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

Sandy Hook to Bay of Fundy

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

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

VOLUME I

Book 2

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TABLE OF CONTENTS

Volume One: Environmental Inventory

Book Two: Chapters Four and Five

		Page
Chapter 4.0	Major Sounds and Embayments	
4.1	Geology of Major Sounds and Embayments	
4.1.1	Introduction - Maine to Cape Cod	4-2
4.1.2	Sediment Classification	4-2
4.1.3	Major Estuarine Embayments of the Gulf of Maine	4-9
	Passamaquoddy Regions	4-9
	Maine	4-13
	Southern Maine Coast	4-19
	New Hampshire - Maine Border	4-19
	Newburyport, Massachusetts	4-21
	Boston, Massachusetts	4-34
4.1.4	Minor Embayments Bordering the Gulf of Maine	4-37
4.1.5	References	4-43
4.1.6	Introduction - Cape Cod to Sandy Hook	4-49
	Massachusetts	4-49
	Rhode Island	4-54
	Connecticut - New York	4-54
	Other Areas	4-57
4.1.7	References	4-58
4.2	Physical Oceanography	
4.2.1	Introduction to Region North of Cape Cod	4-63
4.2.2	Characteristics of Currents	4-63
	Coastal Shelf	4-63
	Inshore	4-66
	Major Estuarine Embayments	4-67
4.2.3	Tides	4-70
4.2.4	Fresh Water Input	4-74
	General Discription of Freshwater Discharge of Major Basins	4-74
	Temperature and Salinity of the Coastal Shelf	4-77
4.2.5	Characteristics of Circulation	4-89
	Salt Wedge Estuary	4-91
	Partially Mixed Estuary	4-91
	Vertically Homogeneous Estuary	4-91

Chapter 4.0 (Continued)

		Page
	Sectionally Homogeneous Estuary	4-92
4.2.6	Misfits and Variations	4-92
4.2.7	Sea Ice Conditions - Eastport to Cape Cod	4-94
4.2.8	References	4-96
4.2.9	Circulation and Currents - Region South of Cape Cod Introduction	4-200
4.2.10	Tides	4-216
4.2.11	Sea Ice Conditions - Cape Cod to New York	4-218
4.2.12	References	4-220
4.3	Chemical Oceanography of Coastal Waters	
4.3.1	Areas South of Cape Cod	4-352
	Continental Shelf South of Long Island	4-352
4.3.2	New York Bight	4-354
4.3.3	Raritan Bay	4-364
4.3.4	Long Island Sound	4-364
4.3.5	Narragansett Bay	4-370
4.3.6	Massachusetts Bay	4-377
4.3.7	Cape Ann to Cape Elizabeth	4-379
4.3.8	Casco Bay to Eastport	4-395
4.3.9	References	4-406
4.4	Meteorology and Climate	
4.4.1	Introduction	4-416
4.4.2	Southern Sub-Region	4-416
	Precipitation	4-418
	Temperature	4-420
	Humidity	4-420
	Data from Environmental Impact Statements	4-420
4.4.3	Northern Sub-Region	4-429
	Precipitation	4-436
	Temperature	4-436
	Data from Environmental Impact Statements	4-436
4.4.4	Storms	4-452
	Introduction	4-452
	Tropical Cyclones	4-452
4.4.5	References	4-502
4.5	Biological Oceanography	
4.5.1	Mussel-Oyster Reefs	4-507
	Habitat Definition Description	4-507
	Habitat Dynamics	4-507

Chapter 4.0 (Continued)

