifolia, Scytosiphon lomentaria, Asperococcus echinatus, Gymnogongrus griffithsiae and Lomentaria baileyana.

C. Subtidal:

The growth of algae is extremely rich and varied. These seaweeds show a variety of bright colors, such as dark and bright greens, crimson, yellow, brown, purplish brown. Most of the species are small in size. The largest present in April and May were Sargassum filipendula, Dasya pedicellata, and Ulva lactuca, all of which can exceed a foot in length. This growth is typical of warm-temperature regions, rich in Chlorophyceae and Rhodophyceae and lacking the bulky Phaeophyceae of cooler areas.

Some of the more common Chlorophyceae include Bryopsis hypnoides, Cladophora refracta, Codium decorticatum, Enteromopha, and Ulva lactuca. Common Phaeophyceae include Dictyota dichotoma, E. confervoides, Punctaria latifolia and Sargassum filipendula. The common Rhodophyceae include Agardhiella tenera, Callithamnion byssoides, Gigartina aciculosis, Gracilaria foliifera, Hypnea musciformis, Lomentaria baileyanna, Polysiphonia, Porphyra leucosticta and Dasya pedicellata.

Earle and Humm (1964) working in Beaufort Harbor described six

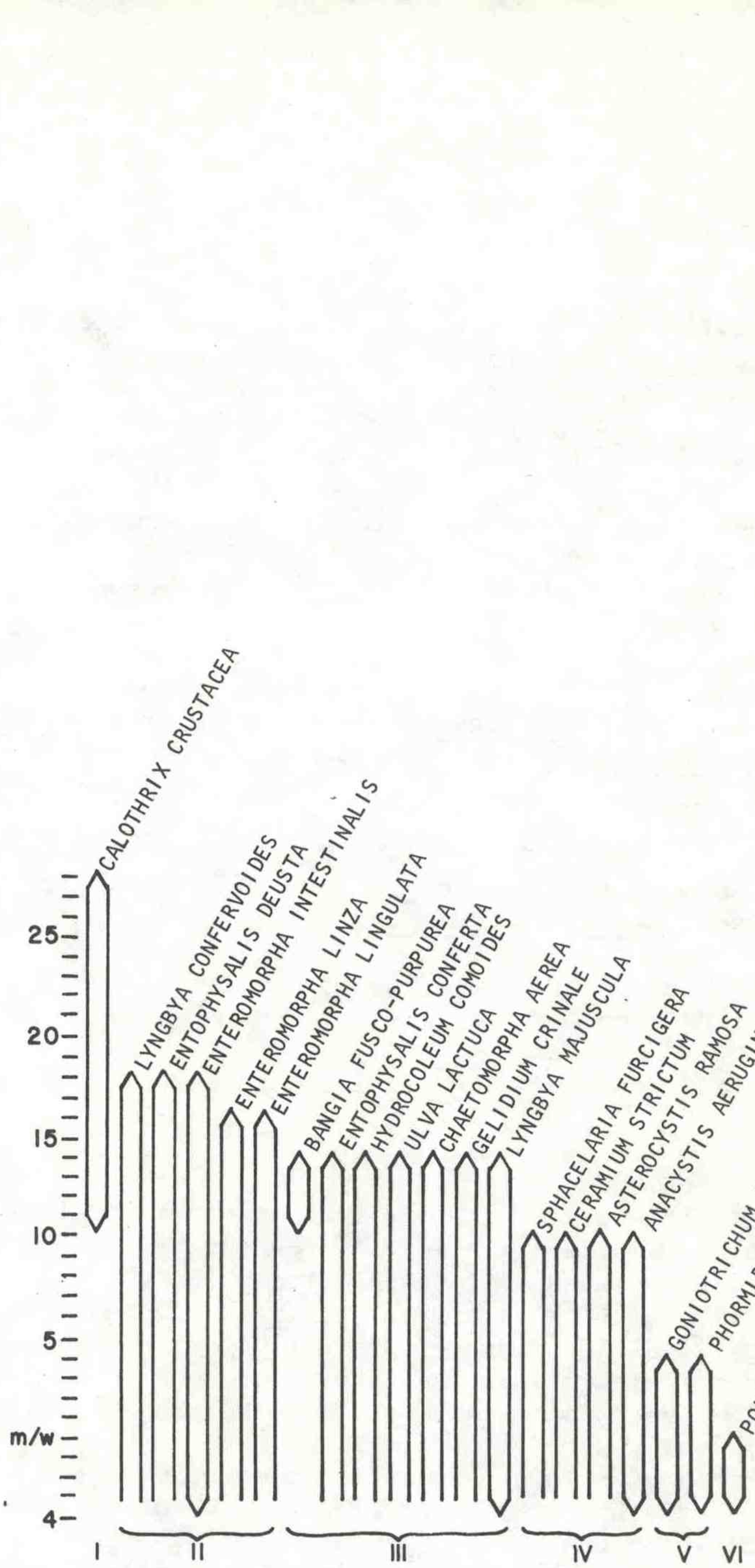


Figure 9.10 A graphic representation of the vertical distribution of the more common marine algae in Beaufort Harbor, N.C., during summer months. Figures on the ordinate are heights above or below mean low water (mlw) in inches. Numbers on the abscissa represent the recognized floristic bands of the intertidal zone, and the brackets indicate the species reaching their upper and sometimes lower limit in each band. The pointed upper end of each bar indicates the upper recorded intertidal limit of each species. A pointed lower end indicates the lowest recorded occurrence of the species, while open lower ends indicate that the lower limit of the species was an undetermined distance below the intertidal zone (Earle and Humm 1964).

floristic zones from stations chosen to provide vertical intertidal surfaces (Figure 9.10). They describe six zones as follows:

1. Calothrix (black) Zone. Calothrix crustacea, occurs from 18 to 28 inches above low water mlw in a zone that is blackish in color.

2. Enteromorpha - Lyngbya Zone. Enteromorpha linza, E. lingulata, E. intestinalis, and Lyngbya confervoides are the most conspicuous species occurring from 18 to 14 inches above mlw. Entophysalis deusta was found on shells.

3. Bangia Zone. Bangia fuscopurpurea characterizes the zone 14 to 10 inches above mlw with Ulva lactuca, Chaetomorpha area, Gelidium crinale, Hydrocoleum comoides, Entophysalis conferta and Lyngbya majuscula.

4. Ceramium Zone. Ceramium strictum is mostly conspicuous from 10 to 4 inches above mlw. Other species include Sphacelaria furcigera, Asterocytis ramosa, and Anacystis aeruginosa.

5. Phormidium Zone. Phormidium fragile and Goniotrichum alsidii occurs 4 inches above down to mlw.

6. Polysiphonia Zone. Polysiphonia denudata occurs from mlw to 4 inches below.

This zonation is provided only for the summer months at Beaufort Harbor, N.C. While there are many similarities to other localities along the North Carolina coast, there are also differences. Within the harbor itself there are striking differences from place to place. The development of the flora differs on similar surfaces having different exposures, either due to differences in wave action or sunlight or both. Different types of vertical surfaces (e.g. rock vs. wood) will differ somewhat in their flora because of the nature of the sbustrate itself. Creosoted pilings typically support an almost pure stand of Lyngbya confervoides, perhaps because this species is tolerant of the toxic compounds that leach from the pressure-treated wood. In some zones the algae encounter competition from sessile invertebrates, especially from barnacles. Some species are adapted to growing on the calcareous substrate of mollusc shells.

Pearse and Williams (1951) observed that reefs occurring off the coast of North Carolina and South Carolina vary in size and depth. Some are close inshore while others reach out to the western edge of the Gulf Stream. These reefs have been generally believed to be composed of coral formations, but those investigated have been shown to have a foundation of Trent Marl of lower Miocene age. The reefs provide

a substrate which supports an abundant growth of algae, dominated by encrusting forms.

The habitats may be classified generally into two types: (1) those that consist of rock (Trent Marl) which extends several feet above the sand sea floor and (2) those which are generally on a level with the sandy sea bottom. The reef surface is uneven and broken by deep cracks and fissures. In the type (1) habitat where the substrate is not influenced by shifting silt and sand deposits, encrusting algae dominate and their crusts exclude the hold fasts of the bulky, larger algae. Calcareous species have been found growing over each other, which results in the death of the covered species. The crusts are formed by species of Peyssonnelia, Lithophyllum, Lithothamnium, and Lithoderma. In the crevices with a shallow covering of sand Cladophora pellucida, Corallina officinalis, Amphiroa brasiliana, A. fragilissima, and Pockiella variegata flourish. In the deep protected fissures Nitophyllum, Rhodymenia, Colopomenia, Halymenia, Chrysymenia, Cryptonema, Grinnellia, and Caulerpa abound.

In type (2) habitats are the large brown algae Sargassum filipendula var. montagnei, Sargassum sp., Dictyopteris polypodioides, D. serrata and Spatoflossum schroederi.

Blumquist and Humm (1946) reported that buoys provide a substrate for several genera and species new to the region. Most of these forms have tropical or subtropical affinities. Collections were made from buoys between Cape Lookout Shoals and New River when buoys were hoisted for cleaning and painting. These buoys are 5 to 20 miles offshore and in about 40 to 100 feet of water. The water in these locations was remarkably clear yielding Secchi disk readings of 15 to 60 feet. The salinity was that of open sea water and only slightly variable; temperature was fairly constant due to the proximity of the Gulf Stream.

Some of the new forms found on the buoys include Oscillatoria subuliformis, Calothrix scopulorum, Bryopsis pennata, Sphacelaria furcigera, Colpomenia sinuosa, Gracilaria mamillaris, Spyridia aculeata var. disticha, and Antithamnion cruciatum var. radicans.

Pearse and Williams (1951) prepared a classification of Carolina marine habitats and their algal communities. Listed are five major marine areas based on salinity and their more distinctive marine algae.

1. Brackish water that is not more than half sea water most of the time. Mostly salt marshes. Common species are Herposiphonia tenella, Caloglossa leprieurii, and Bostrychia radicans.

2. Estuarine water seldom less than 16 to 28 o/oo salinity. Mostly mud flats. Common species are Ulva lactuca and Gracilaria confervoides.

3. Estuarine water seldom less than 25 or over 32 o/oo salinity. Sandy bottoms, stone jetties, and exposed peaty deposits. Characteristic species are Sargassum filipendula, Codium decorticatum, Hypnea musciformis, Gelidium pusillum, and Chondria spp.

4. Oceanic salinities, exposed rocky coast, such as jetty at Cape Lookout and coquina outcrop at Fort Fisher, North Carolina. Common species are Ulva, Enteromorpha sp., and Gelidium crinale.

5. Oceanic salinities, offshore coastal submerged reefs, 12 to 65 feet and more deep. Common species are Pocockiella variegata, Spatoglossum schroederi, Sargassum filipendula var. montagnei, Dictyopteris serrata, Cladophora pellucida, and Caulerpa prolifera.

Virginia - Delaware

In a survey of the macroscopic, attached algae in the vicinity of Burton's Bay, Virginia, 24 species were found in winter collections and 31 species in the summer (Table 6). Of the species present in the winter flora, 50% were absent during the summer, while 61% of the algae in the summer flora were not found in the winter.

Among the more common species in the winter flora were Punctaria latifolia, Scytosiphon lomentaria, and Dictyosiphon foeniculaceus of the division Phaeophyta. During the summer, Agardhiella tenera, Polysiphonia denudata, Gracilaria verrucosa, and Ceramium rubriforme of the division Rhodophyta were very conspicuous. Abundant species during both seasons were Ulva lactuca, Enteromorpha linza and Fucus vesiculosus. The known distributions of Desmotrichum undulatum, Dictyosiphon foeniculaceus, Striaria attenuata, and Callithamnion roseum along the Atlantic coast of North America were extended southward to Accomack County, Virginia by this study (Rhodes, 1970).

The ecology and distribution of benthic marine algae along the coasts of Delaware, Maryland and Virginia, including Chesapeake Bay and its estuaries, has been somewhat neglected. Only in the last eight years have studies been intiated on the marine algae of this region. Zaneveld and Barnes (1965) described the seasonal periodicity of some marine algae in lower Chesapeake Bay. The Cyanophyta from Cape May, N.J. to Cape Hatteras, N.C. have been described (Zaneveld, 1966a) and

preliminary surveys of the marine algae of Delaware (Zaneveld, 1966b) and of Ocean City, Md. (Wulff et al.,1968) have been completed.

In Chesapeake Bay and its tributaries, substrates for macroscopic algae are limited to calcareous matter (primarily shells of Crassostrea virginica, Mercenaria mercenaria and Balanus spp.), wooden artifacts (creosote pilings), and fleshy sessile organisms such as sponges and the tunicate Molgula manhattensis, aquatic angiosperms, Zostera marina and Ruppia maritima, and various salt marsh plants. Swift tidal currents are present, especially in the tributaries, thus increasing turbidity which limits growth. Salinity varies from about 27 o/oo at the mouth of Chesapeake Bay to fresh water in the tributaries, and the annual water temperature range is about 28°C. The low salinity and variable temperature combine to produce a reduced number of marine algal species inhabiting Chesapeake Bay when compared with more northern and southern regions of the east coast of North America (Wulff and Webb, 1969).

Zaneveld and Barnes (1965) report that most of the coastline of the mouth of Chesapeake Bay consists of sand beaches barren of macroscopic algae. Moving between the Virginia capes (Cape Charles and Cape Henry) eastward toward Hampton Roads and the river entrances, the beaches are replaced by mud flats. These are also unsuitable substrates for the growth and development of macroalgae.

The solid substrates of the area fall into two groups; (1) the naturally occurring ones: dead mollusc shells, calcareous housings of cirripedia, the carapaces of crustaceans and the skeletons of hydrozoans and bryozoans; and (2) the artificial: pilings, docks, bulkheads, buoys, cement blocks, bricks, ropes, tires, wrecks of ships, dumped cars, and embedded driftwood.

The three localities studied (Table 7) were chosen for survey and collection because they are basically alike: man-made of granite boulders.

1. South (Thimble Shoal) Island of the Chesapeake Bay Bridge - Tunnel.
2. Little Creek Inlet, western jetty.
3. Fort Wool Island, the southern island of the Norfolk-Hampton Bridge - tunnel.

The stations show a decrease in salinity and wave action as one proceeds from the mouth of the Bay toward the Lafayette and Elizabeth Rivers.

South Island is free of shore runoff and these associated pollution problems and, therefore, offers a good growth site for algae. The genera include Enteromorpha, Cladophora, Bryopsis, Punctaria, Porphyra, Callithamnion, and Polysiphonia. Algae are not found below 4 or 5 meters most probably due to the turbidity of the water.

Little Creek Jetty, at the entrance to Little Creek Harbor, is a 200 foot long rock jetty in 20 feet of water. Most collections were done on and around the west jetty. There is always wave action due to the large amount of ship traffic.

Fort Wool Island has a very profuse marine algal population. Almost every common genus may be found growing at one time of year or another. The granite boulders of this island provide suitable habitats for Gracilaria verrucosa, Agardhiella tenera, Polysiphonia harveyi, Callithamnion byssoides, Bryopsis plumosa, Cladophora gracilis and Grinnellia americana.

There are two seasons - summer and winter - with a climax of vegetative activity in the lower Chesapeake Bay; each peak is followed by a period of decline or even disappearance of certain species.

Typical summer or warm water species are Bryopsis hypnoides, Punctaria plantaginea, Gelidium crinale, Champia parvula, Ceramium fastigiatum, C. strictum, C. diaphanum, and Polysiphonia denudata.

Typical winter or cold water species are Petalonia fascia, Scytosiphon lomentaria, Gracilaria foliifera, and Porphyra leucosticta.

Wulff and Webb (1969) conducted a survey of the intertidal marine algae of the York River estuary. During the spring the intertidal pilings in the York River estuary may be divided into 3 basic floral regions found similarly in other areas by Stephenson and Stephenson (1949-1952): a subtidal zone consisting primarily of Rhodophyta, ranging from mlw to -38; an intertidal region composed mainly a Cyanophyta and Chlorophyta occurring from mlw to +74 cm; and a supratidal zone, from +74 cm to 122 cm having the blue-green alga Calothrix crustacea as its sole occupant. The intertidal could be subdivided into seven floral zones:

1. Monostroma leptodermum and Enteromorpha erecta (lowest level +10 to +14 cm above mlw).
2. Spirulina subsala and Ectocarpus confervoides (+26 cm).
3. Ulothrix flacca, Ulva lactuca and Enteromorpha intestinalis (+38 and +42 cm).
4. Microcoleus chthonoplastes, Enteromorpha prolifera and Porophyrosiphon notarisii (-50 to +54 cm).
5. Enteromorpha linza, Porphyra umbilicalis and Microcoleus lyngbyaceus (+62 to +66 cm extending down to mlw and below).
6. Bangia fuscopurpurea (+66 cm).

7. Entophysalis deusta and Schizothrix calcicola (+74 cm and Calothrix crustacea (found higher than +74 cm).

Mathieson and Fuller (1969) studied the algae found at 63 stations on the Chesapeake Bay and Patuxent River during the summer of 1963. They found 12 species of Chlorophyta, 10 species of Rhodophyta and one species of Phaeophyta. The common greens were Cladophora flexuosa, C. gracilis, Enteromorpha intestinalis, and Ulva lactuca. The reds include Trailliella intricata, Champia parvula, Gracilaria verrucosa, Ceramium rubrum, C. strictum, Dasya pedicellata, Polysiphonia harveyi, and Spyridia filamentosa. The only brown species Sphacelaria fusca, was epiphytic on Zostera marina, in contrast to the lower bay where Zaneveld and Barnes (1965) found several species on rock jetties.

The lack of marine algal-vegetation in the Chesapeake Bay and Patuxent River area seems primarily related to the occurrence of low saline conditions and the absence of a solid substrate. A corresponding correlation with the total biomass and species diversity exists in estuarine areas in New England, where brown and green algae predominate (Mathieson and Fuller, 1969).

Of the several segments of the Atlantic coastline of the United States that are still poorly known as to the benthic marine algal flora, the coastal waters of Maryland are perhaps the most serious gap (Wulff et al., 1968). Wulff made a study of the marine algae from the north jetty at Ocean City, Md., during July and August of 1966. A collection of 34 species was made: 6 Cyanophyta, 16 Rhodophyta, 4 Phaeophyta, and 8 Chlorophyta.

The north jetty consists of large granite blocks fitted together forming a more or less flat top, sides sloping at about 45^{o} and vertical sides extending from low in the intertidal zone to the bottom. Water temperature data are limited, but the expected range is from 2-3^{o}C during winter to about 22-23^{o}C during summer (Pyle, 1962). Salinity data are also scarce but the range is probably between 30 and 33 o/oo. The algal population is not restricted by periods of low salinity. The mean tidal amplitude is 1.03 m and intertidal zonation is clearly evident in a series of color bands. Because of significant wave action the nature of the zonation is complex with the interaction of tide and splash zones.

The algae in the species list may be placed in five geographical groups based on their presently known distribution.

1. Arctic to tropics, cold water north of Cape Cod southward of Cape Canaveral (Cape Kennedy): All Cyanophyta listed,

Bangia fuscopurpurea, Goniotrichium alsidii, Ceramium fastigiatum, Polysiphonia denudata, Giffordia sp. Enteromorpha compressa, E. intestinalis, E. linza, E. prolifera, Ulva lactuca and Chaetomorpha aerea.

2. Arctic to Ocean City: Nemalion multifidum, Callithamnion baileyi, Polysiphonia urceolata, P. novae-angliae.

3. Arctic to Beaufort: Porphyra umbilicalis, Polysiphonia harveyi, Scytosiphon lomentaria, Fucus vesiculosus, and and Enteromorpha minima.

4. Arctic to Cape Canaveral: Porphyra leucosticta, Ceramium rubrum, C. strictum, Petalonia fascia.

5. Cape Cod to tropics: Acrochaetium trifilum, A. virgatulum, Gracilaria foliifera.

The unstable habitats of sand along the Delaware sea coast and the environment of mixed sand and mud inside Delaware Bay do not provide hospitable substrates for algae with a hold-fast, such as found along the rocky shores of New England (Zaneveld, 1972).

Field studies carried out by Zaneveld between 1962 and 1968 along the east coast of Delaware and the shores of lower Delaware Bay, reported the presence of 74 different taxa of marine algae, 69 of which were benthic. Of the benthic taxa 11 belong to the Cyanophyta, 21 to the Chlorophyta, 1 to the Xanthophyta, 18 to the Phaeophyta, and 18 to the Rhodophyta.

The occurrence of algae is seasonal in character as none of the species was found to occur throughout the entire year. The algal population reached its maximum density in the summer months of June, July and August. In regard to geographical distribution, all species recorded were also reported to occur north of Delaware Bay; 4 species of the Chlorophyta, 6 of the Phaeophyta, and 1 of the Rhodophyta while none of the Cyanophyta or Xanthophyta appear to reach their southern limit along the Delaware coast making the marine benthic algae of Delaware temperate - boreal in makeup.

Table 8 shows the distribution of the different divisions of the marine benthic algae of Delaware. Table 9 shows the seasonal occurrence of the marine benthic algae of Delaware between Cape May, N.J. and Cape Hatteras, N.C.

New Jersey

The shoreline of New Jersey from Bay Head to Cape May is made up of coastal islands, separated by bays and inlets. The islands vary in width from a few hundred yards to more than a mile. Above Bay Head there are numerous inlets, but the mainland extends down to the ocean. On the bay side of these islands is salt marsh which has been greatly diminished by New Jersey state efforts to exterminate the mosquito (Richards 1932).

Richards (1932) also provides a concise description of previous work on the algae of New Jersey. Harvey (1852) divided the benthic marine algae of North America into four regions, one of which was Long Island Sound which included New York Harbor and the sands of New Jersey. Shortly afterwards, Ashmead (1857) published a catalogue of the marine algae of Beesleys Point, Cape May County, during the summer of 1855. He recorded 5 browns, 19 reds, and 5 greens. Farlow (1881) states that little has been recorded from the shores of New Jersey and thought the sandy shores might be the reason. Collins (1888) recorded 107 species collected by Mr. S.R. Morse at Atlantic City, a number which could not possibly be found at this present time. Martindale (1889) compiled the most complete list of the algae of New Jersey that has ever appeared. Richards (1932) lists 4 blue-greens, 12 greens, 14 browns and 31 reds. This decrease in species numbers he feels is due in part to inadequate collecting and in part to pollution of water by oil, sewage, dye wastes, the draining of marsh lands, and land and marine erosion.

A trend of decreasing species numbers may have continued over the intervening years because Moeller (1964) working in Barnegat Bay recorded only 7 species of green algae, 12 species of red algae and 2 marine angiosperms. These species are listed in Table 10. The floor of Barnegat Bay is virtually covered by eelgrass, but eelgrass is not present in Great Bay estuary and, is not present in any estuary south of Little Egg Harbor (Moeller, 1964).

Gracilaria is a red alga found frequently on the New Jersey coast. In Great Bay it occurs for most of the year with the exception of spring, but it is quite abundant in July and can be found in considerable quantities unattached among the eelgrass beds in Barnegat Bay.

Agardhiella tenera was found in Great Bay estuary 11 of the 12 months of the year, absent only in March. It seems to be restricted to that area rather than covering the full 47 square miles of Barnegat Bay.

Champia parvula and Dasya pedicellata were frequently found in the early summer and reappeared in the fall in New Jersey waters. Polysiphonia, Spyridia filamentosa, Ceramium, and Chondria baileyana also occurred but not in abundance or for an extended period of time.

TABLE 6. Attached species of marine algae found during the winter and summer months on oyster reefs in Burton's Bay, Accomack County, Virginia. The letters designate relative abundance of the species: A = abundant, C = common, and R = rare, while the hyphen signifies absence in the flora (Rhodes, 1970).

Taxon	Period of Collection Winter	Summer
Chlorophyta		
Bryopsis plumosa	R	C
Entermorpha intestinalis	C	A
E. Linza	C	C
E. plumosa	R	-
Monostroma sp.	-	R
Ulva lactuca	C	A
Phaeophyta		
Desmotrichum undulatum	C	-
Dictyota dichotoma	-	R
Dictyosiphon foeniculaceus	C	-
Ectocarpus siliculosus	-	A
Fucus vesiculosus	C	C
Leathesia difformis	C	-
Punctaria latifolia	A	-
Scytosiphon lomentaria	A	-
Striaria attenuata	R	-
Rhodophyta		
Agardhiella tenera	R	A
Antithamnion cruciatum	R	R
Bostrychia rivularis	-	R
Callithamnion byssoides	-	C
C. corymbosum	-	R
C. roseum	R	-
Champia parvula	R	C
Chondria sedifolia	-	C
C. tenuissima	-	C
Ceramium fastigiatum	-	C
C. rubriforme	-	A
C. rubrum	C	C
Dasya pedicellata	R	R
Erythrotrichia rhizoidea	-	R
Gelidium crinale	R	-
Goniotrichum alsidii	-	R
Gracilaria verrucosa	-	A
G. foliifera	R	C

Rhodophyta		
Grinnellia americana	-	C
Hypnea musciformis	-	R
Lomentaria baileyana	-	C
Polysiphonia harveyi	-	C
P. denudata	-	A
P. nigrescens	A	R
P. subtilissima	R	-
Prophyra leucosticta	C	-
P. miniata (Lyngbye)	C	-
Spyridia filamentosa	-	R

TABLE 7. The seasonal presence of the vegetative thalli of 29 benthic marine algae in lower Chesapeake Bay (Zaneveld and Barnes, 1965)

Species	Winter flora	Spring flora	Summer flora	Autumn flora	Perennial flora
Chlorophyta					
Enteromorphy minima	+		+		Enteromospha intestinalis
Cladophra gracilis	+		+		E. linza
Bryopsis hypnoides			+		Ulva lactuca
Phaeophyta					Cladophora flexuosa
Punctaria plantaginea		+	+	+	Bryopsis plumosa
Petalonia fascia	+	+	+		Rhodophyta
Scytosiphon lomentaria	+	+	+		Gracilaria verrucosa
Rhodophyta					Agardhiella tenera
Bangia fuscopurpurea	+	+	+		Callithamnion byssoides
Porphyra leucosticta	+				Ceramium rubrum
P. umbilicalis	+	+	+		Grinnellia americana
Gracilaria foliifera	+			+	Polysiphonia nigrescens
Dasya pedicellata	+	+	+		
Polysiphonia harveyi	+		+		
Gelidium crinale			+		
Champia parvula			+	+	
Ceramium fastigiatum			+		
C. strictum			+	+	
C. diaphanum			+		
Polysiphonia denudata			+	+	

TABLE 8. Distribution of the Delaware benthic marine algae along the east coast of North America, the Caribbean Islands, and Bermuda (+ = plants present; - = no record; * = washed ashore or floating; ? = uncertain record (Zaneveld, 1972).

Species	Between Cape May, N.J., and Cape Hatteras, N.C.	LOCALITY North of Cape May	South of C. Hatteras	Bermuda/ Caribb. Sea
Cyanophyta				
Entophysalis deusta	May Del.Md.Va.	+	+	+
Calothrix crustacea	Del.Md.Va.N.C.	+	+	+
Spirulina subsalsa	Del.Va.	+	+	+
Schizothrix calcicola	Del.Md.Va.N.C.	+	+	+
Porphyrosiphon splendidus	Del. Va.	+	-	-
Oscillatoria princeps	Del.Va.	+	+	+
Oscillatoria laetevirens	Del.Va.	+	-	+
Microcoleus chtonoplastes	Del.Md.Va.N.C.	+	+	+
Lyngbya confervoides	May Del.Md.N.C.	+	+	+
Lyngbya aestuarii	Del.Md.Va.N.C.	+	-	+
Lyngbya semiplena	Del.Md.Va.N.C.	+	+	+
Chlorophyta				
Ulothrix flacca	Del.	+	+	-
Pilinia rimosa	Del.	+	-	-
Percursaria percursa	Del.Md.Va.	+	-	+
Blidingia minima	Del.Vd.	+	+	+
Enteromorpha marginata	Del.Va.	+	-	+
Enteromorpha prolifera	May Del.Md.Va.N.C.	+	+	+
Enteromorpha intestinalis	May Del.Md.Va.N.C.	+	+	+
Enteromorpha linza	May Del.Md.Va.	+	+	+
Ulva lactuca var. latissima	May Del.Md.Va.N.C.	+	+	+
Ulva lactuca var. rigida	Del.Va.N.C.	+	+	+
Urospora penicilliformis	Del.	+	-	-
Urospora collabens	Del.	+	-	-
Chaetomorpha aerea	Del.Md.	+	+	+
Rhizoclonium kerneri	Del.	+	-	+

Chlorophyta - cont'd:				
Rhizoclonium riparium	Del.Md.	+	+	+
Cladophora albida	Del.Va.	+	+	+
Cladophora crystallina	Del.Va.N.C.	+	+	+
Cladophora flexuosa f. densa	Del. Va.	+	+	+
Cladophora expansa	Del.Va.	+	-	+
Bryopsis hypnoides	Del.Md.Va.	+	+	+
Bryopsis plumosa	May Del.Md.Va.	+	+	+
Vaucheria piloboloides	Del.Va.	+	-	+
Phaeophyta				
Pylaiella littoralis	May Del.Md.Va.	+	-	-
Ectocarpus confervoides	Del.Md.Va.N.C.	+	+	+
Ectocarpus fasciculatus	May Del.	+	-	-
Ectocarpus tomentosus	Del.	+	-	-
Sorcarpus micromorus	Del.	+	-	-
Ralfsia verrucosa	Del.	+	-	-
Elachista fucicola	Del.	+	-	-
Leathesia difformis	Del.Va.N.C.	+	+	-
Punctaria plantaginea	Del.Md.	+	-	-
Petalonia fascia	Del.Md.Va.	+	+	-
Scytosiphon lomentaria	May Del.Md.Va.	+	+	+
Ascophyllum nodosum	Del.Md.Va.	+	+*	+*
Fucus edentatus	Del.Md.Va.	+	-	-
Fucus spiralis	Del.Md.Va.	+	-	-
Fucus vesiculosus	Del.Md.Va.N.C.	+	+*	+*
Fucus vesiculosus var. laterifructus	May Del.Md.Va.	+	-	-
Fucus vesiculosus var. sphaerocarpus	Del.Md.Va.	±	-	-
Fucus vesiculosus var. spiralis	Del.	+	-	-

Phaeophyta - cont'd:				
Sargassum hystrix var. buxifolium	Del.*Va.*N.C.*	+*	+	+
Sargassum natans	Del.*Md.*Va.*N.C.*	+*	+	+
Rhodophyta				
Bangia fuscopurpurea	Del.Md.Va.	+	+	+
Porphyra umbilicalis	May Del.Md.Va.	+	+	?
Agardhiella tenera	May Del.Md.Va.N.C.	+	+	+
Hypnea musciformis	Del.*Md.*Va.*	+	+	+
Gracilaria verrucosa	May Del.Md.Va.N.C.	+	+	+
Gracilaria foliifera	May*Del.*Md.*Va.*N.C.	+	+	+
Phyllophora membranifolia	Del.	+	-	-
Chondrus crispus	Del.Va.	+	-	?
Callithamnion baileyi	May Del.Md.Va.	+	-	-
Spermothamnion turneri var. variabile	Del.N.C.	+	+	+
Pleonosporium borreri	May Del.	+	+	-
Ceramium fastigiatum	May Del.Md.Va.	+	+	+
Ceramium strictum	May Del.Md.Va.N.C.	+	+	+
Ceramium diaphanum	Del.Md.*Va.	+	-	?
Ceramium rubrum	May Del.Md.Va.	+	+	+
Chondria tenuissima	Del.Md.Va.	+	+	+
Polysiphonia harveyi	Del.Md.Va.N.C.	+	+	-
Polysiphonia fibrillosa	Del.*	+	-	+
Polysiphonia subtillissima	May Del.Md.Va.N.C.	+	+	+
Polysiphonia denudata	May Del.Md.Va.N.C.*	+	+	+
Polysiphonia nigrescens	Del.Md.Va.N.C.*	+	+	?

TABLE 9. Seasonal occurrence of the marine benthic algae of Delaware, between Cape May, N.J. and Cape Hatteras, N.C. (+ = vegetative plants present; - = plants absent; a = antheridia; g = gametangia; o = oogonia; s = swarmers; # = small spores; ## = large spores; c = cystocarps; m = monospores; t = tetraspores; p = plurilocular sporangia; r = recepticales; and u = unilocular sporangia (Zaneveld 1972).

	Month											
Species	J	F	M	A	M	J	J	A	S	O	N	D
Cyanophyta												
Entophysalis deusta	-	-	-	+	-	+	+	+	-	-	-	-
Calothrix crustacea	-	+	-	-	-	+	+	+	-	-	-	-
Spirulina subsalsa	-	-	-	-	-	+	-	+	-	-	-	-
Porphyrosiphon splendidus	-	-	-	-	-	+	-	-	+	-	-	-
Oscillatoria princeps	-	-	-	-	-	+	-	+	-	-	-	-
O. laetevirens	-	-	-	-	-	+	+	-	-	-	-	-
Lyngbya confervoides	-	-	-	-	-	+	+	+	-	-	-	-
L. aestuarii	-	-	-	-	-	+	+	-	-	-	-	-
L. semiplena	-	+	-	-	-	+	+	+	+	-	+	-
Chlorophyta												
Ulothrix flacca	-	-	-	+	-	-	-	-	-	-	+	-
Pilinia rimosa	-	-	-	-	-	+	-	-	-	-	-	-
Percursaria percursa	-	-	-	-	-	+	-	-	-	-	-	-
Blidingia minima	+	+	-	+	-	S	S	-	-	-	+	-
Enteromorpha marginata	-	-	-	-	-	+	-	-	-	-	-	-
E. prolifera	-	-	-	+	+	S	S	-	-	-	-	-
E. intestinalis	+	+	+	+	S	S	S	S	S	S	S	-
E. linza	+	+	-	-	S	S	S	S	-	-	S	-
Ulva lactuca var. latissima	-	+	-	-	S	S	S	S	S	-	S	-
U. lactuca var. rigida	-	-	-	+	-	S	-	-	S	-	-	-
Urospora penicilliformis	-	-	-	+	-	-	-	-	-	-	-	-

	J	F	M	A	M	J	J	A	S	O	N	D
Chlorophyta - cont'd.:												
Urospora collabens	-	-	-	+	-	-	-	-	-	-	-	-
Chaetomorpha aerea	-	-	-	-	-	S	S	-	-	-	-	-
Rhizoclonium kerneri	-	-	-	-	-	+	-	-	-	-	-	-
R. riparium	-	-	-	-	-	-	-	-	+	-	-	-
Cladophora albida	-	-	-	-	+	-	S	S	-	-	+	-
C. crystallina	-	-	-	-	-	+	+	-	-	-	-	-
C. flexuosa f. densa	-	-	-	-	S	S	S	S	S	S	-	-
C. expansa	-	-	-	-	-	+	-	-	-	-	-	-
Bryopsis hypnoides	-	-	-	+	-	g	-	-	-	-	-	-
B. plumosa	-	+	-	+	g	g	g	-	-	-	+	-
Vaucheria piloboloides	+	-	-	-	-	a,)	-	-	-	-	-	-
Phaeophyta												
Pylaiella littoralis	u	-	u	-	-	p	p	-	-	-	u	-
Ectocarpus confervoides	+	-	-	u	u,p	p	p	-	-	p	-	-
E. fasciculatus	-	-	-	-	-	p	-	-	-	-	-	-
E. tomentosus	-	-	-	-	-	+	-	-	-	-	-	-
Sorocarpus micromorus	-	-	-	+	-	-	-	-	-	-	-	-
Ralfsia verrucosa	-	-	-	-	-	+	-	-	-	-	-	-
Elachista fucicola	-	-	-	-	-	+	-	u	-	-	-	-
Leathesia difformis	-	-	-	-	+	-	-	-	-	-	-	-
Punctaria plantaginea	-	-	-	u	-	u,p	u,p	-	-	-	-	-
Petalonia fascia	-	-	-	-	-	p	p	-	-	-	-	-
Scytosiphon lomentaria	-	-	-	p	-	p	p	-	-	-	-	-
Ascophyllum nodosum	-	-	-	-	-	r	r	r	r	r	r	-
Fucus edentatus	-	-	-	-	-	-	+	-	-	-	-	-
Fucus spiralis	-	-	-	-	-	-	-	+	-	-	-	-
F. vesiculosus	-	r	r	r	r	r	r	r	r	r	r	-
F. vesiculosus var. laterifructus	-	-	-	-	-	r	r	-	-	-	-	-
F. vesiculosus var. sphaerocarpus	-	-	-	-	-	r	-	-	-	-	-	-
F. vesiculosus var. spiralis	-	-	-	-	-	r	-	-	-	-	-	-

Phaeophyta - cont'd.:

	J	F	M	A	M	J	J	A	S	O	N	D
Sargassum hystrix var. buxifolium	-	-	-	-	+	-	+	+	+	+	-	-
S. natans	-	-	-	-	-	-	+	+	-	-	+	-

Rhodophyta

Bangia fuscopurpurea	-	m	-	m	-	+	+	-	-	-	-	m
Porphyra umbilicalis	#	#,##	-	#,##	-	#,##	-	-	-	#,##	-	#
Agardhiella tenera	+	+	a	a	-	c,t	c,t	c,t	c,t	c,t	-	-
Hypnea musciformis	-	-	-	-	-	-	c,t	c,t	-	-	-	-
Gracilaria verrucosa	+	+	+	c	c,t	c,t	c,t	c,t	-	c	-	-
G. foliifera	-	-	-	-	-	-	-	c,t	-	-	-	-
Phyllophora membranifolia	-	-	-	c,t	-	-	-	-	-	-	-	-
Chondrus crispus	-	-	-	-	-	c,t	c,t	-	-	-	-	-
Callithamnion baileyi	-	-	-	-	-	c,c,t,		-	-	-	-	-
Spermothanion turneri var. variabile	-	-	-	-	-	-	-	+	-	-	-	-
Pleonosporium borreri	-	-	-	a	-	-	-	-	-	-	-	-
Ceramium fastigiatum	-	-	-	-	-	c,t	c,t	c,t	-	-	-	-
C. strictum	-	-	-	c,t	-	c,t	c,t	c,t	-	-	c,t	-
C. diaphanum	-	-	-	-	-	-	c,t	-	-	-	-	-
C. rubrum	a,c,t	a,c,t	a,c,t	c,t	c,t	c,t	c,t	c,t	c,t	-	c,t	-
Chondria tenuissima	-	-	-	-	-	c,t	c,t	c,t	-	-	-	-
Polysiphonia harveyi	-	-	+	-	c,t	c,t	c,t	c,t	-	-	c,t	-
P. fibrillosa	-	-	-	-	-	-	-	-	-	-	+	-
P. subtillissima	-	-	-	-	-	-	t	-	-	-	-	-
P. denudata	-	-	-	-	c,t	c,t	c,t	c,t	c,t	-	+	-
P. nigrescens	-	a,c	-	-	c,t	c,t	c,t	-	-	-	-	-

TABLE 10. Marine plant species present during the survey of Barnegat Bay (Moeller, 1964).

Vascular Plants

1. Zostera marina
2. Ruppia maritima

Chlorophyta

1. Ulothrix implexa
2. Rhizoclonium riparium
3. Enteromorpha prolifera
4. E. linza
5. E. intestinalis
6. Cladophora gracilis
7. Ulva lactuca

Rhodophyta

8. Gracilaria verrucosa
9. G. foliifera
10. Agardhiella tenera
11. Dasya pedicellata
12. Polysiphonia subtilissima
13. Spyridia filamentosa
14. Champia parvula
15. Callithamnion sp.
16. Polysiphonia flexicaulis
17. Ceramium sp.
18. C. fastigiatum
19. Chondria baileyana

TABLE 11. A standing crop estimate of some marine plants of Barnegat Bay (Moeller, 1964).

Marine Plant Components	Zostera	Gracilaria	Agardhiella	"Mixed reds"	Ulva	Enteromorpha	Quadrat total	Total
Frequency in 44 quadrats %	81.8	56.8	31.8	36.4	38.6	9.1		
% Contribution by wt (Relative weight)	68	11	8	2	10	1		
Mean weight oz/yd	11.2	1.8	1.3	0.3	1.7	0.1	16.4	
SD	18	4.3	2.4	0.7	3.1	0.3	17	
SE	3.2	0.8	0.4	0.1	0.5	0.05	3.1	
Range oz/yd confidence limits	4.6-17.8	3.4-0.3	2.1-0.4	0.6-0.08	2,8-0.6	0.2-(-1.0)	22.6-10.1	
Range tons/mile confidence limits	445-1721	24-326	39-205	8-59	55-271			981-2188
Mean weight tons/mils	1083	175	123	34	164	(7?)		1586
Standing crop in bay in tons	19.494	2.975	1476	578	1968			29,182
Plant cover in sq. miles	18	17	12	17	12			18.4

These species are referred to as "mixed reds" in Table 11, which gives some indication of the standing crop of some marine plants of Barnegat Bay.

Ulva lactuca is an abundant summer alga in New Jersey and is present from June to December in the Great Bay estuary, often persisting into January. Extensive beds occurred at Barnegat Beach, but in other areas of the bay it occurred as free floating scraps.

Enteromorpha was abundant in qualitative sampling but only occurred twice in quantitative sampling, so it is common but not abundant.

Ruppia maritima is present in Barnegat Bay and is considered an important food source for aquatic wild fowl.

New York - Connecticut

Conard (1935) described the vegetation of central Long Island and included a section on the marine benthic algae, which occur in Long Island Sound, Great South Bay, and along the Atlantic coast of Long Island. The algal flora of Long Island is a meager one. The larger number of algal associations known to more northern waters have been telescoped into a few in this region. The distribution and occurrence of the algae are treated from the deeper water landward.

Pure stands of Laminaria agardhii occur in dense beds on the seaward side of large rocks and boulders at a depth 2 m below mean low water (mlw) off Eaton's Point. At the eastern end of the island (Montauk Point) L. agardhii grows abundantly together with L. digitata and Rhodymenia palmata. Chorda filum attains a length of 1 m or more and is attached in clusters of 3 or 4 to shells and small stones.

Chondrus crispus forms a red band as it completely covers many rocks from a few cms below mlw to 1 m below. Ceramium rubrum covered the tops of rocks about 30 cm below mlw, the sides of the rocks being covered by Chondrus. Porphyra umbilicalis also occurs in this level. Ulva lactuca was often found attached among the above mentioned red algae and continues to be abundant to 30 cm above mlw. This association was best seen at Easton's Point and was also found on the norther and northeast points of Center Island. At Montauk Point this association of algae includes abundant Champia parvula.

At Easton's Point Anfeltia plicata occurs in isolated tufts about 15 cm below mlw. On the sandy bottom east of Center Island Dasya pedicellata, Grinnellia americana, Ceramium strictum, Callithamnion,

Lomentaria uncinata, and Champia parvula were found attached to occasional pebbles or shells 10-50 m apart over a bottom about 0.5-1 m below mlw. These plants may be more abundant in the deeper waters close by as storms generally wash up numbers of them.

Polysiphonia variegata, Bryopsis plumosa and Gracilaria multipartita grew very abundantly attached to pebbles or stones in the tidal stream on the east side of Center Island.

Until the summer of 1932 Zostera marina covered many square miles of Great South Bay, epiphytized by Polysiphonia variegata, Ectocarpus siliculosus, Ceramium strictum, Callithamnion baileyi and Melosira granulata. In 1932 Zostera had completely disappeared along the Atlantic Coast of Europe and North America due to a disease thought to be caused by Labyrinthula macrocystis (a net slime mold). Between 1931 and 1934, 90% of the eelgrass was killed. It has slowly recovered but has not yet reached its former abundance.

Cold Spring Harbor is on the north side of Long Island about 30 miles to the east of New York City. There are two harbors, an inner harbor which opens from its northeast corner into an outer harbor. A spit, locally called Sand Spit separates the two harbors. The outer harbor opens out to Long Island Sound 5 miles north of the Sand Spit. The study of marine algal vegetation was confined to the inner harbor (Johnson and York, 1915).

The bottom vegetation of the inner harbor as described by Johnson and York (1915) falls into three categories.

1. Those plants growing on loose soil, including two seed plants, Zostera and Ruppia which are rooted in the soft mud, and only two important algae, Ulva lactuca and Enteromorpha clathrata. The latter two are usually unattached, simply resting on the bottom or weighted down by mussels. When looking at the inner harbor at low tide the bottom appears green in most areas due to this formation.

2. Attached benthic algae number about 20 species of which about 7 or 8 including Ulva and Enteromorpha clathrata dominate. Beggiatoa mirabilis occurred quite commonly on the surface of black mud. A species of Cladophora grows in tufts near the low water mark along the inlet during the spring. In the summer it grows up to the high tide mark and can be found in mats among the Zostera beds. Enteromorpha intestinalis was generally found near the high tide mark around the mouth of fresh water streams. Ulothrix flacca was found abundantly above 1.5 ft higher than the low tide mark.

Ascophyllum and Fucus attained their greatest abundance from 1.5 to 6 ft above the low tide mark. Since in the outer harbor the distribution

of these algae is greatest below 1.5 feet, the absence of a suitable substrate in the inner harbor at this level was postulated to account for the upward shift. Scytosiphon lomentaria occurs in the outer harbor all summer and unattached small tangles are found on the bottom loose or attached to rocks scattered between mlw up to the 1 foot level. Pylaiella littoralis occurs during the summer in scattered locations from -6 inches up to 5 or 6 feet.

Of the 13 species of red algae found in the harbor the most important were Chondrus crispus, Porphyra laciniata, and the encrusting Hildenbrandia prototypus. Chondrus occurs abundantly in the inlet during the summer, chiefly on a pebbly bottom between -1 ft and +1 ft above mlw. In the summer Porphyra is relatively rare, but forms extensive sheets during the spring and is comparable to Ulva in abundance. It occurs most abundantly in the channel to the outer harbor between -1 ft and +1.5 ft above mlw. The limits on the open shores of Long Island Sound appear to be -1 to +4 ft above mlw. Hildenbrandia was the most widely spread red algae during the summer growing on pebbles and rocks in both pure salt water and brackish from mlw up to +6 or 6.5 ft wherever proper substrate can be found. Agardhiella tenera, Callithamnion roseum, Ceramium rubrum, Chondria tenuissima, Dasya elegans, Delesseria lepriurii, Gracilaria multipartita, Grinnellia americana, Lomentaria uncinata and Polysiphonia variegata have all been found in the inner harbor at one time or another but never in any abundance.

3. Epiphytic algae on Zostera and Ulva number about 7 or 8 species. Zostera offers a substrate for Spirulina tenuissima, many diatoms, Chaetomorpha aerea, Cladophora, Enteromorpha clathrata, Ceramium rubrum and C. strictum being the most important.

Table 12 taken from Johnson and York (1915) shows the vertical distribution of the algae just described and also includes some algae of the marsh.

There is a considerable number of references to the marine algae of Connecticut in the general literature on American algae. There have been few if any reports on the zonation and structure of the marine algae of the Connecticut coast.

Bailey (1847,1848) published some notes on American algae where species of algae from Connecticut were first recorded. Bailey reported 9 species of marine algae from the New Haven-Stonington area. This was followed some 20 years later by Hall's (1876) list of algae growing within a 20 mile radius of New Haven in Long Island Sound. This list contained some 90 species and varieties, 19 browns, 42 reds, 20 greens and 4 blue-greens which included some freshwater species despite the title. Farlow (1881, 1889) included some Connecticut stations where he noted a species of Fucus from Groton and some species of Lyngbya, Antithamnion, and

Polysiphonia from Noank and a species of Gloiosiphonia from New London. Setchell (1900) recorded four species of brown algae for the state. Collins (1900, 1905) published lists of Connecticut algae which were quite extensive listing almost 200 species and varieties of marine algae (Hylander, 1928).

Hylander's (1928) listing of the algae of Connecticut including both fresh water and marine forms with plates is fairly complete and gives one of the few indications of the distribution of marine algae as to habitat type, i.e., salt marsh, tide pool, depositing or eroding coast, Table 13. The vertical arrangement would be somewhat similar to that reported for Long Island and Rhode Island.

Rhode Island - Massachusetts

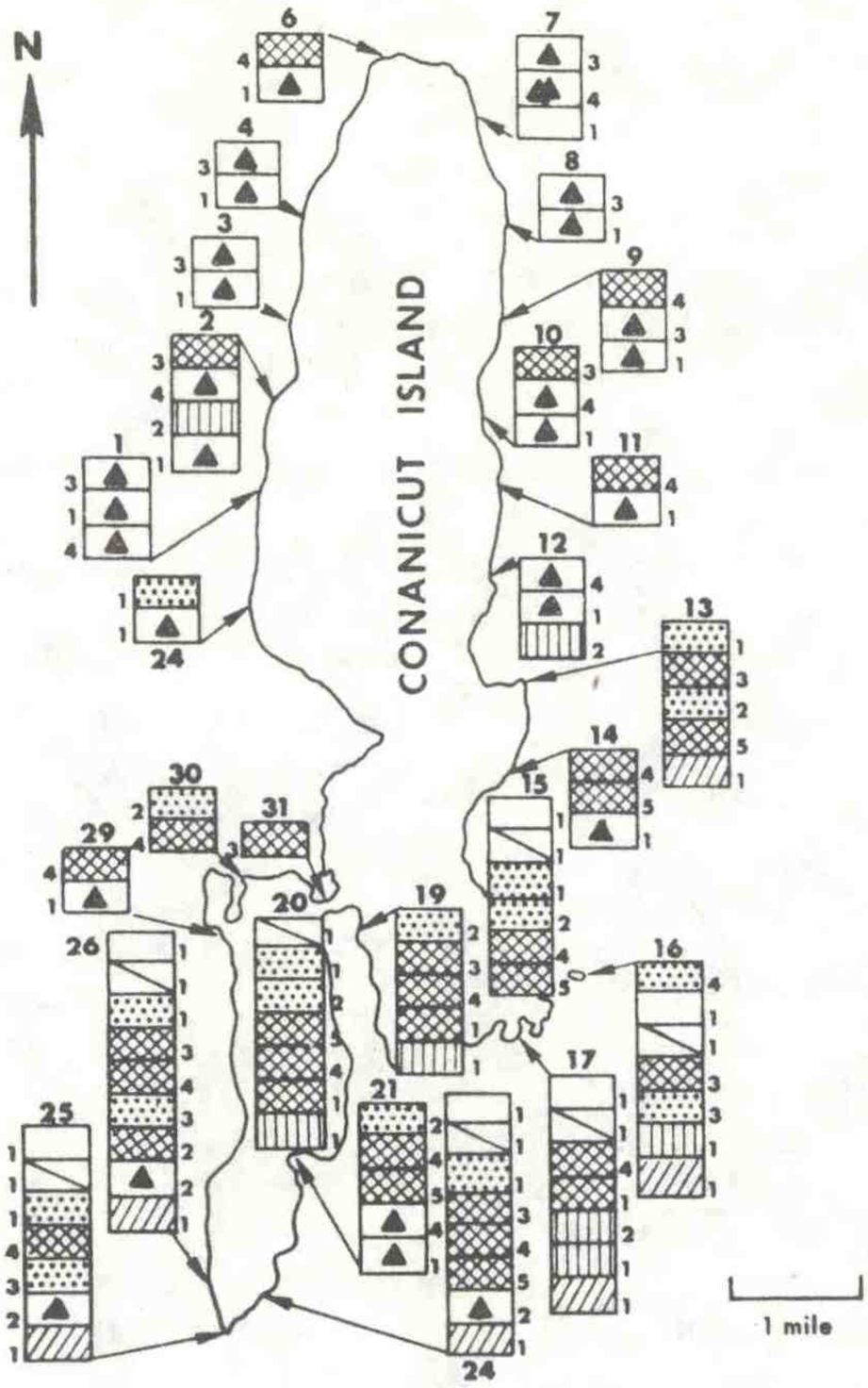
A study of the intertidal marine algal vegetation of Conanicut Island, Narragansett Bay, Rhode Island was conducted by Villalard (1971) during 1967 and 1968. Conanicut Island is a major island in Narragansett Bay, lying perpendicular to the coast (Figure 9.9). Its southern end is thus exposed directly to the sea while the northern end is well-protected, extending halfway up the bay.

The southern shore consists of exposed outcrops of granite and schist, while the east and north shore are mostly sand and shingle beaches occasionally strewn with large boulders. The west coast is predominantly cobble stones and has portions of schist and slate outcrops.

Conditions are generally moderately temperate, but include short periods of ice cover in the winter, about 40 inches of rainfall per year with periods of warm sunny summer and autumn weather. The average spring tide range is about 4 ft with two highs and two lows each day.

The algal vegetation was studied through 27 stations which were set up around the island (Figure 9.11). The greatest density of algal vegetation was recorded at the southern seaward end of the island on the exposed rocky shores. At this location the intertidal vegetation had a vertical range of 7.5 ft. The algae on the north landward end of the island was rather sparse in comparison and restricted to a vertical range of 4 ft. Little or no algal vegetation occurred on the sand or shingle beaches with the exception of encrusting red algae on some cobble stones. Vegetation was abundant on granite and schist outcrops (Villalard, 1971).

Algal zonation was well developed (Table 14), exhibiting nine color bands on the exposed southern shores and only two or three color bands in the more protected regions. On the southern exposed shores there was Calothrix (black) and Bangia (red or brown) in the supratidal



Calothricion
1. Calothrix crustacea

Bangion
1. Bangia fuscopurpurea

Enteromorphion
1. Blidingia minima
2. Enteromorpha intestinalis
3. Enteromorpha linza
4. Prasiola stipitata

Chrondrion
1. Chrondrus crispus
2. Gigartina stellata
3. Hildenbrandia prototypus
4. Scytosiphon lomentaria

Fucion
1. Ascophyllum nodosum
2. Fucus edentatus
3. Fucus spiralis
4. Fucus vesiculosis
5. Ralfsia verrucosa

Rhodomenion
1. Rhodomenia palmata
2. Ulva lactuca

Laminarion
1. Laminaria digitata

zone; Blidingia (green), Fucus spiralis (brown) and Enteromorpha linza (green) in the upper mid-intertidal zone; Fucus vesiculosus (brown), Ulva lactuca (green) and Chondrus crispus (red) in the middle and lower intertidal zone; and Laminaria agardhii (brown) in the upper subtidal zone. On large boulders and in protected rocky regions, Ascophyllum nodosum (brown) was found with Fucus vesiculosus. In exposed areas Gigartina stellata (red) was found with or replaced Chondrus crispus. The sparse vegetation of the protected cobble and sand beaches exhibit only the two or three color bands of Fucus vesiculosus or F. spiralis (brown), Hildenbrandia prototypus (red) and Chondrus crispus (red) in the mid intertidal zone. The Calothrix (black, supratidal zone) and the Laminaria (brown, subtidal zone) zones are almost entirely absent.

The algal vegetation is perennial but somewhat seasonal, becoming more abundant in spring and maximum during June, July and August. The lichen Verrucaria microspora occurs in the Calothrix (black) zone of rocky areas and in the spring and early summer Microcoleus lyngbyaceus appears in this zone. Urospora penicilliformis and Ulothrix flacca become well-developed in the Bangia (red) zone during spring. Dumontia incrassata and Scytosiphon lomentaria appear in the mid-intertidal zone during spring with Dumontia disappearing in June and Scytosiphon becoming more abundant in summer. Fucus spiralis occurs in a sketchy upper mid-intertidal band, F. vesiculosus and more sparsely F. edentatus in the mid-intertidal, with Ascophyllum nodosum replacing Fucus in protected areas and behind rocks. Chondrus crispus is the most uniformly present species around the island. The subtidal zone is predominated by Laminaria agardhii, L. digitata, Rhodymenia palmata and Ulva lactuca (Villalard, 1971).

Tidepools of the high intertidal fringe have species of Enteromorpha and Cladophora, in the upper mid-intertidal zone the crustose forms of Hildenbrandia prototypus and Ralfsia verrucosa occur and in the lower intertidal zone Laminaria digitata, Rhodymenia palmata and Ulva lactuca (Villalard, 1971).

Villalard recorded a total of 104 species of attached algae making up the intertidal algal vegetation of Conanicut Island. Three are Cyanophyta, 28 Chlorophyta, 29 Phaeophyta and 44 Rhodophyta. Forty-one species are perennial and 63 annual.

The macroscopic algae of the coastal ponds of Rhode Island were studied and reported on by Wood and Palmatier (1954). The coastal ponds of Rhode Island form an almost continuous series stretching from the southwest corner of the state to the Massachusetts border interrupted by Narragansett Bay and the Sakonnet River. The ponds are separated from the sea by a continuous sand beach. The salinity of the ponds vary as some have permanent breachways, some periodic breachways or none at all. The inland shores are generally rocky and suggest the original coast while

the seaward shores are sandy, an extension of the barrier beach (Wood and Palmatier, 1954).

Table 15 lists the macroscopic algae found together with some environmental factors for the coastal ponds of Rhode Island.

The macroscopic algae of Point Judith Pond, a large estuary several miles southwest of Narragansett Bay, was studied by Vaughan (1971) during the year 1967-1968 (Table 16). Table 17 shows the seasonal occurrence as species diversity, pointing out the great seasonal fluctuation in the flora in abundance and in number of species which can occur among the marine algae.

The Cape Cod area was very early recognized as particularly interesting (Harvey's "Nereis Boreali-Americana", 1852-1852; Farlow's List of the Sea Weeds or Marine Algae of the South Coast of New England, 1873 and his report "The Marine Algae of New England", 1881) in that it seemed to separate a northern flora of arctic origin from a more temperate flora characteristic of the south (Kingsbury, 1969). The reason for the local character of the algal flora north of the Cape is the low range of water temperature which continues through the summer months (Davis, 1911).

The waters south of Cape Cod, including Vineyard Sound, Buzzards Bay, Narragansett Bay, Long Island Sound, and the regions that lie in between are effectively protected from the influence of cold water north and east of the Cape, and consequently become relatively warm during the summer season. Since the water is generally shallow it permits a fairly quick response to atmospheric and seasonal changes. The winter temperature falls close to the freezing point, but rises in the summer to 70°F and higher. Some of the most sheltered harbors and bays may even become much warmer during the summer and regularly freeze over in the winter. This wide range of temperature throughout the year is expressed by sharp seasonal changes in the character of the flora (Davis, 1911).

The marine algae south of Cape Cod may be grouped into what Harvey (1852, p. 26) calls the flora of Long Island Sound, extending from Cape Cod to New Jersey where a habitat problem of increasing rock-free sandy shores provides an inhospitable substrate for benthic marine algae.

The shoreline of Woods Hole, of the Elizabeth Islands and of the neighboring regions along Vineyard Sound and Buzzards Bay consists of boulders and stones or sandy and stony beaches where it is exposed to wave action of tidal currents. The sheltered coves, bays and harbors generally have a sandy or muddy shore with scattered deposits of gravel, stones or boulders. There are no outcroppings of rock, except in the vicinity of New Bedford Harbor, and thus no perpendicular or slanting rock faces and rock pools. Because of this there is not the very characteristic

TABLE 12. Vertical distribution of the more common algae of Cold Spring Harbor (after Johnson and York 1915).

Tide Levels	Vegetational Belts	Thallophytea			
		Supra-Littoral Beach		Supra-Littoral Marsh	
12 feet		Species	Range*	Species	Range
11 feet		Cladonia sp.	9 to 12	s Lyngbya sp.	8 to ?
10 feet	Supra-Littoral Belt. 8 to 12 feet (Storm Beach and Supra-Littoral Marsh.)				
9 feet					
8 feet					
		c Rhizoclonium tortuosum	2 to 8		
		s Calothrix (4 sp.)	6 8		
		s Microcoleus chthonoplastes	4 7.5		
		c Vaucheria sp	5 7		
	Upper Littoral Belt. 6.5 to 8 feet (On all shores.)	c Enteromorpha intestinalis	0 7.25		
		s Lyngbya (8 sp.)	2 2.75		
7 feet		c Capsosiphon fulvescens	1.5 7.5		
		c Monostroma oxyspermum	2.5 7.5		
6.5 feet		s Spirulina tenuissima	0 7		
		p Ascophyllum nodosum	-1 to 7		
6 feet		p Fucus vesiculosus	0 7.25		
		p Fucus vesiculosus spiralis	1.5 6		
		c Rhizoclonium tortuosum	2 8		
		c Rhizoclonium riparium	6 7.5		
		r Bostrychia rivularis	3 7		
		c Ulothrix flacca	3 6.5		

5 feet

Mid-littoral Belt.
1.5 to 6.5 feet.
Mid-littoral Marsh and
Mid-littoral Rockweed
Association

4 feet

3 feet

2 feet

1.5 feet

s	Anabaena torulosa	4 to	7
s	Lyngbya aestuarii	4	7
s	Microcoleus chthonoplastes	4	7.5
p	Ralfsia clavata	?	5
r	Hildenbrandia prototypus	-1	7
c	Enteromorpha intestinalis	0	7.5
c	Monostroma oxyspermum	2.5	7.5
c	Capsosiphon fulvescens	1.5	7.5
c	Vaucheria sp	5	7
c	Cladophora expansa	4	7
p	Pylaiella littoralis v. robustus	-1.5	4.5
r	Caloglossa leprieurii	1	5
s	Rivularia atra	5	6
r	Porphyra umbilicalis	0	4

1 foot

0 foot = M.L.W.

Bottom Vegetation
-5 to +1.5 feet.
(Lower Littoral and Sub-
littoral Belts.)

-1 foot

-2 feet

c	Ulva lactuca v. latissima	-5 to	4
c	Enteromorpha clathrata	-1	7
c	Enteromorpha intestinalis	0	7.25
p	Ascophyllum nodosum	-1	7
p	Fucus vesiculosus	0	7.25
r	Porphyra umbilicalis	0	4
r	Ceramium rubrum	-2	1.5
r	Ceramium strictum	-2	1.5
p	Pylaiella littoralis v. robustus	-1.5	4.5
r	Chrondrus crispus	-2	0
p	Ectocarpus confervoides	0	2
r	Hildenbrandia prototypus	-1	7
r	Agardhiella tenera	-1	1.5
s	Spirulina tenuissima	0	7
r	Caloglossa leprieurii	1	5

-3 feet

* The two numbers given under "range" indicate the levels (above mean low water) between which the species usualls grow.
The species are given in each belt in the order of prevalence.
The small letter before the name of each species shows to the eye, in glancing down the column, the phylogenetic relationship of the forms of each belt. Thus: c = Chlorophcea, p = Phaeophycea, r = Rhodophycea, s = Schizophycea (Cyanophyta).

TABLE 13. The distribution as to habitat of the more common marine algal associations of Connecticut (after Hylander, 1928).

Intertidal Zone Associations of Eroding Seacoasts

Cyanophyta

Gloeocapsa
Pleurocapsa
Calothrix
Isactis

Chlorophyta

Monostroma
Ulva
Enteromorpha
Ilea
Protoderma
Ulothrix
Stichococcus
Hormiscia
Chaetomorpha
Rhizoclonium
Cladophora
Bryopsis

Phaeophyta

Ectocarpus
Sphacelaria
Desmotrichum
Punctaria
Scytosiphon
Phyllitis
Ascophyllum
Fucus
Pylaiella
Ralfsia

Rhodophyta

Bangia
Porphyra
Ceramium
Nemalion
Polysiphonia
Hildenbrandia

Subtidal Zone Associationd of Eroding Seacoasts

Chlorophyta

Bryopsis
Cladorphora
Chaetomorpha
Ulva

Phaeophyta

Ectocarpus
Pylaiella
Desmarestia
Laminaria
Mesogloia
Chorda
Cladostephus
Punctaria
Chordaria

Rhodophyta

Agardhiella	Gracilaria
Ahnfeltia	Grinnellia
Antithamnion	Hildenbrandia
Callithamnion	Lomentaria
Ceramium	Phyllophora
Chondrus	Melobesia
Champia	Nemalion
Corallina	Polyides
Cystoclonium	Polysiphonia
Chondria	Seirospora
Dasya	Spermothamnion
Delesseria	Spyridia

Intertidal Zone Associations of Depositing Seacoasts

Cyanophyta

Spirulina	Microcoleus
Oscillatoria	Anabaena
Lyngbya	

Chlorophyta

Ulva	Enteromorpha
Monostroma	Vaucheria

Phaeophyta

Ectocarpus	Phyllitis
Pylaiella	Halothrix
Ascocyclus	Stilophora

Rhodophyta

Agardhiella	Bangia
Ahnfeltia	Porphyra

Subtidal Zone Associations of Depositing Seacoasts

Chlorophyta

Ulva

Phaeophyta

Ectocarpus	Phyllitis
Pylaiella	Halothrix
Ascocyclus	Stilophora

Rhodophyta

Agardhiella
Ahnfeltia
Ceramium
Polysiphonia
Gracilaria

Marsh Associations

Cyanophyta

Chroococcus
Gomophosphaeria
Spirulina
Lyngbya
Microcoleus
Nostoc
Anabaena
Oscillatoria

Chlorophyta

Monostroma
Cladophora
Rhizoclonium
Ulothrix

Phaeophyta

Fucus
Sphacelaria
Ectocarpus

Tide Pool Associations

Cyanophyta

Chroococcus
Entophysalis
Gomophosphaeria
Spirulina
Amphithrix
Oscillatoria
Lyngbya
Calothrix
Rivularia
Plectonema

Chlorophyta

Cladophora
Enteromorpha
Vaucheria
Ulothrix
Prasinocladus

Phaeophyta

Desmarestia
Dictyosiphon
Scytosiphon
Phyllitis
Ralfsia

Rhodophyta

Ahnfeltia
Ceramium
Cystoclonium
Polyides

TABLE 14. Relative vertical distribution of the intertidal marine algae along the coast of Conanicut Island with respect to the major horizontal zones (after Villalard 1971).

TABLE 15. Tolerance ranges of the macroscopic algae of the coastal ponds of Rhode Island to certain environmental factors (after Wood and Palmatier, 1964).

Species	Access of sea water	Bottom type	Salinity Range o/oo NaCl	pH Range
Agardhiella tenera	permanent	sand, cobble	25.1-30	8.1-9.5
Ceramium fastigiatum	permanent, temporary	sand	0.0-20.0	7.6-8.5
Ceramium rubrum	permanent, temporary	sand, boulders	5.1-35.0	7.6-9.5
Chaetomorpha linum	permanent, temporary	sand, cobble	20.1-35.5	8.1-9.0
Champia parvula	temporary	sand, cobble, boulders	15.1-35.5	8.6-9.5
Chondria tenuissima	permanent, through other ponds	sand, cobble	20.1-30	
Chondrus crispus	permanent	sand	20.1-35.0	7.6-8.5
Cladophora spp.	permanent, temporary, through other ponds, storms, none	sand, cobble boulders	0.0-30.0	7.6-9.5
Cladostephus verticillatus	permanent	sand, cobble	20.1-30	8.1-9.0
Dasya pedicellata	permanent	sand, boulders	20.1-30	8.6-9.0
Enteromorpha clathrata	permanent, storms	sand, cobble, boulders	20.1-35	7.5-9.0
Entermorpha intestinalis	permanent, temporary, throuth other ponds, storms	sand, cobble, boulders	0.0-35.0	7.6-9.0
Enteromorpha prolifera	permanent, storms	sand, cobble, boulders	20.1-35	8.1-9.0
Fucus vesiculosus	permanent	sand, boulders	20.1-35	7.6-8.5
Gracilaria confervoides	through other ponds	sand, cobble, boulders	5.1-35	7.6-9.0
Griffithsia tenuis	permanent	boulders	25.1-30	8.1-8.5
Lomentaria baileyana	permanent	boulders	25.1-30	8.1-8.5
Lyngbya spp.	permanent	sand, cobble, boulders	5.1-30	8.1-9.5
Oscillatoria spp.	permanent, through other ponds, temporary	sand, cobble, boulders	0.0-30	7.6-9.0
Polysiphonia harveyi	permanent, through other ponds, storms	sand, cobble, boulders	5.1-35	7.6-9.0
Polysiphonia subtilissima	permanent, through other ponds, temporary, storms	sand, cobble, boulders	0.0-35	7.0-9.0
Polysiphonia variegata	permanent	sand	20.1-35	8.1-9.0
Rhizoclonium sp.	permanent, through other ponds	sand, cobble	0.0-30	7.6-9.0
Sargassum filipendula	permanent	sand, cobble	20.1-30	8.6-9.0
Spyridia filamentosa	permanent, temporary, storms	sand, cobble, boulders	5.1-30	8.1-9.5
Spirogyra spp.	permanent, through other ponds,	sand, cobble, boulders	5.1-30	8.1-9.5
Ulva lactuca	permanent, temporary, storms	sand, cobble, boulders	5.1-35	7.6-9.5

TABLE 16. Seasonal occurrence of macroscopic algae of Point Judith Pond, R.I. July 1967 to June 1968 (Vaughan 1971).

Species	J	A	S	O	N	D	J	F	M	A	M	J
Agardhiella tenera	X	X	X	X	X			X	X	X	X	X
Ahnfeltia plicata	X		X	X					X	X		
Ascophyllum nodosum	X	X	X	X	X	X	X	X	X	X	X	X
Asparagopsis hamifera	X											X
Bangia fuscopurpurea									X	X	X	
Ceramium rubrum	X	X	X	X	X	X	X	X	X	X	X	X
Chaetomorpha linum	X	X	X	X		X	X		X			X
Chondrus crispus	X	X	X	X	X	X	X	X	X	X	X	X
Chorda tomentosa	X								X	X	X	X
Chordaria flagelliformis	X	X										X
Cladophora gracilis	X	X	X							X		X
Codium fragile	X	X	X	X	X	X	X	X	X	X	X	X
Cystoclonium purpurem									X	X		
Desmarestia viridis	X				X	X	X	X	X	X	X	X
Dumontia incrassata	X							X	X	X	X	
Ectocarpus confervoides	X	X	X	X			X	X				
Elachistea fucicola	X	X		X	X	X						X
Enteromorpha intestinalis	X	X	X	X	X	X	X	X	X	X	X	
E. linza		X	X						X			X
E. minima	X	X	X	X				X	X	X	X	X
E. prolifera	X	X							X	X	X	X
Fosliella lejolisii	X	X	X	X				X	X	X	X	
Fucus edentatus	X	X					X	X	X	X		X
F. evanescens								X	X		X	
F. vesiculosus	X	X	X	X	X	X	X	X	X	X	X	X
Gigartina stellata	X	X	X	X		X			X		X	X
Gracilaria verrucosa	X	X										X
Grinnellia americana					X							X
Hildenbrandia prototypus	X	X	X	X	X	X	X			X	X	
Laminaria agardhii	X	X	X	X	X	X	X	X	X	X	X	X
Monostroma grevillei								X	X	X		
Petalonia fascia		X							X		X	X
Phyllophora membranifolia	X	X	X		X				X	X	X	X
Phymatolithon laevigatus	X							X	X			X
Polysiphonia elongata	X		X			X	X					X
P. harveyi	X	X	X						X	X	X	X
P. urceolata	X									X	X	X
Porphyra umbilicalis	X	X	X	X				X	X	X	X	X
Punctaria plantaginea	X	X	X			X	X	X	X	X	X	X
Pylaiella littoralis						X	X	X	X	X	X	
Rhodymenia palmata	X	X	X	X	X	X	X	X	X	X	X	X
Scytosiphon lomentaria	X	X	X						X	X	X	X
Sphaerotrichia divaricata	X		X									X
Spongomorpha arcta	X						X	X	X	X	X	
Ulva lactuca	X	X	X	X	X	X	X	X	X	X	X	X

TABLE 17. Seasonal occurrence of macroscopic algae of Point Judith Pond, R.I. As diversity (number of species) per month from July 1967 to June 1968 (Vaughan, 1971).

Month	Number of Species Found
July	40
August	31
September	28
October	20
November	17
December	18
January	19
February	25
March	39
April	32
May	30
June	35

association of algae which may be noted in tide pools and on rock faces where there is conspicuous development of colored bands or zones of vegetation between and below tide marks as can be seen at Newport and at Nahant, near Boston. The illustrations of zonation are small in scale and must be studied in detail as was done by Davis, 1911 for Spindle Rocks in Woods Hole harbor. The chief reasons for the comparatively undeveloped character of algal vegetation zones can be listed: 1) the small tides give a relatively narrow strip of coastline, usually only a few feet wide; 2) a shore of boulders, frequently broken by sand or gravelly beaches, lacking rock faces for attachment; 3) the absence of a marked boreal flora, except for a few representatives found chiefly in the winter and early spring, depriving the region of a number of species of Monostroma, Alaria, Dictyosiphon, Fucus, Laminaria, Sacchorhiza, Gigartina and Halosaccion which are conspicuous north of the Cape; 4) the scraping of ice during the winter season prevents development of some brown and green species (Davis 1911).

A general description of the marine algal vegetation is presented below from Davis (1911). A more detailed and complete discussion of the algal succession on Spindles Rock and for the deeper waters of Buzzards Bay and Vineyard Sound is not included here but may be found in the above mentioned work.

Supratidal Fringe

Calothrix may be found on stones and woodwork, C. pulvinata is the most conspicuous on wood pilings of wharves. C. scopulorum grows conspicuously on rocks near or above the high water mark. Bangia fuscopurpurea and Ulothrix flacca commonly form patches on rocks and woodwork near the high water mark.

Rocks and stony beaches above the low water mark frequently exhibit striking growths of species of Ulva, Enteromorpha, Monostroma and Cladophora. Ulva lactuca var. rigida is common on rocks exposed to wave action. Enteromorpha intestinalis is often abundant in quiet waters attached to stones and shells and sometimes to woodwork as is Entero-Morpha linza. E. Minima is very common in the spring and summer near the high water mark. In the spring Monostroma grevillei is abundant on stones and larger algae a little above low water. Cladophora albida forms patches on rocks in the summer. Spongomorpha arcta is very abundant in the spring on wharves and harbor walls. C. flexuosa and C. glaucescens are also abundant on rocks in the summer season. C. gracilis achieves prominence in quiet sheltered waters. These forms are generally responsible for the conspicuous green zones on wharves, rocks and beaches above the low water mark together with Ulothrix flacca which also occurs in the intertidal zone.

Ascophyllum nodosum grows plentifully over rocks near low water and above in somewhat sheltered conditions. Its best vegetation condition is found during the winter and spring. Fucus vesiculosus with its several forms and varieties, is more plantiful than Ascophyllum, growing over a wide zone from below the low water mark to the middle of the intertidal zone. It is also found in its best vegetative condition during the winter and spring. Ascophyllum and Fucus frequently form a mixed association at Woods Hole, which during the winter develops a broad zone in the intertidal region not subject to ice scraping.

Nemalion multifidum is a very characteristic summer species frequently forming a broad red zone on rocks a little above low water, apparently requiring some degree of exposure to air. Porphyra umbilicalis frequently develops heavy growths on the harbor walls at Woods Hole near the low water mark. Porphyra leucosticta is a common spring species common on larger algae and on Zostera. Chondrus crispus is a conspicuous member on exposed rocks of the zone of red algae occurring generally below Ceramium rubrum and species of Polysiphonia. It also occurs below the low tide mark and is an important year round species.

Scytosiphon lomentaria is an abundant species occurring on rocks and stony beaches during the winter and spring when it develops extensive growth and can cover large areas whereas it all but disappears during the summer.

Many species occur below the surface dominated by the brown Chorda filum, C. tomentosa, Laminaria agardhii and L. digitata. During the summer Sargassum filipendula is common in the warmer more sheltered regions of the bay and sound. Chordaria flagelliformis forms extensive mats on stones and rocks a little below tide level during the summer months. Ralfsia clavata is very abundant on stones and shells at the low water mark and below.

Dictyosiphon and Desmarestia are commonly found growing over sandy and stony bottoms. Chondria, Polysiphonia, Dasya, Corallina and Ahnfeltia are also common subtidal species.

Zostera marina, eelgrass, is very abundant in all sheltered regions of both bay and sound, forming thick beds in shallow waters. It was frequently found at inshore stations of the survey, and also at scattered stations in deep waters of the bay and sound, being dredged in 2 to 13 fathoms over sandy, stony and muddy bottoms. The thick extensive beds develop in 2-12 ft of water in the coves, bays and along sheltered coasts.

When the Zostera grows in very quiet and shallow waters the blue-green alga, Anabaena torulosa, is common on the mud at the base of the plants, frequently breaking loose and floating on the surface as slimy masses. Lyngbya majuscula sometimes forms extensive tufts which can break free to also float on the surface. Hydrocoleum glutinosum and Gloeocystis zostericola form coatings on the leaves and Enteromorpha clathrata, E. plumosa, with other species and sometimes species of Cladophora will grow in loosely attached masses. These algae are all forms which might be expected in brackish water.

When the Zostera grows in more open or exposed situations, the list of epiphytes includes species which are never found in brackish water. Among these the following are most conspicuous:

Cladophora gracilis
Ectocarpus confervoides
E. siliculosus
Desmotrichum balticum
D. undulatum
Punctaria latifolia
Castagnea zosterae
Porphyra leucosticta
Chantransia virgatula
Callithamnion byssoideum
C. corymbosum
C. roseum
Ceramium fastigiatum
C. strictum
C. tenuissimum
Seirospora griffithsiana
Spyridia filamentosa
Dasya pedicellata
Polysiphonia harveyi
Melobesia lejolisii

Jordan (1874) published a list of 81 species of algae for Penikese Island.* Some of this material has been reinvestigated by Davis (1911), Lewis (1924) and Taylor (1937). Doty's (1948) work was an attempt to assemble the records of the algae of Penikese Island in a concise manner. It is from this work that the following brief description was taken for the algal vegetation of Penikese Island.

In general the Cyanophyta were recognized as belonging to one of three categories. The first was those species restricted to particular

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* Penikese Island, one of the southernmost of the Elizabeth Islands, was the site of the first marine biological station in North America (1873-74). It persisted for only two years but led to the establishment of the Marine Biological Laboratory at Woods Hole, Mass.

habitats or hosts. For example Calothrix parasitica in the fronds of Nemalion or Isactis plana on the fronds of Punctaria. The second category included those species found in or on calcareous remains of molluscs and similar substrates at Hyella caespitosa, Mastigocoleus testarum, Lyngbya lutea and Plectonema terebians. The third category of species was that component comprising the Calothrix or black zone of the supratidal region. Here Calothrix crustacea and Plectonema calothrichoides dominated, other species such as Calothrix scopulorum, C. vivipara, Entophysalis granulosa and Plectonema norvegicum were frequent. Late in the season Rivularia atra became conspicuous near mean high tide level as hard, gelatinous black, pin-head-size hemispheres on barnacles and rocks.

Among the Chlorophyta, Prasiola stipitata often appears in the supratidal zone. Blidingia minima and some forms of Ulothrix flacca occur on rocks which are often sprayed in the same zone. Enteromorpha intestinalis appears when there is exposure to fresh water or in rock pools where salinity varies greatly. In coves and along open shores among boulders affording some protection, E. linza was often the dominant form, usually above Ulva lactuca which became conspicuous in the most protected areas. At no place was Cladophora a dominant alga.

There were no conspicuous brown algal communities in the supratidal regions, but in the intertidal and subtidal regions they were the dominant forms. Fucus spiralis occupied the upper part of the intertidal zone with F. vesiculosus just below and with Ascophyllum nodosum about 1 foot lower than the F. vesiculosus. Ralfsia verrucosa becomes dominant on rocks and barnacles in restricted areas as small coves, in the middle of the intertidal zone or below Fucus and Ascophyllum. In the comparatively quiet waters Laminaria agardhii was conspicuous just below low tide often together with Chorda filum and Sargassum filipendula. In the most exposed areas Laminaria digitata was most conspicuous.

As with the brown algae, there were no dominant forms of red algae in the supratidal region. In the intertidal zone Bangia fuscopurpurea mixed with Calothrix or Codiolum sometimes showed as a distinct dominant association in the upper reaches of the intertidal zone. Polysiphonia novae-angliae and Ceramium rubrum extend below the intertidal zone, but often dominated in the lower reaches of the intertidal zone. Hildenbrandia prototypus is often a dominant form between the upper and subtidal zone species. Chondrus crispus extended down in some places to a depth of 40 feet and in exposed areas, Corallina officinalis formed a conspicuous band downwards for about 9 feet. On rocks and shells over sandy bottom Dasya pedicellata, Ceramium rubrum and Champia parvula were usually dominant in the lower levels of the upper subtidal zone.

Summary

The importance of Nantucket Shoals - Cape Cod and Cape Hatteras as boundaries in the distribution of marine algae along the Atlantic coast of North America has long been noted. Harvey, as early as 1852-1858, in his "Nereis Boreali-Americana," divided the marine algae of this coast into four main geographic regions. These were (moving from south to north) first, the shores of the Gulf of Mexico to the Florida Keys; second from Cape Florida to Cape Hatteras; third, from Cape Hatteras to Cape Cod; and last the coast north of Cape Cod extending to Greenland (Villalard 1971).

Farlow (1881), in the first major work dealing with the majority of the East Coast marine algae, confirmed Harvey's opinion as to the importance of Cape Cod as a southern boundary limit for many cold-water species (Humm 1969).

Setchell (1915, 1917, 1920) drew some conclusions regarding the marine floristic regions of the world after study of both the Pacific and Atlantic coasts of North America. He believed that temperature was the primary factor in distribution and subsequently divided the world's marine algae into zones based on isotherms. These zones were (moving from warm to cold or equator to pole):

1. Tropical, 25^{o} to 30^{o} C
2. North subtropical and south subtropical, 20^{o} to 25^{o} C
3. North temperate and south temperate, 15^{o} to 20^{o} C
4. Lower boreal and lower austral, 19^{o} to 15^{o} C
5. Upper boreal and upper austral, -2^{o} to 10^{o} C

Setchell felt that most marine algae were confined to a single temperature-limited zone, that some species may extend through two zones, and rarely a few species may extend through three zones (Humm 1969).

Nantucket Island - Cape Cod is probably the more distinctive boundary as a small portion of the Labrador Current swings south to the north side of the Cape before moving off to the northeast; while on the south side, warmer waters from the influence of the Gulf Stream produce a rather abrupt temperature differential, especially during the summer. Even so, it is not so much a boundary as a transition zone because there are several warm bays north of the Cape with species extending from the tropics in the summer. South of the Cape there are several areas in which the algae are more characteristic of more northern waters such as Montauk Point, Long Island, where a year-round development of kelp occurs (Humm 1969).

At Cape Hatteras the Gulf Stream moves offshore. A cool inshore current moves south along the mouth of the Chesapeake Bay and Virginia Capes before it also moves offshore to Cape Hatteras north of the Gulf

Stream. The convergence of these currents as at Nantucket Island - Cape Cod would suggest that Cape Hatteras would also be a distinct boundary; however, strong northeast winds force the colder waters inside the Cape into the Pamlico and Albemarle Sounds especially in the winter. This makes the boundary or transition zone more nearly at Beaufort Harbor, N.C. (Humm 1969).

The distribution of marine algae along the East Coast has been characterized neatly in a proposal by Humm (1969) that there are two geographic populations, one having originated and being centered in the tropics with a northern boundary of Cape Canaveral (Kennedy). The other originated and is centered in the cold waters of the northwest Atlantic with its southern boundary, Cape Cod.

Thus, the marine algae outlined in this survey consist of the components of a vast transition zone composed of the more eurythermal species from both population centers. The algae are subject to general salinity problems in estuaries and tide pools,substrate problems in the lack of a suitable substrate (i.e., rocky shores) south of New York - New Jersey, seasonal changes in flora (i.e., winter-summer), thermal and chemical pollution and so on.

Table 18 gives the comparative phenology and seasonal periodicities of some of the more common marine algae along the east coast of North America. It should be stated, however, that the incompleteness of available species distributions and the paucity of intensive yearround investigations of marine benthic algae on many parts of the coast in the study area together with the demands for space and time have made this survey somewhat general and at times, unfortunately dependent on existing older literature.

TABLE 18. Comparative phenology of the reproductive and seasonal periodicities of some benthic marine algae along the east coast of North America.

Legend: + = present; - = absent; ± = dormant; ? = data as interpreted from the reference by the present authors; a = anteridia; c = cystocarps; F = fructificating, but the type of fructification is not indicated; fa = form; g = gametangia; M = maximum development; m = monospores; t = tetraspores; var. = variety; X = not mentioned or insufficient data only.

References used in compiling this table are indicated as follows: NEA = northeastern coast of North America (Taylor, 1957); WH = Great Pond, Woods Hole, Mass. (Conover, 1958); ChB = lower Chesapeake Bay (Zaneveld and Barnes, 1965); B = Beaufort, N.C. (Hoyt, 1920); CL = Cape Lookout, N.C. (Williams, 1948). NEA and CL refer to the open Atlantic Ocean; WH, ChB, and B to estuaries (Zaneveld and Barnes, 1965).

			Winter			Spring			Summer				Autumn	
Species	References	Remarks	12	1	2	3	4	5	6	7	8	9	10	11
Enteromorpha intestinalis	NEA		+	+	+	+	+	+	+	+	+	+	+	+
	WH		+	+	+	M	M	M	+	+	+	M	+	+
	ChB		-	-	-	+	+	+	M,s	M,s	M,s	M,s	S	-
	B		-	-	-	+	M	M	-	-	-	-	-	-
	CL		+	+	+	+	+	+	+	+	+	+	+	+
Enteromorpha minima	NEA		-	-	-	-	-	-	+	+	+	-	-	-
	WH	X												
	ChB		+	+	+	-	-	-	M,s	M,s	M,s	-	-	+
	B	X												
	CL		-	+	+	+	+	+	-	-	-	-	-	-
Enteromorpha linza	NEA		-	-	-	-	-	+	+	+	+	-	-	-
	WH		+	+	+	M	M	M	+	M	+	M	M	+
	ChB		+	+	+	+	+	+	M,s	M,s	M,x	M,s	s	+
	B		-	-	+	+	+	+	-	-	-	-	-	-
	CL		-	+	+	+	+	+	-	-	-	-	-	-
Ulva lactuca	NEA		+	+	+	+	+	+	+	+	+	+	+	+
	WH		M	+	+	M	M	M	M	+	+	+	+	+
	ChB		+	+	+	+	+	+	M,s	M,s	M,s	M,s	+	+
	B	var.	+	+	+	M	M	M	+	+	+	+	+	+
	CL		M	M	M	+	+	+	+	+	+	+	+	+
Cladophora flexuosa	NEA	?	+	+	+	+	+	+	+	+	+	+	+	+
	WH		M	+	+	M	M	M	M	+	+	+	+	+
	ChB		-	-	-	-	-	s	s	s	s	s	-	-
	B		-	-	-	-	+	-	-	-	-	-	-	-
	CL	X	-	-	-	-	+	-	-	-	-	-	-	-

Species	References	Remarks	12	1	2	3	4	5	6	7	8	9	10	11
Cladophora gracilis	NEA	?	+	+	+	+	+	+	+	+	+	+	+	+
	WH	fa	+	-	-	+	+	+	M	+	+	M	M	M
	ChB		±	-	-	-	-	-	s	s	s	s	+	±
	B	X												
	CL	X												
Bryopsis hypnoides	NEA	?												
	WH	X												
	ChB		-	-	-	-	-	-	g	g	g	+	-	g
	B	X												
	CL		-	-	-	-	-	+	+	+	+	-	-	-
Bryopsis plumosa	NEA	?	-	+	+	+	+	+	+	+	-	-	-	-
	WH		+	+	+	M	M	+	+	-	-	-	-	+
	ChB		-	-	-	-	+	+	m	m	m	+	-	-
	B	X												
	CL	?	+	+	+	-	-	-	-	-	-	-	-	-
Petalonia fascia	NEA	?	±	±	±	+	+	+	F	F	+	+	±	±
	WH		M	+	+	M	M	+	+	-	-	-	-	+
	ChB		-	M	M	M	M	+	+	+	+	-	-	-
	B		M	M	M	M	M	-	-	-	-	-	-	+
	CL		+	+	+	-	-	-	-	-	-	-	-	+
Scytosiphon lomentaria	NEA		F	F	F	F	F	F	+	+	+	+	+	+
	WH		+	+	+	+	+	+	+	+	-	-	-	+
	ChB		-	+	+	M	M	M	+	+	-	-	-	-
	B	X												
	CL		+	+	+	+	+	-	-	-	-	-	-	-
Bangia fuscopurpurea	NEA		-	-	-	+	+	±	±	±	-	-	-	-
	WH		-	+	M	M	+	-	-	-	-	-	-	-
	ChB		+	m	m	-	-	m	m	m	-	-	-	-
	B		+	+	+	+	+	+	-	-	-	-	-	-
	CL	X												
Porphyra leucosticta	NEA		-	-	-	+	+	+	-	-	-	-	-	-
	WH		+	+	M	M	+	±	-	-	-	-	-	-
	ChB		±	+	M	M	c,a	±	-	-	-	-	-	-
	B		+	+	M	+	M	+	-	-	-	-	-	-
	CL		+	+	+	+	+	+	-	-	-	-	-	-

Species	References	Remarks	12	1	2	3	4	5	6	7	8	9	10	11
Porphyra umbilicalis	NEA	?	-	-	-	±	±	±	+	F	F	+	±	±
	WH	X												
	ChB		±	+	M	M	c,a	±	±	±	-	-	-	-
	B	X												
	CL		-	-	+	c,a	c,a	-	-	+	+	+	-	-
Gelidium crinale	NEA	?	±	±	±	±	±	±	±	F	F	±	±	±
	WH		-	-	-	-	-	+	M	M	M	M	+	-
	ChB		-	-	-	+	-	-	-	+	t	+	-	-
	B	?	+	+	+	+	+	+	+	+	+	+	+	+
	CL		+	+	+	+	+	+	M	M	+	+	+	+
Gracilaria verrucosa	NEA	?	±	±	±	±	±	±	±	+	+	±	±	±
	WH		+	+	+	+	M	M	M	M	M	M	M	+
	ChB		+	±	±	+	+	+	t,c	t,c	+	+	t	t
	B		-	+	+	+	F	F	F	F	F	F	F	+
	CL	X												
Gracilaria foliifera	NEA	?	±	±	±	±	±	±	±	F	F	F	F	±
	WH	X												
	ChB		-	-	+	-	-	-	-	-	-	±	±	c
	B		+	M	M	F	F	F	F	F	F	F	F	+
	Cl	var.	-	-	-	-	-	-	-	+	c,a	+	+	-
Agardhiella tenera	NEA		-	-	-	+	+	+	F	F	F	+	±	-
	WH		±	±	±	±	+	+	+	M	M	+	±	±
	ChB		±	±	±	±	±	t+c	t,c	t,c	c	M	±	±
	B		M	M	M	M	M	M	+	+	+	+	+	+
	CL		-	-	-	-	+	+	+	-	-	-	-	-
Champia parvula	NEA		±	±	±	±	±	-	F	F	F	F	±	±
	WH	-	-	-	-	-	-	M	M	M	+	+	-	-
	ChB		-	+	-	-	-	-	+	t	t	+	-	-
	B		+	-	-	+	M	M	+	+	+	+	+	+
	CL	X												
Callithamnion byssoides	NEA	?	±	±	±	±	±	±	F	F	F	±	±	±
	WH		+	+	+	M	+	+	+	-	-	-	-	M
	ChB		±	±	-	-	±	+	+	t	t	+	+	+
	B	X												
	CL		-	-	-	-	-	t,c,a	t,c,a	t,c,a	-	-	-	-

Species	References	Remarks	12	1	2	3	4	5	6	7	8	9	10	11
Ceramium fastigiatum	NEA	?	±	±	±	±	±	±	±	F	F	±	±	±
	WH	X												
	ChB		-	-	-	-	-	-	+	t	t	+	-	-
	B	X	X											
	CL	?	+	+	+	+	+	+	+	+	+	+	+	+
Ceramium strictum	NEA	?	±	±	±	±	±	±	F	F	F	±	±	±
	WH	X												
	ChB		-	-	-	-	+	-	t	t	t	+	t	+
	B		-	-	+	+	M	M	+	+	-	-	-	-
	CL		+	+	+	+	M	M	M	+	+	+	+	+
Ceramium diaphanum	NEA		-	-	-	+	+	+	+	F	F	+	-	-
	WH	X												
	ChB		-	-	-	-	-	-	c	t	t	-	-	-
	B	X												
	CL		-	-	-	-	-	-	+	+q	+	-	-	-
Ceramium rubrum	NEA		+	+	+	+	+	+	F	F	F	+	+	+
	WH		±	±	±	M	+	+	+	+	+	M	M	M
	ChB		+	+	t,c	+	+	+	t,c	t,c	+	+	+	t,c
	B	-	-	-	-	-	-	-	-	-	-	-	-	-
Grinnellia americana	NEA		-	-	-	-	-	+	F	F	-	-	-	-
	WH		-	-	-	-	-	-	+	+	M	+	-	-
	ChB		-	-	t	-	-	+	t	t	t	+	+	-
	B		+	M	M	M	M	M	+	+	+	-	-	-
	CL		-	-	+	+	+	+	+	-	-	-	-	-
Dasya pedicellata	NEA		-	-	-	-	-	-	F	F	F	F	-	-
	WH		-	-	-	-	-	-	-	-	+	+	+	+
	ChB		-	+	t,c,a	+	-	-	-	t	+	-	-	-
	B		+	+	+	F	F	M	-	-	-	-	-	-
	CL		-	-	-	-	-	+	+	+	-	-	-	-
Polysiphonia harveyi	NEA	?	±	±	±	±	±	±	F	F	F	±	±	±
	WH	var.	+	+	+	+	+	M	M	M	+	+	+	+
	ChB		±	±	t,a	-	-	+	t,c	t,c,a	t,c	+	+	+
	B		-	-	-	-	-	-	+	t	t	t	t	-
	CL	X												

Species	References	Remarks	12	1	2	3	4	5	6	7	8	9	10	11
Polysiphonia denudata	NEA		±	±	±	±	±	±	±	t	t	t	+	t
	WH		±	±	±	+	+	+	+	+	M	M	d	d
	ChB		-	-	-	-	-	-	+	t,c	t	t	+	t
	B		-	-	-	-	-	-	+	t	t	t	-	-
	CL	-	-	-	-	-	-	-	+	+	+	-	-	-
Polysiphonia nigrescens	NEA		+	+	+	F	F	F	F	F	F	-	-	-
	WH	X												
	ChB		-	-	t,c,a	±	+	+	c	c,a	c	+	-	-
	B		-	-	-	+	F	+	-	-	-	--	-	-
	CL		-	-	-	+	M	+	-	-	-	-	-	-

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Marine Geology

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Marine Geology

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Introduction

The Middle Atlantic Bight is perhaps the best studied continental margin in the world. Many historically important geologic studies were done first on this shelf and slope, including early studies on shelf sediments and sedimentary processes (Bailey, 1851; Pourtales, 1870, 1872; Shepard and Cohee, 1936; Stetson, 1938, 1939), the first comprehensive and precise bathymetric charts based on echo soundings (Veatch and Smith,

1939, as well as early seismic refraction studies (Ewing et al., 1937, 1938) which have been so essential to our understanding of the structure and history of the continental margin. The history of 19th century exploration has been summarized by Schopf (1968), and the 20th century investigations have been discussed by Emery (1966), Uchupi (1963) and Emery and Uchupi (1972).

The most comprehensive report published on the Middle Atlantic Bight is contained within the recent book by K.O. Emery and Elazar Uchupi (1972), "Western North Atlantic Ocean: Topography, Rocks, Structure, Water, Life and Sediments". Because the book discusses the entire western North Atlantic margin, the many aspects pertaining to the Middle Atlantic Bight tend to be general and scattered throughout the book.

This paper focuses on several key topics relating to the geology of the Middle Atlantic Bight: morphology, structure, sediments and modern processes.

With man's increasing utilization and alteration of the shoreline, estuaries and shelf, it becomes increasingly important to document and predict his impact upon the area. Hopefully by understanding present-day parameters, we can gain better insights into the practical utilization of the economic and esthetic resources of the area.

Regional Physiography and Geology

The physiography and geology of the land bordering the Middle Atlantic Bight have been discussed by Fennemann (1938), Murray (1961), Maher (1965, 1971), Uchupi (1968b) and Emery and Uchupi (1972), and thus need be mentioned only briefly in this paper. Pre-Mesozoic metamorphic and igneous rocks dip gently east from the Appalachian mountains and underlie the continental shelf and slope. South of Long Island the pre-Mesozoic rocks outcrop within the Piedmont Province. Seaward is the Coastal Plain Province, which is comprised mainly of post-Triassic sediments and has regional dips of less than 1 m/km. The subaerial Coastal Plain decreases in width to the north from more than 300 km at Cape Hatteras to less than 50 km in northern New Jersey. East of Long Island it is completely submerged except for appearances on Long Island, Block Island and Martha's Vineyard. These islands represent a cuesta of Cretaceous and Tertiary rocks marking the landward edge of the Coastal Plain (Johnson, 1925; Maher, 1971). As will be seen in a later section of this paper, the Coastal Plain continues over much of the continental shelf (locally buried by up to 100 m of sediment) to the north and east, and locally the upper strata have provided much of the surficial sediment in such areas as Georges Bank and Nantucket Shoals.

The shoreline along much of the southern Middle Atlantic Bight is underlain by 2000 to 3000 m of Cretaceous and younger sediments, while

southern New England contains exposures of mainly Paleozoic metamorphic and igneous rocks, broadly termed the New England Upland (Fennemann, 1938) (Figures 10.1 and 10.11). Rocky shorelines are limited to those areas in which the New England Upland intersects the shoreline, principally in the states of Connecticut and Rhode Island. Even here, however, coastal elevations rarely exceed 50 m.

The coastal morphology of the Middle Atlantic Bight changed markedly during the Quaternary. The entire area north and east of northern New Jersey was covered by several Pleistocene glaciations (Figure 10.2). Long Island, Block Island, Martha's Vineyard, Nantucket Island and Cape Cod are covered largely by glacial moraine deposits. The area south of Long Island also was influenced by the low stands of sea level, which resulted in drowned river channels, most characteristically represented by Delaware and Chesapeake Bays.

The Middle Atlantic Bight is composed of four major drainage systems. The area from Cape Cod to the New York-Connecticut state line is characterized by a number of rivers that drain directly south from the New England Upland. The Connecticut River accounts for over 60% of the water discharge in the area (Table 1a and 1b). The area from the New York-Connecticut state line to Cape May, New Jersey is drained primarily by the Hudson River. The drainage system between Cape May and Cape Henry, Virginia includes those rivers which empty into Delaware and Chesapeake Bays. The major rivers in this area are the Delaware River in Delaware Bay and the Susquehanna, Potomac, James, Rappahannock and York Rivers in Chesapeake Bay. Rivers south of the Susquehanna River include those draining Piedmont areas and those which drain primarily Coastal Plain terrain. In contrast, northern rivers drain primarily those areas that were covered or strongly affected by Pleistocene glaciation. The effect of this difference between northern and southern rivers will be discussed in a following section. The fourth drainage system extends from Cape Henry to the Neuse River, North Carolina, south of Cape Hatteras. Within the northern part of this area, the most important river is the Roanoke River, which discharges an average of 244 m^3/sec (Table 1b).

The Shoreline

The shoreline along the Middle Atlantic Bight can be characterized by the embayed estuaries and barrier islands which are typical of the shore south of Long Island.

Estuaries

The Middle Atlantic Bight contains three major estuaries - Chesapeake Bay, Delaware Bay and New York and James River estuaries

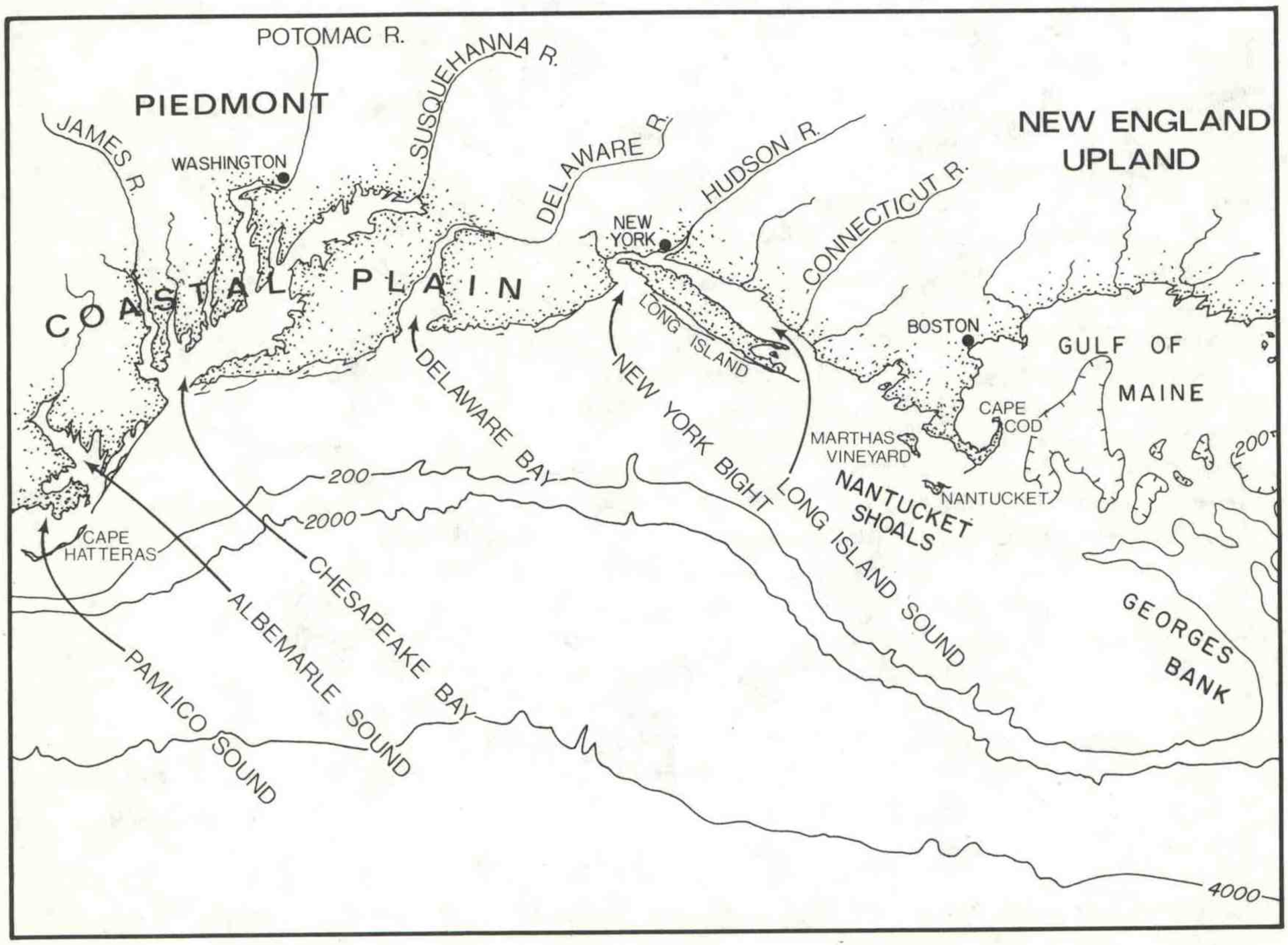

Figure 10.1. Geographic and physiographic locations within the Middle Atlantic Bight. The area bounded by the 200 m isobath represents the continental shelf. The continental slope is defined roughly by the 200 and 2000 m isobaths.

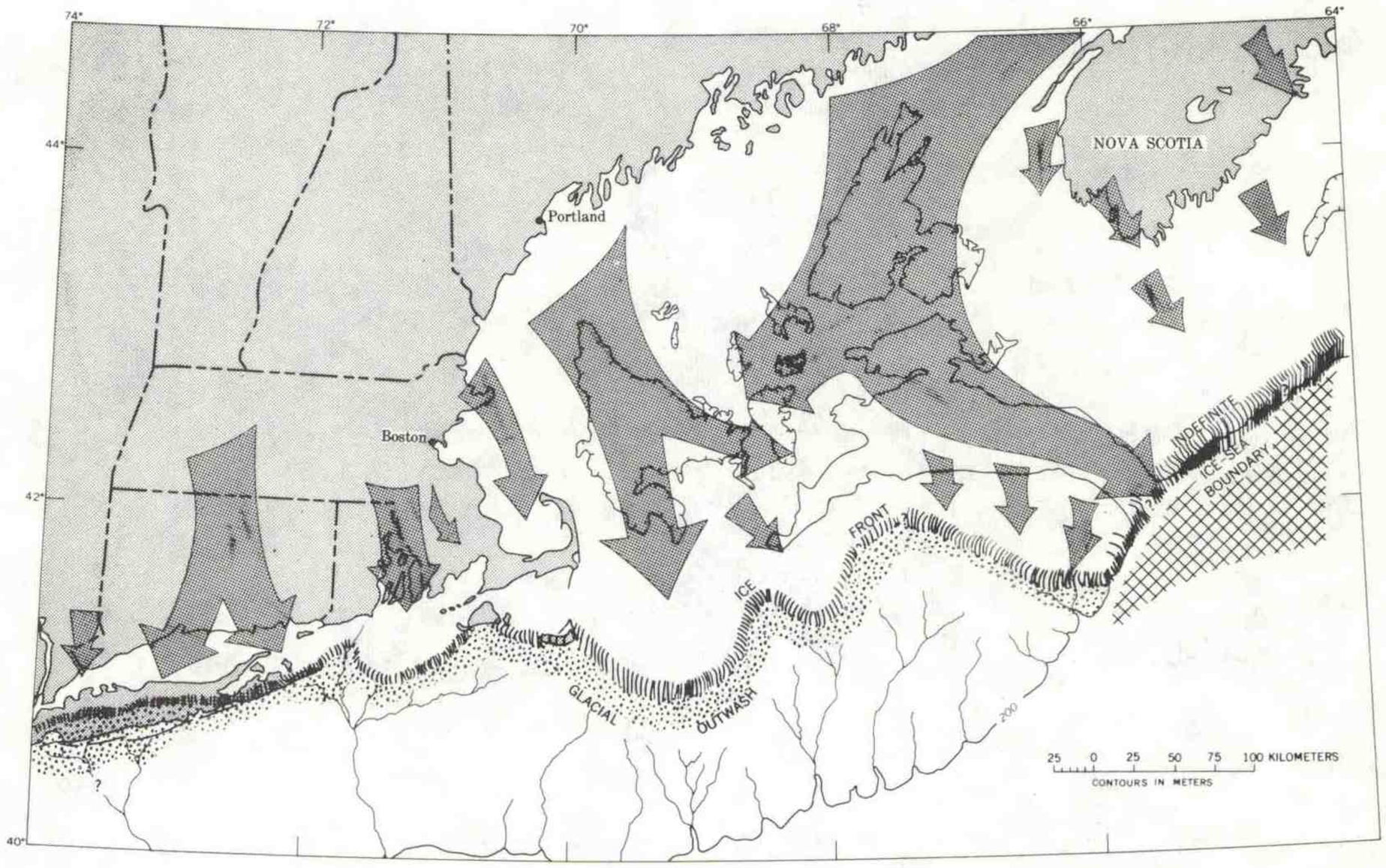

Figure 10.2. Schematic position of the glacial ice sheet in southern New England and the adjoining continental margin during the last Wurm glaciation. From Schlee and Pratt (1970).