			Page
		Effect of Man-Induced Stresses	4-509
		Biological Components	4-510
		References	4-541
	4.5.2	Worm-Clam Flats	4-544
		Habitat Definition Description	4-544
		Habitat Dynamics	4-544
		Effect of Man-Induced Stresses	4-548
		Biological Components	4-550
		References	4-566
	4.5.3	Shallow Salt Pond	4-569
		Habitat Definition Description	4-569
		Habitat Dynamics	4-569
		Effect of Man-Induced Stresses	4-571
		Biological Components	4-573
		References	4-595
	4.5.4	Salt Marshes	4-596
		Habitat Definition Description	4-596
		Habitat Dynamics	4-596
		Effect of Man-Induced Stresses	4-598
		Biological Components	4-600
		References	4-617
	4.5.5	Plankton-Based Pelagic-Estuarine	4-618
		Habitat Definition and Description	4-618
		Habitat Dynamics	4-618
		Effect of Man-Induced Stresses	4-621
		Biological Components	4-622
		References	4-624
Chapter 5.0	Exposed Shorelines		
5.1	Geology of Sand Beaches - Maine to Cape Cod		5-4
	5.1.1	Physiography	5-4
		Bedrock Land Structure Control	5-4
		Submergence and Formation of Second-Order Physiographic Shoreline Features	5-5
		Late-Pleistocene Glaciation/Post-PTeistocene Sea Level Changes, Gulf of Maine	5-5
		Sources of Sediment	5-12
	5.1.2	New England Beaches	5-19
		Barrier Beaches	5-19
		Pocket Beaches	5-24
		Standplain Beaches	5-25
		Tombolos and Spits	5-25
		Beach Erosion-Accretion	5-25

Chapter 5.0 (Continued)

		Page
5.1.3	Maine Beaches	5-32
	Popham Beaches - Phippsburg	5-32
	Old Orchard Beach - Biddeford	5-33
	Saco Bay Sediments - Saco	5-41
	Wells-Kennebunk Area - Ogunquit	5-49
	Long Sands/Short Sands Beaches - York	5-55
5.1.4	New Hampshire Beaches	5-58
	Rye Gravel Beach - Rye	5-58
	Hampton/Seabrook Beaches - Hampton, Seabrook	5-61
5.1.5	Massachusetts Beaches	5-64
	Salisbury Beach - Salisbury	5-64
	Plum Island - Newburyport	5-64
	Crane Beach - Ipswich	5-77
	Coffin Beach - Essex	5-84
	Cape Ann Beaches - Gloucester, Rockport	5-86
	Boston Basin Beaches	5-88
	White Cliffs to Nobscusset Point - Plymouth	5-101
	North Dennis Beaches - Dennis	5-107
	Brewster, Eastham, Wellfleet Beaches - Dennis, Brewster, Eastham, Wellfleet	5-107
	Outer Cape Cod Beaches - Provincetown to Monomoy Island	5-113
5.1.6	References	5-140
5.2	Wind and Wave Climate	5-148
5.2.1	Winds	5-148
5.3	Biological Oceanography	5-155
5.3.1	Sandy Shores Habitat	5-155
	Habitat Definition/Description	5-155
	Habitat Dynamics	5-155
	Effect of Man-Induced Stresses	5-158
	Biological Components	5-158
	References	5-163
5.3.2	Rocky Shores Habitat	5-164
	Habitat Definition/Description	5-164
	Habitat Dynamics	5-164
	Effects of Man-Induced Stresses	5-168
	Biological Components	5-169
	References	5-179

Chapter 4 Major Sounds and Embayments

		Page
4.1.1	Introduction - Maine to Cape Cod	4-2
4.1.2	Sediment Classification	4-2
4.1.3	Major Estuarine Embayments of the Gulf of Maine	4-9
	Passamaquoddy Regions	4-9
	Maine	4-13
	Southern Maine Coast	4-19
	New Hampshire - Maine Border	4-19
	Newburyport, Massachusetts	4-21
	Boston, Massachusetts	4-34
4.1.4	Minor Embayments Bordering the Gulf of Maine	4-37
4.1.5	References	4-43
4.1.6	Introduction - Cape Cod to Sandy Hook	4-49
	Massachusetts	4-49
	Rhode Island	4-54
	Connecticut - New York	4-54
	Other Areas	4-57
4.1.7	References	4-58

The following is an integrated description of Major Sounds and Embayments. A more detailed description of this region will be found in Section 4.5, Biological Oceanography, where individual habitats such as worm and clam flats, mussel and oyster reefs, and shallow salt ponds will be described more thoroughly.

This entire region is, in general terms, that area lying inshore from the open ocean or Offshore Region previously presented in Chapter 3.0. The area is roughly defined as that lying behind the major headlands but also including sounds and estuaries. The delineation of the physical and geological areas will not necessarily overlie or closely resemble the biological habitat limits. In places terms such as inshore, nearshore, coastal shelf,and estuaries will also be used in parts of this section in describing the geological, physical, and chemical aspects.