TABLE 1a. Major drainage areas along the Middle Atlantic Bight - their drainage area, water discharge and suspended load. Data from Curtis et al.,(1973).

Area	Drainage Area (km^2)	Water Discharge m^3/sec	Suspended Matter $x10^6$ tons/yr
Cape Cod Bay to NY-Conn. State line	46,537	986	780
NY-Conn. State line to Cape May, N.J.	50,391	928	970
Cape May to Cape Henry, Va.	205,283	2,866	5,262
Cape Henry to Neuse River, N.C.	73,199	799	1,361

TABLE 1b. Major rivers along the Middle Atlantic Bight - their drainage area, water discharge and suspended load. Data from Wilson and Iseri (1969) and Curtis et al., (1973). Data in parentheses from Dole and Stabler (1909).

Area	Drainage Area (km^2)	Water Discharge m^3/sec	Suspended Matter $x10^6$ tons/yr
Connecticut River	(28,416)	606	(81)
Hudson River	(34,304)	< 645	(367)
Delaware River	17,560 (33,536)	564	749 (380)
Susquehanna River	62,419	1,141	1,953 (845)
Potomac River	24,996	388	786 (913)
James River	(26,624)	284	(898)
Roanoake River	(24,960)	244	(2.263)

within Chesapeake Bay, Long Island Sound, Narragansett Bay and Buzzards Bay (Figure 10.1). General discussions of the coastal environment of New England and the general circulation and sedimentation patterns within estuaries have been given by Meade (1971, 1972a). An extensive review of the literature pertaining to sediments and sedimentary environments of the U.S. estuaries was compiled by Folger (1972a). Each of the Middle Atlantic Bight estuaries will be discussed in the following paragraphs along with reference to some of the more important studies made in each area.

Buzzards Bay and Narragansett Bay are small estuaries lying just south of the New England Upland. Both river flow and incoming suspended matter is low in these bays. Sediment distribution depends upon the local topography and upon water circulation (Hough, 1940; Moore, 1963; Rhoads, 1967; Rhoads and Young, 1970; McMaster, 1960). Morton (1972) estimates that only about 10 percent of the suspended matter brought into Narragansett Bay actually escapes into Rhode Island Sound, the rest remaining trapped within the bay.

Long Island Sound (Nichols, 1964) and New York Harbor (DeFalco, 1967) receive most of their fresh water from the Connecticut and Hudson Rivers, respectively. These two estuaries are distinguished from others along the Middle Atlantic Bight by the high density of population and industrialization along much of the shoreline. Probably no area in the United States has received the impact of human activity that this area has. Industrial pollution, duck farming, dumping of dredge spoils and extensive shipping activity have all played their parts in altering these estuaries and their shorelines.

Delaware and Chesapeake Bays are by far the largest estuaries in the eastern United States. The rivers emptying into these two bays drain more than 200,000 km^2 and discharge more than 2800 m^3 of water each second. The geology and geomorphology of the coastal environments of Delaware Bay have been documented by Kraft (1971a, 1971b) and his coworkers at the University of Delaware. Although this bay is smaller in area than Chesapeake Bay, the main channel of the estuary reaches depths of more than 60 m and much of the bay has depths exceeding 20 m. Most of the sediment entering the estuary remains trapped; Oostdam and Jordan (1972) found a net transport of sediment into the estuary in two of the three stations they took within the bay. At present, Delaware Bay is shoaling at the rate of 15 cm/century (Oostdam and Jordan, 1972). Moody and Van Reenan (1967) detected 15 to 20 m of sediments filling in the mouth of this estuary. Presumably this deposition occurred since the last rise in sea level, some 5000 years ago.

Chesapeake Bay is the drowned drainage system for the Susquehanna, Potomac, James, Rappahannock and York Rivers. The bay is more than 250 km long and 40 km wide at its widest point; water depths generally are less than 18 m (Ryan, 1953; Hack, 1957). The Susquehanna contributes

1,953 tons of suspended matter yearly (Curtis et al., 1973; Table 1b), which accounts for about 25% of the annual river-borne total suspended matter brought into the area (according to the calculations of Curtis et al., 1973; Table 1a). Although most of the sediment is brought in during spring floods, most is deposited in the upper 40 to 45 km of the estuary (Schubel, 1972). During major floods, however, sediment can move much further into the bay. Only 10% of the suspended matter escapes from Chesapeake Bay (Biggs, 1970) and much of this may be derived from coastal erosion rather than river-borne sediment (Schubel, 1973). No doubt one reason for the large amount of coastal erosion is the large influence of wind-induced waves in this broad estuary (Emery and Uchupi, 1972). Although the average deposition within the bay is difficult to measure, Meisburger (1972) found up to 30 m of fill in what was probably a Pleistocene drainage system at the mouth of the bay. Presumably this sediment is late Pleistocene and Holocene in age.

One particularly unique aspect of Chesapeake Bay is that it contains several sub-estuaries. Foremost are the James and Rappahannock River estuaries. Although these estuaries have been extensively studied (see Nichols, 1972; Nelson, 1972); their sedimentological impact upon Chesapeake Bay seems to be small. For example, according to Nelson (1972), the average stream flow in the Rappahannock is 47 m^3/sec and the suspended load is 7.4 tons per year.

The North Carolina estuary system is unique with respect to the rest of the Middle Atlantic Bight in that its seaward boundary is defined by a series of barrier islands. Prior to the formation of these islands, the estuary apparently was opened to the shelf waters (Welby, 1973). The North Carolina estuary system landward of Cape Hatteras contains four separate estuaries. Albemarle Sound (fed by the Roanoke River) and Pamlico Sound (fed by the Neuse and Pamlico Rivers) are much larger in size than Core Sound and Bouge Sound to the south. Although the Roanoke River carries a heavy suspended sediment load, most of the sediment within the central part of Albemarle and Pamlico Sounds is derived from shelf sands (Pels, 1967; Duane, 1962; Pickett and Ingram, 1969; Pickett, 1973).

Although each estuary along the Middle Atlantic Bight has unique characters, they also possess many similar properties. All are positive outflow of freshwater into the ocean (Pritchard, 1967). The exact configuration of the fresh and salt water wedges depends upon the shape of the estuary, the flow of the river water (and thus the season and climate) and the tidal stage. Similarly, the amount of suspended matter within the river water depends upon the season (flood or non-flood), the tidal stage and the terrain which is drained. Northern rivers tend to have relatively high flow rates and low suspended matter loads (Table 1b). Meade (1969a) has explained this difference as being due to the differences in terrain which are drained. Sediment in northern sections was scraped clean by Pleistocene glaciers, thus leaving little material

available for modern erosion. In contrast, the southern areas are covered with relatively easily erodable sediments.

Generally the sediments in the central portions of the estuaries are coarse, while those in the more restricted parts are fine grained. The amount of organic matter varies directly with the amount of fine sediment, but as a rule, polluted estuaries contain more than 5 to 15% organic matter while unpolluted estuaries contain far less (Folger, 1972b).

At present the sedimentation rates in Middle Atlantic estuaries generally range between 15 and 40 cm/century. This is below the average for all Atlantic estuaries (Emery and Uchupi, 1972) and locally may not be as rapid as the present rise in sea level (see below).

Barrier Islands

The second major shoreline feature along the Middle Atlantic Bight is the more or less continuous string of barrier islands that stretch from Montauk Point, Long Island to Cape Hatteras. Most of the barrier islands stand less than 4 m in elevation although some sand dunes can exceed 10 m. The islands tend to be long and relatively narrow, usually less than 1 km in width. The lagoons standing leeward of the islands are connected to the sea by occasional inlets which separate the islands from one another.

The origin of barrier islands is still debated. Hoyt (1967) concluded that the barrier islands off the southeastern United States formed as mainland beaches and were isolated during the Holocene rise in sea level. According to Pierce and Colquhoun (1970), 40% of the barrier islands immediately north of Cape Hatteras formed during the Holocene transgression, but the remaining 60% are secondary, having evolved by longshore drift and seaward progradation over the shelf. Fisher (1968) has suggested that the Middle Atlantic barrier islands have evolved as a series of coastwise prograding spits. The progradation of Cape Henlopen on the southern mouth of Delaware Bay (Figure 10.3) would support this assumption, as would the magnitude of beach sand transport along the Middle Atlantic Bight (Table 2). However, eroding shorewared faces often expose relict (2000 to 5000 years old) intertidal peat marshes, over which the barrier islands must have formed (see Kraft, 1971b). This suggests that these islands must be at least partly relict (see also Dillon, 1970).

The present-day barrier spits not only migrate along the shoreline (see Figure 10.4), but they also are eroding landward (Figure 10.3). Between 1919 and 1961 the shoreline between Rehoboth Beach and Little Bay, Delaware receded 25 to 85 m (Moody, 1964) and somewhat similar rates of recession have been noted along the Virginia and New Jersey barrier islands (Swift et al., 1972a; Harris, 1954). Ordinary winter storms can

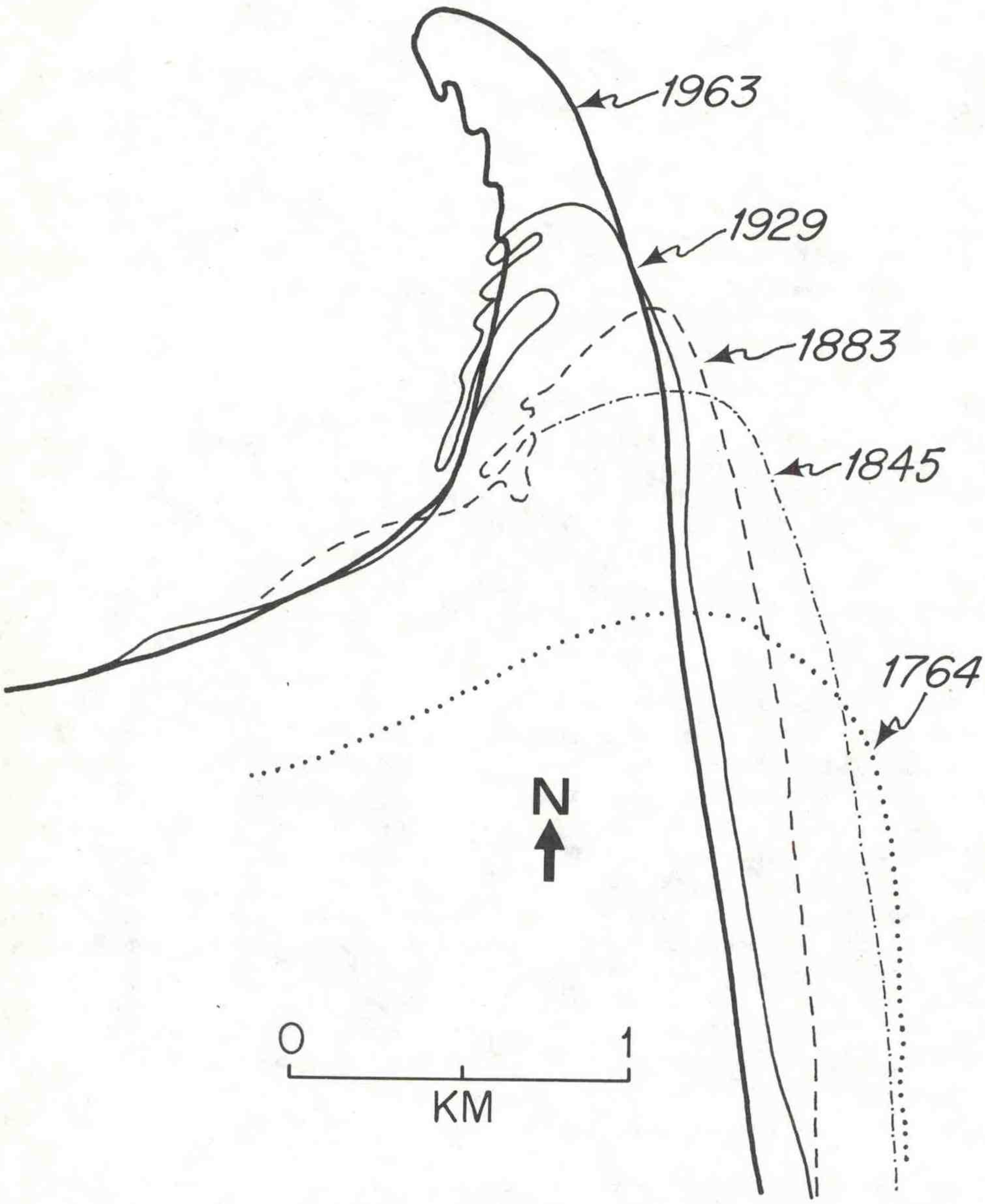

Figure 10.3. Historical migration of Cape Henlopen, Delaware according to a comparison of surveys made in 1764, 1845, 1883, 1929 and 1963. Note the gradual northward and shoreward migration of the spit. After Moody (1964).

TABLE 2. Direction and amount of sand transport along the beaches-barrier islands in the Middle Atlantic Bight.

Area	Transport of Direction	Average Amount m^3	Reference
Long Island, S. Shore	W	340,000	Taney, 1961
Sandy Hook, N.J.	S		Antonini, 1962
Barnegat Inlet, N.J.	S	40,000	Caldwell, 1966
Ocean City, N.J.	S	300,000	Johnson, 1956
Cape Henlopen, Del.	N	170,000	Duane et al., 1972
Ocean City, Md.	S	130,000	Duane et al., 1972

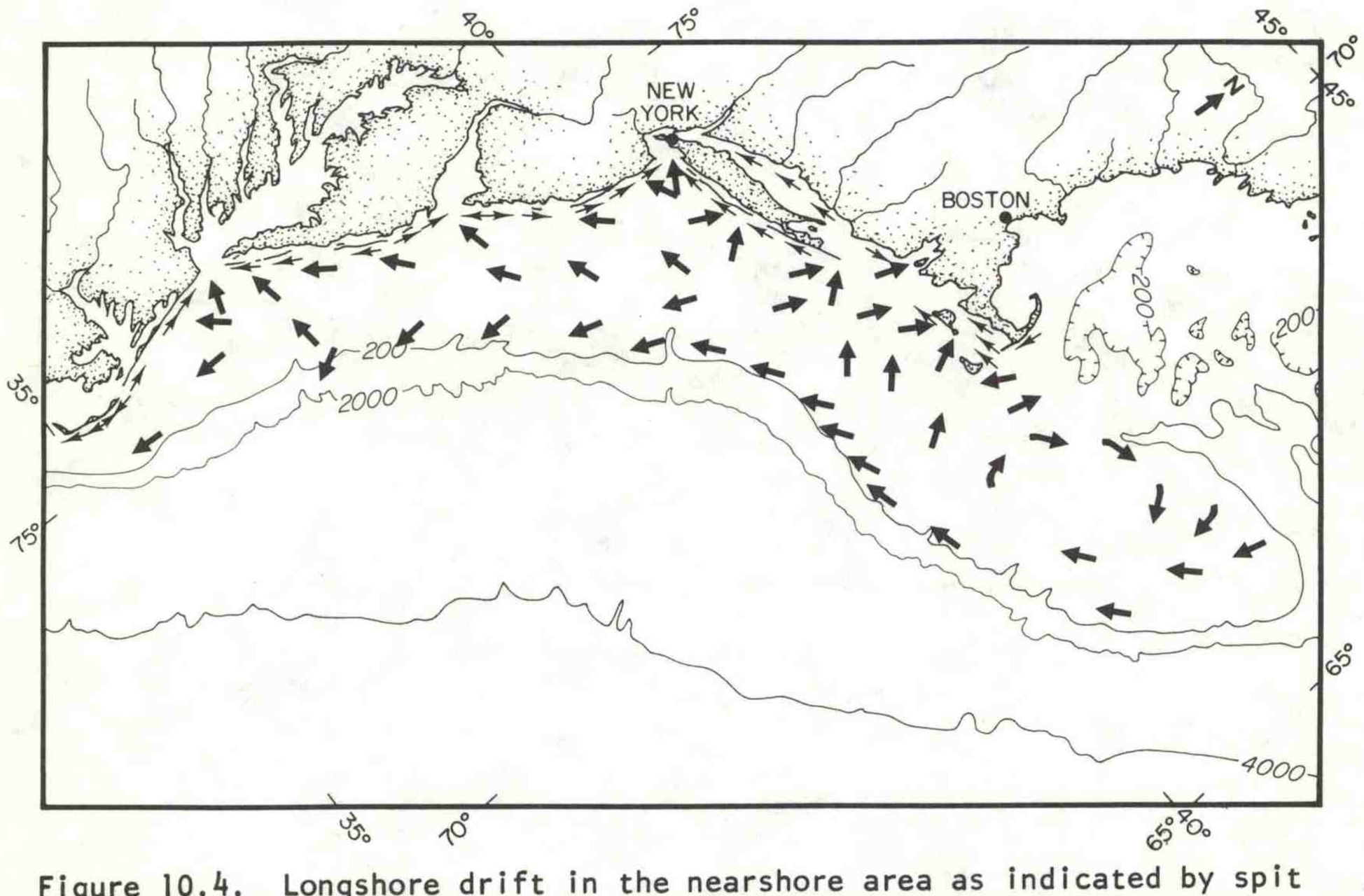

Figure 10.4. Longshore drift in the nearshore area as indicated by spit migration (small arrows) and bottom drift (large arrows) on the shelf as derived from bottom-drifter observations. After Bumpus (1965), Norcross and Stanley (1967), Muench (1966), Langfelder et al. (1968), Swift et al. (1970), Kraft (1971a) and Emery and Uchupi (1972).

cause major regression of beach lines, but progradation generally occurs during the following summer months, so that within an annual cycle the position of beaches probably remains more or less constant. This has been observed on Long Island (Taney, 1961), New Jersey (Strahler, 1964), Delaware (Kraft, 1971b) and North Carolina (Dolan, 1966). Most of the net landward migration results from major storms. Overwash of island sand into the leeward lagoons is a major source of sediment for both the lagoon and the interior part of the island. As a result of this overwash, however, the island tends to migrate landward (Dolan and Godfrey, 1973). Major storms can plug inlets or open new ones, although normal waves and tides also can change inlet configurations (Harrison et al., 1964). Natural coastal vegetation (Dolan and Godfrey, 1973) and underlying peat and tree stumps (Johnson, 1925; Kraft, 1971a) tend to limit landward migration. With the increased influence of man and his modern technology upon the ecology of coastal beaches and barrier islands, however, the impact of major storms can be expected to be more severe (Burton et al., 1965; Dolan and Godfrey, 1973).

Barrier islands are composed mostly of sand. Emery and Uchupi (1972) have measured a gradual decrease in the mean diameter of the beach sands from southern Long Island to as far as Georgia. Generally off Long Island less than 20% of the beach sand is composed of sizes finer than 250 microns, while between Cape Henry and Cape Hatteras the finer size grains average more than 30% of the sediments (Emery and Uchupi, Figure 275). Carbonate content within the barrier island sands generally is far less than 5% (Milliman, 1972). Those sediments containing higher quantities of $CaCO_3$ generally are rich in coarse mollusk shells (McCarthy, 1931).

The beach sands from southern New England and Long Island appear to be derived from nearby moraines, but longshore transport can change their composition and surface texture (Colony, 1932; Krinsley et al., 1964). On Cape Cod heavy mineral deposits tend to form as sheets on the beach, locally up to 15 cm thick. These heavies probably were derived primarily from glacial outwash and redistributed by waves and wind (Trumbull and Hathaway, 1968a). South of Long Island the beach sands tend to be more similar in composition to shelf sands than to river material (McMaster, 1954; Martens, 1956; Frank and Friedman, 1971; Swift, Dill and McHone, 1971). McMaster, Frank and Friedman argued that the similarity in composition may indicate that the beach sands were derived from the shelf. Swift, Dill and McHone (1971) concluded that mineralogic gradients which are perpendicular to the shoreline have resulted in situ fractionation during shoreface retreat of beach sand. However, it may be that beach abrasion has preferentially removed less resistent minerals as river-derived sands move by longshore drift (Colony, 1932).

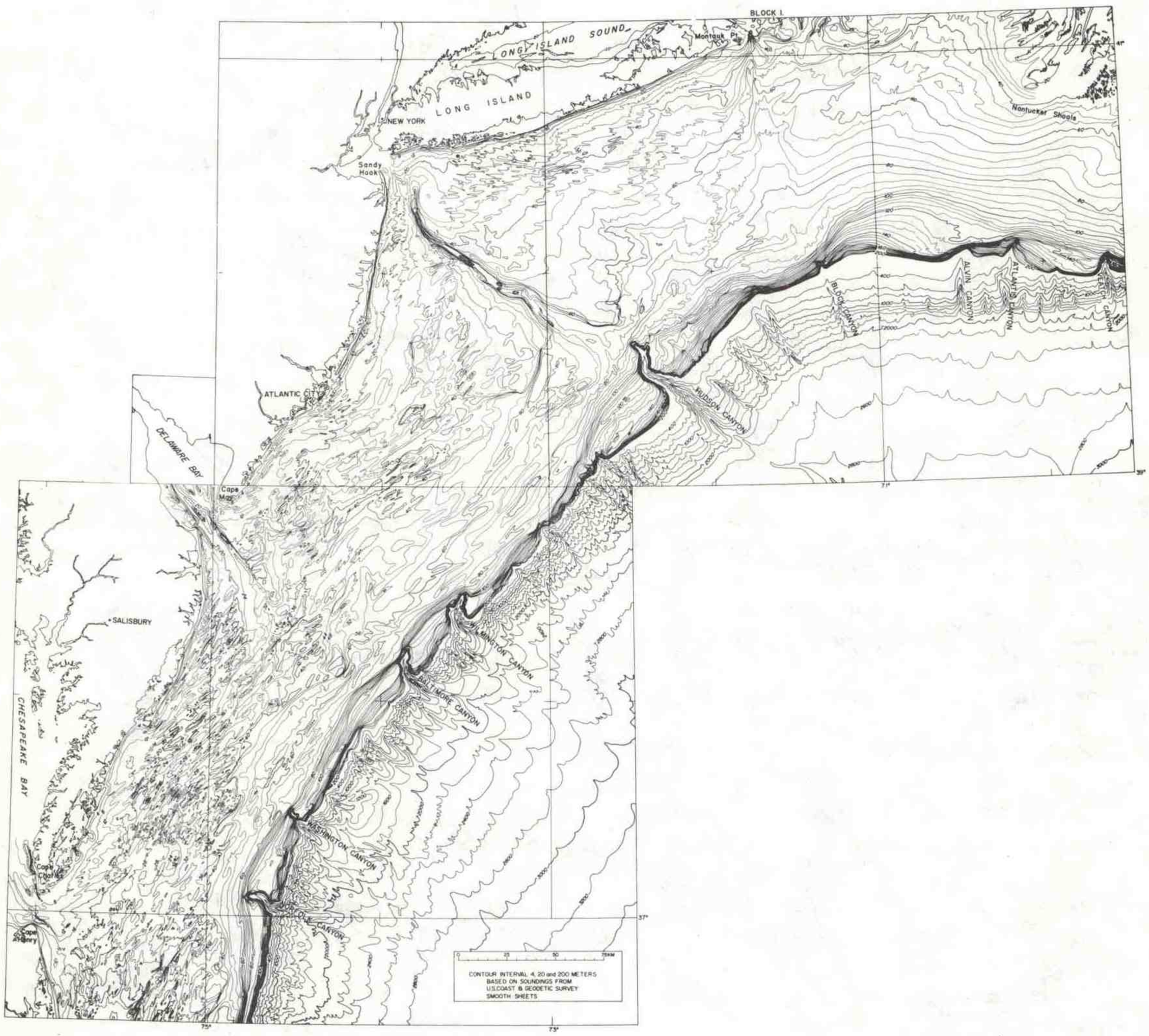

Figure 10.5. Bathymetric chart of the Middle Atlantic Bight area, from Nantucket Shoals to Cape Henry, Virginia. Depth intervals are 4 m on the shelf and 20 m on the slope. From Uchupi (1970).

Coastal Marshes

Coastal marshes have evolved over much of the Middle Atlantic Bight coastline as a result of the restricted environments formed by the estuaries and barrier islands. In contrast to the sandy sediments on the barrier islands and in central portions of many of the barrier island lagoons and estuaries, the salt marshes are dominated by organic-rich silts and clays. Non-organic sediment is derived from landward sources, but also from the seaward influx of terrigenous sediment (Meade, 1972a, 1972b). The relative importance of these two sediment fluxes, however, has not been thoroughly documented (Boon, 1973).

In many places the coastal marshes were established 4 to 5 thousand years ago, concurrent with the decreasing rate in sea level transgression and the consequent establishment of modern estuaries, barrier islands and lagoons. Prior to that time salt marshes were located across what is presently the continental shelf and migrated landward as sea level rose rapidly during the early Holocene (Emery et al., 1965, 1967; Emery and Milliman, 1971; Emery and Uchupi, 1972). Much of the modern coastal wetlands has been severly altered or destroyed by man's activities during the past 300 years.

Physiography of the Continental Margin

Continental margins generally consist of three separate physiographic provinces, the continental shelf, the continental slope and the continental rise. Shelves extend from the shoreline to approximately 100 to 200 meters water depth. Declivities average less than 0°10' in most areas. Slopes extend from the shelf break to depths of about 2000 to 3000 meters; gradients range from 2° to more than 7°. The continental rise is a wide, gently sloping sedimentary apron that extends to the deep-sea proper. Declivities generally average less than 1°.

The continental margin off the eastern United States, particularly the Middle Atlantic Bight, is probably the best surveyed area in the world. The U.S. Coast and Geodetic Survey carried out a closely-spaced echo-sounding survey in the early and mid 1930's in the area between Nantucket Shoals and Cape Henry, Virginia. Navigation was based on acoustic ranges, with an accuracy that is still considered excellent. As a result of this and other surveys, Veatch and Smith (1939) published a series of 1:200,000 bathymetric charts of the area. Soundings on the shelf were contoured in 5 fathom (9 m) intervals and those on the slope in 25 fm (45 m) intervals. Uchupi (1968b) using the same raw data, presented three 1:1,000,000 charts encompassing the area from Nova Scotia to the Florida Keys. Contour intervals on the shelf were 20 m and on the slope 200 m. A more accurate chart of the Middle Atlantic Bight area, where the soundings are most dense, was drawn by Uchupi (1970) on a 4 m contour interval for the shelf and 20 m interval for the slope (Figure 10.5). Stearns and Garrison (1967) used the same raw data used by Veatch,

Smith and Uchupi to make a series of 15 1:125,000 charts of the Middle Atlantic Bight area, as far south as Cape Henry, with 1 fm contours on the shelf. More recently, a bathymetric chart (in 12 ft. contour intervals) has been issued for the area from Cape Henlopen to Cape Hatteras (Goldsmith et al., 1973).

The Middle Atlantic continental shelf varies in width from 200 km south of Cape Cod to 140 km off New Jersey and 25 km off Cape Hatteras. Shelf gradients range from 0°03' off New York to 0°07' off Cape Hatteras and shelf break depths vary from 160 m south of Cape Cod to 120 m at Norfolk and 50 m at Cape Hatteras.

The continental slope begins at the shelf break with a marked increase in declivity. Off Cape Hatteras the gradients average between 4 and 5° and north of Cape Henry about 4° (Uchupi, 1968b; Rona, 1969). North of Hudson Canyon the upper slope shallower than 1000 m has a declivity of about 1° while the lower slope (1000 to 2000 m) averages about 3°, but in places has gradients in excess of 7° (Uchupi, 1968b; MacIlvaine, 1973). The continental slope off the Middle Atlantic Bight is marked by numerous canyons and gulleys (Figures 10.5 and 10.8). The larger canyons include Veatch, Atlantis, Alvin, Hudson, Wilmington, Baltimore, Washington, Norfolk and Hatteras Canyons. These canyons will be discussed in further detail in a following section.

The continental rise extends from the base of the continental slope to the edge of the Sohm and Hatteras Abyssal Plains. Water depths range from 2000 to 5000 meters. Although occupying the largest area within the east coast continental margin (630,000 km^2; Emery, 1966), the continental rise lies outside the limits of the Middle Atlantic Bight proper and therefore will not be discussed further in this paper.

Continental Shelf

The continental shelf off the Middle Atlantic Bight exhibits a great variety of morphologic features. Because of the extensive geological and geophysical research done in this area, there has been a considerable amount of speculation on the nature and origin of these features. Uchupi (1968b) classified the shelf morphologic features into two broad categories: erosional (such as river channels and terraces) and constructional (such as sand swells and possibly some terraces). The problem with classifying features in this way is that the origin is implied. Swift et al. (1972b) tried to classify on the basis of morphology. Small scale elements, according to these workers, include emphereral features, such as ripples and sand waves. Although these are probably depositional in origin, the exact mode and time of origin depend upon location. Large scale elements, apparently those which can be easily defined by an ordinary echo sounder, are divided into broad groups. First-order features include shore-connected ridges and swales, and isolated ridges and swales. Second-order features are represented by

cape-associated shoals, inlet-associated shoals and ridge fields. Third-order features include shoal-retreat massifs, shelf traverse valleys, cuestas, deltas and scarps (Swift et al., 1972b). For the average worker, however, this classification is arbitrary and cryptic. Why, for example, should shore-connected ridges necessarily be assigned to a different order than inlet-associated shoals or ridge fields? In the following discussion, these continental morphologic features will be considered: ridge and swale topography, shelf-traverse channels (valleys), deltas and relict shorelines and terraces.

Probably the most visually characteristic feature on the Middle Atlantic shelf is the abundance of ridge and swales (also referred to as sand ridges and sand shoals) that dominate most of the inner shelf, Nantucket Shoals and Georges Bank (Figure 10.6 and 10.7). These features are abundant in water depths shallower than 75 m; south of Long Island most are located in water depths shallower than 30 m (Swift et al., 1972b). Most nearshore ridges are linear in configuration while ridges associated with inlets and capes tend to be arcuate.

A comprehensive study of linear ridges along the Middle Atlantic Bight has been made by Duane et al. (1972). Most of these nearshore ridges trend at 20° to 30° angles with the shoreline; in some cases they actually merge with the shore face. Ridge spacing tends to be about 2 km, amplitude about 2 to 10 km and length 9 to 56 km (Swift et al., 1972b). Submersible side-scan sonar studies have shown second-third-and-fourth-order sand ripples and dunes superimposed upon deeper-water ridges (Sanders et al., 1969; McKinney and Swift, 1973). Second-order features which stand 2 to 5 m high, may be the result of time-averaged storms; third-order features which are about 1 m in amplitude, probably formed during a particular storm, and fourth-order features, generally about 6 cm high, are primarily wave ripples.

The origin of the ridge and swales system on the continental shelf has been the subject of considerable speculation. Many workers have considered them to be relict beach dunes formed during the Holocene transgression (Veatch and Smith, 1939; Shepard, 1963; Sanders, 1962; Emergy, 1968a; Kraft, 1971a), while McKinney and Friedman (1970) suggested that the system off southern Long Island may be related to submerged stream systems. McClennen (1973) has concluded that the ridge and swale topography off New Jersey are drowned beach-lagoon complexes produced by the Holocene Transgression. Emery and Milliman (1971) described a brackish water oyster shell found on a mid-shelf ridge off Virginia and suggested that the oyster was deposited in intertidal depths after formation of the sand ridge itself. More recent workers (Uchupi, 1968b and references cited below), however, have considered that most of the nearshore ridges and swales are recent in age.

In reality, the origin and age of the ridge and swale topography varies from area to area. The ridges off southern New England, including

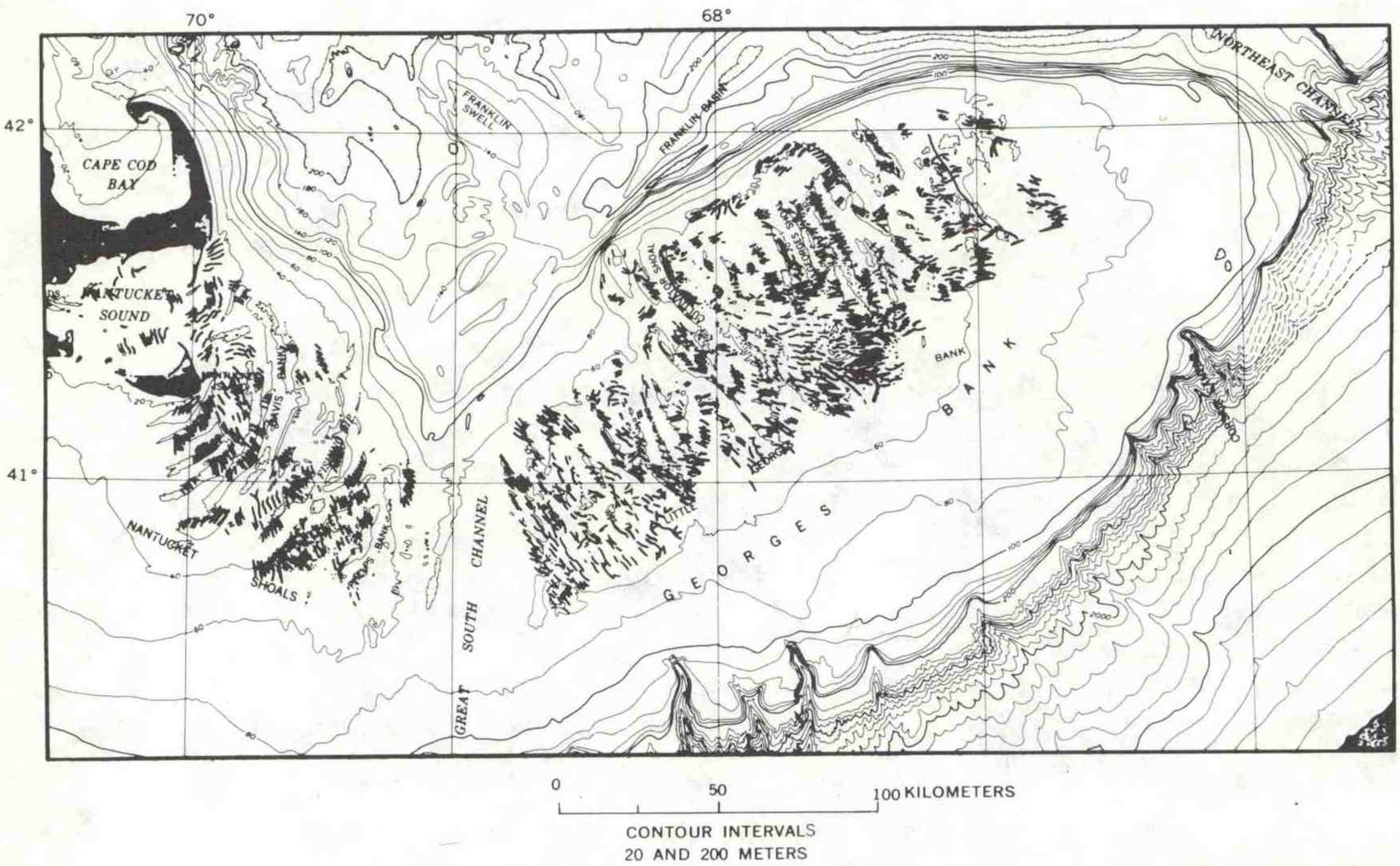

Figure 10.6. Distribution of sand ridges and swales on Nantucket Shoals and Georges Bank. From Uchupi (1968).

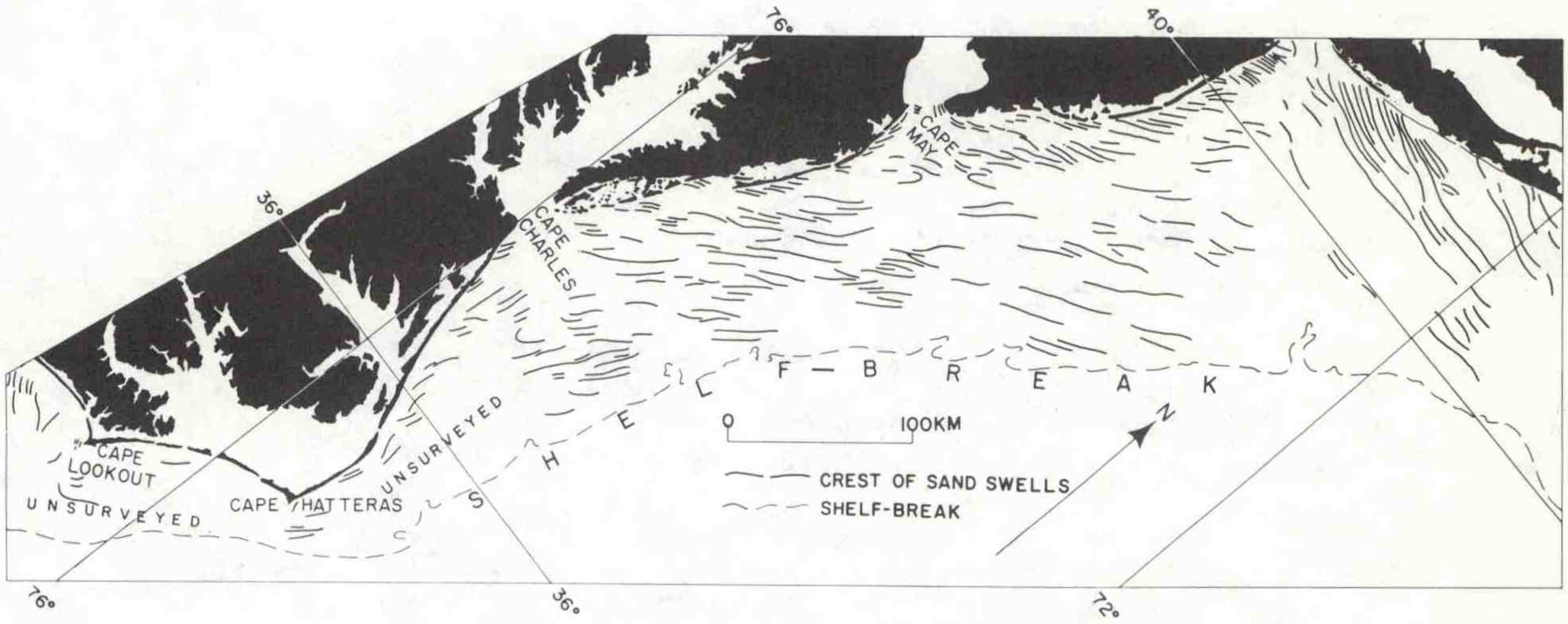

Figure 10.7. Sand ridges and swales on the shelf between Long Island and Cape Hatteras. From Uchupi (1968).

those on Georges Bank and Nantucket Shoals probably represent relict features that have been maintained or perhaps altered by tidal current activity (Owen et al., 1967; Smith, 1969; Sanders et al., 1969). In each of these areas, tidal currents are sufficiently strong to transport all sediment sizes. It seems probable that the arcuate ridge and swale features found in the mouths of estuary inlets and off capes are also tidally controlled, although the sand waves do seem to migrate seaward (Ludwick, 1972; Swift, 1973). Most inlet shoals are not relict; in the case of Chesapeake Bay, the sand waves directly overlie the buried Susquehanna Channel (Ludwick, 1972) which presumably was filled during and after the Holocene transgression.

Most of the sand ridge fields along the inner continental shelf appear to be transgressive Holocene sands which overlie late Pleistocene and early Holocene transgressive sediments. Seismic profiles and vibrocores off Virginia (Shideler et al., 1972; Swift et al., 1972a), New Jersey (Stahl et al., 1973; Swift et al., 1972b) and other areas along the inner Middle Atlantic Bight (Duane et al., 1972) indicate roughly the same stratigraphy: Holocene transgressive sand, ranging between and 9 meters thick, overlying a mud to muddy sand which has been dated as early Holocene and probably was deposited in a lagoon or restricted neritic environment. This mud overlies a relict Pleistocene sand (Shideler et al., 1972; Sheridan et al., 1973). Such a sequence corresponds closely with the theoretical transgressional model proposed by Fischer (1961). In some areas, notably the ridges off southern New Jersey, layers of peat may be present. This Quaternary sequence averaging 17 to 60 m in total thickness overlies Miocene strata.

In some are areas nearshore linear ridges have been historically active. Moody (1964) measured a net movement of 125 m in a 42-year period in the ridges off Bethany Beach, Delaware. During a major storm in 1962, the ridge migrated nearly 80 m, primarily in response to south-flowing storm-generated currents (Moody, 1964). Apparently movement of the sand-ridge system off False Cape, Virginia is also related to storm activity (Swift et al., 1970, 1972b). Duane et al., (1972) have suggested that ridges on Chincoteque Shoals (Maryland) have moved as much as 3 km during a period of 53 years. Although Harris (1954) noted marked long-term changes in the nearshore topography off southern New Jersey, he did not correlate this with sand ridge migration.

To briefly summarize, nearshore sand ridges (linear shoals) appear to be sand waves that periodically migrate over a late Pleistocene-early Holocene substrate. Arcuate ridge and swale features in or near inlets and capes are associated with tidal activity. Ridge and swale topography further offshore may be entirely relict or relict features which have been modified by modern processes, presumably tidal currents or major storms.

Another important feature of the Middle Atlantic shelf is the abundance of relict stream channels that traverse the shelf. The most prominent channel is the Hudson River Channel which extends from the mouth of Hudson Canyon shoreward to the inner New York Bight. Relief of the channel varies from 20 to 40 m, and the declivity is generally 3 to 4 times that of the surrounding shelf floor. Other visually obvious surface expressions of relict stream channels include inner Delaware Channel, the inner part of Great Egg Channel and part of Block Island Channel. Each of these channels is bounded or terminated by subcircular plains which may be relict deltas (Emery and Uchupi, 1972; Swift et al., 1972b). Other channels shown in Figure 10.8 have been reported by Mc Kinney and Friedman and Swift et al. (1972b), but they may represent the imagination of the authors rather than representing actual channels. While most workers have postulated that these channels are the result of submerged subaerial river channels, Swift (1973) has indicated that the Delaware Bay Channel may have formed under shallow-marine conditions.

Many other stream channels on the continental shelf are buried under sediment, so that their existence can be determined only by continuous seismic profiling. Buried channels shown in Figure 10.8 are will-documented in the area from western Long Island Sound to Block Island (McMaster et al., 1968; Tagg and Uchupi, 1967; Grim et al., 1970; McMaster and Ashraf, 1973a, 1973b) and in Nantucket Sound (Emery and Uchupi, 1972). The stream channels appear to be cut into pre-Pleistocene bedrock, perhaps Coastal Plain strata. The channels apparently were subsequently buried and altered by glacial loads during the Pleistocene (McMaster and Ashraf, 1973a). Coch (1973) has suggested that modern sand movement is burying former valleys between Long Island and Block Island. Continuous seismic profiling studies off New Jersey, the Delmarva Penninsula and Virginia show some indications of buried channels, but not nearly to the extent seen off southern New England. It is possible, however, that further studies will reveal more buried channels.

The Middle Atlantic exhibits four terraces and shorelines.[1] The Nicholls, Franklin, Fortune and Block Island shorelines (names by Veatch and Smith, 1939) lie at depths of approximately 140, 100, 65 and 40 m on the shelf seaward of New York (Figure 10.8). These shorelines shoal to the north and to a lesser extent to the south. To the north, the Nicholls shoreline becomes emergent in southern Maine (Emery and Uchupi, 1972, Figure 22). Near Cape Hatteras the shorelines occur in depths less than 50 m (the Fortune disappears south of New Jersey). These variations in shoreline depth are related to glacial rebound in the north together with possible subsidence off the New York-Delaware area and uplife to the south (see the section of late Quaternary sea levels in this paper). As Emery

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[1] Subaerial Pleistocene terraces have been noted in Virginia (Oaks and Coch, 1963), but they are not as well developed as the subaerial terraces in the southeastern United States (Hoyt, 1972).

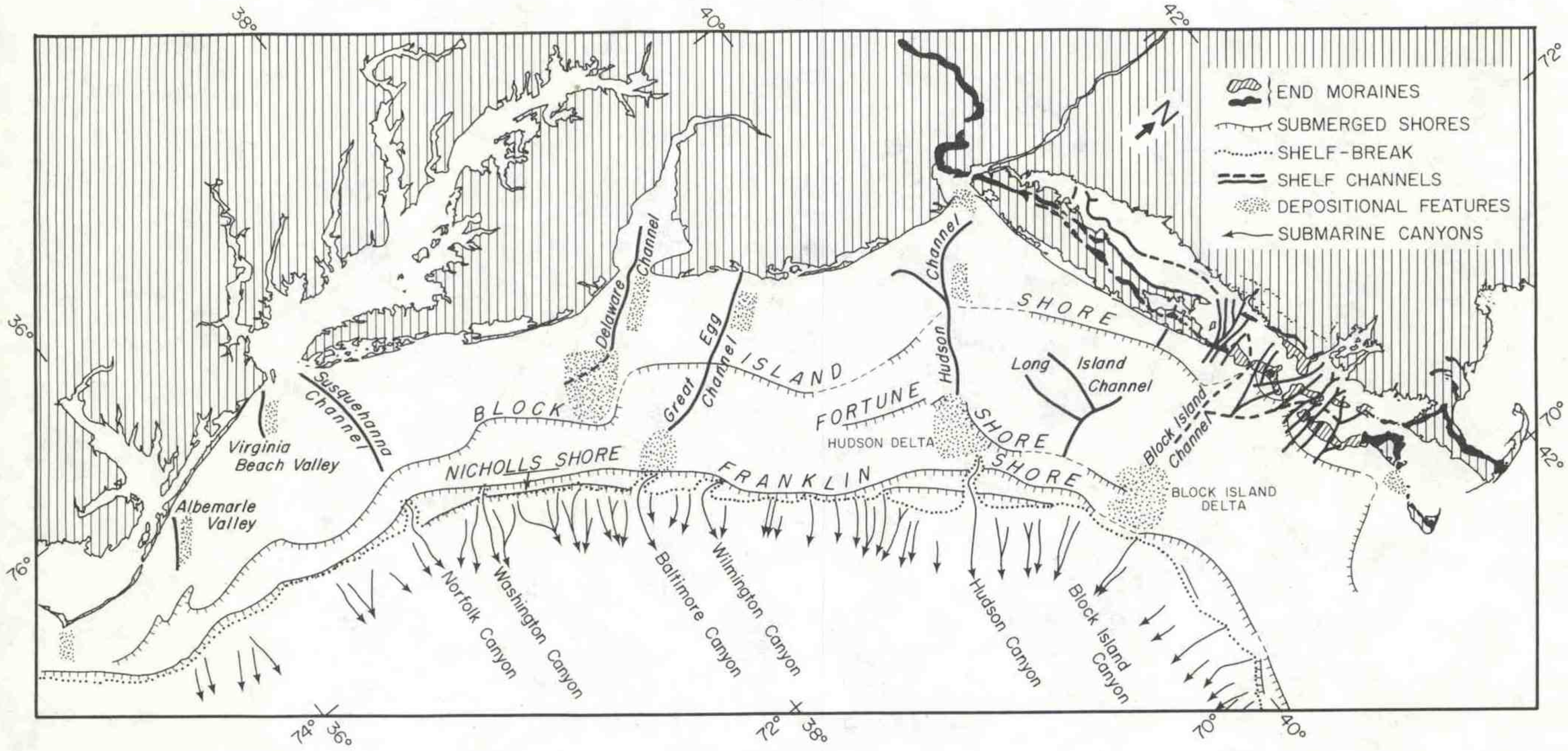

Figure 10.8. Schematic chart of the various morphologic features on the continental shelf (excluding sand ridges and swales) and upper slope. Dashed shelf channels are filled with sediment. After data and charts in Emery and Uchupi (1972), Swift et al. (1972b), McKinney and Friedman (1970), Grim et al. (1970) and McMaster and Ashraf (1973b).

and Uchupi point out, this latitudinal variation in shoreline depth illustrates the extreme difficulty in correlating world-wide shorelines with eustatic low stands in sea level.

Early seismic profiles across the shorelines off New York were interpreted as showing that the shorelines were depositional in origin (Ewing et al., 1960; 1963), but subsequent work by Knott and Hoskins (1968) indicate that these terraces were primarily erosional with subsequent stages of sediment progradation. The time of formation is not known, but the finding of carbon-14 deficient littoral mollusks on the Nicholls shore (Richards and Werner, 1964; Ewing et al., 1963) would indicate a pre-Würm II age.

Continental Slope

In contrast to the continental shelf, our knowledge about the morphologic features on the continental slope is relatively poor. One reason for this is that the density of echo-sounding lines is not sufficient nor is navigation generally accurate enough to define smaller-scale features. Equally important is the fact that the cone diameter of the sound waves in deeper water is too wide to define small-scale features. Where closely spaced surveys have been run, however, the continental slope shows a more varied topography than previously suspected. Figure 9 shows two bathymetric charts of well-surveyed small areas less than 100 km apart on the lower slope south of Martha's Vineyard. The eastern area consists of a series of closely spaced gullies which cut the slope; relief of the individual gullies is about 20 to 50 m. The western area is more smooth, with only one major gully emptying into Alvin Canyon. Using pressure gauge readings in Alvin, however, Emery and Rose were able to delineate small scale features in the western area that were not detected from the surface ship (Figure 10.9). Noteworthy is the series of roughly parallel ridges a few meters high that run normal to the slope.

As mentioned in an earlier section, the average gradient of the continental slope off the Middle Atlantic Bight varies from 2 to 7°. However these average values do not indicate the much greater range in local declivities. For example, the slope off Cape Hatteras has an average gradient of 4 to 5° but is actually composed of a series of vertical rock outcrops separated from one another by gently sloping scree aprons (Heezen and other, 1959; Milliman et al., 1967). Similarly, Mac Ilvaine (1973) found that the lower continental slope south of Martha's Vineyard, although having a local gradient of 7.6°, actually is characterized by four distinct types of topography: smooth sediments, hummocky sediments, talus slopes and rock outcrops. In contrast, the upper slope is characterized by relatively smooth sediments with displays current lineations and burrows (MacIlvaine, 1973).

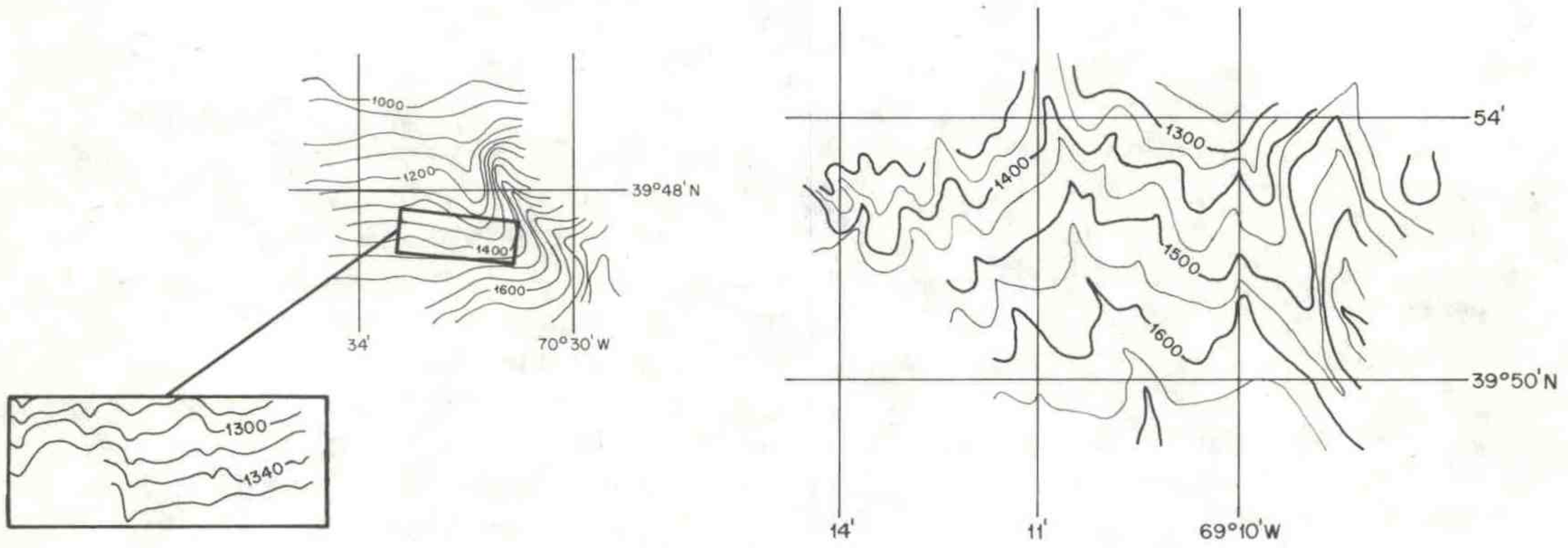

Figure 10.9. Morphology of two areas on the southern New England lower continental slope. The bathymetry of part of the western area also was surveyed by the deep submersible Alvin. The results of this survey are shown in the left figure. Depths are in meters. After Emery and Ross (1968) and Emery and Uchupi (1972).

Probably the most distinguishing feature on the Middle Atlantic continental slope is the number of gullies and canyons that transect the slope. Most begin on the outer shelf and extend onto the rise (Figures 10.5 and 10.8). Pratt (1968) has pointed out that New England canyons have built channels across the continental rise, while those south of Hudson Canyon have cut deep channels into the rise. He explained this difference by the fact that the more southerly canyons drained major Pleistocene rivers, whereas the New England Canyons probably were shaped partly by the advances of Pleistocene ice sheets.

The most prominent canyon is Hudson Canyon, which averages 12 to 15 km in width and 100 to 160 m in relief on teh upper slope and nearly 600 m on the lower slope. Again, averages declivities of the canyon walls are meaningless, since the walls are composed of a series of near-vertical outcrops and gradual sloping talus slopes (see Ross, 1968; Trumbull and Hathaway, 1968b).

All the canyons along the Middle Atlantic Bight appear to be erosional in origin (Uchupi, 1968a; Kelling and Stanley, 1970; Trumbull and McCamis, 1967; Ross, 1968; Emery and Uchupi, 1972). Present-day erosion probably includes elements of turbidity current movement, mass slumping and perhaps even biological erosion (Dillon and Zimmerman, 1970). Kelling and Stanley (1970) speculated about a possible fault controlling the northward swing in the head of Wilmington Canyon on the shelf (Figure 10.5), but prior work by Uchupi (1968a) showed no such fault. Dredged rocks from the canyon walls (Stetson, 1949; Northrop and Heezen, 1951; Gibson, 1965; Gibson et al., 1968) indicate that the canyons cut into at least Cretaceous strata, but the age of the canyons themselves is not known.

Structure and History of the Continental Margin

At present our understanding of the structure and history of U.S. Atlantic continental margin depends primarily upon geophysical data. Where the data are poor or their availability is restricted, our knowledge suffers. Due to the lack of multi-channel seismic reflection profiles and the lack of test borings in the area, our insight into the deeper structure of the Middle Atlantic shelf is limited to gravity and magnetic data together with seismic refraction profiles. Because seismic reflection profiles can penetrate the upper 0.5 to 2 km of sediment on the shelf, our knowledge of the shallow structure (generally post-Cretaceous in age) is somewhat better. Excellent reviews of the general structure and history of the area have been presented by Drake et al. (1968) and Emery and Uchupi (1972).

Deep Structure

Magnetic anomaly trends on the Middle Atlantic continental margin show a general continuation of patterns seen on land (Figure 10.10), although the amplitude is subdued offshore as the basement is buried by increasing amounts of sediment. The major magnetic feature on the continental margin is the slope anomaly which occurs over the outer shelf to upper mid-slope, with values generally greater than 600 gammas. The slope anomally trends more or less continuously from north to Georges Bank to the northern part of the Blake Plateau (Figure 10.10). This anomaly generally is assumed to represent a deeply buried ridge system behind which much of the continental shelf accreted (Drake et al., 1959, 1968; Emery, 1968c). Calculations place the magnetic body 8 to 10 km below the surface, or some 4 to 5 km deeper than the ridge feature seen by seismic profiling. This suggests that a considerable amount of sedimentary strata might have accumulated on the ridge before the entire feature was buried (Emery and Uchupi, 1972).

Drake and Woodward (1963) suggested that the slope anomaly is interruped at about latitude 40°N by an E-W extension of the Cornwall-Kelvin Fault system. This proposed transcurrent fault is suggested to connect the New England seamounts with the fault system in northern New Jersey; it probably was last active in the late Paleozoic. More recent magnetic studies on the shelf by Taylor et al. (1968) have failed to identify the offset in magnetic anomalies proposed by Drake and Woodward, thus suggesting that perhaps the Cornwall-Kelvin fault does not exist. Instead the data presented by Taylor et al. (Figure 10.10) indicates a possible anomaly trending north from northern Virginia and intersecting the Kelvin fault (Emery and Uchupi, 1972).

A chart of simple Bouguer gravity anomalies shows values of approximately 0 to 100 milligals over most of the shelf, and a steep gradient from the shelf to the upper continental rise, where values exceed 300 (Emery and Uchupi, 1972: Figure 117). The steep gradient undoubtedly represents the transition from continental to oceanic basement.

Free-air gravity anomalies over the shelf generally are less than 50 milligals. Greatest excursions occur near the shelf edge, where maximum and ninimum values can reach as high as 50 to 85 and -40 to -60 milligals, respectively. Worzel (1966) explained this as an edge effect plus a 20 km seaward displacement of the mantle depths with isostatic adjustment. However, Emery et al. (1970) suggested that these highs and lows may be related to the excess mass associated with the postulated ridge system.

With these data plus seismic refraction information and limited stratifraphic control from deep wells, the structure and general history of the pre-Cenozoic continental margin can be reconstructed. With the

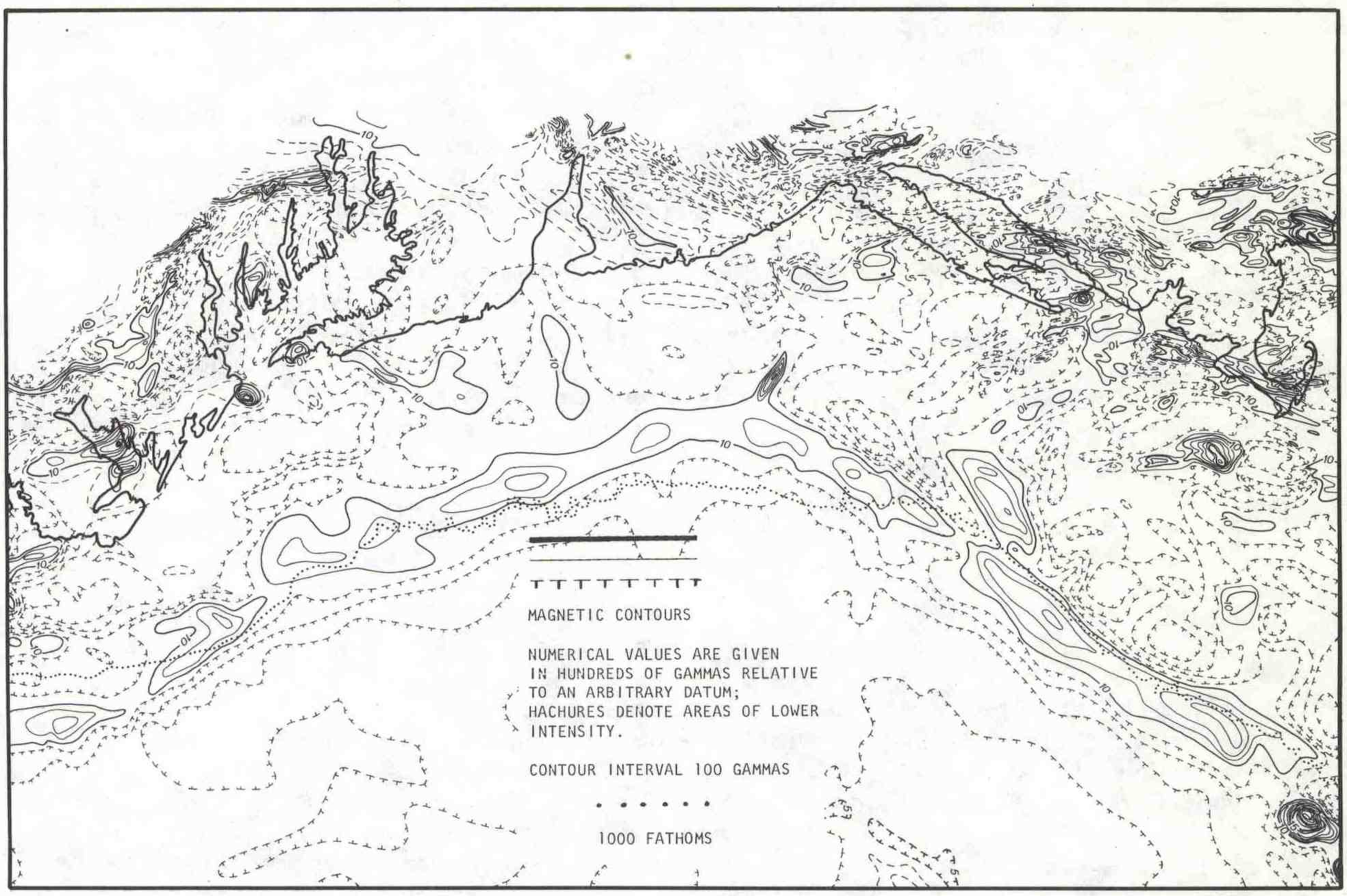

Figure 10.10. Magnetic anomalies over the northeastern United States. After Taylor et al., 1968.

break-up of the North American continent from Europe-Africa during the first stages of sea-flooring spreading in the late Plaeozoic, a ridge-trench system formed at the boundary of the thinned continental crust. As this trailing edge of the westward drifting North American continent separated from North Africa, it formed an ideal trap behind and upon which sediments could accrete. Drake et al. (1968) postulated a series of two ridges and throughs along the outer margin but subsequent studies have rejected this model (Emery et al., 1970; Emery and Uchupi, 1972). Fragmentary stratigraphic data gathered from seismic refraction velocities and the logs from test borings suggest that the early sediments were largely shallow-water carbonates and evaporites.[2]

Apparently with continued erosion of the Appalachian Mountains and subsidence of the shelf "basin", terrigenous sedimentation became prevalent in the later Mesozoic. However, scattered data suggest that carbonate accretion continued on the ridge system near and south of Cape Hatteras probably well into the Cenozoic (Uchupi and Emery, 1967; Emery and Uchupi, 1972). Maximum subsidence and sediment accumulation occurred on the shelf, particularly along the axis of the Baltimore Canyon Trough - Georges Bank Trough (Maher, 1971); total sediment accumulation exceeds 12 km (Figure 10.11, 10.12). Sediment thickness in the exposed Coastal Plain of the Middle Atlantic Bight are freatest in the Salisbury Embayment (Richards, 1948), but generally less than 2 km. Pre-Cenozoic sediment thickness seaward of the ridge complex averages less than 2 km (substrate thicknesses in Figure 10.11 from 10.12). Schematic sections across the margin off Cape Cod, New York and Cape Hatteras are shown in Figure 10.13.

Shallow Structure

The large number of seismic reflection profile studies made on the Middle Atlantic continental shelf (Ewing and others, 1960, 1963; Hoskins, 1967; Uchupi and Emery, 1967; Uchupi, 1968a, 1970; Knott and Hoskins, 1968; Garrison, 1970; Emery et al., 1970) gives us an excellent picture of the general Tertiary and Quaternary structure of the margin. Once more, however, the lack of stratigraphic control in many ways restricts our interpretation of the history. Several representative groups of seismic reflection profiles from various areas on the Middle Atlantic

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[2]Acoustic "Basement: (with velocities greater than 4.5 km/sec) had been assumed by most workers to be igneous and metamorphic Paleozoic rocks, but Emery and Uchupi (1972) suggested that shallow-water Jurassic limestones drilled on the Scotian Shelf (Canada) may represent "basement". Assuming that similar deposition occurred to the south, late Paleozoic and early Mesozoic strata off the Middle Atlantic Bight also may be dominated by such carbonate and evaporite sediments.

continental outer shelf and slope are shown in Figures 10.14-10.17.

By the late Cretaceous or early Tertiary, sediment had spilled over the ridge system and was accumulating on the rise. This fact is confirmed by the presence of Horizon A (Eocene in age - Ewing et al., 1969) which extends across the rise and into the North Atlantic basin proper. What had been primarily an upbuilding of the continental shelf gave way to progradation of the shelf and slope and up-building of the rise. As in the Mesozoic, maximum accretion of shelf sediment occurred within Baltimore Canyon Trough (Figure 10.12), but thicknesses were generally less than 1.5 lm as opposed to more than 2 km over much of the slope and rise, especially south of Long Island.

According to Garrison (1970) the main phase of upbuilding and out-building came during the Oligocene, when a series of deltas were deposited across the shelf south of Long Island, thus prograding the shelf a significant distance seaward. The sediment which did escape to the deep sea tended to accumulate on the continental rise, especially off southern New England, where Cenozoic sediment cover is minimal (Moore and Curray, 1963; Hoskins, 1967; Emery et al., 1970) (Figures 10.14, 10.15). In contrast, the slope south of Hudson Canyon appears to be one of slow continual out-building (Moore and Curray, 1963; Uchupi, 1970; Uchupi and Emery, 1967), (Figures 10.16, 10.17), although the total accumulation on the slope has been far less than that on the rise, where Tertiary sediments exceed 2 km in thickness (Figure 10.12). The continental slope off Cape Hatteras has had practically no Cenozoic progradation (Figure 10.17); presumably this is the result of the erosive power of the Guld Stream (Heezen et al., 1959).

The best documented section of the Middle Atlantic continental margin is the Quaternary, which in most places occupies the upper 40 to 100 m of sediment (Figure 10.18). In the nearshore areas of southern New England and Long Island, Quaternary sediments are mostly glacial moraine and outwash deposited during the various Pleistocene ice advances (for example, see Zeigler et al., 1960). Drainage systems which cut across the Coastal Plain formations were filled and deformed by Pleistocene glaciation (McMaster and Ashraf, 1973a, 1973b). The sediment on the outer shelf is present as a series of prograding deposits. Ewing et al. (1960, 1963) and Knott and Hoskins (1968) recognizes 5 deltas off New Jersey and New York, each one probably representing a different ice age. Presumably the sediments of Long Island were derived primarily from the rivers draining the neighboring continent, although probably at least some of the sediment was glacial (see the section on sediments in this paper).

At present the Middle Atlantic continental margin appears to be tectonically quiet. The proposed Cornwall-Kelvin Fault system probably has not been active sincethe Mesozoic and probably much earlier. However some seismic activity is occurring in the Ramapo Fault in northern

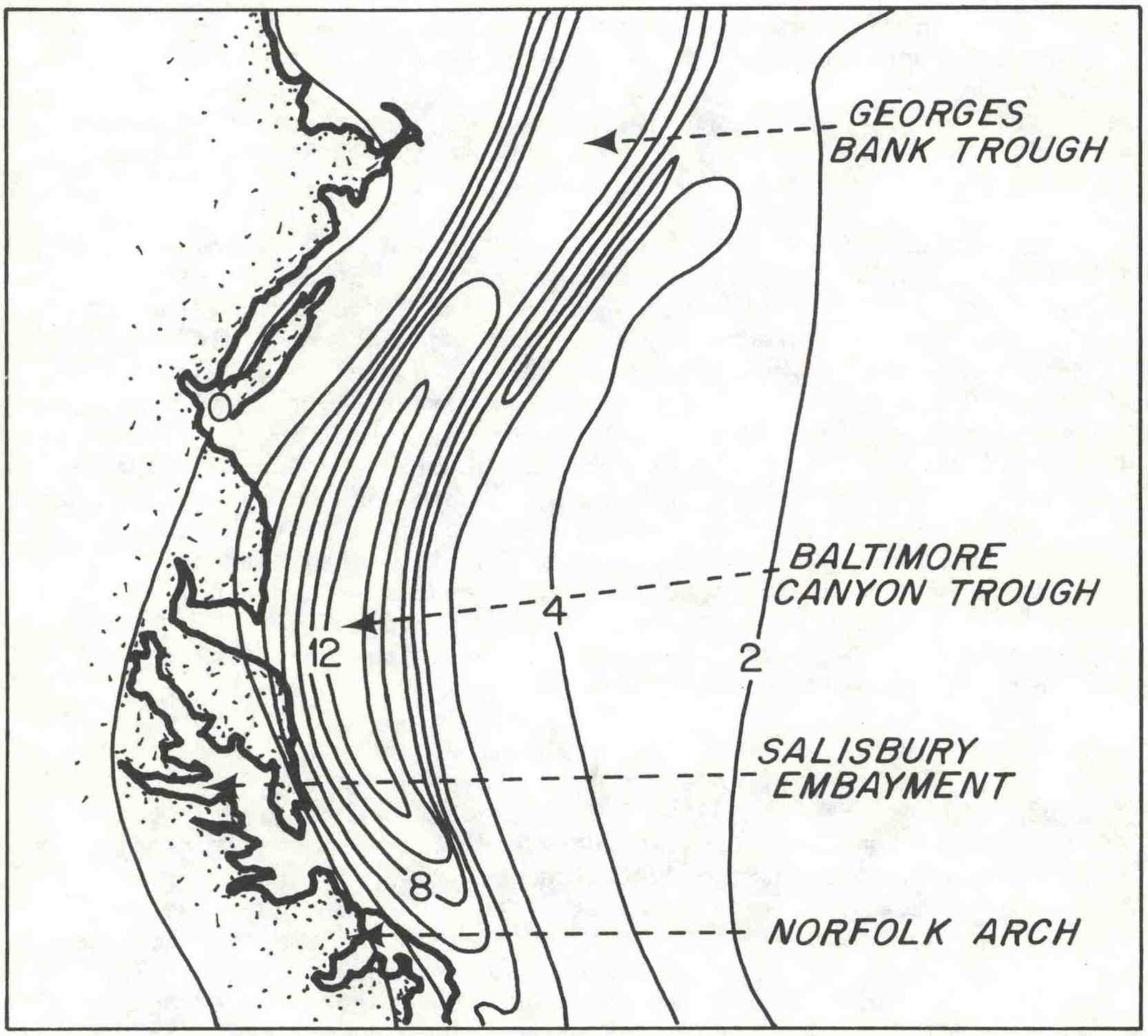

Figure 10.11. Total sediment thickness (in km) on the Middle Atlantic Coastal Plain and continental margin. After Emery and Uchupi (1972); modified by E. Uchupi (1973; pers. comm.).

Figure 10.12. Post-Mesozoic sediment thickness (in km) on the Middle Atlantic Coastal Plain and continental margin. Note that the greatest accumulations occurred on the slope and rise, especially south of New England, as opposed to the great thicknesses of shelf sediments which accumulated primarily during Mesozoic times (compare the Figure 10.11). After Emery and Uchupi (1972).

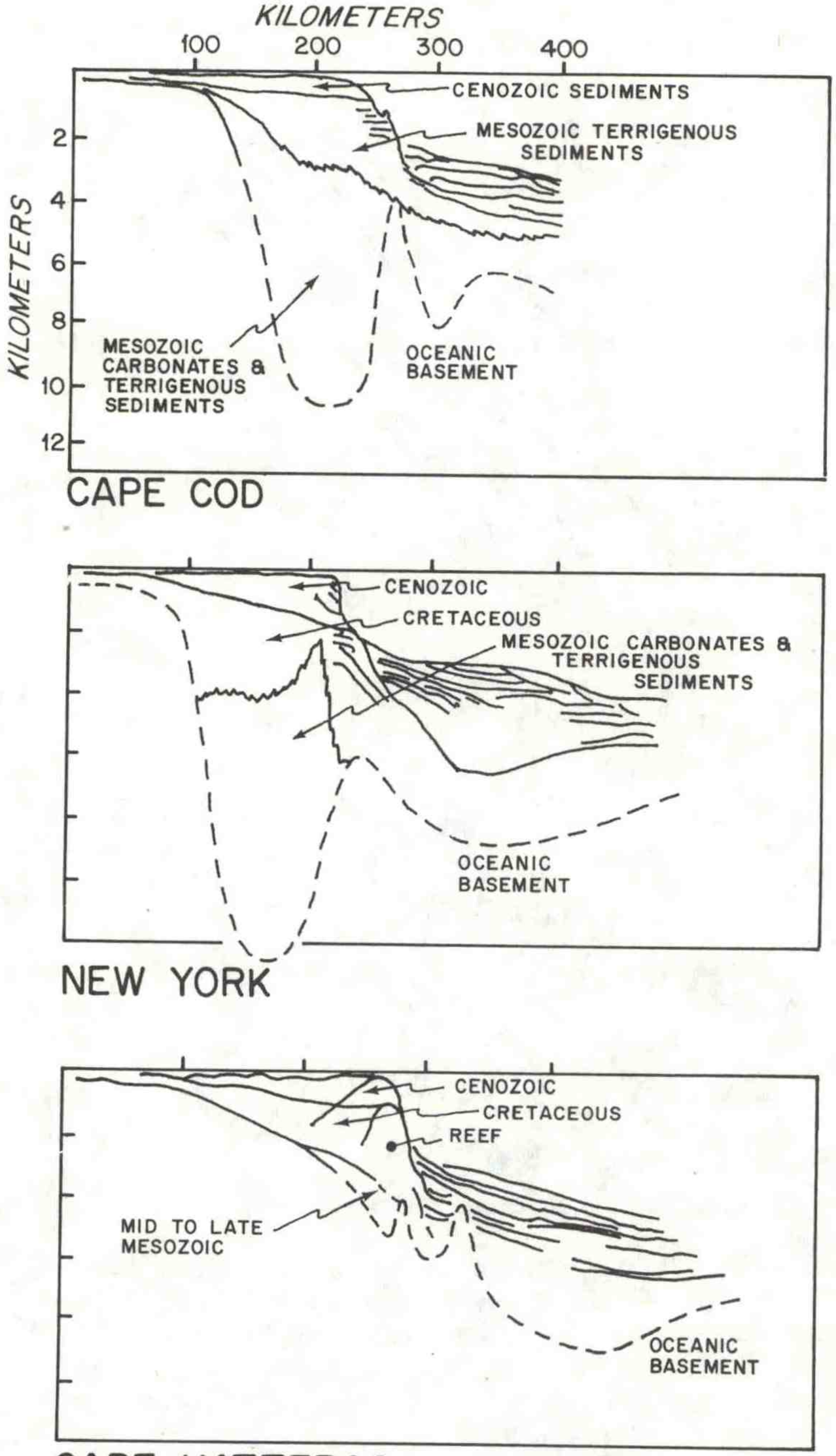

Figure 10.13. Schematic structural sections across the Middle Atlantic continental margin. Top, south of Cape Cod; middle, east of New York; bottom, off Cape Hatteras. After Emery and Uchupi (1972); Drake et al. (1959; 1968); and Maher (1965).

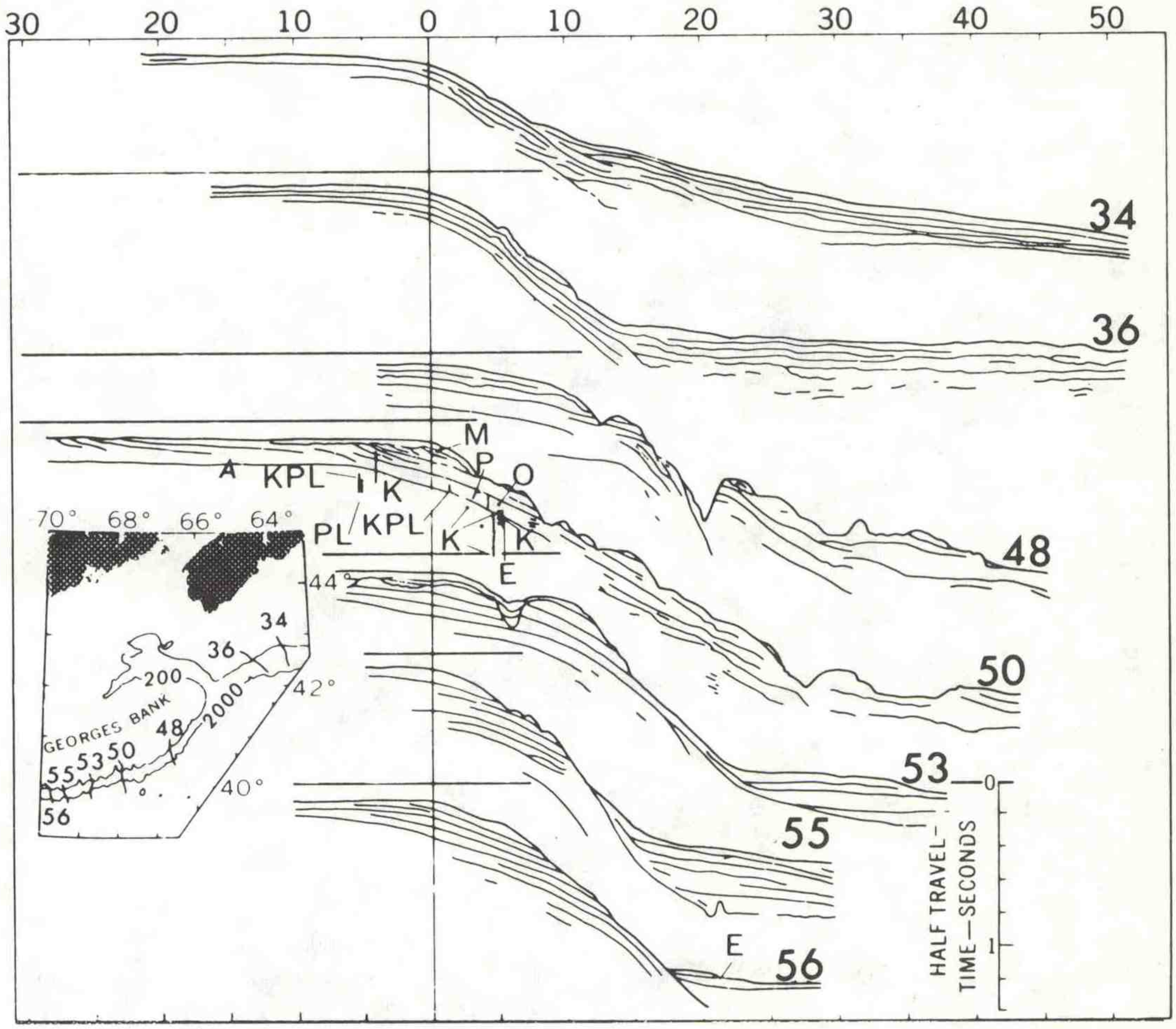

Figure 10.14. Shallow seismic profiles across Georges Bank. Note the great accumulations of sediment on the rise and relatively little on the slope. From Uchupi (1970).

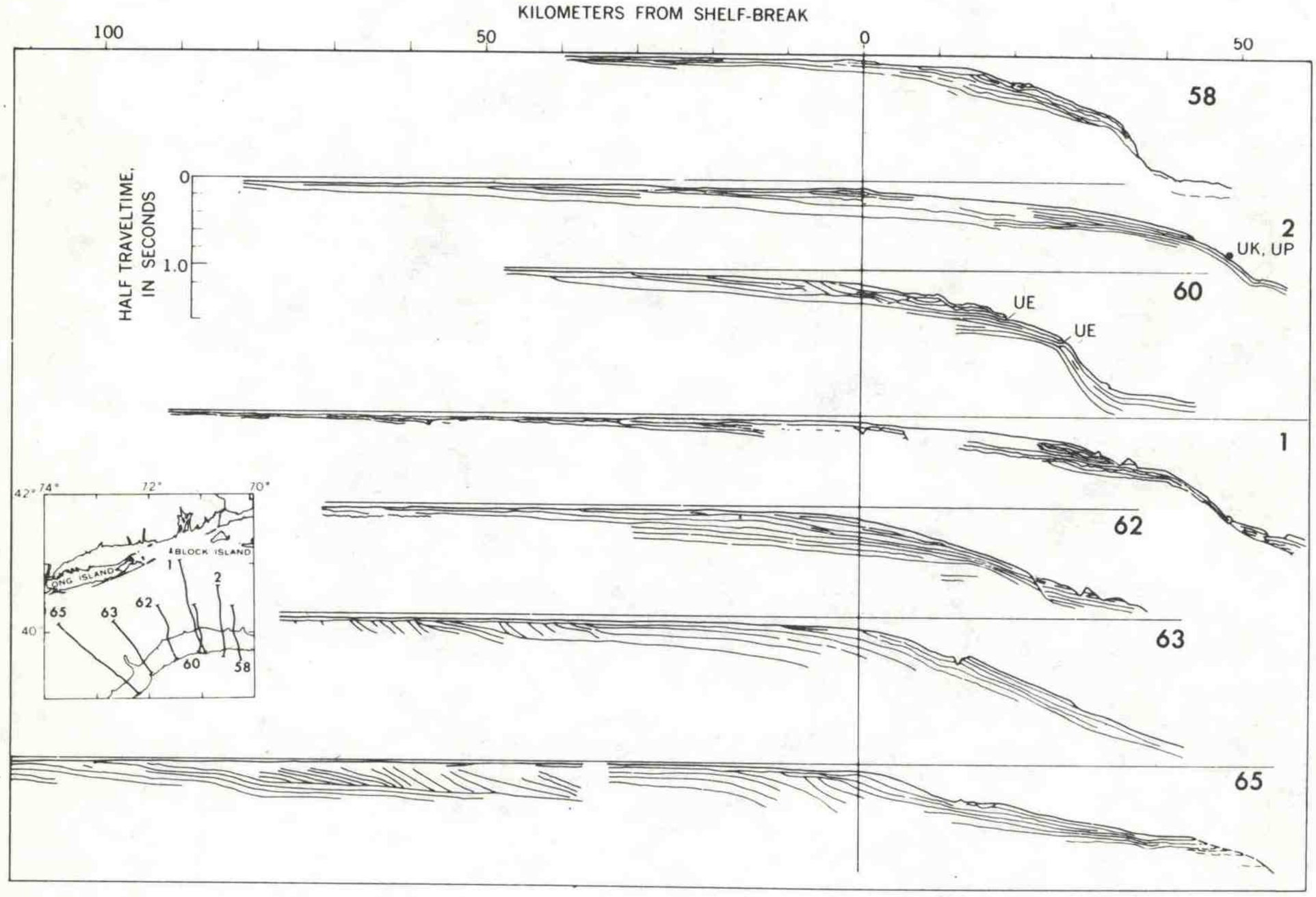

Figure 10.15. Seismic reflection profiles off southern New England and Long Island. Note the lack of shelf and slope progradation in the top two profiles, a continuation of the trend seen in Figure 10.14, and the marked progradation seen in the bottom two profiles. From Uchupi (1970).

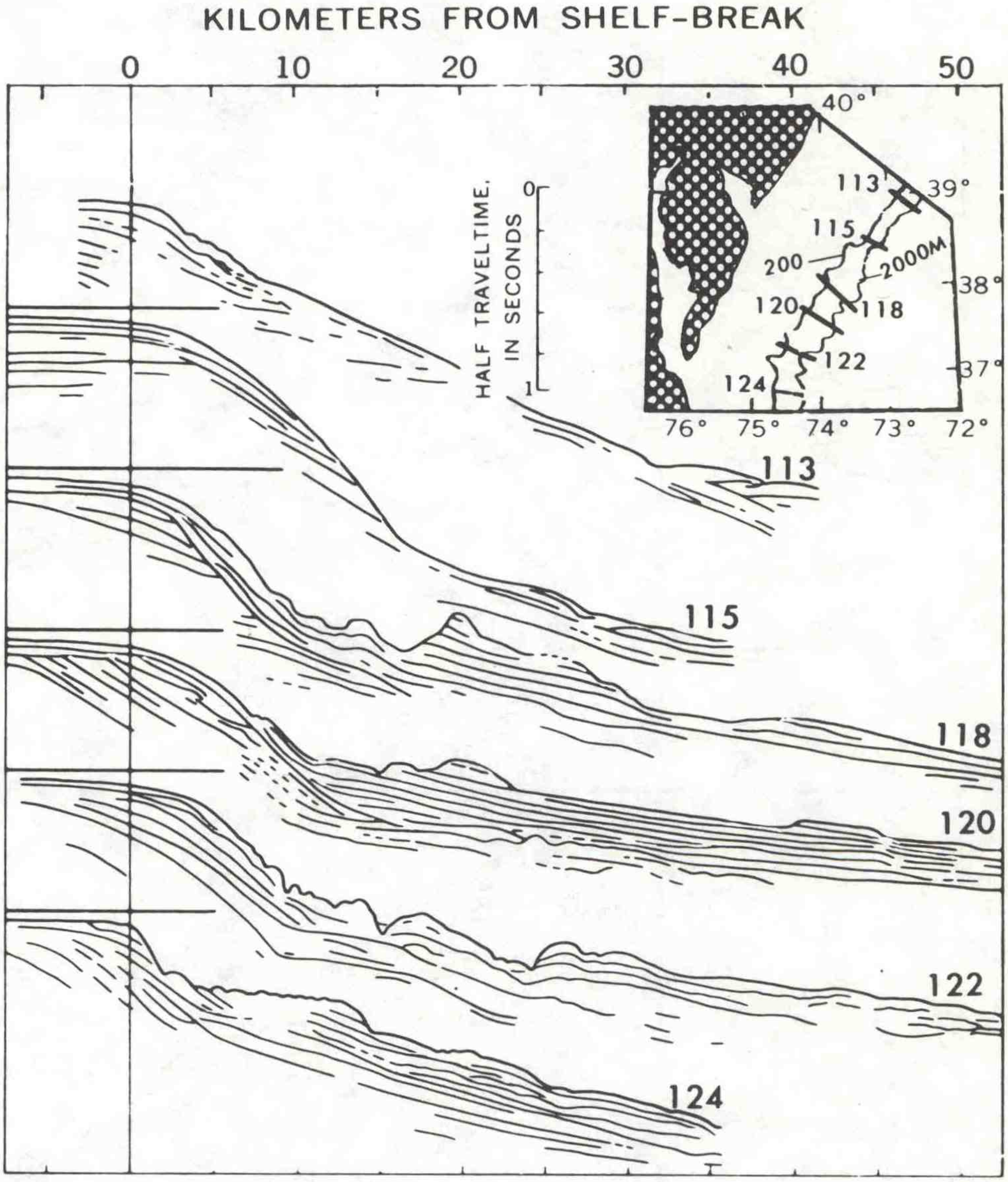

Figure 10.16. Seismic profiles on the outer shelf, slope and rise between New Jersey and Cape Henry. Note shelf progradation and also the several major slumps along with erosional scars. From Uchupi (1970).

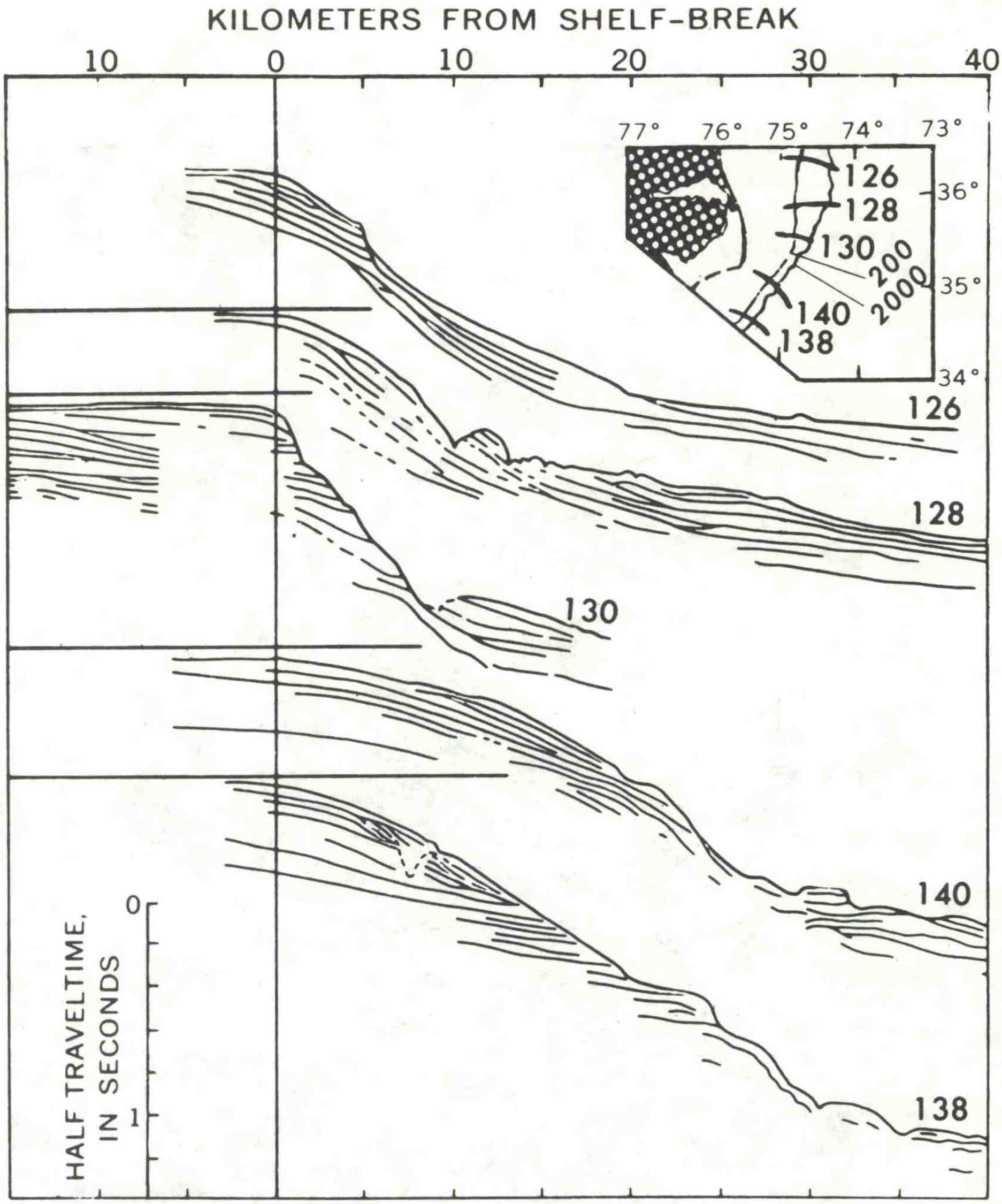

Figure 10.17. Seismic profiles off Cape Hatteras. Note that the slope directly off Cape Hatteras (profile 130) is strongly erosional in character, while to the north, the slope is progradational (although not nearly to the extent seen off Long Island and New Jersey). From Uchupi (1970).

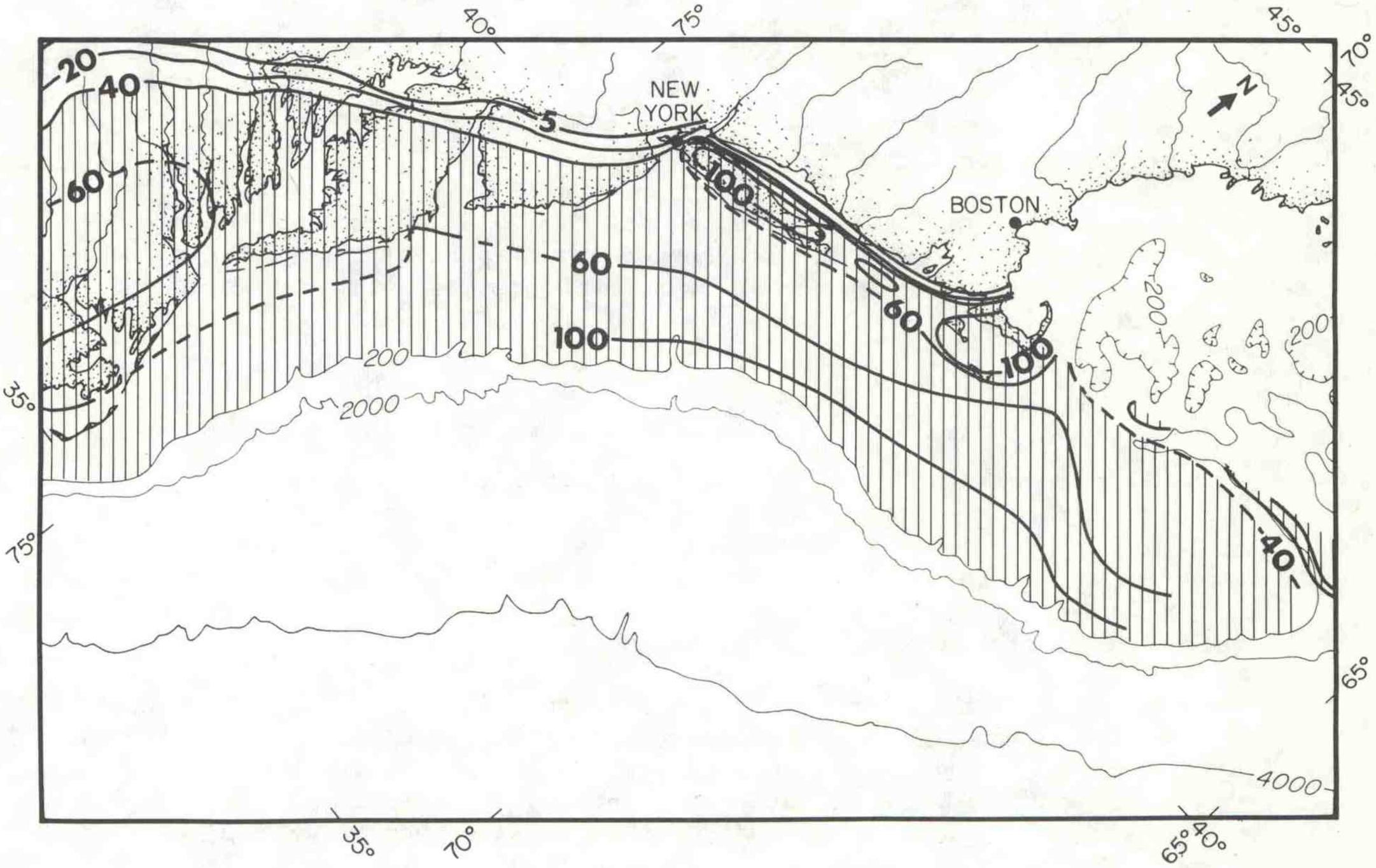

Figure 10.18. Thickness of post-Miocene sediments on the Middle Atlantic Coastal Plain and continental margin (in meters). Greatest accumulations occur off Long Island and southern New England, where glacial moraines in places account for more than 100 m of Pleistocene sediment. This chart is based on few data (because of the lack of stratigraphic control) and thus may be subject to considerable revision when new data are available. After Emery and Milliman (1971).

New Jersey (Page et al., 1968), and since the early 1960's the epicenters of a number of minor earth quakes have been located across central New Jersey and the adjoining continental shelf (J.C. Hathaway, 1973, pers. comm.). This epicenter trend parallels the proposed Cornwall-Kelvin fault system, but is about 100 km to the south. Emery and Uchupi (1972) also have proposed a Norfolk Fracture Zone on the basis of earthquake epicenters off Virginia, but the significance of this earthquake zone and the one off central New Jersey is not known.

Continental Margin Sedimentation

To understand sedimentation on the Middle Atlantic continental margin one must document the source and age of present-day surficial sediments, sediment input and the various processes which control deposition and erosion.

Sediments

The sediments of the Middle Atlantic Bight have been studied by a great number of geologists and oceanographers. The accessibility of the area to many laboratories and universities has allowed workers to collect many samples quickly and comparatively inexpensively. Potential economic and geologic importance of some of these studies has also facilitated accumulation of sedimentologic data.

The relict nature of the shelf sediments (Emery, 1952, 1968a) was documented in the 1930's when Shepard and Cohee (1936) and Stetson (1938, 1939) showed that they were much coarser than what one would predict from Johnson's (1919) shelf-at-grade concepts. The exact nature, age, source and effect of ancient and modern processes, however, were not documented completely until the comprehensive investigation of the area by the Woods Hole Oceanographic Institution and the U.S. Geological Survey in the 1960's. More than 1000 samples were collected from the Middle Atlantic Bight, with the sample spacing generally 18 km apart (Figure 19). Laboratory analyses included size (Schlee, 1973; Hollister, 1973), petrology (Ross, 1970; Milliman, 1972; Trumbull, 1972), carbonate content (Hulsemann, 1967), petrology of the gravel fraction (Schlee and Pratt, 1970) and color (Stanley, 1969). A compilation of these data plus unpublished analyses of organic carbon and nitrogen were presented by Hathaway (1971). General reviews of these data and previous studies have been by Uchupi (1963), Emery (1965a), Milliman et al., (1972) and Emery and Uchupi (1972).

Size

The continental shelf sediment is dominated by sand (62 to 2000 microns in diameter) (Figure 10.20). Over much of the area sand consti-

tutes more than 98% of the total sediment. Sediments with high gravel concentrations occur on Nantucket Shoals, Georges Bank and the inner shelf off New Jersey (Schlee, 1964); locally gravel can comprise more than 75% of some shelf sediments (Figure 10.21). Schlee, (1968) has suggested that the gravel off southern New England is mostly fluvial in origin while most of the gravel off northern and eastern New England was transported to the shelf by ice. Mud is present in only small amounts on the shelf, except for some nearshore areas, the shelf off Cape Hatteras and a large area south of Martha's Vineyard (Figure 10.22). Most of the nearshore mud is fluvial, but some may be derived from underlying strata (see below).

Sediments on the continental slope and rise are dominated by silt and clay (Figure 10.20). Most of the sand is biogenic (calcareous), although patches of terrigenous sand occur in the axes of some canyons (Hathaway, 1971; Keller et al., 1973).

Sediment Color

Sediments in the Middle Atlantic Bight tend to be yellow or greenish in color (Figure 10.23). The predominance of yellow sediments is closely related to the distribution of iron-staining within these sediments (Figure 10.24). Stanley (1969) has concluded that the olive and brown colors on the slope and rise are mostly a function of the relatively oxygen-rich environment due in part to the active circulation in the area.

Most of the sands on the continental shelf contain between 5 and 50% iron-stained grains. Significantly low concentrations occur seaward of Chesapeake and Delaware Bays, while comparatively high concentrations are found east and south of Long Island and on much of Nantucket Shoals and Georges Bank. Iron-staining in most shelf sediments probably reflects depositional history although to a lesser extent it may reflect sediment source (Judd et al., 1970). High concentrations may represent sediments deposited in or transported along oxygen-rich beach environments during lower stands of sea level, while relatively clear grains may have been deposited in reducing environments. If this latter assumption is true, the lack of iron staining in sediments seaward of Delaware Bay and Chesapeake Bay may indicate that these sediments were deposited in estuarine environments. The relatively iron-stained sediments of Georges Bank and Nantucket Shoals may indicate the proximity of underlying Coastal Plain sediments rather than Quaternary deposition (see below).

Carbonate Concentrations and Assemblages

Calcium carbonate is a minor component in Middle Atlantic shelf sediments. Carbonate content generally averages less than 5% (by weight)

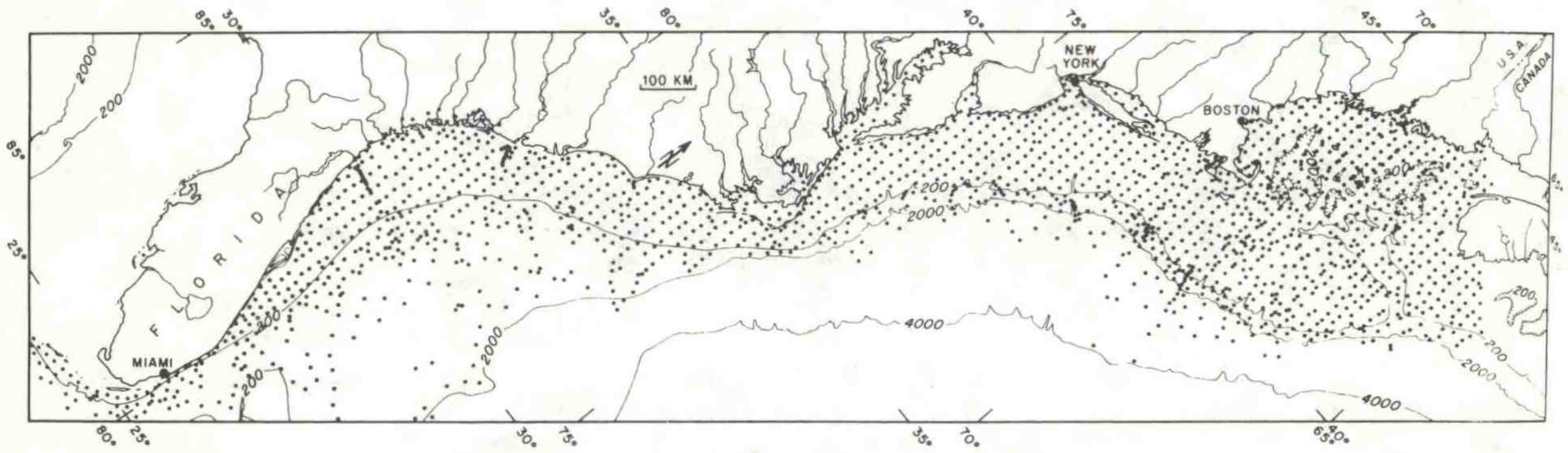

Figure 10.19. Distribution of surface sediment samples on the continental margin off the eastern United States. These samples were collected by the Woods Hole Oceanographic Institution and the U.S. Geological Survey using Smith-McIntyre, Campbell and van Veen grab samplers.

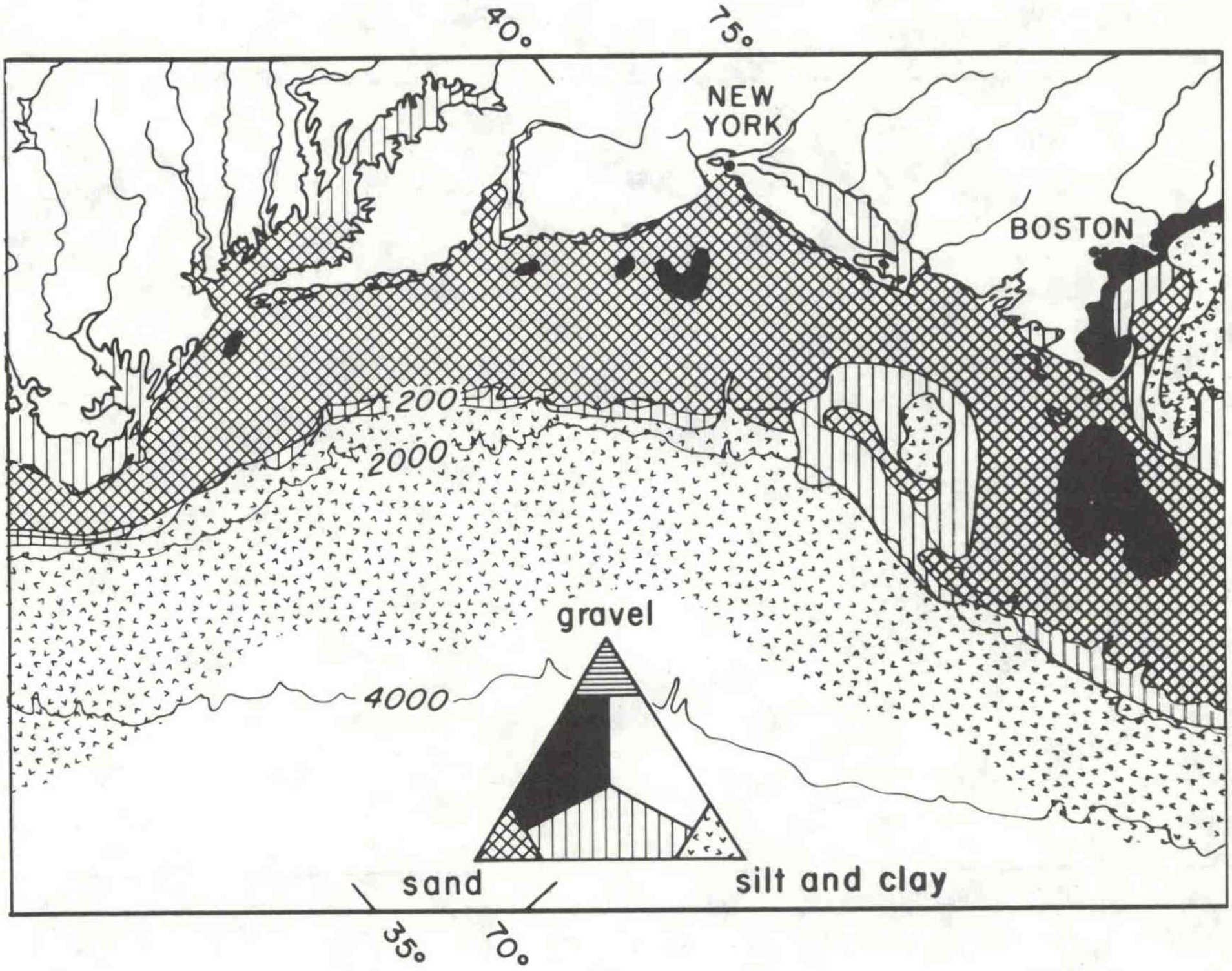

Figure 10.20. Distribution of model sizes of sediments from the Middle Atlantic continental margin. After Milliman et al. (1972).

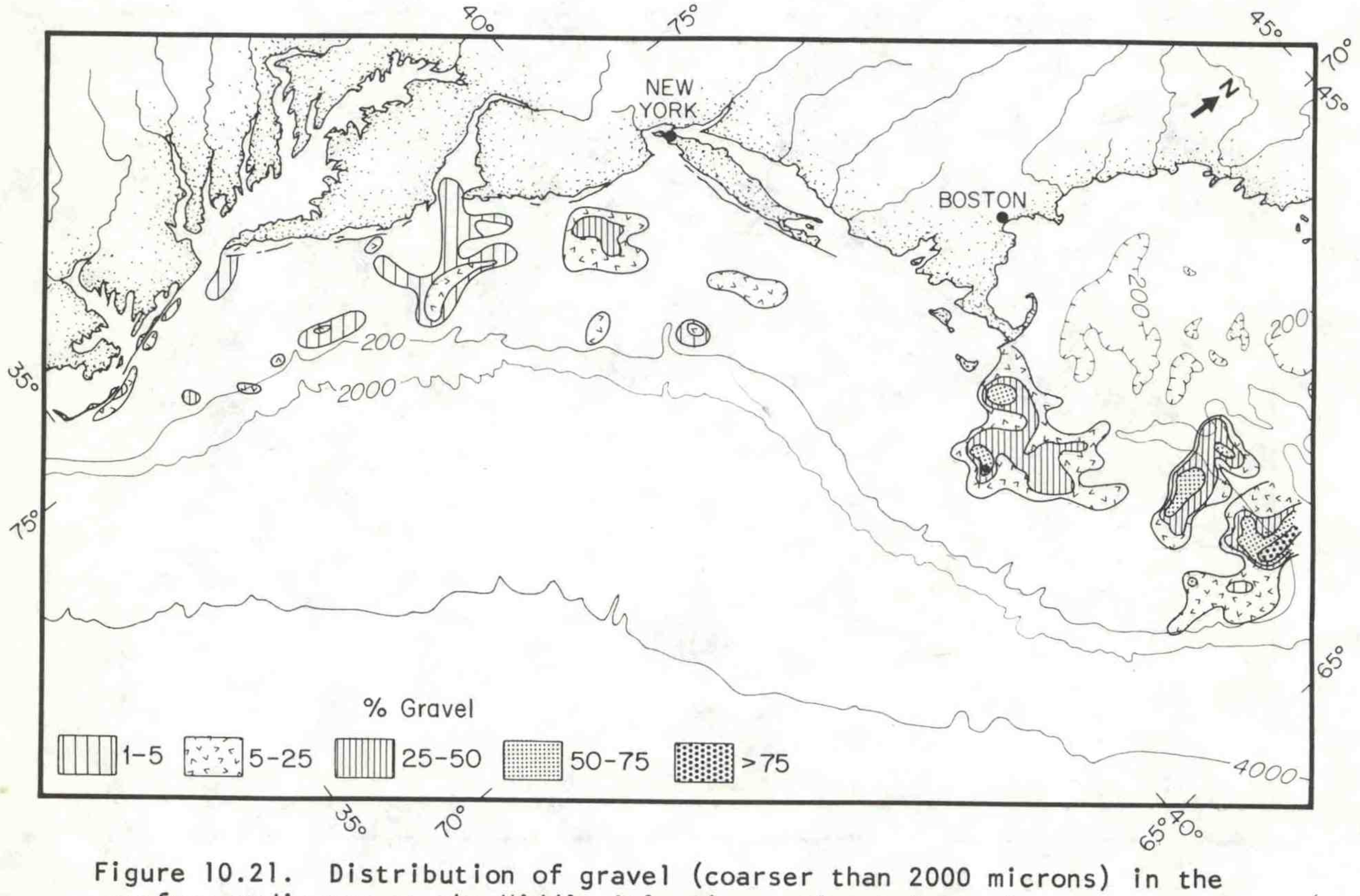

Figure 10.21. Distribution of gravel (coarser than 2000 microns) in the surface sediments on the Middle Atlantic continental margin.

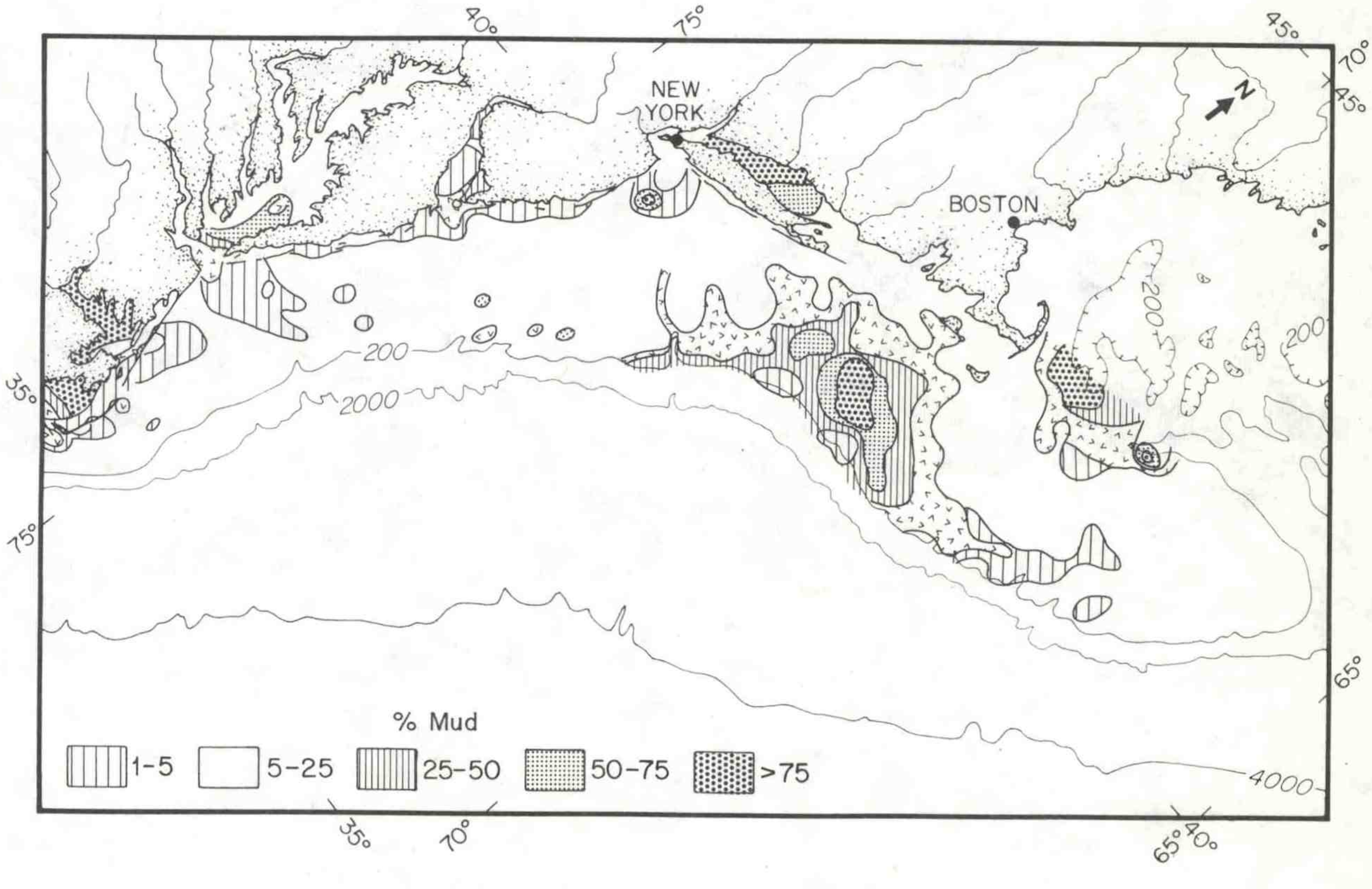

Figure 10.22. Distribution of mud (silt and clay) in the surface sediments on the Middle Atlantic continental margin.

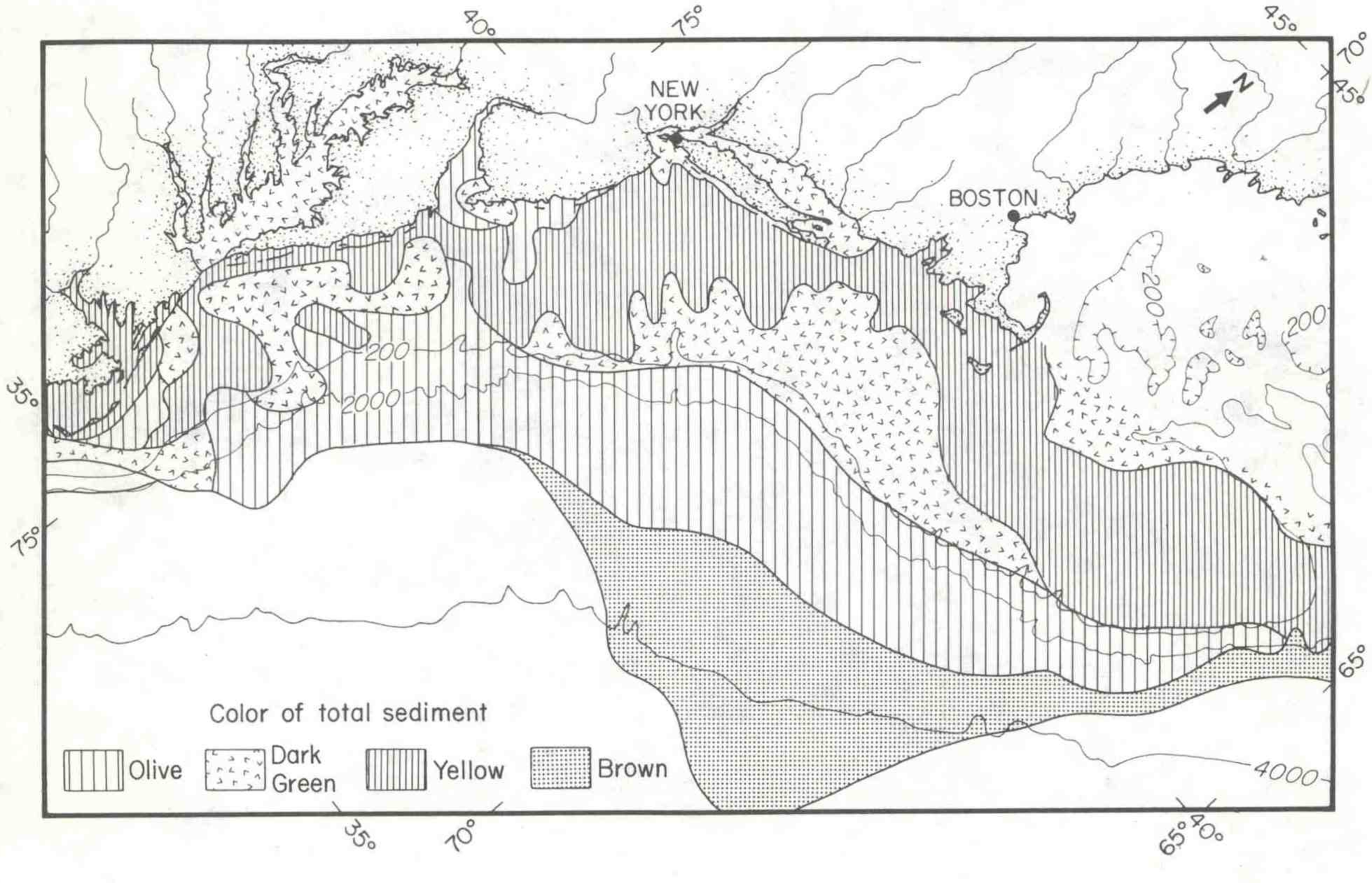

Figure 10.23. Color of shelf and slope sediments. After Stanley (1969).

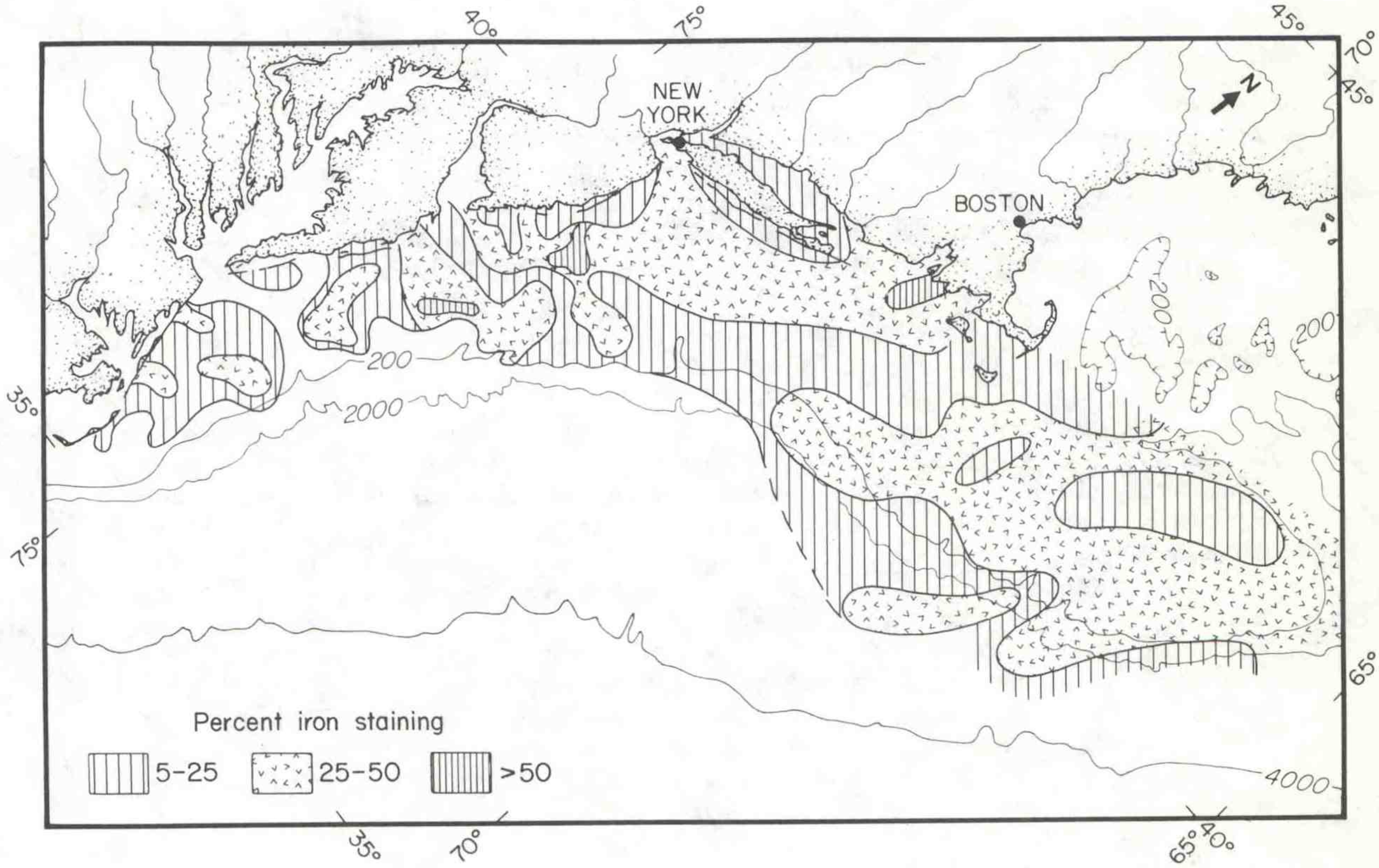

Figure 10.24. Distribution of iron-stained grains in the 125-250 micron fraction in the surface sediments. After Milliman et al. (1972).

and most sediments contain less than 2% (Figure 10.25). Patches of carbonate-rich sediment, containing up to 65 percent $CaCO_3$, occur on Georges Bank and Nantucket Shoals. Carbonate content on the slope is higher than the shelf, but seldom reaches 75%. The low shelf and slope values characteristic of the Middle Atlantic Bight are in marked contrast to the high values in sediments south of Cape Hatteras (Milliman et al., 1972).

The dominant carbonate components on the shelf are mollusk fragments, derived primarily from bivalve shells. Some are relict, having been deposited during lower stands of sea level. The presence of brackish water oysters in shelf sediments (Merrill et al., 1965) is one indication of this shallow-water fauna. Other mollusk fragments, however, are modern in age. Locally, echinoid plates are important components of shelf sediments, especially in inner and mid-shelf sediments north of Cape May (Figure 10.26). Large concentrations of the echinoid Echinarchinus parma have been observed living on the shelf off southern New Jersey (Emery et al., 1965) and it seems probable that most echinoid fragements in shelf sediments are modern in age.

Sediments relatively rich in benthonic foraminifera occur seaward of Delaware and Chesapeake Bays and in the mud patch south of Martha's Vineyard. Parker (1948) found that in depths of 0 to 15 m, the foraminifera fauna is dominated by various species of Elphidium. Between 15 and 90 m, Quinqueloculina seminulum, Eggerella advena and Triloculina sp. are diagnostic species. In the depth range of 90 to 300 m, the number of individuals and total species increases greatly; Lagenidae are common (Parker, 1948). Barnacle valves occur in relatively high concentrations in the high carbonate sediments on Georges Bank and Nantucket Shoals, but otherwise are minor components (Figure 10.26). These barnacle-rich sediments are similar in assemblage composition to those on the Scotian Shelf (Milliman et al., 1972) and on Grand Banks (Muller and Milliman, 1973).

Continental slope sediments are dominated by the tests of planktonic foraminifera. Benthonic foraminifera, echinoid plates and in places coccoliths can be common, but seldom abundant.

Heavy Minerals

A number of workers have reported on the composition and distribution of heavy minerals in the Middle Atlantic shelf sediments (Alexander, 1934; McCarthy, 1931; McMaster and Garrison, 1966; Stetson, 1938; Ross, 1970; McKinney and Friedman, 1970; Swift, Dill and McHone, 1971; and MacIlvaine, 1973). Most of the data discussed in the following paragraphs are taken from analyses of D.A. Ross and reported in Ross (1970), Hathaway (1972), Milliman et al., (1972) and Ross (in prep).

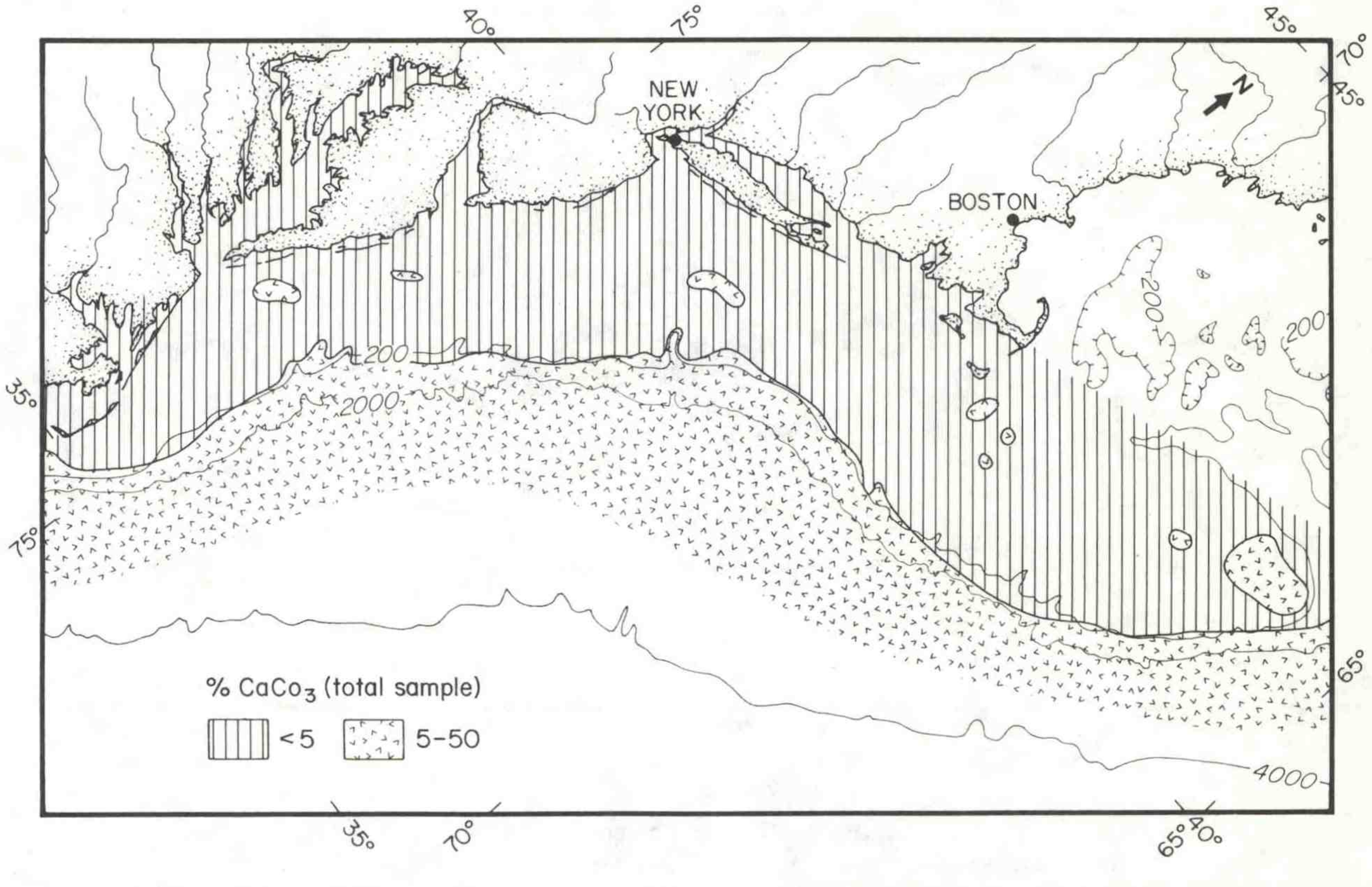

Figure 10.25. Distribution of calcium carbonate in the surface sediments on the Moddle Atlantic continental margin. After Milliman et al. (1972).

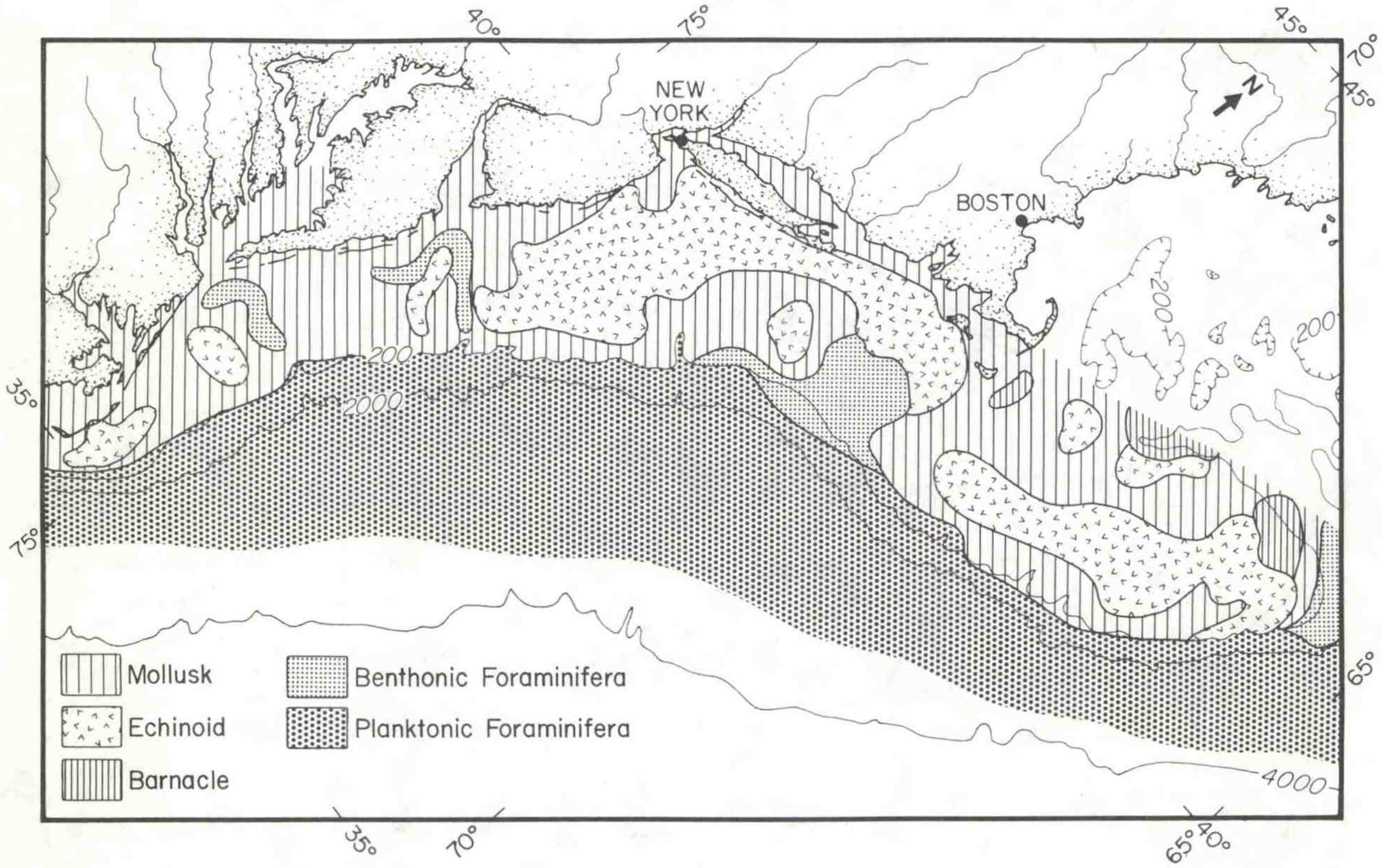

Figure 10.26. Carbonate assemblages on the Middle Atlantic continental margin. Mollusk assemblages are composed primarily of mollusks (60 to 100%) and contain an average of 3% $CaCO_3$. Echinoid assemblages contain 20 to 100% echinoid fragments and 0 to 80% mollusk debris; average carbonate values are 2%. Benthonic foraminifera facies contain similar amounts of carbonate and contain large quantities of benthic foraminifera (20 to 70%) and mollusks (15 to 70%). Barnacle assemblages are composed primarily of barnacle valves and mollusk fragments; carbonate values range from 15 to 60%. From Milliman et al. (1972).

Heavy minerals (minerals with specific gravities greater than 2.87) in the sand-size fraction generally average 2 to 4% on the shelf and less than 2% on the slope (Figure 10.27). South of Long Island are several large areas in which sediments contain more than 4% heavies. Highest concentrations occur on the outer shelf off southern New Jersey, where concentrations can exceed 15% (Hathaway, 1971). The limited number of existing heavy mineral data prevents us from delineating possible relict strand lines or placer deposits.

Four minerals dominate the non-opague heavy fraction. Amphiboles are common on the shelf, especially between Cape Henry and Cape Hatteras, and on the slope south of New Jersey (Figure 10.28). Being comparatively non-resistant to abrasion, it occurs in only small quantities in exposed high-energy areas such as Georges Bank. Epidote is present in relatively small quantities north of Cape Hatteras, but is prominent in sediments to the south (Figure 10.29). In contrast, garnets are abundant north of Cape Hatteras and decrease to the south. Heavy minerals on the shelf off central New Jersey and southeast of Long Island contain more than 45% garnet (Figure 10.30). Staurolite is common on Georges Bank and off Lond Island; it decreases towards Cape Hatteras but to the south it increases again (Figure 10.31). Zircons are prominent (greater than 15%) in the sediments seaward of Chesapeake Bay and locally on Nantucket Shoals and Georges Bank. Hypersthene is present in uniformly low amounts north of Cape May, but to the south relatively high concentrations (10 to 15%) extend across the middle and outer shelf. Kyanite is also important in the area near Cape Hatteras (Swift, Dill and McHone, 1971).

Local variations may be significantly greater than previously suspected. For example, McMaster and Garrison (1966) have suggested that Block Island Canyon forms a dividing line between New England and Hudson sedimentary provenances. West of Block Island Channel, according to McMaster and Garrison (1966), the heavy minerals are dominated by garnet, while to the east opaques and amphibole assemblages predominate. Similarly, MacIlvaine (1973) found four different heavy mineral assemblages on the outer shelf and continental shelf south of Martha's Vineyard. The outer shelf sediment is characterized by an epidote-rich assemblage, the shelf break by garnet, the lower slope and upper rise by hornblende, and parts of the lower slope by pyrite (presumably authigenic). While the significance of these various assemblages is not completely clear, to some extend they indicate different sources and/or depositional environments.

Light Minerals

Sand-size minerals less dense than 2.87 are composed mostly of quartz, feldspar and glauconite. Some slope and estuary sediments also contain small quantities of diatoms.

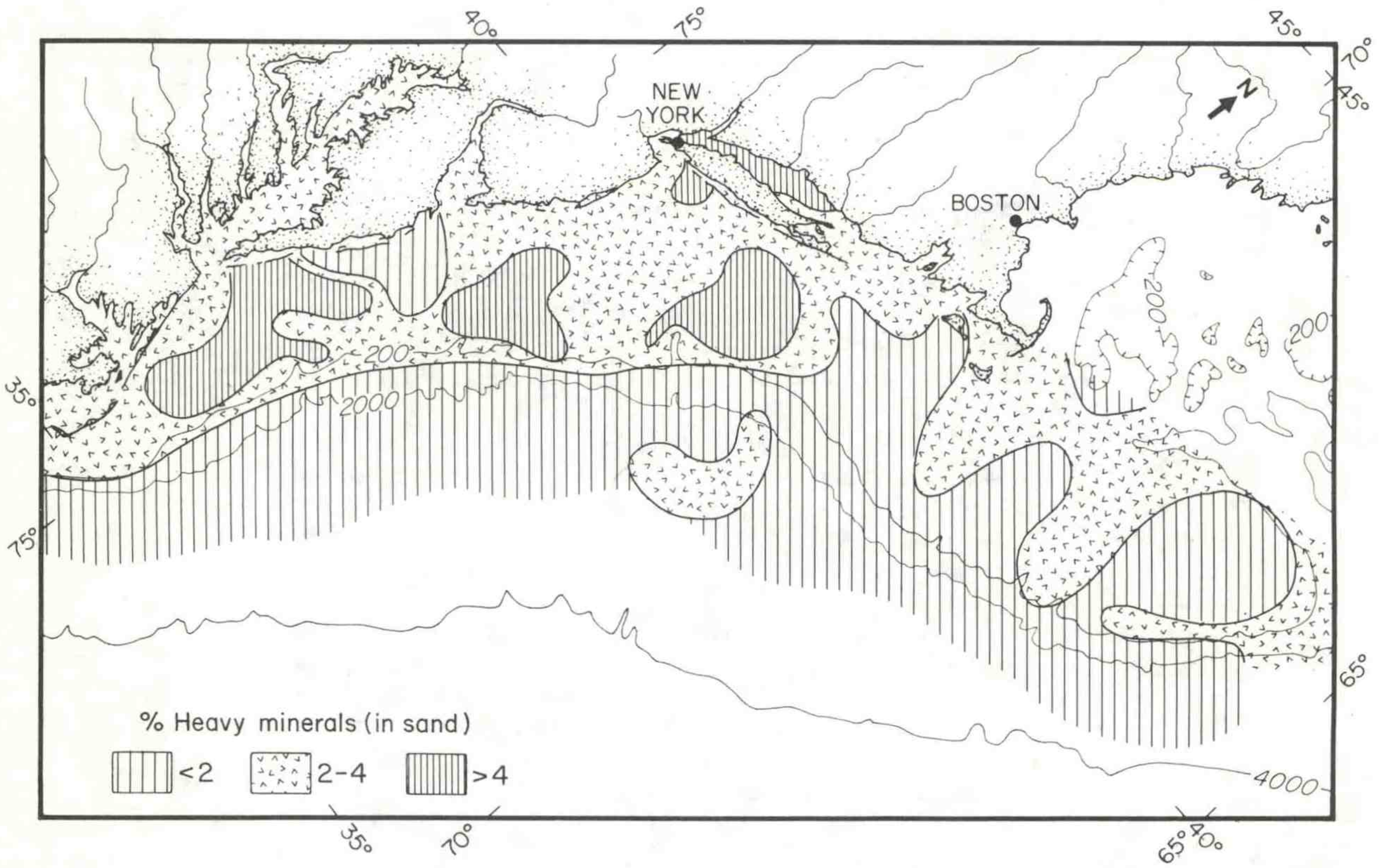

Figure 10.27. Distribution of heavy minerals on the continental shelf and slope.

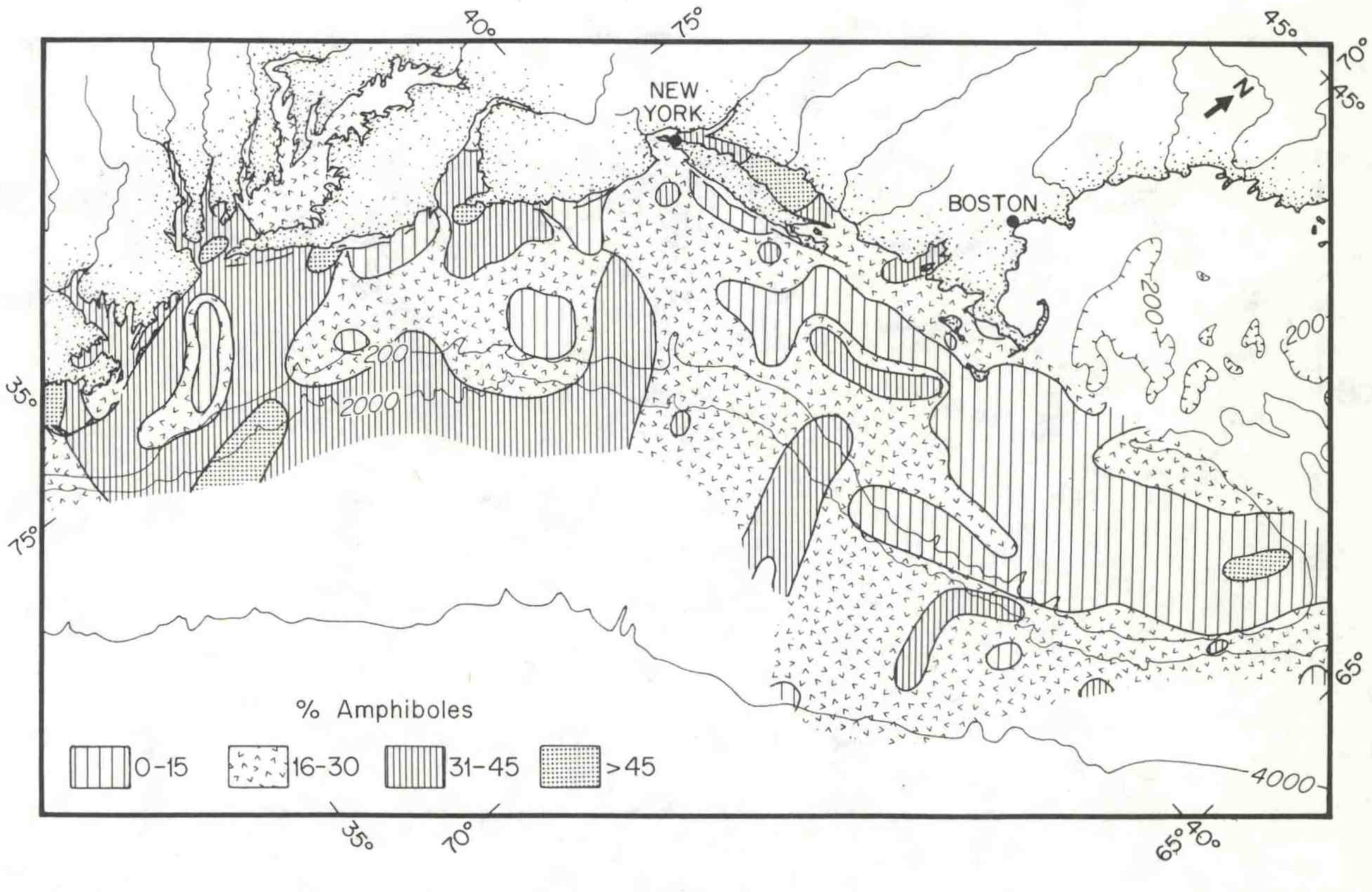

Figure 10.28. Distribution of amphiboles within the heavy mineral fraction. Unpublished data from D.A. Ross.

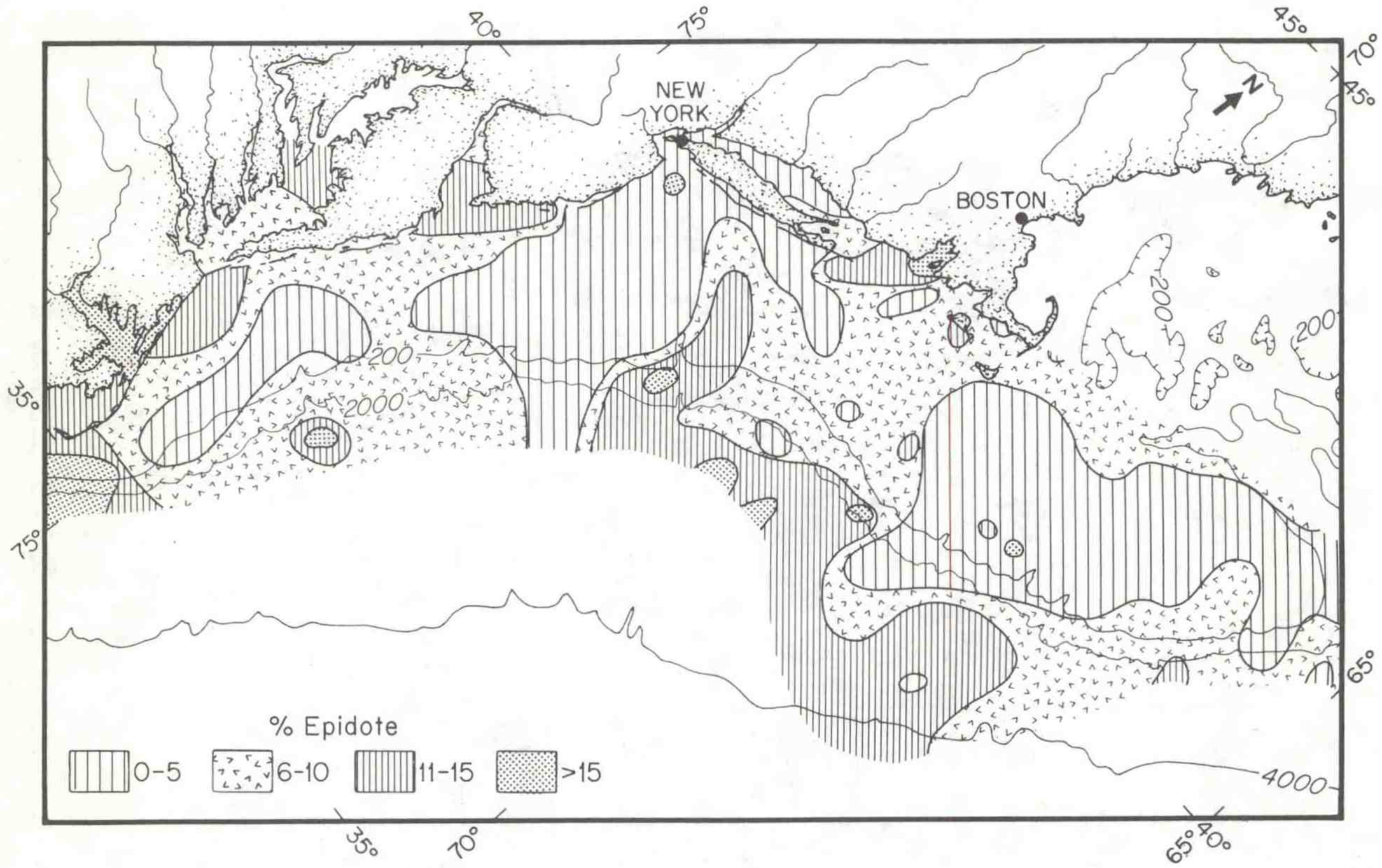

Figure 10.29. Distribution of epidote within the heavy mineral fraction. After Milliman et al. (1972).

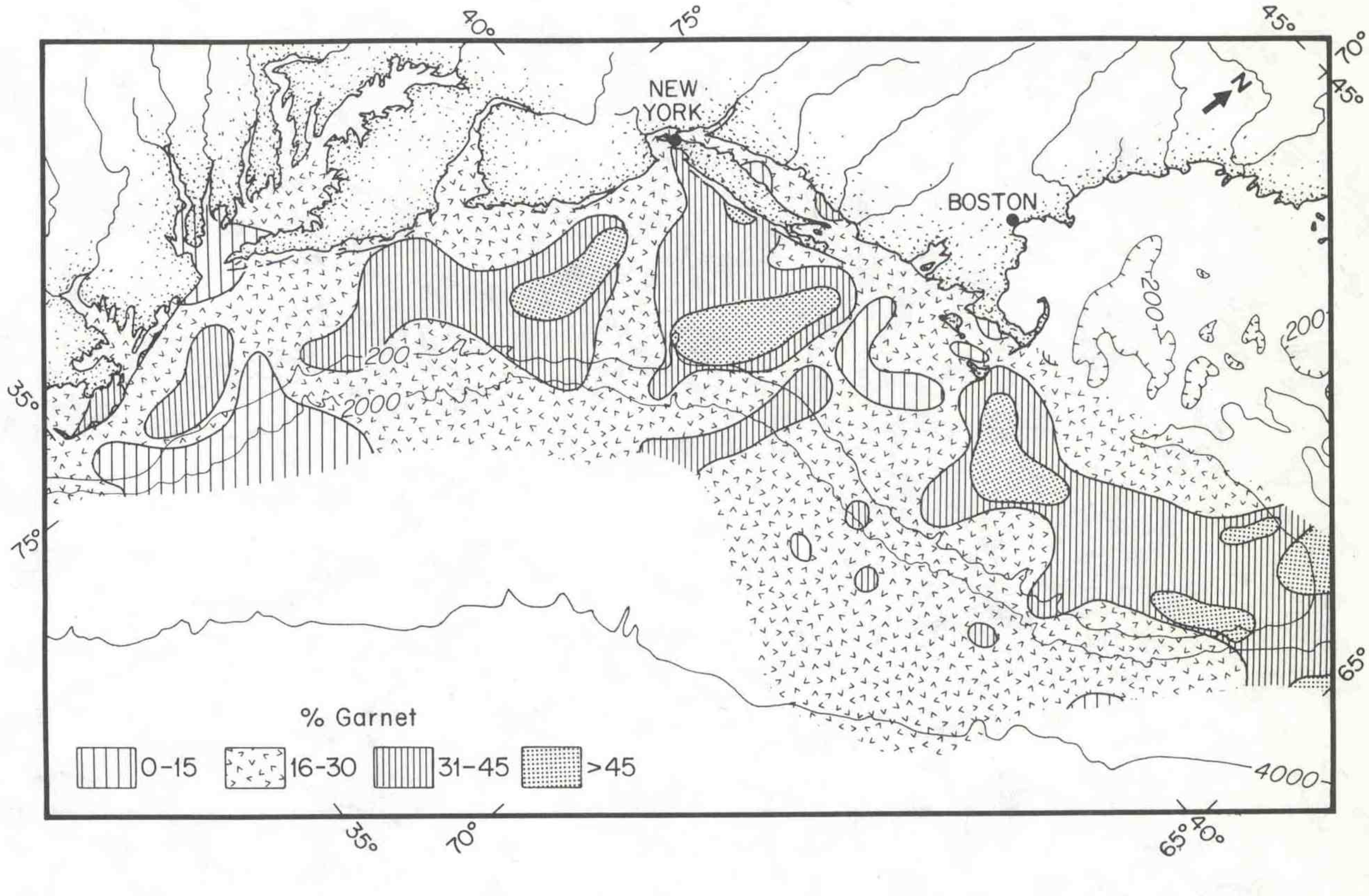

Figure 10.30. Distribution of garnets within the heavy mineral fraction. After Milliman et al. (1972).

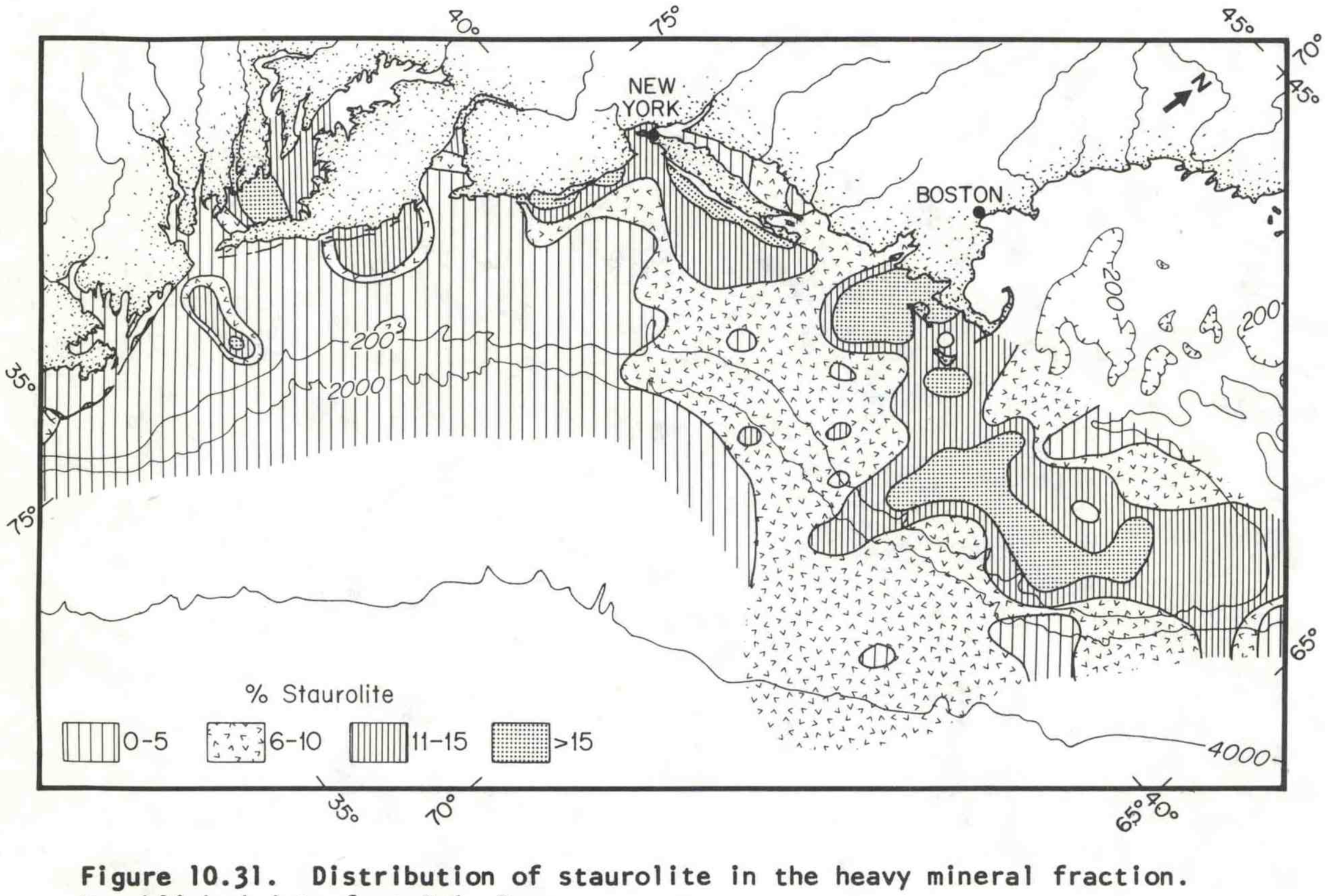

Figure 10.31. Distribution of staurolite in the heavy mineral fraction. Unpublished data from D.A. Ross.

Glauconite pellets, primarily reworked and rounded foraminifera molds, are present in fairly large quantities over much of the shelf off Long Island and New Jersey (Figure 10.32). Glauconite in the 125-250 micron fraction ranges up to 25%. Judging from similar glauconite-rich sands on New Jersey beaches, much of this material probably was derived from Cretaceous and lower Tertiary glauconite-rich strate (Colony, 1932; McMaster, 1954), either subaerial or subaqueous outcrops.

Glauconite also is present in relatively high concentrations on parts of Georges Bank and Nantucket Shoals. Alexander (1934) suggested that the glauconite near Nantucket Shoals authigenic, but more probably it was derived from underlying Coastal Plain strata (Milliman et al., 1972).

Quartz and feldspar are the most prominent minerals on the continental shelf. The distribution of feldspar relative to quartz is particularly interesting with respect to the source and age of shelf sands. Bands of feldspar-rich sands (arkose according to Pettijohn, 1957) extend across the shelf seaward of Chesapeake Bay, Delaware Bay, New York Harbor and eastern Long Island (Figure 10.33). Presumably these sediments were derived from the rivers that feed these four estuaries - namely the Susquehanna, Delaware, Hudson and Connecticut Rivers. The arkosic nature of these relict sands probably is indicative of the mode of erosion during glacial times when chemical weathering was insignificant (Milliman et al., 1972). This would indicate that the sediments have not moved significantly since deposition prior to or during the Holocene transgression.

The remainder of the continental shelf sediment south of Long Island is dominated by subarkosic sands, with 10 to 25% feldspar in the 125 to 250 micron fraction. McMaster and Garrison (1966) have indicated that feldspars west of Block Island are dominated by soda-lime types, while to the east potash-feldspar predominates. Presumably, as in the case of heavy minerals (see above) this reflects sediment input from the Hudson River and New England rivers, respectively. McKinney and Friedman (1970) have suggested that feldspar content increases offshore in response to decreasing chemical weathering, presumably a relict of colder Pleistocene climates.

The sediments on Nantucket Shoals and Georges Bank contain surprisingly small quantities of feldspar, generally 5 to 10%. The only reasonable source for this quartz-rich sand must be the underlying Coastal Plain strata, since New England river sediments tend to be rich in feldspar.

Clay Minerals

The composition and distribution of layered silicates along the

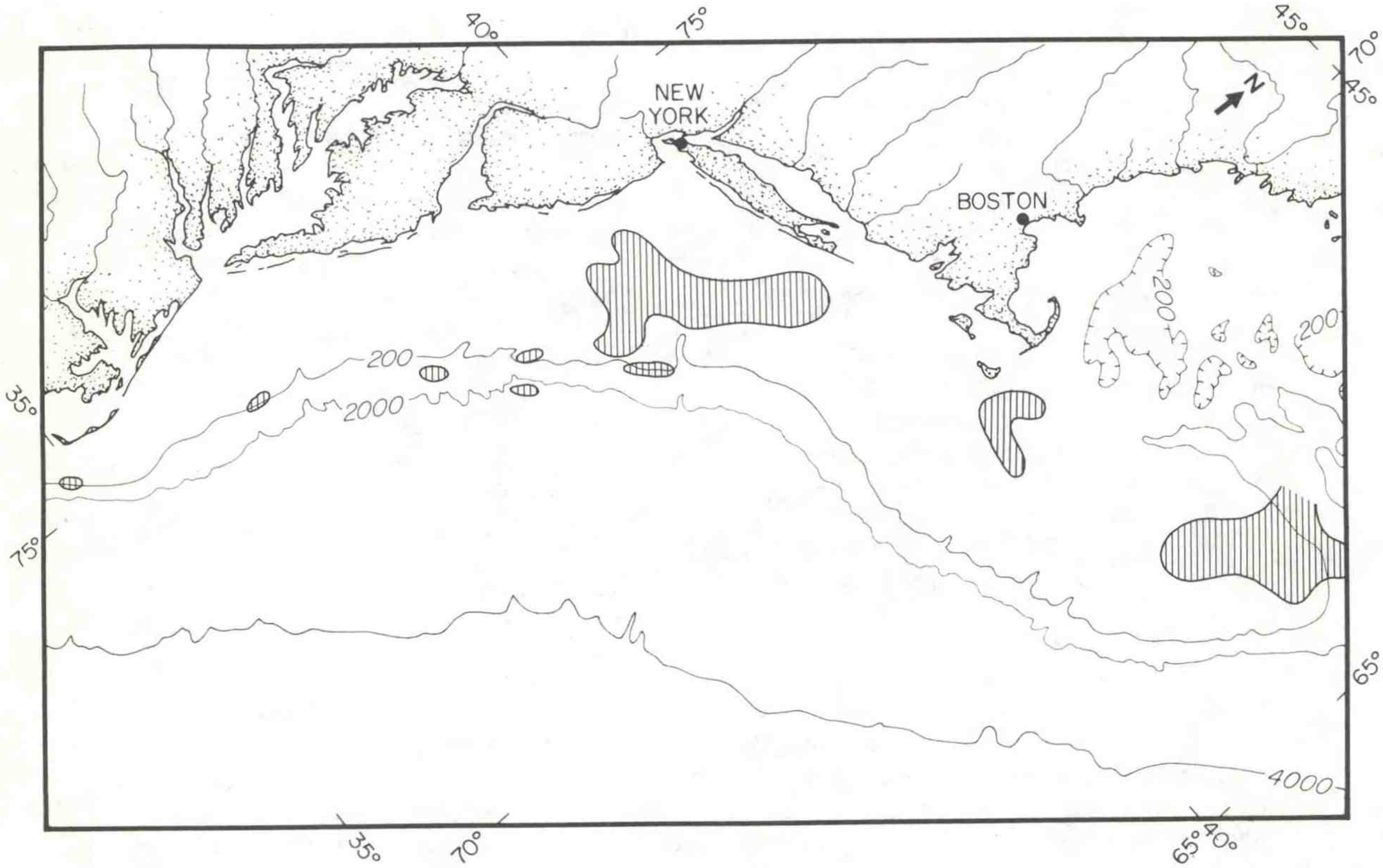

Figure 10.32. Shelf sediments containing 5 to 25% glauconite in the 125-250 micron insoluble fraction. From Milliman et al. (1972).

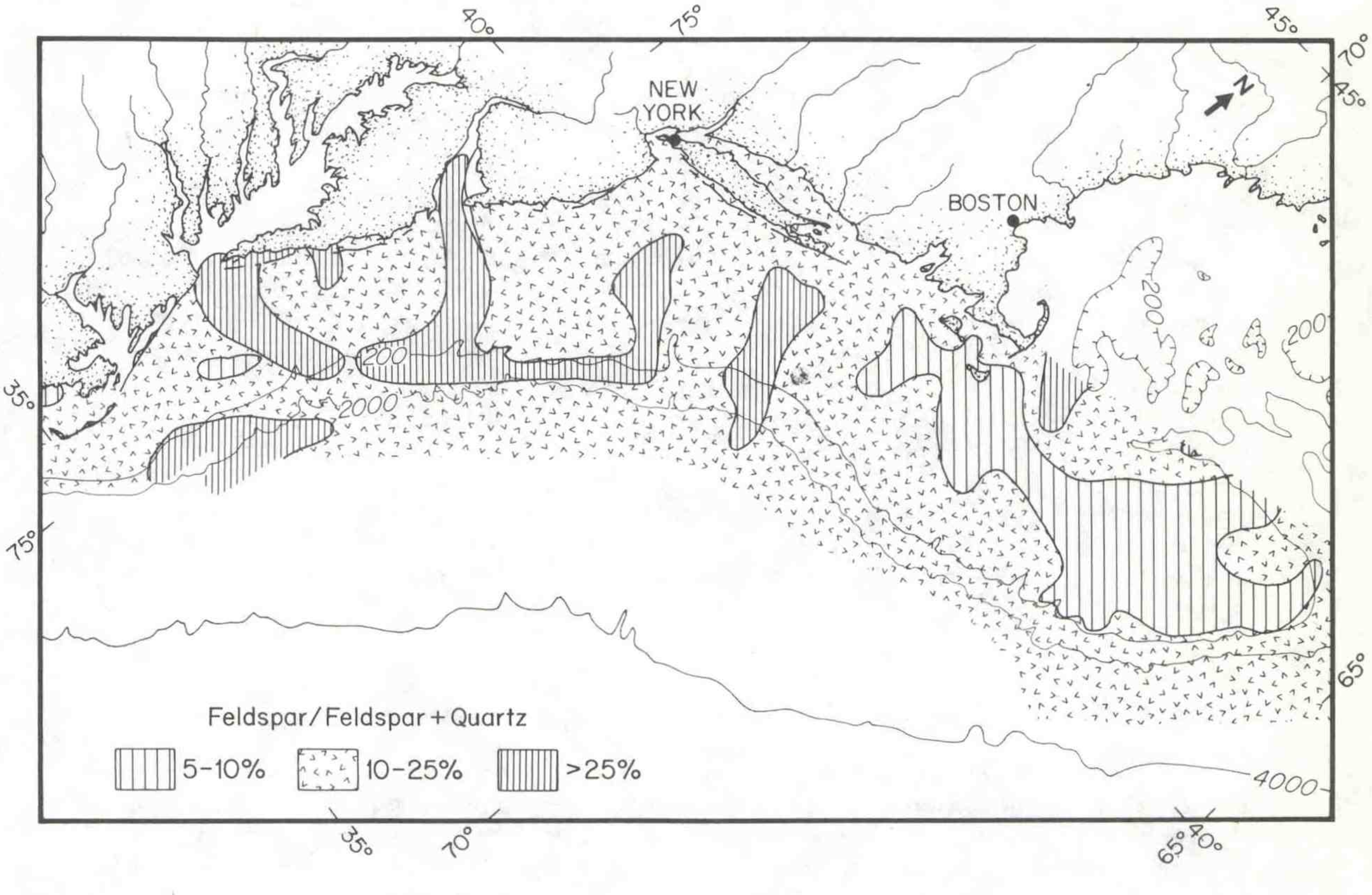

Figure 10.33. Ratio of feldspar to quartz + feldspar in the surface sediments on the continental margin. After Milliman et al. (1972).

eastern United States continental margin were reported and summarized by Hathaway (1971, 1972). Owing to the almost complete lack of clay-size material, data for continental shelf sediments are absent.

Middle Atlantic Bight sediments contain large quantities of illite (generally 50 to 60% in estuaries and on the outer shelf) and chlorite (30 to 40%) (Figures 10.34 and 10.35). Kaolinite and montmorillonite are present in much smaller amounts. South of Chesapeake Bay, however, kaolinite increases markedly (Figure 10.36) and illite and chlorite decrease, reflecting the increased influence of chemical weathering in southern climates. Similar trends in clay mineral distribution are found in slope, rise and abyssal plain sediments (Biscaye, 1965).

Hathaway (1972) noted that the sediment presently being contributed by rivers flowing into both Chesapeake and Delaware Bays is considerably lower in illite and chlorite content and higher in kaolinite and dioctahedral vermiculite. Presumably this difference in shelf and estuary sediments on the one hand and river sediments on the other indicates differences in source and/or age of the sediments themselves. Hathaway (1972) has suggested that the shelf clays probably are Pleistocene and early Holocene in age, thereby explaining their highly unweathered state. High concentrations of kaolinite and dioctahedral vermiculite in the river sediments, on the other hand, no doubt are the result of erosion during the warmer Holocene times. Possibly the shelf sediments are contributing a significant amount of the clay-size material accumulating in modern estuaries, thus explaining their similarity with outer shelf compositions (Hathaway, 1972; Meade, 1972a).

Organic Matter

The quantity of organic matter in a sediment can be expressed in terms of nitrogen content, organic carbon or total combustible material. Kjeldahl nitrogen analysis is preferred by many workers because of its greater reproducibility and accuracy. Nitrogen content in continental shelf sediments in the Middle Atlantic Bight is ususally less than 0.100%, and over large areas values are less than 0.010%. In the upper arms of estuaries and in semi-enclosed basins such as inner Long Island Sound, nitrogen values exceed 0.300%. On the continental slope, organic content can be greater than 0.200%, but it decreases on the rise (Figure 10.37).

The organic (nitrogen) content of a sediment varies with size of the sediment; the more silt and clay, the higher the organic content (Kuenen, 1950). When plotted against size, organic nitrogen values on the shelf fall in a similar trend as do the fine-grained nearshore and estuarine sediments (Figure 10.38). Nitrogen values in southern slope and rise sediments lie along a similar trend, but sediments from the slope and rise north of Hudson Canyon contain distinctly lower concentrations. This suggests that either offshore organic productivity is

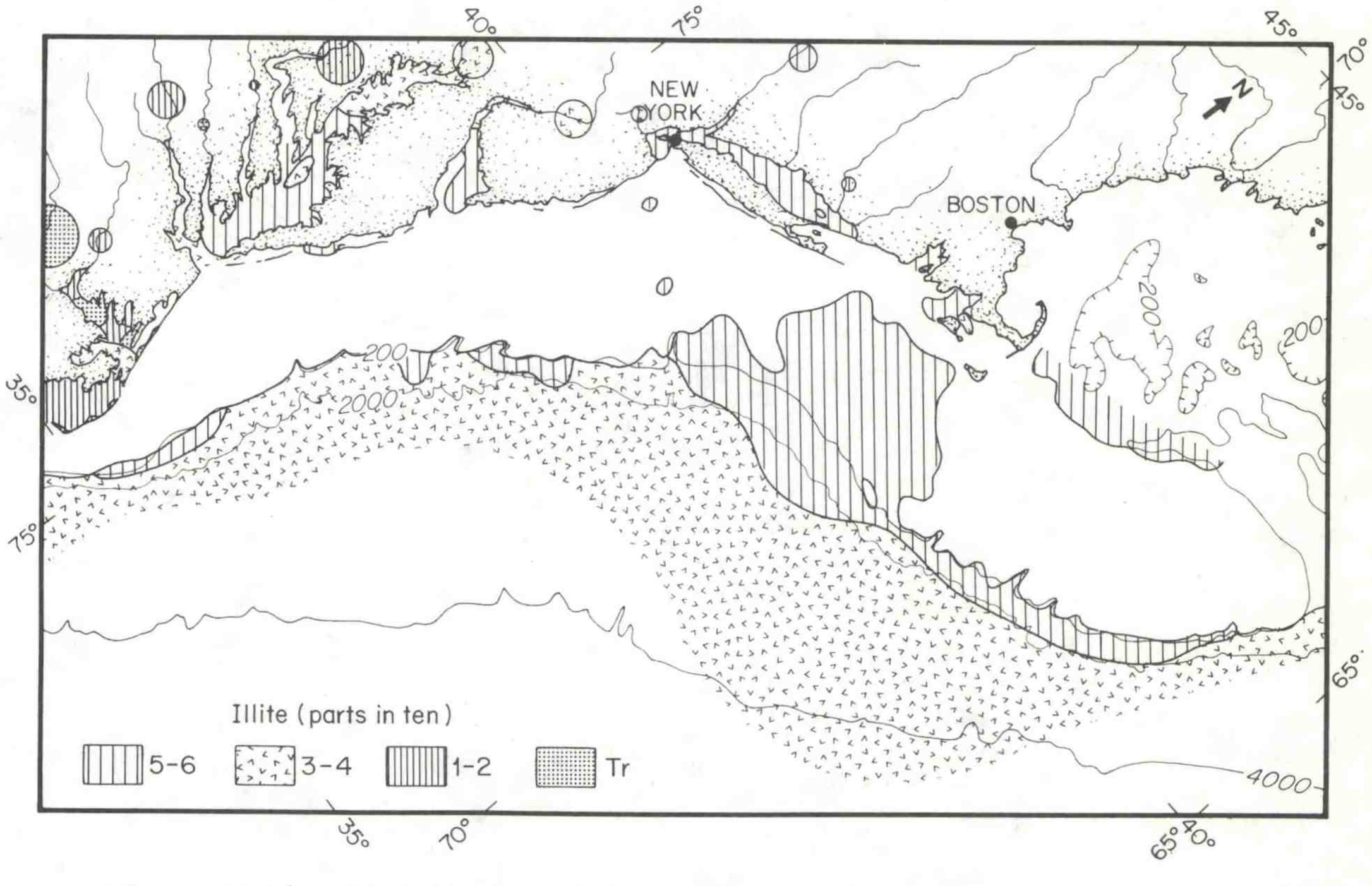

Figure 10.34. Distribution of illite in the clay fraction (finer than 2 microns). After Hathaway (1972).

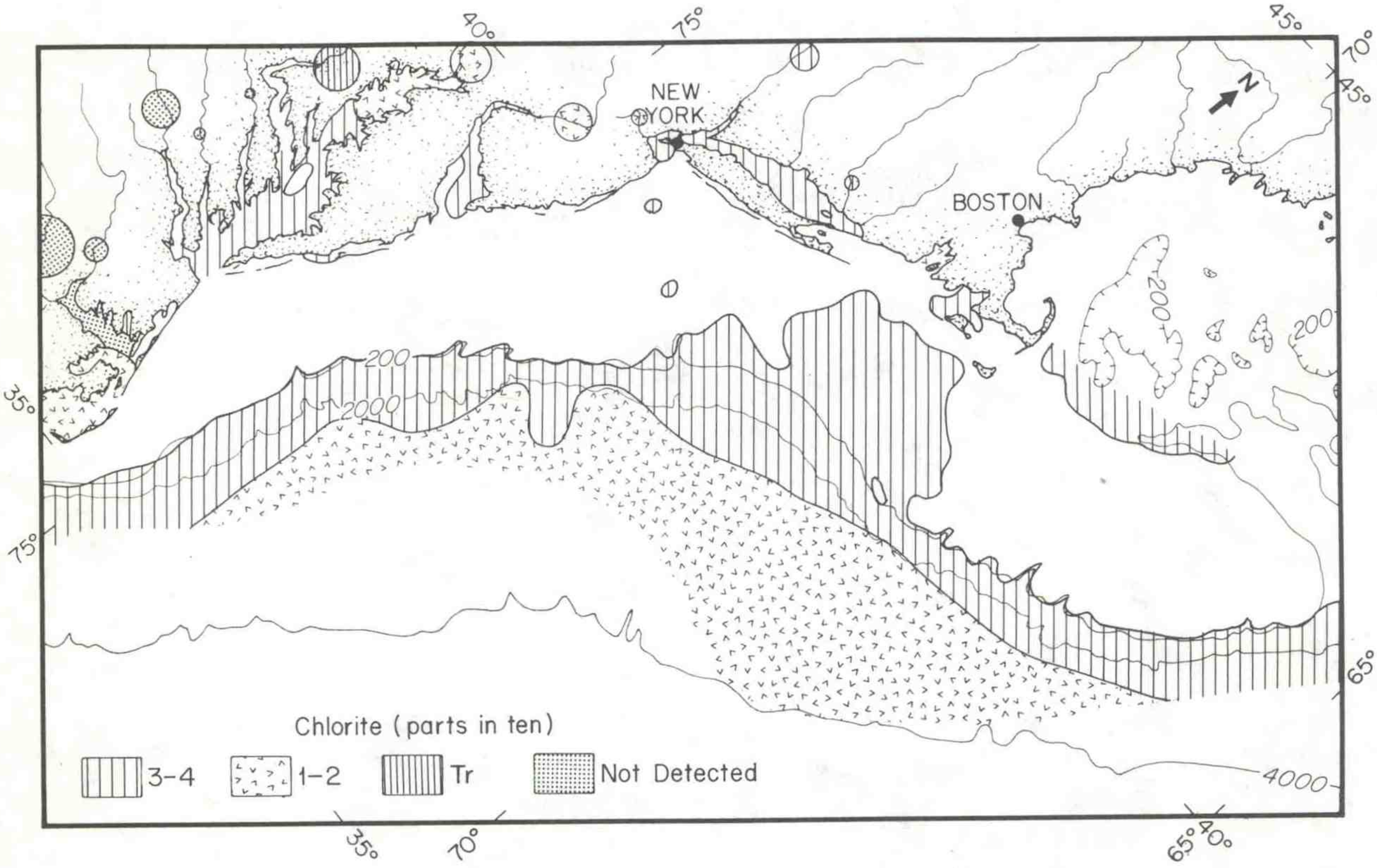

Figure 10.35. Distribution of chlorite in the clay fraction. After Hathaway (1972).

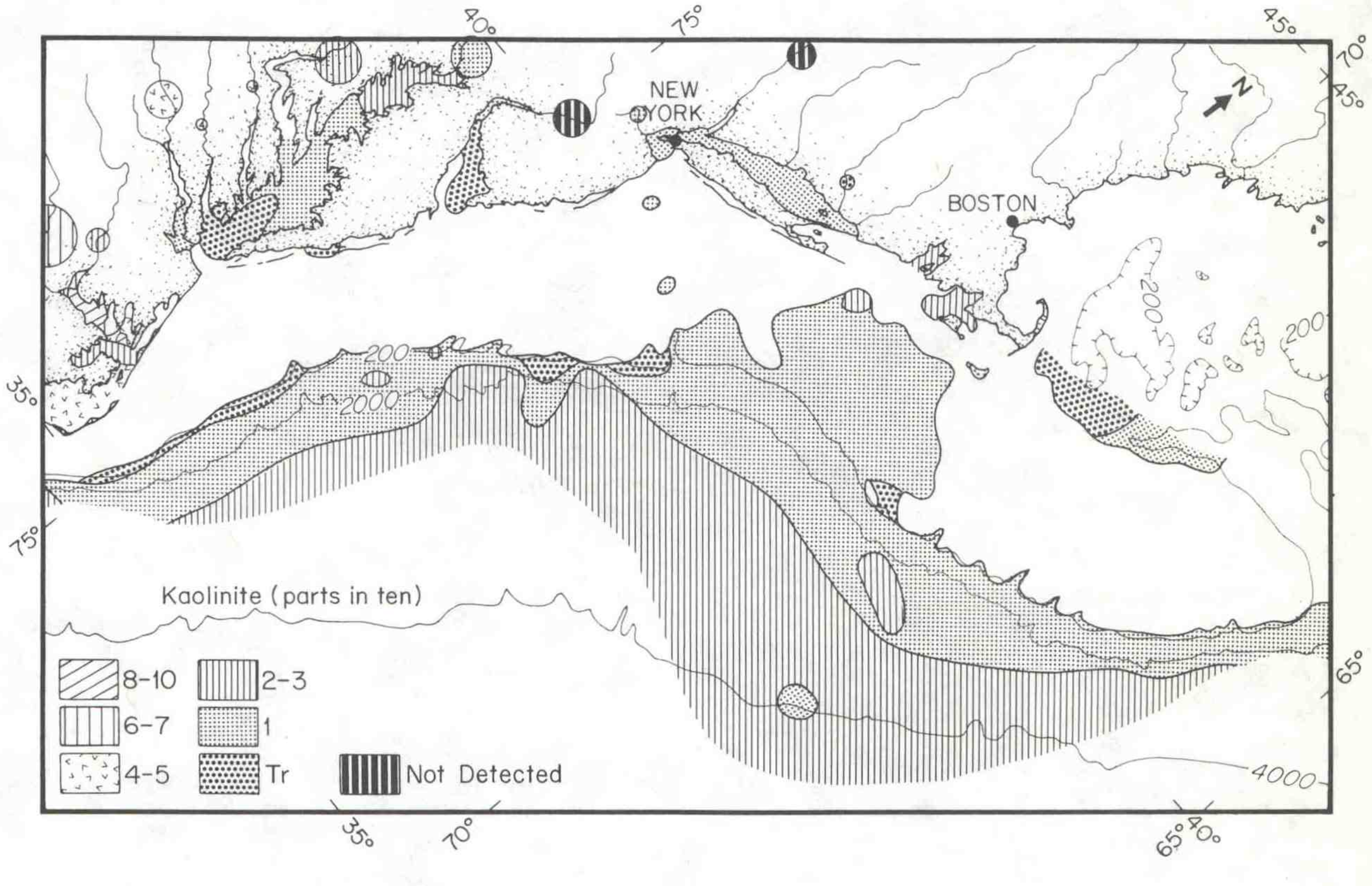

Figure 10.36. Distribution of kaolinite in the clay fraction. After Hathaway (1972).

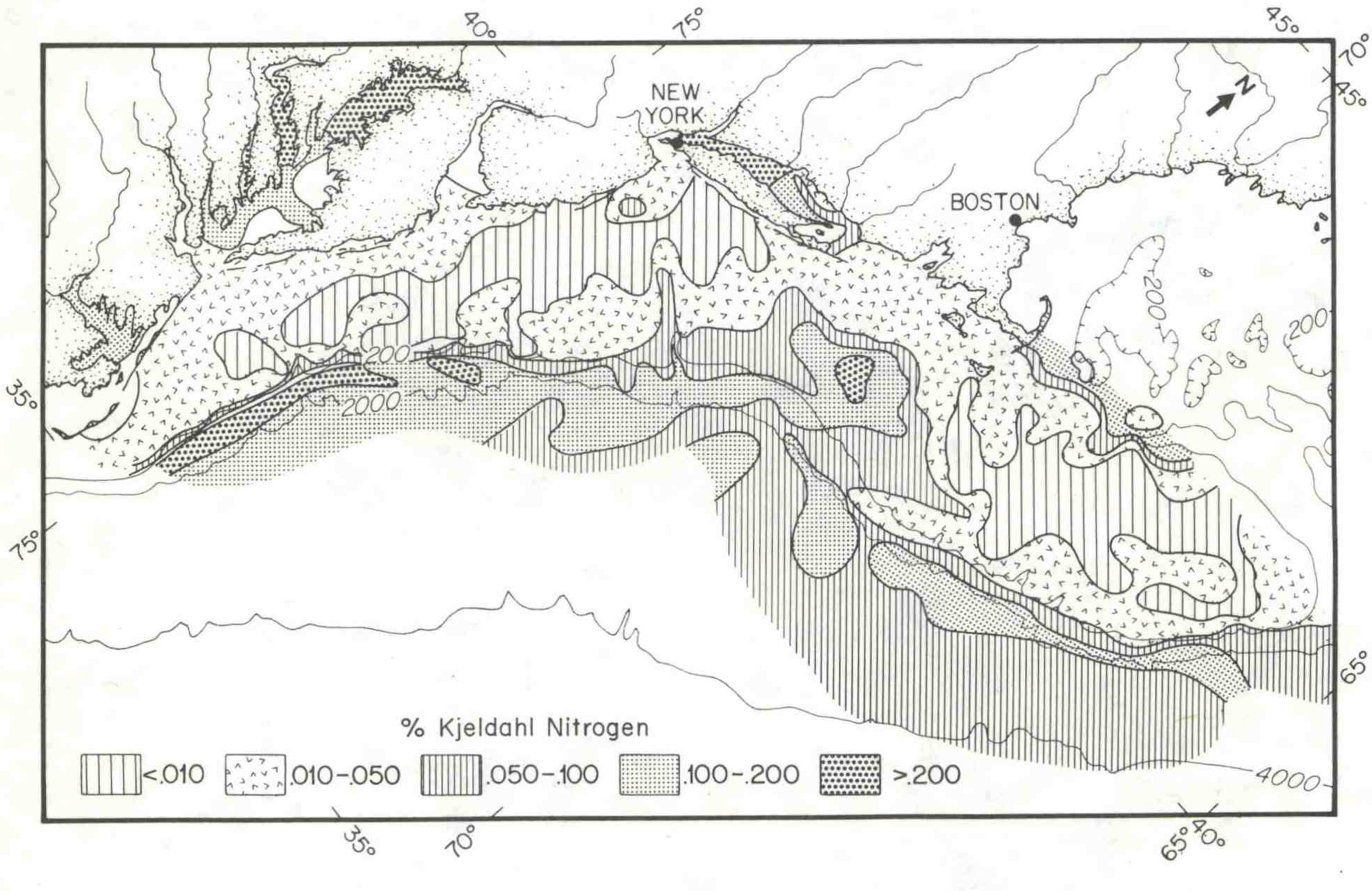

Figure 10.37. Distribution of Kjeldahl nitrogen in the continental margin sediments.

higher on the southern slope and rise or that shallow-water organic matter is being transported to this area. As will be seen in the following paragraphs, there is some evidence to suggest that offshore transport may account for at least a part of this difference.

The ratio of organic carbon to nitrogen content varies greatly within the Middle Atlantic Bight. Sediments in the upper parts of Chesapeake Bay and New York Harbor have C/N ratios which locally exceed 20/1. The composition of shelf sediments is more uniform, with values generally ranging from 3/1 to 11/1. Sediments with high ratios occur on the shelf south of Long Island, the outer shelf off Delaware and the seaward edge off Virginia (Figure 10.39). Low C/N ratios occur over much of the rest of the shelf, with much of the area having ratios lower than 6/1. Continental slope sediments contain ratios ranging from 6.5/1 to 8.5/1. Rise sediments north of Hudson Canyon exhibit values less than 6/1.

The C/N ratio depends upon the type of organic material(s) and perhaps also on the age of the organic substance(s) present in the sediment. Emery (1960) found that diatom oozes off southern California have C/N ratios averaging 5/1, which closely parallel the low values on the Middle Atlantic continental rise. Similarly, terrigenous organic matter tends to contain relatively high C/N ratios, which would explain the high ratios found in some of the estuaries. The variation in C/N values throughout the shelf may reflect the age of the sediment, relict material being more likely to contain terrigenous organic matter. Although not clearly shown in Figure 10.39, C/N ratios in slope sediments south of Hudson Canyon are slightly higher than those to the north, perhaps suggesting that at least some of the southern slope material is derived from the shelf.

Source and History of the Middle Atlantic Bight Sediments

Continental margin sediments generally encompass three ages - modern, relict (deposited during the last lower stand of sea level) and residual (derived from nearby subaqueous outcrops or older sediments) (Emery, 1952, 1960; Milliman et al., 1972). Similarly Middle Atlantic Bight sediments have three major sources: fluvial, glacial and biogenic. On the basis of these two parameters, the history of Middle Atlantic Bight sedimentation can be interpreted (Figure 10.40).

As mentioned above, the surficial sediments in most estuaries, coastal lagoons and barrier islands are assumed to be modern in age, although some of the sediment may have been reworked from shelf sediments (as suggested by the clay data of Hathaway, 1972). Similarly, the fine-grained sediment in the nearshore areas are considered modern, although possibly some of the mud was derived from underlying Pleistocene and early Holocene strata exposed by migrating sand ridges (see Swift et al.,

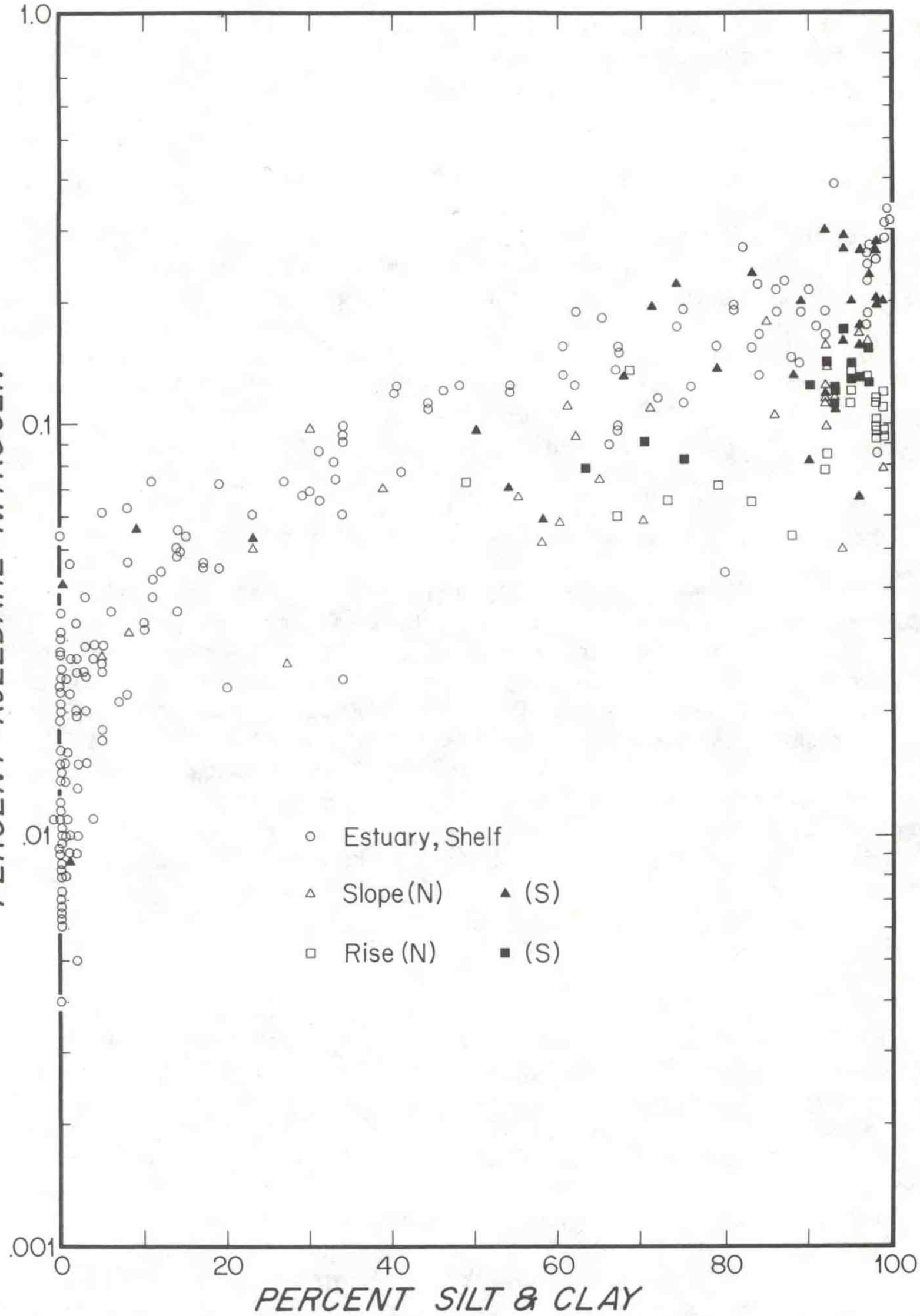

Figure 10.38. Variation in Kjeldahl nitrogen and sediment size (as expressed by % silt and clay).

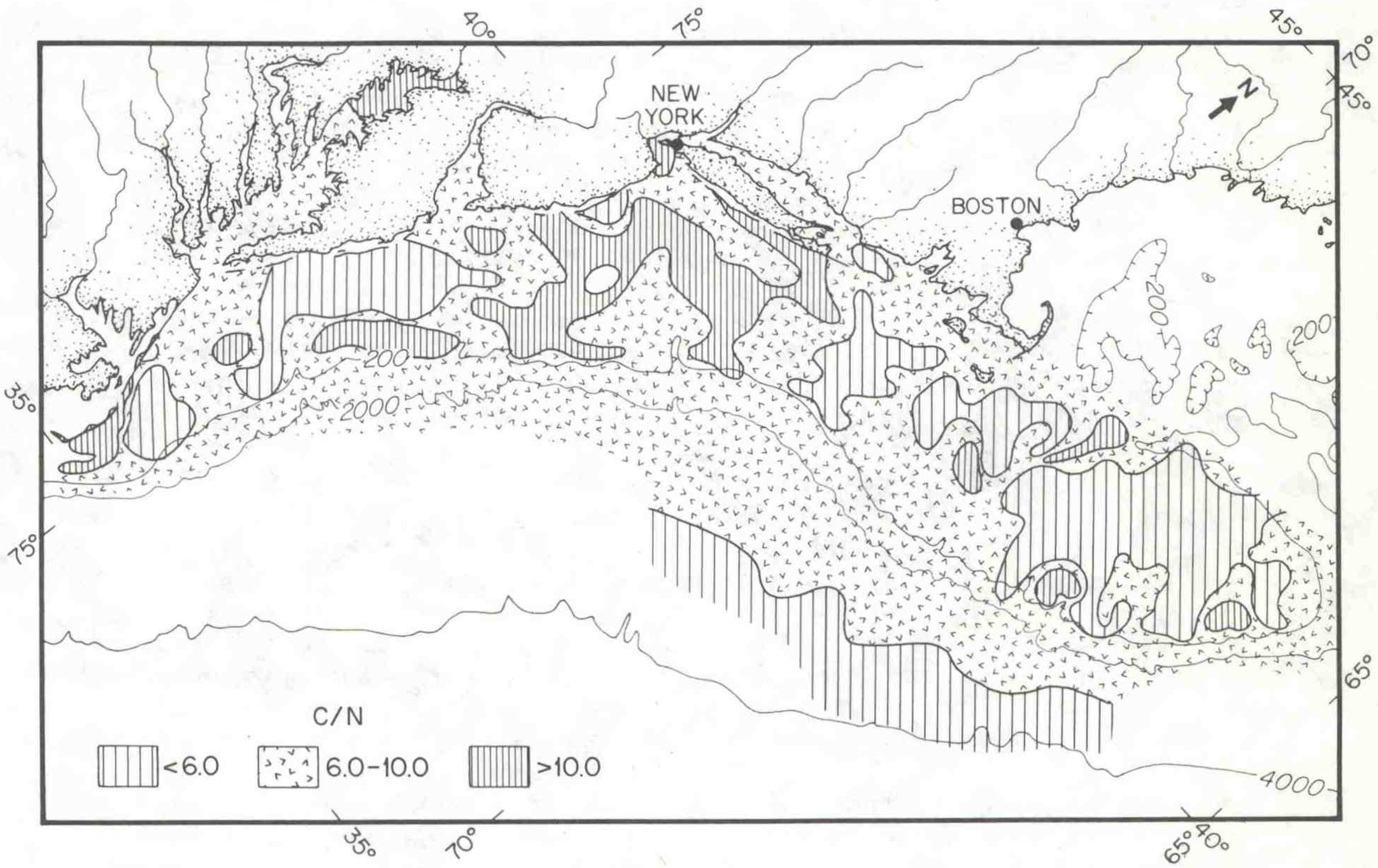

Figure 10.39. Distribution of organic carbon to Kjeldahl nitrogen in continental margin sediments.

1972b).

Most shelf sediments south of Long Island are composed of sand. The coarse nature of these sediments, the possible relict channel systems suggested by the feldspar content (Figure 10.33), and the presence of subaerial and littoral fossils, such as peat (Emery et al., 1965, 1967) brackish-water oyster shells (Merrill et al., 1965) and elephant teeth (Whitmore et al., 1967) suggest that these sediments (Figure 10.41) are relict. Carbon-14 dates of these deposits show that they were deposited during the last 11,000 years, generally during the Holocene transgression. Presumably most of these sediments were transported to the shelf by major rivers which drain the area - notably the Connecticut, Hudson, Delaware and Susquehanna Rivers.

Geomorphic and sedimentological data indicate that sediments north of the Long Island-Martha's Vineyard area are primarily glacial in origin. Glacial sediments which extend as far south as the Delaware shelf presumably were transported southwards by longshore drift (Ross, 1970; Blackwelder, 1970), although possibly some of these sediments were derived from the Delaware River which drained glacial terrain (Blackwelder and Pilkey, 1972).

The muds south of Martha's Vineyard have been considered to be modern (Stetson, 1938; Emery, 1965a, 1968a; Trumbull,1972), but they probably are relict, as indicated by the presence of cold-water gastropods which presently live further north (Schlee, 1973). MacIlvaine (1973, pers. comm.), however, has found warm-water foraminifera in these same sediments, which may indicate that the mud was deposited during the Holocene transgression, when temperatures were still warming. One possible source of the mud is glacial outwash (Schlee, 1973); another is erosion from Nantucket Shoals (McMaster and Garrison, 1966).

Sediments on Nantucket Shoals and Georges Bank are largely residual, having been derived from underlying Coastal Plain strata. The residual nature of the sediments is seen in the presence of mid-Tertiary fossils (Wigley, 1966; Stanley et al., 1967), concentrations of glauconite (Figure 10.32), the suborthoquartzitic nature of the light fraction (Figure 10.33), and the relatively large concentrations of staurolite and low concentrations of epidote and amphiboles (Figures 10.28, 10.29 and 10.31). Seismic profiles indicate that this area is underlain by as much as 100 m of reworked and unstratified sediments which presumably were reworked by Pleistocene glaciers (Knott and Hoskins, 1968).

Modern sediment is accumulating on most parts of the continental slope, although locally, "non-deposition" or erosion predominate. Average sedimentation rates are poorly defined at present. MacIlvaine (1973) found that Holocene accumulation on the upper slope and upper rise off southern New England has been greater than 15 cm/1000 years,

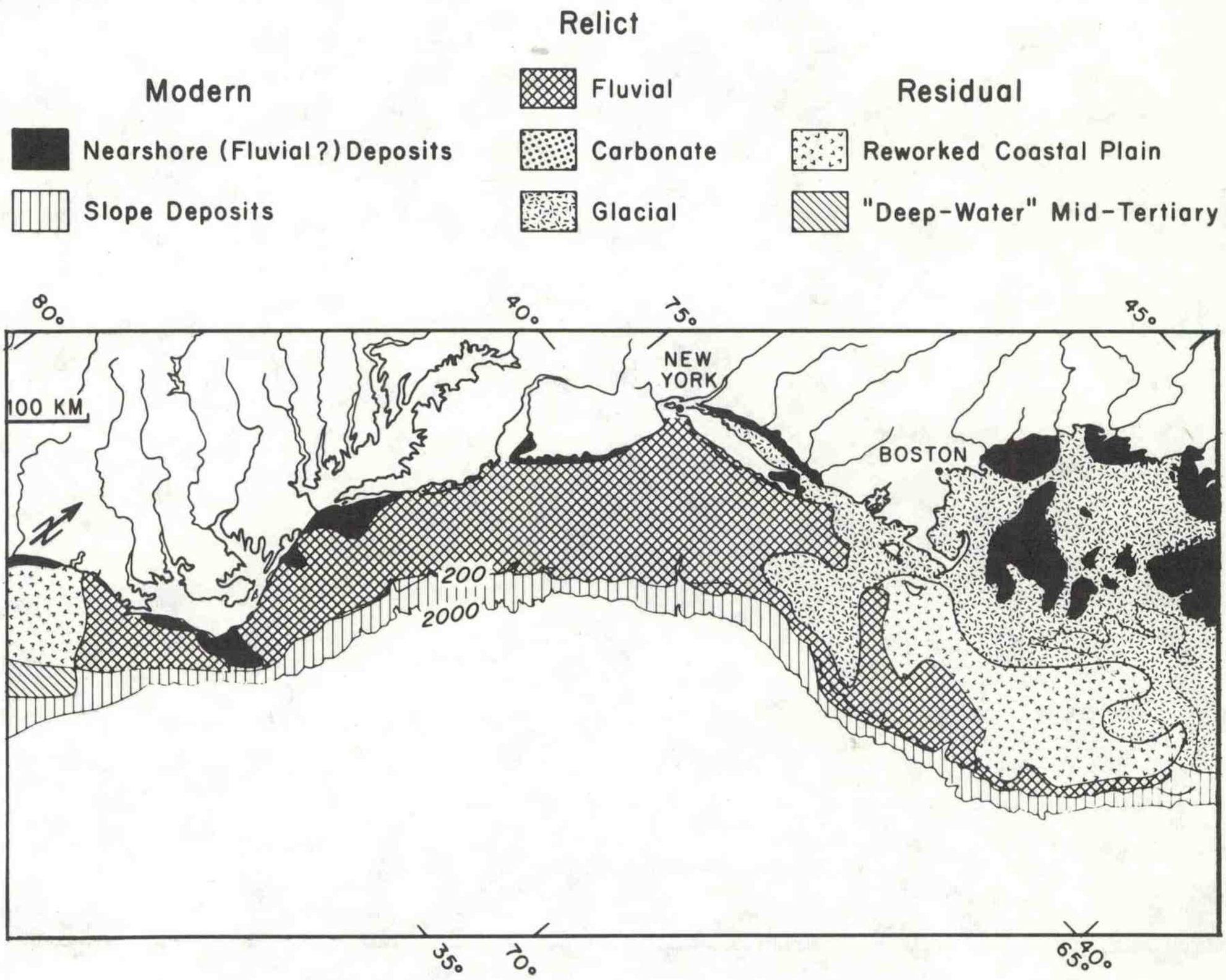

Figure 10.40. Source and age of sediments from the Middle Atlantic continental margin. After Milliman et al. (1972).

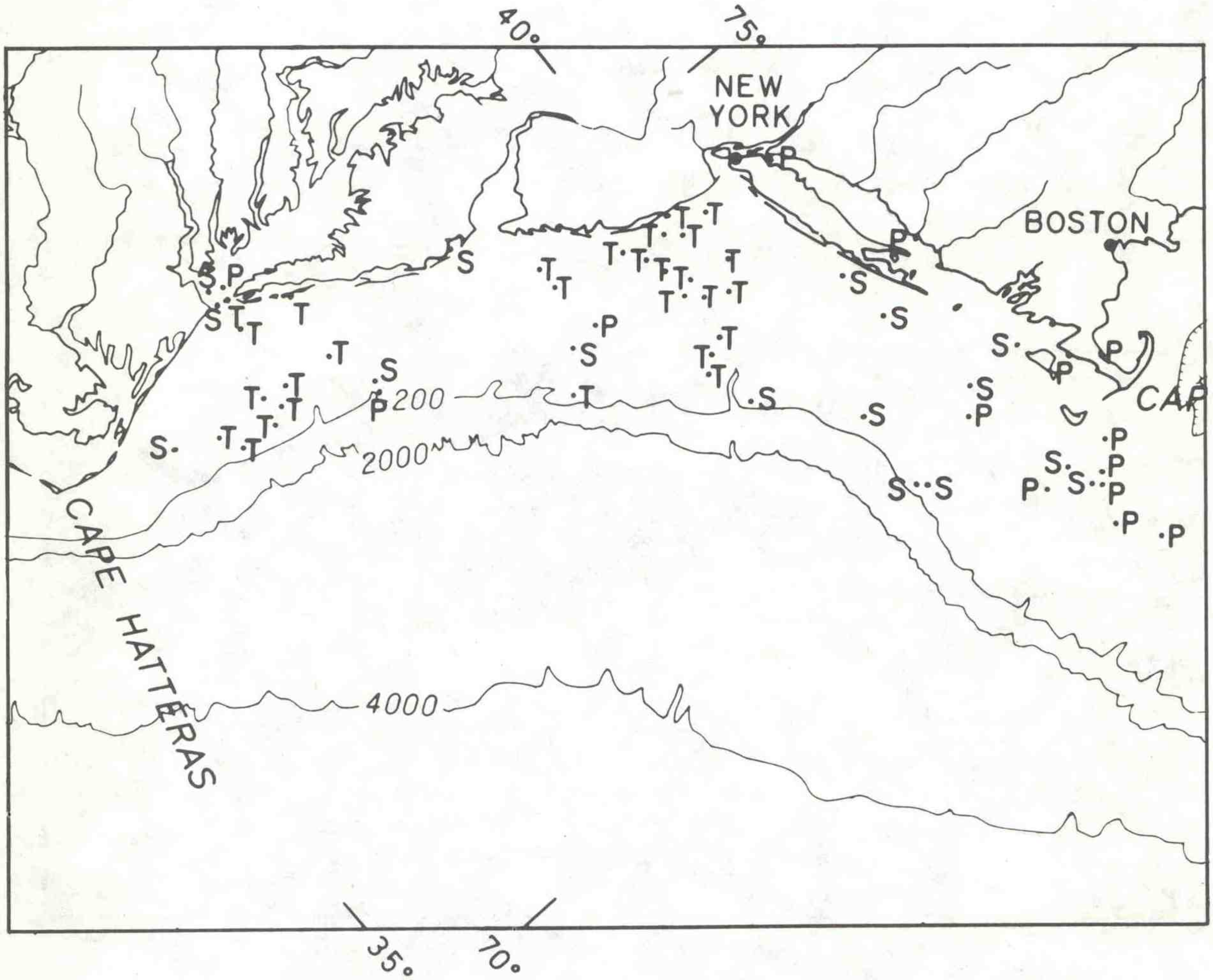

Figure 10.41. Locations of indicators of low stands of sea level on the continental shelf. (T) stands for elephant teeth, (P) for peat, and (S) for shallow-marine mollusk shells. After Emery and Milliman (1971).

while on the lower slope it has been less than 2 cm/1000 years. Presumably both deposition and erosion were greater during the Pleistocene, as is indicated by the higher sedimentation rates noted in upper slope cores and the great number of massive slump deposits detected by seismic profiling (MacIlvaine, 1973).

Ericson et al., (1961) reported that deposition rates on the upper slope and rise south of Hudson Canyon average 6.8 cm/1000 years. Sediment accumulation on the lower rise is 3.4 cm/1000 years.

Quaternary Fluctuations in Sea Level

During Pleistocene glaciations, sea level fell as water was incorporated into continental ice caps. Sea level regressions and transgressions can be mapped across continental shelves by obtaining radiometric dates of shallow-water indicators. Oyster shells, oolite, peat deposits and beach rock are among the more common indicators which are dated. Thusfar most of our information has been restricted to the last glaciation, due to the limit of about 30,000 years by the carbon-14 method and by the fact that most shelf sediments appear to have been deposited during the last lower stand.

According to present data, sea level about 30,000 years ago was approximately at present-day levels. With the buildup of glaciers in the northern hemisphere, sea level fell slowly until about 21,000 years ago, when it fell more rapidly (Figure 10.42). By 15,000 years before present, the maximum extend of the late Wurm glaciation, sea level stood at least 120 meters below present level (Milliman and Emery, 1968; Emery and Milliman, 1971). Subsequently land glaciers began their world-wide retreat and sea level rose rapidly at a rate of nearly 12m/1000 years until about 5 thousand years ago, when the rate fell to less than 2 m/1000 years (Redfield, 1967; Emery and Garrison, 1967; Milliman and Emery, 1968).

While this picture applies for the entire East Coast, it does not take into account regional variations due to uplift or subsidence. Using the data from various areas along the Middle Atlantic Bight (Bloom and Stuiver, 1963; Stuiver and Daddario, 1963; Kaye and Barghoorn, 1964; Newman and Rusnak, 1965), Newman and Rusnak concluded that the coastline of Virginia has undergone uplift during the past 5000 years relative to New Jersey and Cape Cod and subsidence relative to Connecticut and Northeastern Massachusetts (Figure 10.42). Newman and Munsart (1968) suggested a high stand of sea level on the Virginia coast about 5000 years ago, corresponding with the proposed late Holocene high stand of Fairbridge (1961), but there are no other data to support this observation. Harrison et al., (1965) suggested a significant uplift (some 50 m) in outer Chesapeake Bay during the past 15,000 years and uplift of 1.5 m in the last 1900 years. Newman and March (1968) indicated that the northeastern shelf is down-

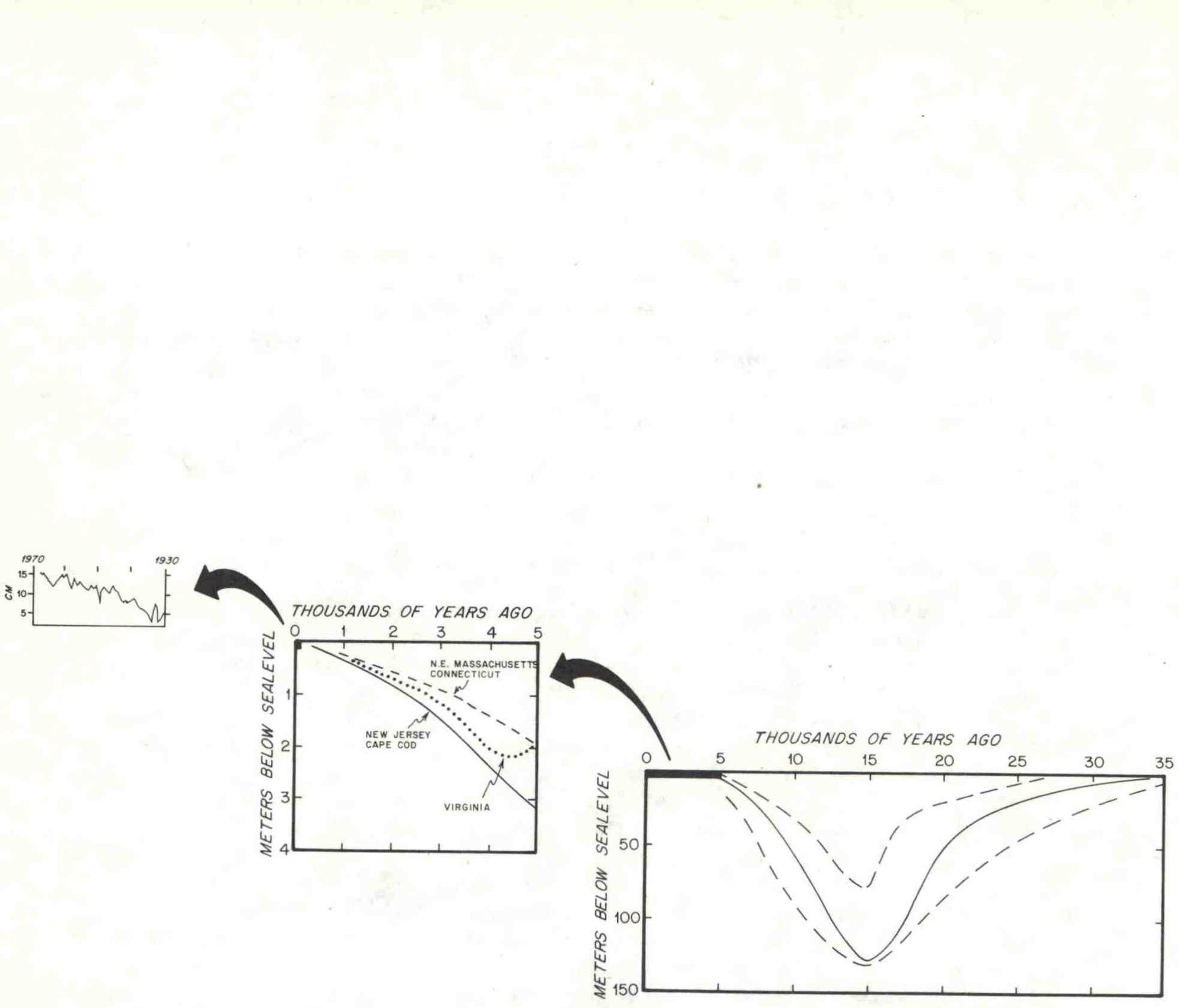

Figure 10.42. Sea levels on the U.S. Atlantic continental margin during the past 35,000 years. The figure on the right shows sea level from 5,000 to 35,000 years ago; the dashed lines show the range of values (after Milliman and Emery, 1968). The middle figure shows the relative rise in Holocene sea level in various areas along the Middle Atlantic Bight (after Newman and Munsart (1968). The figure on the left shows fluctuations in sea level along the Middle Atlantic coast as portrayed in tide gauge records for the past 40 years (after Meade and Emery, 1972).

warping, but other data do not support this conclusion (Milliman and Emery, 1968). Perhaps some of the variation in proposed sea levels, especially where small absolute differences are involved, may come from not correcting accurately for the compaction of peat or other sediments (Bloom, 1964), from picking erroneous indicators of low sea levels (such as using fresh-water peat instead of salt-marsh peat) or using material that is contaminated with young or old carbon.

During the past 40 years sea level has risen at a rate of about 3 m/1000 years; fluctuations in yearly sea level, however, in part are related to total annual runoff (Meade and Emery, 1972) (Figure 10.42). Hicks (1972a, 1972b) has found that the rise in sea level has been relatively similar between southern Maine and Hampton Roads, Virginia, but that southern Maine has subsided an average of 0.214 cm/yr relative to Hampton Roads. Presumably this indicates either an uplift in the south or subsidence in the north.

Modern Sedimentation on the Continental Margin

The lack of modern sediment accumulation over most of the continental shelf can be explained by the paucity of sediment reaching the shelf and/or the by-passing of this sediment and its eventual deposition in the deep sea. Both possibilities are discussed in the following sections.

Sediment Input

As was shown in Tables 1a and 1b, the total load of river-borne sediment entering the Middle Atlantic Bight is about 8400 thousand tons per year (Curtis et al., 1973). These estimates vary considerably from the estimates made earlier in the century by Dole and Stabler (Table 1b) and reflect man's influence through increased erosion (by clearing forests, farming and urbanization) in some areas and decreased river run-off and trapping sediment (by building dams) in others. Thus estimates of suspended matter in modern rivers are not indicative of the quantity of suspended matter that reached the estuaries prior to the arrival of white man in North America. Meade (1969b) has concluded that the present-day estimates are 4 to 5 times higher than the actual rates in 1942.

Present calculations suggest that little of the suspended matter brought in by rivers actually reaches the ocean. Although concentrations of suspended matter in estuaries can exceed 2 mg/l, nearshore values seldom exceed 0.125 mg/l (Figure 10.43). In addition, most of the material in the outer shelf water is composed of combustible and noncombustible (for example, diatom frustules) organic matter (Figure 10.43). The clay minerals within the suspended matter are diagnostic of the "northern

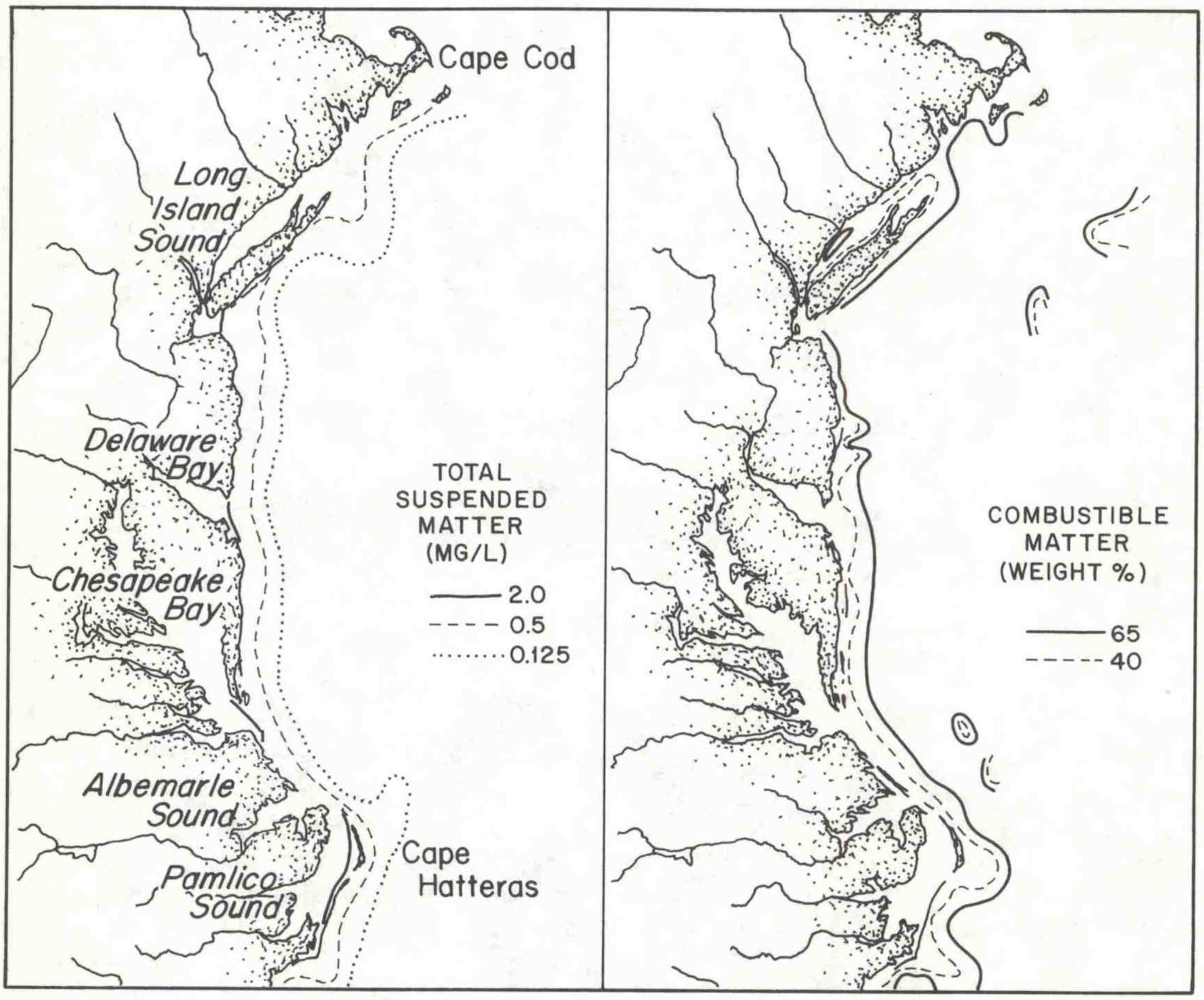

Figure 10.43. Distribution of total suspended matter (left) and combustible percent (right) in the waters off the Middle Atlantic Bight. After Manheim et al. (1970).

assemblage", with large percentages of illite and chlorite (Meade et al., in prep). Near Cape Hatteras, however, montmorillonite and kaolinite become common, indicating the influx of a southern assemblage of clay minerals (Pierce et al., 1972; Meade et al., in prep.).