4.1 GEOLOGY OF MAJOR SOUNDS AND EMBAYMENTS

4.1.1 INTRODUCTION - MAINE TO CAPE COD

The major embayments of Maine, New Hampshire, and Massachusetts are, for the most part, estuaries where ocean water is diluted by fresh water. The various estuarine basins have originated by the drowning of river valleys, the drowning of glaciated valleys, building of barrier bars or beaches seaward of low-coastal plains, and drowning of tectonically-produced basins.

The truly estuarine portions of the major embayments are drowned river valleys, but the embayments themselves may have originated by barrier bar building or by tectonic activity. From Portland, Maine south, the major estuarine basins are drowned river valleys further segregated from open marine waters by large barrier islands or spits with the exception of Boston Harbor, a graben or fault produced basin. North of Portland the estuaries are confined to submerged river valleys with unmodified mouths. A few small coastal basins in Maine are classified fjords, such as Somes Sound on Mt. Desert Island.

4.1.2 SEDIMENT CLASSIFICATION

In general, estuaries can be broadly divided into two constituent sediment categories: the fine-grained estuaries and the coarse-grained ones.

The fine-grained estuaries, as the name implies, are dominated by mud sediment delivered to the estuary as a suspensate and deposited along the margins of the estuarine channel. Further, fine-grained estuaries are characterized by long, linear basins with a single channel flanked by mud flats and mussel reefs at the mouths of the basins. Coarse-grained estuaries, on the other hand, are dominated by sand-sized sediment and a variety of complex sand body morphologies

both within and immediately outside the basin inlets.

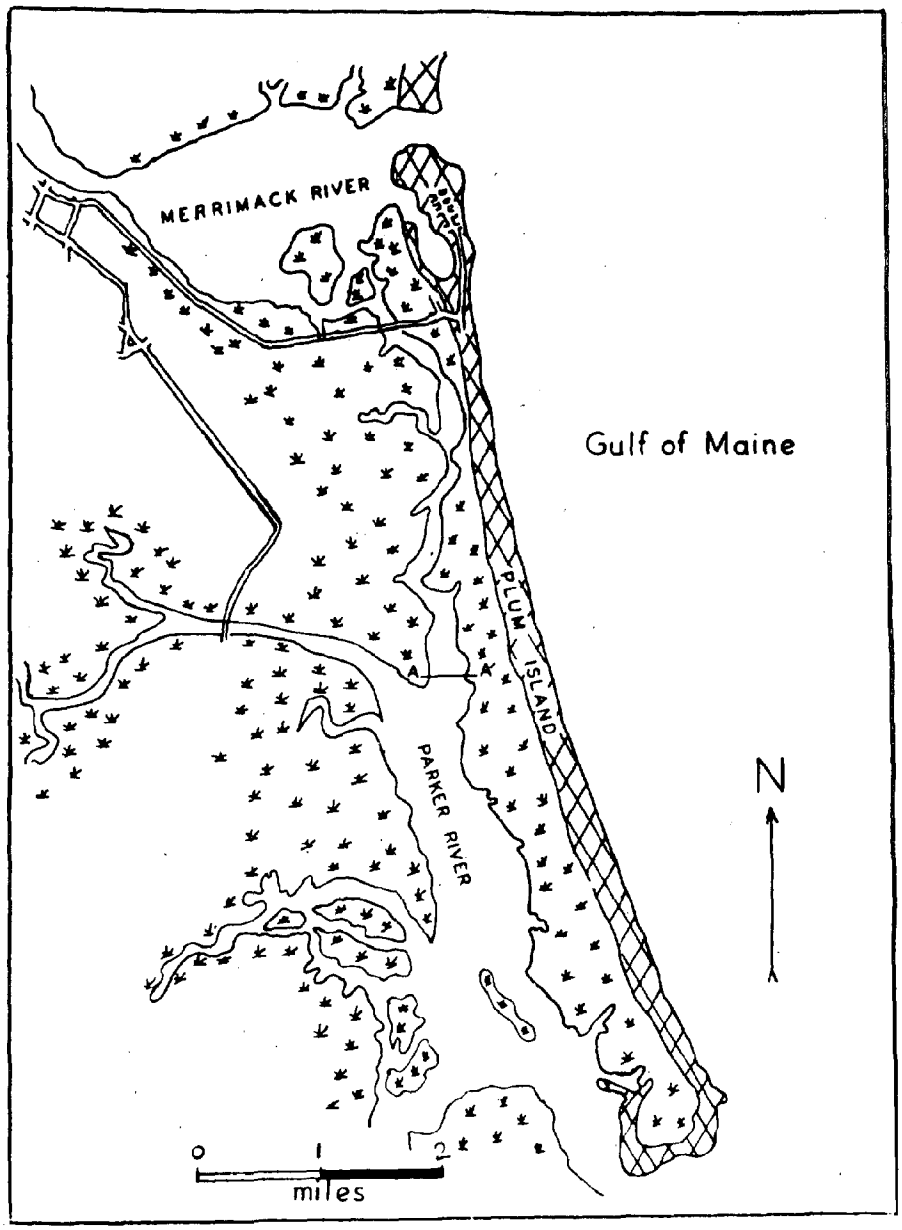
The fine-grained estuaries of New England are also dominated by fluvial input and exhibit moderately to highly stratified circulation patterns. Mud is the dominant sediment as the fluvial waters deliver large quantities of silt and clay to the estuary. Only minor volumes of sand are delivered to these estuaries as bedload or suspended load as most of the large rivers have sediment-retaining dams over much of their length. Sand may be delivered to the lower segment of the estuary from adjacent beaches during periods of flood tide and storm surges, but the high rate of river discharge throughout most of the year in a fine-grained estuary in effect subdues the duration and strength of flood tidal currents, thereby preventing large quantities of sand from entering the estuary.

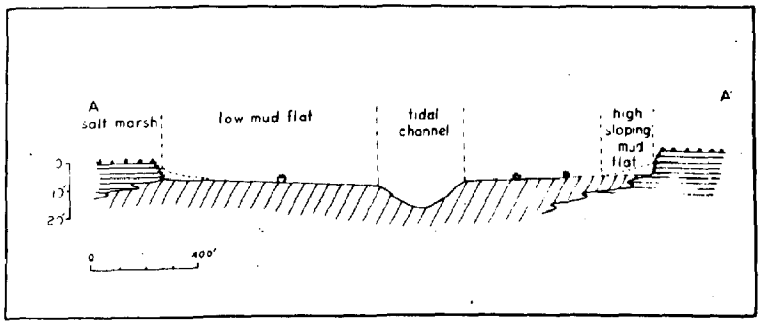
The coarse-grained estuaries, however, are typically well-mixed estuaries where the tidal currents dominate over river discharge. These estuarine basins are typically, at least in part, broad, marsh-filled lagoons fronted by barrier islands. Sand is delivered to the basin through the inlets during rising tides (Hayes, 1969).

The lower to mid-portions of the estuaries exhibit sand bars, sand-floored channels, and, on higher surfaces, muddy clam flats and salt marsh. Commonly coarse-grained estuaries exhibit several channel systems which converge just inside the basin mouth. The upper portion of the channel complexes are characterized by mudflats as current velocities are reduced and incapable of transporting sand-sized grains this far up the estuary (Hayes and McCormick, 1967). Figure 4-1 shows a schematic cross-section through the Parker River Estuary, a coarse-grained type.

The forms of sand accumulation in the coarse-grained estuaries of New England have been detailed by Hayes (1969). The most common types of sand bodies are ebb deltas (subdivided into swash bars, ebb sand sheets, and submarine lunate bars), flood deltas (made up of clam flats, spillover lobes, ebb shields, ebb spits, and sand flats covered with flood-oriented sand waves), channel-bottom sand wave fields, mid-channel bars and point bars. An example of the morphological elements of a typical New England ebb-tidal delta is in a coarse-grained estuary as shown in Figure 4-2 while Figure 4-3 shows the elements of a flood-tidal delta. Hayes (1969) further states:

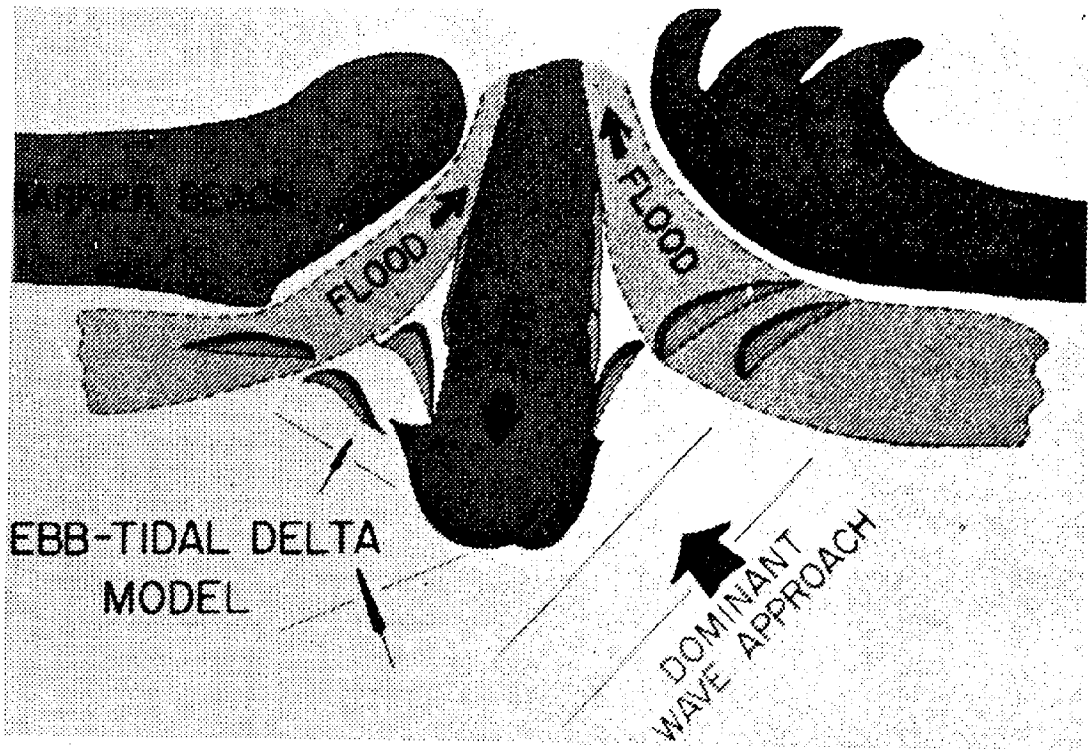
> "Smaller forms, such as sand waves, mega-ripples, and asymmetric ripples, abound on the surfaces of these features (larger sand accumulations). Four factors: time-velocity asymmetry of tidal currents, topographic shielding, vertical position with reference to mean low water, and residual ebb currents in major channels, are the primary controls of the type, abundance, and orientation of these smaller bed forms on the larger sand bodies.





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

TRIGOM PARC	FIGURE 4-1	Location and Schematic Section Across a Tidal Channel-Parker River (Hayes and McCormick, 1967)