Recent studies by Meade and co-workers show that suspended matter concentrations are considerably higher in bottom waters, but that a considerable amount of the inorganic fraction is resuspended bottom sediment. A preliminary calculation shows a standing crop of suspended inorganic matter over the entire Middle Atlantic Shelf (landward of the 183 meter curve) of about 0.5×10^6 tons (Meade et al., in prep.). Since much of this material appears to be resuspended bottom sediment, it seems unlikely that much river-borne sediment is escaping onto the shelf. This assumption agrees with that of Biggs (1970) who found that less than 10% of the Chesapeake Bay suspended matter actually escapes the bay, and also agrees with other observations discussed elsewhere in this paper.

If normal river flow does not contribute sediment to the shelf, it is possible that sediment input does occur during major floods. For example, Schubel (1973) observed that the Susquehanna River probably carried more sediment into Chesapeake Bay during a one-week flood in 1972 than during the previous 10 years. The effect of flooding upon the input of suspended matter in the Middle Atlantic Bight, however, has not yet been studied.

Some modern sediment may be derived from the biogenic production of calcium carbonate. On the slope planktonic foraminifera are a prominent contributor, but the low quantities of carbonate within most sediments indicate that biogenic material is not an important sediment component on the Middle Atlantic shelf. Eolian transport of sediment also seems to be low, although relatively large quantities of pollen and industrial smoke ash can reach North Atlantic sediments by easterly-blowing winds from the industrialized Atlantic coast (Folger, 1970).

The greatest sediment influx in the entire area occurs through the disposal of waste in New York Bight. Gross (1972) calculated that 4.6 million tons of solid waste were deposited annually in New York Bight between the years of 1964 and 1968. Of this 76% was dredge spoils from New York Harbor, 12% constructional rubble, 7.6% solids from waste chemicals and 4.3% in sewage sludge. An additional 0.8 million tons are dumped yearly into the western part of Long Island Sound (Gross, 1972). Considering that most river-borne sediments are trapped within the estuaries, dumping in New York Bight and Long Island Sound far exceeds all natural input on the shelf. Many workers have investigated the impact of dumping on the composition of surrounding sediments and marine life (Gross et al., 1971; Gross, 1972; Pearce, 1970; Pearce et al., 1971; National Marine Fisheries Service, 1972a, 1972b - especially sections 2 and 5), but at present the picture is not clear. This may result from the relatively long time required for spoils to affect the surrounding

areas or it may mean that dumping has little overall effect.

Sedimentary Processes

Although the composition of Middle Atlantic shelf sediments is relict, that is, the line between supply and sediment has been (and remains) broken (Curray, 1965), several lines of evidence indicate that shelf sediments are in or are approaching textural equilibrium with the present-day shelf environment (Milliman et al., 1972; Swift, Stanley and Curray, 1971):

1) Coarse sediment tends to occur near the shelf break, while finer sediment occurs on the slope and to some extent landward of the shelf break (Emery, 1965a). The best example of this coarsening of shelf break sediment is the area south of Martha's Vineyard, where middle and outer shelf and upper slope sediments are predominately mud, but the shelf break sediment is sand (Figure 10.20). Possibly the fine sediments are winnowed out by breaking internal waves (Cacchione, 1970; Southard and Cocchione, 1972; Cacchione and Southard, 1973) or by the tidal prism as it impinges upon the continental shelf (Fenner et al., 1971).

2) The well-rippled sediment on much of the shelf (see the section on shelf morphology) indicates that shelf sediment is actively reworked, although the evidence of relict river deposits (as indicated by the linear bands of feldspar-rich sediments extending across the shelf) suggests that the net transport of the sand fraction may be relatively small (Milliman et al., 1972).

3) Suspended matter concentrations within the water column increase near the bottom (Meade et al., in prep.) and are significantly higher near the shelf break (Owen et al., 1967; Lyall et al., 1971; MacIlvaine, 1973). Meade et al., (in prep.). have suggested that the inorganic fraction is composed primarily of resuspended bottom sediment (see above).

The lack of sediment accumulation on the shelf indicates that any sediment which does enter the Middle Atlantic Bight either is transported eventually back into the coastal system or by passes the shelf and is deposited in the deep-sea. Landward transport of shelf sediment is seen by the measurement of bottom currents (Figure 10.4) and suspended matter (Manheim et al., 1970; Biggs, 1970; Oostdam and Jordan, 1972), the similarity between estuarine and shelf sediments and their dissimilarity with modern river sediments (Pevear and Pilkey, 1966; Hathaway, 1972; Pilkey and Field, 1972) and general considerations (Guilcher, 1963; Rusnak, 1967; Meade, 1969a, 1972b).

The fact that sediment is accumulating on the slope at rates of up

to 15 cm/1000 years (see above) would indicate that modern sediment is transported and deposited in the deep sea. Offshore transport may be more possible on relatively narrow shelves (for example the shelf off Chesapeake Bay - Schubel and Okuba, 1972) than on a wide shelf. Presumably sediment movement occurs preferentially down the axes of canyons and gullies (Trumbull and McCamis, 1967; Kelling and Stanley, 1970). Measurements of currents in canyon axes shows that although the direction and magnitude may vary, the net transport is down gradient (Fenner et al., 1971; Stanley et al., 1972; Keller et al., 1973; Ross, 1968; Trumbull and McCamis, 1967). On the other hand, currents in some parts of the slope may be sporadic at best. For example, Emery and Ross (1968) found that a current of 70 cm/sec on the upper slope south of Martha's Vineyard caused little sediment erosion. Moreover, MacIlvaine (1973) found that tracks from the submersible Alvin left by Emery and Ross were visible 3 years later, thus indicating that current-induced erosion was minimal during this period.

Probably the most important mechanisms in downslope transport are turbidity currents (Ericson et al., 1961; Eittreim et al., 1969) and mass movements by creep, slump and landslides. Biological activity can effect the erosion of hard substrate (Dillon and Zimmerman, 1970), but organisms are also important in eroding unconsolidated sediment by their normal burrowing, excavating and feeding activities (Emery and Ross, 1968).

Economic Resources on the Middle Atlantic Margin

The most obvious subsurface resource on the Middle Atlantic continental margin is petroleum (Emery, 1965b, 1968b), especially on Georges Bank, where salt (possibly indicative of diapirs) and Jurassic carbonates may provide favorable petroleum traps and reservoirs (Schultz and Grover, 1973). Other areas with petroleum potential are the shelves surrounding the proposed Kelvin-Cornwall fault system (Emery, 1968b) and the Baltimore Canyon Trough. At present the importance of petroleum resources in these areas is unknown (at least to marine geologists within the academic community), but hopefully future exploration will help define possible economically viable deposits.

Heavy minerals, while perhaps locally concentrated on the shelf, at present do not seem to provide any economic potential (Emery and Noakes, 1968). A more obvious and immediate economic resource on the continental shelf is sand and gravel. Manheim (1972) estimates that 400 billion tons of sand grading 75% or more is present in the upper three meters of shelf sediment off the northeastern United States. As the Boston to Washington megapolis expands over presently existing sources of sand and gravel, new sources will be needed for these materials, which are to important for the construction industry.

Concluding Remarks

At present marine geologists probably know more about the bathymetry, morphology, sediments, structure and history of the Middle Atlantic Bight continental margin than any other area in the world. Total sediment thickness on the margin probably exceeds 12 km in places and generally is greater than 8 on the outer shelf. The continental shelf accreted behind a magnetic high, probably a volcanic ridge system. When sediment began spilling over the ridge, probably in the Mesozoic, the continental slope and continental rise began accreting.

The present-day shelf morphology is strongly related to the Quaternary history of the area. Glacially-influenced topography dominates much of the shallow-water sediments and the morphology north and east of Long Island, while sediments to the south are dominated by fluvial sediments, presumably deposited during the Holocene transgression. The ridge and swale system, which dominates the inner shelf morphology, is a modern feature which migrates during major storms. Similar ridge and swales on the middle and outer shelf may be relict features locally influenced by modern hydrographic conditions.

At present little sediment is entering the shelf from the modern rivers. What little sediment does escape the estuary system appears to either bypass the shelf and be deposited on the slope and rise, or is reworked back into the nearshore system. Thus estuaries are acting as two-way sinks: they trap sediments moving in from rivers and also shelf sediment being brough in by landward flowing bottom currents.

Despite our insights into this area, there are many questions which need clarification. Some of these are:

1) How does our proposed model relate to the real structure and stratigraphy. At present much of our knowledge of the deep structure (and history) of the margin comes from magnetic, gravity and seismic refraction data. Multi-channel seismic data are practically unavailable outside of the petroleum industry. Similarly, without good stratigraphic control defined by many deep borings, we cannot get an accurate handle on the absolute time scale.

2) Although our knowledge of the morphology of the shelf is excellent, we know comparatively little about slope morphology. Moreover, we need to know much more about what processes (and whether they are presently active) control various types of morphologic features that occur on the shelf and slope.

3) What is the net flux of sediment in and out of the estuarine system? Does sediment escape primarily during storms, and if so, what is its ultimate fate. A well-planned cruise on the shelf seaward of some major estuaries immediately following a catastrophic event (flood and/or

storm) might provide answers to many of these questions.

4) If sediment is bypassing the shelf, what are the processes which are responsible? How do they redistribute artificially-induced sediment, such as dredge spoils implaced in New York Bight, and what is the resulting impact upon the surrounding sediment and biologic communities?

As man continues his utilization of the continental margin, these questions must be answered, both in the search for economic resources and also in understanding and predicting the effect of man's influence on the continental margin environment.

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Offshore Weather and Climate

Offshore Weather and Climate

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Offshore Weather and Climate

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Introduction

An overview of the weather and climate of the region from Cape Hatteras to Cape Cod is presented in this chapter. Spatial and temporal distributions of weather elements such as sky cover, air temperature, relative humidity, wind speed and direction, visibility and precipitation are discussed. These individual weather elements are placed in the context of the general atmospheric setting of the Mid-Atlantic offshore region. A summary of the heat-energy budget and sea-surface temperature regime of the study area provides additional insight into the

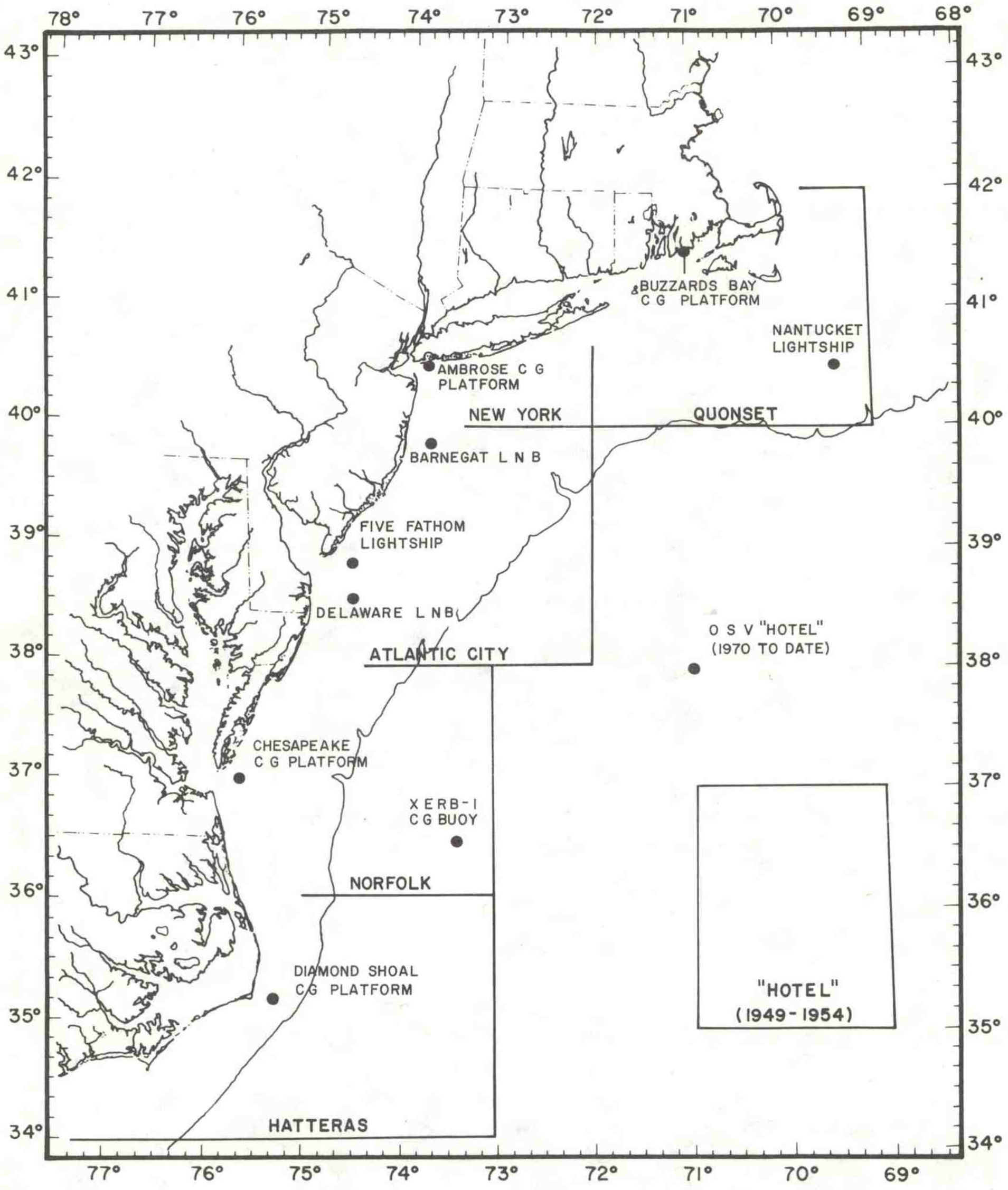

Figure 11.1 Location map

resultant weather patterns. Storms of tropical and non-tropical origin, perhaps the most dramatic weather features of the study area, are also discussed.

Coastal sea areas are among the world's least known regions in terms of meteorological and climatological considerations. There are few detailed observations, monitored over long periods of time, for this water/land/air interface. Therefore this chapter emphasizes the weather and climate of the offshore* area.

The primary data is from ships-in-passage, collected by the U.S. Naval Weather Service. Figure 11.1 shows the five offshore areas that contain available data. Additional observations for Ocean Station Vessel "Hotel" (also called "Atlantic 10" and "How" in earlier years) are also summarized (U.S. Department of Commerce, 1956). In 1970 OSV "Hotel" was reactivated in a new location, shown in Figure 11.1 and observations are currently published in Mariners Weather Log.

Nearshore data collection stations such as lightships, ocean platforms, and navigational buoys are also shown in Figure 11.1 (McLeod, 1970; Giraytys and Harrell, 1973). These fixed stations, together with satellite observations, particularly of cloud and sea-surface conditions (Barrett, 1970; Krishna et al., 1971; Hanson, 1972; Barrick, 1972), will be useful in the future in delineating weather processes in this area of marked horizontal gradients of such meteorological parameters as air temperature, humidity, and heat-budget components at the sea surface.

Although a considerable portion of the East Coast of the United States is included in the base map, Figure 11.1, climatological analyses for land areas are not included in this chapter. A summary of some of the main sources for land-based information has been given by Oliver (1973).

General Atmospheric Setting

The U.S. East Coast is an area with several unique atmospheric features. Throughout the year, but especially during the winter months, the area is one of the hemisphere's major areas of cyclogenesis. Extra-tropical storms frequently traverse the region in response to the average position of the upper-level long-wave trough, centered approximately along 70^{o} to 80^{o} W longitude (Klein and Winston, 1958), and the position

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* In this chapter the term "coastal" or (or "nearshore") refers to the sea area bounded by the coast and a distance seaward of approximately 30 nm. "Offshore refers to the sea area at a greater distance from the coast.

Table 1. Climatological data summaries for offshore areas.

Sea Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sky Cover (eighths)													
Quonset	5.5	5.2	4.6	4.8	4.7	4.4	4.7	4.4	4.3	4.2	5.1	5.6	4.8
New York	4.8	4.5	4.4	4.7	4.6	4.2	4.5	4.3	4.0	3.9	4.7	4.7	4.4
Atlantic City	5.0	4.8	4.3	4.3	4.3	4.1	4.2	4.2	3.9	3.8	4.5	4.9	4.3
Norfolk	4.9	4.8	4.5	4.2	4.3	4.2	4.2	4.4	4.1	3.9	4.3	4.8	4.4
Hatteras	5.2	5.2	4.9	4.2	4.5	4.6	4.7	4.7	4.4	4.6	4.6	5.0	4.7
"Hotel"	6.1	6.3	6.4	5.3	5.2	4.9	5.0	4.7	4.4	5.1	5.7	6.1	5.5
Air Temperature (°C)													
Quonset	3.6	2.9	4.6	7.6	11.2	16.2	20.1	20.8	18.4	14.6	10.6	5.9	11.8
New York	3.3	2.2	5.1	8.6	13.1	18.3	22.2	22.3	19.5	14.9	10.4	5.1	12.5
Atlantic City	5.7	5.0	6.7	9.9	14.1	19.5	23.7	23.8	21.2	16.7	12.3	7.6	14.1
Norfolk	8.1	7.9	9.6	12.9	17.1	22.1	25.3	25.4	23.0	18.6	14.2	9.9	16.3
Hatteras	13.2	13.4	14.6	18.0	21.7	24.7	26.8	27.0	25.2	21.7	18.1	14.7	20.0
"Hotel"	15.7	14.6	14.4	17.6	20.7	23.4	26.1	26.2	24.8	22.4	19.2	15.8	20.2
Relative Humidity (%)													
Quonset	80	79	79	82	83	85	86	84	82	78	79	77	81
New York	77	74	76	78	82	84	80	79	75	74	73	76	77
Atlantic City	77	77	78	80	83	85	83	82	80	77	75	76	80
Norfolk	75	74	76	78	79	81	82	80	78	76	73	74	77
Hatteras	74	74	73	74	77	80	80	79	77	74	72	73	76
"Hotel"	72	69	71	73	76	79	81	77	74	71	68	71	74
Wind Speed (kts)													
Quonset	16.9	17.0	15.7	13.3	10.7	10.1	9.4	10.3	11.6	13.7	15.4	17.1	13.2
New York	15.1	15.3	13.7	12.5	10.2	9.8	9.3	9.2	10.9	12.1	14.5	15.4	12.2
Atlantic City	16.5	16.1	15.1	13.1	10.9	10.3	10.5	10.7	11.8	13.8	15.2	15.6	13.2
Norfolk	16.1	15.7	15.4	13.8	11.8	10.9	10.7	10.9	12.2	13.9	14.7	15.2	13.4
Hatteras	17.8	18.2	17.3	15.9	13.8	12.6	12.2	11.8	13.1	15.4	15.8	16.5	15.0
"Hotel"	(21)	(22)	(22)	(19)	(17)	(13)	(12)	(15)	(16)	(15)	(18)	(21)	(18)

of the polar front jet stream. Their paths are generally from southwest to northeast. The polar front, a marked horizontal thermal gradient in the troposphere, often lies over the area. It provides energy for storm development and maintenance, and separates air masses of polar and tropical origin.

Figures 11.2a and 11.2b show the average position of the surface polar front and the generalized tracks of migratory low and high pressure systems during January and July, based on the work of Namias and Clapp (1949), Klein (1957), and Reed (1960). The mean positions of these features are present in the study area during January. In the following months, however, the seasonal circumpolar vortex contracts. By July, only a weakened polar front and a secondary storm track are present. The seasonal shifts of these features have profound effects on the weather and climate to be described in the following section.

Features of the Offshore Climate

Table 1 presents monthly averages of sky cover, air temperature, relative humidity and wind speed for the six sea areas shown in Figure 11.1 Detailed monthly graphs of these weather elements, as well as solar climate, visibility, significant weather, and wind direction are presented in Figure 11.3 (a through l). In these figures, 80% of the observations are for the years 1950 to 1968. The remainder of the observations extend back 100 years. The U.S. Naval Weather Service Command (1970a, 1970b) has emphasized that these reports were taken by ships-in-passage which tend to avoid bad weather, thus introducing a bias in the observations. Although this systematic error remains in these data, a quality control program was used on the data which eliminated most random errors.

Figures 11.3k,l present a similar graphic summation for sea area "Hotel", based on unpublished data from the National Climatic Center for 1949 to 1954. Because a primary mission of the ocean vessel station was weather observation, these data should be more representative of the full range of weather conditions than the data for the five ocean areas mentioned above.

The descriptions of spatial and temporal changes in selected climatic elements which follow are provided to give an overview of the offshore climate in the study area. Additional information can be obtained in the oceanic climatological analyses prepared by the U.S. Navy (1955) and the U.S. Department of Commerce (1959).

Solar Climate

The horizontal bar graphs indicate the relative length of daylight, which varies from approximately 9 1/4 hours in sea areas Quonset and

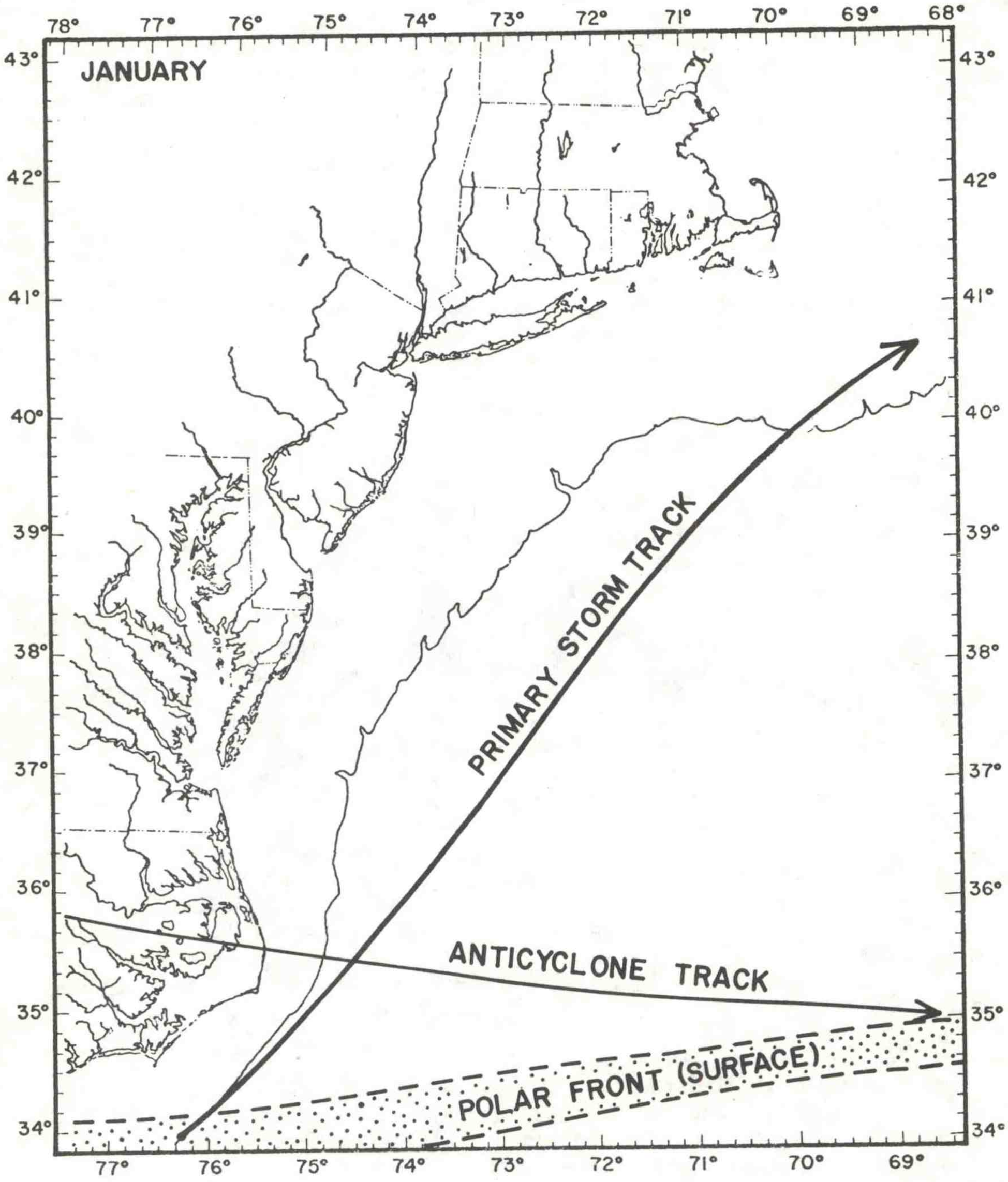

Figure 11.2a Synoptic-scale features in the study area during January.

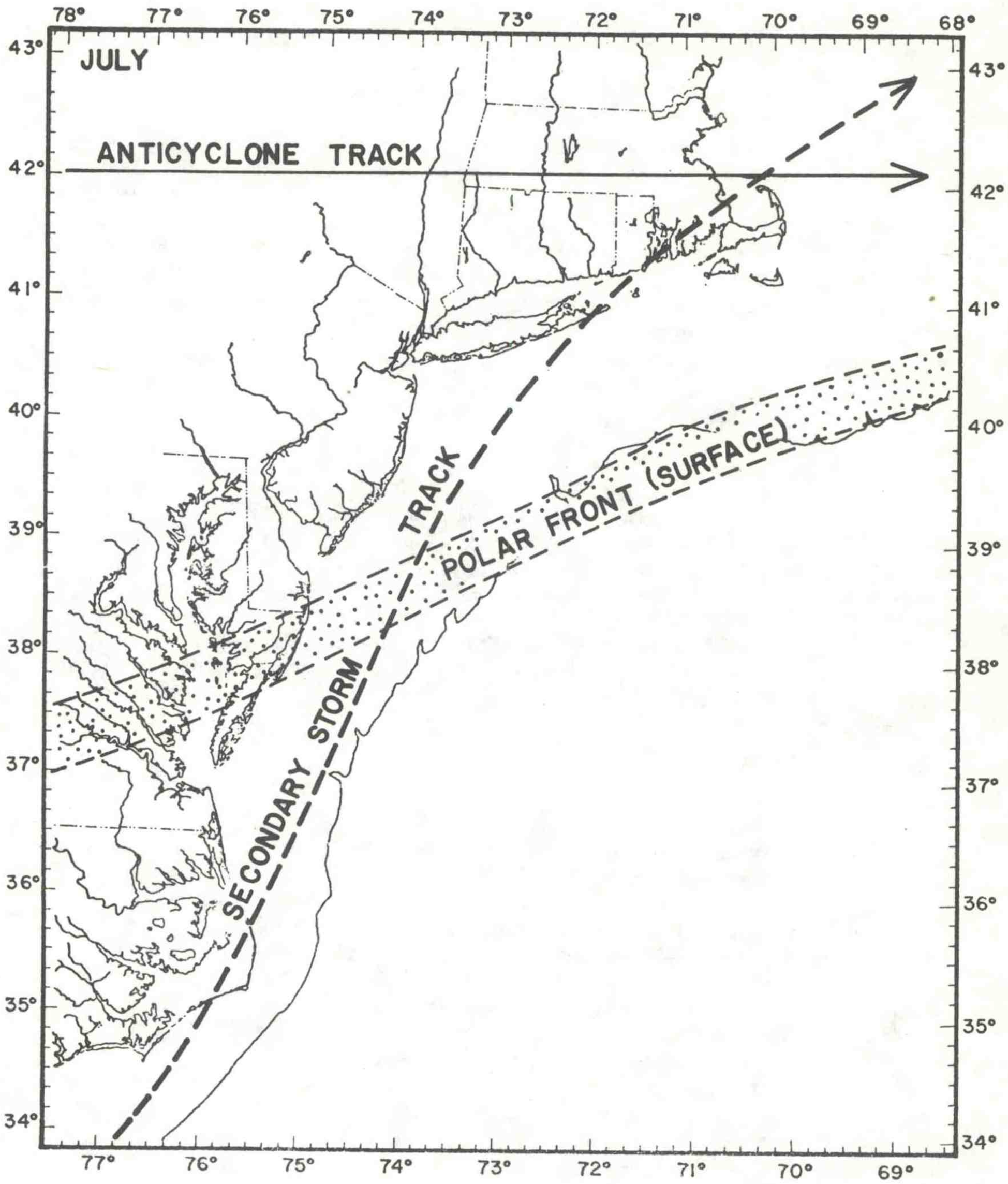

Figure 11.2b Synoptic-scale features in the study area during July.

New York during December to slightly more than 15 hours in these areas during June. Farther south, in sea areas Cape Hatteras and "Hotel", the corresponding range is from about 9 3/4 hours to 14 1/2 hours.

The solar diagrams indicate the azimuth of the rising and setting sun in each area during each month of the year, as well as the altitude of the sun at local noon. Variations of sun's azimuth are insignificant over the latitudinal spread of the sea areas. In each area, however, the annual variation of azimuth is considerable, with the rising/setting sun tracing its apparent movement from southeast/southwest in winter, and from northeast/northwest in summer. At midwinter, noon solar altitude varies from 26° in the north to 32° in the south. By mid-summer these angles have increased to 72° in the north and 78° in the south.

Sky Cover

Cloud cover ranges from a monthly average minimum of 3.8 eighths during October at Atlantic City to 6.4 eighths during March at "Hotel" (Table 1). The histograms in Figure 11.3 often show the U-shape characteristic of sky-cover frequently distributions. On frequent occasions, clear or mostly clear skies (0-2 eighths) or overcast and obscured sky conditions (8 eighths) are observed. In the period December through February, the greatest degree of cloudiness occurs in all sea areas ranging from 4.5 eighths to 6.3 eighths. Minimum cloudiness, ranging from 3.8 eighths to 4.4 eighths, occurs during September or October.

Visibility

The three northern sea areas, Quonset, New York,and Atlantic City report frequencies of reduced visibility (less than 2 nm) more often than the southern areas. This increase in visibility is mainly caused by fog and haze, which are least common in sea area "Hotel". In the Hotel sea area, the percentage of time with visibility greater than 10 nm is significantly less than in the other regions. Possibly this is an indication of the prevalence of air masses that have had lengthy trajectories over water. The three northern areas indicate marked variation in the frequency of visibility of less than 2 nm during the year, with greatest values usually occurring during late spring and early summer. This seasonal variation is most marked in the Quonset sea area, where the frequency of fog and haze reaches high values - more than one-quarter of all observations during May, June, and July. Visibility in the Quonset area is less than 1/2 nm 13% of the time during June.

Significant Weather

The occurrence of fog and haze has been mentioned above. Of the remaining weather events tabulated in the synoptic meteorological summaries, precipitation is the element most frequently observed. Jacobs (1968) provides a series of maps wherein precipitation in the study area is depicted as being evenly distributed throughout the year. His analysis is supported by the current analysis with but one exception. In sea area "Hotel" strong wintertime cyclonic activity, replaced by the influence of the so-called Bermuda high pressure system during the summer months, produces a marked seasonal variation in the frequency of occurrence of precipitation. Over 20% of the three-hourly observations taken in the "Hotel" area record precipitation during February, but this value falls to about 8% during June, July, and August.

The regional analysis, Figure 11.3, also indicates that precipitation is more frequently experienced during the winter half-year, November through April, at "Hotel" than in the areas located nearer the East Coast.

Although snow has been reported in all areas, the frequency of its occurrence decreases significantly from north to south, and everywhere remains less than half that of rain. Snow is most frequently observed in the Quonset area where it is reported during 5.3% of the February observations.

The final significant event, thunder activity, occurs most frequently throughout the study area during the summer months when the percentage figure reaches 8.2% during August at "Hotel". Thunderstorms have been reported in all areas during the winter but the frequency of such observations is usually considerably less than 1%, except at sea area "Hotel" where it is close to 1%.

Air Temperature

On an annual basis Cape Hatteras and "Hotel" sea areas are the warmest of the regions, with temperatures of 20.0°C (68.0°F) and 20.2°C (68.3°F) respectively. The latter area experiences the smallest annual temperature range of all the areas, 11.8°C (21.3°F), because of its distance from land. The other areas, closer to the East Coast, record greater annual range of air temperature, with the greatest range observed in the New York area (20°C)(36°F). The regional analysis displays frequency distributions of the temperature observations. For the year as a whole these distributions tend to be bimodal in sea areas Quonset, Atlantic City, and Norfolk. This could indicate the combined influence of maritime tropical and polar air masses.

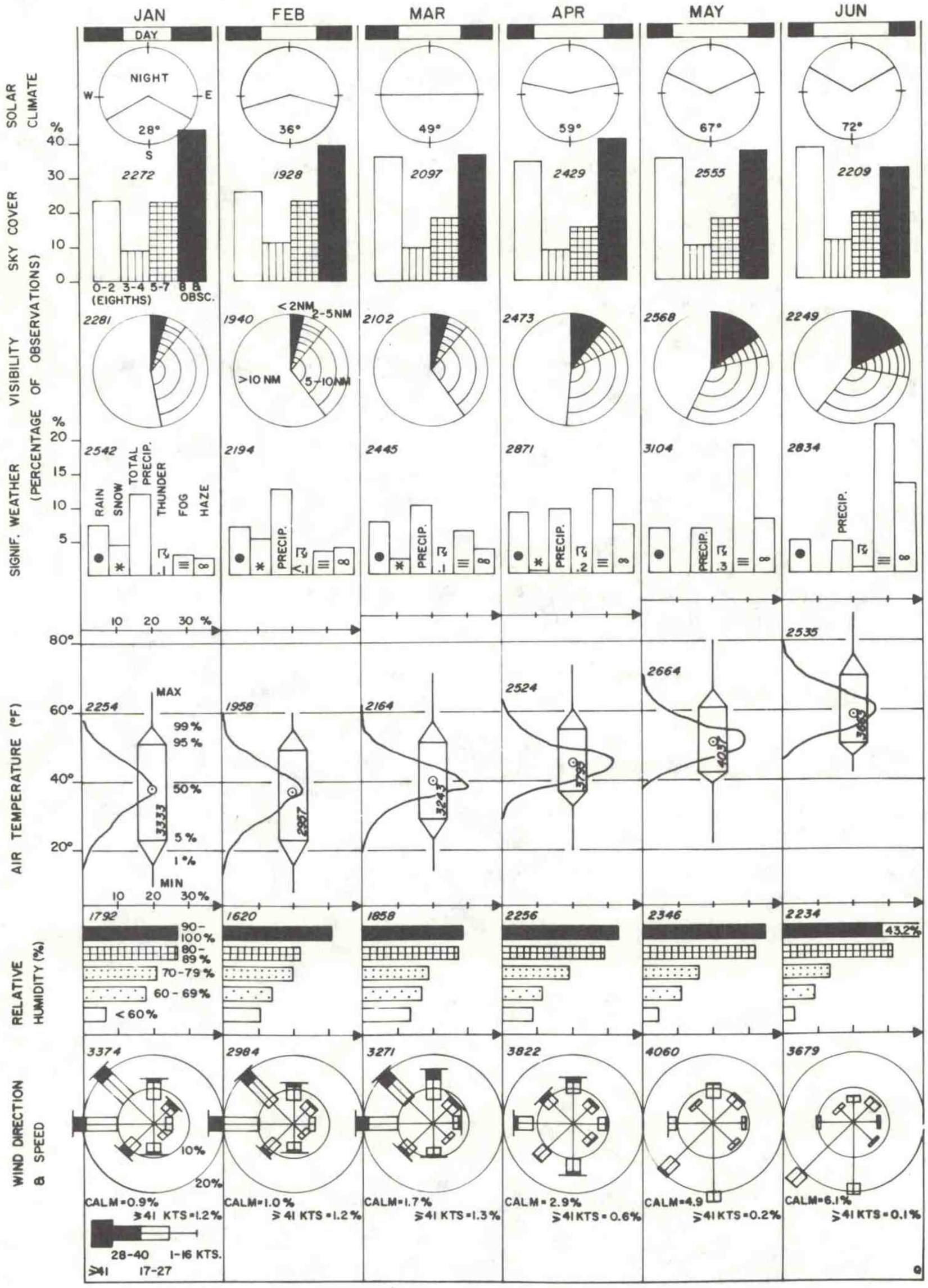

Figure 11.3a Regional climatological analysis for Quonset sea area.

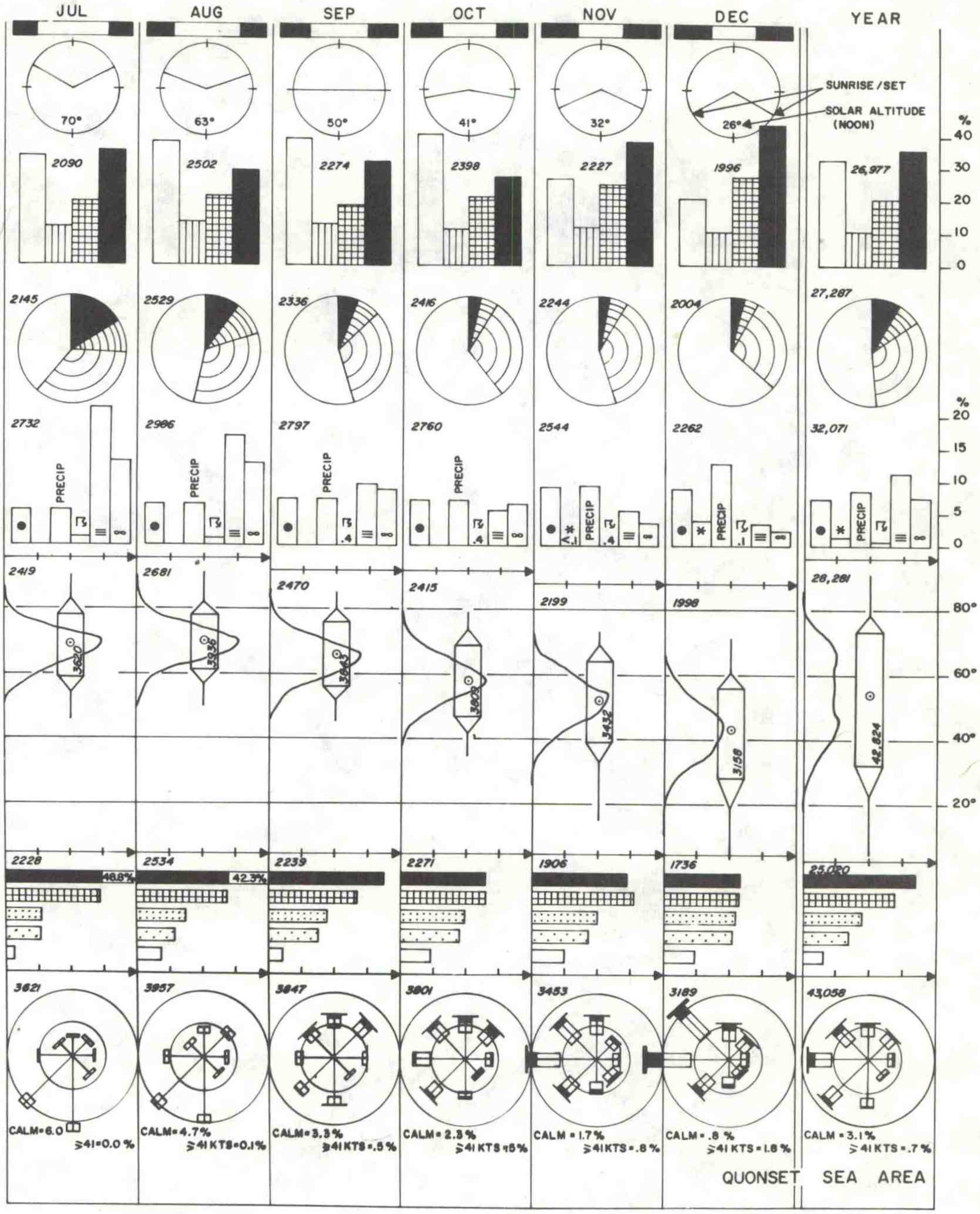

Figure 11.3b Regional climatological analysis for Quonset sea area (Cont'd).

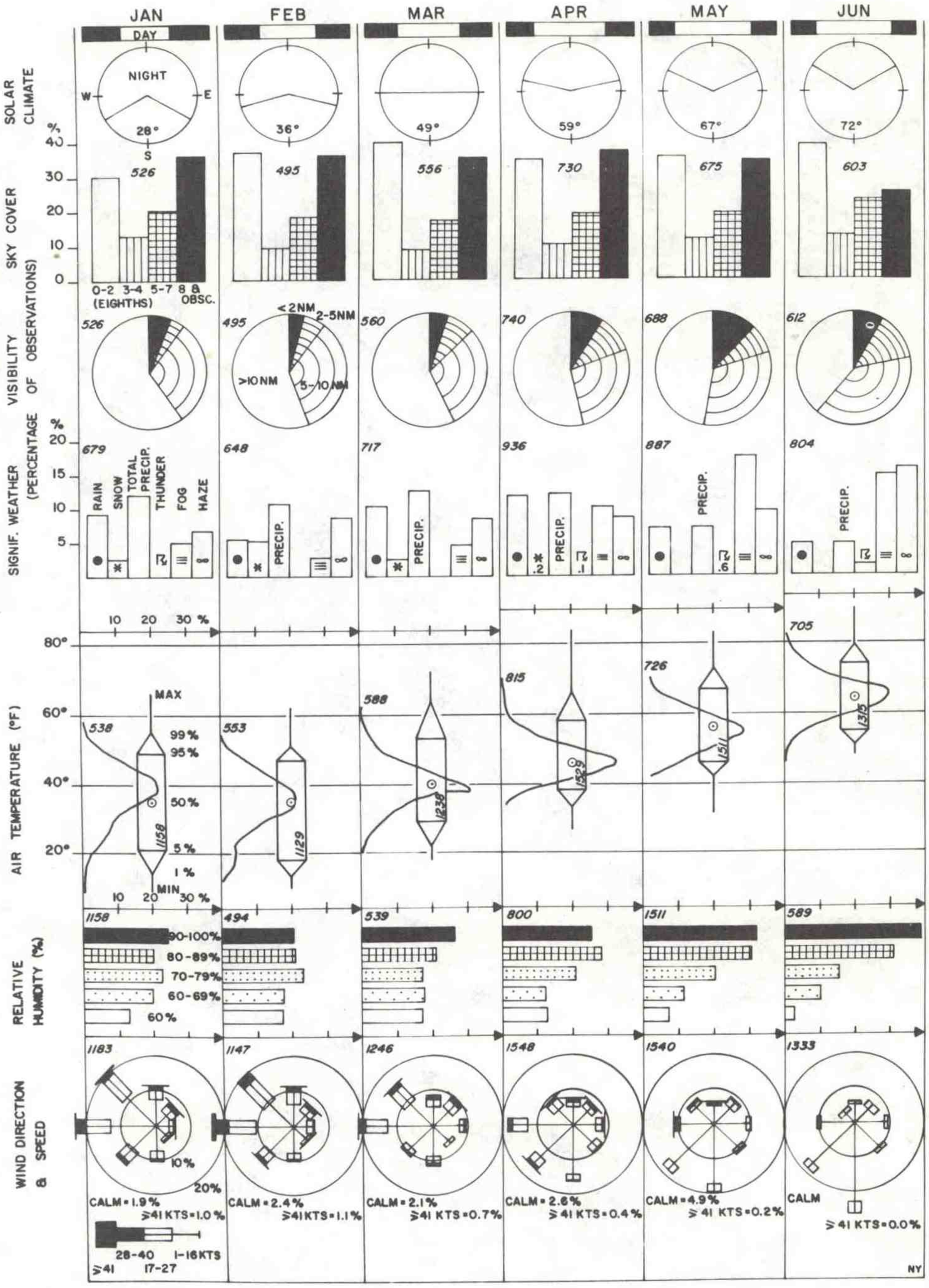

Figure 11.3c Regional climatological analysis for New York sea area.

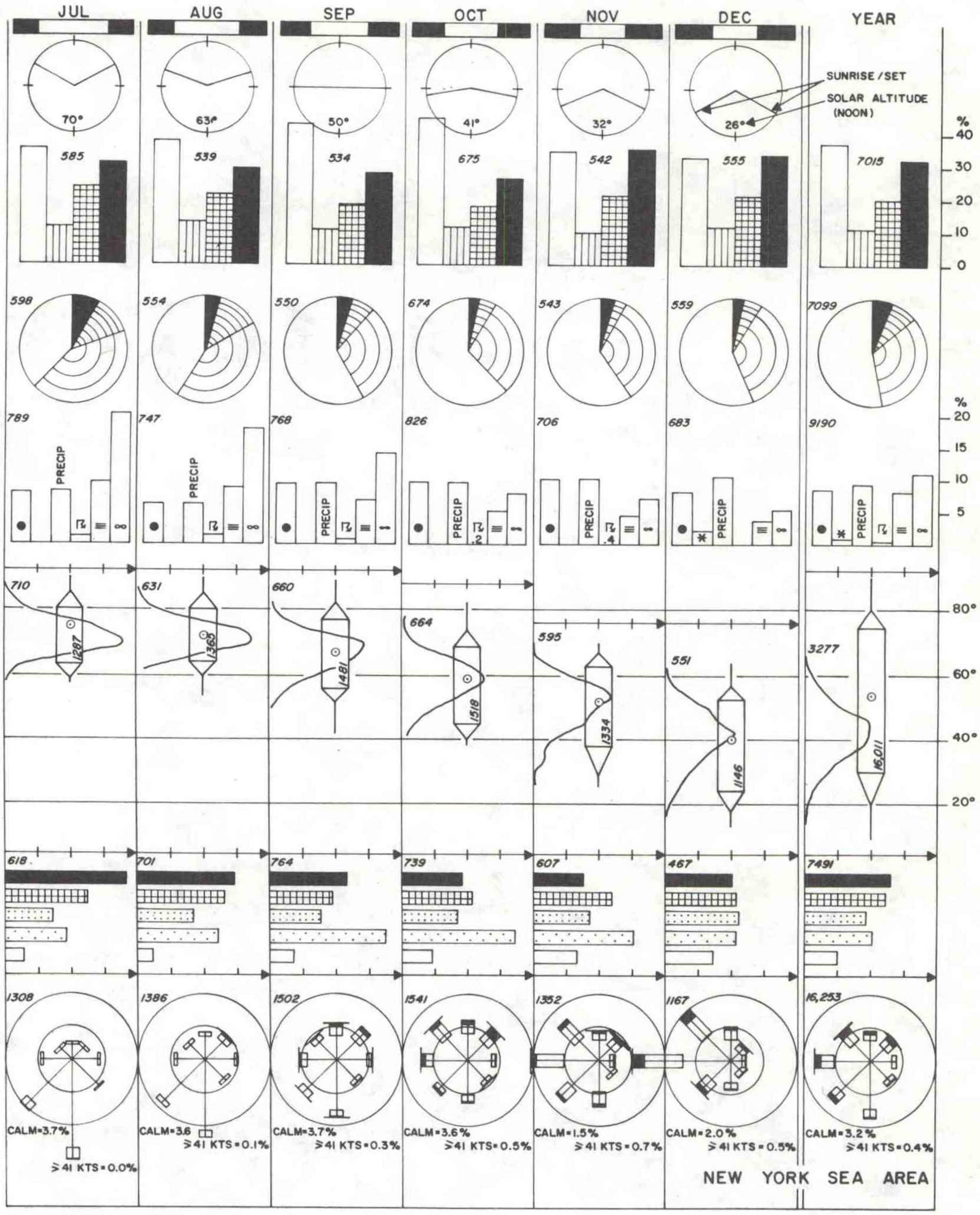

Figure 11.3d Regional climatological analysis for New York sea area (Cont'd).

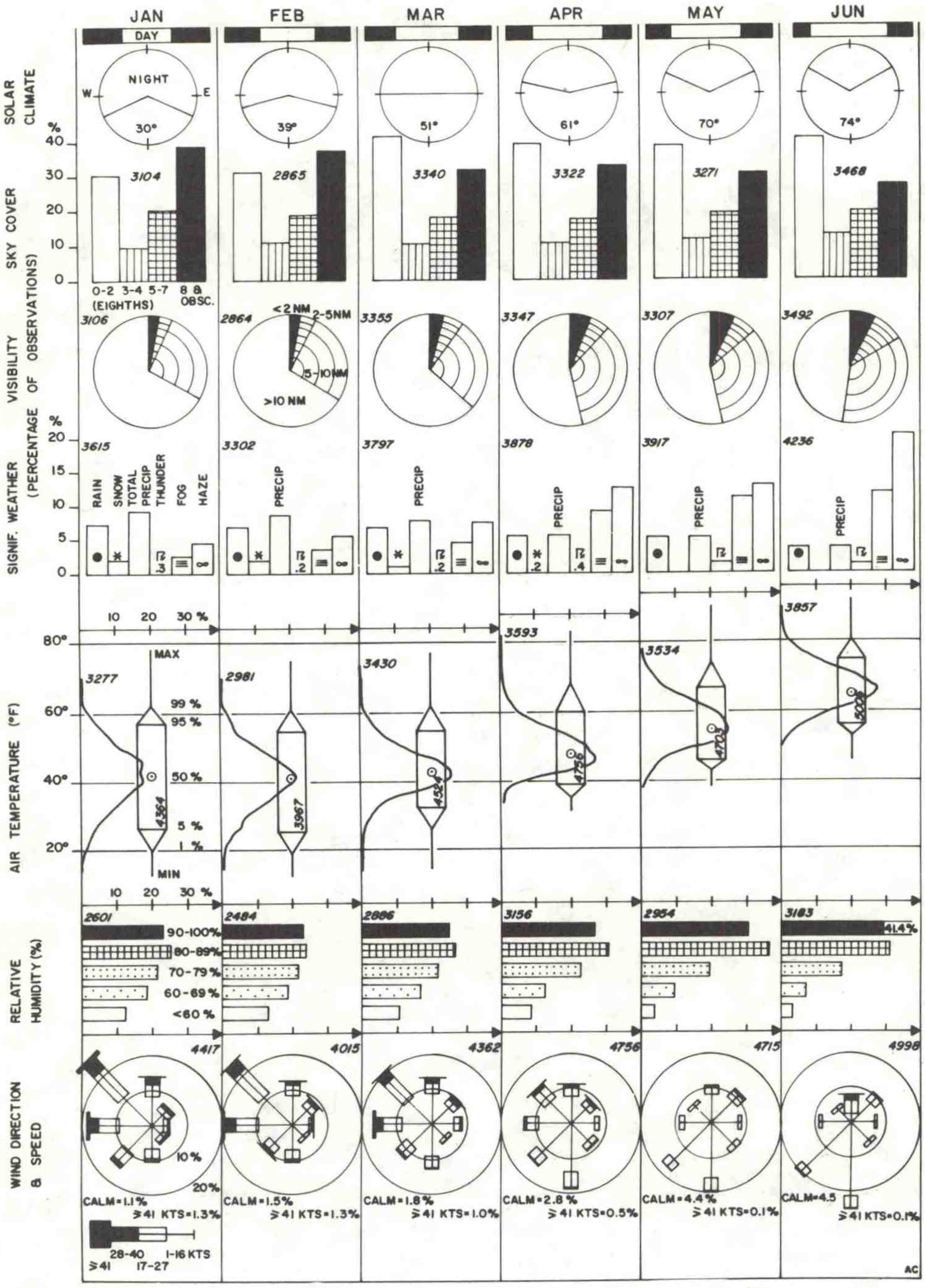

Figure 11.3e Regional climatological analysis for Atlantic City sea area.

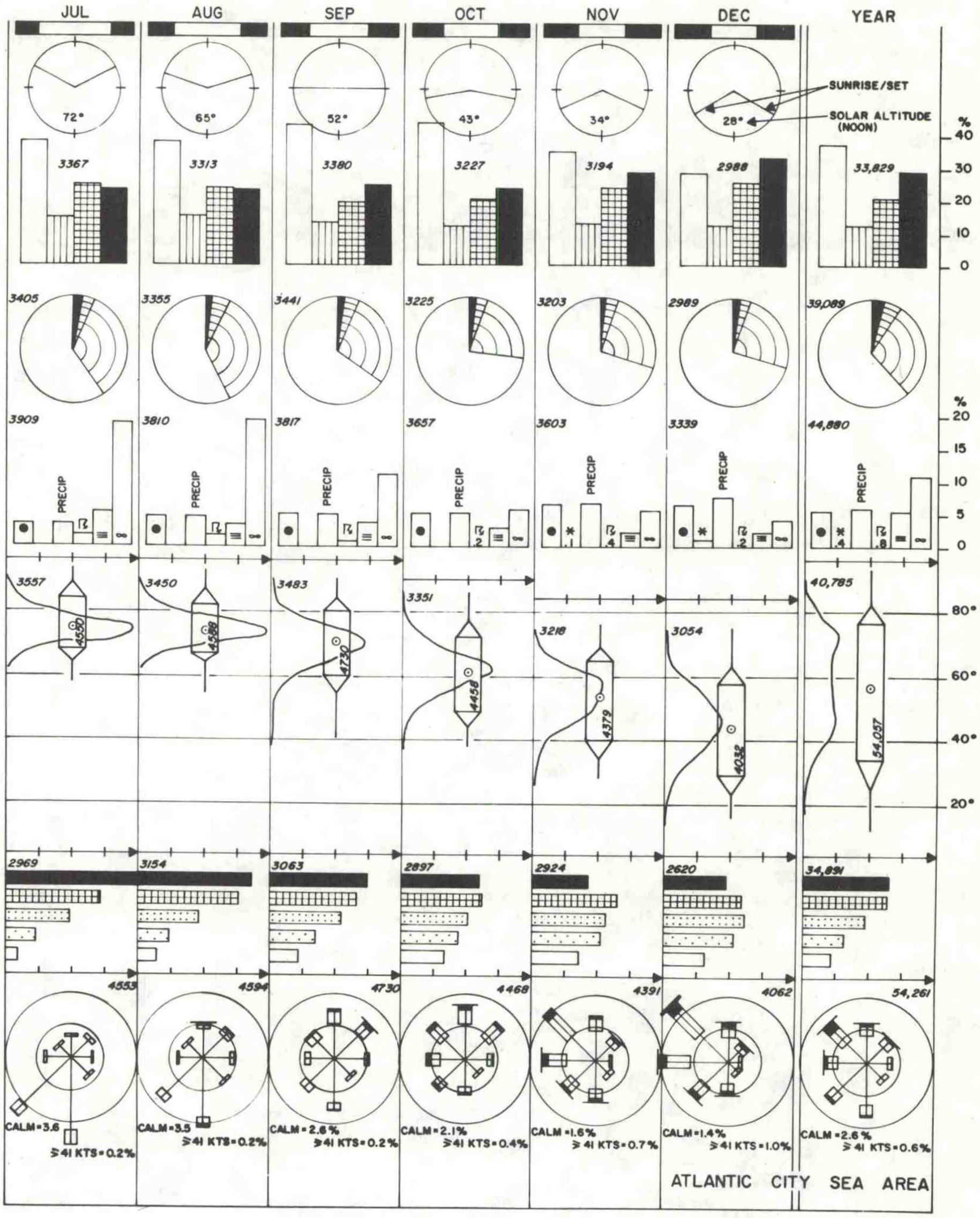

Figure 11.3f Regional climatological analysis for Atlantic City sea area (Cont'd).

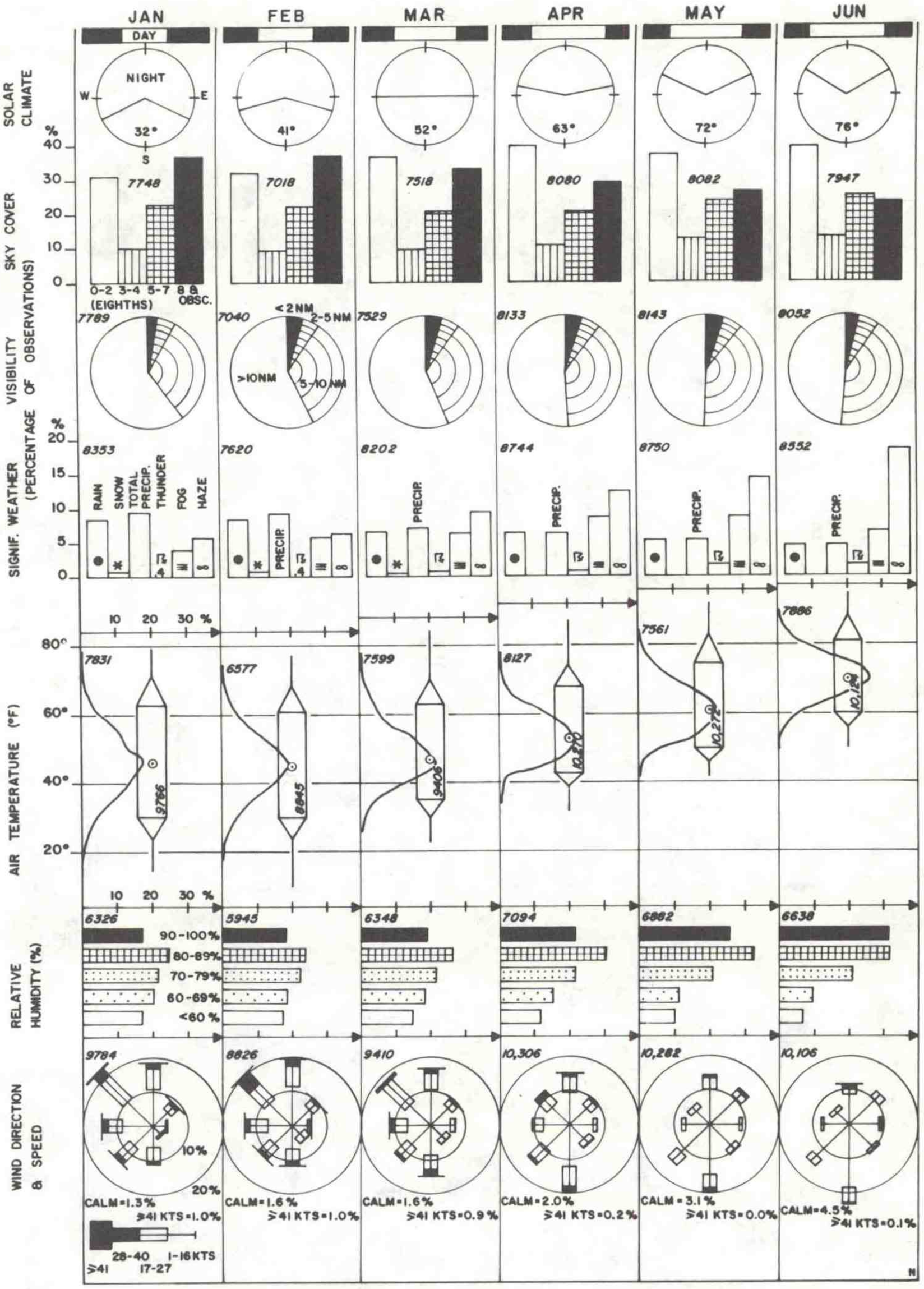

Figure 11.3g Regional climatological analysis for Norfolk sea area.

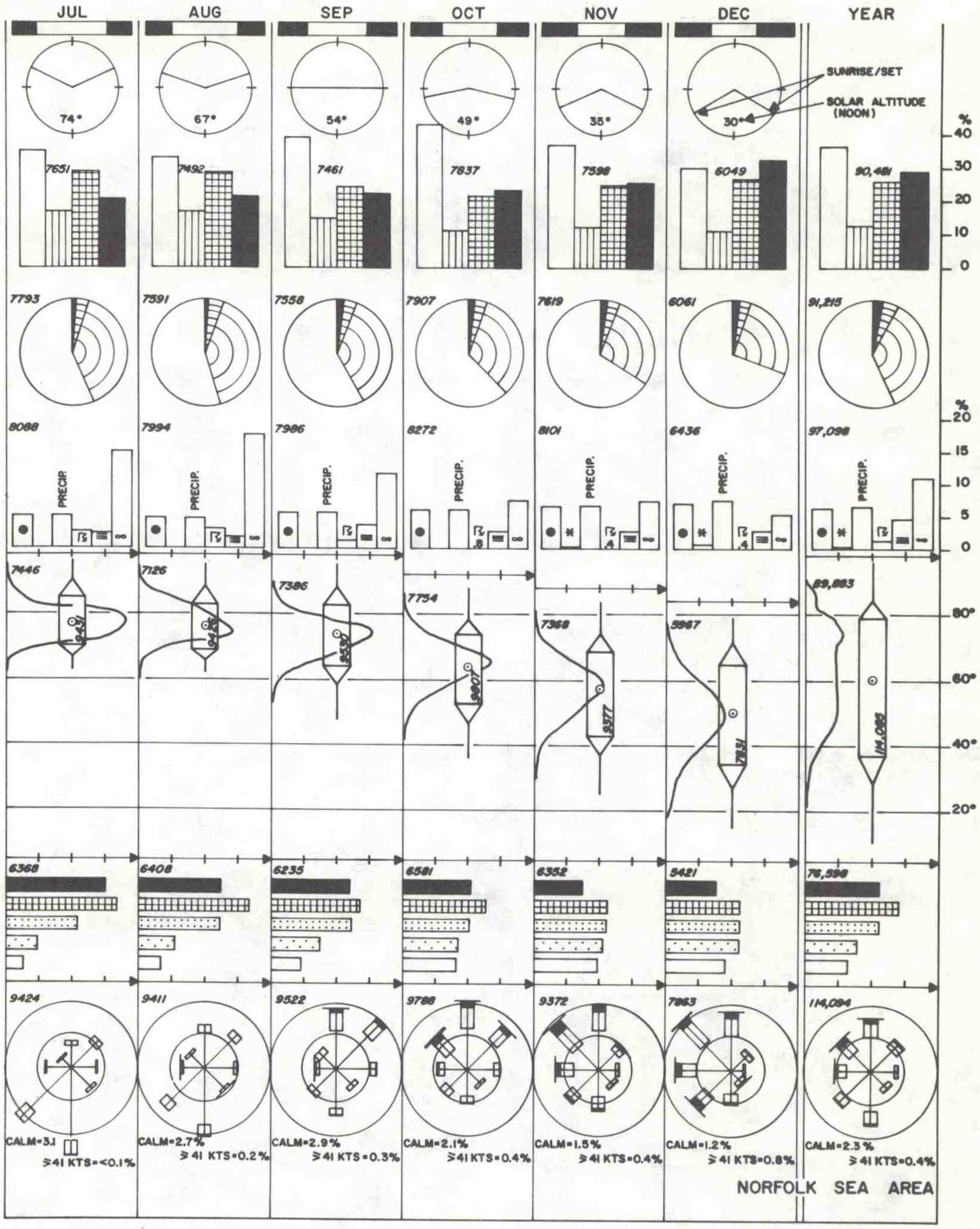

Figure 11.3h Regional climatological analysis for Norfolk sea area (Cont'd).

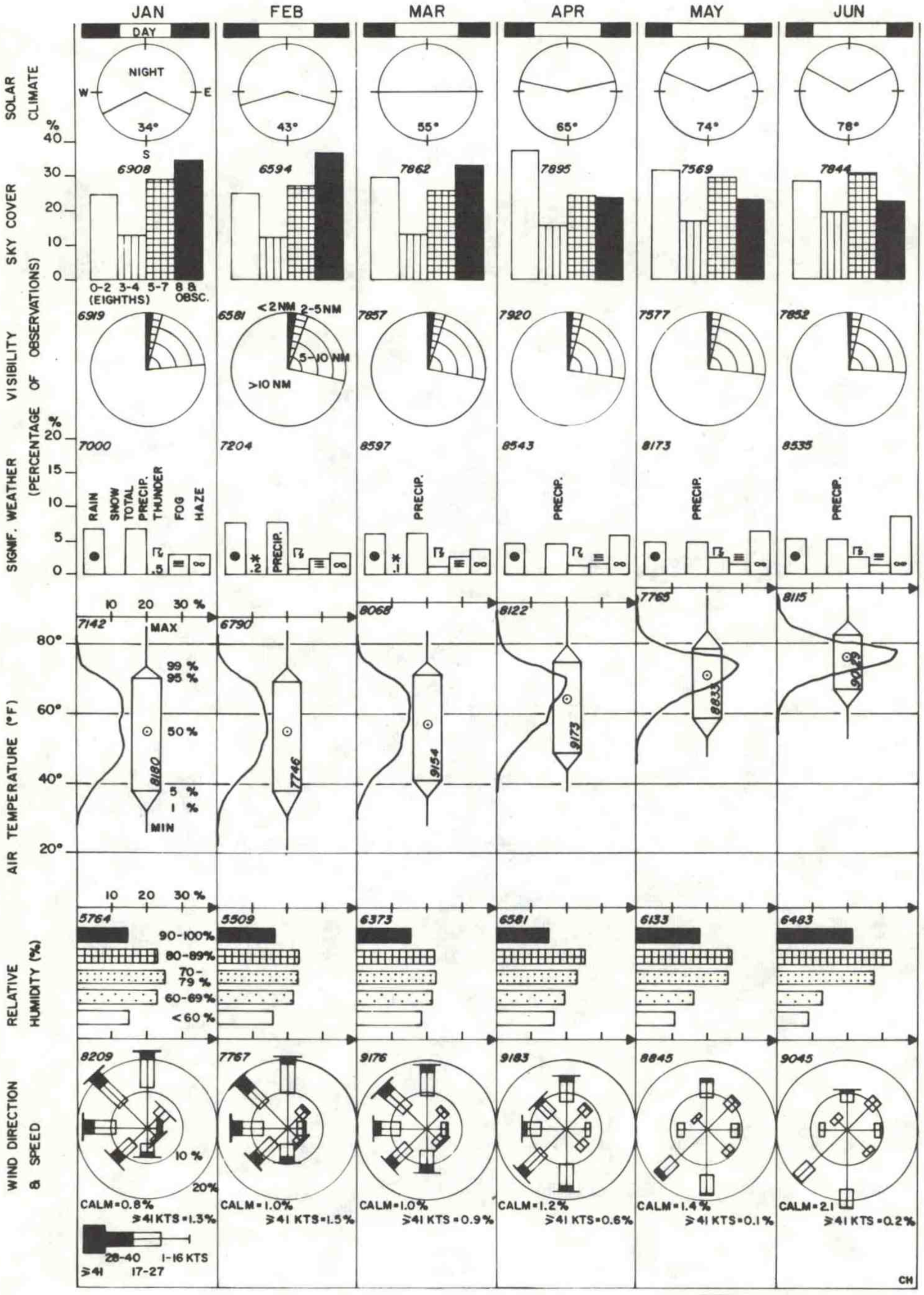

Figure 11.3i Regional climatological analysis for Cape Hatteras sea area.

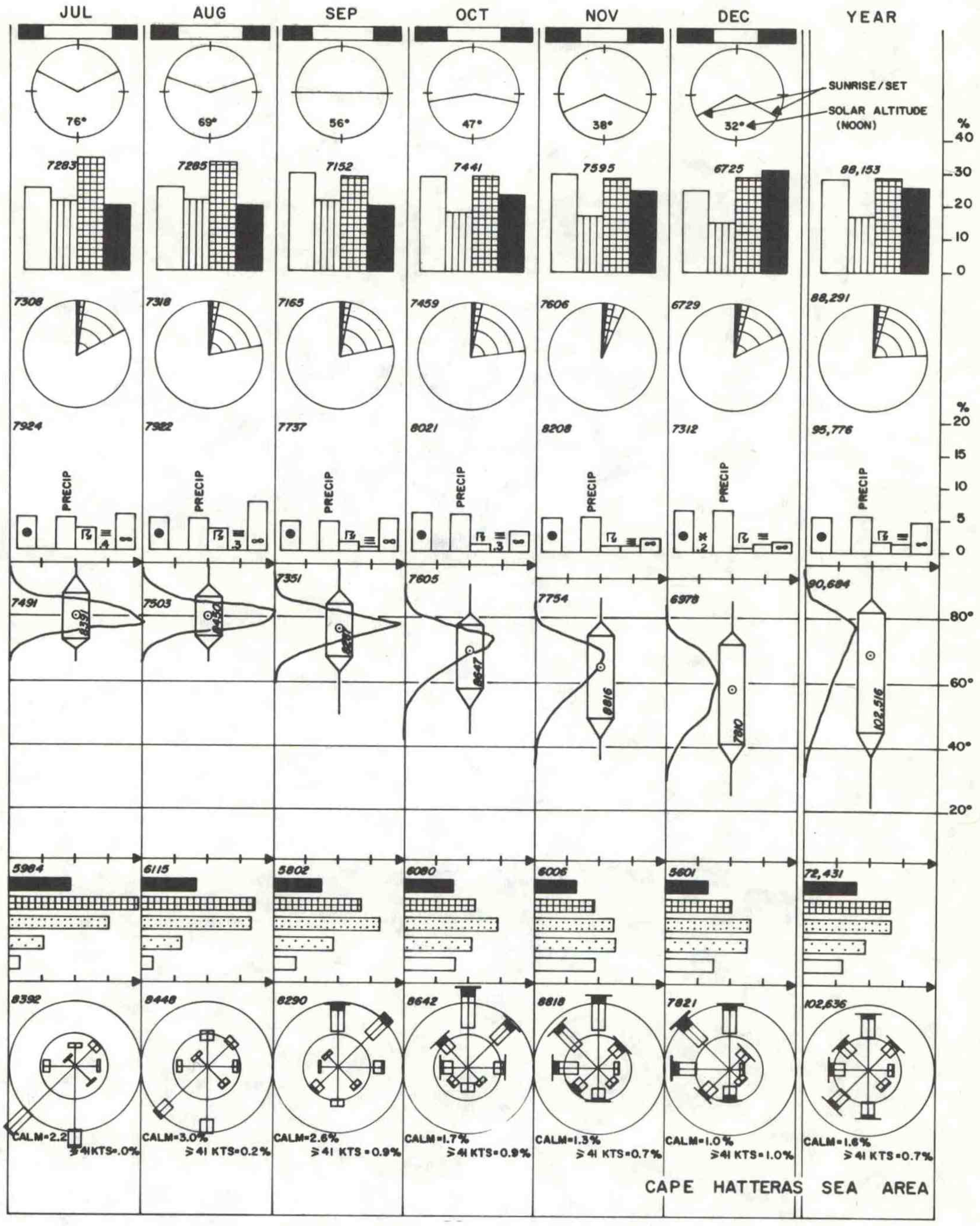

Figure 11.3j Regional climatological analysis for Cape Hatteras sea area (Cont'd).

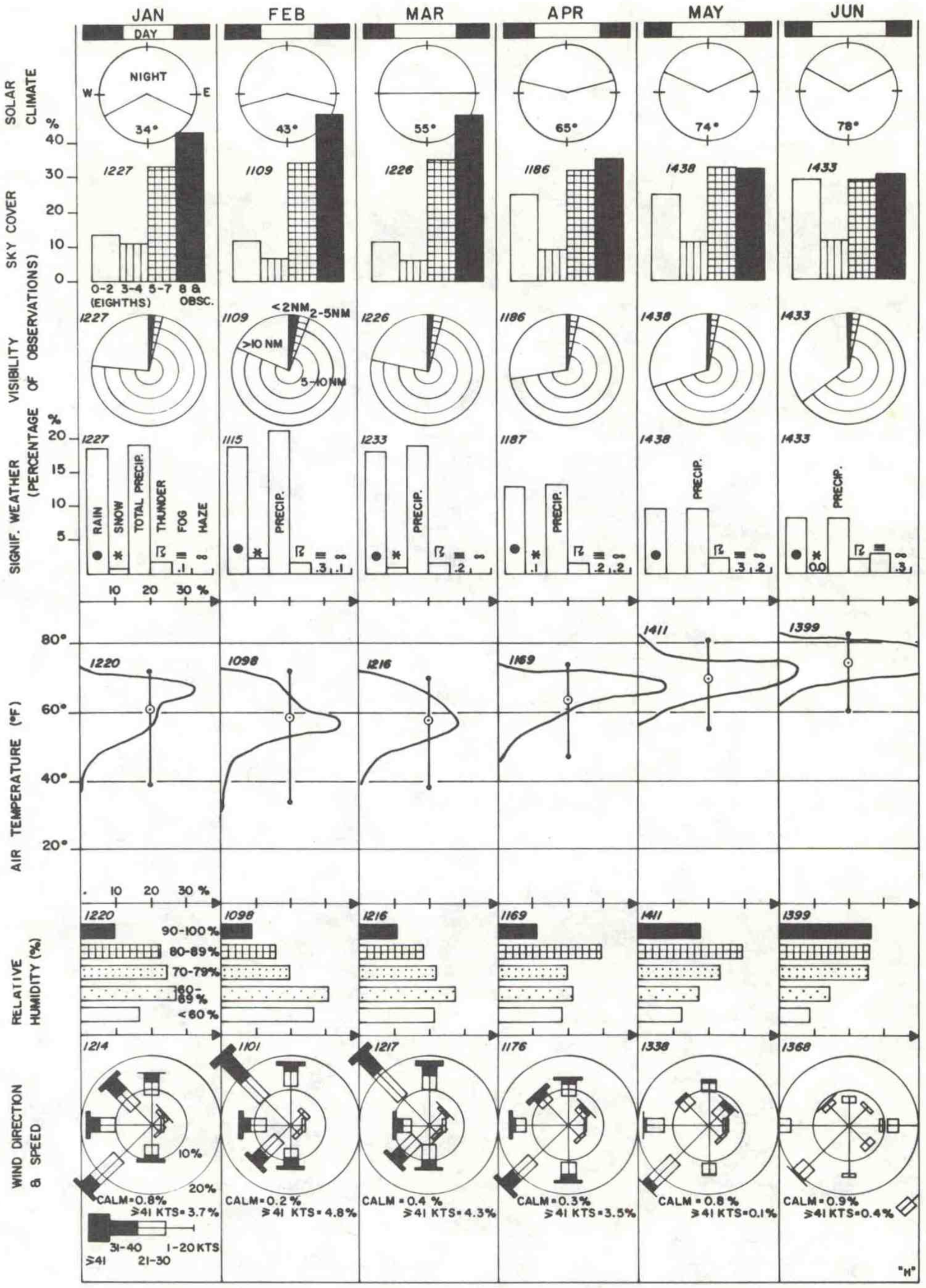

Figure 11.3k Regional climatological analysis for "Hotel" sea area.

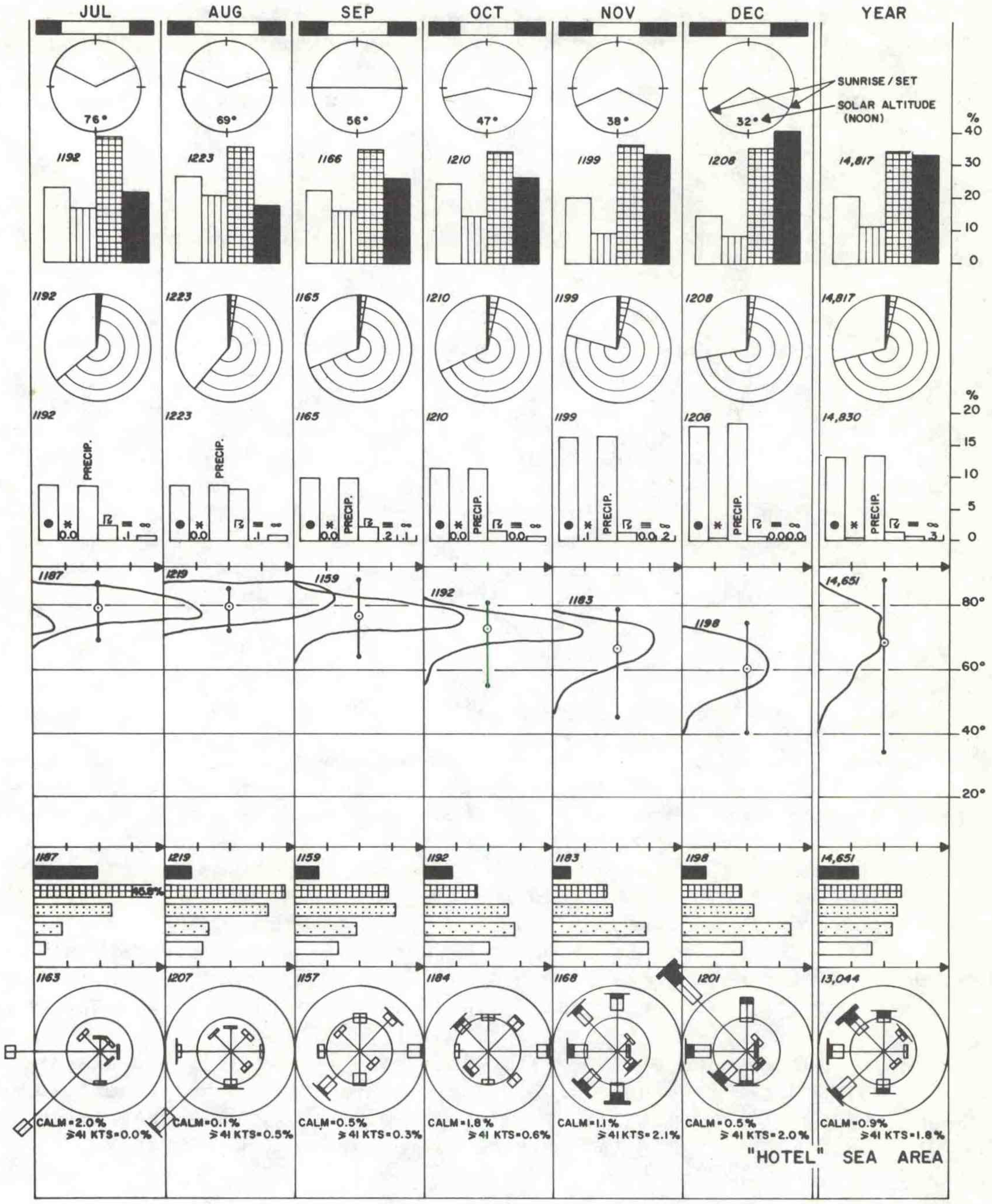

Figure 11.31 Regional climatological analysis for "Hotel" sea area (Cont'd).

All the sea areas show considerably greater temperature ranges during the winter months than during the summer months. During the latter season the polar front is much more often located north of the study area, and air mass contrasts are less pronounced.

Although absolute maximum and absolute minimum temperature data must be treated with caution, it is observed that all areas attain temperatures near 32°C (90°F) on occasion. The absolute minima, on the other hand, show marked regional differences, ranging from -13.3°C (8°F) in Quonset to near 0°C (32°F) in "Hotel".

Relative Humidity

Values of this element are, of course, rather high in all sea areas, usually in excess of 70%. Some annual variation, on the order of 6% or 7%, is present in all areas. As indicated in Table 1 "Hotel" reports the lowest over-all values of relative humidity, especially during November and during the following winter months, when the monthly averages are near 70%. The bar graphs in Figure 11.3 reflect this and present these data in more detail. It is not immediately apparent why sea area "Hotel", the area farthest from land, would show this characteristic.

Wind Direction and Speed

The regional analysis summarizes wind conditions in the form of compound wind roses. The graphic technique shows wind direction and speed at a glance. Throughout the study area winds are predominantly westerly throughout the year, but they show a marked tendency to shift from northwest during the winter to southwest during the summer. Wind speeds reflect the greater cyclonic activity of the winter months. Monthly averages, in excess of 20 kts, are indicated in Table 1 for "Hotel" from December through March. These data were reduced by a slightly different method than those for the other areas and therefore they are enclosed in parentheses. These data should, however, be comparable.

The percentages of time with wind speed in excess of 40 kts are clearly indicated in Figure 11.3. They can be seen to be present to a significant extent, about 1% of all observations, in all areas during the winter half-year. A maximum of 4.8% is reached at "Hotel" during February.

Storm Activity

The frequency of storms of both tropical and extra-tropical origin and their potential for causing damage make them important weather events in the study region. Indeed, storm tracks and occurrences are

important elements in weather forecasting (Miller, 1946; Markgraf and Macht, 1955, 1956; George, 1960; Andrews, 1963; Brandes and Spar, 1971; and Bosart, 1973). The role of storms in the latitudinal transport of heat, momentum, and other atmospheric properties is discussed by Jacobs (1951), Bunker (1960), Bjerknes (1961), Pyke (1965), Manabe and Bryan (1969), Vowinckel and Orvig (1969), and Sellers (1973).

Tropical cyclones are circulations around low pressure centers which originally develop over tropical oceanic areas. In the North Atlantic their formation usually occurs between 10°N and 30°N latitude, in areas where surface water temperatures are above 26°-27°C (Cry, 1965). The term "tropical disturbance" refers to an observed rotary circulation pattern without closed surface isobars. A tropical depression is a more intense circulation with one or more closed surface isobars and sustained winds equal to or less than 33 kts. A tropical storm has winds greater than 33 kts but less than 63 kts. The term hurricane refers to a cyclone with sustained winds greater than 63 kts (Alaka, 1968). Cry (1965) provides the most recent comprehensive climatology of tropical cyclones in the North Atlantic. Positions, intensities, seasonal patterns and shifts are summarized by months and other calendar periods for the years 1971-1973. For 500 tropical cyclones occurring during the period 1901-1963, the points of origin almost always occur south of Cape Hatteras. In a few isolated cases, however, points of origin recorded in October have been observed near the latitude of Hatteras but at least 5° of longitude offshore. Geographical positions at which tropical cyclones reach hurricane intensity are usually located south of the study area. Only on three occasions during the 63-year period has a storm initially reached hurricane intensity within the study area.

The point of storm recurvature, the most westerly position of a cyclone center, has been observed within the study area on numerous occasions, but only in the month of September and occasionally in August. Prediction of storm movement at the point of recurvature is difficult.

Graphic summaries of tropical storm and hurricane days for five oceanic regions are presented in Figure 11.4 (Cry and Haggard, 1962). In their region III, which contains the study area of this report, the frequency of these days is widely distributed in time, from mid-June to early November, with the greatest frequency taking place during September.

Total annual frequency data of tropical cyclones and hurricanes, analyzed by Cry (1965), for the period 1901-1963 for the entire North Atlantic Ocean show a significant upward linear trend. An

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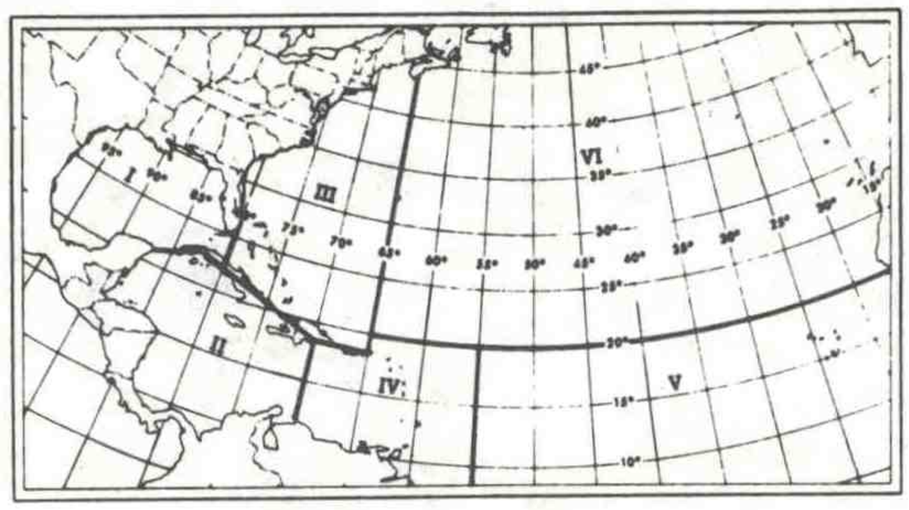
*Publication of Mariners Worldwide Climatic Guide to Tropical Storms at Sea, with up-dated material, was recently announced by the National Climatic Center, NOAA.



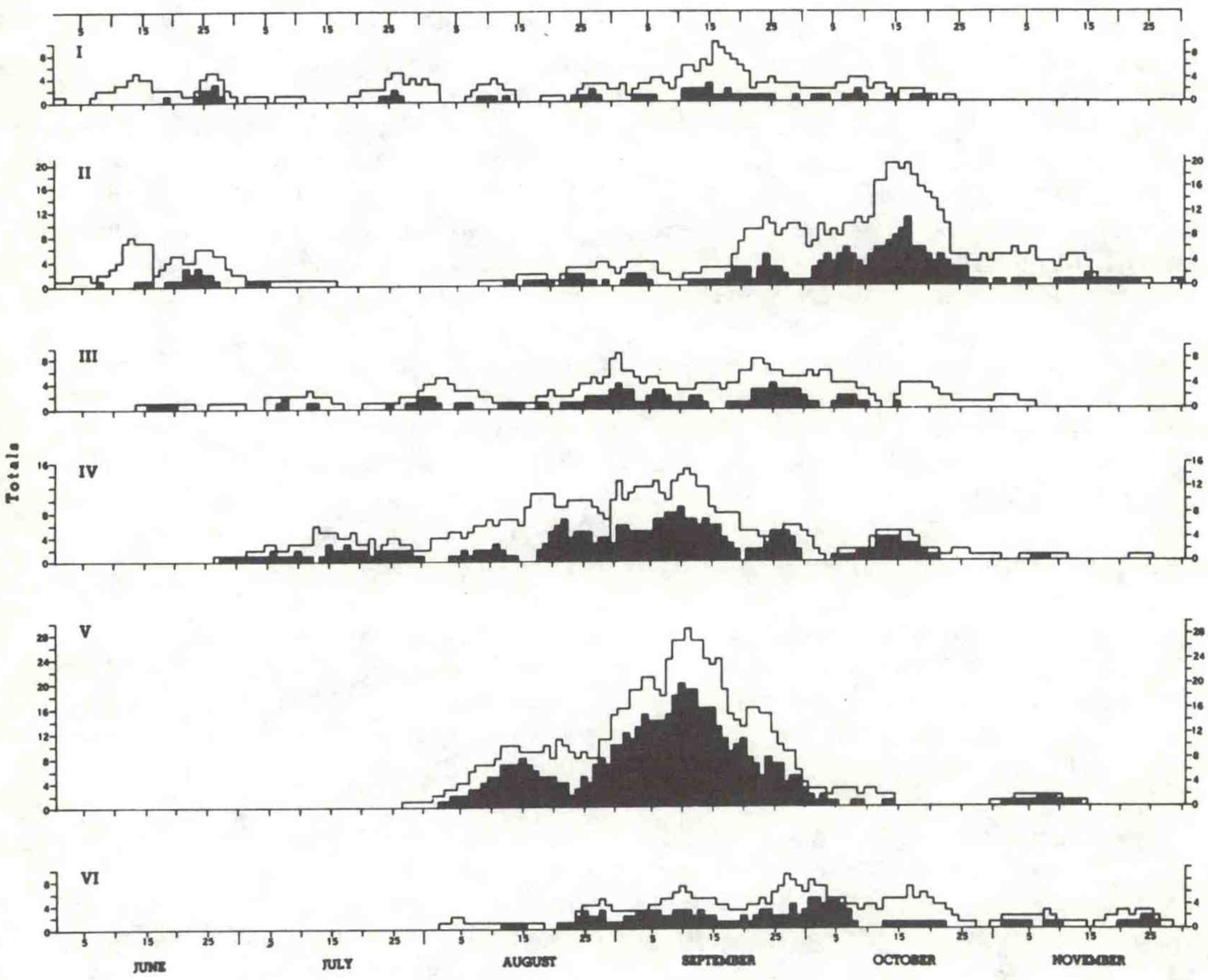


Figure 11.4 Distribution of tropical storm and hurricane days (1901-1960) in various regions of the North Atlantic Ocean (Cry and Haggard, 1962).

average increase of 1.8 tropical cyclones has occurred over the 63 year period. The six-per-year occurrence at the beginning of the data period rises to approximately eight-per-year during the early 1960's. Data for tropical cyclones affecting the East Coast exclusively, however, show no such upward trend in frequency of occurrence. Cry suggests that this may be due to (1) a recent eastward shift in the tropical area of storm development, with recurvature taking place farther to the east, away from the coast; or (2) to the gradual improvement in storm reportage at sea that has taken place during recent years; or (3) to a combination of these two factors.

The publications mentioned above contain extensive references to tropical cyclones in the North Atlantic, as does a bibliography prepared by the Coastal Plains Center for Marine Development Services (1970) and its supplement (1972).

Burton et al (1965) use storm damage data for the period 1935-1964 to determine the frequency of damaging storms, of both tropical and extra-tropical origin, along the East Coast. Figure 11.5 presents one aspect of their assessment, in which number of storms producing significant reported damage are plotted along specific reaches of coastline. The decadal increase in the number of these storms, partially due to increased coastal development, and to the vulnerability of the southern New England coast should be noted.

Cyclogenesis along the U.S. East Coast is discussed by Andrews (1963). An important factor in the process is the large contrast between cold polar air masses of continental origin and the warmer maritime air overlying the sea surface. This temperature contrast is intensified by the presence of the Gulf Stream, and is related to the upper-air polar front. Andrews notes a number of local factors contributing to cyclogenesis, including the curvature of the East Coast shore line, the orientation of the Appalachian Mountains, and differential friction between air and sea.

The persistence of an upper-air trough near the East Coast of North America on normal upper-air maps is associated with cyclogenesis in all months of the year, especially during the period October to April. At this time of year, Andrews (1963) notes the following three types of cyclogenesis:

Type A: A cyclone first appears as a wave on a cold front.
Type B: A cyclone appears as a secondary cyclone near the Middle Atlantic coast along the warm front of an older cyclone.
Type C: A cyclone develops as a blocked low off the coast. Its formation is related to the breakdown of large-scale planetary circulation in the upper westerlies.

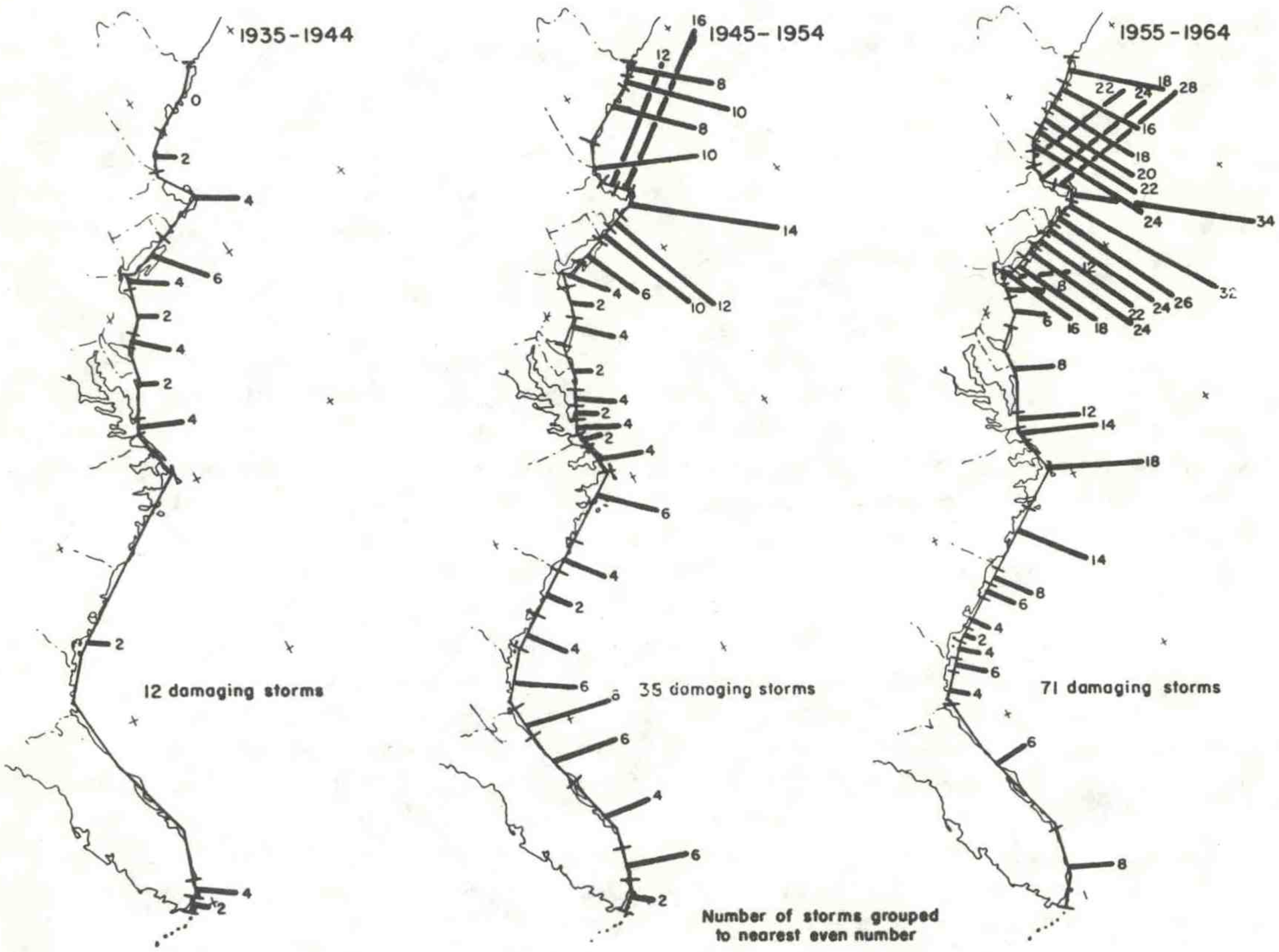


Figure 11.5 Number of storms that have produced significant reported damage along indicated reaches of the U.S. East Coast (Burton et al., 1965).

Sea Surface Temperatures and the Gulf Stream

Figures 11.6 (a through l) present the mean sea surface temperatures and mean position of the Gulf Stream for each month of the year for the study area. These maps are based on nearly 100 years of data published by the U.S. Naval Oceanographic Office (1969). The temperature fields, as depicted by the isotherms, are quite smooth since they represent the means of many observations within each one-degree latitude/longitude grid. Other compilations of these data have been made, notably by Bohnecke (1936), the U.S. Navy Hydrographic Office (1944), Fuglister (1947), the U.S. Department of Commerce and the U.S. Department of the Navy (1959), and Schroeder (1966). In all of these publications the data base is shorter than that used here and the maps cover much larger areas. There are, of course, differences between the temperature fields in each of these studies due to a combination of factors. Some of these factors are: the method used to obtain the averages; the duration of the data set; and the contouring technique used. Schroeder (1966) states that her maps yield spot temperature estimates south of Cape Hatteras which differ from the corresponding values taken from Bohnecke and Fuglister by $+2^{o}$ to $+3^{o}C$. Since Schroeder's data covered a longer time period than the others, it is possible that this indicates a real change in water temperature. The data used to prepare the maps presented here cover the longest time period presently available. As will be shown below the actual month-by-month and day-by-day variation in temperature are substantially greater than any variation between atlases.

In addition to the mean fields, some estimate of the variability of the temperature about the mean is useful. No statistical studies are available on the variability of the sea surface temperatures over long periods of time. To assess the order of magnitude of possible deviations from the mean, the reader should consult Figure 11.7 which shows the mean temperature for a particular month, March, 1970. Anomalies greater than $6^{o}C$ are observed near Cape Hatteras and in other areas anomalies from $3^{o}C$ to $4^{o}C$ are indicated. Figure 11.8 provides an estimate of the intensity and spatial extent of sea surface anomalies on a one-month time scale. These means, however, are smooth when compared with the instantaneous surface temperatures shown in Figure 11.9. This map is a composite based on aircraft observations taken on 17, 18, and 24 March 1970 as observed by an airborne infrared radiometer. These charts are published monthly by the U.S. Coast Guard (1970). Although the area covered is restricted in extent, it is obvious that an instantaneous measure of the sea surface temperature shows extremely tightly packed isotherms which are not smooth in outline. Instantaneous departures from long-term means for March exceeded $10^{o}C$ off Cape Hatteras on the days observed.

It is believed that these anomaly patterns are caused by the following two factors: (1) a feedback mechanism, coupling the atmos-

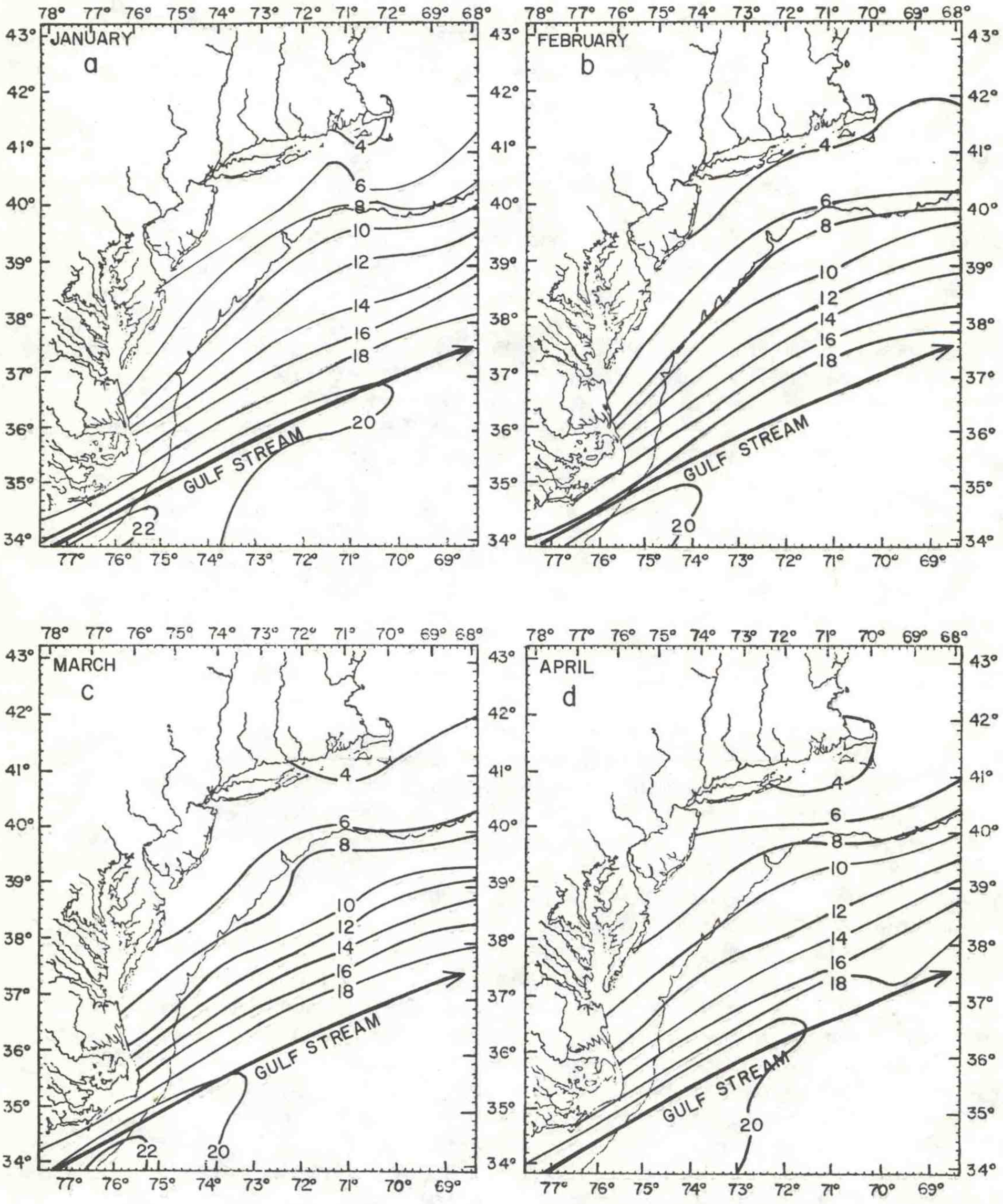


Figure 11.6(a through d) Mean sea surface temperature, January-April (Gulf Stream refers to axis of mean current).

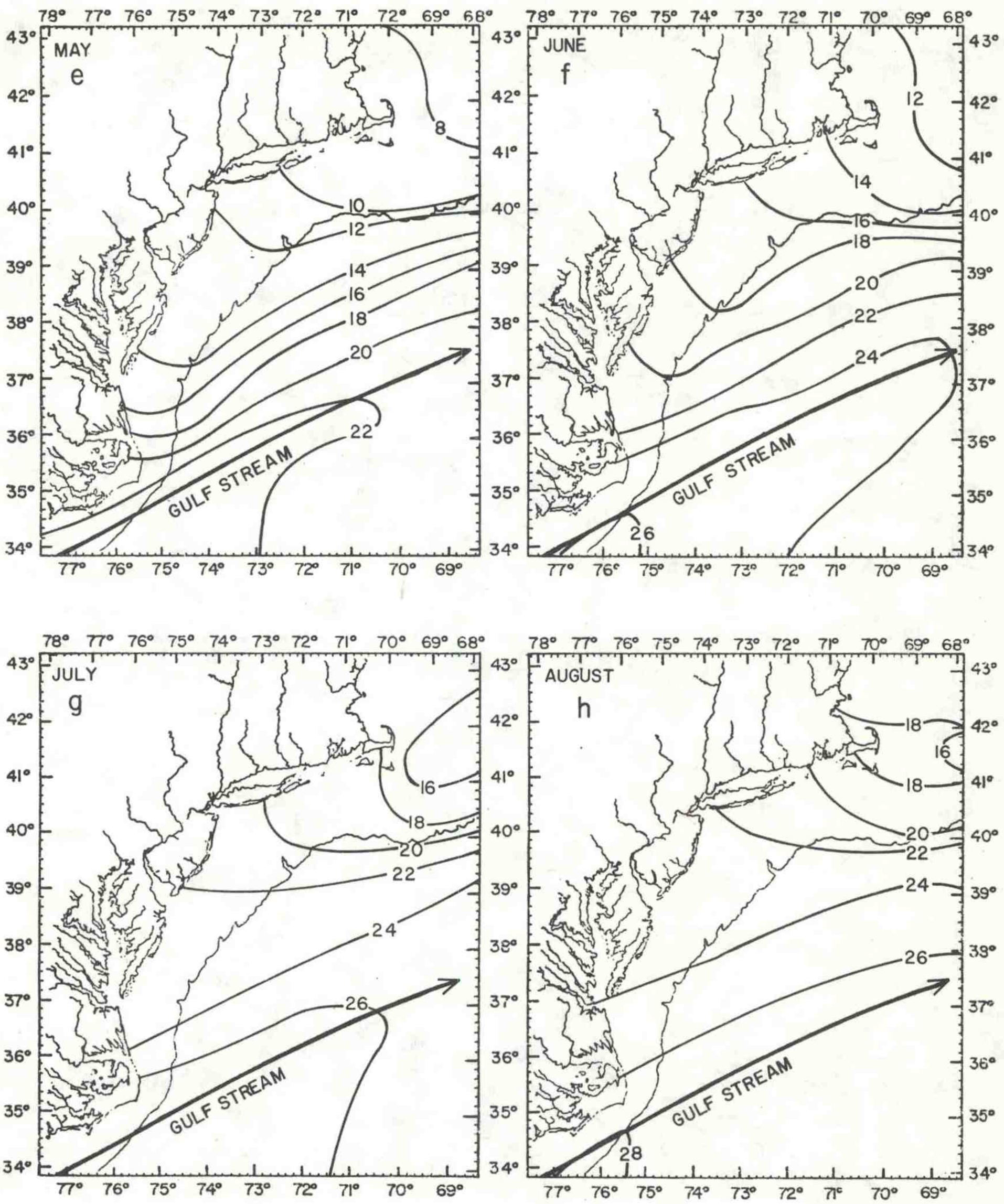


Figure 11.6 (e through h) Mean sea surface temperature, May-August (Gulf Stream refers to axis of mean current).

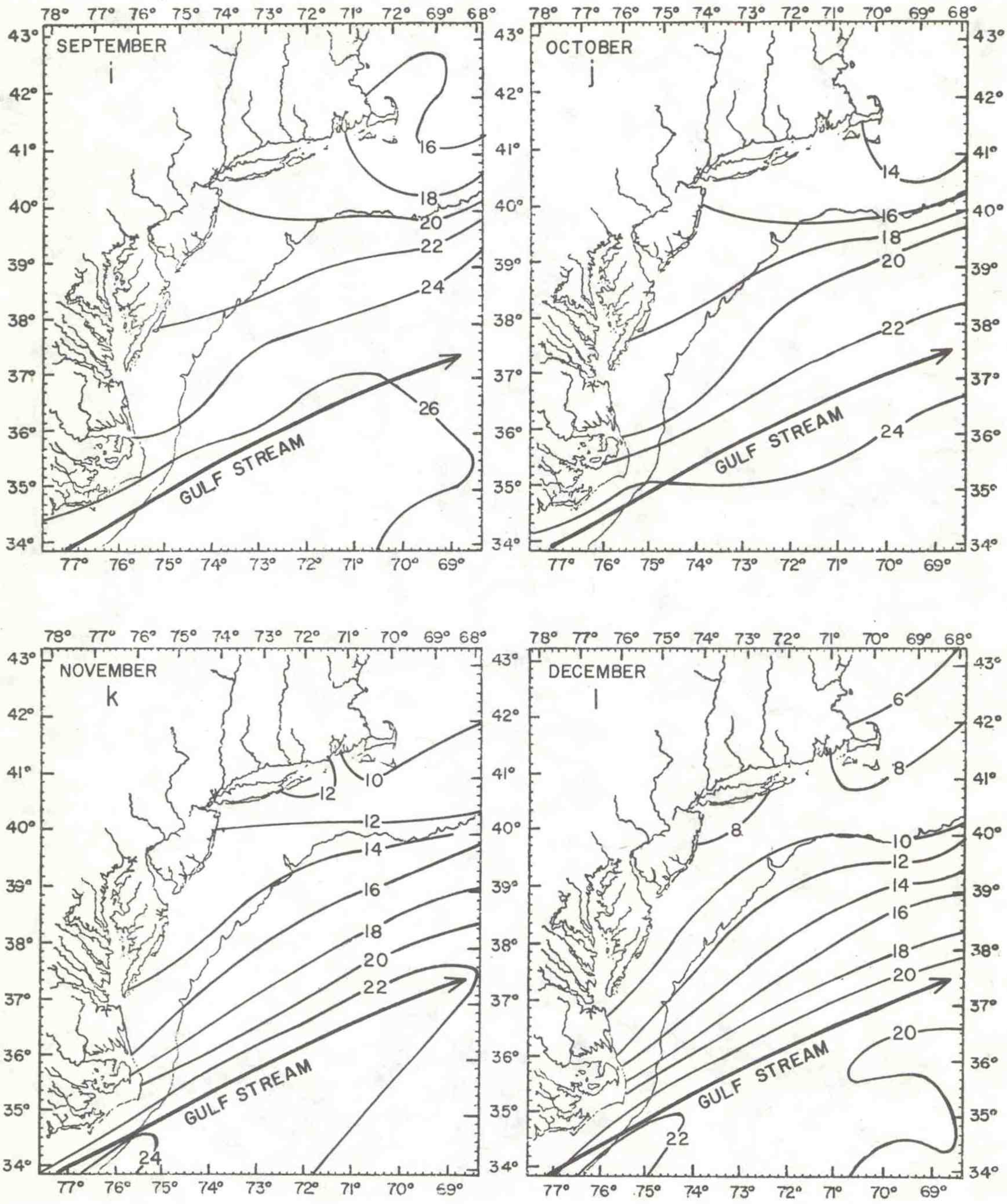


Figure 11.6(i through l) Mean sea surface temperature, September-December (Gulf Stream refers to axis of mean current).

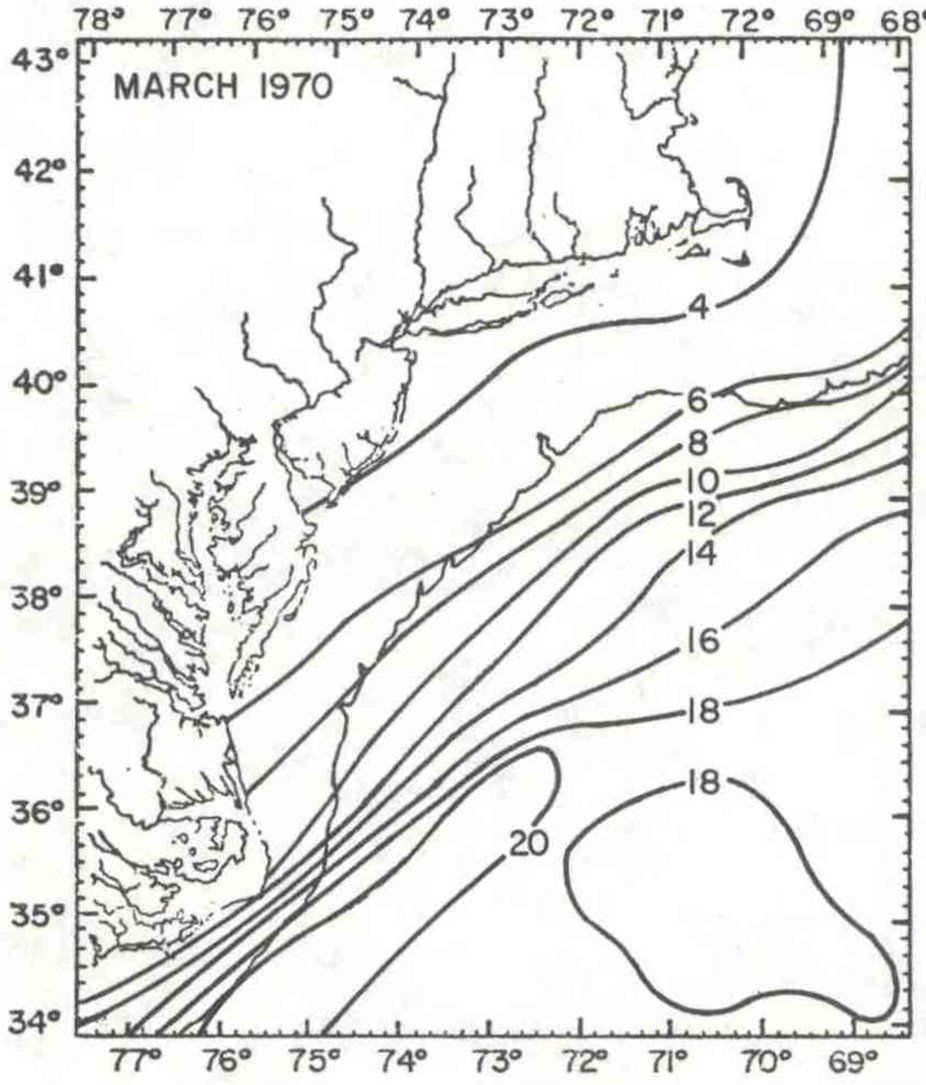


Figure 11.7 Sea surface temperature for March, 1970.

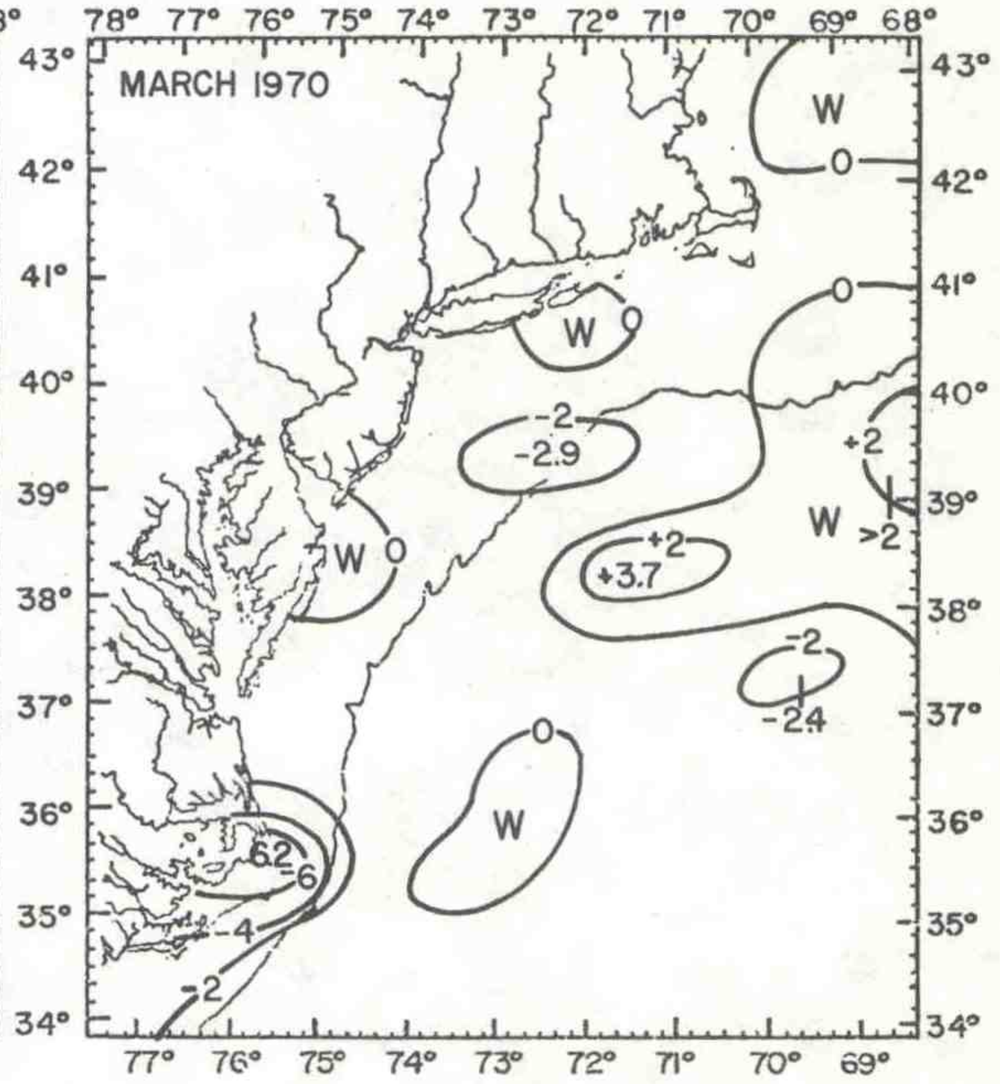


Figure 11.8 Sea surface temperature anomaly for March, 1970.

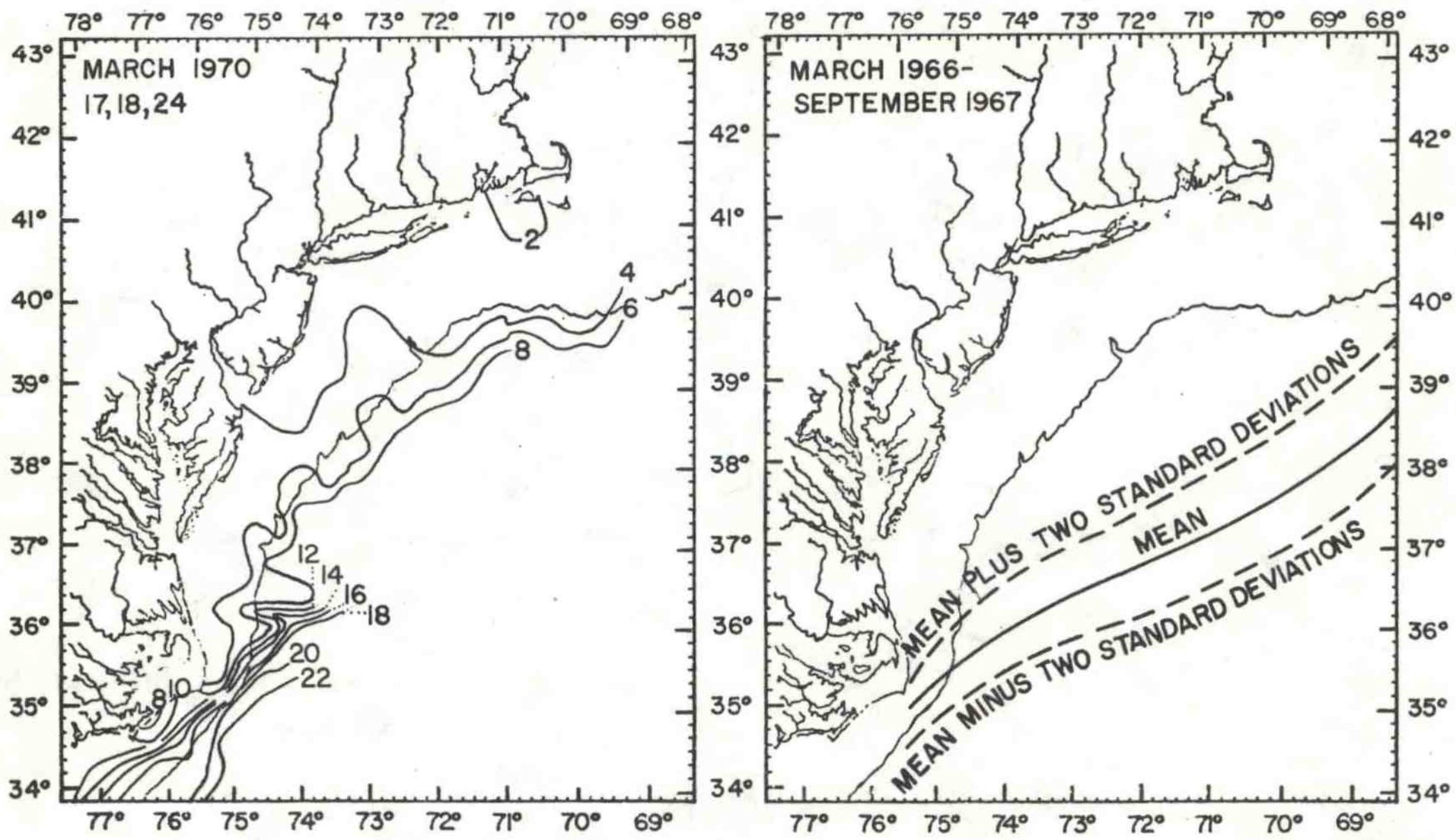


Figure 11.9 Sea surface temperature (^{o}C) for March 17, 18, and 24 of 1970.

Figure 11.10 Mean position of the northern edge of the Gulf Stream and its spatial variation, March 1966 - September 1967.

phere and ocean (Namias, 1960) and (2) lateral movements of the Gulf Stream itself. The mean position of the maximum current in the Gulf Stream is shown by the heavy arrow in Figure 11.6. At the sea surface the northern edge of the Gulf Stream can usually, at least in winter, be indicated by the close packing of isotherms. Figure 11.10 shows the results of a detailed study of the northern edge carried out by the U.S. Naval Oceanographic Office (1967). Plus or minus two standard deviations from the mean implies that 95% of all observations fell between the two dashed lines. A northward movement of the Gulf Stream will shift and compress the isotherms northward, causing large anomalies of temperature.

In summary, mean sea surface temperature maps should be used with caution, since temperatures for a given month may be $5^{o}C$ higher or lower than the long term mean and for periods of several days the deviations from the mean may be as large as $10^{o}C$.

Heat Budget at the Ocean Surface

The temperature of the sea surface is controlled to a large extent by the heat balance at the surface; that is, by the difference between heat gained and heat lost. The heat balance cannot be directly determined but must be computed from the following relation:

$$A = R + S + LE$$

where R is the net radiation at the surface; S , the turbulent heat exchange between the surface and the atmosphere (sensible heat); and LE, the heat used to evaporate water from the surface (latent heat). A, calculated as the residual, represents the heat exchange between the surface and the underlying water layers.

R represents the difference between the heat gained by solar radiation (direct and diffuse) and lost by long-wave radiation. It is computed from the following equation:

$$R = Q\ (1 - \alpha\ ) - I$$

where Q is the radiation incident on the outer boundary of the atmosphere; α is the albedo (reflectivity of the earth-atmosphere system); and I is the infra-red radiation lost to space by the earth-atmosphere system. Q can be realted to cloudiness by the following equation:

$$Q = Q_{o}\ (1 - an - bn^{2})$$

where Q_o is the radiation received in the absence of clouds and n is the cloud amount in tenths. a and b are empirically determined

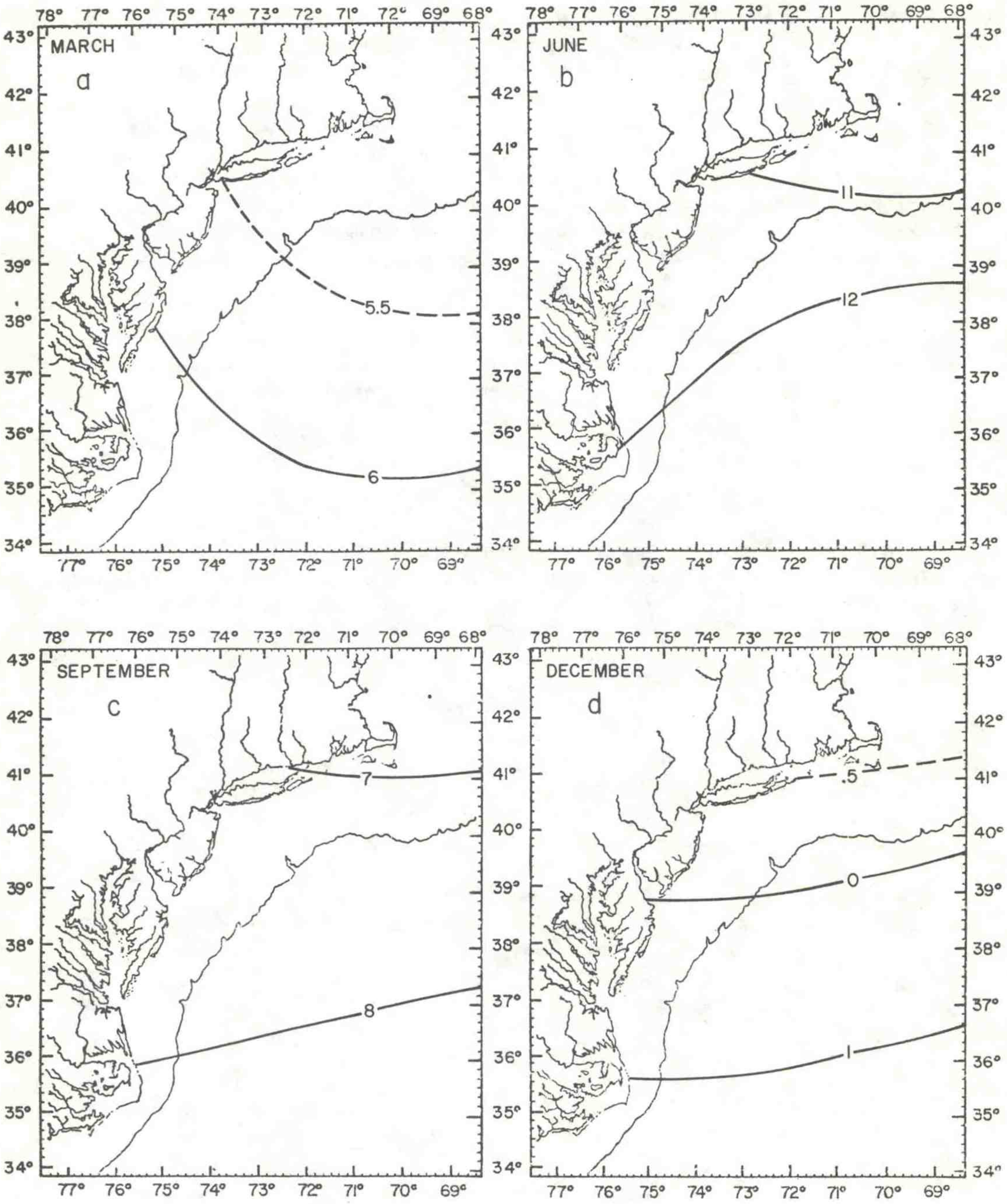


Figure 11.11(a through d) Radiational heat gain at ocean surface, selected months (K cal/cm^2/mo).

I is a complex function of temperature, clouds, and humidity.

S and LE are both found from relations involving the wind stress on the water surface. LE is determined from the equation:

$$LE = k\ u\ (q_w - q_a)$$

where k is a constant, u the wind speed and $(q_w - q_a)$ the difference between the humidity of the surface and the air. S is similarly determined from

$$S = k\ u\ (T_w - T)$$

where $(T_w - T)$ is the temperature difference between the surface and the air. These formulations for latent heat and sensible heat transfer are derived from theoretical consideration involving air-sea interactions and are the least accurate of the heat budget parameters. A, the residual, is determined by correctly summing the individual components.

Each of the heat-budget terms on the righthand side of the above equation is mapped (Figures 11.11, 11.12, and 11.13) for the following approximate seasonal conditions: March (spring), June (summer), September (autumn), and December (winter). All data are taken from the Atlas of the Heat Balance of the Earth by Budyko (1963). Details of methods of calculation and data sources can be found in the introduction to this work which has been translated into English (U.S. Department of Commerce, 1964).

Figure 11.11 (a through d) reveal that the ocean surface in the study area receives radiational heat during all seasons except mid-winter when, at the time of lowest solar altitude, there is a slight radiational heat loss in the northern part of the area. The maps representing sensible heat, Figure 11.12 (a through d), indicate that there is a transfer of sensible heat upward from the ocean surface to the atmosphere throughout the year, but especially during winter and spring when the greatest difference between the temperature of the ocean surface and the air is encountered.

Because of the magnitudes of the turbulent exchange processes in this part of the North Atlantic Ocean and the large amount of heat involved in the evaporation process, evaporative heat loss, Figure 11.13 (a through d) is considerable during much of the year, as in the case of sensible heat exchange, especially during winter and spring. Maximum values are encountered in the area of the Gulf Stream. This heat loss, representing as much as 200 cm of evaporated water on an annual basis, is, to a great extent, supplies through an upward transfer of heat from underlying water layers to the surface. Figure 11.14 indicates this amount for the year as a whole.

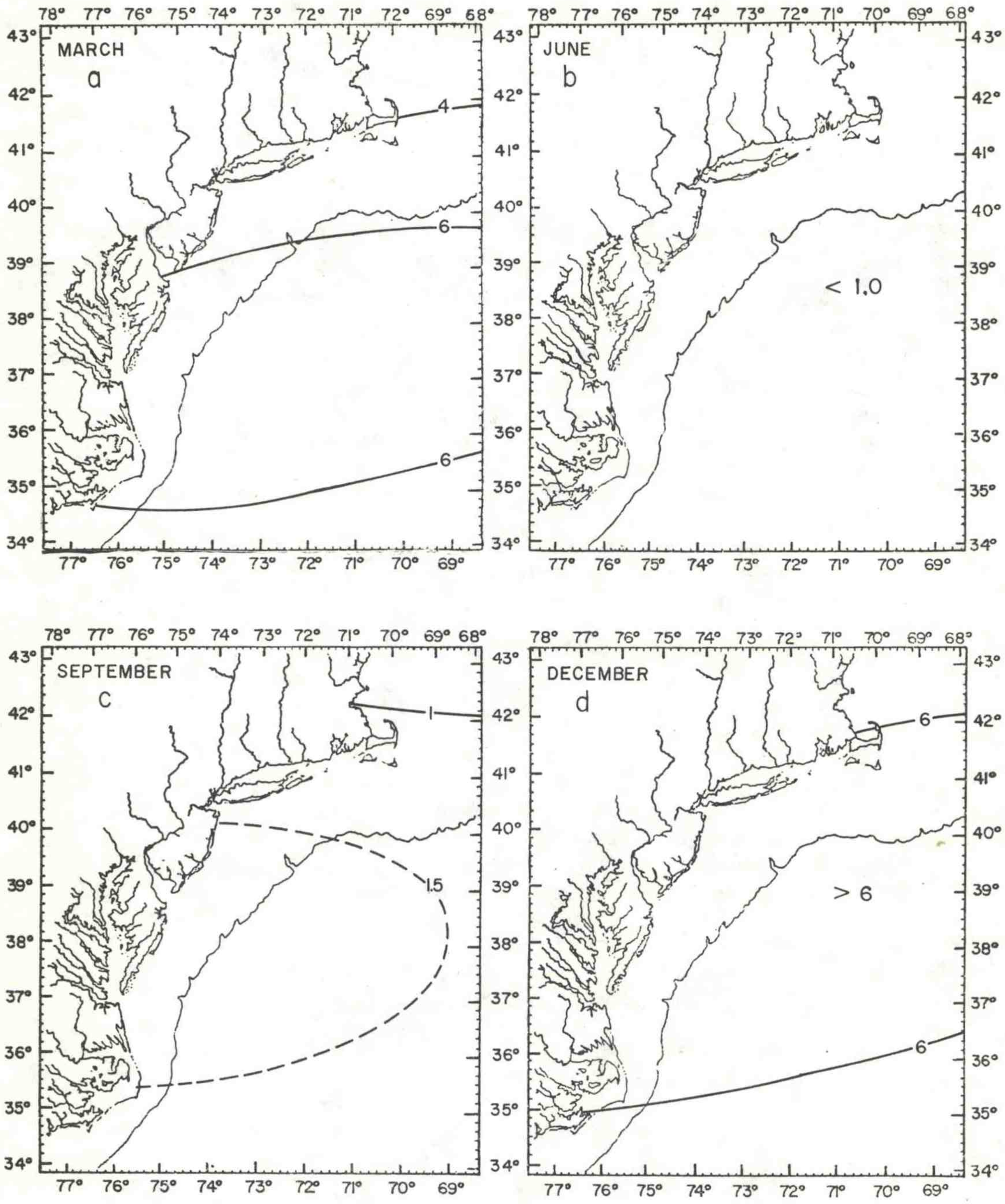


Figure 11.12 (a through d) Sensible heat loss at ocean surface, selected months (K cal/cm^2/mo).

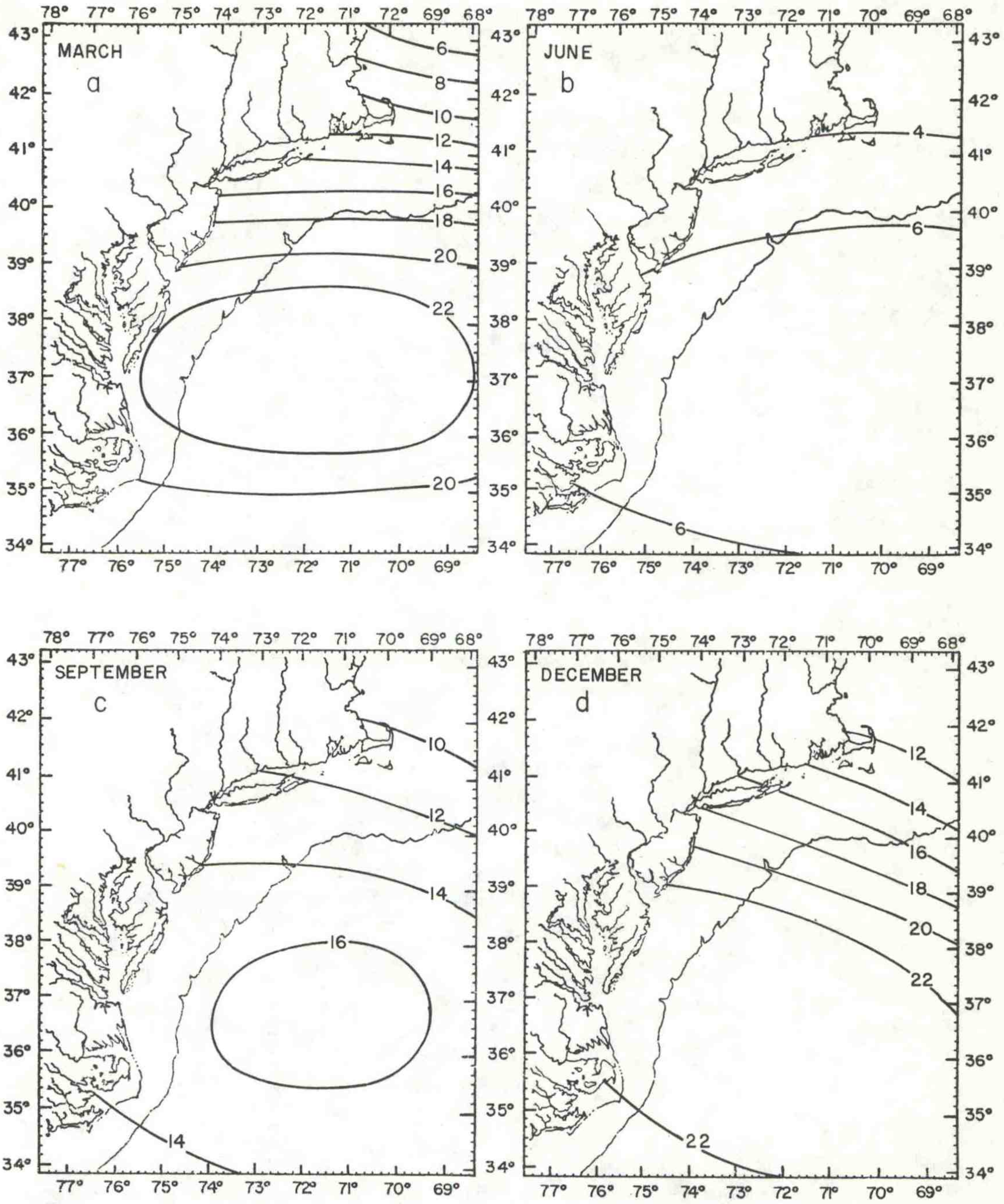


Figure 11.13 (a through d) Heat lost by evaporation at ocean surface, selected months (K cal/cm^2/mo).

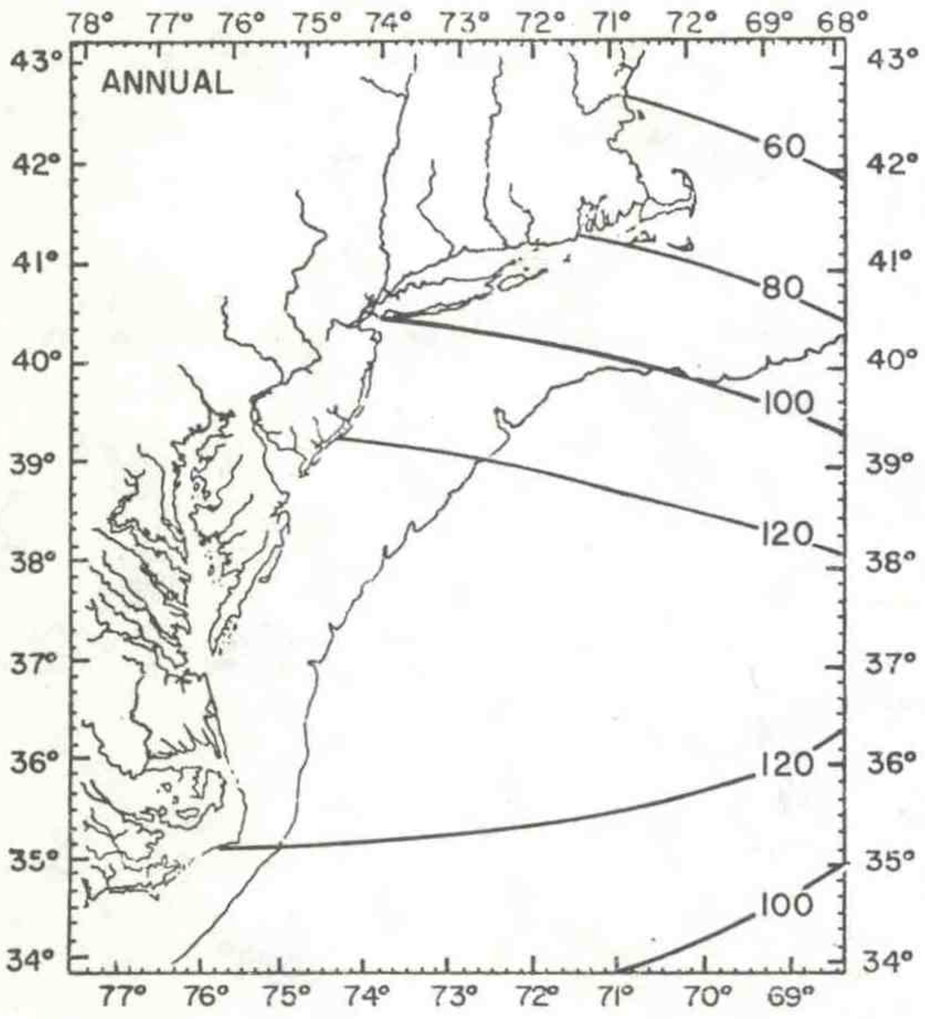


Figure 11.14 Annual heat exchange between lower layers of water and ocean surface (K cal/cm^2/yr).

Bay Ice and Icebergs

According to an atlas prepared by the U.S. Naval Oceanographic Office (1968), bay ice, with a concentration of at least one-tenth coverage, can be expected in many of the bays and inlets of the East Coast as far south as Cape Hatteras from December through March, with the greatest extent developing during February. However, conditions are highly variable from year-to-year. Summaries of seasonal ice conditions are regularly published in Mariners Weather Log.

Although extremely rare, icebergs have occasionally been sighted in the study area. Table 2 lists those that are on record. It should be emphasized that International Ice Patrol reports did not begin until 1913. Two sightings have been reported since that year, but the sighting of January 1916 is in disagreement with the Ice Patrol's record, according to Capt. E.A. Delaney, U.S. Coast Guard. Capt. Delaney also reports (personal communication, 1973) that no icebergs have been sighted south of 42^{o}N and west of 69^{o} W since compilation of these data.

Summary

Climatic elements, storm occurrences, sea surface temperatures, and heat budget elements have been summarized for the offshore area from Cape Hatteras to Nantucket Shoals. This area is an active meteorological and oceanographic region influenced by the atmospheric polar front and the Gulf Stream. The polar front separates air masses of polar and tropical origin; and the Gulf Stream is a boundary between

Table 2. Chronological observations of ice at sea in the study area.

Date	Description	Location
Aug 1831	several bergy bits	36°20'N, 67° 47'W
Sept 1895	2 bergs 300-400 ft lg. and 30 ft high, accompanied by icefield about 2 nautical sq miles in area	36°35'N, 71°31'W
Aug 1903	40 ft piece of ice 3 feet high	37°30'N, 71°30'W
May 1911	small iceberg	40°45'N, 69°20'W
Jun 1912	3 pieces of ice	37°30'N, 74°24'W
Aug 1915	growler	40°46'N, 68°24'W
Jan 1916	30 ft piece of hummocked ice 2 ft high	33°20'N, 71°00'W

Sargasso Sea and continental slope water. The study area itself lies near a land-sea boundary with strong gradients of atmospheric parameters. These factors and others produce sharp climatic variations in the offshore region from Cape Hatteras to Nantucket Shoals.

Recommendations

1) A detailed analysis of observations from coastal lightships and navigational buoys should be undertaken with a view toward delineating horizontal atmospheric gradients of climatic elements and heat-energy budget components in the nearshore area.

2) A study of the accuracy and usefulness of marine weather forecasts in the study area should be made as an aid to weather sensitive operations.

3) A study of climatic change and the effects of the "climatically sensitive area" south of Newfoundland and Nova Scotia on circulation in the study area could be made. This mechanism is discussed in Lamb (1972, p. 342) and Lamb (1973).

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Coastal Zone Utilization

Coastal Zone Utilization

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Coastal Zone Utilization

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Introduction

Background and Statement of Purpose

The northeast region of the United States is today the most densely populated and urbanized area of the nation, having evolved over the last 250 years from a few isolated port cities to the continuous high density settlement commonly referred to as the "Northeast Megalopolis." This evolution from seaboard trading centers, to major commercial and industrial centers, to metropolitan areas, and finally to an interconnected system of metropolitan development had its origins in the founding of two early colonies, one at each end of the region. In 1607, the first

permanent English settlement was established in Jamestown, Virginia, followed shortly thereafter by the settlement of Plymouth, Massachusetts in 1620. Fed by an expansion in waterborne trade, colonial industrial development, and immigration from abroad, population began to cluster and grow in these and other villages situated along principal waterways. By the mid-1700's, the major port centers were relatively densely settled, as Boston, New York, and Philadelphia had each exceeded a population of 8,000 people. Nineteenth century industrialization, aided by an expanding transportation network and increased immigration, continued to swell the growth of the established urban centers and helped create new and widespread areas of high population density. As effective land transportation developed to replace water transportation in the area, cities became linked by heavily trafficked main line railroads and express highways, and urbanization began to spread along these axes. Eventually, the coalescing of adjacent areas merged the older nodes into what is now the North Atlantic lineal intercity corridor.

To meet the needs of residents of this corridor and adjacent areas, the land and water resources of the coastal zone from Cape Hatteras, N.C. to Nantucket Shoals have been called upon to accommodate a wide range of uses attendant to human activity, including recreation, commerce and industry, transportation, waste disposal, agriculture, and housing. The purpose of this chapter is to develop a comprehensive picture of the scope and extent of coastal zone utilization in this region. To accomplish this objective, data will be presented in two forms, as follows:

(1) General economic, demographic and land-use patterns for the region as a whole. Detailed information regarding coastal utilization is best viewed within the broad context of the overall status of development. Demands for multiple use of the resource base are a direct function of the magnitude of economic activity and the distribution of population.

(2) Specific statistical information by category of use for appropriate sub-regions. Categories to include recreation, manufacturing and extraction, energy, transportation, water systems and waste disposal, agriculture and open space, residential, and other significant aspects of land and water use.

Choice of Geographic Data Base

Primary data relevant to the two lines of investigation described above are available from a number of public and private sources, e.g. the Bureau of the Census and Office of Business Economics (Dept. of Commerce), the Bureau of Outdoor Recreation (Dept. of Interior), Edison

Electric Institute, etc. Each such source arranges its data according to geographic areas appropriate to the activity of interest, and - unfortunately - the mapping of such data onto a hybrid base such as the coastal zone frequently involves an enormous amount of disaggregation and reaggregation. For this reason, it is desirable to identify a geographic base that is adaptable to the information requirements regarding coastal zone utilization and for which the task of data reorganization has already been done. Usually, water resource planning efforts generate the most comprehensive and up-to-date materials for any coastal region, and in this case, a major study has recently been completed relative to the northeastern U.S. This study, which provides the foundation for this chapter, is the 1972 North Atlantic Regional (NAR) Water Resources Study[1], which was authorized by the 1965 Water Resources Planning Act (PL89-80) and carried out under guidelines set by the U.S. Water Resources Council.

The NAR study comprises a main report and two annexes, and the following appendices:

A.	History of Study	L.	Water Quality and Pollution
B.	Economic Base	M.	Outdoor Recreation
C.	Climate/Meteorology/Hydrology	N.	Visual and Cultural Environment
D.	Geology and Ground Water	O.	Fish and Wildlife
E.	Flood Damage/Reduction/ Water Management	P.	Power
F.	Upstream Flood Prevention/ Water Management	Q.	Erosion and Sedimentation
G.	Land Use and Management	R.	Water Supply
H.	Minerals	S.	Legal and Institutional Environment
I.	Irrigation	T.	Plan Formulation
J.	Land Drainage	U.	Coastal and Estuarine Areas
K.	Navigation	V.	Health Aspects

The choice of the NAR hydrologic area as the geographic base is particularly appropriate to the effort at hand. First, the region as a whole is broad enough to provide information on the complete range of economic, demographic and land-use patterns that influence resource utilization in the coastal zone. As shown in Figure 12.1*, the NAR extends 1000 miles from the St. John River Basin in northern Maine to the James River Basin in southern Virginia. The region generally extends 200 miles westward from the Atlantic Ocean for its entire length and has 172,586 square miles of land and water surface, or about five percent of the nation. The region has been divided into 21

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*Due to an editor's error, Figures 12.1 to 12.14 begin on page 12-135.

[1]North Atlantic Regional Water Resources Study, prepared by the North Atlantic Regional Water Resources Study Group (U.S. Army Corps of Engineers, North Atlantic Div.) for the North Atlantic Regional Water Resources Study Coordinating Committee (May, 1972).

hydrologically-defined areas, a number of which are specifically coastal in nature, as shown in Figure 12.1. The NAR data fill the dual need for generalized information on a region-wide basis and for specific information relative to a set of coastal sub-regions between Cape Hatteras and Nantucket Shoals.

Some Potential Difficulties and their Resolution

While the organization of the NAR data is clearly useful within the present context, the fact that it corresponds to hydrologic or river-basin areas presents some difficulties with respect to the coastal portion of the region. In particular, a number of the areas shown in Figure 12.1 (nos. 8, 12, 15, 19, 21) extend much too far inland to warrant inclusion as a coastal sub-region; yet each of these areas have significant coastal portions, i.e. the Norfolk-James River Basin, the Washington-Potomac River Basin, and Philadelphia-Delaware River Basin, and southerly sectors of the Hudson and Connecticut River Basins. Another difficulty is the fact that the NAR coastal subregions carry past the coastal zone of interest on the northerly end, and fall short on the southern end.

These geographic mis-fits create an element of inconvenience, but the difficulties are relatively easily resolved and do not detract significantly from the overall value of the data base. In many cases, the data for regions 8, 12, 15, 19 and 21 can be segregated in such a way as to provide the necessary information for the estuarine areas not covered by the coastal sub-regions. This leaves the northern coast of North Carolina as the only real gap in the NAR data base, but due to the low degree of utilization of this area, it is felt that sufficient information can be obtained from alternate sources. Undoubtedly, there will be some inefficiencies in utilizing this approach, but they are far outweighed by the high quality and up-to-date nature of the information available in the NAR study. Wherever inefficiencies occur which seem particularly troublesome, attempts will of course be made to draw on supplementary sources.

Overview of Demographic, Economic and Resource Patterns in the North Atlantic Region[2]

The basic factors affecting the level and location of coastal zone utilization are population, degree of economic activity, and resource

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[2]The discussion in this section is based wholly on the materials presented in the following volumes of the North Atlantic Regional Water Resources Study (1972): "Report", at pp. 39-88; "Appendix G-Land Use and Management", at pp. 4, 37-60, 232-235. In most cases, this represents the latest data available on a regional basis. Although the population data is derived from the 1960 census, it serves the purpose of presenting an overview of trends for the region. A more up-to-date and detailed analysis of demographic patterns is found in another section of this report.

use in the regions that comprise the markets for coastal-related goods, services, and amenities. It is important, therefore, to review some of the major demographic, economic, and resource patterns which characterize the North Atlantic Region (NAR), the hinterland that is served in large measure by the coastal zone from Cape Hatteras to Nantucket Shoals.

Population

In 1960, the population of the NAR exceeded 44.6 million, representing 26 percent of the national total. As shown in Table 1, this population has been projected to nearly double by the year 2020, to 86, 261,000 persons. This rate of growth is about four-fifths of that projected for the country as a whole, and as a result the NAR's share of the projected national population in 2020 will decline to about 22 percent.

TABLE 1. NAR Population, 1960 with Projections to 1980, 2000, 2020

Year	Population (thousands)
1960	44,654
1980	55,643
2000	69,612
2020	86,261

The NAR is the most urbanized region of the U.S., and increasingly fewer residents have purely rural backgrounds and outlooks. Total rural population in 1960 was 8.6 million and is projected to increase to 13.1 million in 2020. Although increasing absolutely, the rural population has been experiencing a decline in the share of population, a trend that is projected to continue (Table 2). The most dramatically changing sector of the rural population is the farm sector, which in 1960 had

TABLE 2. Rural-Urban Distribution of Population 1960, with Projections to 1980, 2000, and 2020.

Year	% Rural	%Urban
1960	19.3	80.7
1980	17.2	82.8
2000	16.0	84.0
2020	15.2	84.8

dwindled to approximately 11 percent of the people in rural areas. This trend is also expected to continue, and by 2020 the farm population would represent only 3 percent of the rural population and a mere one-half of one percent of the total population.

Consistent with the trend toward urbanization is the fact that the NAR, with 26 percent of the nation's population located on but 5 percent of the land, is the most densely populated U.S. region of its size. Figure 12.2 shows the 1960 population density for the NAR, while Figure 12.3 shows the projected density for 2020. As indicated in Table 3, the average density in 1960 was 264 persons per square mile--five times the national average--and the projection for 2020 is 522 persons per square mile. The geographical distribution of this population, however, is far

TABLE 3. Average Population Density for NAR, 1960, with Projections to 1980, 2000, 2020

Year	Density (persons per square mile)
1960	264.0
1980	333.9
2000	421.4
2020	522.1

from even. Most of the people in the region are tightly concentrated in an urban belt[3] following the coastline from Boston to Washington, with an "island" of urbanization around Richmond, Virginia. This urban belt has less than 40 percent of the NAR's total area, but over 80 percent of its 1960 population. The average gross density of this coastal strip was 714 persons per square mile, almost three times the NAR average. The five core cities of Washington, Baltimore, Philadelphia, New York, and Boston--excluding suburbs--contained almost three out of every ten NAR residents, a consequence of densities ranging from 24,500 persons per square mile in New York City to 11,900 persons per square mile in Baltimore. Surrounding the central cities are the suburban areas, with population densities ranging from 1,000 to 10,000 persons per square mile. It is expected that new population growth in the coastal belt will be located in these expanding suburban fringes within the established metropolitan areas. It is also expected that the coastal belt will experience a continued increase both in size and in its share of the NAR's overall population, but at a slower rate than that prior to 1960.

[3] This band, defined on the basis of county density measurements, includes densely developed urban nodes as well as interstitial and peripheral open areas lying in the path of future growth. There is some disagreement as to its areal extent, with estimates ranging from a low of 51,000 square miles to a high of 67,690 square miles.

As a whole, the seaboard belt of urbanizing counties, cities, and metropolitan areas represents the living environment for the overwhelming majority of the NAR population. The demands which these megalopolitan residents place on the coastal zone are in large measure a function of driving time, and Figure 12.4 shows that nearly all the tidal shoreline of the NAR is within 2-1/2 hours of the seaboard belt, and much of the coast is less than 1 hour away from the major urban concentrations. This dense and highly mobile population combines with a heavy concentration of employment and economic activity to produce the great intensity of activity that is a dominant feature of life in coastal areas in the NAR.

Economic Activity

Economic activity in the North Atlantic Region is a dominant force in the American economy by almost any measure, even though it has been growing more slowly than the nation as a whole. Jobs were provided for about 26 percent of the workers in the United States in 1960 in the NAR, and residents of the area received 30 percent of the total personal income generated in the U.S. that year. NAR per capita income was thus 14 percent above the national average, as indicated in Table 4.

TABLE 4. Employment, Personal Income*, and Earnings*, NAR and U.S. 1960

	NAR	TOTAL U.S.	NAR/U.S.
Total Employment (millions)	17,564	66,373	.26
Total Personal Income (millions)	107,705	377,928	.30
Per Capita Income	2,435	2,134	1.14
Total Earnings	87,954	309,601	.28
Per Worker Earnings	5,008	4,665	1.10

* Figures are in 1958 dollars

The most important economic activities in the NAR are manufacturing, federal government, and the finance and service industries, all of which accounted for nearly 60 percent of the 1962 earnings generated in the region (the national average for these activities is 55 percent). In contrast, extractive industries (mining, agriculture, forestry, and fisheries) play a relatively small role in the regional economy. Mineral production in the NAR, for example, accounts for only 11 percent of the value of the total mining output of the U.S. (See Table 4-a), and extractive industries as a whole account for only 1.5 percent of the earnings generated in the NAR, far below the national average of 6 percent. The relative importance of population-related activities such

TABLE 4-A. Mineral Production in the North Atlantic Region and Comparable United States Production in 1964 1/ 2/

Commodity	North Atlantic		United States		North Atlantic Percent of the United States	
	Quantity (thousands)	Value (thousands)	Quantity (thousands)	Value (thousands)	Quantity	Value
Cement:						
Portland.....376-pound barrels..	70,956	$214,415	366,304	$1,168,987	19.4	18.3
Masonry.....280-pound barrels..	5,308	14,043	22,397	63,305	23.7	22.2
Clays.....short tons..	6,212	16,795	52,853	192,539	11.8	8.7
Coal:						
Anthracite.....do....	17,184	148,648	17,184	148,648	100.0	100.0
Bituminous.....do....	31,073	137,744	486,998	2,165,582	6.4	6.4
Copper.....do....	4	2,356	1,247	812,901	0.3	0.3
Emery.....do....	9	172	9	172	100.0	100.0
Feldspar.....long tons..	96	847	587	5,389	16.3	15.7
Gem stones.....	NA	97	NA	1,474	----	6.5
Iron Ore (usable).....long tons, gross weight..	4,941	71,060	84,300	802,331	5.9	8.9
Lead (recoverable content of ores, etc.).....short tons..	1	192	286	74,936	0.3	0.3
Lime.....do....	3,024	38,552	16,089	223,167	18.8	17.3
Natural gas.....million cubic feet..	14	3,792	15,547	2,387,689	0.1	0.2
Peat.....short tons..	88	991	640	6,198	13.8	16.0
Salt.....do....	4,654	28,833	31,623	200,706	14.7	14.4
Sand and gravel:						
Commercial.....do....	105,595	134,269	621,392	700,051	17.0	19.2
Government-and-contractor.....do....	25,126	9,646	247,387	194,041	10.2	5.0
Stone:						
Crushed.....do....	142,940	243,724	722,724	1,037,365	19.8	23.5
Dimension.....do....	734	37,343	2,545	96,970	28.8	38.5
Talc 3/.....do....	415	2,469	890	6,218	46.6	39.7
Zinc (recoverable content of ores, etc.) 4/.....do....	124	33,805	575	156,308	21.6	21.6
Value of items that cannot be disclosed: Aplite, asbestos, cement (natural), cobalt, abrasive garnet, gold, greensand marl, kyanite, magnesium compounds, manganiferous residuum, mica, potassium salts, pyrites, silver, titanium concentrates, tripoli, and wollastonite.....	XX	26,815	XX	301,180	XX	8.9
Grand total.....	XX	$1,166,608	XX	$10,746,157	XX	10.9

NA Not available. XX Not applicable.

1/ Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

2/ Includes some peripheral counties.

3/ Includes soapstone and sericite-schist.

4/ Includes recoverable zinc valued at yearly average price of Prime Western slab zinc, East St. Louis market. Represents value established after transportation, smelting, and manufacturing charges have been added to the value of ore at the mine.

as trade, state and local government, transportation, and construction is about the same in the NAR as in the nation as a whole. The importance of the NAR in the national economy is illustrated by the fact that, in 1962, nine of the eleven major industries in the region took a greater share of the U.S. total than the population share of the region would call for.

Table 5 lists employment data for selected industries in the NAR in 1960. Since manufacturing, government, finance, and services are relatively labor-intensive, they tend to be localized in and around the

TABLE 5. NAR Employment by Selected Industries 1960

Industry	No. Employed
Agriculture, Forestry & Fisheries	401,800
Mining	51,500
Manufacturing	5,578,500
Food & Kindred Products	457,700
Textile Mill Products	325,100
Chemicals & Allied Products	307,800
Paper & Allied Products	206,500
Petroleum Refining	59,300
Primary Metals	271,100
Armed Forces	423,600
Other	11,108,700

densely populated coastal urban belt. Within the principal cities of this belt, there has been a marked shift from blue-collar factory work to white-collar office employment. Inland areas adjacent to this belt are distinguished, on the other hand, by the relatively greater importance of manufacturing in their economic base. Finally, the outlying exurban belt has a relatively greater portion of land devoted to forests, parks and open spaces, agriculture, and mining.

The NAR is presently growing at a slower rate than the nation as a whole, as measured by population, employment, and income. As an older, more mature region with a homogeneous industrial mix, its original leading position is being gradually eroded by younger regions entering periods of substantive growth. Data projected for the NAR and the U.S. to the year 2000 indicates that the NAR is expected to continue at a slower growth rate than the U.S., but that the difference between these rates is expected to continue to decrease over this projection period as other regions begin to approach the NAR in terms of industrial mix. The rates of projected population and employment growth on average in the NAR are four-fifths the U.S. rates; those for total personal income and earnings slightly higher. Employment in agriculture, forestry, and fish-

ing is projected to decline at rates about one-third faster than total U.S. rates, mining nearly ten times as fast. The projected growth rates in manufacturing employment in the NAR are less than one-half the U.S. rates. By 2020, these rates would lead to the levels of employment, income, and earnings indicated in Tables 6 and 7.

TABLE 6. Projected Employment, Personal Income*, and Earnings*, NAR and U.S. -- 2020

	NAR	TOTAL U.S.	NAR/U.S.
Total Employment (millions)	35,271	159,178	.22
Total Personal Income (millions)	1,147,251	4,934,146	.23
Per Capita Income	13,315	12,411	1.07
Total Earnings	876,177	3,718,754	.23
Per Worker Earnings	24,841	23,360	1.06

* Figures are in 1958 dollars.

While employment in the NAR is expected to grow at a rate commensurate with population, it will exhibit a continuing shift in composition--fewer production jobs in the manufacturing sector and more white collar and service jobs in office buildings. The distribution of new employment growth among belts in the region is expected to follow the pattern of population change, although manufacturing activity is likely to continue its shift from central cities to suburbs, reflecting the need for greater amounts of less expensive land, the continued elaboration of the highway network and a decreasing dependence on the coastal railroads as a transportation system. Finally, agriculture, forestry, fishing, and mining are projected to decrease in relative (and, in some cases absolute) importance as land values are pushed upward by the spread of urbanization and industrialization. However, an element of uncertainty exists here: the crisis in power generation and the development of coal gasification techniques, for instance, could introduce new vigor into the coal extraction industry, or the advent of controlled thermonuclear fusion could render it obsolete. Then, too, there are the untapped mineral reserves of the continental shelf, such as the huge beds of oil and gas off Long Island, whose exploitation depends on the political resolution of opposing pressures of economics and environmental protection.

Resource Use

The North Atlantic Region covers a total area of 110,456,000 acres, of which 4,720,000 acres are water, and contains an abundance of natural

resources. The topography of the region, as illustrated in Figure 12.5, is composed of a series of low mountainous ridges separated by narrow fertile valleys leading to coastal plains with tidal streams. Adequate moisture throughout the region provides a vegetative cover that is primarily forest, interspersed with cropland, pasture, city and town across the varying topography. Surface water resources are generally abundant in the region, but unevenly distributed in relation to points of need. Groundwater resources in the region, for large-scale use, are abundant only in limited geologically-defined localities such as the Coastal Plain, sandstone and carbonate rock belts, and sand and gravel beds generally adjacent to rivers and large streams. A summary of the total developable water resources in the NAR is shown in Table 8.

In general, land and water characteristics of the NAR have not served to limit economic development. There is no evidence of a scarcity of land for urban growth in the NAR as a whole, and physical features offer few serious constraints to development despite wide variations in

TABLE 8. Summary of Total Developable Water Resources in the NAR

Category	Amount*
Presently Available	26,778
Additional Yield	
Surface Storage	35,675
Ground Water	9,408
Total Practical Development	71,843

* Figures are in million gallons per day

land form and topography. With respect to water resources, the NAR as a whole is well-endowed, and droughts have been comparatively mild and localized. However, these resources are increasingly subject to man's impact, and the prospect of 40 million additional people in the NAR between 1960 and 2020 may be expected to increase exponentially the many problems now confronting the region's cities and metropolitan areas. With the competition for land resources becoming more intense and the uneven regional distribution of water more acute, planning and management of these resources to meet human needs and desires--for both economic well-being and environmental amenities--will assume greater importance.

Table 9 is a summary of land-use (by type) and water areas in the NAR in 1963. Urban, agricultural, and forest activities are the principal contenders for land resources within the region, and their distribu-

tion is shown in Figure 12.6. Forest land[4] is the largest single land use in the NAR and occupies approximately 66 percent of the total land area. Forests occupy all physiographic positions within the region and are the main cover type at higher elevations and on mountain tops. The distribution and percent of commercial forest land is illustrated in Figure 12.7.

Cropland[5] is the second largest land-use in the NAR, accounting for 15 percent of the total land area. The major crops are corn, white potatoes, tobacco, soy beans, fruit and vegetables, and (to a limited extent) sweet potatoes and small grains. About 6 percent of the total land in the NAR is classified as pasture[6], which is utilized for grazing primarily for the dairy enterprise. The cool humid climate and seasonal distribution of rainfall on the region is excellent for the production of pasture grass, found mostly on steep and stony soils not suited for cultivation. The distribution and percent of cropland pasture cover in the NAR in 1968 is shown in Figure 12.8.

Urban[7] areas comprise but 6 percent of all the land in the NAR, and urban land use rates high in this region by national comparison. Urban land is used primarily for residential, commercial, and industrial purposes. Intensively developed urban land in the NAR in 1962 is shown in Figure 12.9 and represents 5,468 square miles, or 4.2 percent of the total land. It is interesting to note that 80 percent of the region's approximately 50 million people live on this small percentage of the region's land comprising the urban megalopolis. With the trend towards more urban and less rural population has come a demand for developable land which has taken many wetland and forest areas and increased land

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4 Forest is land which is at least 10 percent stocked by forest trees of any size and capable of producing timber or other wood products or capable of exerting influence on the water regime. Both public and private forest lands are included.

5 Cropland is land currently tilled including cropland harvested, crop failure, summer fallow, idle cropland, cropland in cover crops or soil-improvement crops not harvested nor pastured, rotation pasture, and land being prepared for crops.

6 Pasture is land in grass or other long-term forage growth that is used primarily for grazing. Pasture includes all grazing land with the exception of pasture in crop rotation.

7 Urban refers to all places, including suburban or exurban, incorporated or unincorporated, of 1000 inhabitants or more.

values and taxation on agricultural land near urbanizing areas. Thus, it has now become increasingly difficult for agriculture and other non-urban uses in some areas of the NAR to compete with urban uses in the face of intense economic pressure.

Land which is not classified as cropland, pasture, forest, or urban is referred to as "Other" land[8] and comprises 6.5 percent of the NAR land area. Other land is subdivided into other farmland and other nonfarmland categories. Approximately 1.7 million acres are classified as other land in farms, including farmsteads, farm lanes and idle or waste land. The primary use of idle other land is for cover for wildlife and recreation. There are 5.2 million acres of other nonfarmland in the region, with roads, highways, and open idle rural tracts adjacent to urban areas comprising the major portion of this type.

Water areas[9] over 40 acres account for the remaining 4 percent of the total land and water area of the NAR, and much of this area is located along the coast. Unfortunately, many of the lakes are located in areas not easily accessible for human use or are so far north that their temperature may limit their use for recreational purposes.

In the future, shifts are expected to occur for all the land uses described above. Cropland and pasture is expected to decrease in favor of urban and other land, while forest acreage is expected to remain relatively stable with some shifts of better land to urban development. These shifts are projected to the year 2020 in Table 10.

To this point, the discussion of the resource base of the NAR has been framed primarily in terms of type of surface coverage. In order to complete this overview of resource use, it is appropriate to describe, in a broad sense, a number of activities which represent regional assets essential to the satisfaction of human needs but which have not as yet been dealt with herein. The activities to be considered are those related to energy production, transportation, water supply, waste disposal, recreation, and the visual environment.

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8 Other land includes farmsteads, farm lanes, wasteland, service stations, rural nonfarm residences, country churches and school grounds, roads and highways, and tracts of any size of open, idle, rural nonfarm land.

9 This includes permanent inland water surface, such as lakes, reservoirs and ponds having 40 acres or more of area; streams, sloughs, estuaries, and canals one-eighth of a statute mile or more in width; deeply indented embayments and sounds, and other coastal waters behind or sheltered by headlands or islands separated by less than one nautical mile of water and islands having less than 40 acres of area. It does not include water surface of the ocean, bays, the Great Lakes, or Long Island Sound.

TABLE 10. Projected Land-use as a Percentage* of Total Land Area 1980, 2000, and 2020

Type	Percent of Total Land		
	1980	2000	2020
Cropland	11.4	8.2	6.0
Pasture	5.4	3.8	2.6
Forest	68.3	69.1	67.0
Other	6.7	8.3	10.1
Urban	8.2	10.6	14.3

*Figures are averaged over NAR subregions

Electric power consumption in the NAR accounts for over 20 percent of the national electric load, and this energy demand will generally increase (in the absence of fuel shortage) in proportion to higher income, population, and technological progress. Power requirements were 243,300 giga watt-hours in 1968 for the NAR from all classes of power users: rural, residential, commercial, industrial, and all others. Those requirements were 80 percent of the general market area in which the NAR lies. It is estimated that the market load will increase to 625,000 giga watt-hours of energy and 116 giga watts of capacity by 1980. As of the end of 1968, the NAR market area was supplied by an aggregate generating capacity of 64,497 mega watts, of which 51,879 mega watts were located in the region itself. Steam-electric capacity amounted to 84 percent of the total power supply in the market area, while hydro-electric and pumped storage capacity accounted for another 12 percent. Table 11 includes 1969 data for all generating facilities in the NAR, both utility and industrial, together with scheduled or planned capacity additions through 1975. The megalopolis from Washington to Boston is the most concentrated load area of the region, and is expected to

TABLE 11. Total Generating Capacities*, 1969, and Planned Additions Through 1975

Type of Prime Mover	Installed Capacity (1969) (MW)	Planned Additions (through 1975) (MW)
Fossil Steam	48,010	21,217
Nuclear Steam	1,656	25,750
Conventional Hydroelectric	3,974	8,332
Pumped Storage	1,170	
Internal Combustion/Gas Turbine	4,032	7,870
Total	58,842	63,169

* includes utility and other known facilities. Utilities contributed only 21.5 percent of the total number of systems but accounted for 97.8 percent of the market energy requirements.

experience considerable growth due to the availability of coastal waters as a source of cooling both for industry and large electric generating stations.

The primary methods of transportation of people and goods throughout the NAR have changed from coastal sailing ship and horse carriage to supertanker and superhighway. The facilities servicing these modes of travel cover most of the land in the "other" land-use category. The network of limited access highways--either existing, under construction, or proposed--is shown for the NAR in Figure 12.10. In that same year, ports in the region handled a total of 510 million tons of foreign and domestic waterborne commerce. The four major bulk commodities of metallic ores, coal, crude petroleum, and petroleum products comprised about 66 percent of waterborne tonnage in 1966, while general cargo accounted for only 13 percent of the volume by weight.

Water from public or central water supply systems satisfies many needs in the NAR--domestic, industrial, commercial, and municipal. Some 1,200 central water supply systems service almost 42 million people in the region, almost 88 percent of the population. Surface waters supply approximately 7 percent of this service, with the remainder from ground water sources. Average use in 1965 was about 5.5 billion gallons per day, of which 4.7 billion gallons per day was for domestic purposes. The population serviced by central water supply systems is projected to increase from the present 88 percent to 92 percent by the year 2020. The total industrial water intake for the region is 7,340 million gallons per day (mgd), of which 3,836 mgd are fresh water, 2,756 mgd are brackish water, 120 mgd are waste water, and 628 mgd are publicly supplied fresh water. Approximately 17 percent of the self-supplied fresh water is developed from ground water. Table 12 shows the region's 20 major water-using activities and lists their total use in 1965.

The waters of the NAR serve as a sink for the disposal of a wide variety of wastes, including oxygen-demanding wastes, infection agents, plant nutrients, heat, organic chemicals, sediments, and other mineral and chemical substances. Of the total regional population (36.8 million), 83 percent were served by waste water collecting systems, with 12 percent of the water untreated, 48 percent given primary treatment, and 40 percent given secondary treatment or better. Presently, about 2,300 known municipal, institutional, and federal sources in the NAR discharge wastes which exert a biological oxygen demand (BOD) equivalent to untreated wastes from a population of about 16.4 million. There are at least 337 combined (storm & municipal) sewer systems in the region, serving an estimated population of 17.2 million. The remaining 17 percent of non-industrial waste water needs were served by individual disposal systems (septic tank, cesspools) at 2.4 million separate housing units and an unknown number of business establishments. Industrial discharges contribute the BOD equivalent of untreated waste from

another 40 million people, and the pulp and paper industry accounts for about 35 percent of this waste load. The most significant sources of

TABLE 12. NAR Industrial Water Withdrawals, 1965

Industry	Total Use (mgd)
Chemicals & Plastics	2,362
Primary Manufacturing	1,675
Paper	1,166
Petroleum	740
Livestock and Rural Domestic	398.3
Food	392
Transportation Equipment	266
Machine Equipment	142
Glass & Clay	130
Fabrics	120
Electrical Equipment	97
Rubber	91
Metal Products	72
Scientific Instruments	40
Leather	16
Miscellaneous Manufacturing	13
Apparel	6
Tobacco	5
Printing	4
Furniture	2
Wood Products	1

thermal pollution in the NAR are nuclear and thermal electric power generating plants. Thermal loadings are expected to increase significantly due to an anticipated rise in population and electric power requirements. The coastal waters of the NAR receive untreated or partially treated waste loads from 700,000 registered small craft in the form of human fecal matter, litter, motor exhaust and oil; and offshore waters have long been used by municipalities and industries as disposal sites for rocks, mud, dredging spoil, sewer sludge, and industrial waste.

The use of recreational resources in the North Atlantic Region has become very heavy, brought on by easy access to most inland and coastal recreational facilities, ever increasing mobility in an expanding population, and larger disposable incomes. The recreational resource base ranges from extremely plentiful in northern New England to very deficient in the highly populated Long Island area. Figure 12.11 shows the 1965 distribution of public open space in the NAR, where recreation

opportunities are often restricted because of a lack of additional federal and state recreation areas. Table 13 gives estimates of the summer days of participation in 1965 for seven major outdoor recreation activities, of which five are water-dependent. The most popular water

TABLE 13. Participation in Outdoor Recreation in the NAR, Summer 1965*

Activity	New England	Mid-Atlantic	South Atlantic
		days/person	
Boating	2.71	0.93	1.15
Sailing	0.62	0.15	0.15
Canoeing	0.19	0.11	0.17
Water-skiing	0.75	0.13	0.24
Swimming	11.33	7.45	6.02
Camping	0.66	0.23	0.37
Picnicking	4.82	2.75	2.55

* days of participation per person 12 years and over in selected outdoor recreation activities for the 1965 summer season, by census regions.

recreation activity throughout the NAR is swimming, whether in pools, lakes, ponds, reservoirs, creeks, streams, or the sea. Recreators by the million flock to beaches in Virginia, on the Delmarva peninsula, the Jersey shore, Long Island and Cape Cod. There again, the satisfaction of increasing recreational needs is hampered by the low degree of public ownership; only 11 percent of the total North Atlantic shoreline is in public hands for recreation. The resource base for recreational boating is primarily the protected areas of estuaries and embayments, waterways such as the intra-coastal waterway, lakes, reservoirs, and other inland flat waters of adequate surface area. The total water surface in the NAR is shown in Table 14 to be over seven thousand square miles, and there are six million acres of protected recreational boating waters in the region. Since this is the equivalent of half an acre for every NAR family, the limitations on boating are in the form of inadequate shoreline facilities as opposed to congested water surface. Forests and state parks provide additional recreational opportunities in the NAR,

TABLE 14. Total Water Surfaces in the NAR

Surface Type	Area (Sq. miles)
Small Surface (under 40 acres)	764.0
Large and Intermediate Surfaces (over 40 acres)	6,610.9
Total	7,374.9

as camping and picnicking in these facilities has become very popular with people wishing to set up close to other recreation activities. Only one-tenth of forest acreage is maintained in public ownership, and the forest environment thus provides the major base for future development of federal, state and private recreation facilities in the region.

The visual quality of landscape resources, while largely subjective to each individual, are no less important than the more tangible, objectively measurable assets to the region. Landscapes are analyzed from two interacting points of view: the nature of the land form, and the type of human use, indicated by landscape units (See Figure 12.12). The dominant land forms in the NAR are mountains, steep hills, and rolling hills, which together cover four-fifths of the surface area (See Figure 12.5). The landscape units which have the greatest percentage of land in the NAR and are highly valued are Forest-Town (40.2 percent) and Forest-Wildland (28.1 percent) (See Figure 12.6). Farmland has a visual influence on 38 percent of the NAR, and dominates 15 percent of the region, while cities, suburbs, and towns exert influence on about one-third. One-fourth of the region includes mixed landscapes of towns and forests, or towns and farms, and important vacation centers are often found in these visually rich and varied areas. Water is also an important element in visual landscapes, and greatly augments the visual appeal of other physical elements of scenery. In particular, the coastline landscapes of the entire region are among its most outstanding visual resources. Figure 12.13 is an indication of landscape quality in the NAR, based on consideration of the geographic distribution, juxta-position, and contrast of different landscapes. The juxtaposition of different land forms and different patterns often create composite land-scapes of diversity and high quality. The coastline of the NAR, for example, falls within the concept of a composite landscape for essentially its entire length. The very sharp edge which is created at the land-sea interface combined with immediately adjacent land forms and landscape units creates landscapes that are almost universally recognized as of high quality. Within this series, however, is to be found the greatest number of landscape misfits--products of insensitive develop-ment of coastlines in and around all major cities. Another regional problem is the considerable distance between quality and composite landscapes and the major population centers. A summary of visual resource needs is shown in Figure 12.14.

Concluding Remarks

Within the next fifty years, the North Atlantic Region will double in population and area of developed land. This growth will materially affect land requirements and will influence the quantity and quality of water that will be needed for industrial, municipal, cultural, and visual purposes. The quality of life that will result from this growth could

vary enormously, depending on public and private development decisions, and this poses a major challenge to effective resource planning and management at all levels of government.

A major issue facing the region is how to allocate its land resources among development alternatives in such a way as to meet objectives of efficiency in food and fiber production, environmental quality, and regional economic development. Urban space is clearly required for people to live, work and play. At the same time, open fields and forests are needed to provide visually pleasing landscapes, wildlife refuge, grain and forage for domestic animals, cropland to till and watersheds to draw upon. Unfortunately, measures designed to serve one objective are often counterproductive with respect to the others. For example, the isolation of land uses in separate areas of the region, though proven most efficient from a land capability standpoint, would be an unacceptable alternative due in part to the great loss in readily available contrast and quality of the environment. By the same token, practices of zoning, taxation, and speculation designed to encourage urban development may keep land from being put to its most efficient productive use. So while an abundance of land is physically available in relation to the totality of demands, definite distributional problems are strongly in evidence.

The situation described above is especially acute within a day's drive of major metropolitan areas, as the dominant influence on land use in the NAR emanates from these areas which desire to grow into adjacent lands and to share in the use of exurban lands for such purposes as recreation, transportation, mineral and water production in addition to normal food and fiber productions. Yet some patterns of urban growth are wasteful of resources, and many problems stem from the dispersed and underorganized development of land. Land development presently occurs within a largely unregulated system of private ownership and physical disarray, both functionally and visually. Affluence, which contributed to the disarray, permits escape from the most affected areas and can lead, in turn, to the further degradation of new areas. All this points to the need to accord great emphasis to means for improving and advancing land development practices, especially at the local level. Achieving a reasonable degree of conformity between local practices and regional conservation and development objectives is one of the most urgent and difficult problems facing public decision-makers in the North Atlantic Region.

Coastal Zone Utilization in the North Atlantic Region

Organization

The purpose of this section is to present a more detailed analysis of the development and use of coastal and estuarine areas in that

portion of the NAR lying between Cape Hatteras, North Carolina, and Nantucket Shoals. For purposes of presentation, this geographic area has been divided into five coastal sub-regions, which are listed in Table 15 together with the NAR areas corresponding to each subregion.

TABLE 15. Study Sub-Regions and Corresponding NAR Coastal Areas**

Subregion	NAR Area
A-Rhode Island and Southern Mass.	9*-Southeastern New England
B-Connecticut, New York, Long Island	8- Connecticut River Basin (coastal reaches only)
	10*-Thames and Housatonic River Basins
	13*-Southeastern New York, Metropolitan
C-New Jersey and environs	14*-Northern New Jersey
	16*-Coastal New Jersey
	15 -Delaware River Basin (Philadelphia and coastal reaches only)
D-Chesapeake Bay Region	18*-Chesapeake Bay and Delmarva Peninsula
	19 -Potomac River Basin (Washington and coastal reaches only)
	20*-Rappahannock and York River Basins
	21 -James River Basin (Norfolk and coastal reaches only)
E-Cape Hatteras Region	-Northern coast of North Carolina (Not covered by NAR)

*Designates NAR Areas sufficiently coastal in character to be considered in their entirety.

As indicated in the table, Areas 9, 10, 13, 14, 16, 18, and 20 are sufficiently coastal in character to be considered in their entirety, while Areas 8, 12, 15, 19 and 21 extend much too far inland to warrant inclusion as uniquely coastal regions. As indicated in the introduction to this chapter, the data for the coastal and estuarine reaches of these latter areas will not be so complete as that for the former ones, but this is not regarded as a serious difficulty due to the possibility of disaggregation of information in many cases.

The discussions for each subregion will be preceded by an overview in illustrative form of major residential, industrial, recreations, transportation and utility, and open-space locations along the coastal

perimeter (Figures 12.16-12.20,12.22-12.26, 12.31-12.35, 12.42-12.46, 12.55-12.59). Beyond this, each NAR Area for the subregion in question will be examined separately (or, if convenient, in combination with the coastal portion of an adjacent area not considered uniquely coastal). The format of these discussions will generally follow that used in Section II and will include, to the greatest extent possible, the following elements[10]: (1) general physical description of area, with emphasis on shoreline characteristics, use and ownership, etc.; (2) population distribution and economic base (income and employment); (3) land-use, including land in commercial farm and forest production, and mineral extraction; (4) public utility base (water resources and electric power); (5) major coastal uses, including commercial navigation, recreation, fishing, waste disposal, etc. To the extent practicable, each section will be concluded with a brief listing of the major problems perceived to confront each coastal area of interest.

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10 Except where specifically noted in the text, the data presented in this section are derived wholly from the North Atlantic Regional Water Resources Study, as follows:

Appendix B - Economic Base: pp. 84-186
Appendix G - Land Use and Management: pp. 38-55, 101-183
Appendix H - Minerals: pp. 6-15
Appendix I - Irrigation: Exhibit 2
Appendix K - Navigation: pp. 89-191
Appendix L - Water Quality and Pollution: pp. 161-408
Appendix M - Outdoor Recreation: p. 5.
Appendix N - Visual and Cultural Environment: pp. 73-272
Appendix P - Power: pp. 33-55.
Appendix R - Water Supply pp. 77-161.
Appendix U - Coastal and Estuarine Areas: pp. 18-22, 179-253.

Shoreline ownership and use data throughout the section are based on Department of the Army, Corps of Engineers, National Shoreline Study--Regional Inventory Report--North Atlantic Region, Vol. I (1971).

Subregion A. Area 9 - Southeastern New England

General Characteristics. This area consists of the coastal portions of Massachusetts and Rhode Island, as shown in Figure 12.15. The Massachusetts coastline from Provincetown to the Rhode Island border consists of 440 miles, of which 370 are beaches. Separated from the "mainland" by the Cape Cod Canal, the shoreline of the Cape Cod peninsula consists almost entirely of sandy beach varying from relatively narrow barrier beaches along the southern portion to extensive dune formation along the outer sections of the lower cape. Of the several islands located off the southern coast of Cape Cod, Martha's Vineyard and Nantucket are the best known. From Buzzards Bay to the Rhode Island border the coast is a mixture of barrier beaches, deep indentations, low rocky headlands, marshes and ponds. Rhode Island, with approximately 340 miles of shoreline including Block Island, is dominated by Narragansett Bay, which comprises 170 square miles and 150 miles of shoreline. The Rhode Island coastal area is primarily low and flat and contains many fresh-water ponds and lakes as well as salt-water ponds behind barrier beaches along the southern sector. River drainage in Area 9 south of Cape Cod consists of the Agawam and Mattapoisett into Buzzards Bay; the Seekonk and the Taunton into Narragansett Bay; and the Pawcatuck into Block Island Sound. Land forms for the non-coastal portions of the area consist of 75% rolling hills and 25% undulating land, and landscape units consist of 49% city (2000 square miles of center, intermediate, and fringe city use) and 51% forest-town. The overall quality of the landscape is ranked as medial.

Ownership[11] of the Massachusetts coastline from the Rhode Island border to Provincetown (Cape Cod) is divided into 340 miles private, 50 miles public (state/local), and 50 miles federal. The public property is primarily municipal (in the form of beaches or property fronting town street ends), the State owns three state parks,and the federal government owns the Monomoy Wildlife Reserve and the Cape Cod National Seashore (27,000 acres). The use of the shorefront in this sector, with the exception of city or town development, is primarily recreational, with 90 miles of public and 335 miles of private use, leaving only 15 miles of non-recreational use.

The Rhode Island shoreline is divided into a 190 mile long southerly sector (Block Is. to outer Narragansett Bay - 140 miles of beach) and a 150 mile stretch in Narragansett Bay (45 miles of beach). Ownership of the southerly stretch includes 145 miles private, 40 miles state/local,

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11 This section is based on data presented in Department of the Army, Corps of Engineers, No. Atlantic Division, National Shoreline Study-Regional Inventory Report, North Atlantic Region, Vol. I (1971).

AREA 9 SOUTHEASTERN NEW ENGLAND

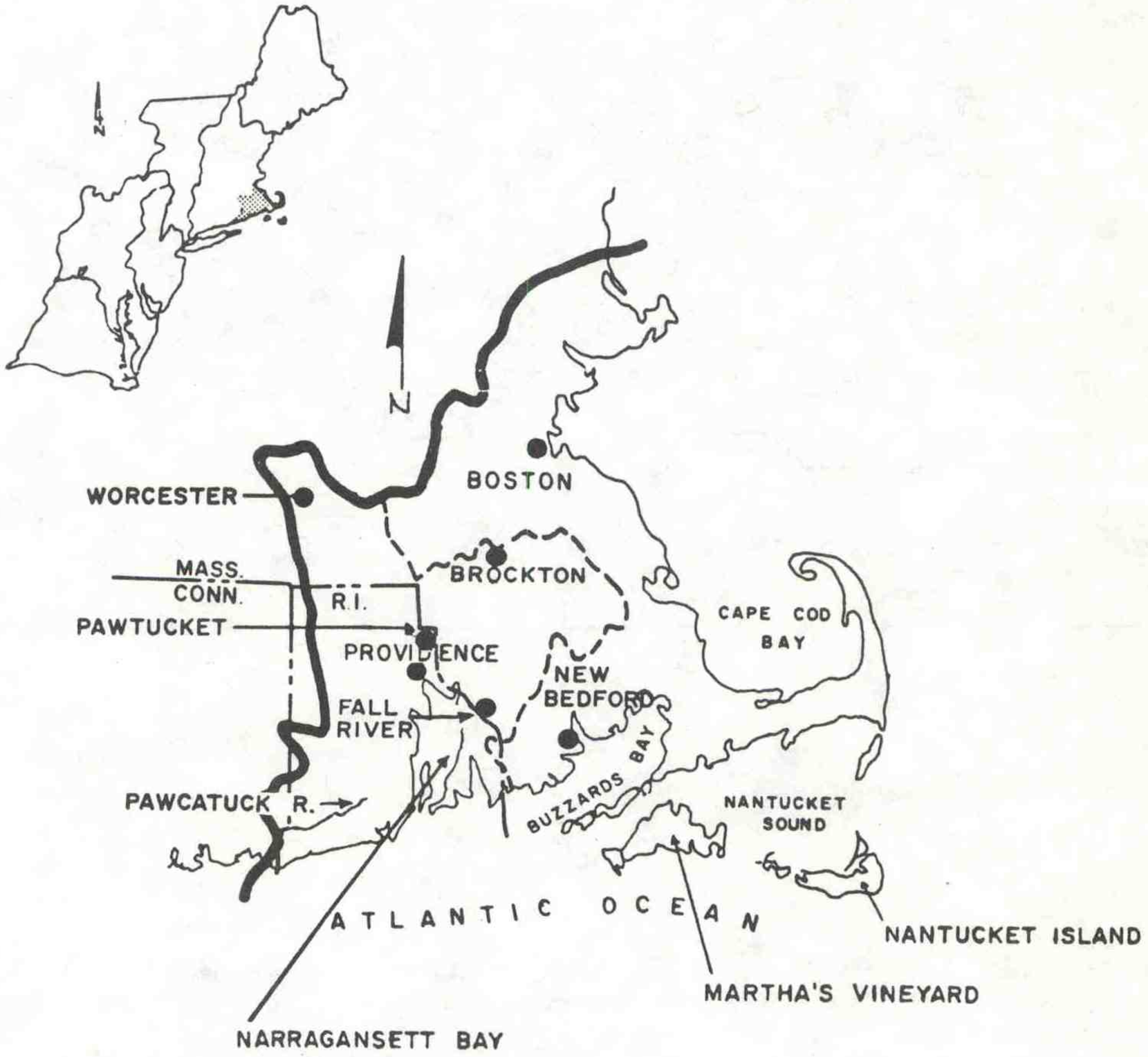
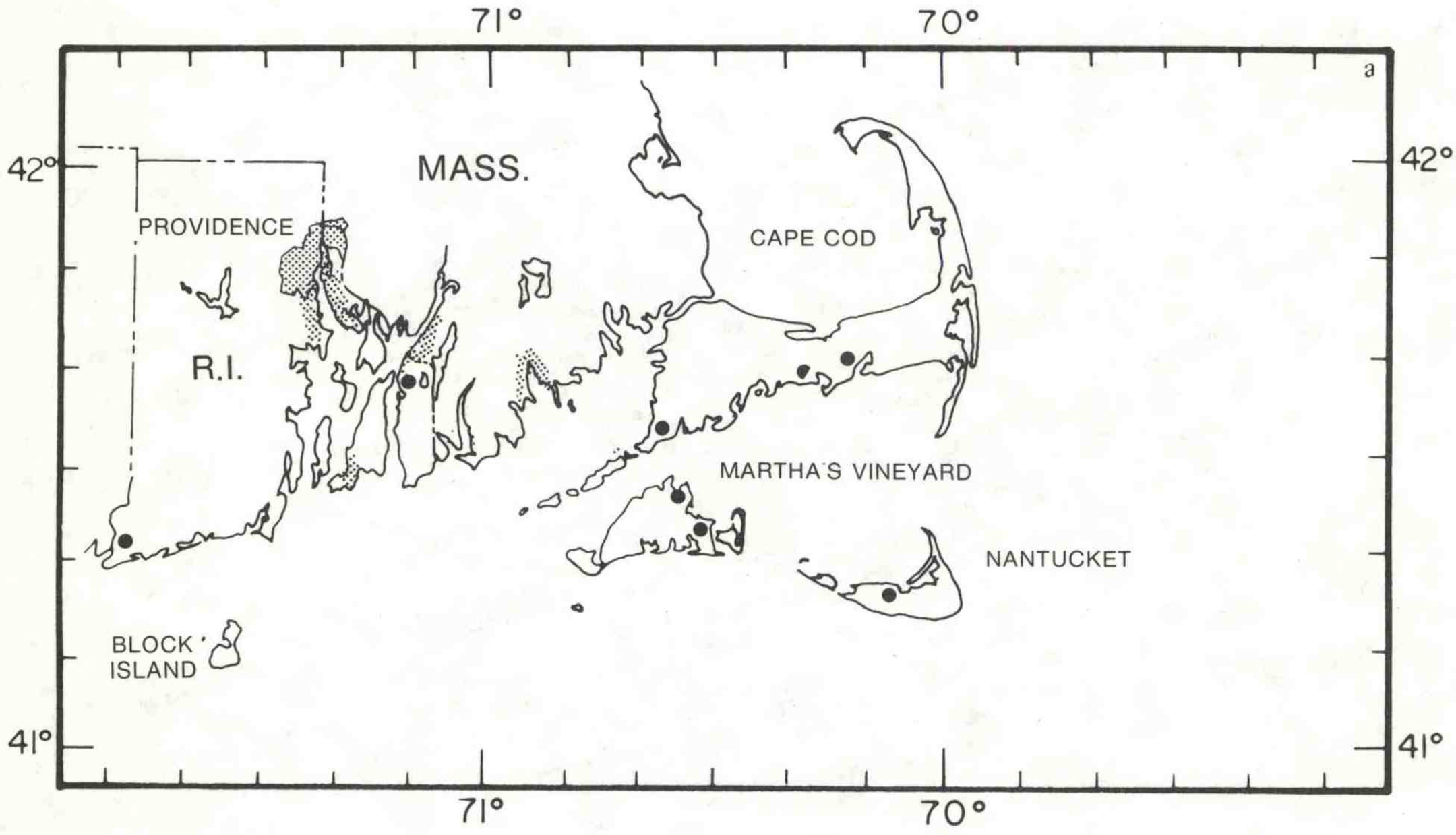


Figure 12.15 Regional map of the coastal portions of Massachusetts and Rhode Island.

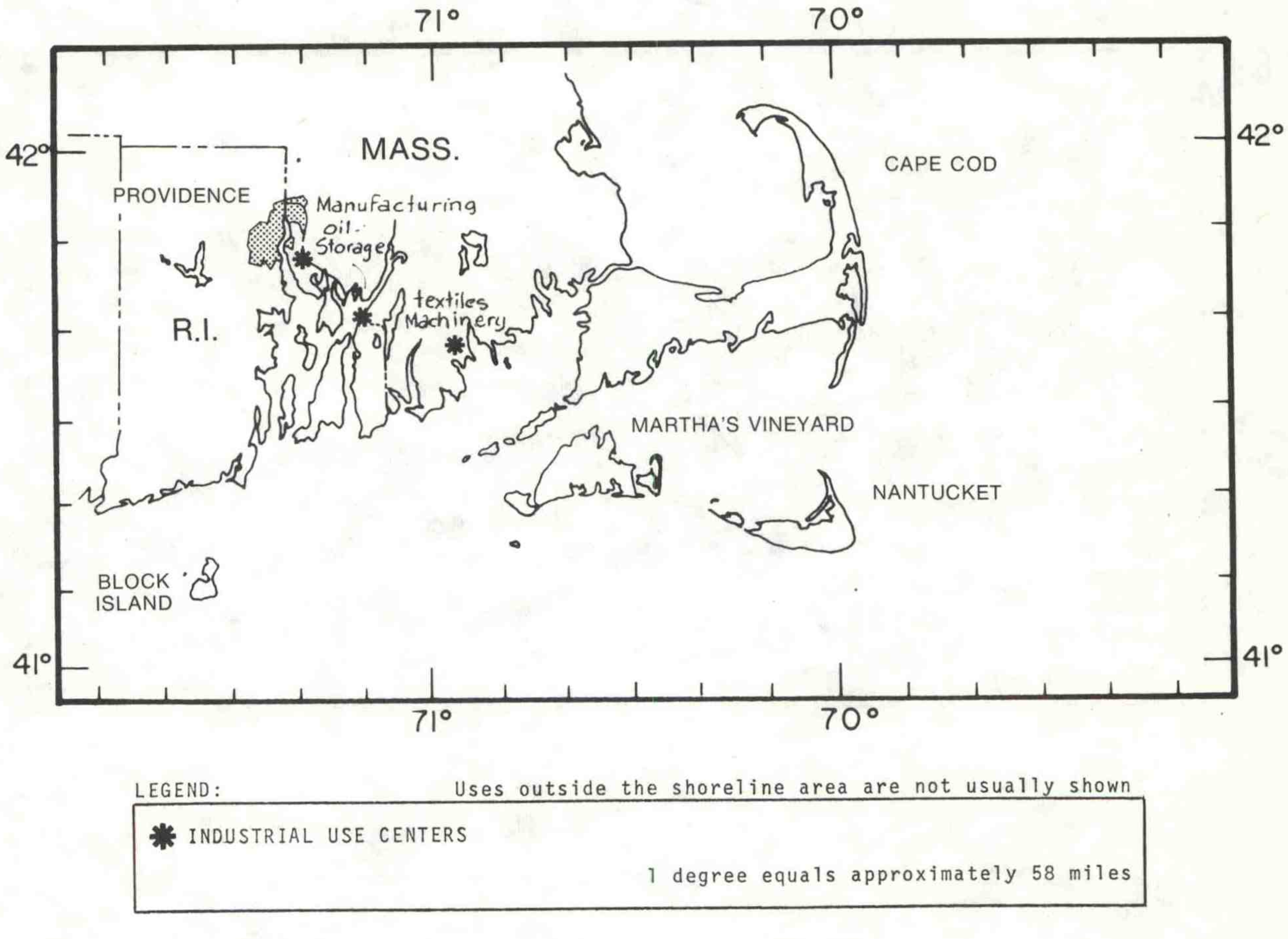


LEGEND: Uses outside the shoreline area are not usually shown

- ● Municipality (significant to area - no specific size)
- ▒ Extended population density

1 degree equals approximately 58 miles

Figure 12.16 Major residential locations, coastal and offshore areas, Rhode Island and southeastern Massachusetts.

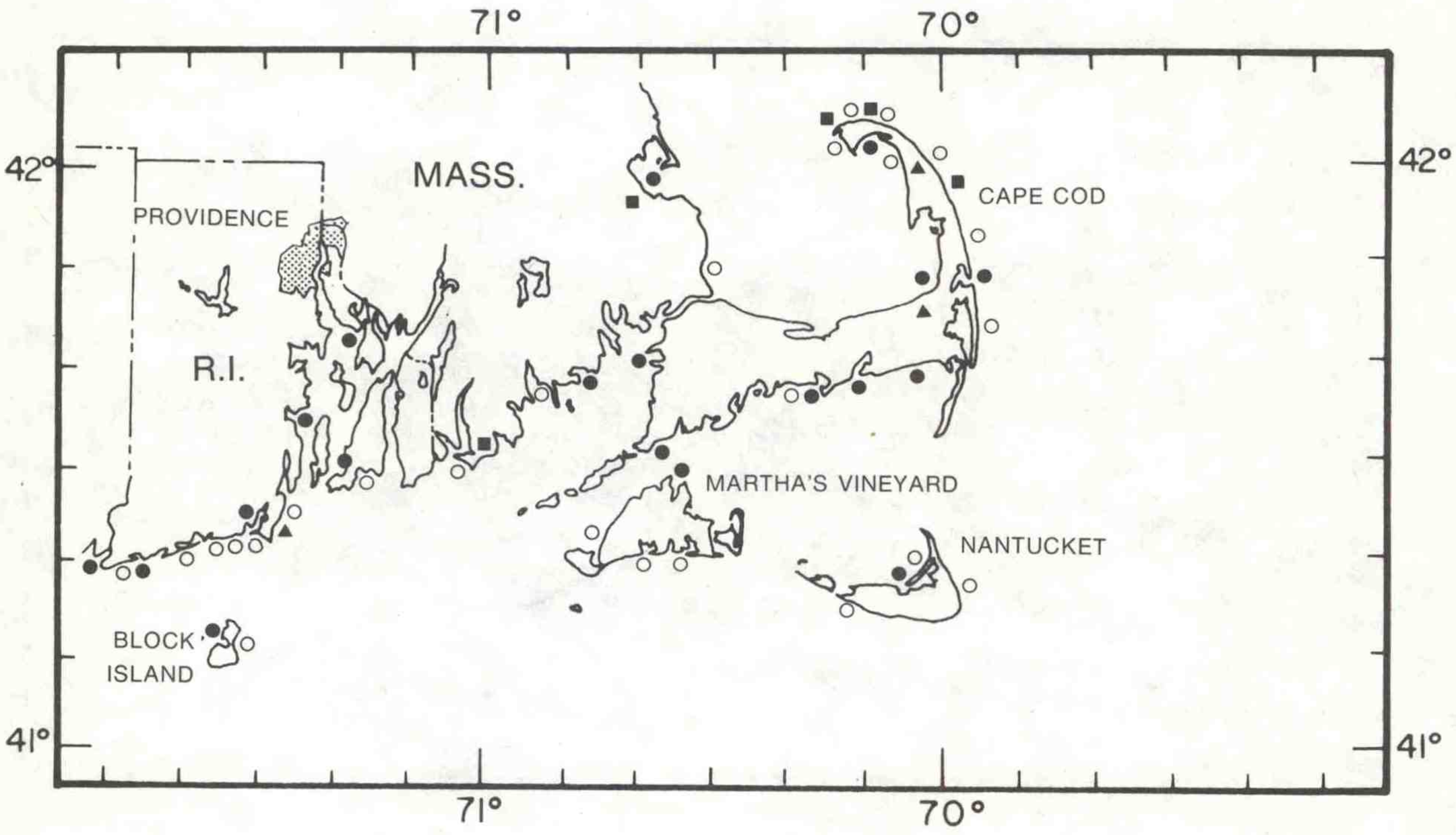


LEGEND: Uses outside the shoreline area are not usually shown

✱ INDUSTRIAL USE CENTERS

1 degree equals approximately 58 miles

Figure 12.17 Major industrial locations, coastal and offshore areas, Rhode Island and southeastern Massachusetts.



LEGEND: Uses outside the immediate shoreline are not usually shown.

○ BEACHES	▲ CAMPS
● BOATING	■ PARKS

1 degree equals approximately 58 miles

Figure 12.18 Major recreation locations, coastal and offshore areas, Rhode Island and southeastern Massachusetts.

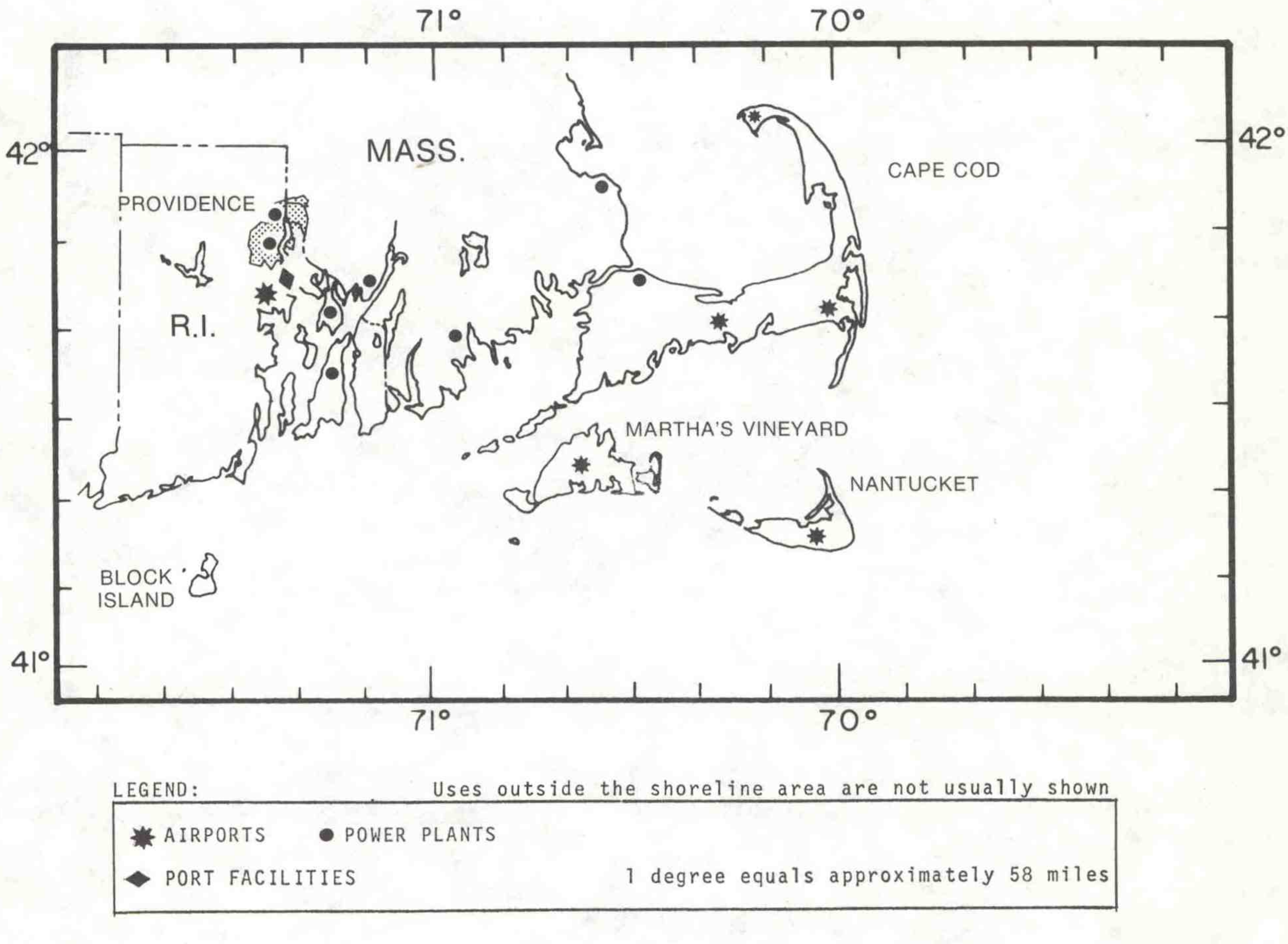
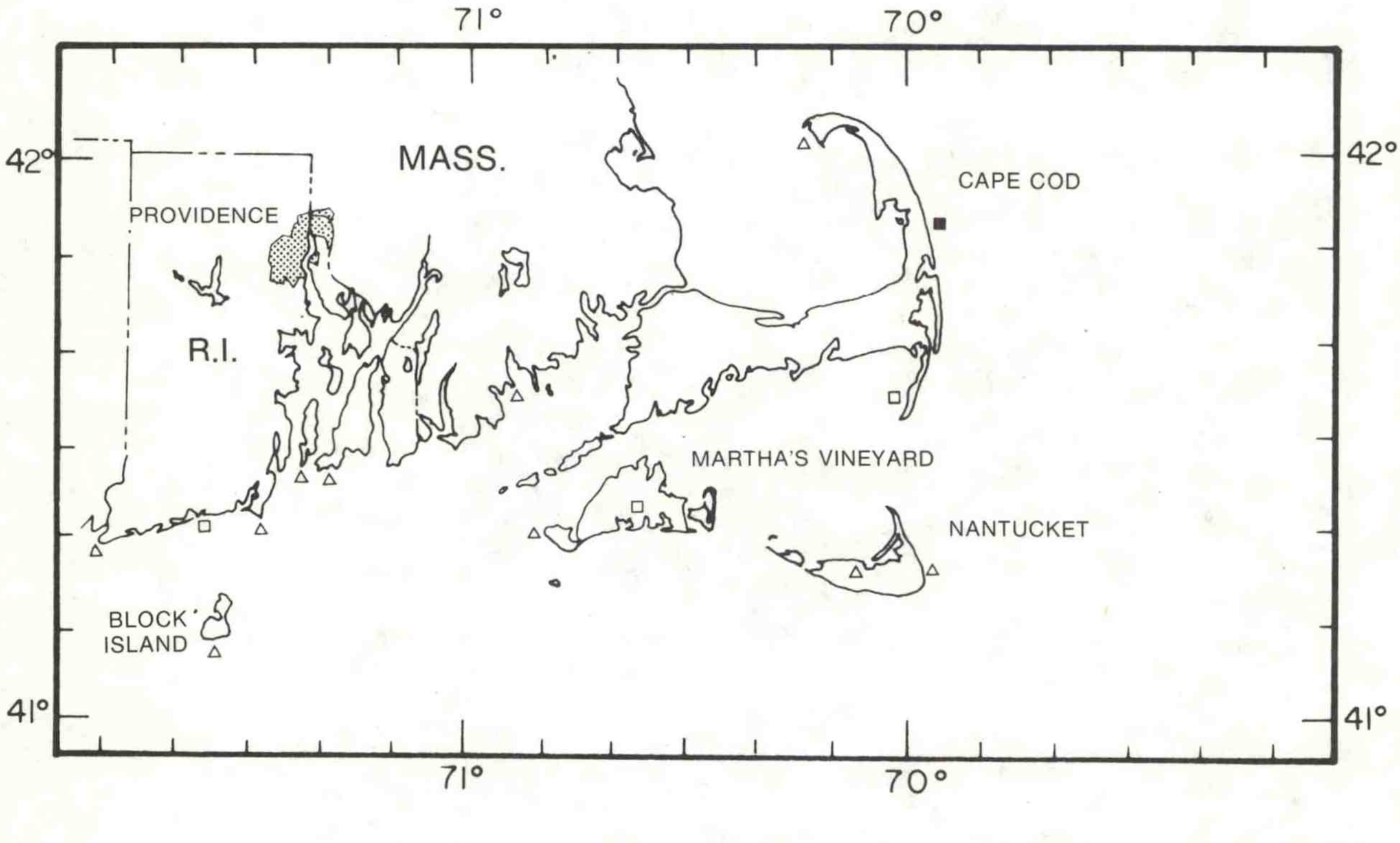


Figure 12.19 Major transportation and utility facilities, coastal and offshore areas, Rhode Island and southeastern Massachusetts.



LEGEND: Uses outside the shoreline area are not usually shown

□ Preserves or Forests ■ Parks or Seashore reserve

△ Scenic Areas or Special Sites 1 degree equals approximately 58 miles

Figure 12.20 Major open-space and scenic areas, coastal and offshore areas, Rhode Island and southeastern Massachusetts.

and 5 miles federal. In Narragansett Bay, the shorefront is estimated to be in excess of 90 percent privately-owned. In terms of shore use, almost all of the non-federal mileage is used for recreational purposes. Other uses within urbanized areas are commercial and industrial. In 1965, it was estimated that about 88 percent of the Rhode Island shoreline was in more or less a "natural" state and that approximately 4,200 acres of salt marsh and meadow were available along the shoreline.

Population and Economic Base. A summary of population, personal income, earnings and employment for Area 9 over the period 1959 to 2020 is shown in Table 16. Of the 1964 population of almost 5 million, a mere 141 thousand was classified as rural.

Cape Cod, Nantucket, and Martha's Vineyard are sparsely settled regions having, according to the 1960 census population densities of 179, 77, and 56 people per square mile, respectively. Economically, these regions are almost completely dependent on tourism and its supportive activities, e.g. the construction industry. Some commercial fishing is also done on Cape Cod, but it is not a major contributor to the economy. The population of all of these areas increases dramatically during the summer months, and the year-round population of Cape Cod has steadily climbed in recent years.

The southeastern portion of Massachusetts between the Rhode Island border and Cape Cod is an area of more dense population and considerable industrial activity. The major population center directly on the coast is New Bedford. At the present time this area is economically depressed. A second population concentration is found slightly inland at Fall River.

The coastal area surrounding Narragansett Bay is an area of high population concentration with a peak density at the head of the bay in the communities around Providence. Another population cluster exists around the Port of Newport. In contrast, the coastal areas along Block Island Sound are more sparsely settled with Washington County having a population of 178 per square mile according to the 1960 census. Projections show that the population will increase by some 37% by the year 2020, but that it will be more evenly dispersed as the highway system improves. The influx of summer residents to the coastal area is moderately high on the mainland and very high on Block Island. No data is available to indicate what percentage of these are from out-of-state and what percentage are relocations from other parts of Rhode Island.

The coastal population receives a per capita income comparable to the national average and is expected to maintain this ratio through the year 2020. Although the United States Navy has been the largest single employer in the Rhode Island coastal zone, manufacturing is the chief source of basic income to the area. Other significant economic activities relate to ship-building, recreational boating, and tourism. Commercial fishing is still a significant source of income to certain areas, although its pattern of activity is changing.

TABLE 16. North Atlantic Hydrologic Area 9. Population, Personal Income, Earnings and Employment, Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	4,301,468	4,324,527	5,311,400	6,516,700	8,093,800
Total Personal Income (000-$58)	10,005,645		23,269,100	48,846,200	104,244,700
Per Capita Income ($58)	2,326		4,381	7,496	12,880
Per Capita Relative (US=1.00)	1.090		1.070	1.047	1.038
Total Earnings (000-$58)*	8,094,785		18,147,600	37,815,600	78,772,100
Per Worker Earnings ($58)	4,717		8,355	14,095	24,168
Per Worker Relative (US=1.00)	1.011		1.034	1.035	1.035
Population	4,301,468	4,324,527	5,311,400	6,516,700	8,093,800
Total Employment	1,716,085	1,723,669	2,172,000	2,683,000	3,259,400
Participation Rate (Empl/Pop)	.399	.399	.409	.412	.403
Employment by Selected Industries					
Agriculture + Forestry + Fisheries		17,277	13,100	10,500	8,000
Mining		731	500	400	300
Manufacturing	602,851	621,200	666,500	717,200	
Food + Kindred Products	44,904	34,900	30,200	27,900	
Textile Mill Products	62,155	32,300	21,300	14,600	
Chemicals + Allied Products	13,054	16,500	20,000	23,500	
Paper + Allied Products	17,404	20,200	23,100	25,700	
Petroleum Refining	2,664	1,100	600	300	
Primary Metals	16,269	19,700	22,200	24,400	
Armed Forces	55,163	43,500	43,500	43,500	
Other	1,047,647	1,493,700	1,962,100	2,490,400	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

Land-Use. A land-use and water area summary for Area 9 is shown in Table 17, which lists total land and water area together with the amounts and percent distribution of types of surface coverage (cropland, pasture, forest, urban, water area, other) in 1963. In that year, 442 square miles (11.7%) of the Area's total land area was intensively developed,

TABLE 17: Land-Use and Water Area, NAR Area 9 - 1963

Cover Type	Amount (thousand acres)	Percent Distribution
Cropland	145	5
Pasture	59	2
Forest	6,616	55
Urban	518	18
Water		
-under 40 acres	28	1
-over 40 acres	282	10
Other	280	9
TOTAL	2,928	100

and 5.5 percent of the land area was in crop production, with 2,867 commercial farms (part-time or retirement) in operation. Also in 1963, there were 1.7 million acres of commercial forestland in the area, of which 115,000 acres were publicly-owned, 10,000 acres were devoted to the forest industry, and 1.6 million acres were farm-owned or private. With respect to mineral extraction in the area, the most significant commercial products are sand, gravel, stone, and clay. In 1969, the estimated combined value of production of these minerals was $31.8 million.

The primary land use on the Cape Cod peninsula is recreational, both public and private. The two main public facilities are the Roland C. Nickerson State Forest and the 27,000 acre Cape Cod National Seashore. Associated with this open space land-use pattern are commercial developments and, in the southeastern portion of the Cape, some cranberry farms. A significant portion of land is federally-owned including Otis Air Force Base and sections adjacent to the Cape Cod Canal. The islands south of Cape Cod are largely undeveloped. This is particularly true of the Elizabeth Islands chain which forms the eastern boundary of Buzzards Bay; only the outermost island is extensively used for permanent and seasonal residence. The same general pattern of undeveloped land in private ownership holds true for Nantucket and Martha's Vineyard. Here, however, there are some heavily used public areas including a state forest on each of the islands.

A review of land-use in the coastal zone of Rhode Island shows a prevalence of residential areas. Along the southern coastal portions of

the state, a great deal of space is also occupied by usage classified as "recreation and conservation". This includes the Burlingame State Park, the Ninigret Conservation Area, and some 28 miles of sand beach, both public and private. Little industrial land-use is found in this area, and the extent of commercial land use is moderate and generally interspersed among the residential areas. Some federal military use is also found, i.e., Charlestown Auxiliary Naval Air Station, but a high percentage of the land is still classified as "vacant".

As one moves up into Narragansett Bay the percentage of "vacant" land rapidly dwindles and land-use patterns become more fixed. Federal military land-use (until recently) has been high in the southern portion of the bay.[12] The Navy controls 31 miles or nearly 8 percent of the total shoreline. The Navy also controls extensive portions of the southern half of the bay waters. Commercial and industrial uses also increase as one moves north into the bay until, in the Providence area, they match residential use. Recreational uses are also significant in this highly urban area. These include several parks (Goddard Memorial, Colt, and Haines Memorial), as well as several fishing areas and beaches, both public and private.

Block Island has a large portion of vacant land. The rest of its land use can be classified as residential with some commercial land use devoted to the seasonal tourist industry.

Public Utilities. Of the total 1964 population of Area 9, approximately 94 percent (4.8 million people) were served from public water supply systems. The 230 central systems in the Area distributed an average of 617 million gallons per day (m.g.d.) with surface sources supplying about 74 percent of this water and ground water development the remaining 26 percent. Presently available water resources in the area comprise 800 m.g.d. Diversions from Area 8 (Connecticut River) and Area 7 (Merrimack River) provide almost half of the surface water supply in the Area.

Area 9's total industrial water intake is 322 m.g.d., of which 170 m.g.d. are self-supplied, 58 m.g.d. are publicly-suppled, and 94 m.g.d.

---

12 The recent decisions to close the federal installations in the Narragansett Bay area will release many prime coastal locations for non-military uses. Though representing a dark cloud of severe economic disruption to the region in the short-term, there may be a silver lining in the long-run. Since these facilities were retained until recent years, decision-makers now have some fresh (and perhaps more economically significant) options that might not have been available had the sites been long-since developed in a manner comparable to adjacent areas.

are brackish. The chemical industry is the largest water user in the Area with a self-supplied intake of 69 m.g.d. Of the remaining 101 m.g.d. the paper, fabric, and primary metals industries use 27 m.g.d., 13 m.g.d., and 14 m.g.d. respectively, with the balance distributed among 10 other industries, none of which withdraws more than 10 m.g.d. Livestock and rural domestic water requirements are 9.2 m.g.d. Other important uses of water supply are for irrigation of farmland (17,600 acres) and non-agricultural irrigation (golf courses, institutional, etc. - 16,600 acre-feet). About 30 percent of the agricultural water comes from ground water and 70 percent from surface water sources. The predominant source of water for nonagricultural irrigation is from ground water.

The electric power requirements of Area 9 during 1969 were met by 5,618 megawatts (MW) of installed generating capacity. The distribution of this capacity by type of prime mover, together with scheduled or planned addition for the area through 1975, is shown in Table 18. The most recent power plant siting development in the southern portion of the area is a 542 MW steam generating plant on the Cape Cod canal.

TABLE 18. Total Electric Generating Capacity and Planned Additions - Area 9 (MW).

	1969	1975
Steam Electric		
Nuclear	---	650
Fossil	5,385	2,532
Hydroelectric	3	---
IC/GT	230	454
TOTAL	5,618	3,636

Major Coastal Uses. The major coastal uses in Area 9 include commercial navigation, commercial fishing, water-oriented recreation, and waste disposal. Each of these is considered below.