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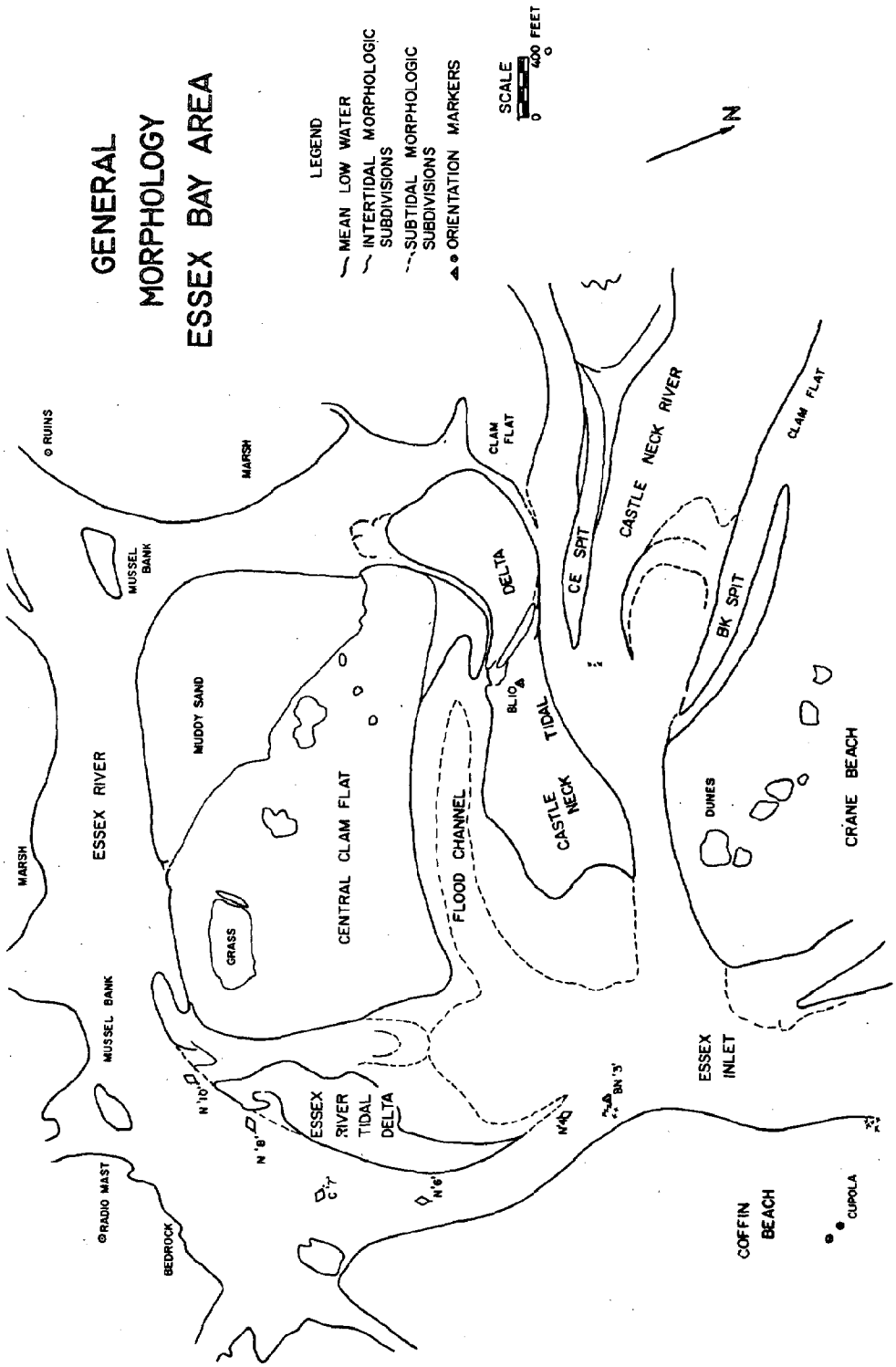
TRIGOM PARC	FIGURE 4-2	Morphological Elements of an Ebb-Tidal Delta. (Hayes, et.al., 1973)



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TRIGOM PARC	FIGURE 4-3	Morphological Elements of a Flood Tidal Delta (Boothroyd, 1969)

Of major importance is the prominence of flood currents as sand-transporting agents. Most of the intertidal sandy areas are dominated by flood-formed features; therefore, the dominant transport direction is landward with resultant infilling of the estuaries from barrier beaches and/or offshore sources."

Flood tidal deltas are the largest, dominant sand body within the coarse-grained estuaries. This sand body consists mainly of gently seaward-dipping sand surfaces covered with flood-oriented sand waves. Delta margins are raised surfaces called ebb shields, or, where spits generate off from the delta, ebb spits covered by ebb-oriented mega-ripples. In places the deltas are cut by spillover lobes (a lobate ridge) formed by ebb currents (Hayes, Boothroyd, and Hine, 1970).

While the above-mentioned sand bodies, channels, and mudflats dominate the channel areas, inter-channel areas of the coarse-grained estuaries and channel-margin areas of fine-grained estuaries are built up by salt marsh organic matter. Early studies of New England salt marshes dealt with hypotheses of plant succession and marsh development (Mudge, 1847; Shaler, 1884; Davis, 1910) while more recent studies (Redfield, 1967; McCormick, 1968; Hartwell, 1970; and Farrell, 1971) have been concerned with marsh stratigraphy, organic content, and water content.