The extensive land transportation system in Area 9, as shown in Figure 12.21, ranks it among those most complementary to the development of commercial navigation in the entire NAR. Only Philadelphia has a radial transportation system as direct to, or in a location as central to comparable major population centers. With respect to waterways, the highly irregular coastline of the area has been very favorable to the development of ports and harbors. Boston, Providence, and Fall River have authorized channel depths between 32 and 40 feet deep, and up to 1,200 feet in width. Ten other ports in the area have access channels 15 to 24 feet deep and about 200 feet wide. Cape Cod Canal, with a depth of 32 feet, is a short cut across Cape Cod which eliminates more than 100 miles from the alternative round-about shipping route.

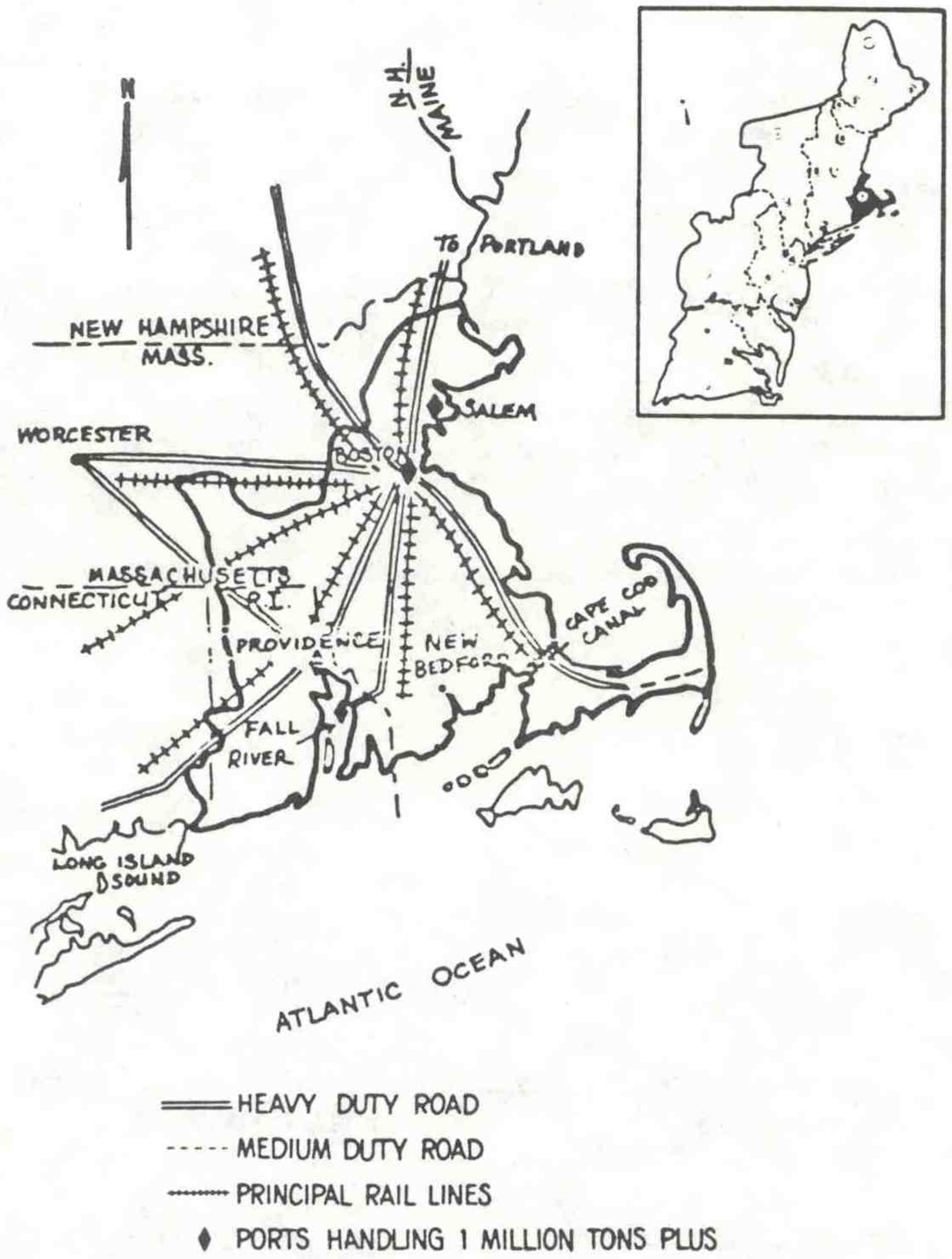


Figure 12.21 The transportation system of southeastern New England.

The waters of the Rhode Island-Cape Cod sector are used for transportation by five major groups: commercial cargo carriers, naval vessels, commuter carriers, commercial fishing vessels, and recreational boats. When the many secondary activities associated with these uses (e.g. cargo handling, marina development, channel dredging, etc.) are taken into account, it is clear that the economic impact of this water traffic is considerable. Commodity demand in Area 9 is generated by some 4.7 million people (1960), 97 percent of which reside within 40 miles of the deep-water ports of Boston and Providence. The Ports of Boston, Providence, Fall River, Salem, and New Bedford account for more than 95 percent of the waterborne commerce to meet this demand.

The Port of Providence is the fourth largest in New England and has been developed along a 2.5 mile section of the Providence River about 10 miles from Narragansett Bay. Its 10-mile-long access channel is 40 feet deep and 600 feet wide. Port facilities include 23 piers, wharves and docks. Ten are supported by open, covered and cold storage (60 acres, 150,000 square feet, 1.6 million cubic feet), and have access to the railroad. Thirteen were designed to receive or ship petroleum products, and are supported by a petroleum storage capacity of 1.2 million tons. There are no major development restrictions in the main channel to Providence; however, just above Providence bridges restrict horizontal clearance to 50 feet and vertical clearance to 9 feet. Commerce grew at an average rate of 1% for the 19 years through 1967, but had a higher average of 1.3% over the last 10 years of that period. Commerce averaged 9, 120,000 tons for the three years prior to 1968 and the 1970 commerce was 9,870,000 tons. Projected commerce is expected to have an annual growth rate between 1.3% and 2.5%, and will reach a level of roughly 12 million tons by 1980.

Minor port facilities are located at Fall River and New Bedford, and these harbors handle primarily petroleum products. New Bedford is the base for a passenger ferry service connecting with Cuttyhunk, the end of the Elizabeth Islands chain. Other connections with the offshore islands of Nantucket and Martha's Vineyard are made through the Cape Cod ports at Falmouth and Hyannis. In New Bedford, waterborne commerce averaged a 0.5% annual decline during the 19 years through 1967, but averaged an 8.9% annual growth over the last 10 years of that period. Commerce averaged 450,000 tons for the 3 years prior to 1968. The 1970 commerce was 615,000 tons. The annual growth rates range from 2.3% to 3.5%. In Fall River, commerce grew at an average annual rate of 4.8% for the 19 years through 1967 but had a much higher average growth of 6.2% over the last 10 years of that period. Commerce averaged 3,850,000 tons for the three years prior to 1963. Commerce in 1970 was 4,330,000 tons. The projected annual growth rates range from 2.3% to 3.5%.

Commercial fishing is pursued throughout the coastal waters of the Rhode Island-Cape Cod region, but the once large shellfishing industry has

been sharply curtailed in recent years. In part this is due to the mysterious disappearance of the oyster. Another factor has been the restriction placed upon the industry due to the polluted waters at the head of Narragansett Bay. However, as this segment of the industry has declined, the finfish catch has increased both in volume and value. Thus the total catch in 1965, landed primarily at Point Judith, amounted to 48.7 million pounds, valued at $4.6 million.

Recreation is by far the largest-scale use of Area 9's coastal regions. The most popular forms of water-oriented recreation pursued in the area in 1965 included boating (2.71 participation days per person), sailing (.62 p.d.p.), water-skiing (.75 p.d.p.), and swimming (11.33 p.d.p.)[13]. In Rhode Island, the beaches in Narragansett Bay recorded over 1.7 million user days in 1967; the entire coastal area as of 1969 contained some 26 yacht clubs, 25 yacht basins and harbors, 35 boat yards, eight charter boat enterprises, and 14,800 registered pleasure craft (motorized); and it has been estimated that nearly 40% of the boating time in offshore waters was devoted to sport fishing. On Cape Cod and the offshore islands, the local economies are based almost entirely on recreation. Most of the shorefront is used for either public or private recreation, and boating is extremely popular. Nearly 100,000 motor launches were registered throughout Massachusetts in 1969, and coastal marinas are common. Along with boating, sportsfishing is also popular. There are about 400,000 anglers in the state and about 3.5 million game fish were caught in coastal waters in a recent year.

As with most coastal waters, those of Area 9 are used extensively for waste disposal. Table 19 shows the organic waste loads from 151 non-industrial (municipal, institutional, federal) and 115 industrial sources known in 1960, as expressed in population equivalents for existing treatment levels. The most serious waste disposal problems arise in Narragansett Bay, which receives the sewage wastes of about 90% of the population of Rhode Island, some 150 million gallons per day. Twenty percent of these wastes receive primary treatment, 70% receive secondary treatment, and 1% receive tertiary treatment.

TABLE 19. Organic Waste Loads in Area 9 - 1960

Load Type	Waste Load (P.E.) (thousands)
Non-Industrial	2,220
Industrial	2,526
TOTAL	4,746

13 These figures are based on average participation rates for persons 12 and over for the New England region as a whole.

The remainder of the wastes are not treated at all. Along the southern Rhode Island coast, some areas do not have central treatment facilities, so that the burden on the coastal waters is also increased by leakage from septic tanks of many of the shore residences. In addition, no regulations now exist concerning waste disposal from boats. Consequently, the large volume of water traffic discussed above also dumps its untreated wastes into the coastal waters.

Major Coastal Problems. In the Massachusetts coastal portion of Area 9, problems invovling recreation and the conservation of wetlands are considered highly significant, while problems relevant to living and non-living resources, water pollution, solid waste disposal, marine transportation, and erosion and flooding are labeled as significant. Localized problems include the decline in commercial fishing in recent years and thermal pollution from nuclear power plants. The supply of recreational facilities is becoming one of the most critical problems in the Massachusetts coastal zone, where recreational demand--from both local residents and out of state visitors--is particularly felt along the coast south of Boston where current facilities are already used to capacity. The establishment of the National Sea Shore has heightened this pressure and between 1963-1968 the number of visits increased from 1.3 to 3.5 million. As the population of this state and the areas to the south increase, more and more pressure will be exerted on its coastal areas to satisfy recreational demands.

Erosion has been evaluated as significant in this area because it seriously affects about 135 miles of the 1200 miles of shoreline. Almost all occurs in the islands off the southern coast and the ocean side of the north-south arm of Cape Cod. Tidal flooding occurs particularly in the Buzzards Bay area. A recurrence of the tidal flood of record there has been estimated to cause damages of about $60 million. Without the existing hurricane barrier in this reach, the estimated damages from this same storm would be about $100 million.

Water pollution, coastal erosion, and tidal flooding are the most highly significant problems along the Rhode Island shores, while problems relevant to living resources, conservation of wetlands, recreation, and marine transportation are also thought to be significant. The pollution of the coastal waters is perceived locally to be the single most important problem. The largest source of these pollutants are municipal and industrial wastes, with sewage from boats also being a contributor. The subterranean waters of the area are also suffering from pollution by industrial wastes. Economically, the pollution in this area has had a severe impact on the shellfishing industry in Narragansett Bay. Even where the resource is still available, the costs of harvesting it are increased by the need to depurate it by treatment of transplant. In addition, the existence of polluted waters has impacted on the extent and desirability of recreational pursuits in the area. Although much effort

and money has been expended in the establishment of waste treatment facilities, the problem is expected to become more severe as growth outpaces facilities and other demands upon the use of the waters increase. Pollution of underground aquifers may become a significant problem as the need for additional water supplies is reached.

The most critical erosion areas are located west of Narragansett Bay, along Cliff Walk in Newport and on Block Island. Tidal flooding is a serious problem in Narragansett Bay. The hurricane of 1938 killed about 250 people in Providence and caused property damage estimated at about $125 million. A recurrence of this storm would cause an estimated $150 million in damages under current conditions and about $200 million without the existing hurricane barrier at Fox Point. This barrier which was completed in 1966 cost $17 million and the proposed Lower Narragansett Bay Barrier has an estimated 1970 cost of about $133 million.

A significant difficulty in this area, in terms of recreation, is public access to the shoreline. Access is limited by the extensive amount of land in private ownership as well as restrictions on parking in areas surrounding municipal beaches. Limited state ownership of shoreline areas further restricts public access; the state owns only about 7 miles of the 340 mile shoreline. In addition there is a lack of facilities for such activities as boat launching.

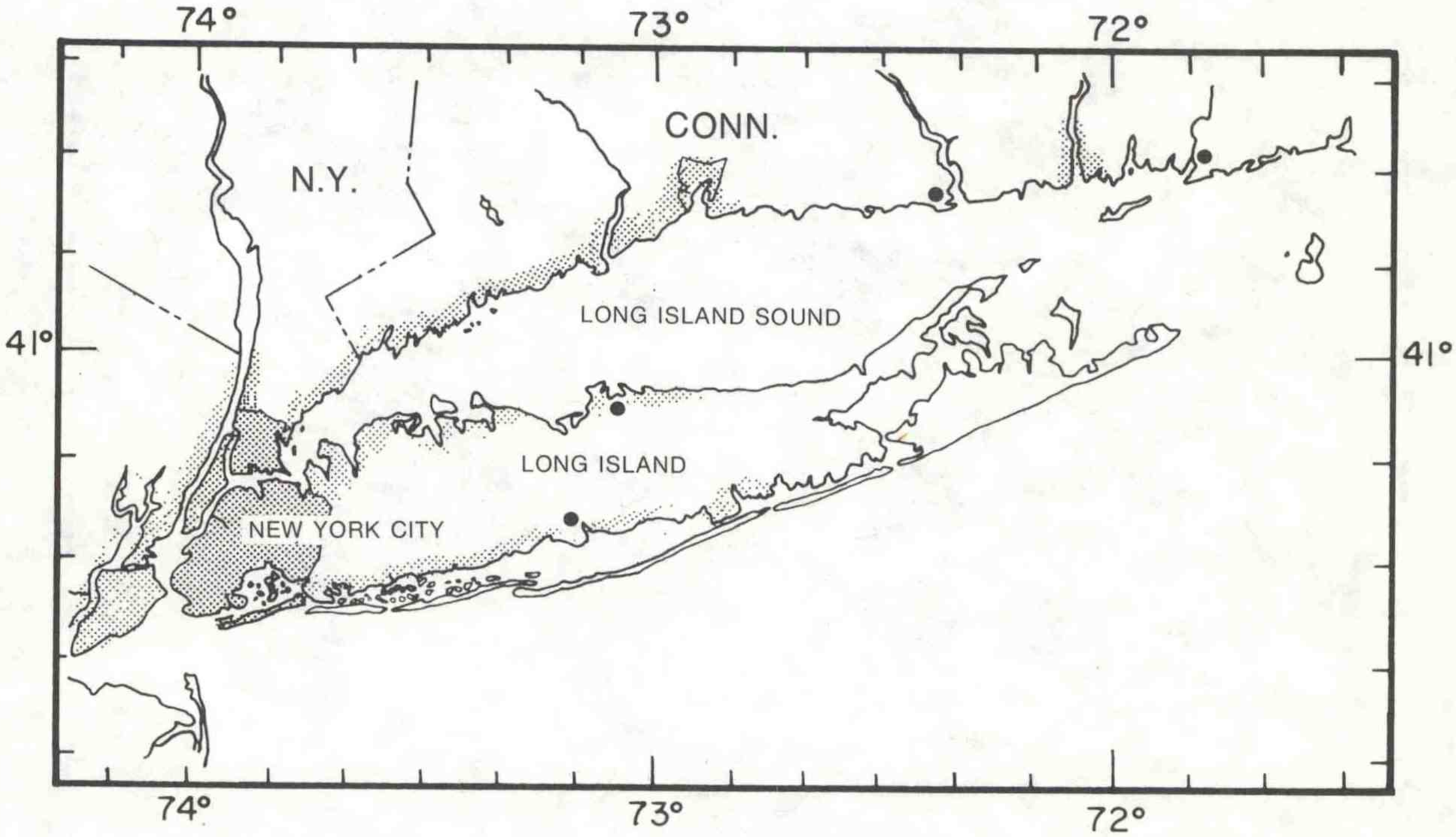
The conservation of the state's wetlands is a significant concern of the people in Rhode Island. The state has less coastal wetlands than any in the NAR, only a third as much as New Hampshire and a seventh as much as Connecticut, the other two states with little wetlands. Over the last decade and a half wetland losses have been kept to an average of 10 acres a year. How this loss compares with the normal expansion and contraction of wetlands through natural cycles of climate, erosion and deposition has not been determined.

For Area 9 as a whole, coastal-related amenity needs include the protection of quality landscapes, preservation of unique landscapes, increasing urban amenities with special recognition of river and waterfront amenity values, and the provision of clean water.

Subregion B. Connecticut, New York, Long Island

Areas 8 and 10 - Connecticut

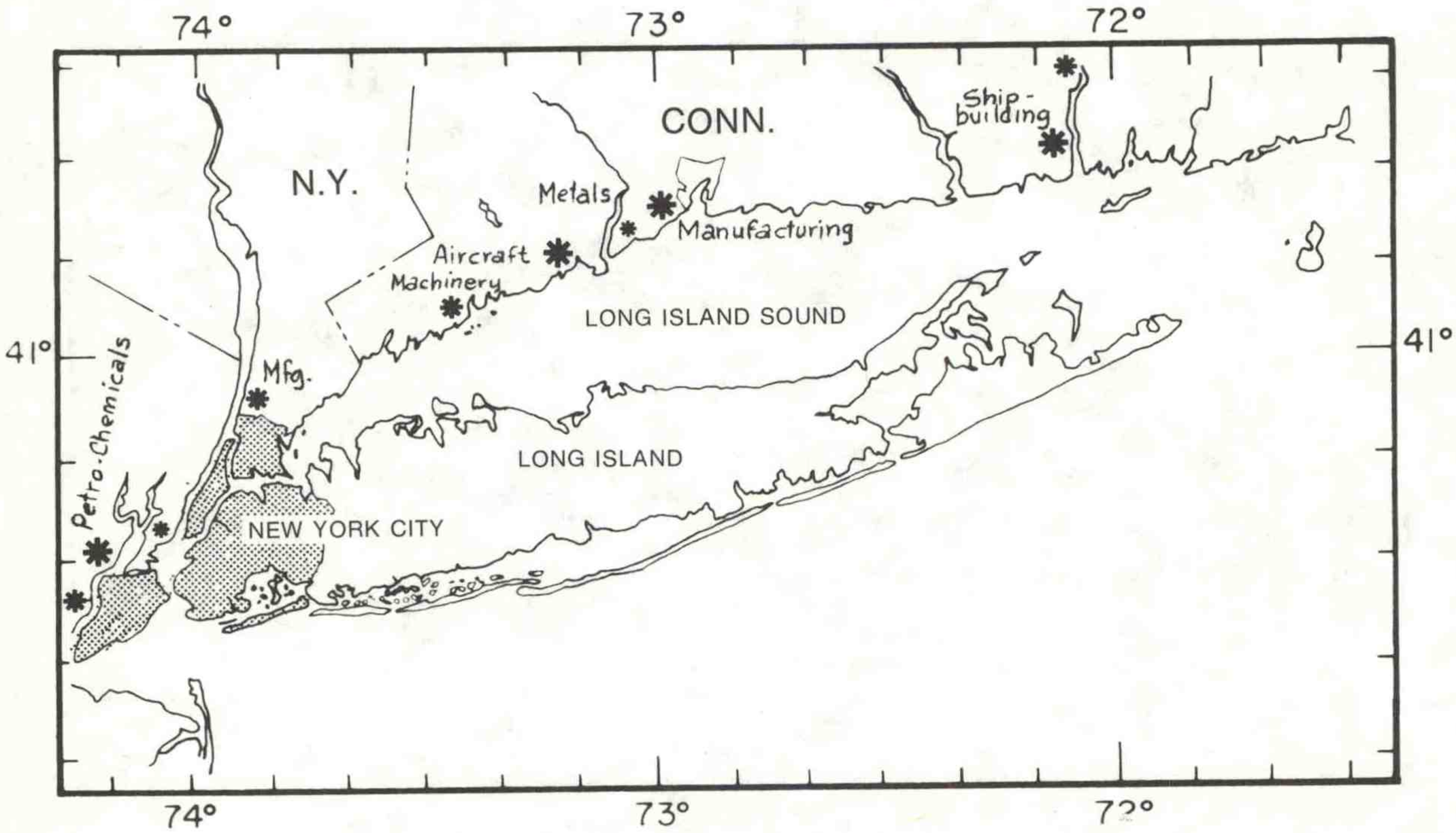
General Characteristics. As shown in Figure 12.27, Areas 8 and 10 contain the Connecticut coastline, which is very irregular with many bays, coves, and promontories. Several small offshore islands dot its central and western portions. Of the approximately 270 miles of shoreline, some 145 miles are beaches, located primarily east of Norwalk harbor. Many of these are narrow, and normal tides approaching the backshore make them



LEGEND: Uses outside the shoreline area are not usually shown

- ● Municipality (significant to area - no specific size)
- Extended population density — 1 degree equals approximately 58 miles

Figure 12.22 Major residential locations, coastal and offshore areas, Connecticut and Long Island, New York.

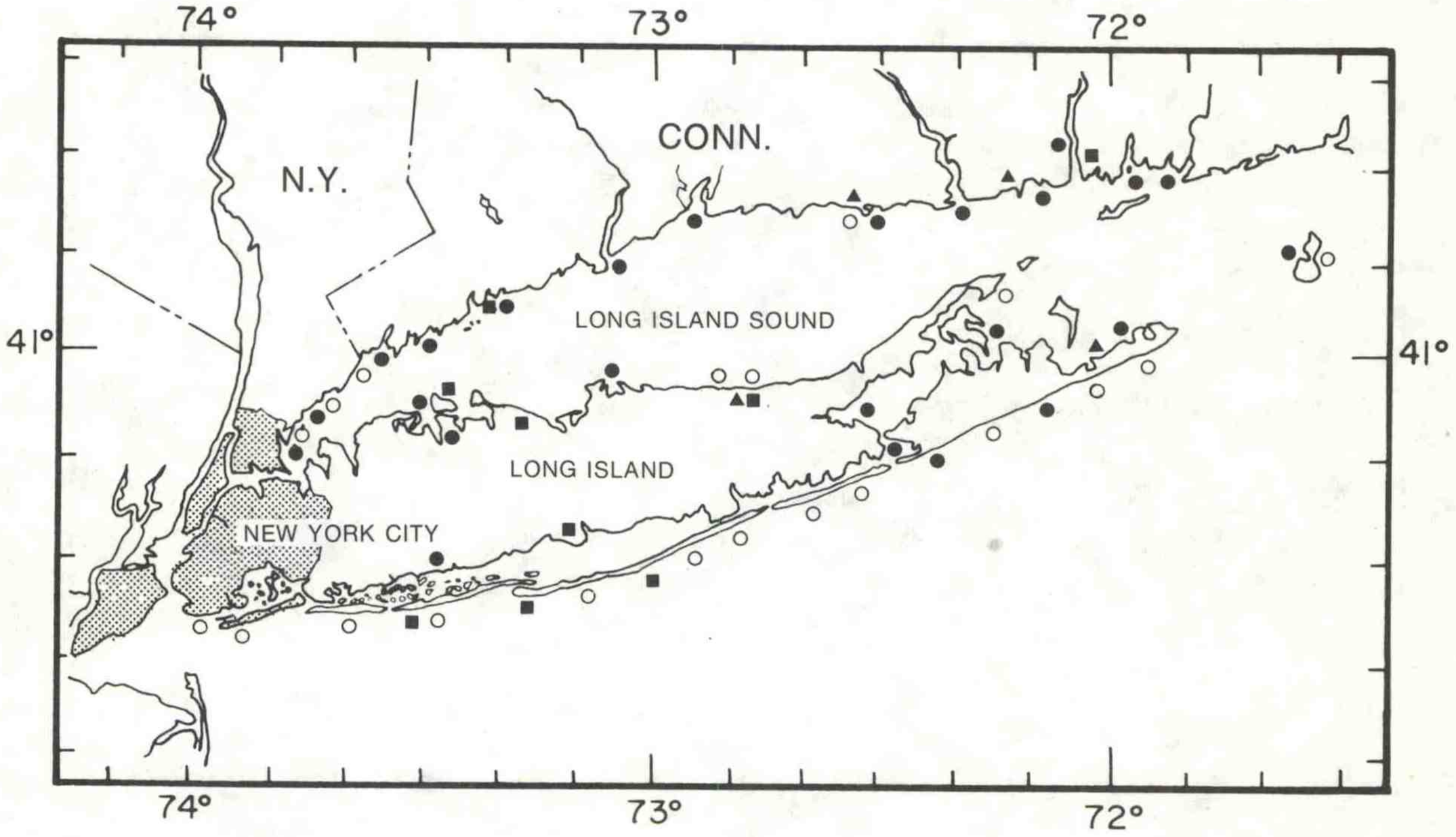


LEGEND: Uses outside the shoreline area are not usually shown

✱ INDUSTRIAL USE CENTERS

1 degree equals approximately 58 miles

Figure 12.23 Major industrial locations, coastal and offshore areas, Connecticut and Long Island, New York.

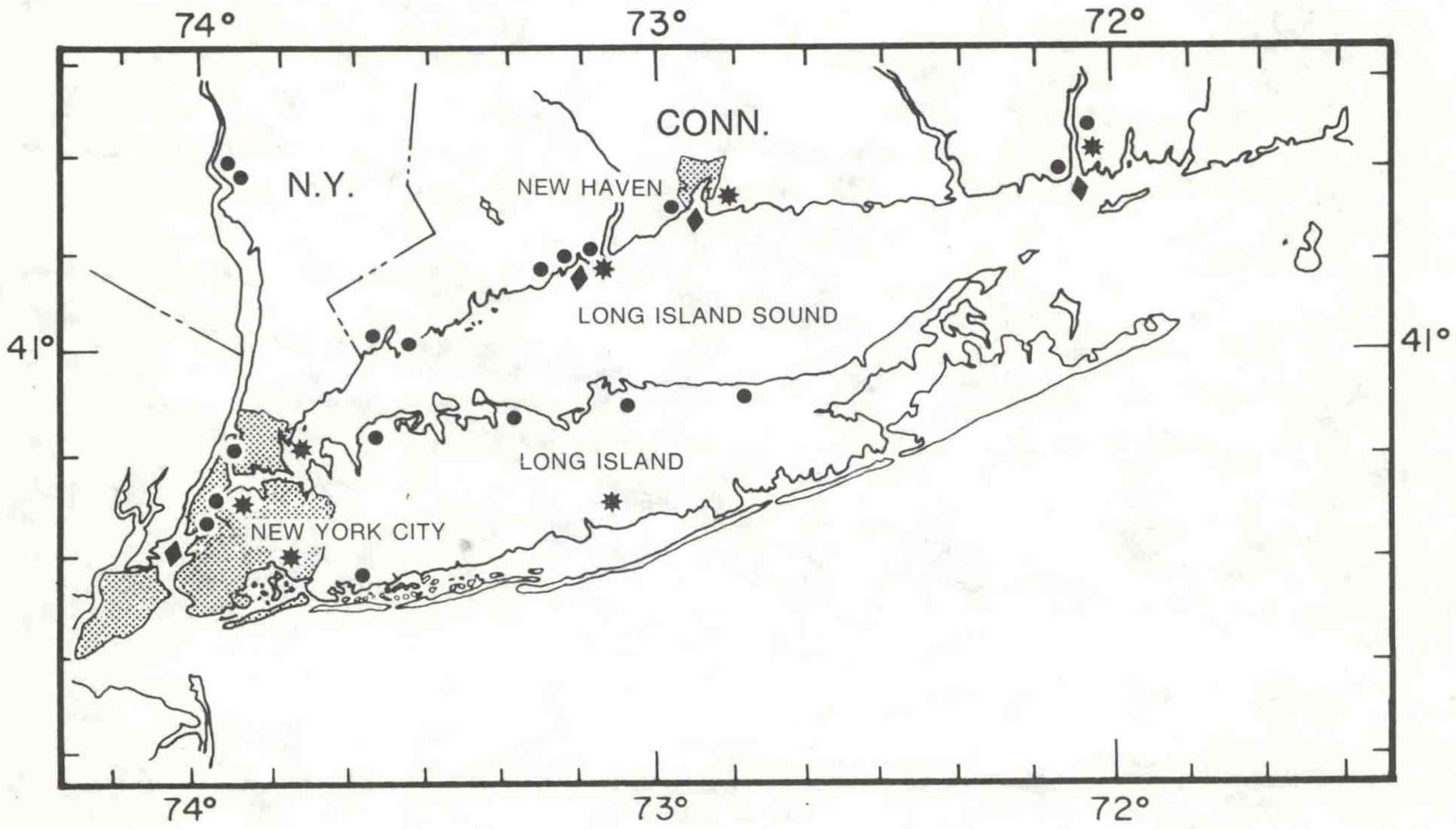


LEGEND: Uses outside the immediate shoreline are not usually shown.

○ BEACHES	▲ CAMPS
● BOATING	■ PARKS

1 degree equals approximately 58 miles

Figure 12.24 Major recreation locations, coastal and offshore areas, Connecticut and Long Island, New York.

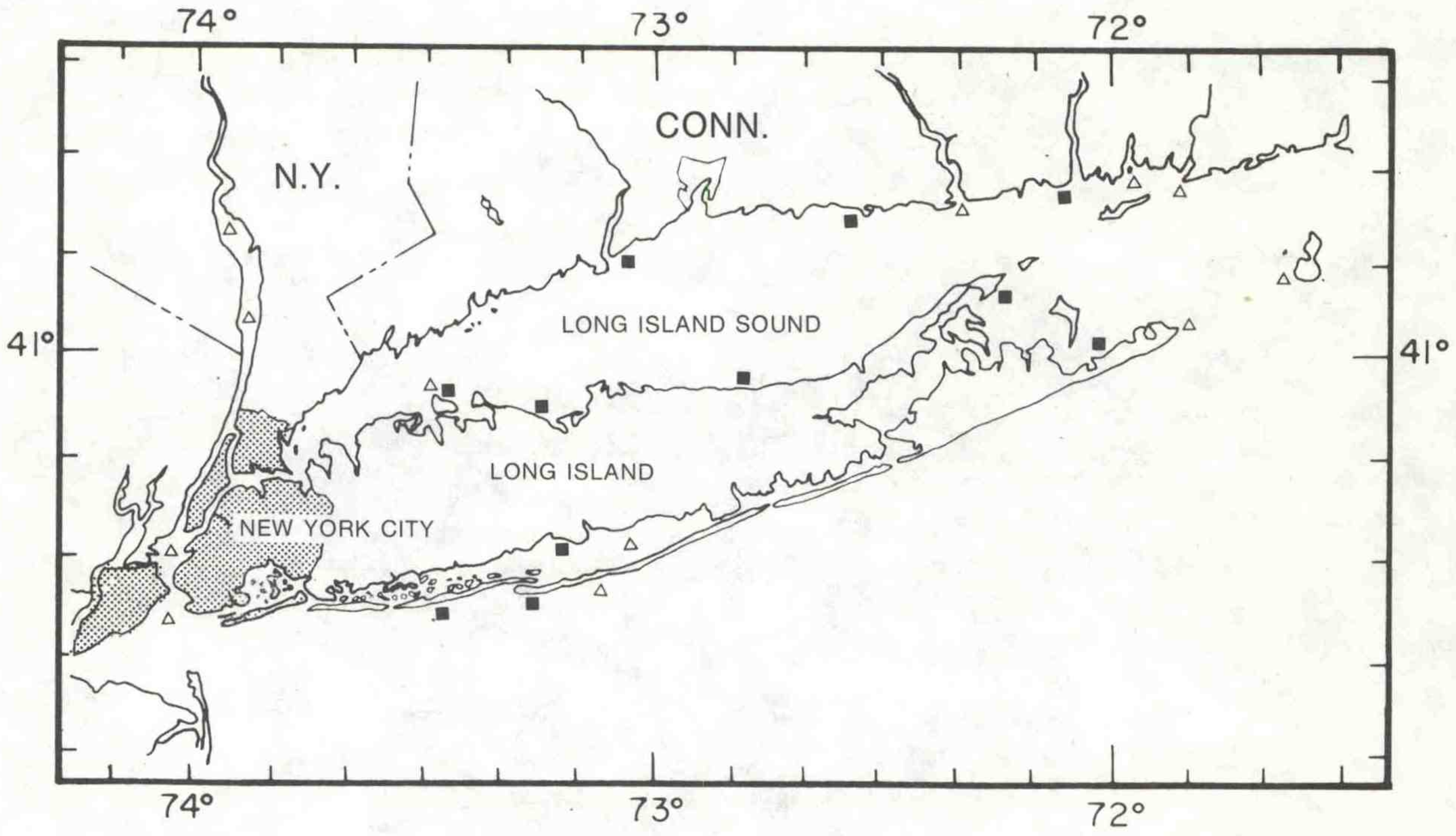


LEGEND: Uses outside the shoreline area are not usually shown

AIRPORTS ● POWER PLANTS

◆ PORT FACILITIES 1 degree equals approximately 58 miles

Figure 12.25 Major transportation and utility facilities, coastal and offshore areas, Connecticut and Long Island, New York.



LEGEND: Uses outside the shoreline area are not usually shown

□ Preserves or Forests ■ Parks or Seashore reserve

△ Scenic Areas or Special Sites 1 degree equals approximately 58 miles

Figure 12.26 Major open-space and scenic areas, coastal and offshore areas, Connecticut and Long Island, New York.

AREA 10 THAMES AND HOUSATONIC RIVER BASINS

Figure 12.27 Regional map of the Thames, Housatonic and Connecticut River basins.

inadequate as protective features or as recreational areas without some modification. West of Norwalk harbor, the coastline is rockier. Three main rivers drain this area. Proceeding from east to west, they are the Thames, the Connecticut, and the Housatonic. In addition, many smaller rivers also drain into Long Island Sound. The principal of these is the Quinnipiac which, at its mouth, forms part of New Haven Harbor. Land forms for the non-coastal portions of Area 10 consist of 80% rolling hills (3500 sq. miles) and 20% steep hills (800 sq. miles), while landscape units consist of 25% city (1100 sq. miles), 68% forest-town (2900 sq. miles), and 7% town-farm (300 sq. miles). The overall quality of the landscape is ranked as medial.

Ownership of the Connecticut shores is divided as follows: 50 miles state/local, 5 miles federal, and 215 miles private. The publicly-owned property includes four state parks and associated beaches, numerous scattered town and city beaches, and two Coast Guard facilities. The use of the shorefront is primarily summer and permanent residential, public recreational, and commercial-industrial within the urban areas. Thirty miles of the shore are devoted to public recreational use. 225 miles are devoted to private recreation, and the remainder to non-recreational private development. Public beaches attract numerous visitors from surrounding areas, with 10 million annual visitations having been recorded for 18 cooperative beach projects within the area. Residential development consists generally of private associations and privately-owned homes, both seasonal or year-round.

Population and Economic Base. A summary of population, personal income, earnings and employment for Area 10 over the period 1959 to 2020 is shown in Table 20. Of the 1964 population of 2 million, only 343,000 was classified as rural.

In comparison with other areas of the state, the western portions of the coastline are densely populated. Here are found the major population centers of Stamford, Norwalk, Bridgeport, and New Haven. This area is quite industrialized and the smaller communities serve as "bedroom towns" for the metropolitan New York City area. The area has a high per capita income with almost 30% of the population earning over $10,000 per year according to the 1960 census. At New Haven, the megalopolis concentration turns north, and the coastal area becomes less heavily populated. Although it possesses some industry, the area between the Quinnipiac and Thames Rivers is primarily oriented toward the recreation and tourist industries. This emphasis is reflected in the increased population concentration during the summer months, a large proportion of which migrates from other areas of the state. In contrast, the area surrounding the Thames estuary has 75% of its employment in the defense industry. This coastal region also maintains an income higher than the national average, as does the state as a whole.

TABLE 20. North Atlantic Hydrologic Area 10. Population, Personal Income, Earnings and Employment, Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	1,893,646	1,898,946	2,550,800	3,359,900	4,104,900
Total Personal Income (000-$58)	4,902,677		11,606,700	25,577,800	53,579,500
Per Capita Income ($58)	2,589		4,550	7,613	13,053
Per Capita Relative (US=1.00)	1.213		1.107	1.063	1.052
Total Earnings (000-$58)*	3,974,249		9,029,300	18,958,300	39,929,700
Per Worker Earnings ($58)	5,274		9,173	15,207	25,677
Per Worker Relative (US=1.00)	1.131		1.135	1.117	1.099
Population	1,893,646	1,898,946	2,550,800	3,359,900	4,104,900
Total Employment	753,561	756,721	984,300	1,246,700	1,555,100
Participation Rate (Empl/Pop)	.398	.398	.386	.371	.379
Employment by Selected Industries					
Agriculture + Forestry + Fisheries		13,719	9,800	7,200	5,200
Mining	998	700	600	600	
Manufacturing	310,959	321,900	339,500	361,500	
Food + Kindred Products	11,874	10,900	10,800	10,700	
Textile Mill Products	16,715	11,500	7,900	5,600	
Chemicals + Allied Products	10,639	15,700	22,500	30,800	
Paper + Allied Products	9,876	13,100	15,800	18,800	
Petroleum Refining	900	700	500	400	
Primary Metals	22,922	17,800	13,800	12,500	
Armed Forces	11,813	9,400	9,400	9,400	
Other	419,232	642,500	890,000	1,178,400	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

Land Use. A land-use and water area summary for Area 10 is shown in Table 21, which lists total surface areas together with the amounts and percent distribution of types of surface coverage in 1963. In that year, 419 square miles (8.9%) of the area's total land area was intensively developed while 8.4 percent was devoted to crop production with 3,470

TABLE 21. Land-Use and Water Area NAR Area 10-1963

Cover Type	Amount (thousand acres)	Percent Distribution
Cropland	237	8
Pasture	159	5
Forest	1,922	66
Urban	249	9
Water		
-over 40 acres	76	3
-under 40 acres	28	1
Other	245	8
TOTAL	2,916	100

commercial farms and 1,529 part-time or retirement farms in operation. Also in 1963, there were almost 2 million acres of commercial forestland in the area, of which 177,000 acres were publicly-owned, 1000 acres were devoted to the forest industry, and 1.8 million acres were farm-owned or private. With respect to mineral extraction in Area 10, the most significant commercial products are stone, sand and gravel, clays, and lime. In 1969, the estimated combined value of production of these minerals was in excess of $23 million. In the southern part of Area 8 (Middlesex County), a production of feldspar, sand and gravel, clays, mica, and stone was valued at $1.8 million.

Despite the heavy population concentration in the western coastal section of Area 10, a large proportion of the land is still considered "open space". These areas, however, are predominantly in private ownership as part of large residential tracts. Only two state parks are located in this area, Sherwood Island State Park and Silver Sands State Park, and little of the available beach area is open to the public. Commercial and industrial land-use predominates in Norwalk, Bridgeport, and New Haven. From New Haven east, almost all the land is classified as residential and open space. An exception is the New London area where a significant portion of the land is federal-owned or zoned for industrial use. Three state parks are located in this portion of the coast - Hammonassett, Rocky Neck, and Harkness Memorial.

Public Utilities. Approximately 1.7 million people, or 83 percent of Area 10's total 1964 population of 2 million received their water supply from 190 central water supply systems. These systems deliver an average of 255 m.g.d. and depend upon surface sources for 84 percent of their water, with the balance obtained from ground water. Presently available water resources in the area comprise 394 m.g.d., and the total practical development is estimated to be 1,373 m.g.d.

The total industrial water intake for Area 10 is 369 m.g.d. of which 94 m.g.d. is self-supplied, 42 m.g.d. is publicly-supplied and 233 m.g.d. is brackish. The primary metals, paper and chemical industries are the major water users in the area with self-supplied intakes of 31, 24, and 15 m.g.d., respectively. The remaining 24 m.g.d. are distributed among nine other industries, none of which uses more than 4 m.d.g. of self-supplied water. The chemical industry utilizes 201 of the total of 233 m.g.d. of brackish water. Livestock adn rural domestic requirements are 21.4 m.g.d. Other uses of water supply are for farmland irrigation (5,100 acres) and non-agricultural irrigation (golf courses, institutional, etc.--11,000 acre-feet). About 25 percent of agricultural water comes from ground water and 75 percent from surface water sources. The predominant source of non-agricultural water is from ground water.

The electric power requirements of Area 10 during 1969 were met by 2,697 megawatts (MW) of installed generating capacity. The distribution of this capacity by type of prime move, together with scheduled or planned additions for the area through 1975, is shown in Table 22.

TABLE 22. Total Electric Generating Capacity (1969) and Planned Additions (1975)- Area 10

Generator Type	1969	1975+
Steam Electric		
- Nuclear	--	1,482
- Fossil	2,220	375
Hydroelectric	132	1,000
Internal Combustion-Gas Turbine	2,697	3,067

Major Coastal Uses. Major coastal uses along the Connecticut shore include commercial navigation, water-oriented recreation, and waste disposal. Each of these is considered below.

As shown in Figure 12.28, land transportation in the Connecticut coastal zone is very well-developed parallel to the shore, but does not expedite movement inland to a great degree. Land transportation is

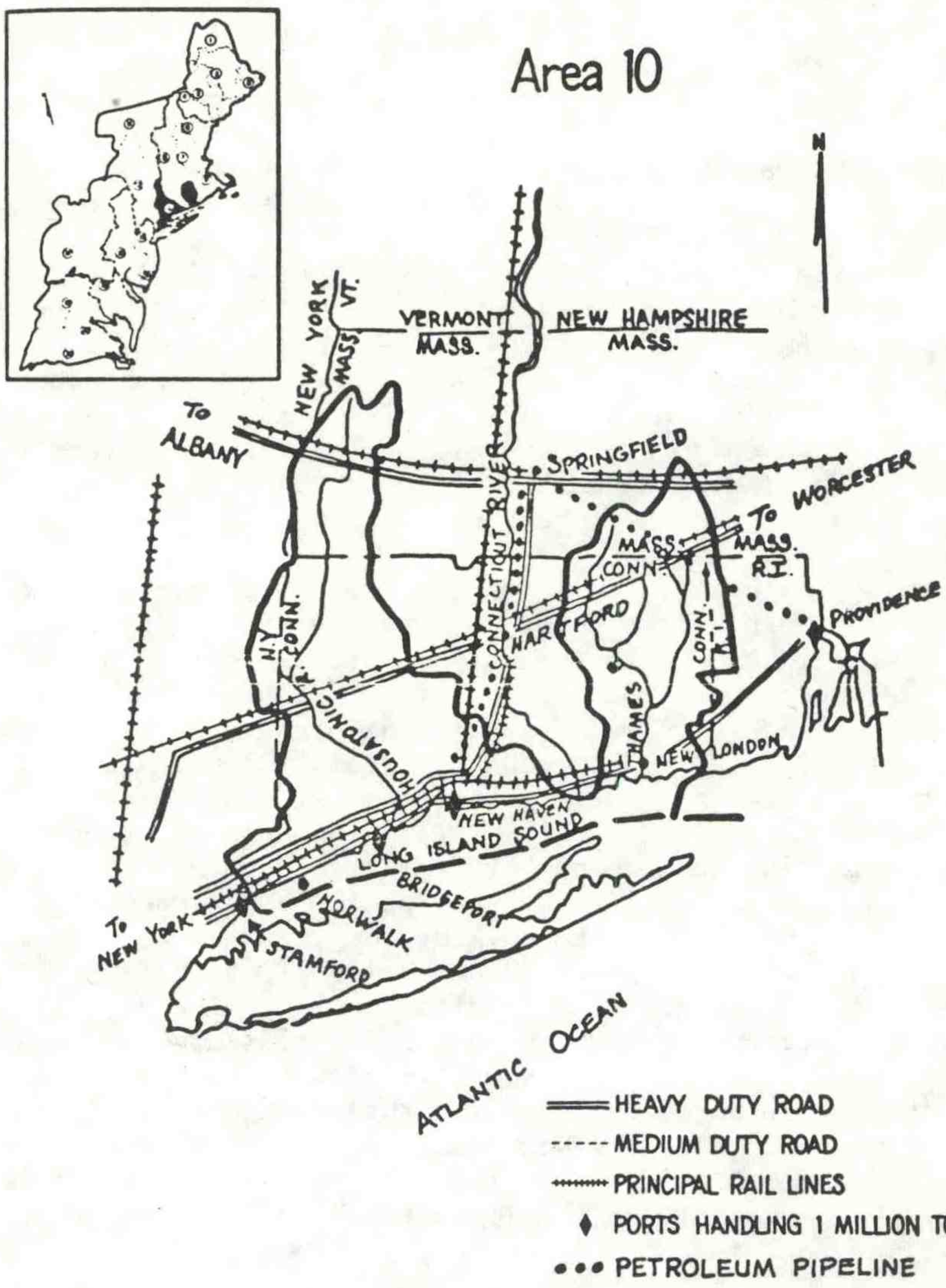


Figure 12.28 The transportation system of the Connecticut coastal zone.

complementary to navigation development around New Haven, but tends to compete with navigation along the rest of the coast because it provides good lines of communication into the area from the major ports of Boston, New Haven, and Albany. This competition is heightened by the fact that rail lines and highways also parallel the Connecticut River. Petroleum pipelines between New Haven, Hartford, Springfield, and Providence probably represent the most severe competition to commercial navigation.

The most important waterways in the area are the Long Island Sound and the Connecticut River. The Sound is exceptionally suited to navigation due to its great natural depths, which range to over 100 feet. In the southern half, safe passage is available for vessels of 40-foot draft, while 30 foot depths are available to within a mile of the Sound's north shore. Bridgeport and New Haven have channels 35 feet deep, New London's is 33 feet deep, and other active waterways have depths averaging about 19 feet. Along the Connecticut River, a 52-mile stretch from Long Island to Hartford has been improved to provide a minimum width of 150 feet and a minimum depth of 15 feet. The Connecticut is generally closed to navigation between November and April because of ice.

Commodity demand in this region is generated by over 3.6 million people (Area 10 and southern half of Area 8), and 3.3 million of these live in close proximity to one of the seven most active ports. New Haven harbor, at the mouth of the Quinnipiac River, ranks as the third largest port in New England in terms of short tons handled. This volume was 11,297,138 tons in 1968, a slight reduction from 1967 but a significant increase over the preceding year. The principal commodities received were petroleum products, as well as large amounts of scrap metal and coal. Other substantial cargo handling facilities on the Connecticut coast, in order of magnitude, are located at Bridgeport, New London, Norwalk, and Stamford. The bulk of the material handled in Norwalk is coal, but the other ports handle primarily petroleum products. In all cases the major cargo handled consists of coastwise receipts. In addition, ferry passenger services at Bridgeport and New London connect with Long Island and off-shore islands primarily during the summer. Projected waterborne commerce for the major port areas to the year 1980 include 15 million tons for New Haven; 4.5 million tons for Bridgeport; 1.5 million tons for Norwalk; 1.3 million tons for Stamford; 3 million tons for the Thames River; 1 million tons for the Housatonic River; and 4.5 million tons for the Connecticut River.

Marine-oriented recreation on the Connecticut coastal zone is extensive, as suggested by the fact that 78 percent of the shoreline is pre-empted by residential and private recreational use. During the summer of 1965, an estimated[14] 22.7 million man-days in Area 10 were

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14 Average New England participation rates X 1965 population. Persons under 12 were assumed to have the same participation rates as those over 12.

devoted to swimming, 5.4 million to boating, 1.2 million to sailing, 1.5 million to waterskiing, and 1.5 million to salt water fishing. There are 130 marinas and 70 yacht clubs with more than 12,000 permanent boat slips or moorages and about 100 launching facilities in Area 10, and there are about 2,000 slips or moorages and 21 launching facilities along the Connecticut River below Hartford. In 1969, almost 50,000 power boats were registered in the state, and by 1980, the total number of pleasure craft along the Connecticut shore is projected to reach 167,000 (with 78,000 registered).

The wetlands and waters of the Connecticut coast have been the sites for many disposal activities. Table 23 shows the organic waste loads in Area 10 from 102 non-industrial and 205 industrial sources known in 1960, as expressed in population equivalents for existing treatment levels. The use of wetlands as dumps has been cited as the most important of the specific causes listed for the destruction of some 294 acres of such areas during the years 1954-1964, primarily in the New Haven area. The uses of the waters for liquid waste disposal is also apparent in the heavily populated sections of the coast west of New Haven. This burden stems not only from coastal sources, but also from the waters draining upland areas. This is particularly apparent in the Bridgeport area where several streams draining into the area are of "D" quality. West of New Haven most areas do not have central sewerage facilities, and leachates from septic tanks cause some problems in coastal waters.

TABLE 23. Organic Waste Loads in Area 10 - 1960

Load Type	Waste Load (Pop. Equiv.) (thousands)
Non-Industrial	634
Industrial	176
TOTAL	810

Although at one time a sizeable industry, the current commercial extraction of theliving resources of the Connecticut coastal zone is a minor activity. In 1968 the entire industry employed only about 400 people, and the total dollar value of the catch in 1969 was only $1.8 million. More than half of this catch is accounted for by lobsters. The other landings include hard clams, oysters, and a variety of finfish landed primarily at Stonington. Included in the latter category are large amounts of flounder, scup, and whiting. Not reflected in this itemization of landings is the extent of the seed oyster market, located in the western portion of the coast around Fairfield and Bridgeport. This segment of the industry has also declined in recent years and its current value is not available.

Major Coastal Problems. The major coastal problem confronting this region is recreation -- how to satisfy the demand. Currently, most

of the Connecticut coastline is either in private ownership or restricted public use as town beaches. The need is for more state park facilities for recreational pursuits and more shorefront access points to help satisfy the increasing demand for fishing and boating areas. A solution to this problem must be found in increased purchase by the state to open these areas up to wider utilization. Improved water quality and beach replenishment activities would also upgrade the quality of the recreational experience in this area.

A second problem of the coastal region is the preservation of a rapidly dwindling supply of coastal wetlands. It has been estimated that 21% of these areas were lost in the fifteen year period between 1954 and 1968. Although efforts are currently underway to protect these areas, higher priority needs to be assigned to these activities to combat the rapidly increasing pressure for housing developments in these areas.

Scattered along the Connecticut coast are approximately 25 miles of shoreline which are subject to critical erosion. Although this area is protected from the full effect of atlantic storms by the presence of Long Island, the shore lacks natural resiliency. The beaches are very narrow and offer little protection to the backshore which consists of erodible unsolidated materials. The sand moves offshore to form bars and spits, and little is returned naturally to the beach between storms because of the lack of beach-building swells.

Tidal flooding is a significant problem along the Connecticut coast although probably not as bad as in adjacent Rhode Island and New York. A recurrence of the tidal flood of record would produce damages of about $66 million. Hurrican protective structures have been provided at Pawcatuck, Stamford, Mystic and Westport. They would prevent an additional $12 million in damages and a funded project at New London would prevent an additional $4 million in damages. A variety of structural and non-structural devices to mitigate these damages have been studied by the U.S. Army Corps of Engineers.

Although not currently a difficulty, thermal effects are likely to become a major concern for this area in the near future. Several power plants now exist in this coastal area, primarily west of the Connecticut River, and indications are that others will be similarly situated to take advantage of a bountiful supply of cooling water as the demands for electrical power increase.

Coastal-related amenity needs for the Connecticut coast as a whole include preservation of shoreline, development of quality landscapes, protection of landscape diversity, and provision of clean water and urban amenities.

Area 13 - Southeastern New York - Metropolitan

General Characteristics. As shown in Figure 12.29, Area 13 contains the coastal areas of Long Island (Nassau and Suffolk counties) and the coastal reaches of the Hudson estuary (New York City and Westchester county). The Nassau-Suffolk area can be thought of as a 1,200-square mile, 20 mile wide peninsula extending 100 miles into the sea with an exposed Atlantic-oriented flank on the south and a semi-protected Sound-oriented flank on the North, with a combined coastline over 500 miles long. The Westchester coast and the western half of the Long Island coast are very irregular, with numerous deep bays and promontories. Eastward the coast becomes regular with very few indentations. Along the entire North Shore, beaches are generally narrow and rocky or pebbly, and usually front high bluffs or small marshes. Except at the heads of embayments, large wetlands are uncommon. Along the Sound, beaches make up 8 of the 42 miles of the coast in Westchester County, 5 of 18 in Nassau County and 75 of 87 in Suffolk County.

The East Shore, with 168 miles of shoreline between Orient and Montauk Points, is almost all beaches, many of which are gravelly and very narrow. They front low bluffs on the north fork and glacial headlands up to 240 feet high on the south fork. Wetlands are common, particularly along the westernmost part of this shoreline. The 108 mile South Shore consists of long 1/4-1/2 mile wide, sandy barrier beaches facing a strong Atlantic surf. Behind these barrier beaches, for almost the entire South Shore, are long, shallow, quiet backbays.

The Hudson estuary, known for its aesthetic appeal, comprises a few narrow strips of sand, marsh and railroad tracks behind which the land rises sharply and falls away inland into rolling forested highlands. Farther south, the steep cliffs of the Palisades across from upper Manhattan mark a transition into the busy urban atmosphere of New York Harbor. Much of the 290-mile shorefront is lined with piers, wharfs, and docks along the Harbor's bays and rivers. Behind the waterfront, urban structures dominate the view and symbolize the vigor of the commercial and industrial activity there. Numerous bridges, tunnels and airports give evidence to the intensity of flow of people and materials. Oceanward of the Verrazano Bridge, which marks the harbor entrance, the 28 miles of oceanfront is all beach. A net westward movement of sand along the barrier beaches of southern Long Island necessitates repeated dredging to maintain channels to New York Harbor.

The land form on this very urbanized area is undulating, with 21 percent of the landscape consisting of a town-farm pattern and the remainder in city units. Quality landscapes are limited to Westchester County and portions of the coastline.

AREA 13 SOUTHEASTERN NEW YORK METROPOLITAN AREA

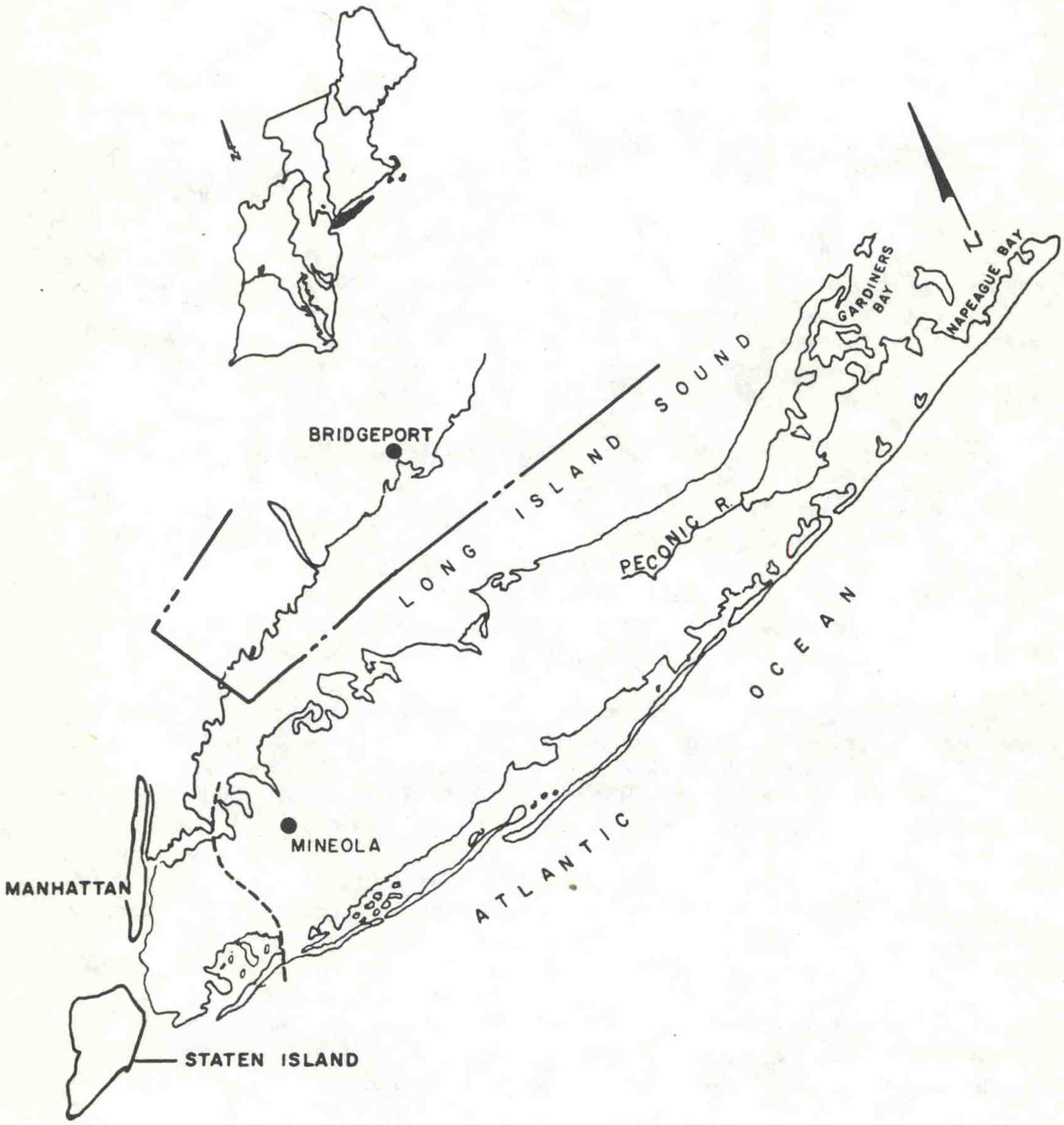

Figure 12.29 Regional map of the southeastern New York metropolitan area.

TABLE 24. Shore Ownership and Development. Area 13 - 1970*

Sector	Ownership (Miles) Federal	State/Local	Private	Development
Fort Wadsworth-Arthur Kill (Staten Island,N.Y.C.)	.3	9	3.7	primarily recreation/ residential, some commerce/ industry
Rockaway Inlet-Norton Point (N.Y.C.)	.02	35	1.6	primarily recreation,some commerce/industry/resi-dential/utility/educa-tional
E. Rockaway Inlet-Rockaway Inlet (N.Y.C.)	1	7	2	primarily recreation/ residential
South Shore (Long Island)	14	36	58	primarily recreation/ residential
South Shore Embayments (Long Island)	14.7	67.4	89.6	primarily recreation/resi-dential, some manufacturing/ commerce
East Shore (Long Island)	4	40	124	primarily recreation/ residential
North Shore (Long Island, and Suffolk Co.)	.2	16	70.8	primarily recreation/ residential, some commerce/ industry
North Shore (Long Island, Nassau Co.)	--	3.6	12.4	primarily recreation/ residential, some commerce/industry
Sound Shore of N.Y.C. (Westchester line to Throgs Neck)	--	10.6	7.2	primarily recreation/ residential,some commerce/industry
Sound Shore of Westchester County	--	9.3	32.4	primarily recreation/ residential (high income)

*Source: See note 12.

The pattern of shoreline ownership and development in the New York-Long Island Sector is shown in Table 24. Shoreline use in New York harbor and along the lower Hudson River is predominately commercial and industrial, whereas along the ocean front of New York City the predominant shoreline uses are residential and recreational. Annual attendance at beaches in New York City in recent years exceeds 30 million, even though water quality for swimming has been marginal at times. Staten Island beaches draw about one million annually, Coney Island about 10 million and the Rockaway beaches about 20 million. Probably the most significant use of the Long Island/Westchester coast is for human enjoyment in the form of outdoor recreation and aesthetic satisfaction. The long oceanfront beaches, especially, are ideal for most forms of beach and water-contact recreation. Where the oceanfront is made reasonably accessible and adequate facilities are provided, the public response has been great. For example, Jones Beach accommodated about 13 million visitors in 1969.

Population and Economic Base. A summary of population, personal income, earnings and employment for Area 13 is shown in Table 25, and for New York City in Table 26. Of the 1964 population of 11 million in Area 13, only 375,000 were classified as rural.

The population and economic data for the New York area read as a familiar litany of superlatives. In 1960, 8.6 million persons residing in New York City represented roughly one-fifth of the population of NAR with a density of 24,783 persons per square mile. This does not allow for the numbers that daily commute into the city. Population density in Westchester County was at 1,860 per square mile in 1960. On Long Island, population densities decrease in almost direct proportion to the distance from the City. The essentially residential character of the Island's development reflects its suburban relationship to the City. Except for a few summer-operated ferries and a low volume of air traffic, the Island is socially and economically isolated from New England, as almost all transportation points toward New York City. The screening effect of the time-distance from the city is very evident--the farther out on the island one goes, the more open is the terrain and natural aesthetic features become more prominent. The pressure of population spreading outward from the city, combined with major recent improvements in transportation, have made Westchester, Nassau and Suffolk Counties among the fastest growing counties in the nation. For example, in 1940 the Nassau-Suffolk population was less than 5% of the 12 1/2 million living in the New York region. By 1985 these two counties are expected to have about 15% of a 22 million population.

New York City is a regional, national and international center of trade. One-fourth of the nation's import-export volume passes through docks of the Port of New York including its New Jersey part. One-fourth of the nation's wholesale trade is conducted in New York, much of which

TABLE 25. North Atlantic Hydrologic Area 13. Population, Personal Income, Earnings and Employment Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	10,491,524	10,557,830	12,241,400	13,778,200	15,490,000
Total Personal Income (000-$58)	30,135,204		62,968,400	120,365,000	227,010,700
Per Capita Income ($58)	2,872		5,144	8,736	14,655
Per Capita Relative (US=1.00)	1.346		1.251	1.220	1.181
Total Earnings (000-$58)*	24,580,216		50,961,900	95,982,100	182,284,200
Per Worker Earnings ($58)	5,695		9,613	15,930	26,860
Per Worker Relative (US=1.00)	1.221		1.190	1.170	1.150
Population	10,491,524	10,557,830	12,241,400	13,778,200	15,490,000
Total Employment	4,315,770	4,345,600	5,301,100	6,025,400	6,786,400
Participation Rate (Empl/Pop)	.411	.412	.433	.437	.438
Employment by Selected Industries					
Agriculture + Forestry + Fisheries	16,935	10,800	6,800	4,300	
Mining	4,441	2,900	2,500	2,000	
Manufacturing	1,186,869	1,129,400	1,037,700	987,700	
Food + Kindred Products	104,303	89,600	78,900	71,600	
Textile Mill Products	48,678	37,500	25,900	18,600	
Chemicals + Allied Products	49,084	55,500	54,400	59,700	
Paper + Allied Products	32,498	33,300	32,100	33,000	
Petroleum Refining	7,909	3,200	1,400	800	
Primary Metals	19,962	24,600	25,500	26,300	
Armed Forces	21,036	13,400	10,800	9,200	
Other	3,116,319	4,144,600	4,967,600	5,783,200	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

is associated with the port. The city is a leading center of banking and financing of industrial and commercial enterprises. Manufacturing in the city is concentrated in apparel, printing and publishing. Also concentrated in the city are cultural, communications, governmental and educational institutions and facilities. Employment in 1960 for the five

TABLE 26. New York City; Population, Personal Income and Earnings, Projected for Selected Years, 1970-2020

	1970	1980	1990	2000	2010	2020
POPULATION	17,140,900	18,905,400	20,875,900	22,925,200	25,123,700	27,532,700
TOTAL PERSONAL INCOME(000-$58)	66,380,446	97,173,525	137,280,122	200,274,573	285,405,709	403,216,142
PER CAPITA INCOME($58)**	3873	5140	6576	8736	11360	14645
PER CAPITA RELATIVE(US=1.00)	1.27	1.25	1.23	1.22	1.20	1.18
TOTAL EARNINGS (000-$58) *	53,907,552	76,946,787	106,833,235	154,188,127	219,144,100	309,428,283
PER WORKER EARNINGS($58)**	.7572	9615	12260	15930	20683	26864
PER WORKER RELATIVE(US=1.00)	1.20	1.19	1.18	1.17	1.16	1.15

* INCLUDING ARMED FORCES PAY

EMPLOYMENT BY SELECTED INDUSTRIES, 1970-2020

	1970	1980	990	2000	2010	2020
POPULATION	17,140,900	18,905,400	20,875,900	22,925,200	25,123,700	27,532,700
TOTAL EMPLOYMENT	7,119,300	8,002,800	8,714,000	9,679,100	10,595,400	11,518,300
PARTICIPATION RATE(EMPL/POP)	.42	.42	.42	.42	.42	.42
AGRICULTURE,FORESTRY + FISHERIES	31,800	28,200	24,500	21,800	19,100	16,300
MINING	5,500	5,200	5,100	4,900	4,700	4,500
MANUFACTURING	1,922,100	1,915,100	1,893,900	1,899,500	1,910,500	1,933,500
FOOD + KINDRED PRODUCTS	149,400	144,300	139,500	136,500	133,200	131,500
TEXTILE MILL PRODUCTS	76,800	66,500	57,400	50,200	44,100	39,000
CHEMICALS + ALLIED PRODUCTS	147,200	151,000	152,100	168,100	183,200	197,300
PAPER + ALLIED PRODUCTS	59,200	61,300	62,100	64,600	68,400	72,000
PETROLEUM REFINING	14,100	9,800	6,500	4,900	3,900	2,900
PRIMARY METALS	60,100	66,900	71,600	77,000	81,800	86,200
ARMED FORCES	31,500	30,400	30,400	30,400	30,400	30,400
OTHER	5,128,300	6,023,900	6,760,100	7,722,500	8,630,700	9,533,600

0 TOO SMALL TO BE PROJECTED BUT INCLUDED IN HIGHER LEVEL TOTALS
** COMPUTED FROM UNROUNDED DATA

boroughs and Westchester County was proportioned 28% in manufacturing 67% in services and 4% in contract construction. By 2020, the largest increase in employment expansion is expected to occur in service industries at the expense of the manufacturing sector.

Land Use. A land-use and water summary for Area 13 is shown in Table 27, which lists total surface areas together with amounts and percent distribution of types of surface coverage in 1963. In that year, 658 square miles (34%) of the area's total land was intensively developed, while 6 percent was devoted to crop production with 1,422 commercial and 240 non-commercial farms. Also in 1963, there were 345,000 acres of commercial forest in the area, of which 342,000 acres were farm-owned or private.

TABLE 27. Land Use and Water Area NAR Area 13 - 1963

Cover Type	Amount (thousand acres)	Percent Distribution
Cropland	63	5
Pasture	4	-
Forest	361	30
Urban	548	45
Water		
-over 40 acres	163	13
-under 40 acres	1	-
Other	77	7
TOTAL	1,217	100

With respect to mineral extraction in Area 13, commercial products include sand and gravel, clays, stone, emery and peat. In 1969, the combined value of production of these minerals was almost $10 million and was generated exclusively in Nassau, Suffolk and Westchester counties.

There are a few undeveloped areas on the shore of New York City that approximate a natural condition. The extensive tidal marsh of Jamaica Bay shelters migrating waterfowl and small marine life, ringed as it is by major airports and city beaches, parks and open space, and urban development. In the southwestern corner of the bi-county area, the demand for residential lands has put increasing pressure on the easy-to-fill wetlands, but in recent years, this use has been increasingly arrested. For the Nassau-Suffolk area, as a whole, about 62% of the land and water surface may be considered broadly as open space and 38%, broadly, as developed. Within the open-space category are vacant (33%) water (14%), agricultural (8%), and recreational (7%). Within the developed category are residential (21% overall, 45% in Nassau County), roadways (8%), institutions (4%), transportation, utilities, and communication (3%), commercial (1%).

Public Utilities. In 1965, approximately 10.7 million people, or 97 percent of Area 13's population of 11 million, were connected to 110 central water supply systems, which distributed an average of 1,404 m.g.d. Approximately 75 percent of this total was derived from surface sources and the remaining 25 percent developed from ground water supplies. Presently available water resources in the area are 623 m.g.d., and diversions from Area 12 (Hudson River) and Area 15 (Delaware River) are relied on to provide the bulk of the surface water supply. Total

practical development of Area 13's water resources is estimated at 1,212 m.g.d.

Area 13's total industrial water intake is 276 m.g.d., of which 13 m.g.d. are self-supplied, 90 m.g.d. are publicly-supplied and 173 m.g.d. are brackish. Self-supplied industrial water is low in this area with the three largest users, transportation equipment, electrical equipment and metal products, utilizing 5 m.g.d., 3 m.g.d. and 2 m.g.d., respectively. Brackish water is used extensively in the area, with the chemicals, food, petroleum and primary metals industries the major users. Livestock and rural requirements are 20.7 m.g.d. Other uses of water supply are for farmland irrigation (37,900 acres) and non-agricultural irrigation (17,900 acre feet), and all of the water used for these purposes comes from ground water.

The electric power requirements of Area 13 during 1969 were met by 10,608 megawatts of installed generating capacity. The distribution of this capacity by type of prime mover, together with scheduled or planned additions for the area through 1975, is shown in Table 28.

TABLE 28. Total Electric Generating Capacity (1969) and Planned Additions (1975) - Area 13 (MW)

Generator Type	1969	1975+
Steam Electric		
- Nuclear	--	850
- Fossil	10,201	2,523
Hydroelectric	--	--
Internal Combustion Gas Turbine	407	1,967
TOTAL	10,608	5,340

Major Coastal Uses. As shown in Figure 12.30, the development of the highways and railroads in Area 13 certainly support navigation development, but are not considered strongly complementary because of metropolitan congestion and bottlenecks. All traffic entering or leaving Area 13 must pass through a portion of New York City, except during the summer when motor vehicles can take advantage of ferry services operated on Long Island Sound. The railroad may be the best form of year-round transportation because special bridges and tunnels provide expedient passage from New York City to multiple and single tracks which extend the length of Long Island along each of its shores and through its central area. High-speed, heavy-duty highways are found in the central and western portions of Long Island, but there is no high-speed movement in the vicinity of New York City. A petroleum pipeline extends from

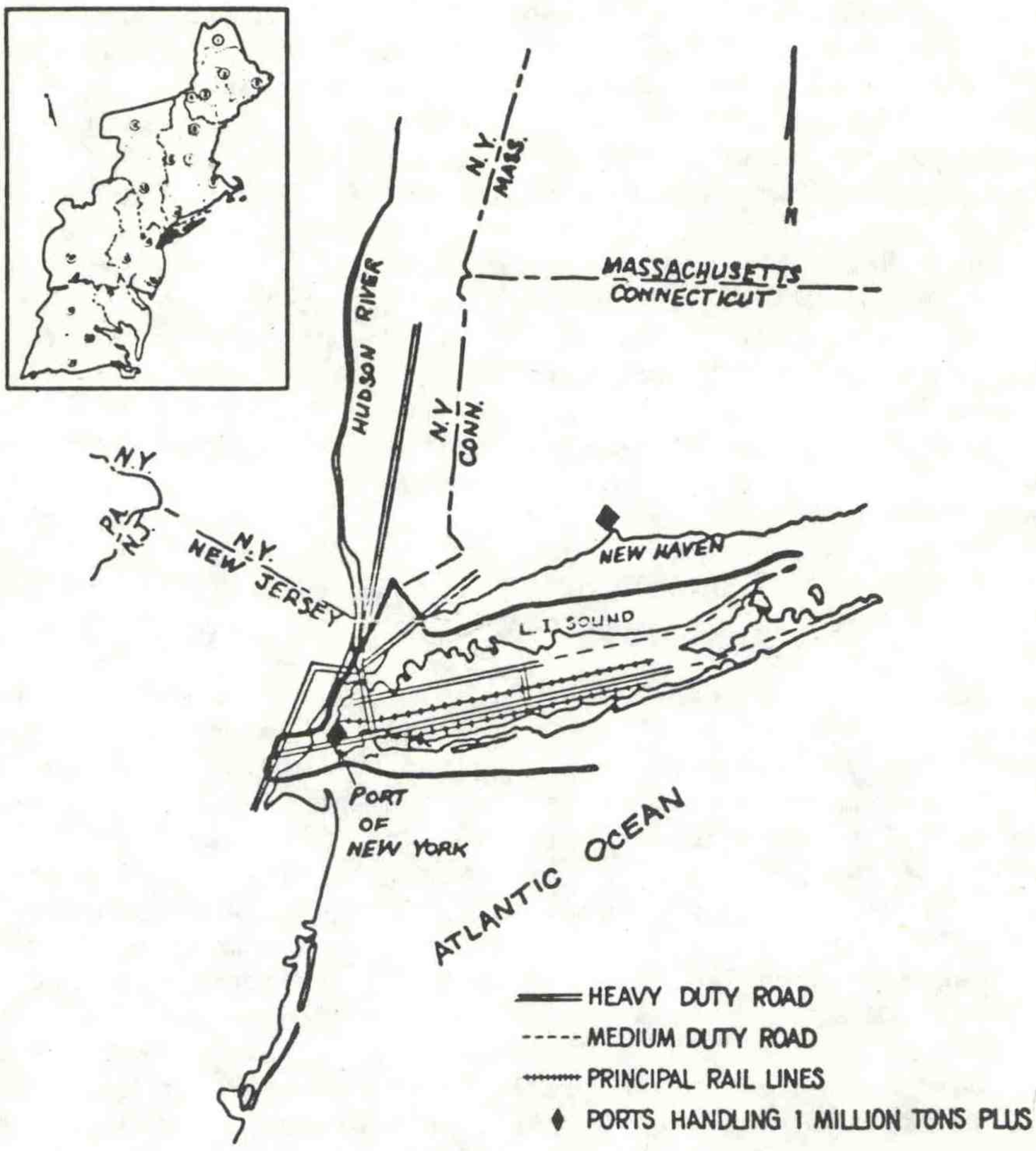

Figure 12.30 The transportation system of the southeastern New York metropolitan area.

Area 14 to Jamaica Bay in the vicinity of Kennedy Airport on the South Shore of Long Island. Rail and highway movement is very good to population centers outside of Area 13.

The waterways in and around Area 13 are extremely favorable to navigation because they are inter-connected and provide well-protected access to surrounding areas. The Hudson River lies to the northwest, Long Island Sound lies to the north, the East River and New York Bay to the west, and the Atlantic Ocean to the south and east. Long Island Sound has natural depths well in excess of 80 feet, only a few hundred feet from the shore in many locations. The East River and New York Bay have been improved extensively. Minimum depths in the East River's main channel are 35 to 40 feet, 40 to 45 feet in the upper Bay, and 45 feet in the lower Bay. The South Shore of Long Island is separated from the deep water of the Atlantic Ocean by an extensive barrier beach system and wide shallow bays. The Hudson River extends from New York City to Albany, and has a minimum depth of 32 feet and widths ranging from 400 to 600 feet. Reported vessel traffic in the area follows national trends. The number of tankers has remained approximately constant since 1955, but the commerce transported has increased several million tons, indicating the use of larger ships. Cargo vessel trips have fallen off by 90% since 1955, and barge traffic has declined by 60%, reflecting the use of vessels of greater capacity and increased harbor efficiency which is reducing local inter-harbor transfers.

Production in Area 13 does not support waterborne commerce because there is primarily light manufacturing in metals and plastics, and large manufacturing in textiles. The demand for and consumption of commodities, on the other hand supports navigational development to a degree unequaled anywhere else in the United States. Over 9 million people live within 10 miles of the port facilities of New York City alone, creating an effective average density of 26,000 per square mile. A commodity used only occasionally by the average individual may be a commodity that can be profitably shipped when its demand is being generated by so many individuals.

Commercial navigation in Area 13 is based primarily in the western portion of the area and is a significant aspect of the landscape. The Port of New York, which includes New York City and the adjacent parts of New Jersey, is the largest port complex in the United States. It handles three times the tonnage of all West Coast ports combined. Within the North Atlantic Region it handles twice the tonnage of the next largest port system, the ports along the Delaware Estuary. Within the Port of New York, however, the annual growth rate of the New York City share has dropped over the period 1955 to 1968 to only 0.4% annually. Because of the relative advantages of the New Jersey ports for accommodating containerized freights and bulk products, future growth will most likely occur on that side. Waterborne commerce between Albany and New York City is declining at an accelerating rate. It consists of fuel and

and construction materials. Passenger pleasure cruise traffic in New York ports had dwindled; pleasure cruises now commonly originate at southern ports for Caribbean cruises.

The East River passes through the heart of New York, with spur channels designed for barge traffic leading into adjacent creeks and rivers, such as the Harlem River. From Upper New York Bay to the Brooklyn Naval Yard on the East River, a distance of 2.5 miles, the channel has a depth of 40 feet. Excluding facilities at the Brooklyn Naval Yard, there are about 140 wharves or piers along the East River, more than 30 of which have adjacent depths compatible with the depth of the waterway. They are used for general cargo, coal, sugar and fuel oil and are supported by petroleum storage of 250,000 tons (90% accessible to wharves with adjacent depths of at least 37 feet), and covered storage of 1.8 million square feet. Many rapid transit tunnels and aqueducts cross the East River limiting channel dredging to about 40 feet below mean low water. Pipelines and cables cross the river and generally lie on or near the existing river bottom. Bridges provide at least 700 feet of horizontal clearance and 127 feet of vertical clearance.

Upper New York Bay is at the head of the East River, and the portion located in Area 13 includes the Buttermilk, Red Hook and Bay Ridge Channels, which are all 40 feet deep. There are about 75 facilities along these channels, 18 of which have adjacent depths of 35 feet or more, and several are served by rail. They are supported by 5.5 million square feet of covered storage, and tend to be specialized for general cargo or marine repairs. Gowanus Creek, an offshoot of the Bay Ridge Channel, has depths declining in stages from 30 feet to 9 feet. Along Gowanus Creek, there are about 60 facilities, most of which are designed for barges, although two have adjacent depths of 35 feet. These facilities are supported by covered storage of 1 million square feet and petroleum storage of 12,000 tons.

In contrast to nearby New York and Connecticut, the Nassau-Suffolk-Westchester area has really no major ports. Of about 12 million short tons handled in this area in 1968, most was accommodated at Hempstead Harbor (5 million), Port Jefferson (2 million), and Port Chester-Westchester Creek (2 million). The receipt of petroleum products and the shipment of sand accounted for almost all of the total. Essentially, all the tonnage is accommodated on the North Shore. Long Island Sound provides a protected waterway primarily for the movement of refined petroleum products from northern New Jersey to the southern New England ports. Car ferries at Port Jefferson and Orient Point move a low volume of traffic to Connecticut and this is only during the summer months. Several ferries link Fire Island, Plum Island and Shelter Island to Long Island. A few of them run all year around.

The commercial fish catch in Area 13 has fluctuated widely over recent years, as it has in most coastal areas. The fluctuations are

especially prominent on a species-by-species basis. In 1968 the dock-side value of the commercial catch was $14.3 million. More than three-quarters of this total was represented by shellfish. Hard clams, almost all of which came from Great South Bay, accounted for about two-thirds of this value with the next most commercially significant species, sea scallops and Northern lobsters, trailing far behind. Among the finfish the most valuable species were the scup, yellowtail flounder, and fluke, but none of these species had a value even close to any of the three shellfish species mentioned.

The most important non-living resources, by far, are fresh water and sand. Like most islands with granular soils, Long Island has a very large lens of underground freshwater, with a defined freshwater-saltwater interface which advances and retreats with variations in precipitation and extraction. The aquifer is one of Long Island's most important natural resources and it supplies all of the freshwater in the bi-county area, but in view of increased requirements estimated in the future, some major problems can be foreseen. To meet requirements in the market area, Long Island's production of sand and gravel has recently averaged about 14 million short tons annually. Most of this is sand, whereas gravel needs are met by imports. The problem on Long Island is to extract the sand in an environmentally acceptable way.

The coastal sectors of Area 13 are called upon to satisfy a wide spectrum of marine recreation needs. During the summer of 1965, an estimated[15] 82 million man-days were devoted to swimming, 10.2 million to boating, 1.7 million to sailing, and 1.4 million to water skiing. The offshore waters are particularly suitable to boating. For shallow-draft craft such as rowboats, motorboats and small sailboats, the South Shore bays have a special appeal. The deeper-draft, hardier, marina-based craft such as cabin cruisers and most sailboats prefer the deeper, broader, but semi-protected waters of the Sound and East Coast. On calm days, the larger recreational craft from the North Shore and Connecticut visit each other's shorelines to fish and put ashore. Sports fishing is closely related to boating and is most prominent along the East Coast. In addition to its recreational aspects, it has a commercial value probably greater than its commercial fishing counterpart. The total number of recreational craft is projected to increase to 491,000 by the year 1980, with 286,000 of these registered.

All of the coasts provide seasonal aesthetic relief from the metropolitan areas where the people work and the residential areas where they live. On the South Shore, fresh salt air, cooling breezes, glimpses of the ocean and nearby undisturbed expanses of wetlands provide a multi-dimensional appeal. The North Shore with its many high promontories

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15 Average Mid-Atlantic participation rates X (times) 1964 population.

emphasizes visual appeal, enhanced by its many coves and the flotilla of sails which speckle the waters during the summer. The East Coast, more than any of the others, has managed to tailor its development to conform aesthetically to its marine environment. Much of its quaint charm stems from its architecture and numerous boat landings which transmit the tang of the sea to the beholder.

Coastal waters of the area are heavily used to dispose of liquid sanitary wastes, solid wastes, and waste heat from industrial cooling water discharges. Table 29 shows the organic waste loads in Area 13 from 97 non-industrial and 42 industrial sources known in 1960, as expressed in population equivalents for existing treatment levels in that year. The waters offshore of the area are used as repositories for certain solid wastes generated in New York harbor such as incinerator residue, sewage sludge, dredged spoils, flyash and construction rubble totalling 9.6 million tons in 1968. Several large thermoelectric generating stations located in New York City use the coastal waters for condenser cooling.

TABLE 29. Organic Waste Loads in Area 13 - 1960

Load Type	Waste Load (Pop. Equiv.) (thousands)
Non-Industrial	4,200
Industrial	7,100
TOTAL	11,300

Major Coastal Problems. There are a number of highly significant coastal problems in this area, including conservation of wetlands, waste disposal, recreation, coastal erosion and tidal flooding, and marine transportation. During the period 1954-1964 Nassau and Suffolk Counties lost 8,200 acres of marshland, 24% of their 1953 total, to landfill. Most of the fill was for residential development and dredging spoil disposal. The pressure for increased filling is reflected in the market value for filled coastal land, about $5,000 to $15,000 an acre. To counter these pressures increased governmental awareness at all levels from the community to the federal government is required and is apparently emerging.

Solid waste disposal is becoming a critical problem in this area. New York City and Westchester County have for some years now relied on landfill for disposing of municipal trash and garbage. The capacity at present landfill sites is expected to be depleted with the next four to seven years. Additional landfill sites on the coastline are not politically feasible.

Another major coastal resource problem in this area is the deteriorating recreational value of the shoreline and waterfront in New York City, where recreational fishing and swimming on otherwise suitable shores are discouraged because of microbial pollutants, and discoloration and odors from chemical pollutants. The southern shoreline of Staten Island and Brooklyn south of the Narrows are the principal areas of concern. Another form of pollution impairing recreational value is the littering and cluttering of the shore by junk oil, abandoned cars, and rotting timbers from disintegrating waterfront structures. On Long Island, the recreation problem is how best to accommodate the outdoor water-based recreational and aesthetic needs of a rapidly growing population. Problems in meeting this demand include the seasonal disuse of the resources (about three-quarters of the year); the inferior beach quality of most of the North Shore, East Shore and backbay coastline; the desire to provide both high and low density beach recreation; and some limitations of access.

The problems of coastal erosion and flooding are especially significant in Area 13. On Long Island, erosion is considered critical on most of the South, East and North Shores. It is minor on the Westchester and backbay shorelines. Along the Atlantic, the shoreline has moved significantly over the past century and a half. The tip of Fire Island has swung alternatively seaward and shoreward a half mile. Because of hurricanes, storms and a southwestward littoral drift - which moves 600,000 cubic yards annually by Fire Island inlet - the ocean shoreline has been eroding in recent years at an average rate of about 3-10 feet a year. On the North Shore the rate has been slower, about 1-2 feet a year for the last century. In New York City, it has been estimated that if a serious hurricane should strike New York Harbor, it would cause, in 1958 dollars, about $2.5 billion in direct damages and a similar amount in indirect damages. About 69% of this damage would occur in the New York City parts (Area 13) of the Harbor and about 40% in the New Jersey part of the Harbor (Area 14). No plan could prevent all these damages, but the potential for very great benefits is evident and is now being studied. Just the provision of emergency plans for excavating and protecting the New York City subway system from inundation and a disastrous loss of life could produce truly tremendous benefits someday.

With regard to marine transportation, the rapid evolution towards economical, very deep-draft tankers and dry-bulk carriers presents special problems to the Port of New York, part of which is located in Area 13. The inadequate depths of existing channels, the probably prohibitive costs of deepening the channels substantially, possible environmental effects, social problems related to possible dislocations of industrial bases closer to a future deep-water facility, and other intraregional implications--all point to the need of a cooperative study involving federal agencies and the affected port authorities to work out a long-range solution.

Subregion C. Area 14 - Northern New Jersey

General Characteristics. As shown in Figure 12.36 this area includes the basins of northeastern New Jersey beginning with the shore of the Hudson River and including the Hackensack, Passaic and Raritan basins, Newark Bay and the New Jersey portions of the channels around Staten Island - Arthur Kill and Kill Van Kull. The area is characterized by low flat topography and extensive tidal marshes, many of which have been reclaimed with landfill. The cliffs of the Palisades along the Hudson comprise the major natural topographic feature in the coastal zone. Nearly two-thirds (1500 sq. miles) of Area 14 consists of rolling hills with the balance (800 sq. miles) in undulating land. Over 52 percent of the area consists of city landscape units (1200 sq. miles), and intensive urban development -- piers, skyscrapers, bridges -- is the predominant characteristic of the coastal reaches. The remainder of the area consists of Town-Farm (800 sq. miles) and Forest-Town (300 sq. miles) landscape patterns, two thirds of which have a combined quality rank of low with the rest evaluated as of medial quality.

Population and Economic Base. A summary of population, personal income, earnings and employment for Area 14 over the period 1959-2020 is shown in Table 30. Of the 1964 population of 4.4 million, only 263,000 was classified as rural. Over two-thirds of the total New Jersey population reside in Area 14, where the population is a high 13,752 per square mile. By 2020 the population of the area is expected to reach 8.4 million inhabitants.

Employment in the area was 1.6 million in 1960 and is expected to double by the year 2020. Personal income in 1960 was well above the national average in the area (by 23%) and projections indicate that it will remain so, decreasing slightly to 15% above the national average in 2020. In 1960 manufacturing accounted for 40% of employment, and services accounted for 58%. The major urban centers in the area are Newark, Jersey City and Patterson-Clifton-Passaic. Manufacturing industries were principally machinery, electrical products, primary and fabricated metals, chemicals and food products. Employment in natural resource extraction industries-- mining, fishing and agriculture--was only 0.9% in 1960 and is expected to decrease by 50% by 2020. Manufacturing by 2020 is expected to increase by 15% and the largest increase (163%) should occur in the service industries to constitute 77% of all employment by 2020.

Land-Use. A land use and water area summary for Area 14 is shown in Table 31, which lists total surface areas together with the amounts and percent distribution of types of surface coverage in 1963. In that year, 408 square miles (18.4%) of the area's total land was intensively

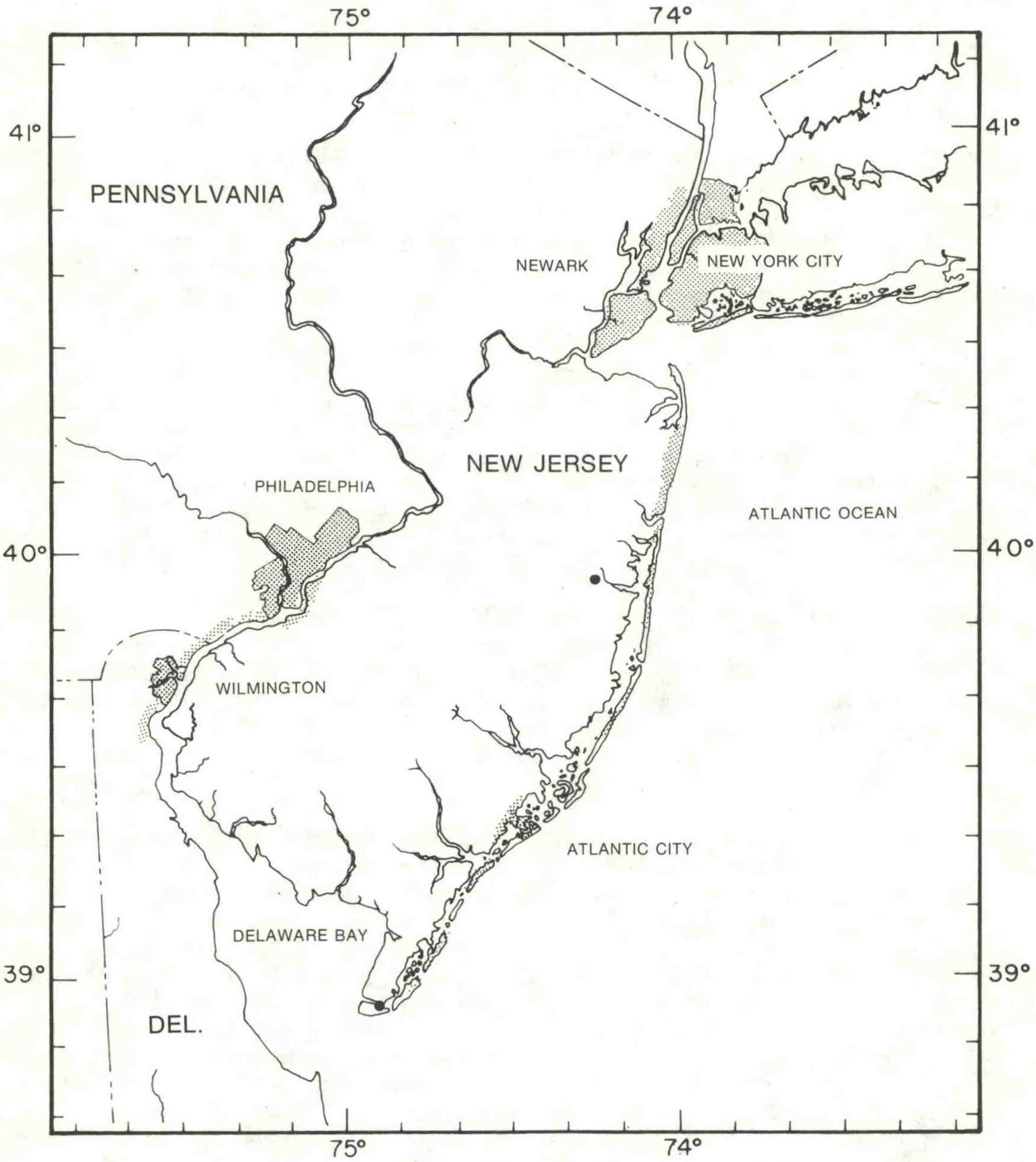

Figure 12.31 Major residential locations, coastal and offshore areas, New Jersey and environs.

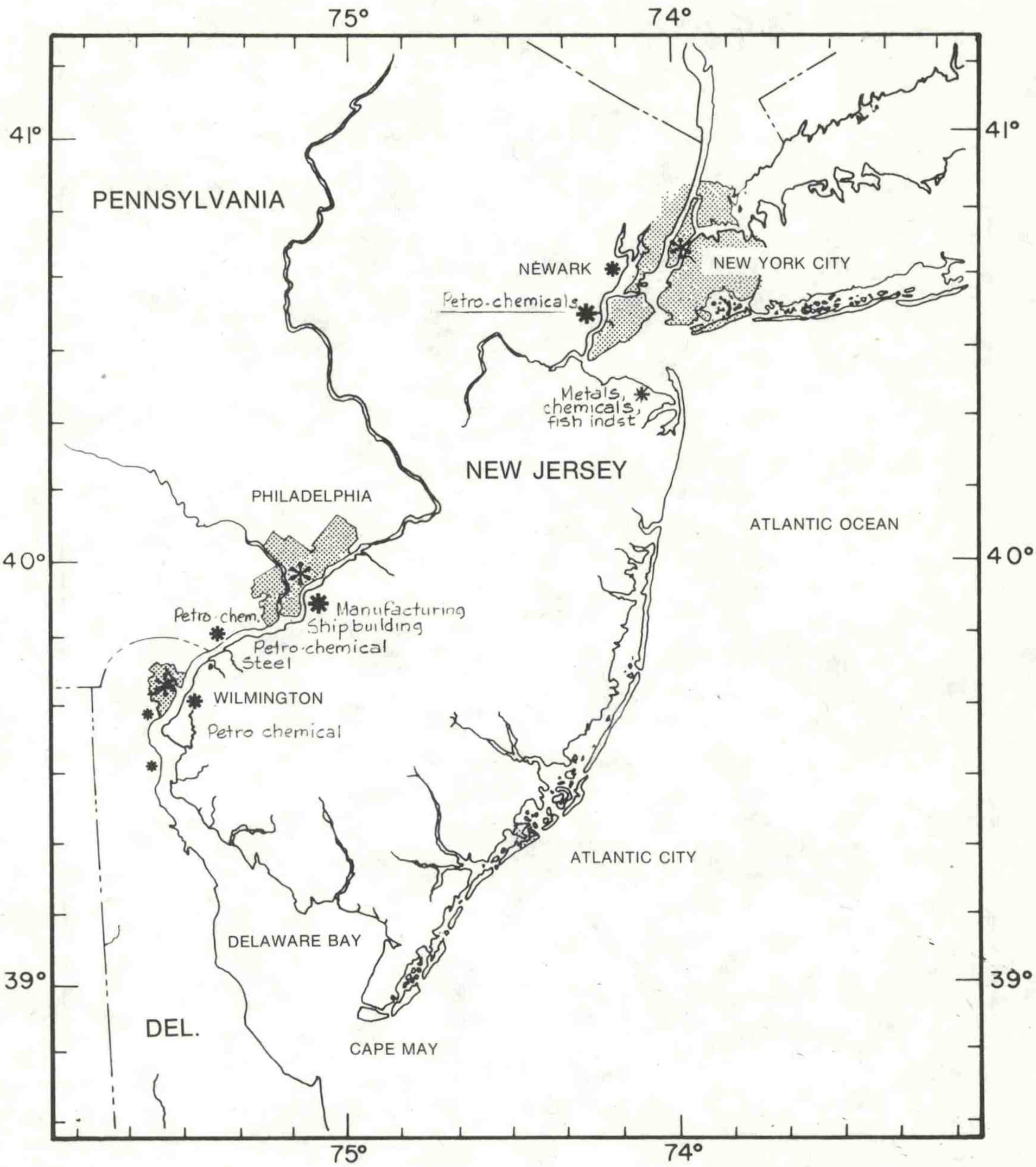

Figure 12,32 Major industrial locations, coastal and offshore areas, New Jersey and environs.

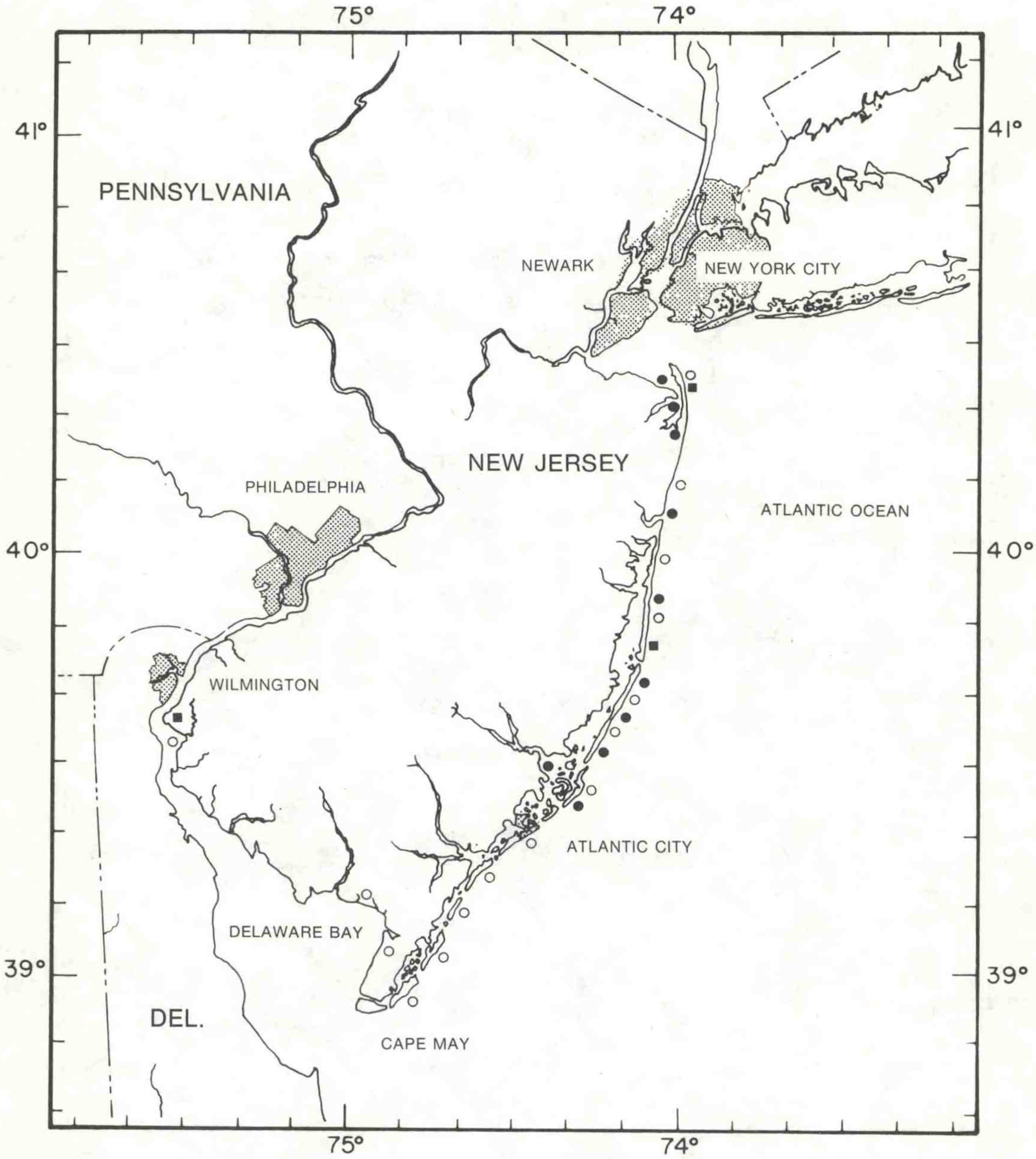

Figure 12.33 Major recreation locations, coastal and offshore areas, New Jersey and environs.

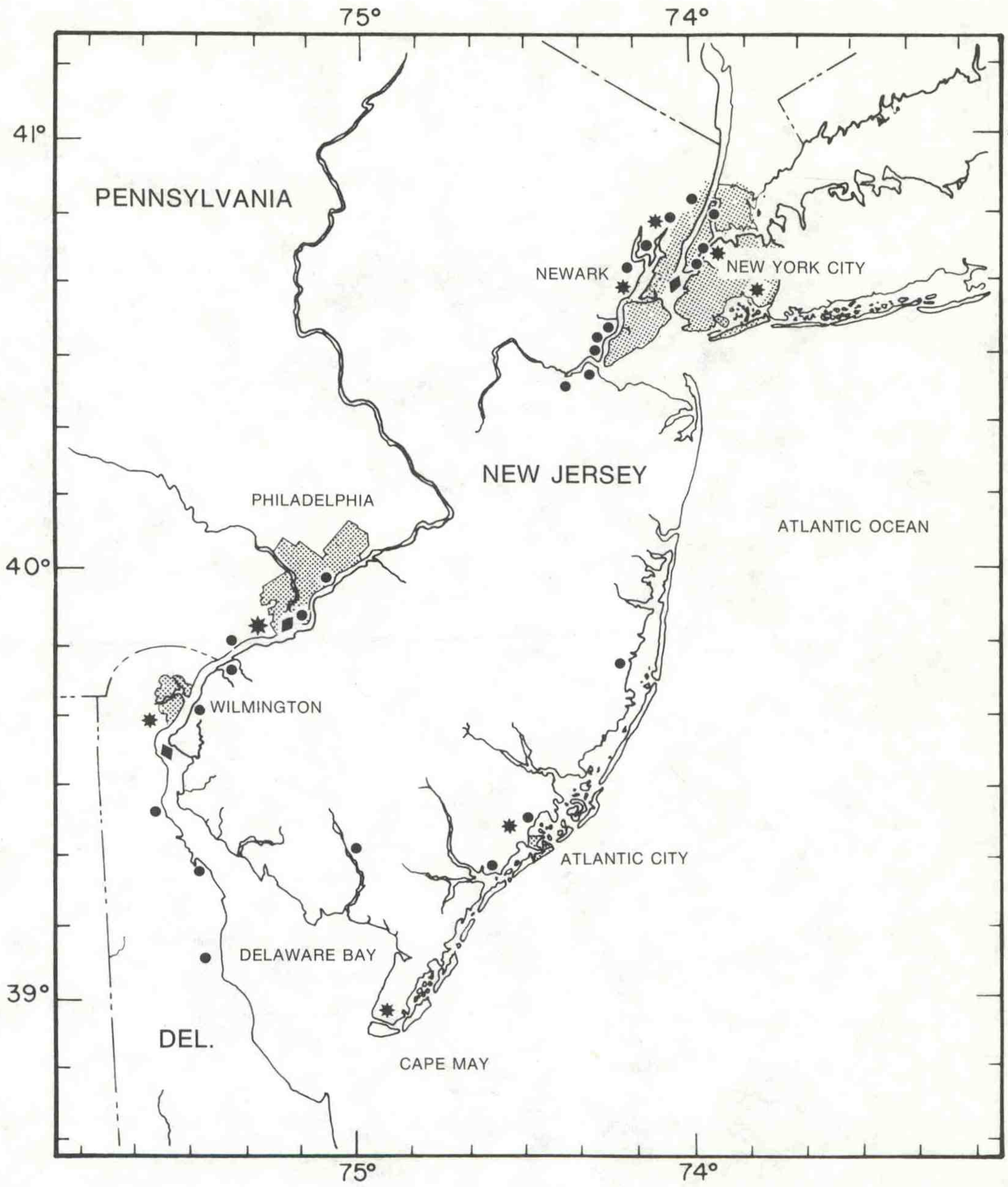

Figure 12.34 Major transportation and utility facilities, coastal and offshore areas, New Jersey and environs.

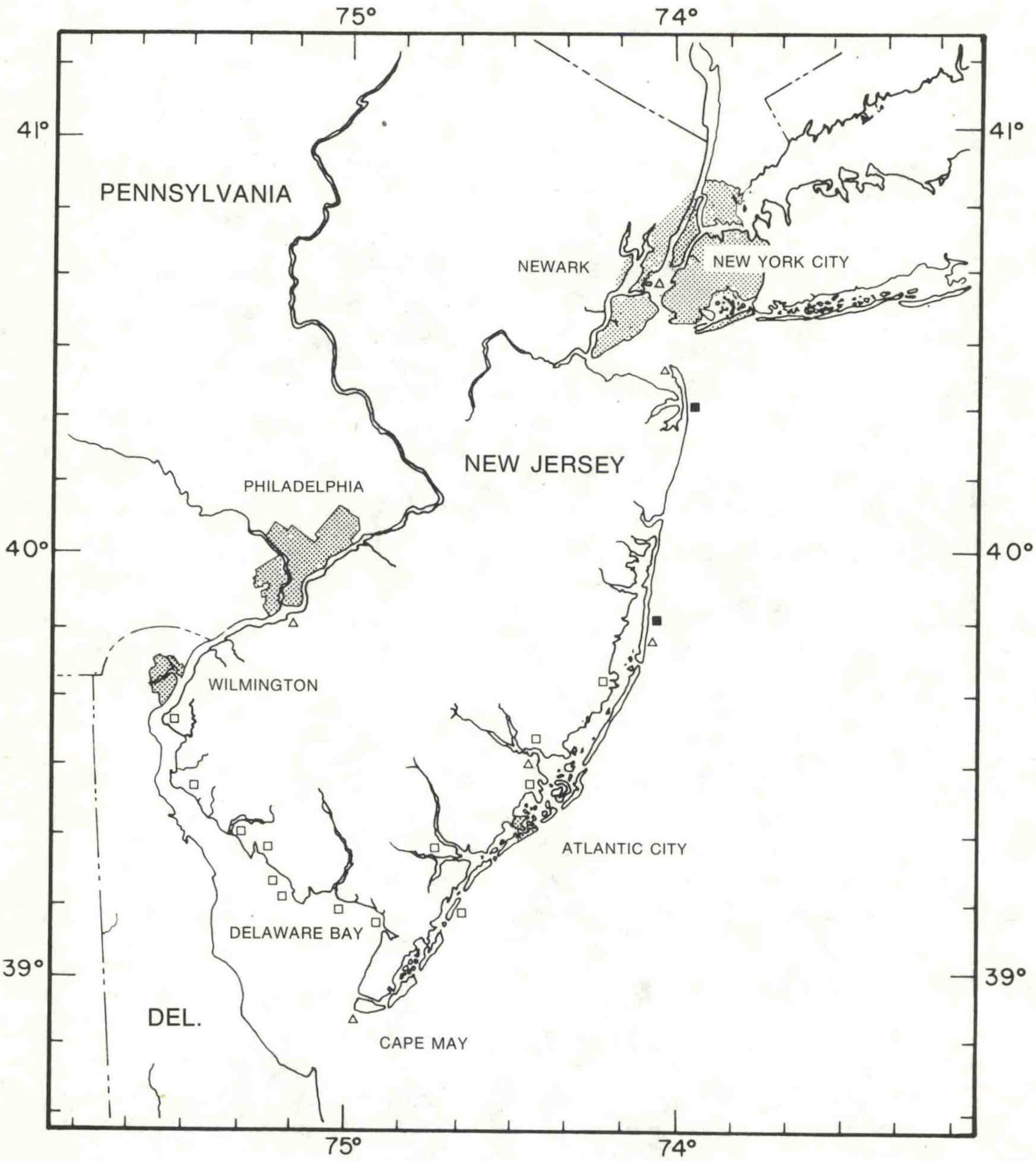

Figure 12.35 Major open-space and scenic areas, coastal and offshore areas, New Jersey and environs.