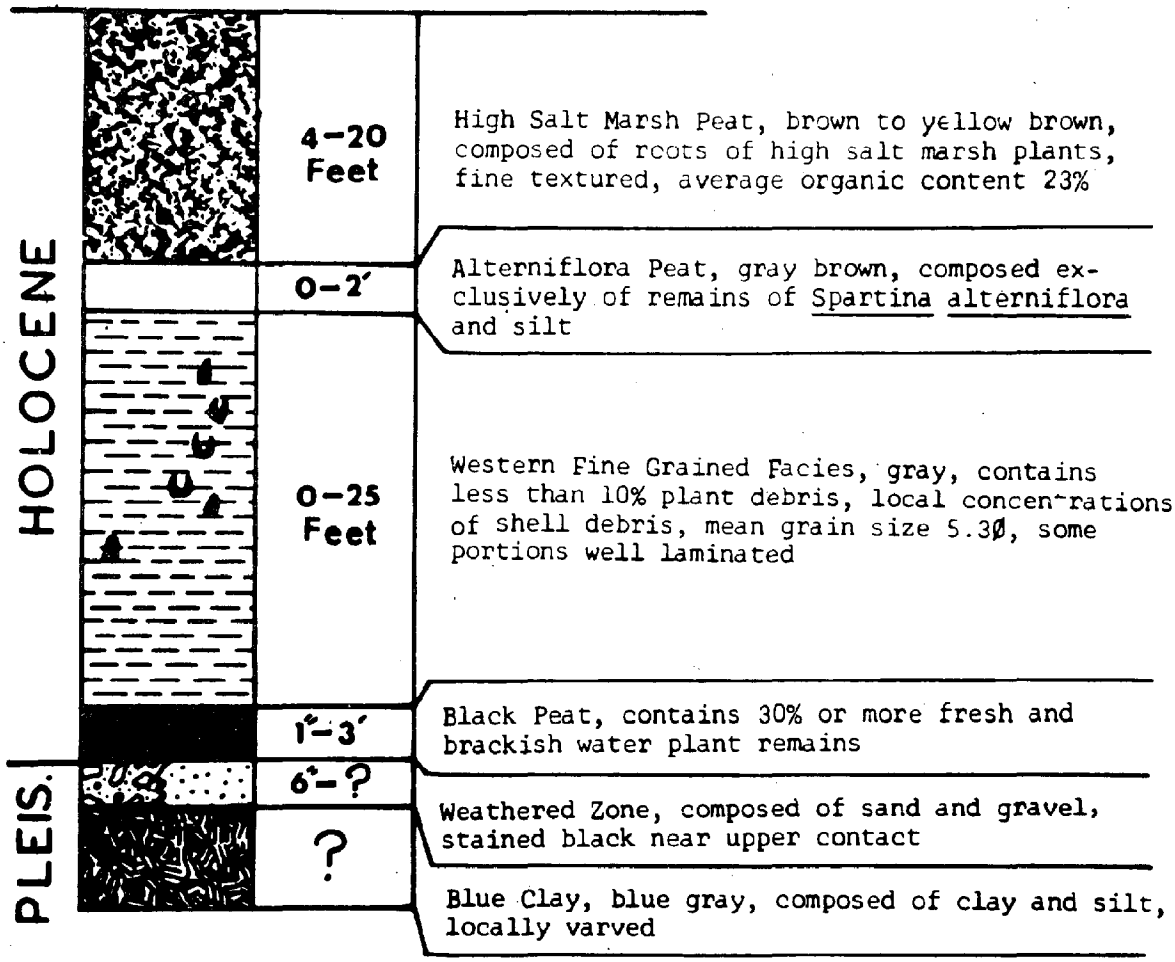
The stratigraphy of marsh peat in New England estuaries is dominated by thick sections of brown to yellow-brown fibrous roots of Spartina patens with an organic content of from 20 percent to 25 percent overlying thinner deposits of organic rich silts and clays mottled by the thick tubular roots of Spartina alterniflora.

This marsh succession overlies three types of sediment facies depending on the locality within the estuary. Marsh tracts immediately bordering uplands overlie thin deposits of black peat derived from fresh and brackish water plants and averaging an organic content of 30 percent or greater.

The black, freshwater peat, in part, overlies Pleistocene or Post-Pleistocene outwash or glacio-marine clays. Marshes are underlain by estuarine, shell-bearing silts and clays in the upper sections of estuaries near channels, while pointbar, channel, and flood-tidal delta sands underlie marsh deposits at the basin mouth (Figure 4-4).

Redfield (1967) has studied the water content of the Barnstable Marsh. The patterns of content variability probably apply elsewhere in New England marsh tracts, although water content due to upland runoff will vary seasonally. High salt marsh peat contains higher than 60 percent volume of water. Where salt marsh exists adjacent to uplands, the water content may be over 80 percent. Intertidal peat, or Spartina alterniflora peat contains between 30 to 60 percent water while estuarine sediments contain less than 30 percent as interstitial water.