AREA 14 NORTHERN NEW JERSEY

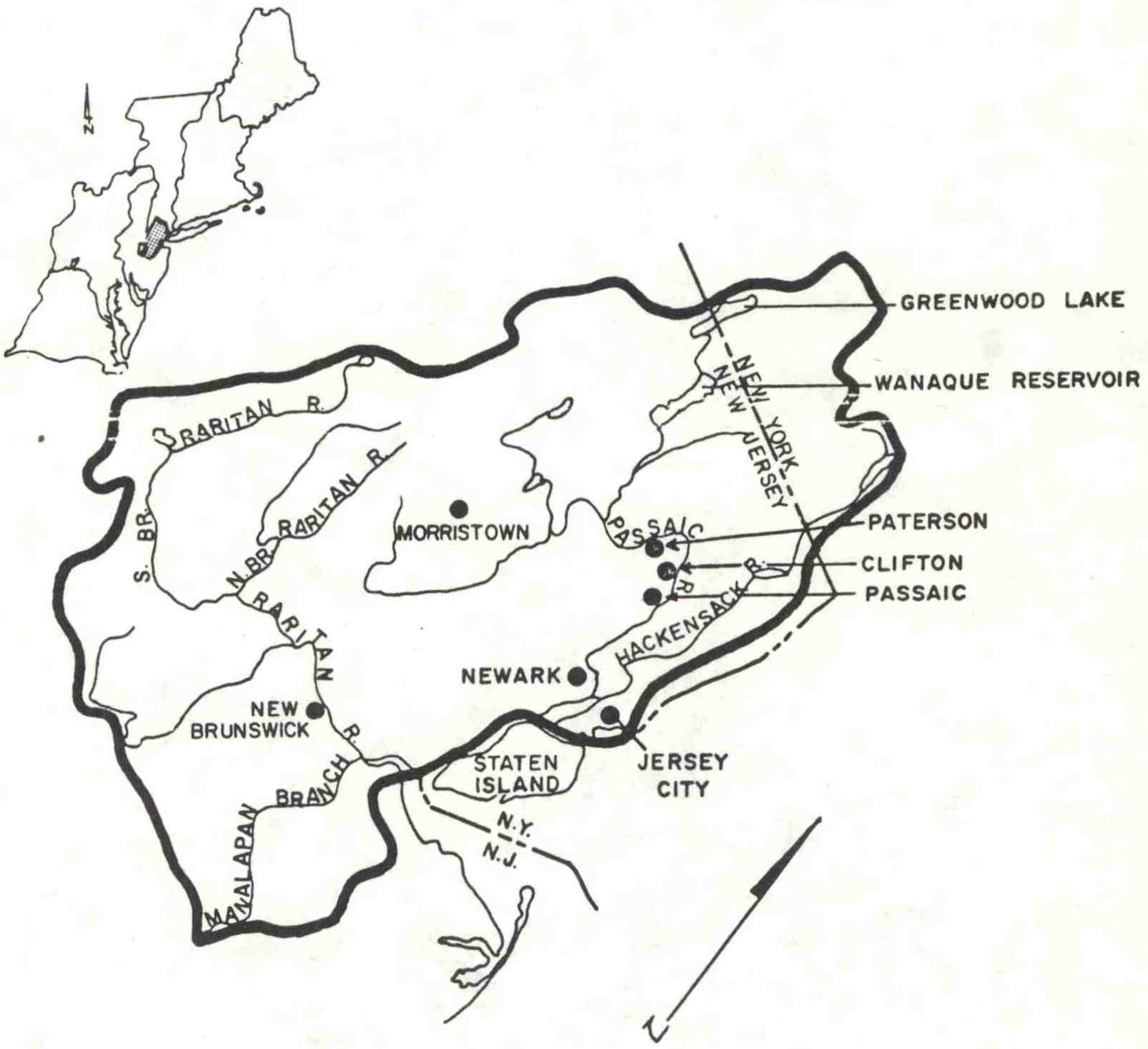

Figure 12.36 Regional map of northern New Jersey.

TABLE 30. North Atlantic Hydrologic Area 14. Population, Personal Income, Earnings and Employment Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	4,083,764	4,118,903	5,192,000	6,720,000	8,427,300
Total Personal Income (000-$58)	11,547,829		26,586,000	58,475,600	122,962,200
Per Capita Income ($58)	2,828		5,121	8,702	14,591
Per Capita Relative (US=1.00)	1.325		1.245	1.215	1.176
Total Earnings (000-$58)*	9,418,567		20,534,100	43,162,000	89,287,600
Per Worker Earnings ($58)	5,748		9,593	15,904	26,829
Per Worker Relative (US=1.00)	1.232		1.187	1.168	1.149
Population	4,083,764	4,118,403	5,192,000	6,720,000	8,427,300
Total Employment	1,638,472	1,649,615	2,140,500	2,713,900	3,328,000
Participation Rate (Empl/Pop)	.401	.401	.412	.404	.395
Employment by Selected Industries					
Agriculture + Forestry + Fisheries		11,921	8,100	5,800	4,100
Mining		2,118	1,500	1,400	1,300
Manufacturing	657,492	679,100	715,400	755,100	
Food + Kindred Products	50,328	46,900	47,300	47,500	
Textile Mill Products	27,807	23,200	18,400	14,600	
Chemicals + Allied Products	76,239	82,400	94,900	109,800	
Paper + Allied Products	21,855	24,300	26,900	30,600	
Petroleum Refining	14,354	6,200	3,200	1,900	
Primary Metals	29,365	39,100	46,300	52,900	
Armed Forces	3,533	2,500	2,300	2,200	
Other	974,551	1,449,300	1,989,000	2,565,300	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

TABLE 31. Land-Use and Water Area - Area 14 - 1963

Cover Type	Amount (Thousand acres)	Percent Distribution
Cropland	229	15
Pasture	45	3
Forest	588	39
Urban	448	29
Water		
- over 40 acres	40	--
- under 40 acres	8	3
Other	162	11
TOTAL	1,520	100

developed, while 15.6 percent was devoted to crop production with 2,083 commercial farms and 792 part-time or retirement farms in operation. Also in 1963, there were 520,000 acres of commercial forest in the area, of which 6,000 acres were publicly-owned and 514,000 acres were farm-owned or private. With respect to mineral extraction in Area 14, the most significant commercial products are sand and gravel, stone and clays. In 1969, the estimated combined value of production of these minerals was well in excess of $33 million.

Public Utilities. Approximately 4.1 million people, or 94 percent of the area's 1964 population, are connected to some 180 central water supply systems, which deliver an average of 513 m.g.d. Seventy-six percent of this water comes from surface sources, with the remainder developed from ground water supplies. Diversion from Area 15 (Delaware River) accounts for a small portion of the surface water supply in the area. Presently available water resources in the area comprise 852 m.g.d., andthe total practical development is estimated to be 1,496 m.g.d.

The total industrial water intake in Area 14 is 1,046 m.g.d. of which 278 m.g.d. are self-supplied, 60 m.g.d. are publicly-supplied, and 708 m.g.d. are brackish. The chemical and paper industries are the major water users in the area with respective self-supplied intakes of 110 m.g.d. and 75 m.g.d. Other significant self-supplied water-using industries include transportation equipment (14 m.g.d.), machine equipment (13 m.g.d.), primary metals (12 m.g.d.), and fabrics (10 m.g.d.). The brackish water intake is mainly for the chemical and petroleum industries. Livestock and rural domestic water requirements are 15.4 m.g.d. Other uses of water supply are for farmland irrigation (8,850 acres) and non-agricultural irrigation (11,200 acre-feet). About 55 percent of the agricultural water comes from ground water and 45

percent from surface water sources. The predominant source of non-agricultural water is from ground water.

The electric power requirements of Area 14 during 1969 were met by 5,261 megawatts of installed generating capacity. The distribution of this capacity by type of prime mover, together with scheduled or planned additions for the area through 1975, is shown in Table 32.

TABLE 32. Total Electric Generating Capacity (1969) and Planned Additions (1975) - Area 14 (MW)

Generator Type	1969	1975+
Steam Electric		
-Nuclear	4,776	472
-Fossil	6	122
Hydroelectric		
Internal combustion/ Gas Turbine	479	1,740
TOTAL	5,261	2,334

Major Coastal Uses. Marine transportation and urban land use, waterborne and solid waste disposal are of special importance in this area's coastal zone.

Commercial navigation is one of the most important activities in Area 14, and its waterborne commerce is at one of the highest levels of the entire North Atlantic Region. Commercial navigation directly supports industries which are major water users, including several power companies. As shown in Figure 12.37 land transportation tends to support navigation in Area 14. Multiple rail lines extend in all directions, linking Area 14 to every major city in the Region and the major rail systems to the north, west and south. Large rail switching yards are located within minutes of the port facilities. Several multiple-land, heavy-duty, high speed roadways provide north-south movement, but the construction of east-west roadways is incomplete. Pipelines for petroleum and natural gas extend into Area 14 from the south and west and provide for the movement of millions of tons of fuels annually. Petroleum pipelines extend from Area 14 to Area 13 to satisfy airport fuel requirements.

Most of the principal waterways of Area 14 are commercially developed and have dimensions suitable for deep-draft vessels. Newark Bay has a project depth of 35 feet for its entire length. The Hackensack and Passaic Rivers, which empty into Newark Bay, have depths ranging from 10 to 32 feet. The Raritan River, which empties into lower New York Bay, varies from 25 to 10 feet as one progresses upriver. The New York and New Jersey Channels have depths generally to 35 feet,

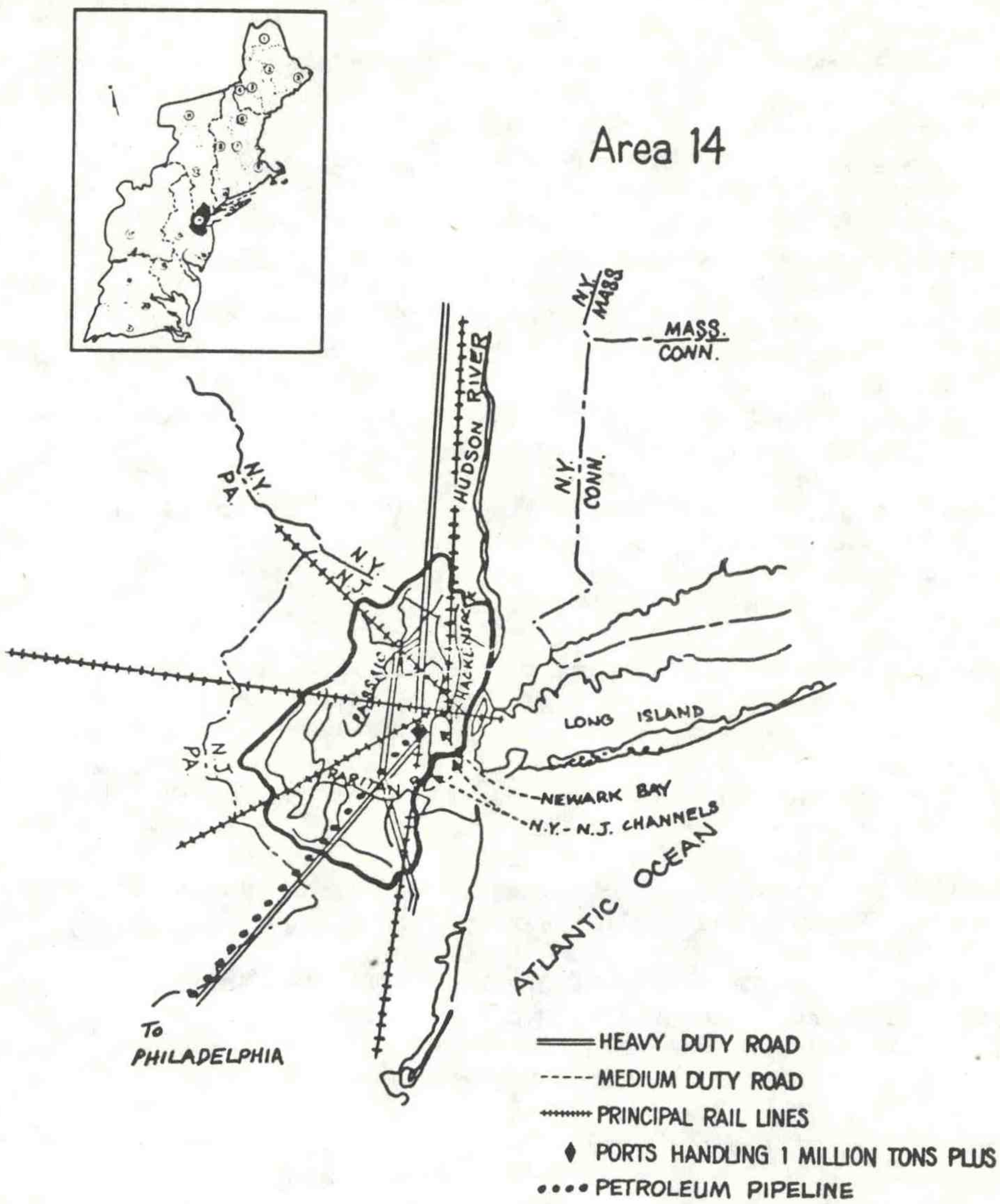

Figure 12.37 The transportation system of northern New Jersey.

although 36-foot draft vessels safely navigate the waterway on high tide. Arthur Kill, the north-south leg of the channels cannot be deepened without extensive rock removal in its northern reaches or widened without complete channel modifications. Thus, further navigation development by deepening or widening would be very costly. Kill Van Kull, the east-west leg of the N.Y.-N.J. Channels, offers no width restriction but is also grounded in rock. Improvements to Newark Bay have encountered rock. While the waterways of Area 14 and its adjacent areas give Area 14 an overwhelmingly powerful and centralized location for the distribution of waterborne commerce, their development restrictions neutralize the advantage to a great extent.

Demand for commodities is generated by 4.6 million people in the immediate area, in concentrations as high as 12,000 per square mile. Thus the population, density, and location is very favorable to navigation development. Extensive industrial development has occurred in Area 14 for the refining of petroleum. This industry also acts as a stimulus for navigation both in consumption and production. Besides being a center for redistribution of domestically-refined petroleum products such as gasoline, it is also important for the chemical by-products of its refineries. Sand, gravel and stone are major commodities by weight. Other industries, which contribute to waterborne commerce, are the textile and machinery industries.

Extensive port facilities line most of the area's waterfront. The containership terminal at Elizabeth, maintained by the Port of New York Authority, is the largest of its kind. It is a key to the continued attraction of a large international general cargo trade in the future. Expansion of container facilities is more likely in New Jersey than in New York City because of the availability of space for storage and marshalling. Major ports are located along the Hudson River below the George Washington Bridge, Newark Bay, the New York-New Jersey channels, the Hackensack, Passaic and Raritan Rivers.

Along the Hudson River shores are 260 facilities, almost all for handling general cargo. About 10% have depths compatible to the waterway. The facilities are supported by covered storage (5 million square feet), storage for cooking oils (105,000 tons), and petroleum storage (120,000 tons, less than 30% accessible to vessels drawing over 21 feet). There are a number of rapid transit tunnels and aqueducts which cross the River, but none are shallower than 52 feet below mean low water. Commerce has been declining at an accelerating rate. It declined at an average annual rate of 3.5% for the 19 years ending in 1967, and declined at a rate of 4.5% during the last 10 of those years. Commerce on the Hudson River averaged 13,480,000 tons for the three years prior to 1968, and the 1970 commerce was 8,850,000 tons. Commerce will continue to decline unless major rehabilitation and development of piers and supporting facilities is accomplished.

Commerce in Newark Bay is mostly general and containerized cargo which is more sensitive to improvements in shore trans-shipment facilities than to additional waterway improvement. More than 30 facilities have adjacent depths of 35 feet and are supported by open and covered storage (4 million square feet), liquid storage (6 million gallons), and petroleum storage (400,000 tons). A railroad bridge restricts horizontal clearance to 200 feet at the entrance of the Bay. Both tankers and dry cargo vessels with drafts exceeding the depth of 35 feet were reported to have entered the waterway in 1970. Waterborne commerce grew at an average annual rate of 3.5% for the 19 years ending in 1967 and increased to 4.8% during the last 10 of those years. Commerce averaged 11,800,000 tons for the three years prior to 1968. The 1970 commerce was 14,720,000 tons. The projected commerce reflects continued development of modern terminal facilities at Port Elizabeth. The annual growth rate ranging from 2.3% to 4.8% will be somewhat affected by developments along competing waterways such as the Hudson River.

In the New York-New Jersey channels, there are approximately 200 wharves. About 90% are specifically designed for the receipt and/or shipment of petroleum products and are supported by petroleum storage (10 million tons). Only about 10% of the facilities have adjacent depths compatible with the depth of the waterway. Pipelines operating at about 45% capacity carried some 14.5 million tons of gasoline and distillate from the Gulf of Mexico to New York in 1969. Between 1967 and 1969, their delivered tonnage was increasing at a 4% annual rate. Tonnage carried in these pipelines is expected to grow at the same or a higher rate of growth as waterborne petroleum commerce over the next 10 years. Crude petroleum and residual fuel oil generate most of the pressure for deepening and widening of the waterways. Waterborne commerce grew at an average annual rate of 1.5% for the 19 years ending in 1967, but its average growth increased slightly to 1.8% during the last 10 of those years. Commerce averaged 85 million tons for the three years prior to 1968. The 1970 commerce was 93,990,000 tons. The annual growth rate is expected to range from 1.5% to 2.5%.

There are about 100 facilities along the navigable portions of the Hackensack and Passaic Rivers, which are generally equipped to handle sand, gravel or petroleum. At the mouth of both rivers, many facilities are devoted to marine salvage. Many bridges cross the rivers, limiting the horizontal clearance to less than 100 feet. Commerce grew steadily at an average rate of about 1% for the 19 years ending in 1967. Commerce averaged 14,600,000 tons for the three years prior to 1968. The 1970 commerce was 14,040,000 tons. The annual growth rate is expected to range from 1% to 2.5%.

Along the Raritan River, fuels have domianted the commerce carried for many years because of the petroleum-oriented facilities near its mouth, and inland electric power plants. Seventeen wharves/piers are

found along the 300-foot wide, 25-foot deep channel which extends 6 miles upriver from Lower New York Bay. They include special handling facilities for coal, chemicals and petroleum, and are supported by petroleum storage totalling almost 1 million tons. Waste disposal has contributed one-third of the commerce during 1968 and 1969. Vessels of 10-foot draft can negotiate an additional 10 miles upriver. A current study is considering the construction of a flood control and water supply dam across the river in the vicinity of Crab Island. No provision for passage of commercial traffic is foreseen at this time. Thus, the development program for commerce has been limited to consideration of improvements downstream of Crab Island. Raritan River commerce grew steadily at an average annual rate of about 2% for the 19 years ending in 1967. Commerce averaged 8,000,000 tons for the three years prior to 1968. The 1970 commerce, however, dropped to 7,810,000 tons. In projecting the commerce the figures from 1967 through 1969 were discounted as they are unusually high.

The tidal waters of Area 14 are heavily used for the disposal of large quantities of liquid wastes from municipal and industrial sources. Table 33 shows the organic waste loads in the area from 69 non-industrial and 42 industrial sources known in 1960, as expressed in population equivalents for treatment levels existing at that time. The poor water quality in the area, together with the great amount of commercial navigation activity, discourages recreational boating, which is not well developed. There are approximately 1,500 permanent berths or moorages in the area, and 25 launching facilities spread among the more than 60 public boating facilities.

TABLE 33. Organic Waste Loads in Area 14 - 1960

Load Type	Waste Load (Pop. Equiv.) (Thousands)
Non-Industrial	2,170
Industrial	8,170
TOTAL	10,340

A very substantial portion of the area's coastal zone is given over primarily to solid waste disposal. The Hackensack Meadowlands comprising 21,000 acres, roughly three-fourths the area of Manhattan, is located north of Newark Bay and contains 12 active sanitary landfill sites used by over 100 communities for dumping garbage and rubbish.

Major Coastal Problems. Water pollution within Area 14 has been severe; it is seen as a consequence of the vigorous industrial activity in the area. Nearly all of the major coastal water bodies in the area are currently classified as suitable for navigation and industrial use, and not suitable for fishing boating or swimming. In the Arthur Kill, wastes in the form of phenols, oils, trace metals and heat reflect the diversity

of industrial effluents in contrast to the effluent from municipal treatment facilities. In terms of BOD, the industrial wastes feeding into Raritan Bay have been estimated to be equivalent to the municipal wastes of more than one million people. The industrial pollution load from Area 14 as a whole has not yet been determined. Research on BOD levels in upstream portions of the Raritan, Passaic and Millstone Rivers indicates that less than 40% of the observed organic loadings can be attributed to known point sources. It is not known whether this relationship holds for the lower reaches of these rivers where industrial plants are concentrated.

With respect to marine transportation, the rapid evolution towards economical very deep draft tankers and dry bulk carriers present special problems to the Port of New York. The problems are particularly significant in that part of the port which is located in Area 14. The Port's existing channels are far shallower than these new vessels require. The cost of deepening is probably prohibitive and environmental considerations can pose problems. If deep draft facilities are located elsewhere, major economic dislocations in Area 14 could occur.

There is little critical erosion in Area 14, but tidal flooding can be a significant problem. Although flooding does not occur frequently a rare, meteorological predictable storm in this intensively developed area could produce major damage. The U.S. Army Corps of Engineers estimates that if the design storm were to hit this area, damages would reach $2 billion, about half direct and half indirect.

Another problem is the difficulty in providing opportunities for outdoor recreation, primarily swimming and picnicking. The coastal zone of the area is not expected to be able to accommodate much, if any, of the demand for swimming. The outdoor recreation plan for the state of New Jersey anticipates that the swimming needs of nearly 100,000 persons in 1980 and 229,500 persons in 2000, will not be accommodated by facilities in the area. Other coastal recreational activities such as boating and sport fishing may be possible if the quality of coastal waters on the periphery of the area is upgraded and other obstacles of safety, congestion, shoreline access and aesthetic blight can be overcome.

Coastal-related amenity needs for Area 14 as a whole include developing quality landscape over 17 percent of the area, protecting landscape diversity in 4 percent, developing clean water in the entire basin, and providing amenities for the metropolitan area.

Area 16 - Coastal New Jersey

As shown in Figure 12.38 the coastal zone of New Jersey includes the shore of Raritan Bay between the Raritan River and Sandy

AREA 16 COASTAL NEW JERSEY

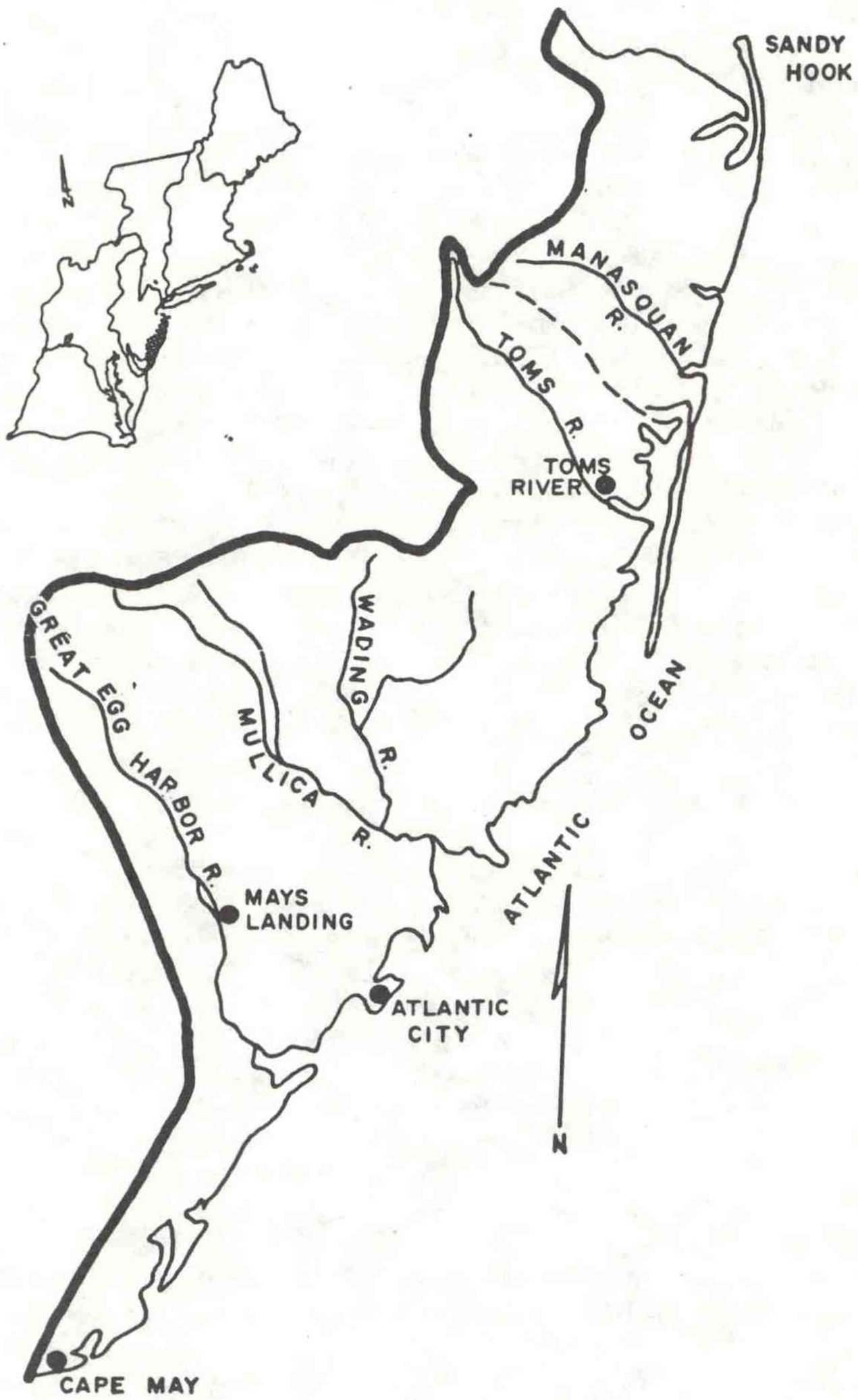

Figure 12.38 Regional map of coastal New Jersey.

Hook, and the ocean shore from Sandy Hook to Cape May. The 20 miles of shorefront on Raritan Bay is characterized by high bluffs and marshlands fronted by narrow beaches and intersected by numerous tidal creeks. The 125 miles of ocean shorefront in this area consist entirely of beach. Most of the beaches are on long sandy barrier islands. Behind the beaches are backbays, salt marshes and meadows that extend several miles inland in some places. Non-coastal land forms in Area 16 are divided between 1500 square miles of flat land (75% of total land area) and 600 square miles of undulating land (25% of total area). Approximately 19 percent of the area is in city landscape units (400 sq. miles), 57 percent is in Forest-Town (1200 sq. miles), and 24 percent exhibits a Town-Farm pattern (1500 sq. miles). The major part of the area is ranked low in visual quality with only 10 percent of medial quality.

Ownership of the 20 miles of shorefront on Raritan Bay is divided into 13 miles private and 7 miles public (.1 mile federal). In this reach, shore development is primarily residential and recreational in character with some commerce and industry. South of Raritan Bay, from Sandy Hook to Cape May, the pattern of oceanfront ownership is 80 miles public, 30 miles private and 15 miles federal. The shores of the backbays are largely wetlands, but there are more beaches there than along other backbays in the North Atlantic Region. Shoreline ownership along the backbays is largely private, and shore development is again recreational and residential in character.

Population and Economic Base. A summary of population, personal income, earnings and employment for Area 16 over the period 1959-2020 is shown in Table 34 of the 1964 population of 760,000, 44,000 were classified as rural. About half of the area population is concentrated in Monmouth county in that portion nearest to the New York metropolitan area. The resident population density is 900 per square mile in Monmouth county and 272 for the remaining counties in Area 16. Employment in the six counties is expected to increase from 230,000 in 1960 to 870,000 by 2020. Over the same period manufacturing employment for the counties is expected to increase by 328% by 2020.

Demographic and economic characteristics of the coastal communities of the Jersey shore differ significantly from the counties as a whole. The Jersey shore is almost exclusively a recreation-based economy. Historically the ocean beaches have been vacation grounds for residents of the Greater New York and Philadelphia areas. The economy of the shore is thus heavily dependent upon the millions of summer visitors attracted by natural and man-made recreation and resort facilities. Income from the areas' resorts in 1968 amounting to $1.8 billion was one of the largest sources of business income in the state. Because of the dependence on tourism during the summer season from June through September the coastal communities are subject to high unemployment during the winter season. For example, in January 1965 over 13% of the work force of Atlantic City was unemployed. Population statistics do not consider the extremely

TABLE 34. North Atlantic Hydrologic Area 16. Population, Personal Income, Earnings and Employment Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	647,233	652,077	1,082,000	1,707,000	2,290,000
Total Personal Income (000-$58)	1,520,243		5,146,700	13,928,300	31,487,000
Per Capita Income ($58)	2,349		4,757	8,160	13,750
Per Capita Relative (US=1.00)	1.101		1.157	1.140	1.108
Total Earnings (000-$58)*	1,241,194		3,624,400	9,955,500	22,659,900
Per Worker Earnings ($58)	5,336		9,185	15,335	26,127
Per Worker Relative (US=1.00)	1.144		1.137	1.126	1.118
Population	647,233	652,077	1,082,000	1,707,000	2,290,000
Total Employment	232,624	234,350	394,600	649,200	867,300
Participation Rate (Empl/Pop)	.359	.359	.365	.380	.379
Employment by Selected Industries					
Agriculture + Forestry + Fisheries		7,951	7,100	6,600	5,100
Mining		210	100	100	100
Manufacturing	34,339	46,900	64,200	73,600	
Food + Kindred Products	6,022	7,200	8,900	9,200	
Textile Mill Products	1,075	1,100	1,100	900	
Chemicals + Allied Products	4,141	7,200	11,400	15,600	
Paper + Allied Products	366	500	800	1,000	
Petroleum Refining	826	500	400	300	
Primary Metals	1,353	2,300	3,500	4,200	
Armed Forces	14,290	14,200	17,100	17,200	
Other	177,560	326,300	561,200	771,300	

D Too small to be projected but included in higher level totals

* Including Armed Forces pay

high influx of people in the summer. For instance, Stone Harbor's resident population of 830 grows to 18,000 during the summer. On a peak summer weekend Asbury Park accommodates 200,000 visitors, and Atlantic City accommodates 500,000 visitors to their beaches and boardwalks. Most of the resident population in the shore area is located in resort towns on the barrier beaches; however, since there is virtually no vacant land remaining on the barrier beaches from Sandy Hook down to Cape May, most of the population growth and development between 1950-60 has occurred on the mainland behind the barrier beaches. The proportion of residents over sixty-five is higher for the coastal resort counties than for the rest of the state indicating the attractiveness for persons in retirement.

Land-Use. A land-use and water area summary for Area 16 is shown in Table 35, which lists total surface areas together with the amounts and percent distribution of types of surface coverage in 1963. In that year, 112 square miles (5.7%) of the area's total land was intensively developed, while 15 percent was devoted to crop production with 1,655 commercial and 446 non-commercial farms in operation. Also in 1963, there were 627,000 acres of commercial forest in the area, of which 73,000

TABLE 35. Land-Use and Water Area - Area 16 - 1963*

Cover Type	Amount (thousand acres)	Percent Distribution
Cropland	212	14
Pasture	21	1
Forest	760	50
Urban	204	13
Water		
-Over 40 acres	121	8
-Under 40 acres	2	-
Other	212	14
TOTAL	1,532	100

were publicly-owned and 554,000 were farm-owned or private. With respect to mineral extraction in Area 16, the most significant commercial products are sand and gravel, magnesium compounds, and ilmenite. In 1969, the estimated combined value of production of these minerals was roughly $8 million.

Land use in the Area 16 coastal zone is for the most part residential and recreational. The barrier beach is so heavily developed that virtually no vacant beachfront exists, exceptions being state-and feder-

ally-owned beaches and scattered vacant parcels around inlets. Commercial land use is concentrated in the central business districts of the larger resort towns, and adjacent to the boardwalks and promenades. Industrial land use is minimal throughout the shore area, most of it occurring along Raritan Bay. Some federally controlled lands no longer of military value such as Fort Hancock on Sandy Hook are being phased out. New Jersey leases part of Sandy Hook beachfront to accommodate intensive day-use recreational demand, but even these expanded facilities are filled early on summer weekends. The marshlands and portions of mainland facing the barrier beaches have only recently begun to be developed as lagoons providing marinas, homes and boating facilities. Large portions of the coastal marshlands have already been reserved as state and federal wildlife refuges.

Public Utilities. Approximately 716,000 people, or 94 percent of the area's 1964 population, are served by some 100 central water supply systems. These systems, which distribute an average of 86 m.g.d., utilize surface supplies for about 36 percent of their water, with the balance developed from ground water. Presently available water resources in the area comprise 845 m.g.d., and the total practical development is estimated to be 1,065 m.g.d.

The industrial water requirements for Area 16 are low, with a total intake of only 28 m.g.d. Of this total, 3 m.g.d. are self supplied and 25 m.g.d. are brackish. There is no publicly-supplied industrial water in the area at present. The chemicals and transportation equipment industries are the freshwater users in the area with respective withdrawals of 2 m.g.d. and 1 m.g.d. The bulk of the brackish water use is for the chemicals industry with a present use of 19 m.g.d. Livestock and rural domestic water requirements are 3 m.g.d. Other uses of water supply are for farmland irrigation (22,800 acres) and for non-agricultural irrigation (3,800 acre-feet). About 55 percent of the agricultural water comes from ground water and 45 percent from surface water, while non-agricultural water is predominantly ground water.

The electric power requirements of Area 16 during 1969 were met by a total of 955 megawatts of installed generating capacity. The distribution of this capacity by type of prime mover, together with scheduled or planned additions through 1975, is shown in Table 36.

Major Coastal Uses. Recreation is the predominant use of the Jersey shore. Of its natural resources, 125 miles of wide ocean beach provide surf bathing and fishing. Deep-sea sport fishing expeditions depart from many of its ports. Fishing and shellfishing are popular throughout the bays and sounds behind the barrier beaches. Pleasure boating enthusiasts benefit from the Intracoastal Waterway whose entrance at Manasquan Inlet at the Northern end of Barnegat Bay passes behind the barrier beach through bays and sounds to Cape May and continues on to

Florida. Man-made recreational resources in the form of boardwalks, promenades, amusement parks and night clubs add to the attraction of the larger resorts such as Atlantic City and Asbury Park. In the summer of 1965, it is estimated[16] that the residents of Area 16 accounted for 5.7 million man-days of swimming, .7 million man-days of boating, 11,400 man-days of sailing, and 99,000 man-days of water-skiing. These figures do not include activities of the out-of-state visitors to the Jersey shore, most of whom come from metropolitan New York and Philadelphia, but increasingly more of whom come from other parts of the North Atlantic Region.

Recreational boating is the most significant aspect of navigation in Area 16. While the number of registered craft in the area is approximately 15,000, based on a strict per capita ownership according to population distribution, there are over 500 public boating facilities with about 22,000 permanent slips or moorages and 300 launching ramps. These facilities have generally been privately developed and support a strong boating tourist economy. Area 16 helps satisfy the recreational needs of Areas 14 and 15, as well as serving many transient boats from both within and outside the NAR. Over 200,000 boats used all or part of the Intracoastal Waterway in 1963. Figure 12.39 shows the competitive nature of the land transportation network to commercial navigation and its strong support for recreational navigation. This network encourages the growth of recreational boating because it places the recreational areas of Area 16 within a 2-hour drive of major urban concentration. This same network severely limits commercial navigation, whose growth is expected to be small, because the area is just a few dozen miles from two of the largest and best developed ports in the region, New York and Philadelphia, and well connected to them by the road and rail network.

Table 37 shows the organic waste loads in Area 16 from 130 non-industrial and 36 industrial sources known in 1960, as expressed in population equivalents for treatment levels existing at that time.

Table 37. Organic Waste Loads in Area 16 - 1960

Load Type	Waste Load (pop. Equiv.) (Thousands)
Non-Industrial	788
Industries	302
TOTAL	1,090

*1965 average Mid-Atlantic participation rates X (times) area population.

Area 16

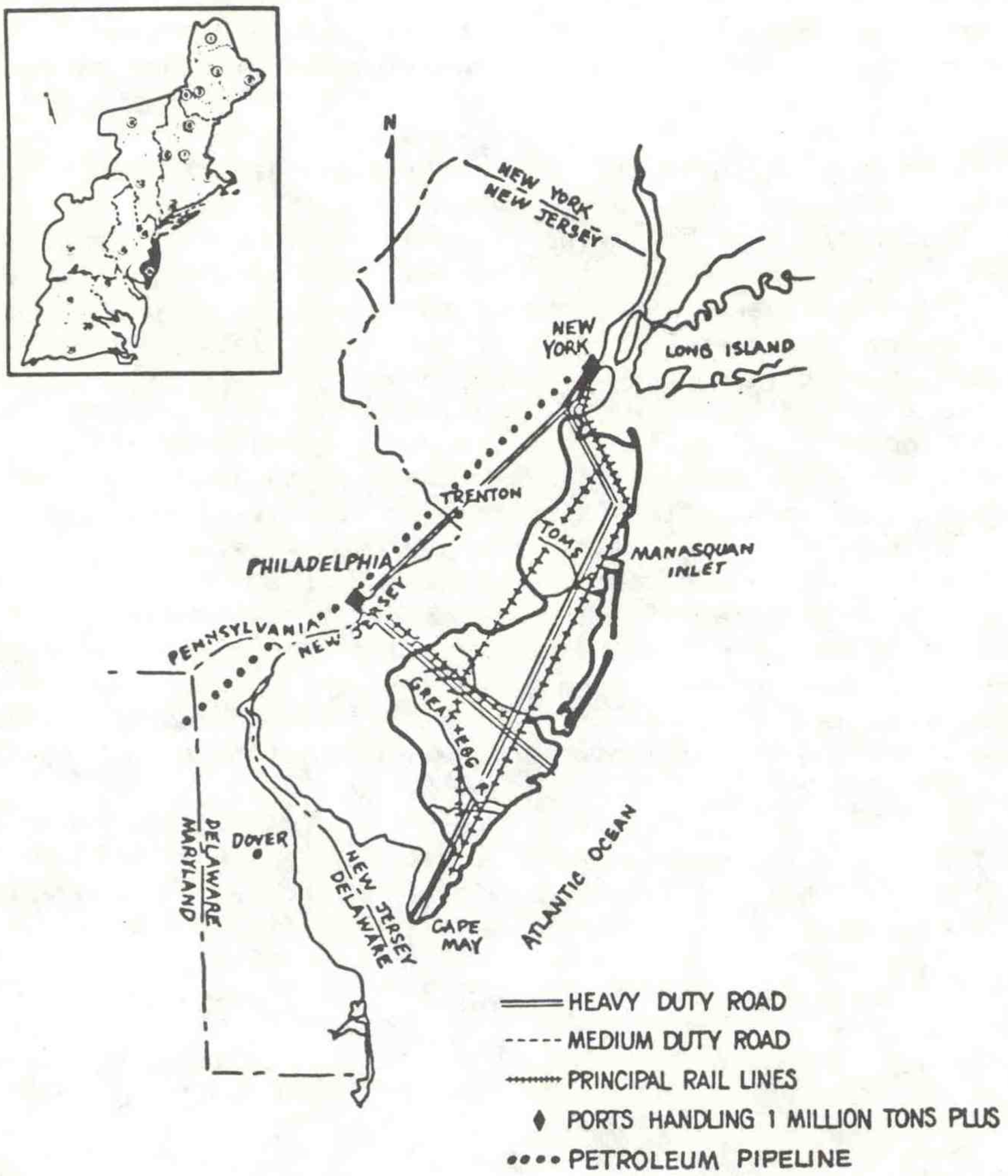

Figure 12.39 The transportation system of coastal New Jersey.

Major Coastal Problems. Coastal erosion and flooding are major problems in this area. Critical erosion occurs along parts of the Raritan Bay - Sandy Hook Bay shores and along most of the oceanfront. The ocean shoreline in this area has a history of alternating movements seaward and shoreward. In the past two decades some reaches have been moving at a rate of up to 12 feet a year oceanward, and others by 16 feet a year landward. One area in particular, the southeast tip of Pullen Island, has been accreting at an average rate of 300 feet a year over the last decade. The more severe storms move considerable quantities of sand too far offshore to be returned between storms by ocean swells. In such an unstable environment groins and jetties must be sited with unusual care. Even the backbay shorelines experience some erosion damage, although its prevalence and intensity are much less than along the ocean. Damages from a recurrence of the tidal flood of record in this area have been estimated by the U.S. Army Corps of Engineers at about $260 million. Nearly half of this damage would be along the heavily populated coastline along Raritan and Sandy Hook Bays.

A related problem of dune erosion along the Jersey coast has been attributed in part to the imprudent siting of houses and structures on unstable frontal dunes. McHarg has shown that by prohibiting any form of development on the frontal dunes, vegetation is more likely to take hold to stabilize and trap dune sand and prevent undue erosion. Unfortunately more prudent development of the barrier beaches to reduce dune erosion is hampered by existing development. Considerable additional information on dune stabilization, of particular applicability to New Jersey's oceanfront, was presented earlier as part of the analysis of the selected problems of coastal erosion and tidal flooding.

Another major problem on the New Jersey shore is the conservation of wetlands. Concern has been expressed for the ability to maintain the quality of these seemingly abundant natural recreational resources in the face of inevitable development. The marshes along the mainland are undergoing development. The lagoon-type development is expropriating large areas of marshland important to fish and wildlife.

The coastal-related amenity needs of the area as a whole include: preservation or protection of 30 miles of shoreline and 300 square miles of unique natural landscapes (Pine Barrens); developing 100 square miles of quality landscape; and obtaining clean water and providing metropolitan amenities.

Area 15 - Delaware River Basin
(Philadelphia and Coastal Reaches Only)

General Characteristics. As shown in Figure 12.40, the coastline of Area 15 consists of Delaware Bay and the Delaware River to the head of the tidewater in Trenton. From Philadelphia south to Penns Grove, the waterfront is highly developed on both banks for industrial and commercial use. The 85 miles of shoreline from Penns Grove to Cape May on the New Jersey side consist of about 50 miles of wetlands and 35 miles of narrow sandy beach fronting marshes. Ownership is apportioned about 45 miles private, 20 Federal, and 20 public. A sparse 12 miles of the shoreline is residential.

The 82 miles of Delaware shoreline from Wilmington to Cape Henlopen consist almost entirely of marshes in the north and of a narrow strip of sand beach fronting more marshes in the south. Ownership is divided about 57 miles private, 14 public and 11 federal. Except for 9 miles for public recreation and 2 miles for commercial purposes, the entire shoreline is undeveloped. Shoreline use is primarily wetland conservation. Little bathing occurs in the bay and shoreline fishing is generally poor. Bay fishing by boat has improved in recent years and is now considered to be good.

Population and Economic Base. The population of Area 15 is heavily concentrated along the Trenton-Philadelphia-Wilmington portion of the New York to Washington urban corridor. A summary of projected population, personal income, earnings and employment for the Philadelphia Water Resources Planning Area [17] is shown in Table 38. This is the second most populous WRPA in the North Atlantic Region, and is highly urbanized with great industrial diversification. For the entire area, employment is the largest in electrical machinery, followed by chemicals, apparel and food. Philadelphia has considerable employment in trade, finance, public administration, professional and business services. Textiles and apparel followed by primary metals are its major manufacturers. Raw materials form the bulk of its port activity with crude petroleum alone accounting for one-half the tonnage handled. Camden, across the river, processes food products and manufactures electrical equipment. Wilmington, the southernmost city on the Delaware River, is noted for its specialization in the manufacture of chemicals. Trenton, at the head of navigation on the Delaware River, manufactures machinery,

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17 Water Resources Plannign Areas (WRPA) are delineated by the Office of Business Economics, Regional Economics Division, of the U.S. Department of Commerce. Philadelphia and the coastal reaches of the Delaware River Basin fall within WRPA 17, which also includes a portion of coastal New Jersey as discussed in the previous section. This overlap is not significant since the great majority of population and economic activity in WRPA-17 is located in the vicinity of Philadelphia/Wilmington/Trenton.

AREA 15 DELAWARE RIVER BASIN

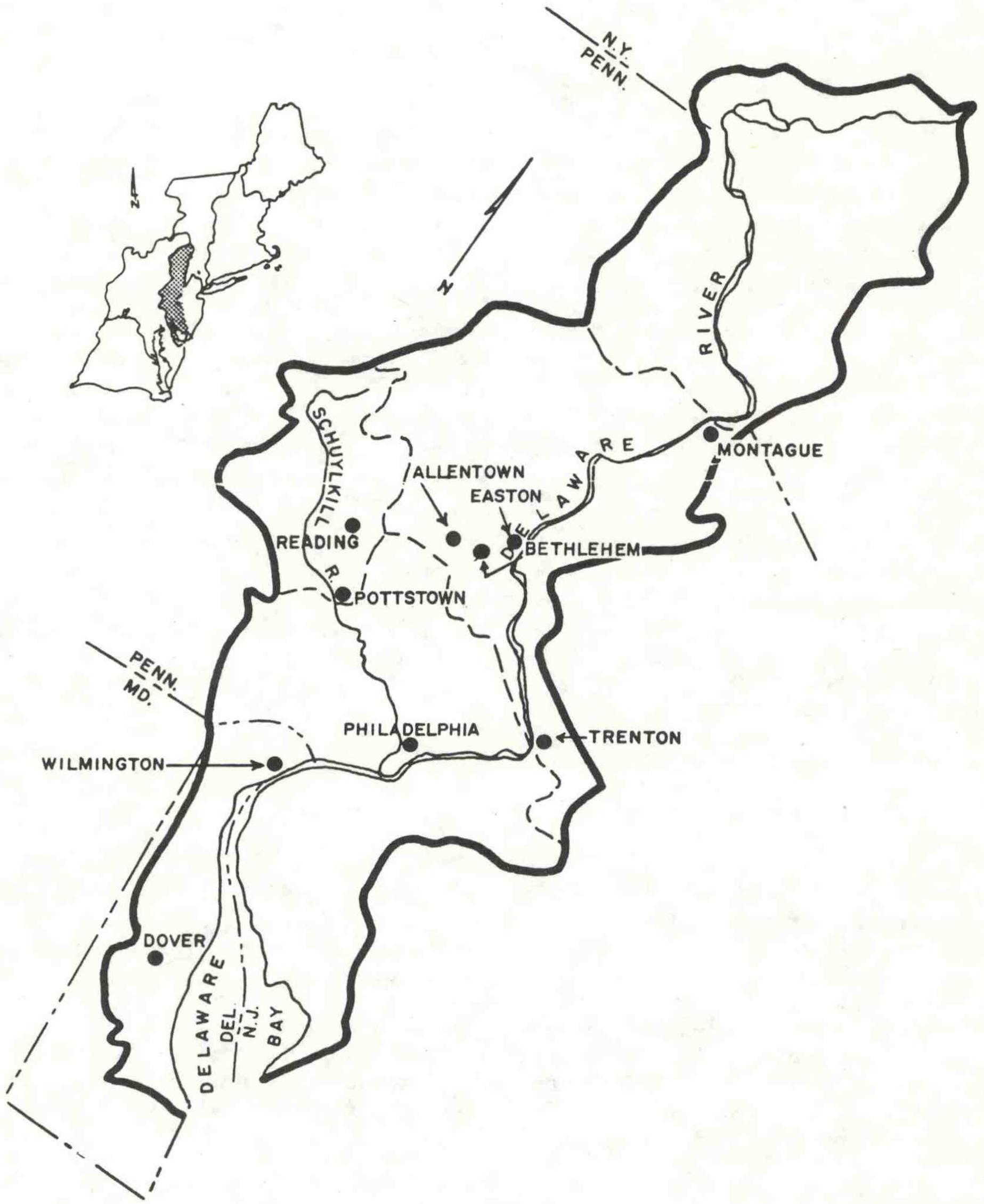

Figure 12.40 Regional map of the Delaware River basin.

TABLE 38. Philadelphia and Vicinity Population, Personal Income and Earnings, Projected for Selected Years, 1970-2020.

	1970	1980	1990	2000	2010	2020
POPULATION	6,336,400	7,152,600	8,178,700	9,183,100	10,313,800	11,602,800
TOTAL PERSONAL INCOME(000-$58)	21,670,324	31,386,835	45,804,069	68,059,812	100,699,191	148,247,206
PER CAPITA INCOME($58)**	3420	4388	5600	7411	9764	12777
PER CAPITA RELATIVE(US=1.00)	1.12	1.07	1.05	1.03	1.03	1.03
TOTAL EARNINGS (000-$58) *	17,339,684	25,039,717	36,289,498	53,578,493	78,785,153	115,383,116
PER WORKER EARNINGS($58)**	6923	8723	11260	14668	19264	25324
PER WORKER RELATIVE(US=1.00)	1.10	1.08	1.08	1.08	1.08	1.08

* INCLUDING ARMED FORCES PAY

EMPLOYMENT BY SELECTED INDUSTRIES, 1970-2020

	1970	1980	1990	2000	2010	2020
POPULATION	6,336,400	7,152,600	8,178,700	9,183,100	10,313,800	11,602,800
TOTAL EMPLOYMENT	2,504,700	2,870,500	3,222,700	3,652,700	4,089,700	4,556,300
PARTICIPATION RATE(EMPL/POP)	.40	.40	.39	.40	.40	.39
AGRICULTURE,FORESTRY + FISHERIES	35,600	31,500	27,400	24,400	21,300	18,300
MINING	1,100	700	600	500	400	300
MANUFACTURING	809,800	858,200	902,700	953,300	1,004,400	1,060,700
FOOD + KINDRED PRODUCTS	70,200	68,400	65,800	63,700	61,600	59,700
TEXTILE MILL PRODUCTS	30,500	23,600	19,800	16,300	13,700	11,500
CHEMICALS + ALLIED PRODUCTS	96,600	118,200	141,900	173,200	204,700	235,700
PAPER + ALLIED PRODUCTS	29,100	33,900	37,700	42,000	46,400	50,200
PETROLEUM REFINING	20,000	18,500	16,100	14,500	12,600	10,700
PRIMARY METALS	45,500	46,700	47,300	49,600	51,400	53,200
ARMED FORCES	63,100	60,800	60,800	60,800	60,800	60,800
OTHER	1,595,100	1,919,300	2,231,300	2,613,800	3,002,800	3,416,300

D TOO SMALL TO BE PROJECTED BUT INCLUDED IN HIGHER LEVEL TOTALS
** COMPUTED FROM UNROUNDED DATA

primary and fabricated metals and pottery. It is close to the site of a large, integrated steel plant recently built in Bucks County, Pennsylvania. Trenton is also the capital of the State of New Jersey and the location of all the attendant administrative functions.

As might be expected, navy and shipyard activity are important in this area centering in Philadelphia. The area is also an education center with more than a dozen universities and colleges including Princeton, Temple, Villanova, Swarthmore and the University of Pennsylvania.

Although the proportion of the labor force working in agriculture is only three-quarters the NAR average, this is a highly productive and

diversified agricultural area with tendencies toward specialization in poultry in the Delaware portion of the area and truck farming in the New Jersey portion.

The New Jersey coast and Lower Delaware Bay portions of the area is more open and rural. Half a dozen towns with populations of over 10,000, including Dover, the capital city of Delaware, are located in this part of the area. The proportion of the labor force working in manufacturing industries here in 1960 was only two-thirds that of the NAR, while for the entire area it was more than 10 percent greater than that of the NAR. Agriculture's share was three times the NAR average while for the whole area it was one-quarter lower than the NAR average. Economic activity in this area is, however, diversifying and as the last remaining major open area adjacent to Philadelphia and the northeast New Jersey-New York City urbanized area, it is receiving an increasing share of economic activity from the expanding megalopolis. The rate of increase in employment in this portion of the area in 1950-60 was two times greater than the NAR average while that for the entire area was only one-third faster. Moreover, the rate of increase in manufacturing employment was greater still.

Philadelphia is a fast growth area having grown at 1-1/4 times the NAR rate in 1950-60. Its industry mix has been advantageous to growth and increasingly so in the 1950-60 decade. It also has a regional share advantage that was greater in 1950-60 than in the 1940-50 period. The chemical industry has the strongest competitive advantage, while fabricated metals, nonelectrical machinery, petroleum and apparel have more moderate ones.

In terms of per capita income this area ranks substantially above the national experience although it has been approaching this average for the past 20 years and is expected to do so. The projected population and employment growth is at a rate about one-tenth greater than the NAR average, while income and earnings are projected to grow at closer to the NAR rate. Agriculture, forestry and fishing employment is expected to decrease more slowly than the overall NAR rate. Manufacturing employment is projected at a rate somewhat above the NAR average. Chemicals and paper have the fastest projected rates of growth among the six heavy water-using industries. Based on projected employment, this area should increase its share of the nation's employment in chemicals and petroleum refining, maintain its share in agriculture, forestry and fishing and have a declining share in other sectors.

Public Utilities. Approximately 6 million people, or 89 percent of Area 15's total 1964 population, were served by 410 central water supply systems. These systems, which distribute an average of 800 m.g.d., utilize surface sources for about 75 percent of their supply with ground

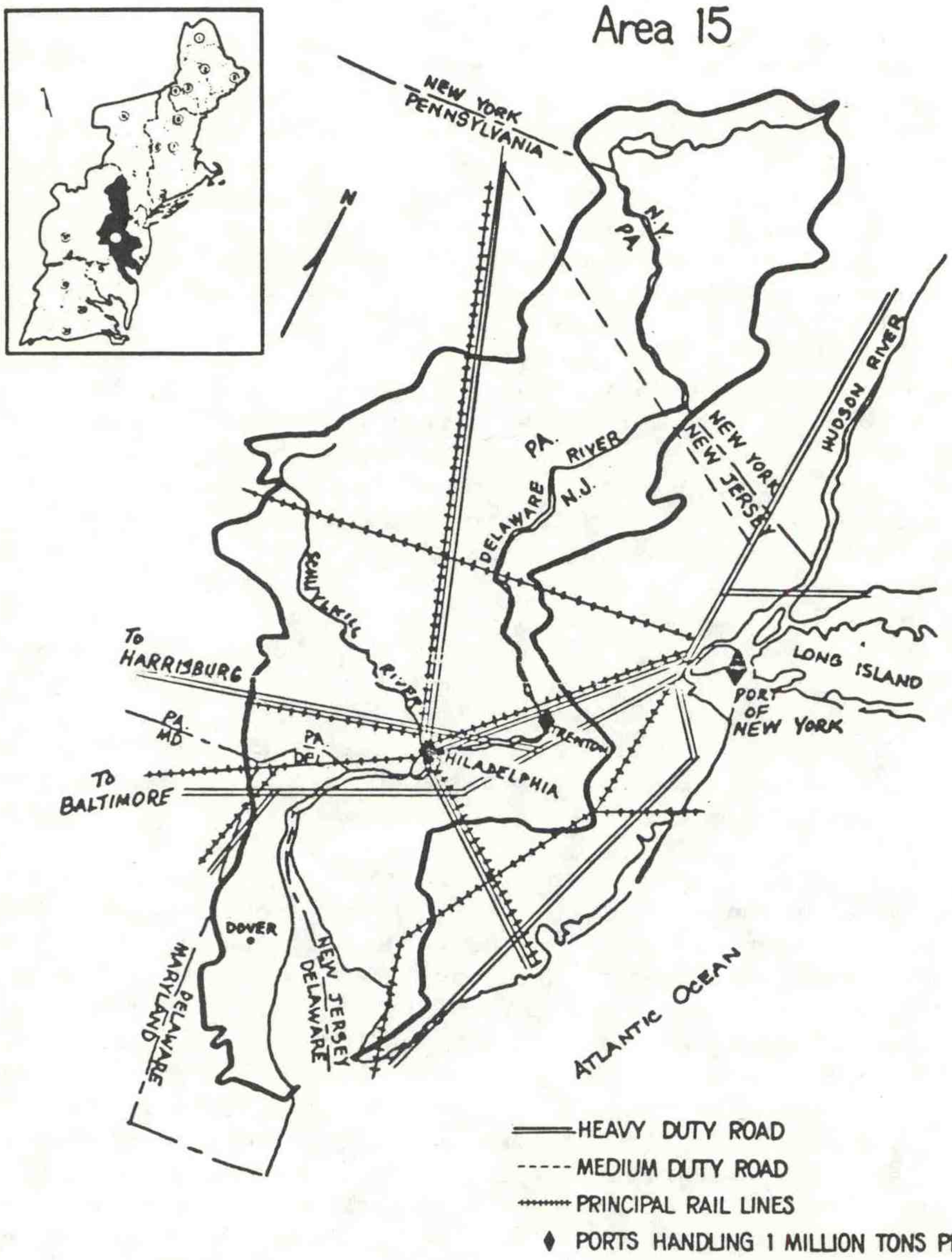

Figure 12.41 The transportation system of the Delaware River basin.

water development accounting for the balance. Presently available water resources in the area comprise 4,840 m.g.d., and the total practical development is estimated to by 7,562 m.g.d.

The industrial water requirements for Area 15 are the highest of all the areas in the North Atlantic Region. The total intake is 1,652 m.g.d., of which 1,000 m.g.d. are self-supplied, 119 m.g.d. are publicly-supplied and 533 m.g.d. are brackish water. The largest self-supplied industrial water user in the area is the primary metals industry with an intake of 475 m.g.d., followed by petroleum (190 m.g.d.), chemicals (124 m.g.d.), paper (77 m.g.d.) and food (30 m.g.d.). Other industries in the area with self-supplied intakes over 10 m.g.d. are fabrics, glass and clay, machine equipment and transportation equipment. The bulk of the brackish water is used by the petroleum, primary metals and chemical industries.

The electric power requirements of Area 15 during 1960 were met by 7,932 megawatts of installed generating capacity. The distribution of this capacity by type of prime mover, together with scheduled or planned additions through 1975, is shown in Table 39.

TABLE 39. Total Electric Generating Capacity (1969) and Planned Additions (1975) - Area 15 (MW)

Generator Type	1969	1975+
Steam Electric		
- Nuclear	--	6,736
- Fossil	6,779	2,928
Hydroelectric	407	1,300
Internal Combustion/ Gas Turbine	746	1,449
TOTAL	7,932	12,413

Major Coastal Uses. Figure 12.41 clearly shows Philadelphia as a center of land transportation from which multiple-lane, high speed, heavy duty roads and rail lines radiate in all directions. Land transportation is extremely complementary to commercial navigation. Philadelphia is one of the cities which is connected to the Colonial Pipeline System. While this normally would be a negative influence to navigation, it is a positive influence in Area 15 because it offers yet another means for large amounts of petroleum to be transported from Philadelphia, the greatest crude oil refining center on the Atlantic Coast. However, only a moderate expansion of pipeline facilities is foreseen due in part to increased hazards to public water supplies from potential pipeline failure.

Marine transportation is important in Area 15, and all of the fourteen major ports on the Delaware River are located above the head of

Delaware Bay, between Wilmington, Delaware and Trenton, New Jersey. The industries along the Delaware River depend upon navigation for the importation of iron ore and petroleum, other bulk commodities and general cargo. Iron ore, crude petroleum and residual oil accounted for over half of the tonnage moved overwater in the Delaware Basin. Collectively the Delaware River ports handled a total volume of 116 million short tons in 1968, second only to the Port of New York in this region. Volume has grown steadily although the rate of growth has declined in recent years. Ports on Delaware Bay itself are minor and their volume has declined sharply over the last quarter of a century.

The Delaware River is commercially navigable for well over 130 miles, providing access to such major cities as Philadelphia and Trenton, and an additional 100 miles for recreational boating. The Chesapeake and Delaware Canal, at the head of the Delaware Estuary, is a 17-mile man-made waterway which was authorized to 35-foot depth to shorten the distance for transit between Baltimore and Philadelphia by about 300 miles. However, controlling depth in the canal is 27 feet. These waterways are relatively free from storm hazards, but have significant physical obstructions to deepening because much of the channel is based on rock. Significant deepening of the river below Philadelphia may interfere with good-water conditions and community water supplies. Trends of reported vessel traffic clearly suggest the waterway is presently inadequate. Since 1955, the total number of self-propelled vessels reported annually has remained constant; while during the same period, tonnage increased some 30 million tons. The number of vessels reported to have required tide to reach port facilities jumped from zero in 1955 to almost 300 in 1968.

The 90-mile, 1,000-foot-wide, 40-foot-deep waterway to Philadelphia provides access to 14 principal port areas including a portion of the Ports of Philadelphia. About one-half of the commerce reported in this stretch of the river is delivered to Philadelphia. Excluding the portion of Philadelphia included in this stretch of the river, there are approximately 60 piers and wharves along the main channel, located primarily between the 60- and 80-mile points. Major facilities in the reach below Philadelphia serve crude petroleum, petroleum products, chemicals and ship repair yards. Waterborne commerce has grown at an average annual rate of 3.3% for the 19 years ending in 1967, but at only 1.2% during the last 10 of those years. Commerce averaged 86,900,000 tons for the three years prior to 1968. Commerce in 1970 was 99,000,000 tons.

Gloucester City, Camden and Philadelphia include 22 miles of port developed waterfront on the Delaware River known as the Ports of Philadelphia. Some 102 piers and wharves lie adjacent to the 40-foot channel that has widths up to 2,300 feet for anchorage. Five facilities are specialized for handling petroleum or ore and are

supported with storage for 1.3 million tons of petroleum. Many others are specialized to handle general and containerized cargo. The Schuylkill River empties into the Delaware at Philadelphia and is extensively developed for commercial navigation for about 6 miles. The present project depth is 33 feet. Along the river are approximately 40 wharves; all but two of these are devoted entirely to petroleum products and are supported by petroleum storage for 1.1 million tons. The two exceptions provide access to a grain elevator with a 2.2 million bushel storage capacity. The waterborne commerce of the Ports of Philadelphia grew very slowly over the 19 years ending in 1967, maintaining an average growth of only 1.2%. During the last ten of those years, however, the average dropped to 0.5%. Commerce averaged 48,600,000 tons for the three years prior to 1968. The 1970 commerce was 52,200,000 tons.

Commerce in lower Delaware Bay, excluding all traffic which merely passes through to destinations elsewhere, has suffered an immense decline over the last twenty-five years. Commerce declined at an annual rate of 13% between 1958 and 1967. Population of the counties flanking the Bay has increased by at least 18% during this decade. Along the Chesapeake and Delaware Canal, commerce grew at an annual average rate of 1.8% for the 19-year period ending in 1967 but at the slightly less rate of 1.5% during the last ten of those years. Commerce averaged 10,500,000 tons for the three years prior to 1968. The 1968 commerce was 9,610,000 tons, composed of coal, chemicals, lumber, paper, coke, grains, machinery, building materials and petroleum. It is expected that coal and petroleum movement will increase significantly when the 35-foot depth is provided.

The second major use affecting the Delaware Estuary is for waterborne waste disposal. Table 40 shows and organic waste loads in Area 15 from 295 non-industrial and 58 industrial sources known in 1969 as expressed in population equivalents for treatment levels that existed at that time.

TABLE 40. Organic Waste Loads in Area 15 - 1960

Load Type	Waste Load (Popu. Equiv.) (Thousands)
Non-Industrial	900
Industrial	1,800
TOTAL	2,700

A great amount of waste load originates along the reach between Trenton and the head of Delaware Bay. In a 1964 survey 1.8 million pounds of oxygen-demanding material were found to be generated daily by numerous industries and municipalities in this reach. These wastes receive varying degrees of treatment prior to discharge. The river water is also used extensively for industrial cooling.

A third major use of the estuary is municipal water supply. Over 200 million gallons a day are withdrawn directly from the river to supply over 50% of Philadelphia's freshwater supply. A potential threat to this water supply is the salt water front, the position of which fluctuates with the freshwater inflow from upstream. Low flow augmentation to stabilize this front is particularly desirable here.

A fourth major coastal use is wetlands conservation. As stated earlier, most of the peripheral land around Delaware Bay is wetlands - tidal flats, salt marsh and salt meadow - often extending inland for several miles. A large portion of these wetlands has already been acquired by state and federal conservation agencies and by private conservation groups. The Bombay Hook National Wildlife Refuge contains 12,000 acres of prime wetland habitat for migrating waterfowl, and Prime Hook National Wildlife Refuge will contain 5,000 acres when acquisition is completed. One reason for the large amount of dedicated land is that these wetlands in their present state are unsuitable for most other forms of development. Superior shoreline recreational facilities are found close by on the Atlantic coast, and most through transportation bypasses the area along the urban corridor to the west, the closest bridge crossing being at Wilmington. Coastal wetlands along the industrialized shore of the Delaware estuary are relatively small in size and deteriorating in quality for wildlife habitats as a result of development and the deposition of dredging spoil along the banks.

Commercial and sport fishing, hunting and water contact recreation are not considered major uses of the Delaware Basin at the present time although these resources could be developed and promoted for future use and enjoyment. There are dozens of recreational harbor and marina-type sites along the circumference of Delaware Bay and many small rivers that support boating, although there is a conflict between commercial and recreational navigation in the lower 100 miles of the Delaware for both water and shore space. There are about 40 public boating facilities on Delaware Bay, including 2,500 permanent slips or moorages and 25 launching facilities.

Major Coastal Problems. The single most important coastal problem in the Delaware Basin is water pollution below Trenton from municipal and industrial sources. Waste loads from primarily municipal and industrial sources are expected to double in the period 1964-1975 and to increase by 5 1/2 times by 2010. The Delaware Estuary Study reported that in 1964, as a result of waste discharges, dissolved oxygen is almost completely depleted in some locations, and gases from anaerobic decomposition of organic deposits are produced regularly during the summer. Coliform bacteria concentrations are very high in the same stretch of river. Acid conditions in the river caused by industrial waste discharges have been observed for several miles above and below the Pennsylvania-Delaware state line. Surface discoloration due to the

release of oil from vessels and surrounding refineries is a common occurrence from Philadelphia to below the state line. Overflows of combined sewerage systems results in a discharge of fecal matter and other offensive solids, floating material, and miscellaneous flotsam which would normally be trapped by the treatment plants. This material in the estuary represents one of the few remaining types of discharges that can affect the aesthetics of the estuary by visible evidence of raw sewage. The net result is a polluted waterway which depresses aesthetic values, reduces recreation, sport and commercial fishing, and inhibits municipal and industrial water uses.

A second major problem in Area 15 is in the field of marine transportation, as the evolution towards economical, very deep draft tankers and dry bulk carriers presents special problems to the Delaware port system. It has been generally accepted that the problems of deepening the estuary channel to accommodate the supervessels are overriding because of rock, the near-surface aquifer and tremendous costs. There may be substantial socio-economic implications, locally and regionally, if the area's industrial base cannot somehow find a way of incorporating the major economics implicity in the use of the new supervessels. A regional offshore offloading facility in Lower Delaware Bay has been proposed; however, the national, regional and local values involved and the economic, social, safety, environmental and jurisdictional interrelationships all point up the need for a careful cooperative study by the federal agencies, the affected port authorities and probably others.

Shoreline erosion is a relatively insignificant problem in this area. It is confined to a few localities such as Broadkill Beach and Lews on the Delaware Shore and Wildwood Villas on the New Jersey shore. According to estimates of the U.S. Army Corps of Engineers a recurrence of the tidal flood of record would cause damages, in 1970 dollars, of about $60 million, mostly in the Philadelphia area.

Subregion D. Areas 18-21 - Chesapeake Bay Region (Characteristics/Population/Economic Base/Land-Use/Utilities)[19]

General Characteristics. This region comprises the Chesapeake Estuary and the Atlantic coastal portions of Delaware and Maryland (Area 18 - See Figure 12.47), together with the major sub-estuarine systems draining on the Bay--the Potomac River (Area 19-Washington Area only - see Figure 12.48), the Rappahannock and York River Basins (Area 20-see

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19 Since the Chesapeake Bay is common to the coastal zone of NAR Area 18 through 21, it is convenient to discuss this sub-region as a whole rather than as a collection of individual Areas. Whenever the data used refers to a specific Area, it will be so noted.

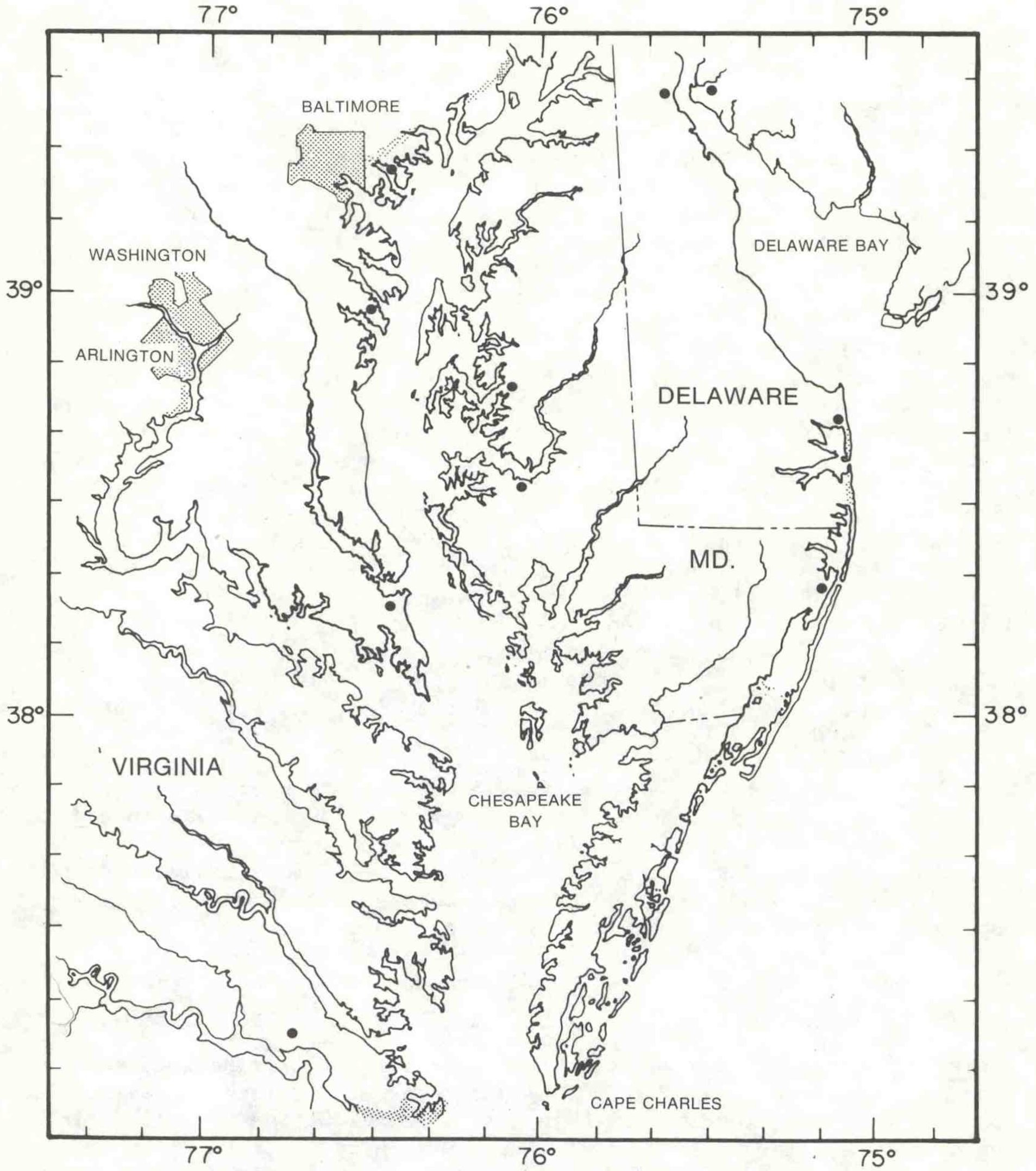


Figure 12.42 Major residential locations, coastal and offshore areas, Chesapeake Bay region.

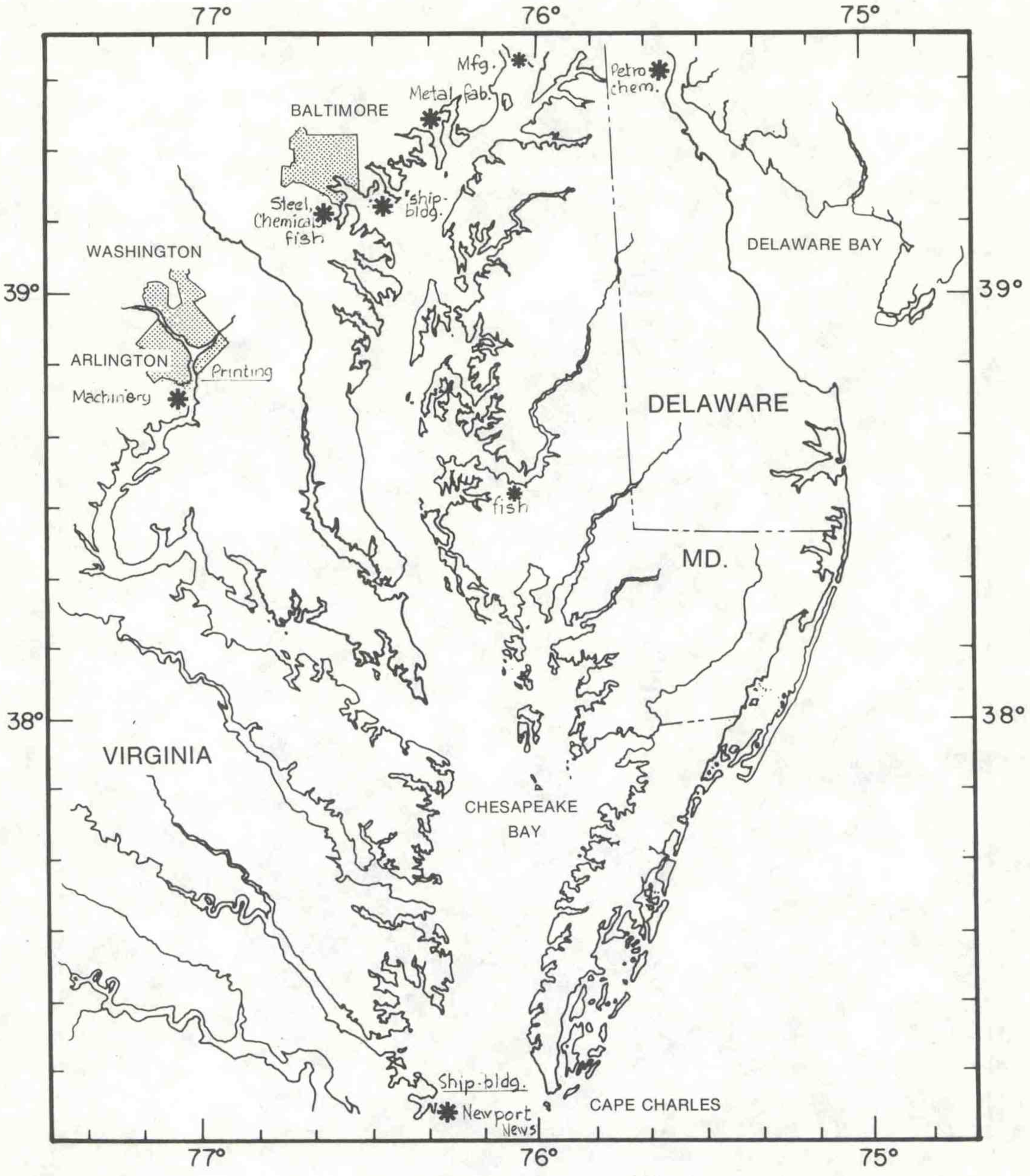


Figure 12.43 Major industrial locations, coastal and offshore areas, Chesapeake Bay region.

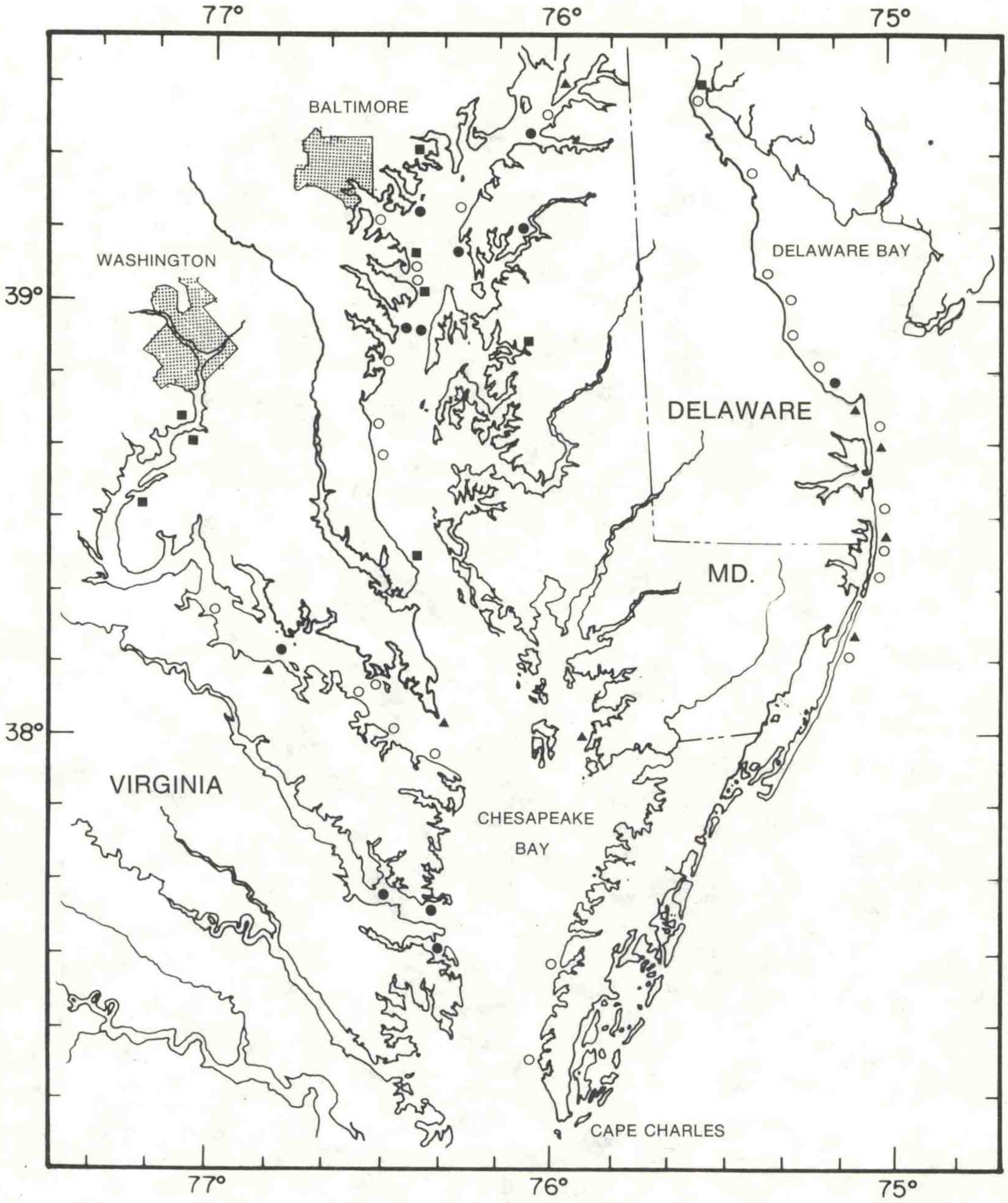


Figure 12.44 Major recreation locations, coastal and offshore areas, Chesapeake Bay region.

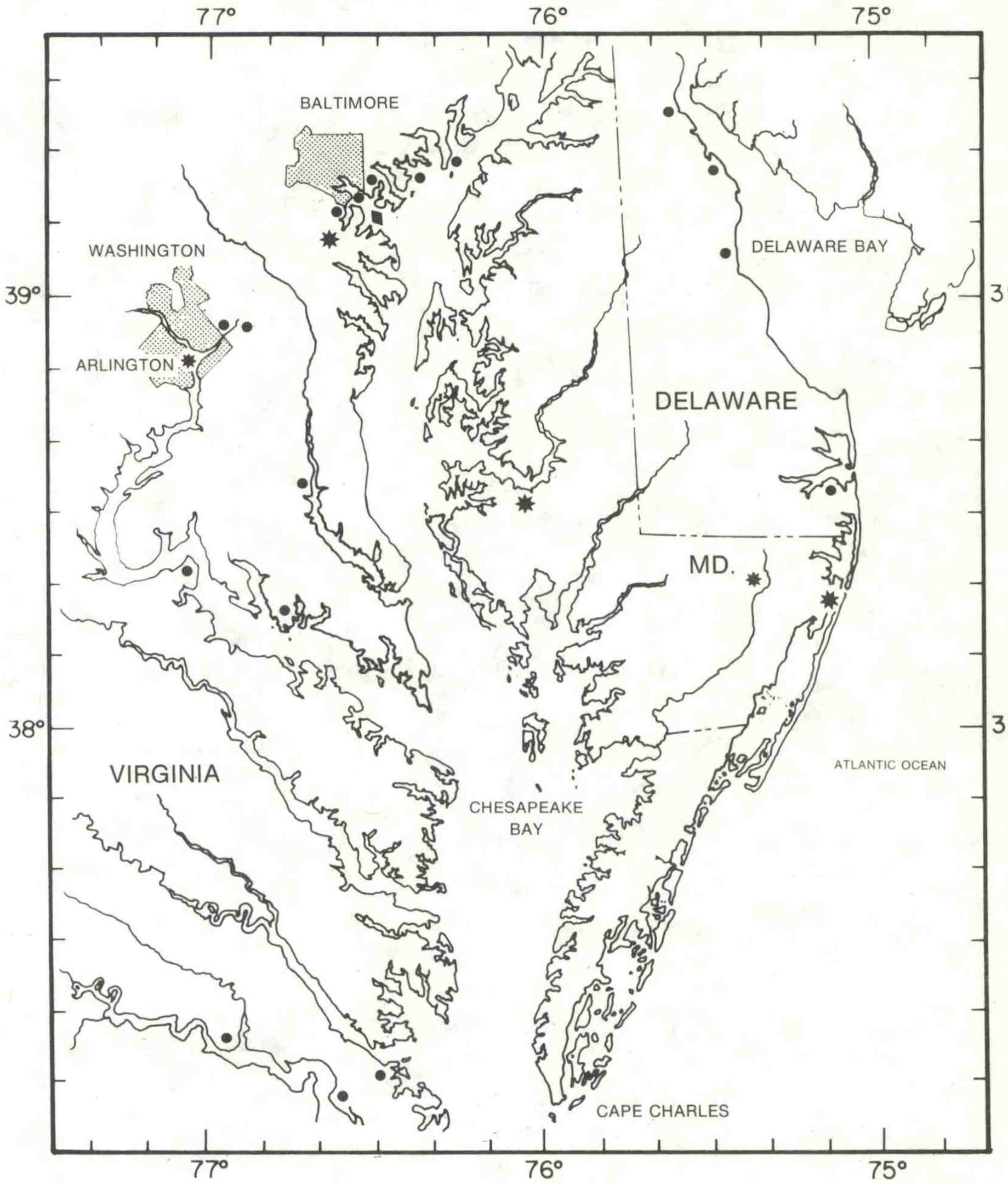


Figure 12.45 Major transportation and utility facilities, coastal and offshore areas, Chesapeake Bay region.

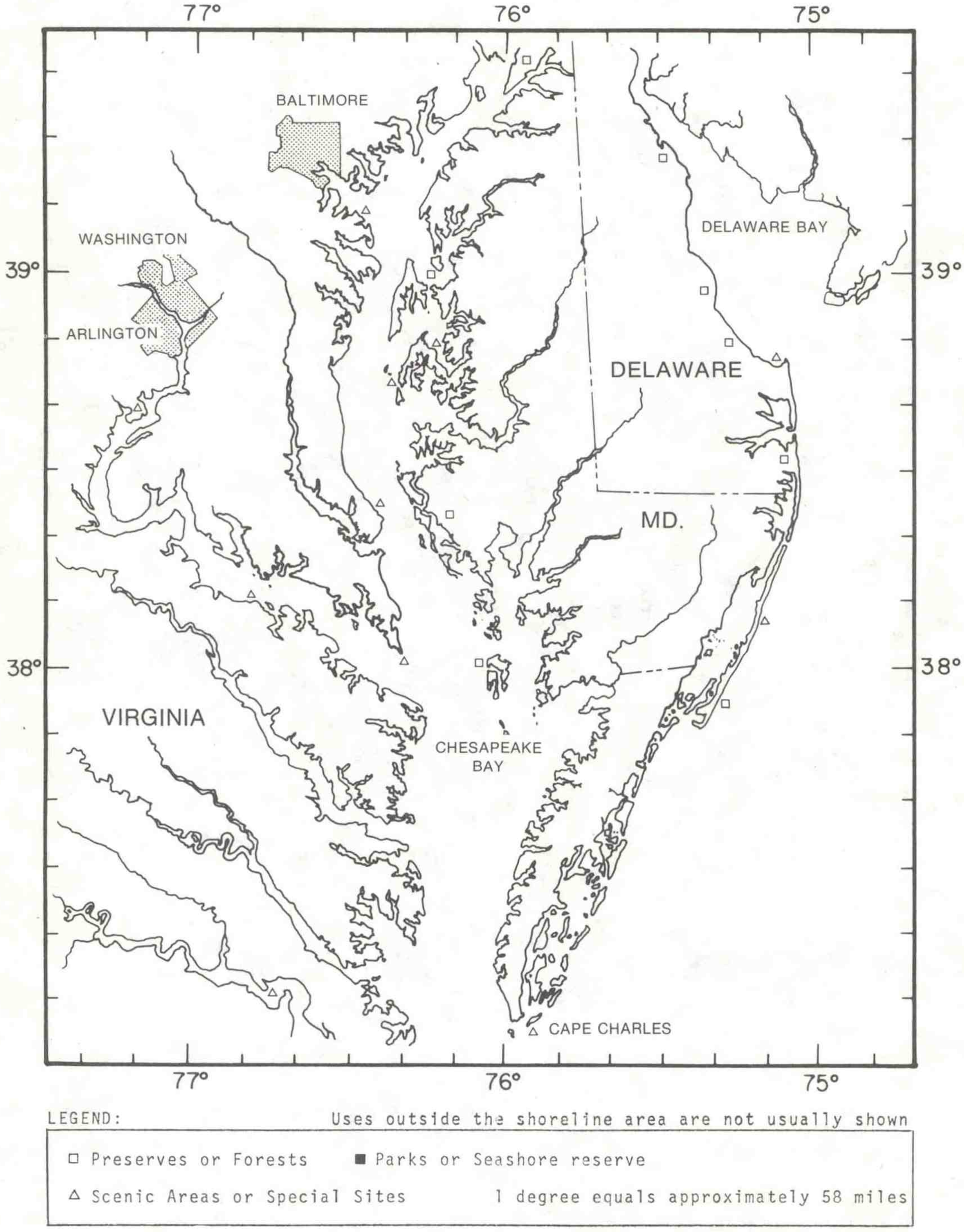


Figure 12.46 Major open-space and scenic areas, coastal and offshore areas, Chesapeake Bay region.

AREA 18

CHESAPEAKE BAY AND DELMARVA PENINSULA DRAINAGE

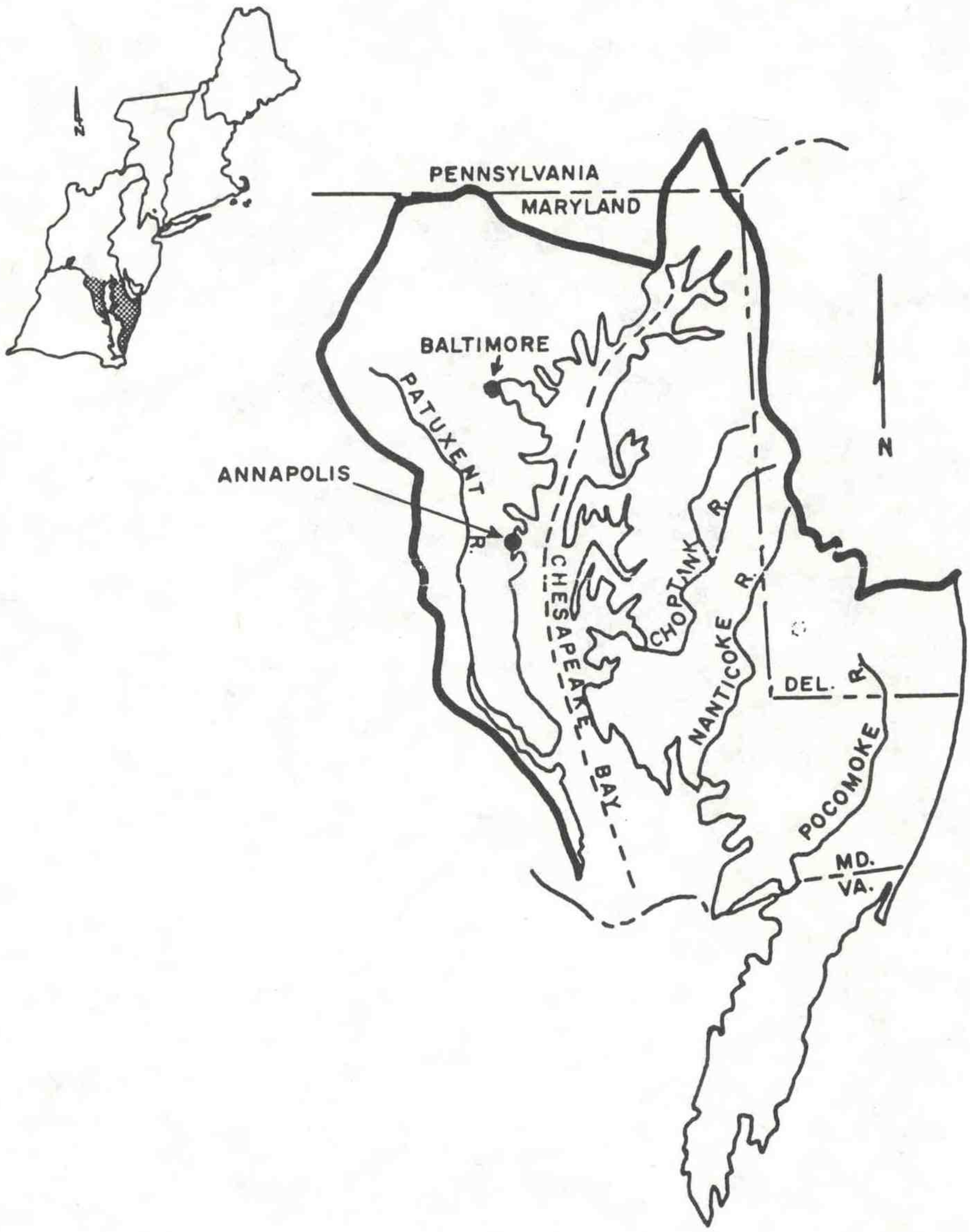


Figure 12.47 Regional map of the Chesapeake Bay and Delmarva peninsula drainage area.

AREA 19 POTOMAC RIVER BASIN

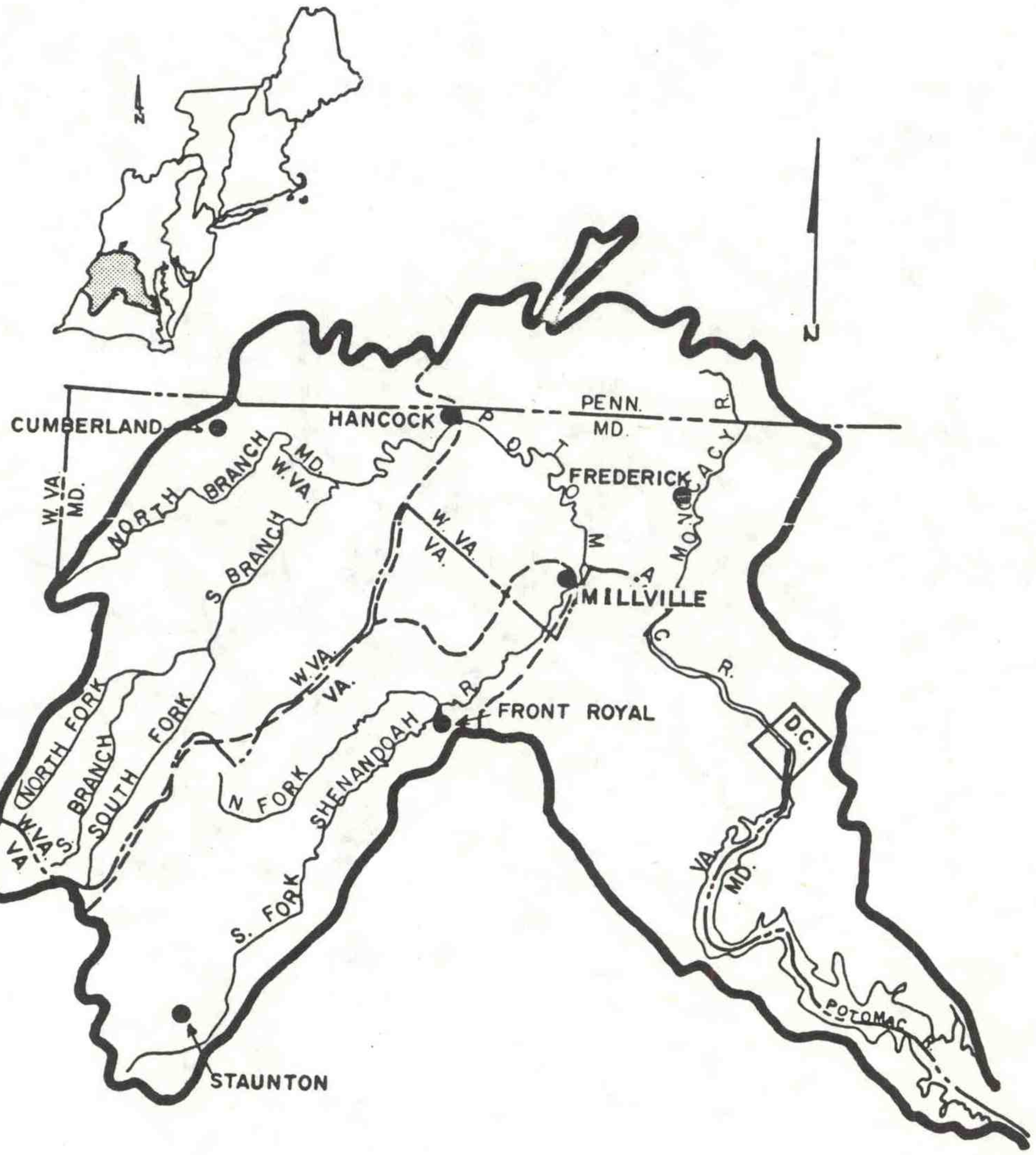


Figure 12.48 Regional map of the Potomac River basin.

AREA 20 RAPPAHANNOCK AND YORK RIVER BASINS

Figure 12.49 Regional map of the Rappahannock and York River basins.

AREA 21 JAMES RIVER BASIN

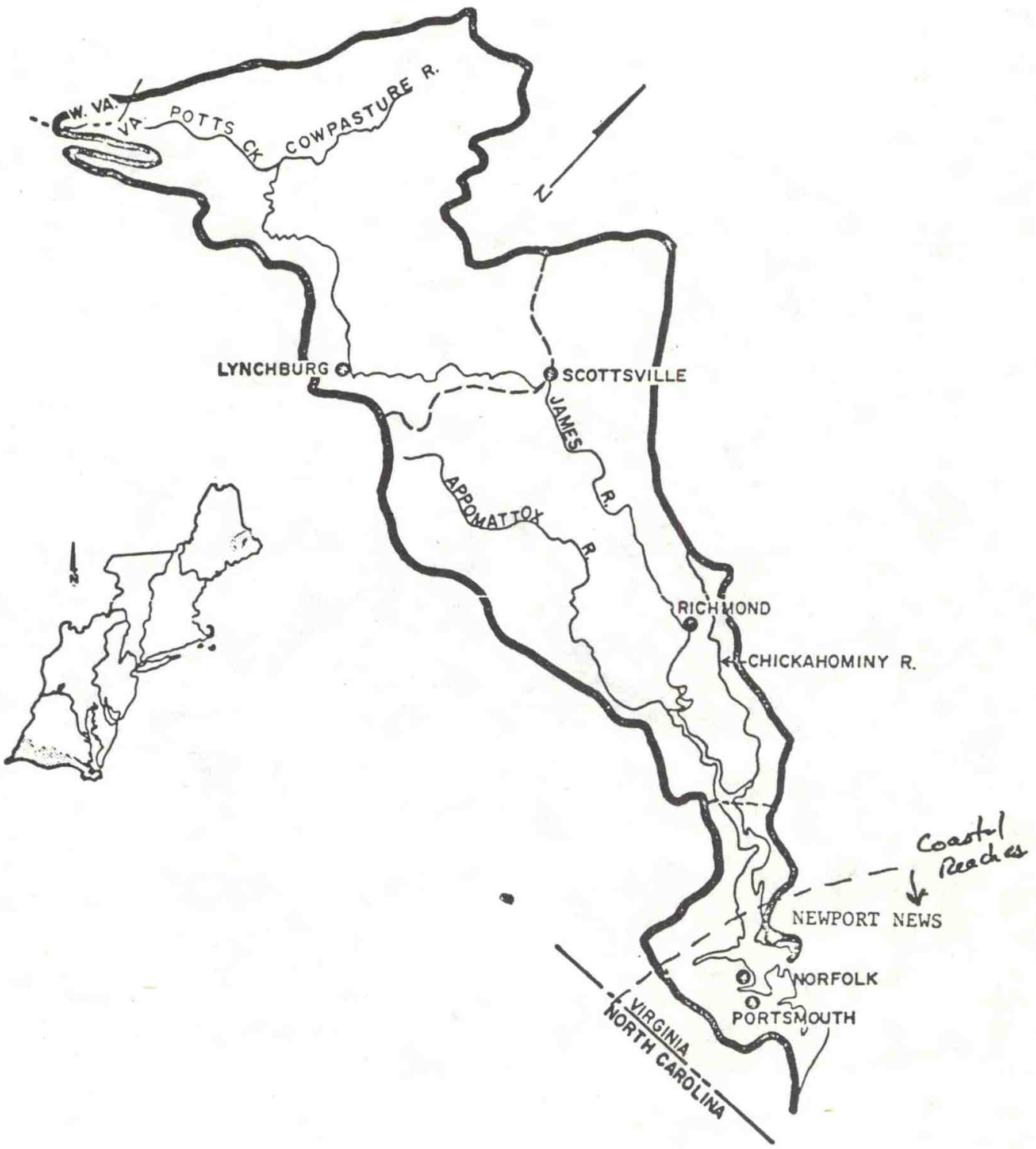


Figure 12.50 Regional map of the James River basin.

Figure 12.49), and the James River Basin (Area 21 - Norfolk Area only - see Figure 12.50). The Chesapeake Bay is the largest estuary on the Atlantic coast, receiving water from a drainage basin of 65,476 square miles. The Bay is about 200 miles long; its width varies from 4 to 35 miles; its surface area is 2,200 square miles; and it has about 2,800 miles of shoreline, two-thirds of which is in the State of Maryland. The Bay's largest tributary is the Susquehanna, the largest river on the Atlantic coast, and the Potomac River provides the largest of the Bay's many sub-estuaries.

The shores of the Chesapeake Bay may be characterized in general as a coastline of submergence with its typical submerged river channels and thick mantle of fairly recent loose sedimentary deposits, wetlands, and very erodable bluffs.

Of approximately 1,900 miles of non-ocean Maryland shoreline, about 280 are on the Bay proper and the rest are on the tributaries. The Maryland shoreline consists almost entirely of extensive wetlands on the eastern shore and banks, bluffs and wetlands on the western shore. Less than 1% (15 miles) of the shore can be considered beach. Ownership is divided about 1670 miles private, 200 federal and 30 public. Most of the federal ownership is concentrated in wildlife areas on the eastern shore and in several military installations on the western shore such as those in Aberdeen Proving Grounds, Edgewood Arsenal, and a number of Navy installations.

The Virginia shoreline on the Bay is approximately 900 miles and includes only a very few, small scattered beaches except for some near Hampton Roads and on the southernmost 25 miles of the Delmarva Peninsula. Most of the remaining shoreline is marshy. Many of the marshes, expecially on the peninsula, are very brackish. Ownership is divided about 735 miles private, 100 public and 65 federal. Most of the federal property is concentrated in military installations in the vicinity of Hampton Roads. Of the 900 miles, only 40 are for public recreational use. Except for the commercial and military facilities in the ports, essentially all the remainder is undeveloped marshes, banks and bluffs.

The ocean sector of the Chesapeake Bay region includes the Atlantic coastal areas of the states of Delaware, Maryland and Virginia. About 120 miles of the ocean front is on the Delmarva Peninsula and 25 miles extend from Cape Henry south to the North Carolina line. All of the ocean front is beach. In Delaware and Maryland it takes the form of long, low, narrow barrier beaches fronting a series of embayments with infrequent narrow inlets connecting them to the ocean. The Virginia shoreline is less uniform. It varies north to south from barrier island, mainland, small buffer islands, mainland and barrier beach. The major embayments are Rehoboth Bay in Delaware, Assawoman Bay in

Delaware and Maryland, Sinepuxent Bay in Maryland, Chincoteaque Bay in Maryland and Virginia, Hog Island Bay in Virginia and North Carolina. Ocean front ownership is divided about as follows: 45 miles (mostly in the southern part of the Delmarva Peninsula) is private; 65 miles (mostly on Assateague National Seashore and Wallops Island) is federal; and 35 miles (mostly in Delaware and southern Virginia) is public. About half the beach is used for public recreation. Most of the remaining half is undeveloped. The backbays throughout this sector exhibit the characteristic pattern found almost everywhere throughout the NAR: their shorelines are almost all wetlands and have very little beach area, ownership is almost all private and the principal use is recreational, featuring small boating, sports fishing and wetlands appreciation. Many of the bachbays in this sector are brackish.

Land forms for the non-coastal portions of Area 18 consist of over 60 percent flat-land (4,400 sq.mi.), about 20 percent undulating land (1,300 sq.mi.), and slightly less than 20 percent rolling hills (1,100 sq.mi.). Landscape units consist of a 40 percent farm-forest pattern (2,900 sq.mi.), 30 percent farms (2,300 sq.mi.), 20 percent town-farm (1,400 sq.mi.), and about 10 percent in city units(700 sq.mi.). The overall landscape quality evaluation ranks two-thirds as medial and about one-third as low. In Area 20, nearly three-fourths of the land form is undulating land (4,300 sq.mi.), about one-fourth is rolling hills (1,500 sq. mi.), and a very small amount is mountainous (100 sq. mi.). Landscape units consist of 24 percent farm (1,400 sq. mi.), 71 percent farm-forest (4,400 sq.mi.), and a small amount of forest-wildland (100 sq.mi.). The combined landscape quality evaluation for the area is three-quarters medial and one-quarter low.

Population and Economic Base. Summaries of population, personal income earnings and employment for Areas 18 and 20 over the period 1959 to 2020 are ahown in Tables 41 and 42. On the western side of Chesapeake Bay, population density increases markedly as the coast is approached. For example, 1970 population densities in the upper, middle and tidal portions of the Potomac Basin (Area 19) were 42, 62 and 297 people per square mile respectively. In the coastal zone itself, population densities are very uneven. Thus the western shore accommodates two of the largest urban centers in the nation: the Baltimore-Washington area and the area around Hampton Roads. During the time span of the NAR study these two concentrations are expected to merge into the Boston-Norfolk megalopolis. In marked contrast, the eastern shore is now and is expected to remain relatively unpopulated. Possibly because of its relatively isolated location even after the opening of the two major trans-bay bridges, the significant year-round population and economic growth experienced by nearby areas has generally by-passed this part of the coastal zone. Future projections contemplate far less growth for this area than for adjacent areas. Similarly, economic activity, on both a total and a per capita basis, is now

TABLE 41. North Atlantic Hydrologic Area 18. Population, Personal Income, Earnings and Employment Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	2,161,762	2,183,937	2,767,300	3,445,300	4,261,300
Total Personal Income (000-$58)	4,695,837		12,264,100	26,105,700	55,012,300
Per Capita Income ($58)	2,172		4,432	7,577	12,910
Per Capita Relative (US=1.00)	1.017		1.078	1.058	1.040
Total Earnings (000-$58)*	3,916,388		9,788,100	20,658,100	43,368,100
Per Worker Earnings ($58)	4,741		8,688	14,365	24,429
Per Worker Relative (US=1.00)	1.016		1.075	1.055	1.046
Population	2,161,762	2,183,937	2,767,300	3,445,300	4,261,300
Total Employment	826,104	834,894	1,126,600	1,438,100	1,775,300
Participation Rate (Empl/Pop)	.382	.382	.407	.417	.417
Employment by Selected Industries					
Agriculture + Forestry + Fisheries	35,459	23,600	16,600	11,600	
Mining	893	700	700	700	
Manufacturing	247,934	306,500	363,300	425,300	
Food + Kindred Products	35,272	34,300	33,500	33,500	
Textile Mill Products	3,045	2,000	1,500	1,100	
Chemicals + Allied Products	15,300	24,700	36,800	49,900	
Paper + Allied Products	6,022	12,000	18,200	26,000	
Petroleum Refining	2,203	1,300	800	500	
Primary Metals	41,278	48,700	54,600	59,700	
Armed Forces	31,552	30,700	31,000	31,200	
Other	519,056	765,100	1,026,500	1,306,500	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

TABLE 42. North Atlantic Hydrologic Area 20. Population, Personal Income, Earnings and Employment Historical and Projected for Selected Years 1959-2020.

	1959	1960	1980	2000	2020
Population	302,999	304,311	381,800	518,100	737,000
Total Personal Income (000-$58)	484,101		1,545,900	3,676,800	9,144,700
Per Capita Income ($58)	1,598		4,049	7,097	12,408
Per Capita Relative (US=1.00)	.749		.985	.991	1.000
Total Earnings (000-$58)*	407,662		1,084,700	2,390,700	5,489,500
Per Worker Earnings ($58)	3,380		7,952	13,393	23,143
Per Worker Relative (US=1.00)	.725		.984	.984	.991
Population	302,999	304,311	381,800	518,100	737,000
Total Employment	120,595	121,159	136,400	178,400	237,200
Participation Rate (Empl/Pop)	.398	.398	.357	.345	.322
Employment by Selected Industries					
Agriculture + Forestry + Fisheries		11,435	7,400	5,500	4,100
Mining		126	D	D	D
Manufacturing	25,581	30,000	36,700	46,300	
Food + Kindred Products	2,998	2,900	3,000	3,100	
Textile Mill Products	592	500	500	500	
Chemicals + Allied Products	2,307	3,000	3,900	5,300	
Paper + Allied Products	1,082	1,600	2,400	3,500	
Petroleum Refining	353	300	300	200	
Primary Metals	302	200	300	300	
Armed Forces	9,136	9,800	9,700	9,500	
Other	74,881	89,200	126,700	177,300	

D Too small to be projected but included in higher level totals
* Including Armed Forces pay

and is expected to remain heavily weighted toward the western shore. For the Bay region as a whole, employment is expected to follow long term trends with increases expected in services and in the chemical, paper and metals industries. Declines are expected in the textiles, petroleum refining, agriculture, forestry, fishing and minerals industries.

The two major concentrations of population and economic activity in the Bay region not included in Areas 18 and 20 are centered around Washington, D.C. and Norfolk, Va. The 1960 population of the Washington metropolitan area (including Arlington and Alexandria, Va.) was 1,018,400, and the gross population densities were 12,400; 6,800; and 6,100 per square mile for Washington, Arlington and Alexandria respectively. As would be expected in the nation's capital, public administration dominates the employment scene, accounting for nearly one-quarter of all jobs. The concentration of armed forces personnel is three times greater than the NAR average reflecting the presence of the defense establishment headquarters here. Medical and other professional services and private household services also command a higher share of total employment here than the NAR average. Less than 11 percent of total employment in the area was employed in manufacturing industries in 1960, and the only manufacturing industry with an above average concentration of employment is printing and publishing which also provides the area's leading manufacturing employment. Nevertheless, metropolitan Washington is a fast growth area with nearly twice the NAR average rate of growth in employment from 1950-1960, and has long enjoyed a higher than national average income.

Newport News-Hampton occupies the peninsula north of Hampton Roads, with Norfolk-Portsmouth on the south side. Hampton Roads is one of the largest and finest harbors in the world. Norfolk-Portsmouth is the location of the largest naval base in the country and the economic fortunes of the area are highly dependent upon this military establishment. The growth in population is very illustrative of the volatility of this type of employment.

The 1960 population of the Norfolk metropolitan area (including South Norfolk, Portsmouth and Newport News, Va.) was 585,400, and gross population densities were 6,100; 3,100; 8,000 and 1,500 per square mile for Norfolk, South Norfolk, Portsmouth, and Newport News respectively. Per capita income in these areas has consistently been below the national average.

The share of total employment working in the manufacturing industries is only 16 percent, one-half the NAR proportion. Manufacturing employment is highly concentrated in the shipbuilding and related metals industries, most of which is located at Newport News. Of the other manufacturing industries, only food and lumber and wood products manufacturing have employment shares approximating the NAR average. All

other manufacturing industries are well below the NAR share of total employment. The area also has a low ratio of employment in the trade and service sectors with the exception of hotels and other personal service and private household services. Military employment was 23 percent of total employment in 1960 (ten times the normal concentration in the NAR), public administration another 10 percent. Besides being headquarters for the Atlantic Fleet, Norfolk is a major military embarkation point, ship outfitting and repair center. Additionally, it is a major commercial port. Both Newport News and Norfolk are deep water coal terminals handling large volumes of bituminous coal shipped from Appalachia by train, making this one of the largest export ports in the country. The concentration of employment in fishing is 6-1/2 times greater here than the NAR average.

Land-Use. Land-use and water area summaries for Areas 18 and 20 are shown in Table 43, which lists total surface areas together with the amounts and percent distribution of types of surface coverage in 1963. In that year, 326 square miles (4.3%) of Area 18's total land was intensively developed; 38 percent was devoted to crop production with 12,000 commercial and 4,300 non-commercial farms in operation; and there were 1.3 million acres of commercial forest, almost all of which was farm-owned or private. Area 20 statistics for 1963 show 79 square miles (1.5%) of the total land area intensively developed; 15.6 percent in crop production with 3,680 commercial and 3,600 non-commercial farms in operation; and 1.9 million acres of commercial forest,

TABLE 43. Land-Use and Water Area - Areas 18 and 20 - 1963

Cover Type	Amount (thousand acres)		Percent Distribution	
	Area 18	Area 20	Area 18	Area 20
Cropland	1,766	582	34	15
Pasture	209	359	4	10
Forest	1,740	2,441	33	64
Urban	228	116	4	3
Water				
-over 40 acres	534	94	10	2
-under 40 acres	29	10	1	-
Other	707	238	6	3
Total	5,213	3,840	100	100

with 90,000 acres publicly owned and 219,000 owned by the forest industry, the balance being farm-owned or private. With respect to mineral extraction, Area 18 produced in excess of $11 million dollars worth of stone and sand and gravel in 1963. Similar data for Area 20 is not available.

Public Utilities. Approximately 1.8 million people, or 77 percent of Area 18's total population, obtain their water supply from 140 central water systems which distribute an average of 260 m.g.d. About 85 percent of this water comes from surface sources and the rest from ground water. A portion of the area's surface supply is diverted from the Lower Susquehanna River. Presently available water resources comprise 1,085 m.g.d., and total practical development is estimated to be 1,468 m.g.d.

The total industrial water intake for Area 18 is 1,173 m.g.d., of which 154 m.g.d. are self-supplied, 45 m.g.d. are self-supplied, 45 m.g.d. are publicly-supplied, 120 m.g.d. are waste water, and 854 m.g.d. are brackish water. This is the only area in the Region where waste water is utilized for industrial water supply. Sewage treatment plant effluent is used by the primary metals industry. The significant self-supplied water using industries in the area are chemicals (50 m.g.d.) primary metals (47 m.g.d.) and food (18 m.g.d.). These same industries are the major users of brackish water. Livestock and rural domestic requirements are 35 m.g.d. Other uses of water supply are for farmland irrigation (30,000 acres) and non-agricultural irrigation (7000 acre feet). About 30 percent of the agricultural water comes from ground water, as does almost all of the non-agricultural water.

In Area 20, some 146,000 people (46% of 1964 total population) are served by 57 central water systems, which distribute an average of 18 m.g.d. of which 83 percent is derived from surface sources. Presently available water resources in the area comprise 78 m.g.d., with total practical development estimated at 1,702 m.g.d. Area 20's total industrial water intake of 92 m.g.d. includes 50 m.g.d. of self-supplied fresh, 2 m.g.d. of publicly-supplied fresh, and 40 m.g.d. of brackish. The chemical industry is the only one in the area which uses a significant amount of self-supplied water, some 48 m.g.d. Brackish water use is almost equally divided between the petroleum and paper industries with respective intakes of 19 m.g.d. and 17 m.g.d. Livestock and rural domestic requirements are 11 m.g.d. Irrigated farmland (1,900 acres) derives 80 percent of its water from surface sources, and non-agricultural irrigation (1,200 acre-feet) relies primarily on ground sources.

The electric power requirements for Area 18 during 1969 were met by 3,466 megawatts of installed generating capacity, whereas the needs of Area 20 were met by 435 megawatts. The distribution of the capacity for each area by type of prime mover, together with scheduled or planned additions through 1975, are shown in Table 44.

TABLE 44. Total Electric Generating Capacity (1969) and Planned Additions (1975) - Areas 18 and 20. (MW)

Generator Type	Area 18		Area 20	
	1969	1975+	1969	1975+
Steam Electric				
- Nuclear	---	1,804	---	1,750
- Fossil	3,049	732	430	845
Hydroelectric	1	--	--	--
Internal Combustion/ Gas Turbine	416	711	5	--
TOTAL	3,466	3,247	435	2,595

Area 18-21 - Chesapeake Bay Region (Major Coastal Uses/Major Coastal Problems

Major Coastal Uses. Along the sectors of this region fronting the ocean (Delmarva peninsula and Virginia seashore), the principal coastal use is for recreation, including aesthetic satsifaction. Other coastal uses, although present, are much less important here. Little commercial fishing is done in these waters, and the only non-living resource extracted is sand and gravel in minor quantities (although it is present in abundance). The large assimilative capacity of the Atlantic relative to the limited wastes from a small, non-industrial population minimizes pollution problems except when outfalls are unwisely run into the small poorly flushed backbays. However, there is increasing concern about the ocean dumping of solid wastes off Area 18 by large cities such as Philadelphia. There are no ports in the area nor any demand for coastal airport on land fill. National defense establishments are minor. Land-use is important principally because of the land's value for enjoyment.

On the Chesapeake Bay itself, the situation is just the opposite as all major coastal uses are present to varying degrees. These include transportation, military use, commercial fishing, outdoor recreation, and waste disposal. Each of these uses will be described below.

Marine transportation is focused on Hampton Roads and Baltimore, which ranked third and fourth among the NAR ports in total tonnage in 1968. Several studies have been made on economic impact of these ports. One study concluded that the total, "direct" and "indirect" economic impact of the port of Baltimore was about $1-1/2 billion in 1966 and represented about 12% of Maryland's gross state product. Another study of the Virginia ports concluded that in 1968 port and related activities generated 94,000 jobs and wages of $0.63 billion. Indirectly an

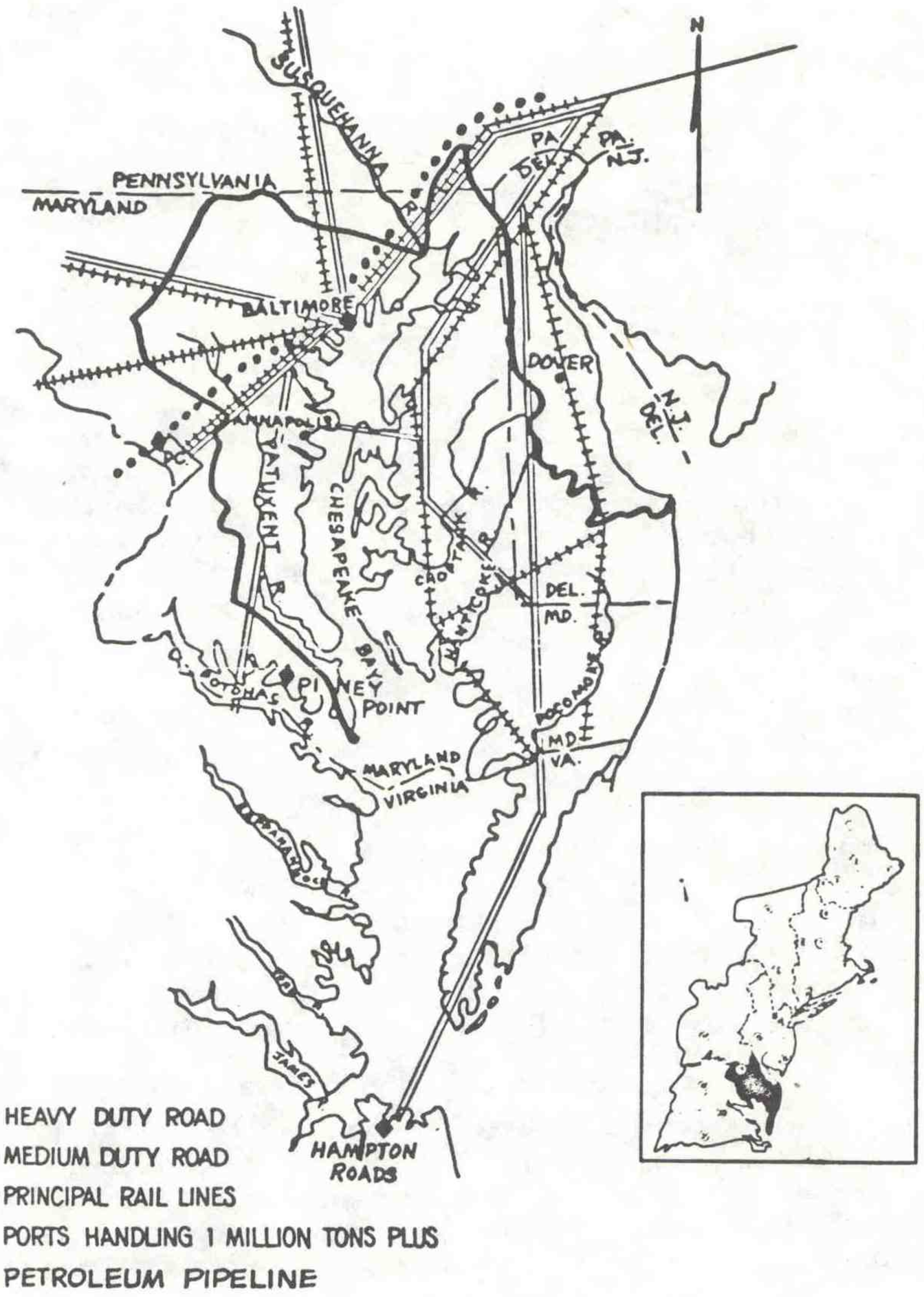


Figure 12.51 The transportation system of the Chesapeake Bay and Delmarva peninsula drainage area.

additional 131,000 jobs were generated. In total, one out of every eight jobs in Virginia were directly or indirectly related to the state's port and harbor activities.

In Area 18, commercial navigation is a large and important activity because it supports large industrial water users (e.g. iron and steel manufacturing, coal exporting). Baltimore presently handles most of the waterborne commerce in the Area. This commerce grew at an annual average rate of .6% during the nineteen years ending in 1967 but at the even slower rate of 0.3% over the last ten of those years. Commerce averaged 42,960,000 tons for the three years prior to 1968. Commerce in 1970 totalled 51,100,000 tons. The projected commerce has an annual growth rate ranging from 1.0% to 2.5%.

As shown in Figure 12.51, land transportation patterns on the western shore of the Bay are well developed to inland and other coastal centers, with Baltimore as the hub because of its historically strategic location. In addition to numerous highways and railway lines, the area is also served by the Colonial Pipeline System which provides for a competitive bulk movement of petroleum products into the area. On the bay's Eastern Shore, land transportation systems have replaced historical patterns of heavy commercial navigation. Former centers of bustling maritime commerce are used for limited tonnages of special cargoes, supporting commercial fishing fleets and recreational fishermen with their markets, and facilitating easy access to recreational areas from metropolitan centers. Key links in the complementary land transportation network are bridges at the mouth and mid-points of Chesapeake Bay.

In Area 19, commercial navigation activity is limited, with only a couple of major ports on the Potomac River (Washington, D.C. and Piney Point, Md). Waterborne commerce at these ports grew at an average annual rate of 2% over the nineteen-year period ending in 1967 but slowed to 0.8% during the last ten of those years. Commerce averaged about 3,600,000 tons for the three years prior to 1968. The 1968 commerce was 3,100,000 tons.

Land transportation in Area 19 (See Figure 12.52) strongly competes with commercial navigation and can be expected to inhibit its development. The Chesapeake and Ohio Canal, which connected the Nation's Capital and Cumberland, Md., and transported over 900,000 tons in 1876, was closed in 1924 due to competition from land transportation. The existing land transportation pattern can be thought of as an extension of the radial system of Baltimore. Land transportation, especially the railroad, is particularly competitive because of the lack of development in the vicinity of the port facilities. In addition, Washington, D.C., is one of the cities that are served by the Colonial Pipeline System, which tends to compete with waterborne petroleum.

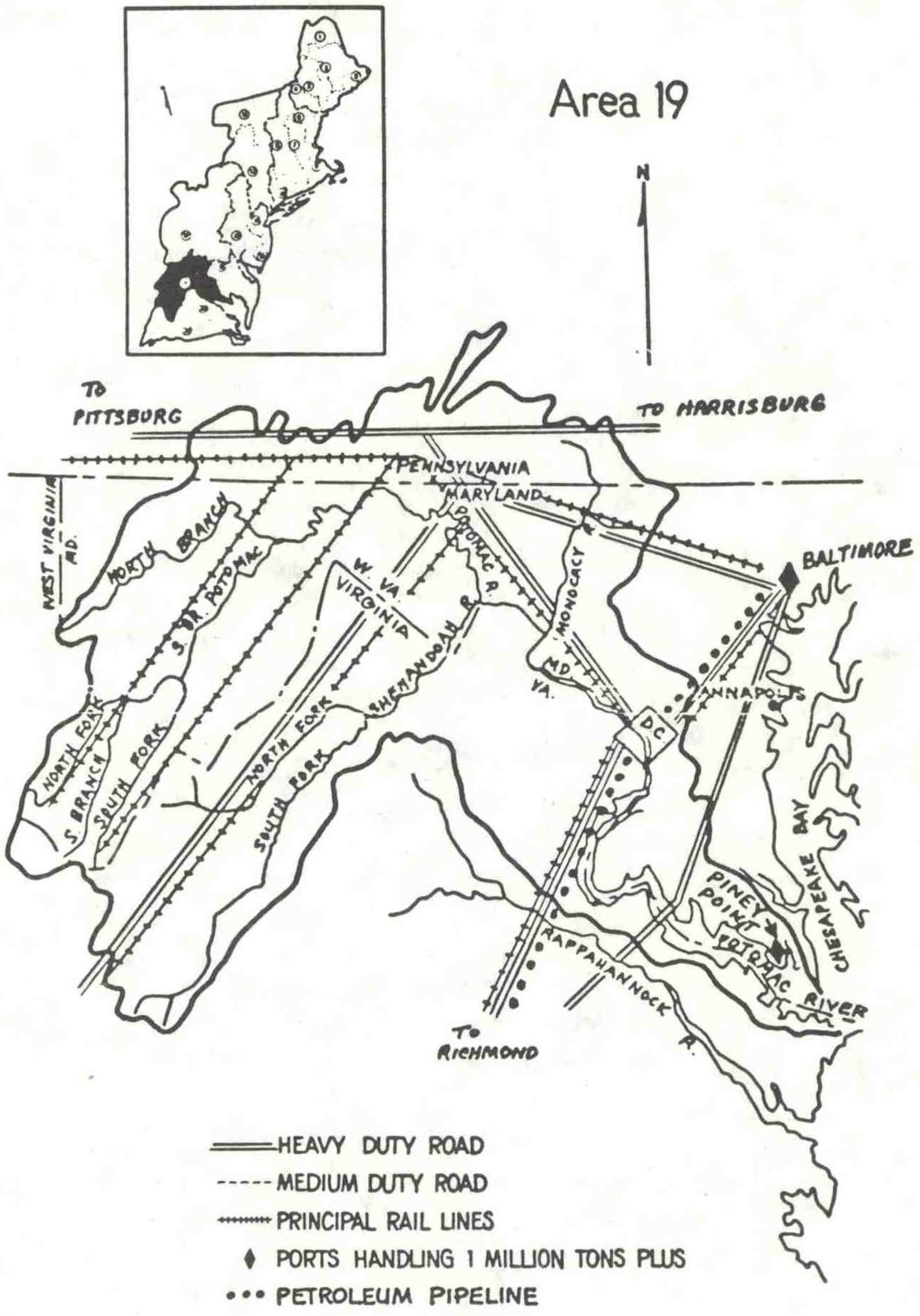


Figure 12.52 The transportation system of the Potomac River basin.

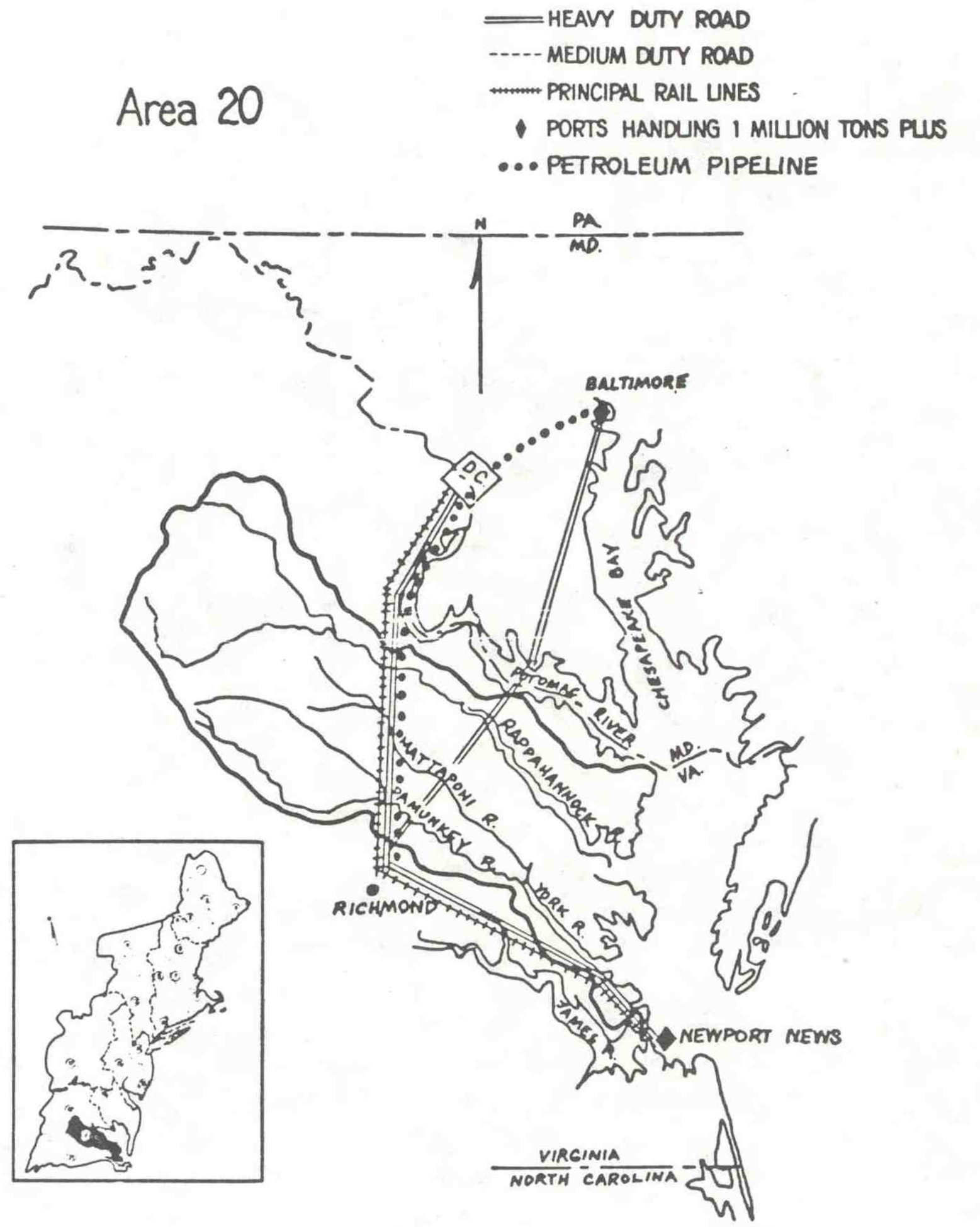


Figure 12.53 The transportation system of the Rappahannock and York River basins.

In Area 20, commercial navigation is not expected to become a significant activity because of physical constraints and lack of good land transportation. Figure 12.53 illustrates that land transportation cannot support or compete with navigation for the simple reason that it is almost undeveloped. Improvement of the land transportation system may result in some reduced commercial traffic (because of the area's proximity to major ports) and increased recreational boating because of its proximity to large urban concentrations. However, he major portion of the commercial traffic is crude oil imports, which is not expected to be affected by land transportation improvements due to the large fixed plant investment in the Yorktown refinery.

Along the York River, waterborne commerce grew at an annual average of 13% over the nineteen year period ending in 1967, but has been rather static during the last ten of those years. Commerce averaged 4,600,000 tons for the three years prior to 1968. The 1970 commerce was 4,700,000 tons on the York River, 5,000 tons on the Mattaponi River, and 54,000 on the Pamunkey River. Along the Rappahannock River, commerce declined at an average rate of 1.6% over the nineteen year period ending 1967; however, the decline accelerated to 7% in the last ten of those years. Commerce averaged 219,000 tons for the three years prior to 1968. The 1970 commerce was 223,000 tons for the Rappahannock River, and nearly 64,000 tons to the river's ports and harbors in the first 40 miles. Commerce is expected to experience little growth in the foreseeable future.

In Area 21, commercial navigation is a very large and important activity, dominated by coal exports, and is expected to grow despite some physical constraints. The Port of Norfolk, which lies along Hampton Roads to the south of the James estuary, includes portions of the estuary and several rivers which pass through the town. Waterborne commerce grew at an average annual rate of 2.5% over the nineteen year period ending in 1967, but declined sharply to an average growth of only 0.5% during the last ten of those years. Commerce averaged 40,400,000 tons for the three years prior to 1968. The 1970 commerce was 53,600,000 tons. A second major port area is Newport News, whose facilities are located along the northern shore of the James River and include coal handling facilities, general cargo facilities, and the Newport News Shipbuilding and Drydock Co. The facilities are fully supported by the road and railroad network. Waterborne commerce grew at an average rate of 1% over the nineteen year period ending in 1967 but underwent a drastic average annual rate of decline of 4.2% over the last ten of those years. Commerce averaged 17,400,000 tons for the three years prior to 1968. Commerce in 1970 was 23,600,000 tons.

Land transportation in Area 21 (see Figure 12.54) complements navigation in the James Rvier Estuary area from Richmond to Hampton Roads. At Richmond, navigation is somewhat limited due to restrictive

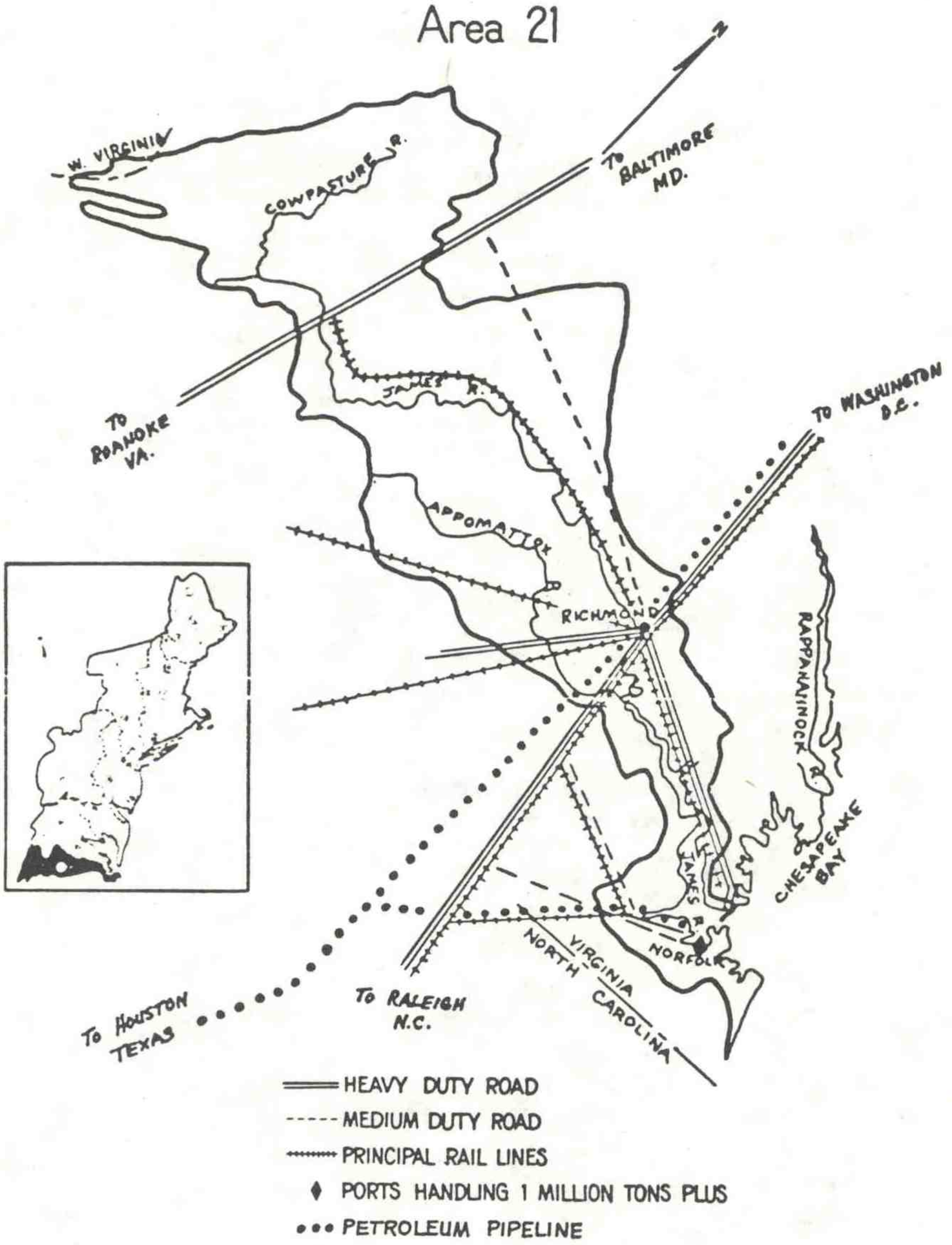


Figure 12.54 The transportation system of the James River basin.

channel dimensions and channel curvature. However, commerce at Richmond terminals is ably and efficiently handled and can be transferred to trucks and railroads operating over high-speed, heavy-duty highways and rail lines radiating to all points of the compass. The Hampton Roads port area, Newport News and Norfolk, is a commercial navigation center well served by excellent railroad, storage, shipping, shipbuilding and repair, and freight-forwarding services and facilities.

A second major coastal use of the bay shores is for military installations. Several Navy facilities, especially those in the Norfolk and Annapolis areas, are dependent upon their coastal locations and contribute significantly to the bay economy. Several Army installations, most only partially dependent upon their coastal location, also contribute importantly to the bay economy. The concentration of military installations around Washington, D.C. is related primarily to the nearby Pentagon.

The third major coastal use in the Chesapeake Bay region is commercial fishing. The total value of the Bay's catch has risen from $25 million in 1950 to $35 million in 1967 although individual species have, of course, shown the sharply different fluctuations so characteristic of marine fisheries. In 1967, the most important species economically were the oyster, hard crab, menhaden, soft clam, and soft crab in that order.

The oyster accounted for about half of the total value. Many of about 200 recorded species are permanent residents. Other more predominantly ocean oriented species spend significant parts of their life cycles in the bay in spawning, nursing or feeding, or in passing through on the way to or from freshwater. In the value of their commercial fish catch, Virginia and Maryland rank ninth and tenth among the nation's 24 oceanfront states with an annual catch of $18 and $17 million respectively. Essentially all of the catch for the two states comes from Chesapeake Bay, not the Atlantic Ocean off their coasts. Within the North Atlantic Region, the bay provides a quarter of the catch. Only Massachusetts, fourth; and Maine, eighth, rank above Virginia and Maryland.

A fourth major coastal use is for outdoor recreation. Average per person participation rates for the mid-Atlantic coastal states (summer, 1965) include .93 days spent boating, .15 sailing, .13 waterskiing, and 7.45 swimming. To satisfy such demands, a large body of water with several thousand miles of coastline immediately adjacent to the southern part of what is expected to become the largest megapolis in the world might be expected to play an important role. The bay is generally filling this need for pleasure boating and sports fishing. About 200,000 pleasure craft are located in the bay area and about

600,000 are expected by 2020. Nearly half these totals can be considered "registered" as defined by the current registration requirements of Maryland and Virginia. Private facilities should be able to satisfy the marina demand, but some increase in public launching facilities may become necessary. Sports fishing is another major recreational use of the bay and also a major industry. Unfortunately, the bay has not been satisfying some other important forms of outdoor water-based recreation and aesthetic needs such as beach lounging, bathing, water skiing, and visual aesthetic satisfaction.

Waste disposal is one of the most prominent uses of the bay and much concern has been voiced in recent years lest the Bay's assimilative capacity be overtaxed. The great and rapidly growing population concentrations on its western shore, associated industrial activity and the relatively sluggish movements of its silt-laden tributary rivers all combine to point up the importance of controlling this use knowledgeably. Control is especially important in the finger-like, slow-flowing, urban-fringed sub-estuaries like the Potomac and the Patapsco.where pollution problems are the worst. A summary of organic waste loads from Area 18 (77 non-industrial and 82 industrial sources known in 1960) and Area 20 (30 non-industrial and 3 industrial sources known in 1960) are shown in Table 45 in terms of population equivalents for existing treatment levels.

TABLE 45. Organic Waste Loads in Areas 18 and 20 - 1960.

Load Type	Waste Load (Pop. Equiv.) (thousands)	
	Area 18	Area 20
Non-Industrial	423	20
Industrial	516	199
Total	939	219

Major Coastal Problems - Bay Portion. The first problem considered herein is how to reconcile the need to dispose of waterborne waste products with the uses of the bay. A very valuable use of the bay lies in its capacity to assimilate waterborne wastes better than most currently known alternatives. However, this capacity is obviously limited by the quantity and toxicity of the waste. Currently, it is not adequately known what this threshold is and what the incremental effects of departing from it are. Of the many uses of the bay, those most influenced by waste disposal are fihsing and swimming. Currently about 42,000 acres of shellfish grounds are closed because of pollution. Pollution also fosters plankton blooms, especially prominent in the Potomac below Washington, Pollution is generally concentrated where flushing and dilution action is the poorest. However, unless and until other problems cited later under recreation are resolved, improvement in water quality will probably have relatively little effect upon swimming in the Bay.

A second major problem considered herein is how to satisfy outdoor recreation needs. Its proximity to population centers makes the bay a candidate for greatly increased recreational demand. Currently most of the recreational use is in the form of boating and sports fishing which are strongly interrelated. The heavy demand for skin contact recreation such as swimming, clamming, and waterskiing is almost completely unsatisfied because of several obstacles, including pollution, jellyfish migration, scarce beachfront, and limited public ownership. As formidable as these obstacles are, there seem to be currently available ways of offsetting or minimizing all of them except the jellyfish. Its control or elimination in an ecologically and economically acceptable way could open up a substantial close-in summer recreation resource to pent-up demand adjacent to one of the largest existing and future concentrations of people in the nation.

A related use which could be better satisfied in the bay area is aesthetic visual satisfaction. Except when one crosses a tributary subestuary or one of the bay bridges, or when one makes a special effort to visit the coast, a resident could go for weeks or months without even knowing the bay is there. With the exception of the above few obvious bridge-crossing necessities, most of the daily travelled ways of the populace seem to be oriented to keep the bay out of sight. Increased effort to identify the relatively few visual promontories in the bay area and route some of the more heavily travelled roads through some of these promontories could provide a most welcome daily aesthetic uplift to many people.

A third major problem considered herein is how to accommodate the bay area to the expected trends in marine transportation. Analysis of marine transportation trends reveals potentially large economic advantages of accommodating more of the world's fleet of deep draft vessels in the NAR. The accommodation of very large tankers does not appear particularly applicable to Chesapeake Bay. However, insofar as dry bulk cargo is concerned, two of the three largest port complexes in the NAR are located on the bay. These are Hampton Roads, which dominates the region's substantial coal export trade, and Baltimore, which ranks with the Philadelphia area as the Region's largest importer of iron ore. The significance of the fixed investments in the current inland coal fields, and the large steel plants currently in the Baltimore area, probably overwhelm possible economies attainable by moving to deeper water even if available. The problems of making the Hampton Roads and Baltimore facilities accessible to the deep draft vessels are substantial, but solutions are at least conceptually possible. If these very deep draft dry bulk carriers can be accommodated in an environmentally and economically acceptable way, the overall impacts on the economic well-being of the bay area and the nation could be very substantial.

About half of the 1,900 miles of Maryland's bay shoreline is subject to erosion. During the century, 1845-1942, the net loss of land was about 25,000 acres on nearly 40 square miles. The 15 most critical miles, with historical erosions rates greater than eight feet annually, are located on Kent Island, Poplar Island, and Tilghman Island on the east shore; and Point Lookout and St. Clements Island in St. Mary's County and Cover Point in Calvert County on the west shore. With a few exceptions, studies have revealed that there currently is no economical solution. The problems in the Virginia part of the bay are similar with the most critical erosion occurring along the lower south shore of the Potomac Estuary and the bay front of Areas 19 and 20. In Virginia, as in Maryland, almost all of the shoreline is privately owned and thus currently ineligible for federal assistance.

Major Coastal Problems - Ocean Portion. Along the oceanfront of the Delmarva peninsula and southern Virginia, recreation and coastal erosion are highly significant problem areas. Each is considered below.

Recreation and aesthetics are dominant along this coast. Rehoboth Beach, Delaware; Ocean City, Maryland; and Virginia Beach, Virginia are each their state's major summertime mass outdoor recreational outlets. In 1969 Ocean City is reported to have accommodated nearly 13 million visitors. Spreading most of that crowd over ten summer weekends conveys a picture of how intensely the beach is used. Much of the ocean front in Delaware and Maryland and on Assateague Island in Virginia is open to the public. The remaining coast of Virginia is mostly privately owned except around Virginia Beach. Every fair summer weekend cars pile up sometimes almost as far back as Washington, D.C. to cross the two-land bay bridge near Annapolis heading to Ocean City and Rehoboth Beach. Medium-density beach-oriented summer residences fill much of the available coastline near these resorts. The part of the Delmarva Peninsula south of Ocean City caters to low density recreation with emphasis on aesthetic satisfaction. The beautiful Assateague Island National Seashore is owned and operated by the U.S. Department of the Interior. Farther south on the peninsula, several barrier islands were recently purchased by a private conservation group from a developer to forestall a reported planned recreational-residential facility for up to 45,000 people. Some ways the area can improve its ability to satisfy the inland recreational demand are by improving accessibility, preserving and enhancing aesthetic appeal by zoning control and other alternative means, and minimizing seasonality factors.

The second major problem in this section is erosion. The long exposed coastline, frequent violent storms especially in the fall and winter, and a generally southward littoral drift combine to present severe coastal erosion problems. Some of the barrier islands between Assateague Island and Cape Charles have been averaging a loss of 15-16 feet a year for at least a century, while Hog Island has lost 50 feet in a single

year. These islands are currently undeveloped, but their wild aesthetic appeal, wildlife habitat and usefulness as a protective barrier to the mainland might justify efforts to preserve them by sand fences, dune grasses or other inexpensive and environmentally compatible means. The northern five miles of Assateague Island has been eroding at a rate of about 35 feet a year for the past 25 years. Along most ot the Maryland and Delaware shores annual losses range from about 3 to as much as 21 feet a year.

Subregion E. North Carolina Coast
Cape Hatteras to Virginia

Cape Hatteras, North Carolina, defines the southern limit of the Middle Atlantic Bight. The Cape Hatteras area extends to the Virginia state line for the purposes of this study as no data is available comparable to the series of reports gathered on the NAR region which formed the informational basis for the preceding sections. Most of North Carolina's vast estuarine complex is included in this section area as well as much of North Carolina's present and planned development. However, North Carolina's entire coastal zone should be discussed for practical considerations when planning any development of the coastal zone. To this end a report entitled "Environmental Reconnaissance Inventory of the State of North Carolina" is under preparation by the Planning Division of the U.S. Army Corps of Engineers but is not yet available. This report should provide a good background for statewide coastal zone management.

The coastal zone extending from the North Carolina state line south to Cape Hatteras consists of a series of ecosystems, which have not yet been severely influenced by man. This coastal zone complex includes large shallow estuaries, barrier beaches and islands, dunes, marshes, mudflats and open coastal water.

The Pamlico-Albemarle-Currituck Sound areas of the North Carolina coast are separated from the Atlantic Ocean by a barrier island system known as the Outer Banks. This vast estuarine complex is characterized by shallow waters reaching a maximum of about 20 feet in Pamlico Sound. The ecology of the estuarine region seems to be controlled to a large extent by fresh water inflow from four river systems entering the estuaries.

The ocean shoreline areas from Cape Hatteras northward are characterized by a relatively narrow barrier beach with wide sandy beaches backed by dunes - almost ideal for recreational development. Figures 12.57 and 12.59 show that recreational development (particularly in the Outer Banks area) has already been extensive. This region also contains several scenic areas and historic landmarks.

In the past, this region has been a producer of tobacco, peanuts, cotton and soybeans, and forest products. Finfish and shellfish resources are also widely utilized. Although a significant amount of agricultural activity continues, it has been supplemented by more recently developed national defense activites, recreational activity and tourism.

Although Figures 12.55, 12.56 and 12.58 do not show significant municipalities, industries, transportation utilities or extended population density areas in this region, indications are that the coastal zone of North Carolina to the north of Cape Hatteras is on the verge of highly significant economic changes of major consequence to the ecological integrity of the coastal zone.

The future of North Carolina's coastal zone north of Cape Hatteras is indicated by information contained in a recent issue of the newsletter published by the Coastal Plains Center for Marine Development Services (Vol. 4, No. 6, Nov.-Dec. 1973). Plans for economic development in the area discussed include: (1) plans for a 300 million dollar gasification plant in Hertford County, bordering Albemarle Sound; (2) multi-million dollar expansions by the Weyerhaeuser Company in Plymouth and by Texas Gulf, Inc. in Beaufort County; (3) plans for new state parks in Gates, Camden and Beaufort Counties; (4) expansion of the harbor at Wanchese into a major fish-handling and processing port; and (5) continuing development of various resort and retirement facilities in the area.

The extraction of high grade phosphate ore in the vicinity of Aurora, North Carolina, is a large and fast-growing operation which involves ore extraction from beneath estuarine sediments. The size of this operation can be gauged to some extent by the fact that a 175 million dollar investment will have been realized by one company from this operation alone by 1975. The ultimate economic and ecological consequences of this development remain to be evaluated.

It seems important to recognize that this planned development will quickly influence population density, muncipal development and transportation utilities.

Despite proposed development, a substantial proportion of the approximately 200 mile length of the Outer Banks of North Carolina is already in national seashore. The Cape Hatteras National Seashore extends for a distance of about 71 miles and the Cape Lookout Seashore, located south of Cape Hatteras, continues for another 55 miles. The Cape Hatteras National Seashore has been developed extensively for public recreation and already accommodates nearly 2 million visitors annually. The area between Kitty Hawk and Nags Head which is a popular and rapidly expanding recreational area is being developed primarily by private interests.

A major recreational attraction of the Outer Banks area is the prospect of good fishing. In addition to the seasonal availability of striped bass and bluefish, the relatively easy access to the Gulf Stream supports a good sportfishery for blue and white marlin as well as other game fish.

Commercial fishing in the area seems highly dependent upon the continued health of the estuaries. Much of the state's commercial finfish and shellfish harvest, such as shrimp, blue crabs, hard clams, bay scallops, menhaden, alewives, channel bass, spot, shad and flounder have some form of estuarine dependence.

Two major problems of the North Carolina coastal zone are sand dune and wetland destruction. The State of North Carolina has acted to protect these areas by passing appropriate legislation. Among these are a Sand Dune Protection Act and two acts prohibiting wetland destruction. A dredge and fill law and the Coastal Wetlands Act regulate activity in marshlands and wetlands.

It seems clear that North Carolina's coastal zone management system must combine an understanding of highly important and delicately balanced ecological systems with man's social systems and economic desires. This concept of multiple-objective management is difficult to develop and enforce, but necessary in order to manage utilization of the coastal zone while preserving coastal zone amenities.

Acknowledgment. Research and plotting for figures showing major residential, industrial, recreational locations; transportation and utility facilities; and open spaces and scenic areas were contributed by John M. Grifalconi.

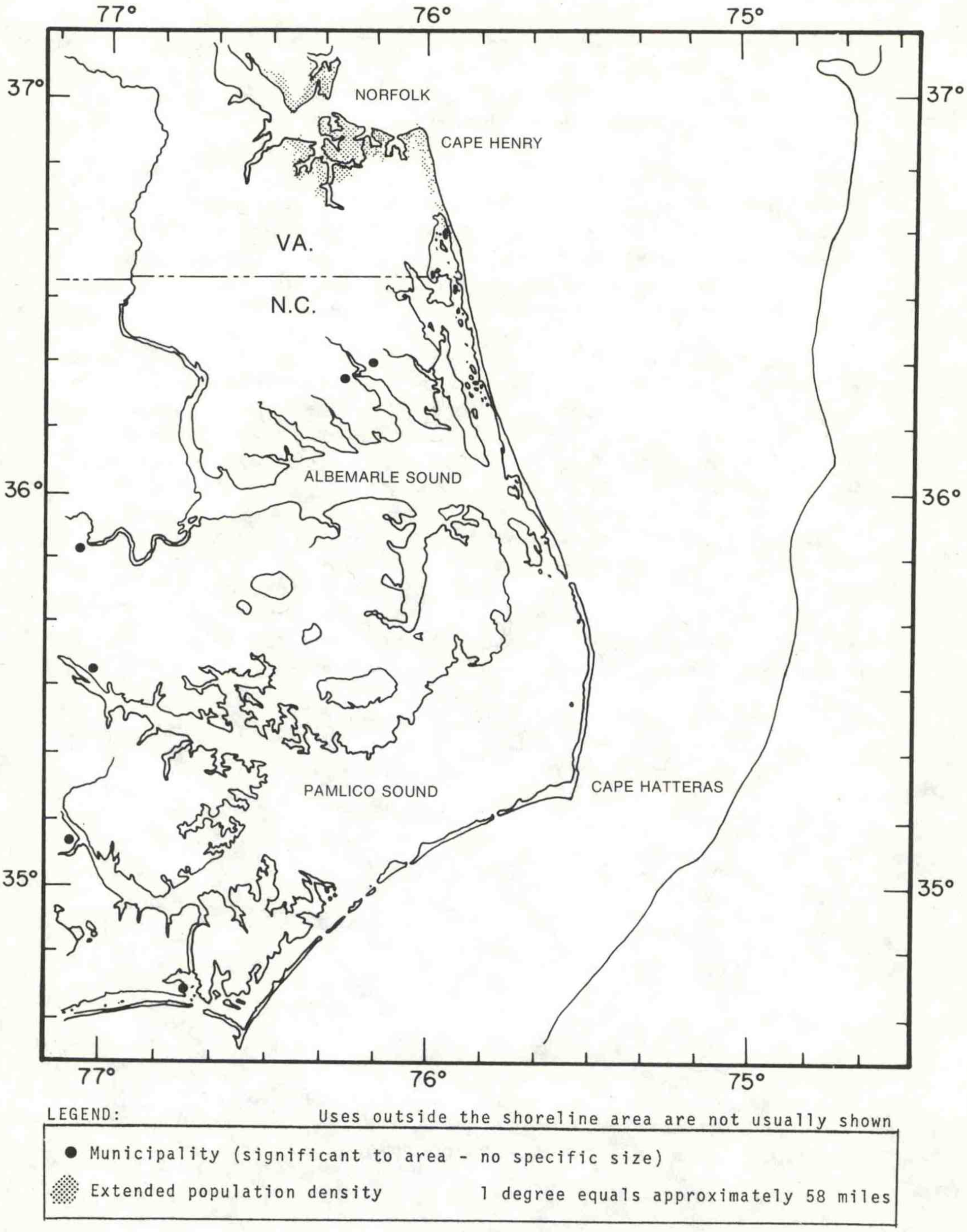


Figure 12.55 Major residential locations, coastal and offshore areas, Cape Hatteras region.

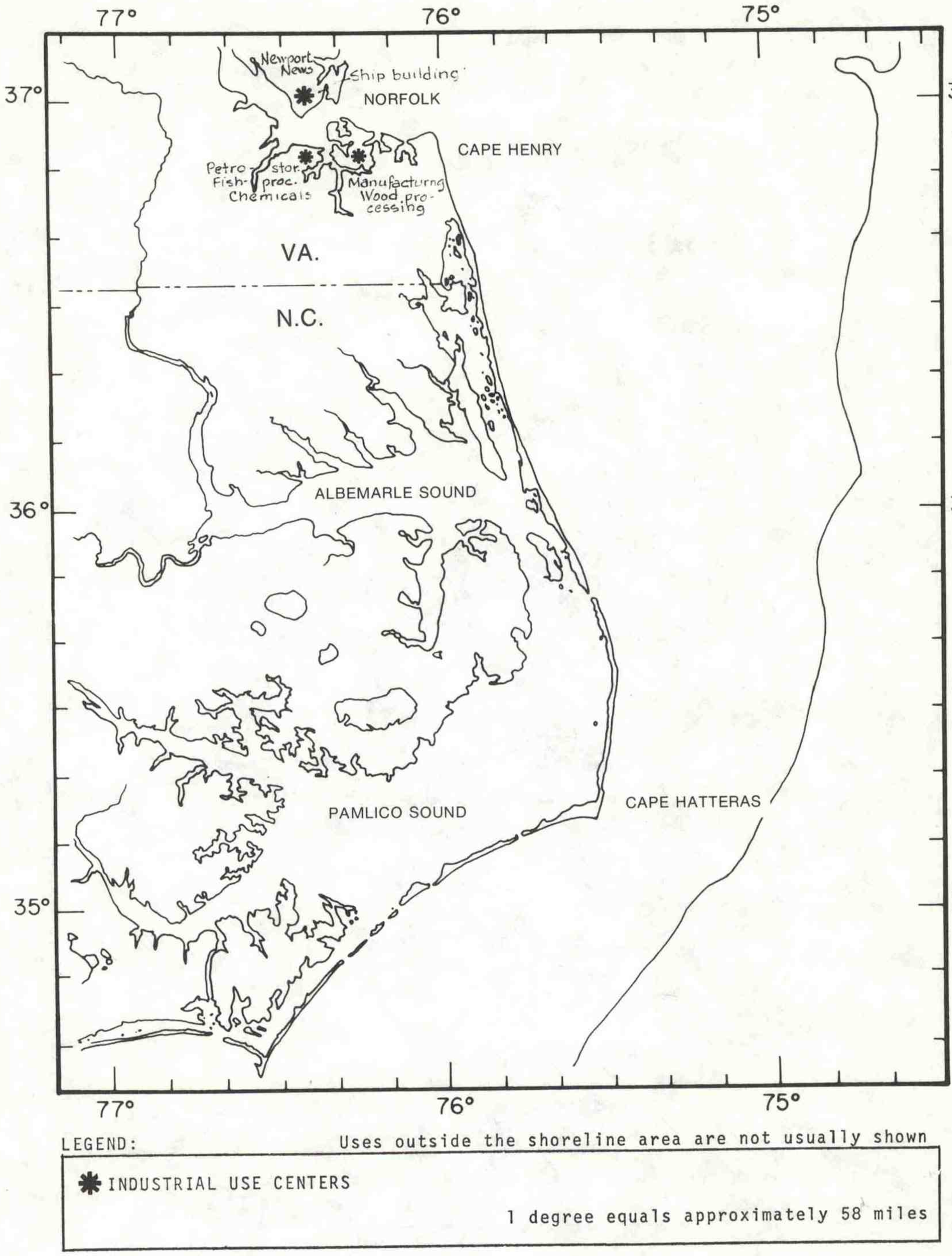


Figure 12.56 Major industrial locations, coastal and offshore areas, Cape Hatteras region.

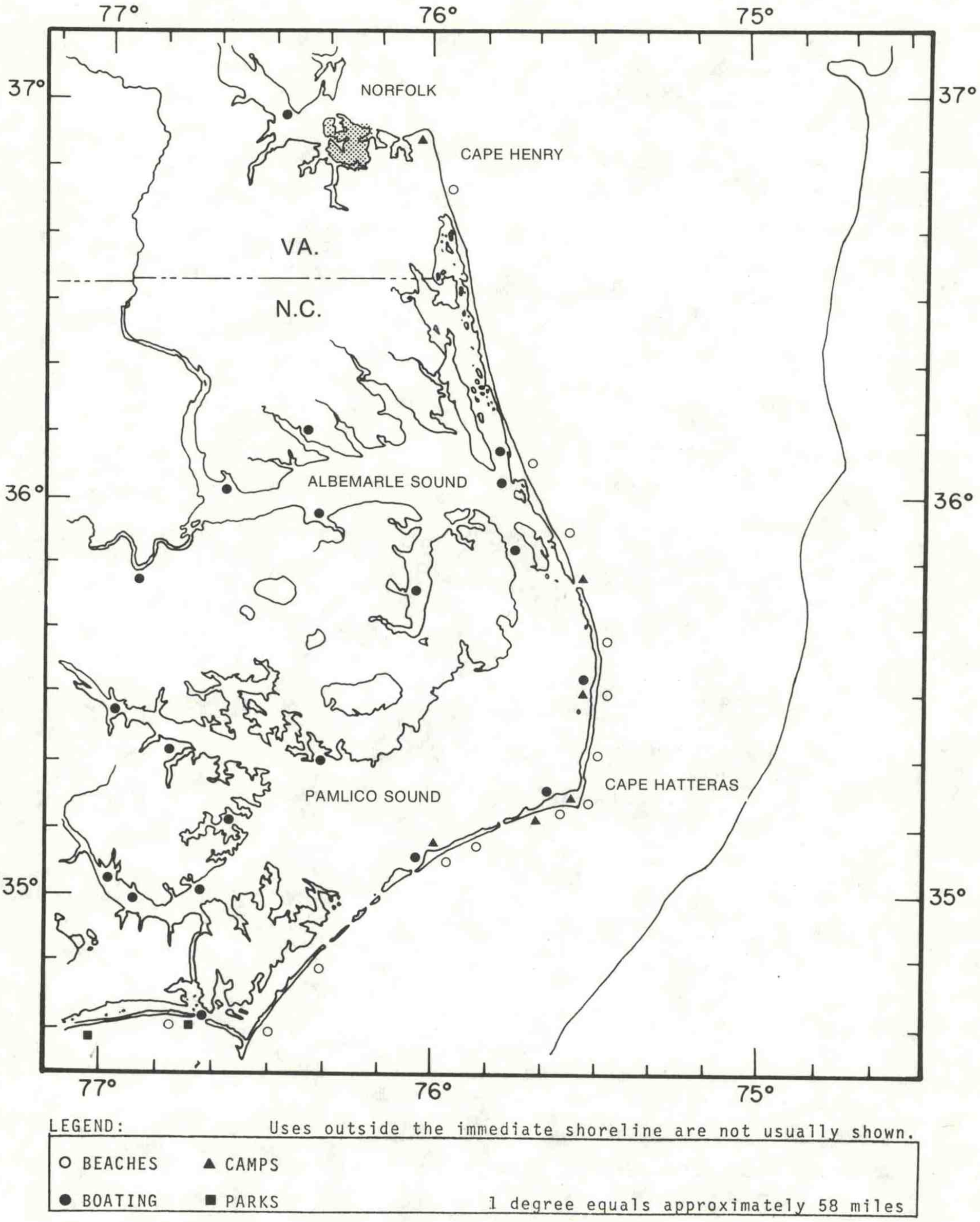


Figure 12.57 Major recreation locations, coastal and offshore areas, Cape Hatteras region.

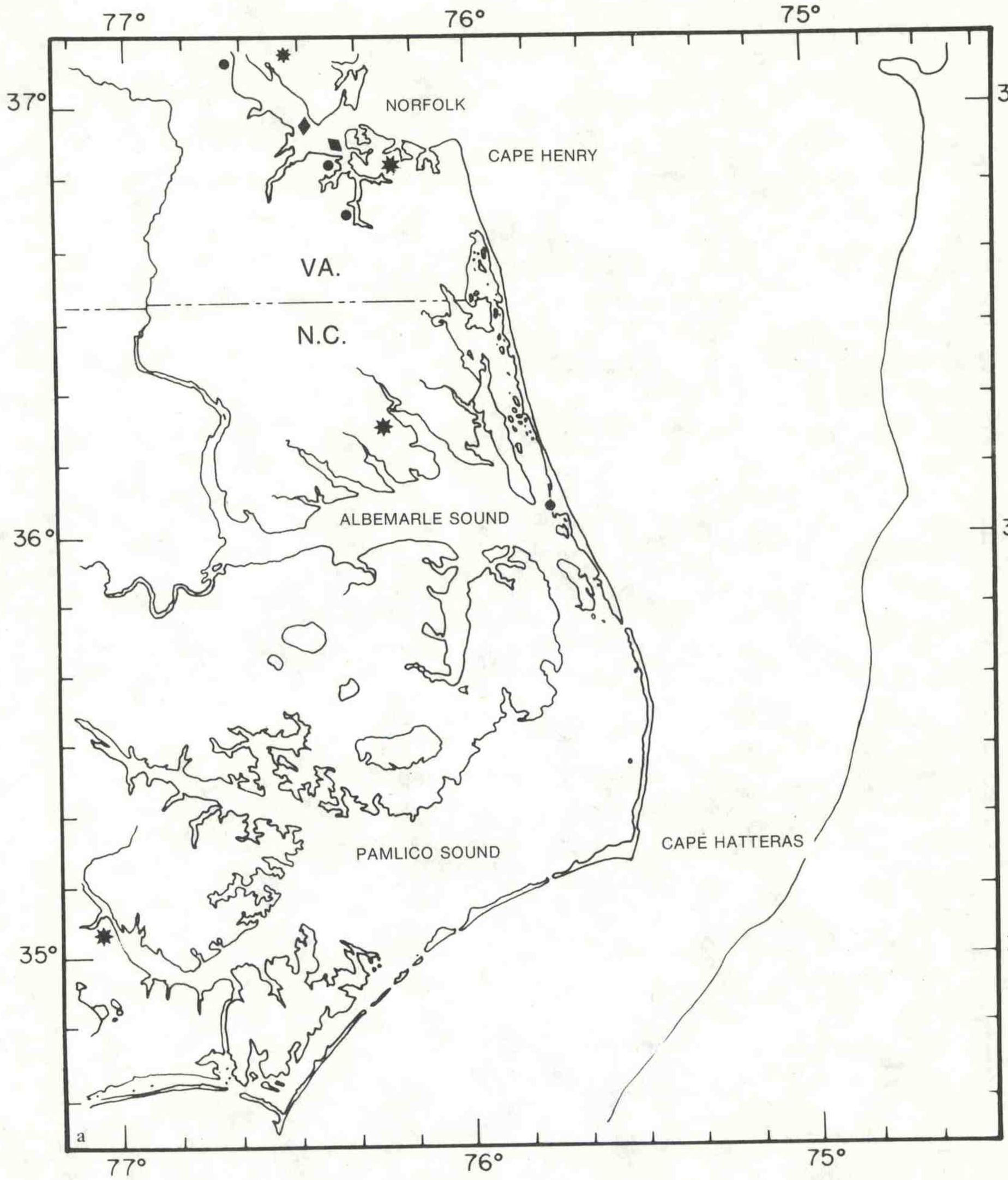


Figure 12.58 Major transportation and utility facilities, coastal and offshore areas, Cape Hatteras region.

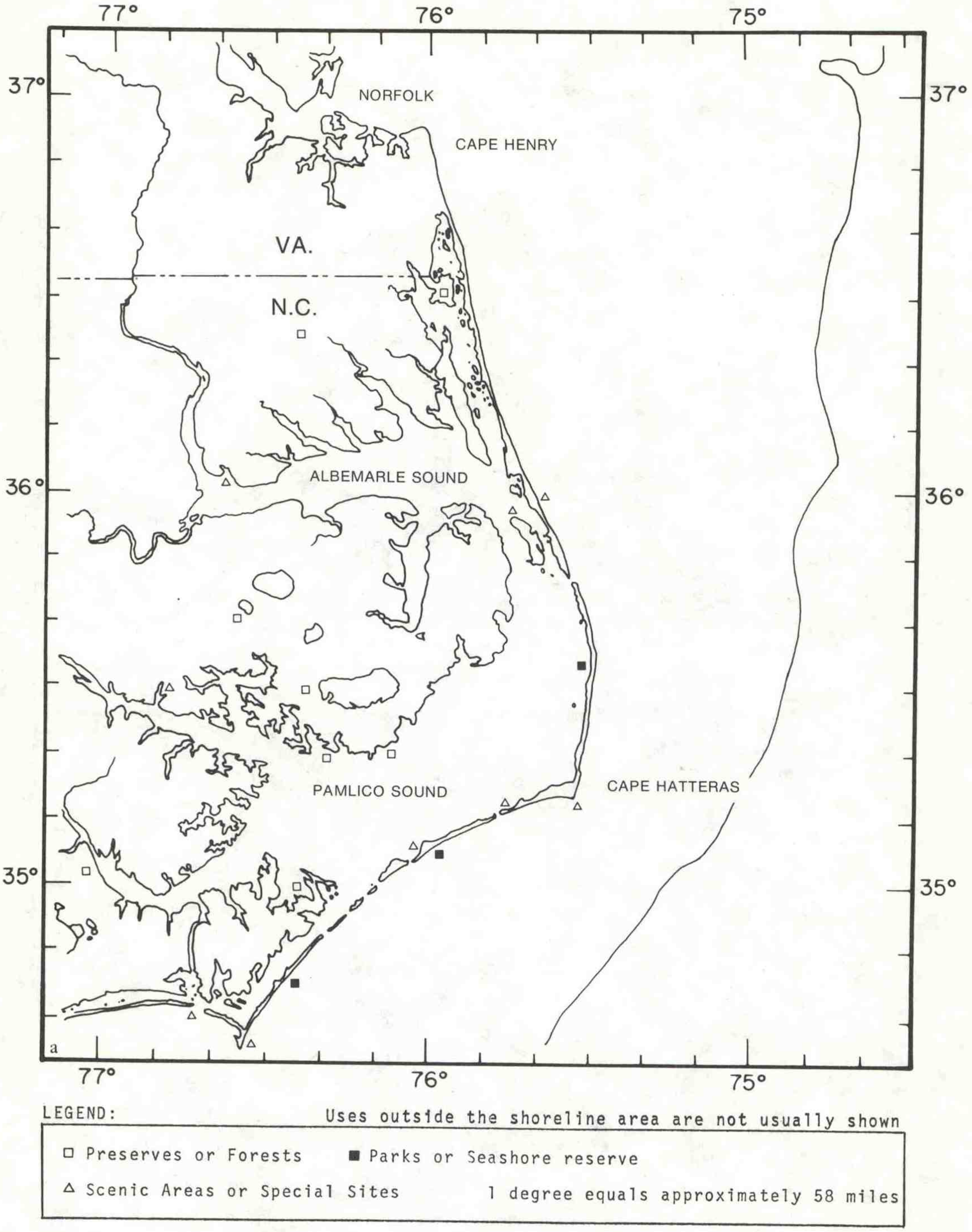


Figure 12.59 Major open-space and scenic areas, coastal and offshore areas, Cape Hatteras region.

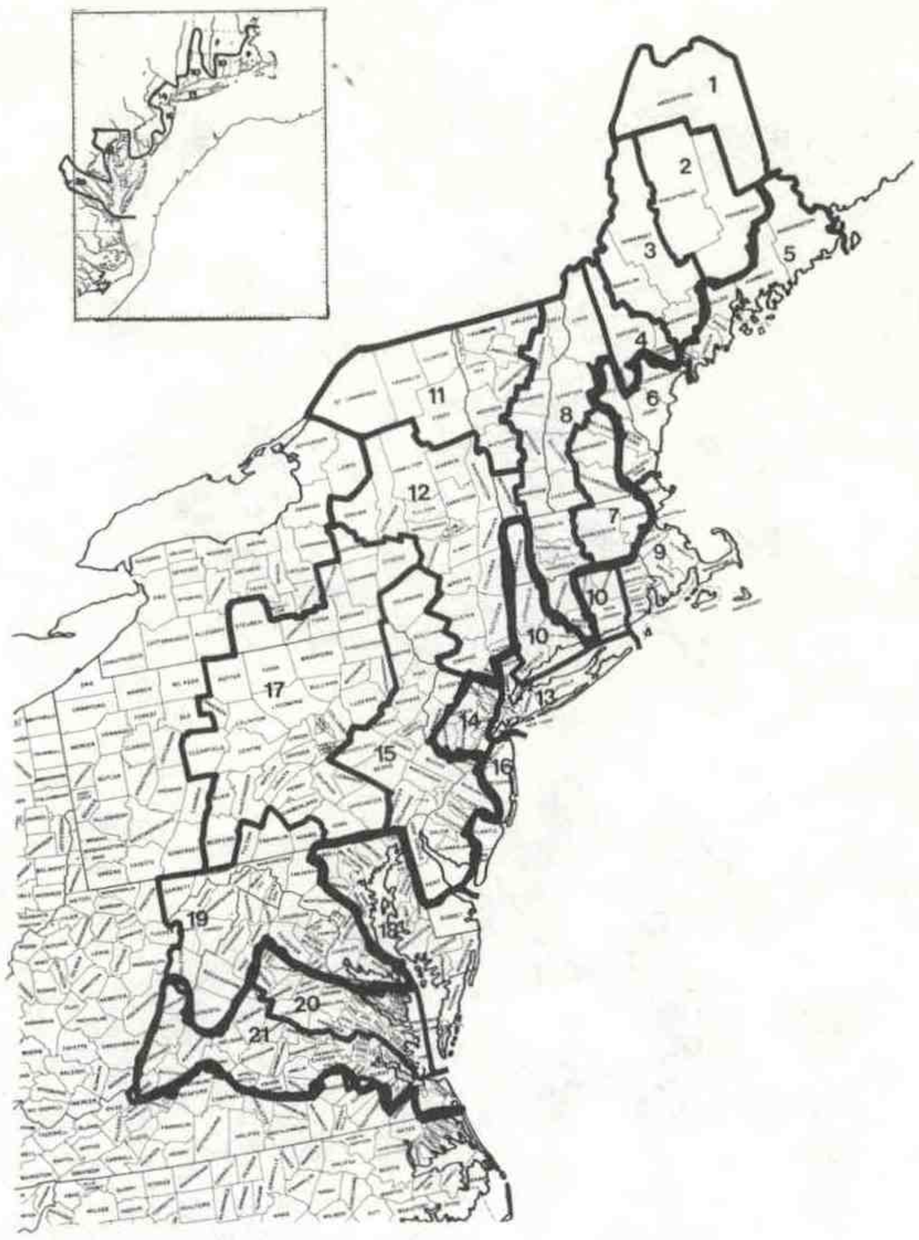


Figure 12.1 The North Atlantic hydrologic region, with coastal areas discussed in this study shown on the inset base map.

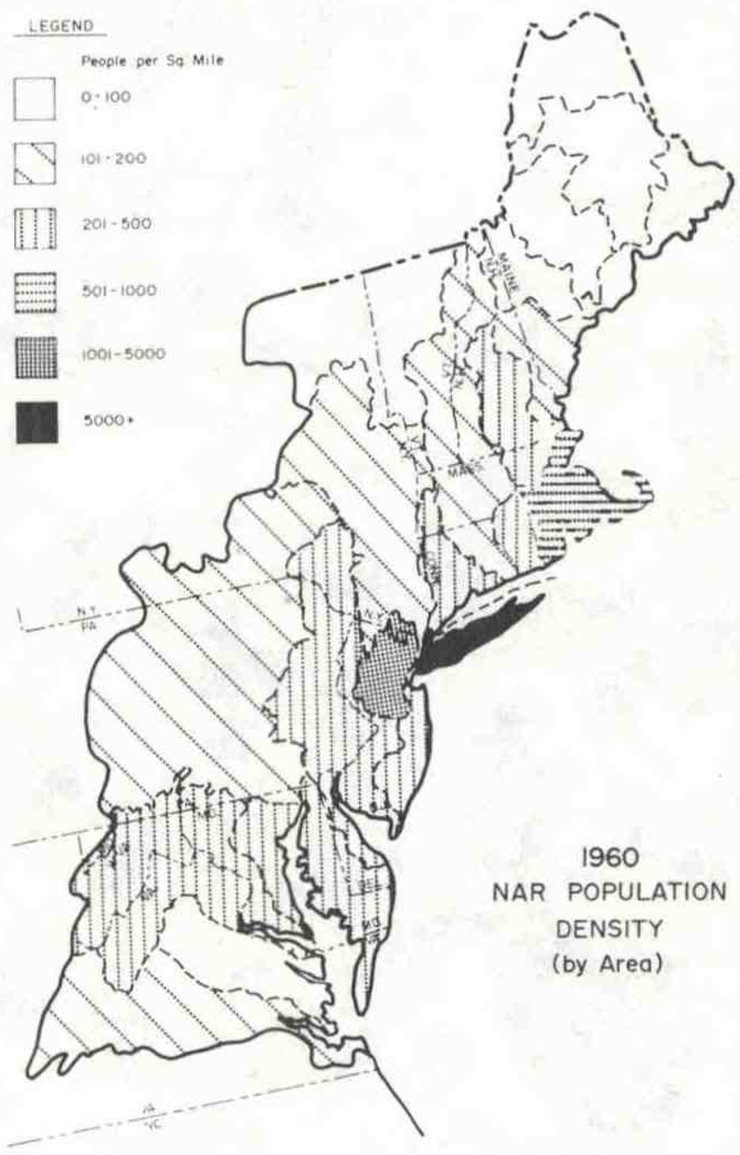


Figure 12.2 Population density of the North Atlantic Region, 1960.

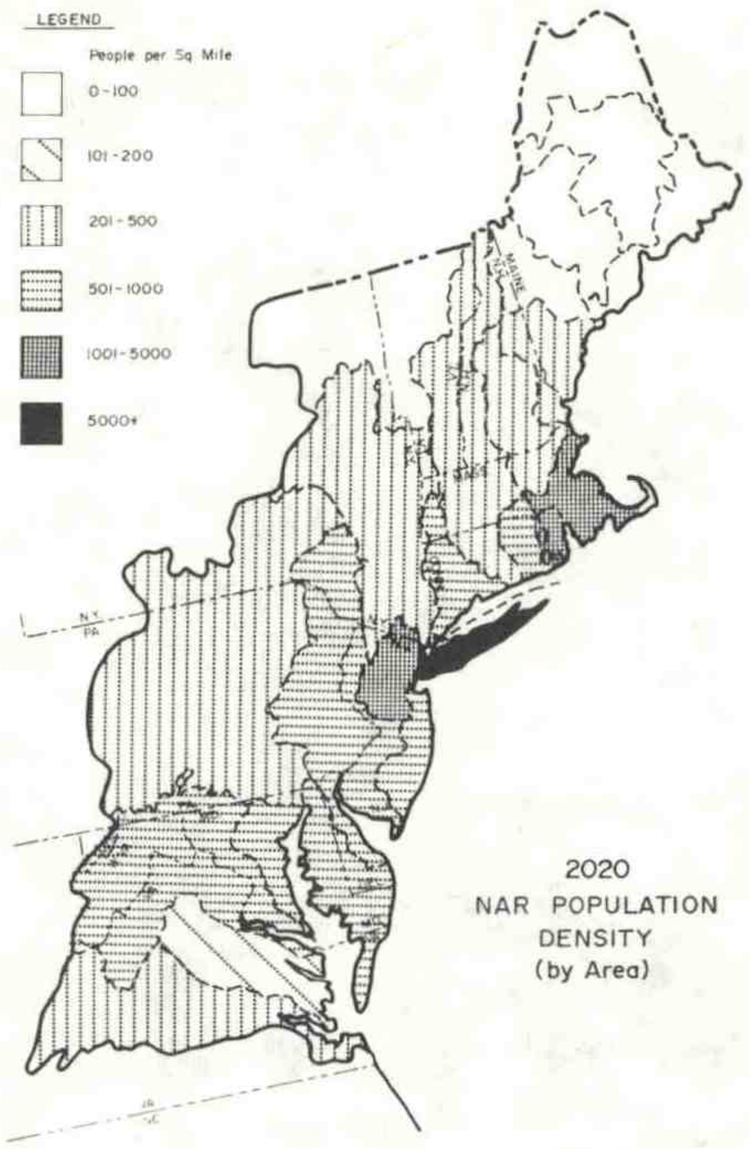


Figure 12.3 Projected population density of the North Atlantic Region, 2020.

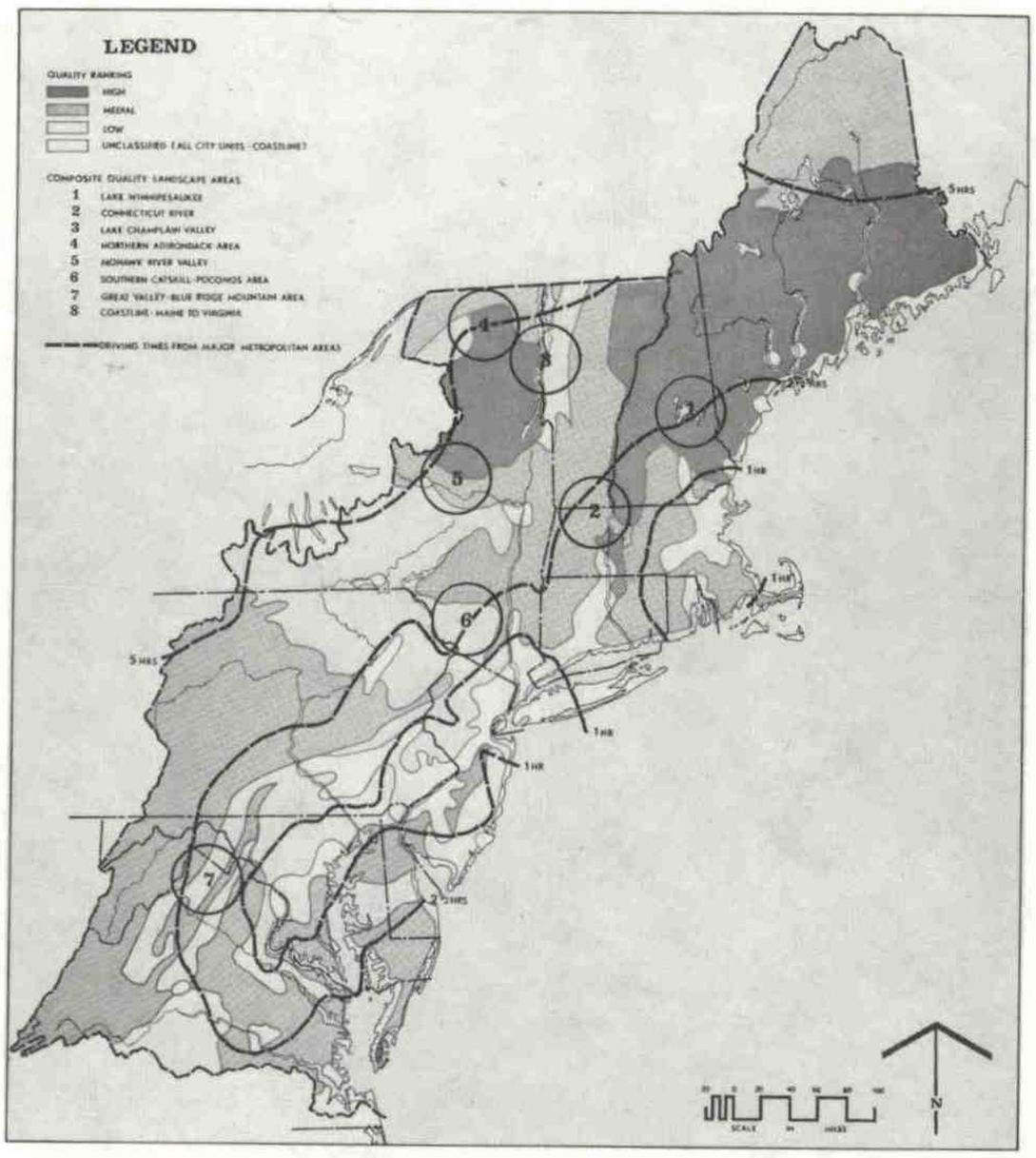


Figure 12.4 The tidal shoreline of the North Atlantic Region with driving times from major metropolitan areas.

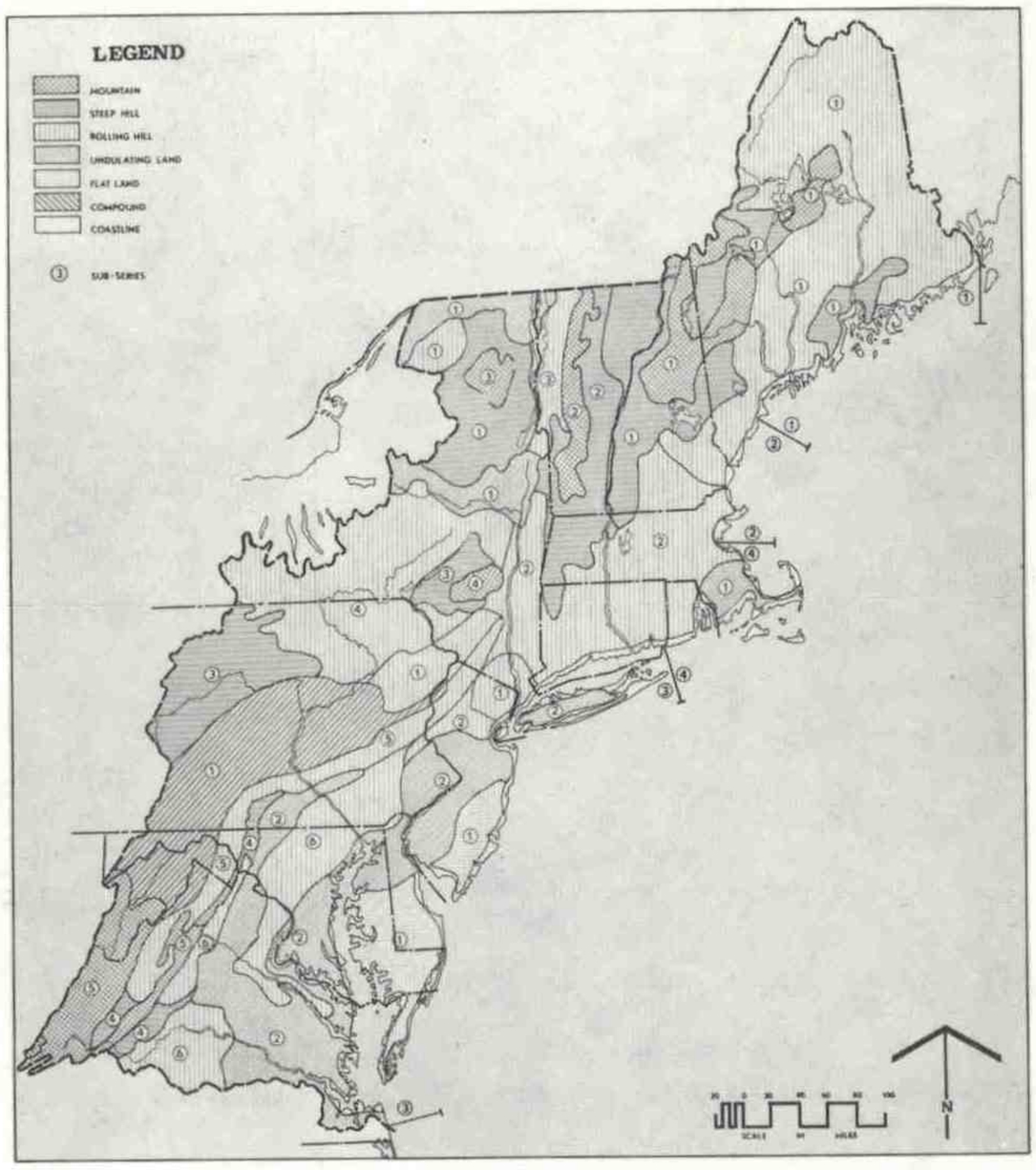


Figure 12.5 Topography of the North Atlantic Region.

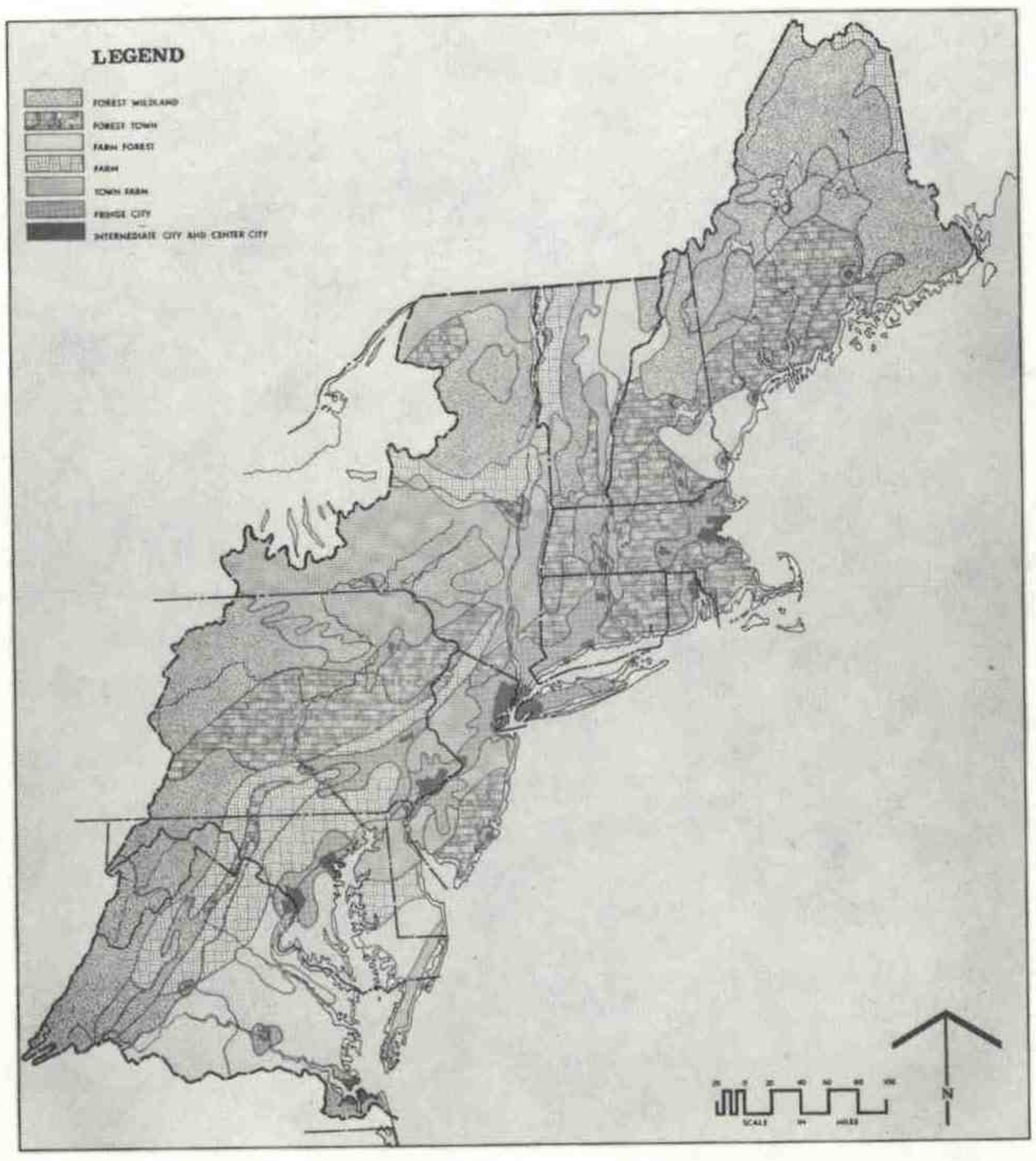


Figure 12.6 Distribution of urban, agricultural and forest activities in the North Atlantic Region, 1970.

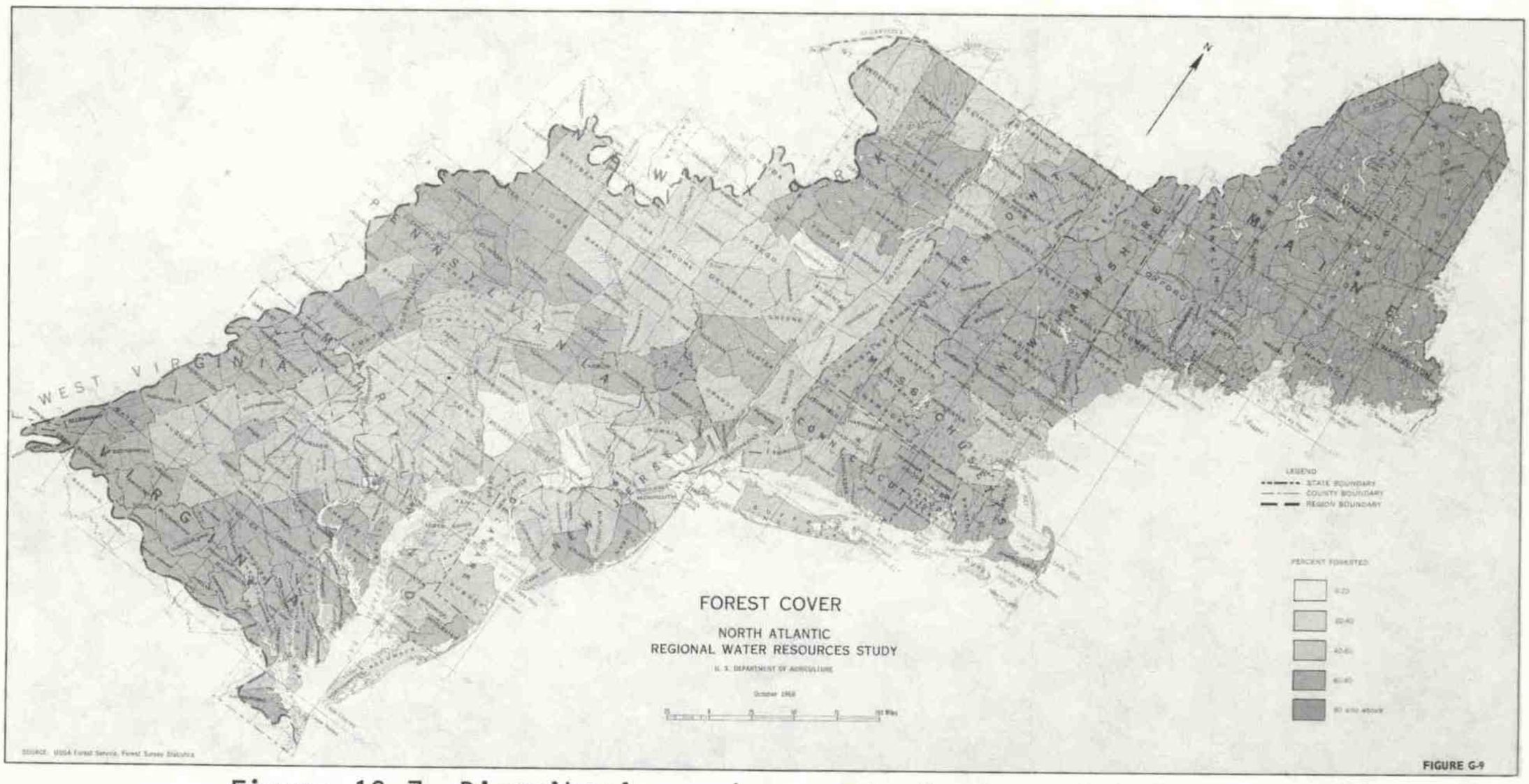


Figure 12.7 Distribution and percent of commercial forest land in the North Atlantic Region, 1968.

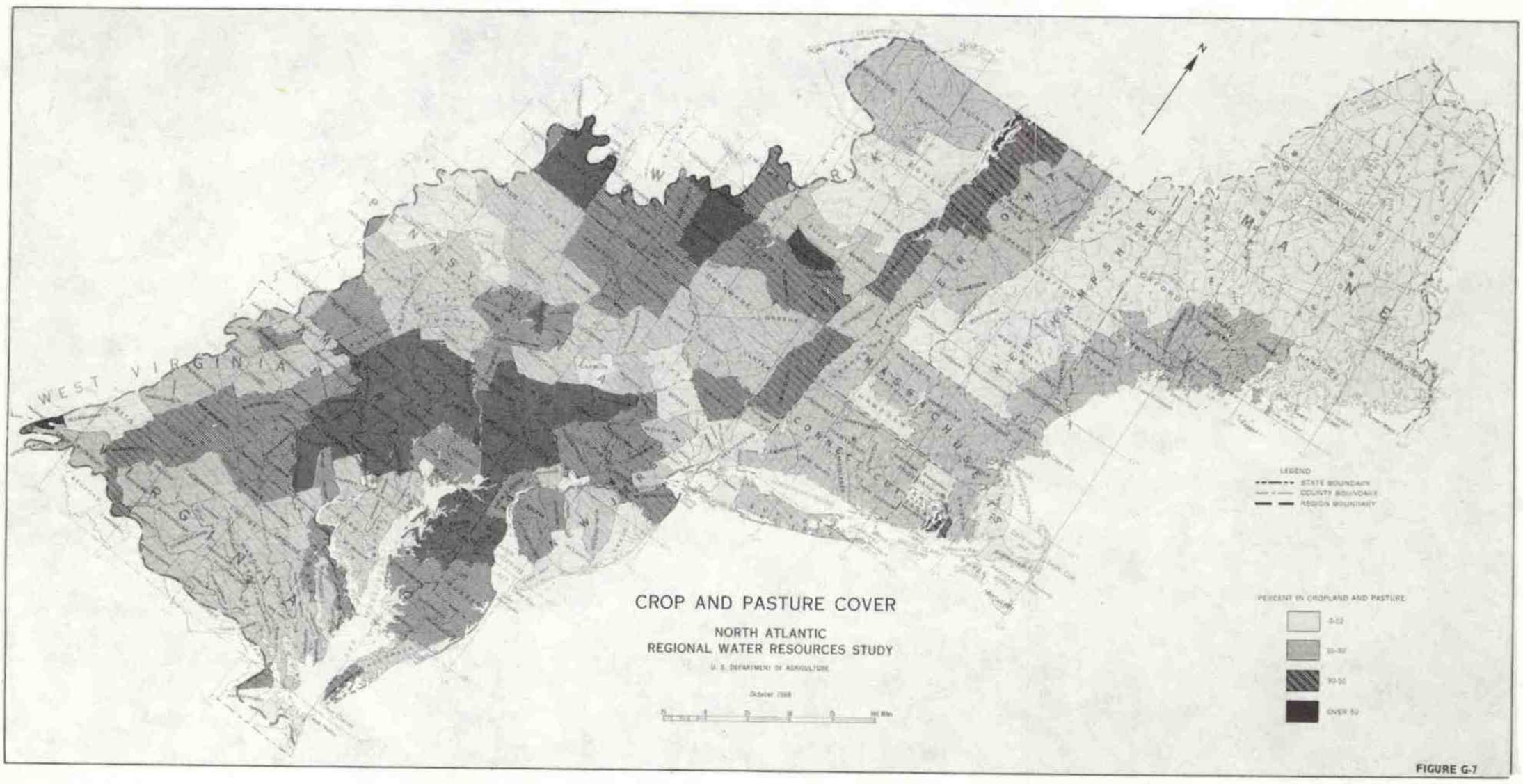


Figure 12.8 Distribution and percent of cropland and pasture cover in the North Atlantic Region, 1968.

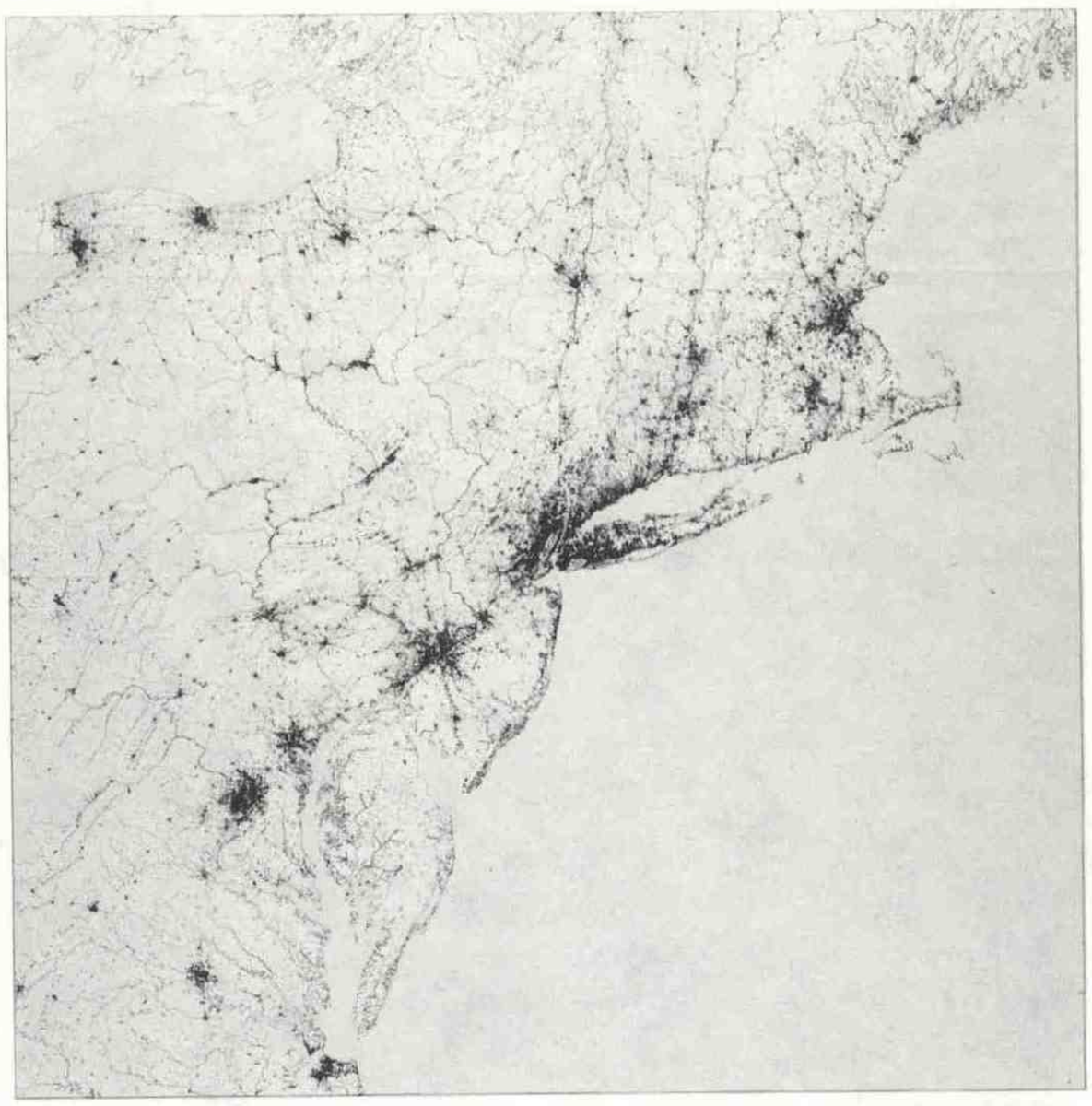


Figure 12.9 Intensely developed urban land in the North Atlantic Region, 1962.

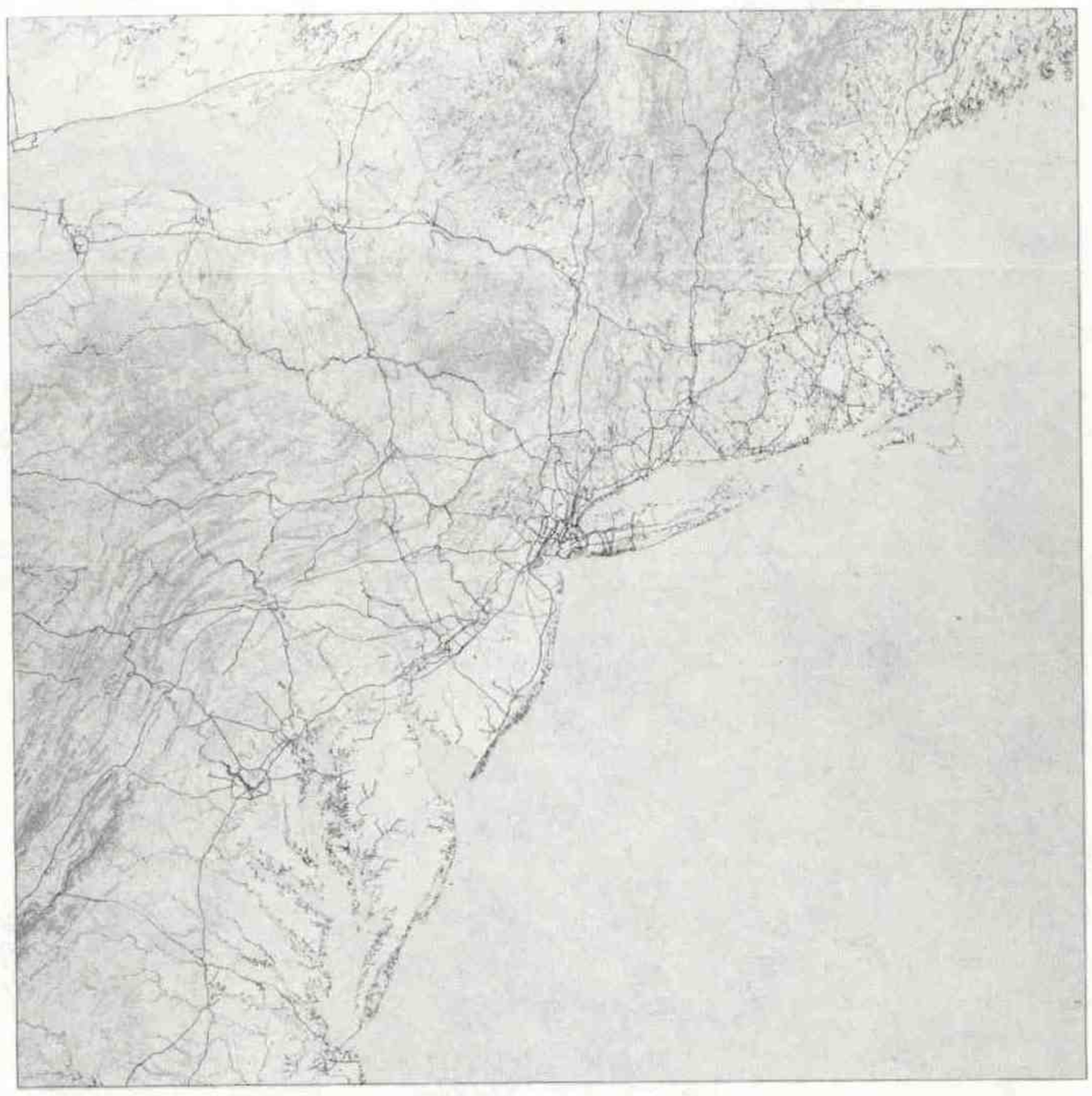
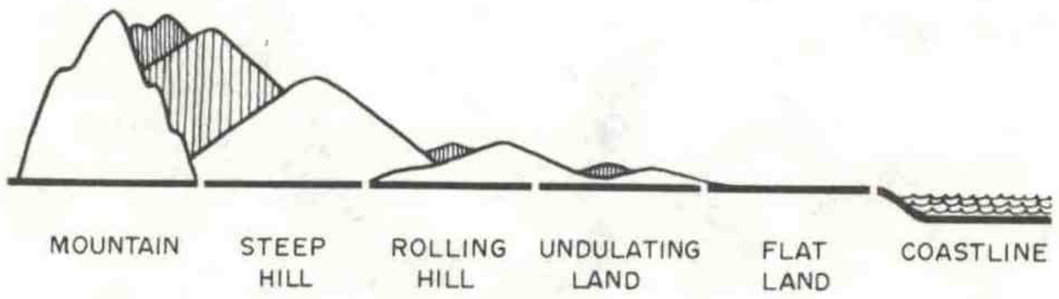
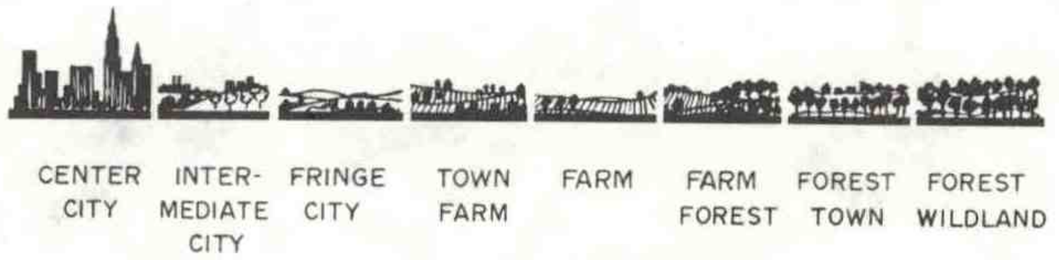


Figure 12.10 Limited access highways, existing, under construction, and proposed, in the North Atlantic Region, 1968.

Figure 12.11 Distribution of public open space in the North Atlantic Region, 1965.



A - LANDSCAPE SERIES



B - LANDSCAPE UNITS

CLASSIFICATION OF NAR
LANDFORMS (A) AND LANDSCAPE PATTERNS (B)

Figure 12.12 The landscape continuum: dominant land forms and land uses in the North Atlantic Region.

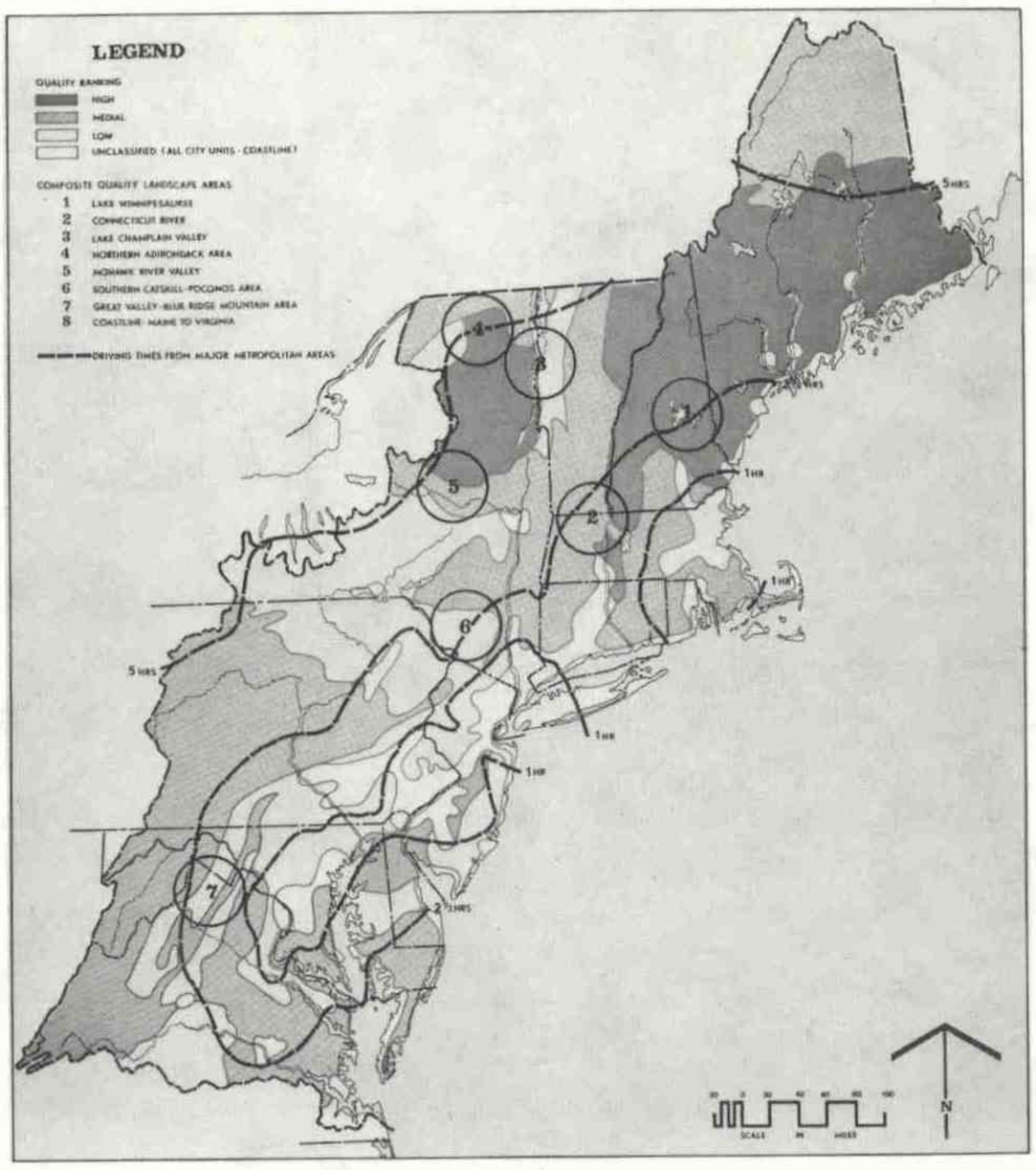


Figure 12.13 Landscape quality of the North Atlantic Region, 1970.

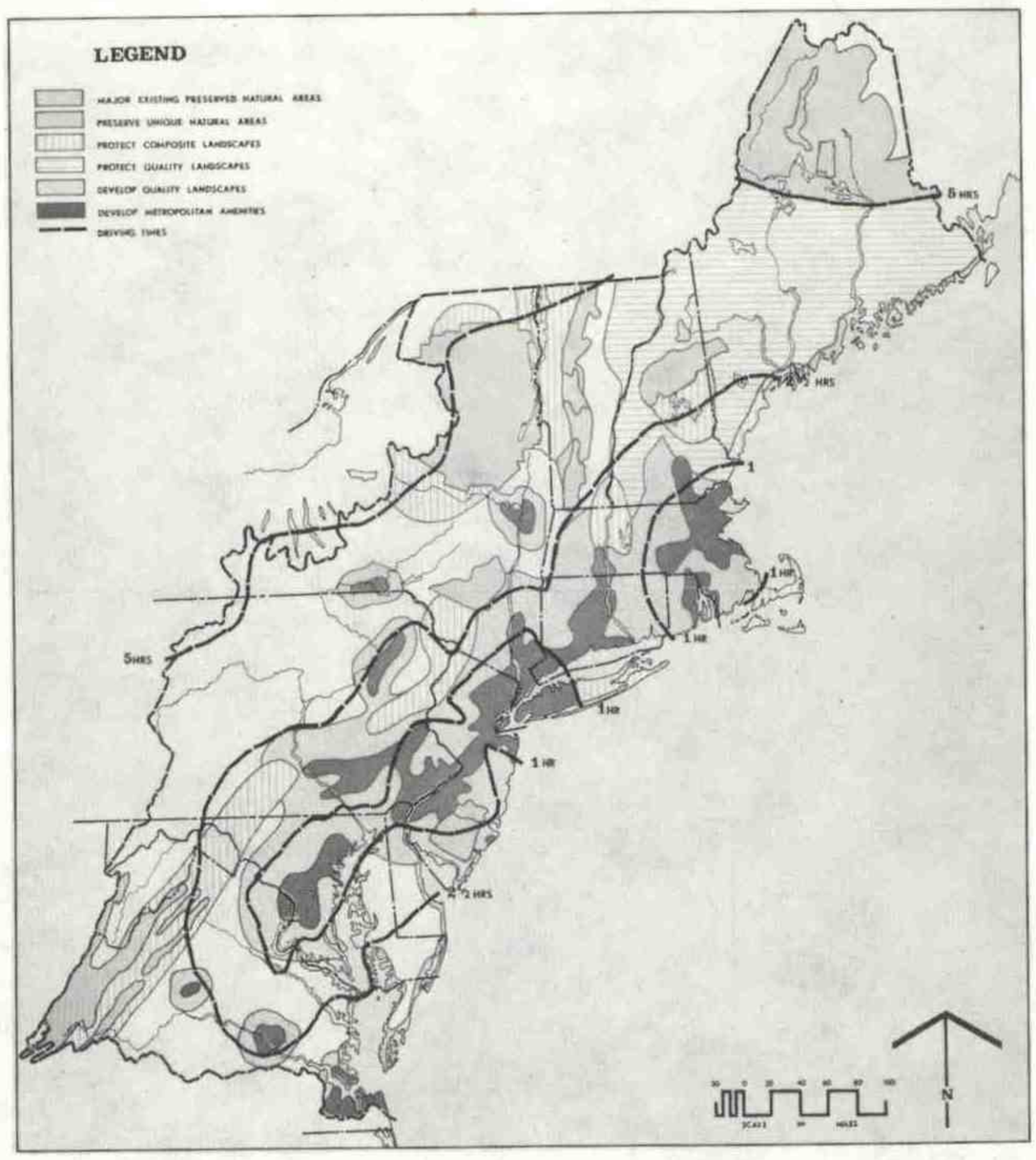


Figure 12.14 Summary of visual resource needs of the North Atlantic Region.