Columnar Section



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TRIGOM PARC	FIGURE 4-4	Typical Salt Marsh Peat Section Found in New England Estuaries (McCormick, 1969)

Figure 4-5 is a section of salt marsh peat moss - Barnstable Harbor.

Coarse-grained and fine-grained estuaries are end members of a continuous transition series of estuaries. Timson (unpublished data) has recognized that coarse-grained estuaries receiving ever increasing fluvial discharge tend towards a morphology more typical of fine-grained estuaries in their mid-portions. The Merrimack River estuary is fine-grained for most of its area, but the Plum Island barrier and a restricted inlet promote coarse-grained deposits close to the estuary's mouth. Great Bay, the Kennebec, the Penobscot, the Saco, and the Passamaquoddy regions are true fine-grained estuaries, while the Scarboro, Wells, Barnstable, Essex, and Hampton estuaries are the closest examples of true coarse-grained estuaries.

4.1.3 MAJOR ESTUARINE EMBAYMENTS OF THE GULF OF MAINE

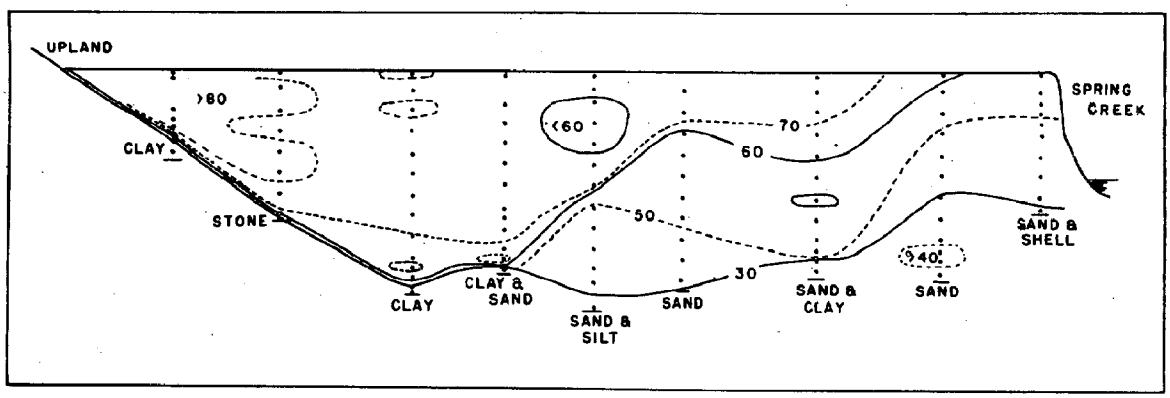
PASSAMAQUODDY REGIONS

St. Croix River Estuary and Cobscook Bay.

Passamaquoddy Bay is a complex coastal basin characterized by tides exceeding seven meters in range. The St. Croix River enters the western central inside border of the Bay from the north, while Cobscook Bay is a smaller, complex basin emptying into the extreme southwest corner of the Bay through Head Harbour Passage and the Gulf of Maine through Lubec Narrows (Figures 4-6 and 4-7).

The coastal geology of the region has been studied by various investigations for the International Joint Commission on the Passamaquoddy Power Project in 1959. The recent sediments of Cobscook Bay are derived from the rivers entering the Bay and from reworked surficial Pleistocene deposits on the upland margins of the Bay complex. Suspended sediment may be transported into Cobscook Bay from Passamaquoddy Bay, although there exists no direct evidence for this phenomenon.

Borings obtained by the U. S. Army Corps of Engineers for the Passamaquoddy Tidal Project (1959) and borings done for the Pittston Company (1973) in Deep Cove off Cobscook indicate that recent marine clays and silts overlie, in varying thickness, up to 13 meters of glacio-marine blue clays. The blue clays directly overlie bedrock. In high velocity channels either ledge or a gravel lag deposit constitutes the bottom. Gravel beaches and sandy tidal flats border islands covered by a thin veneer of outwash sediments, or where Post-Pleistocene blue clays are absent, glacial till. Surface sediments coarsen toward the Bay channels and toward the mouth of the Bay.



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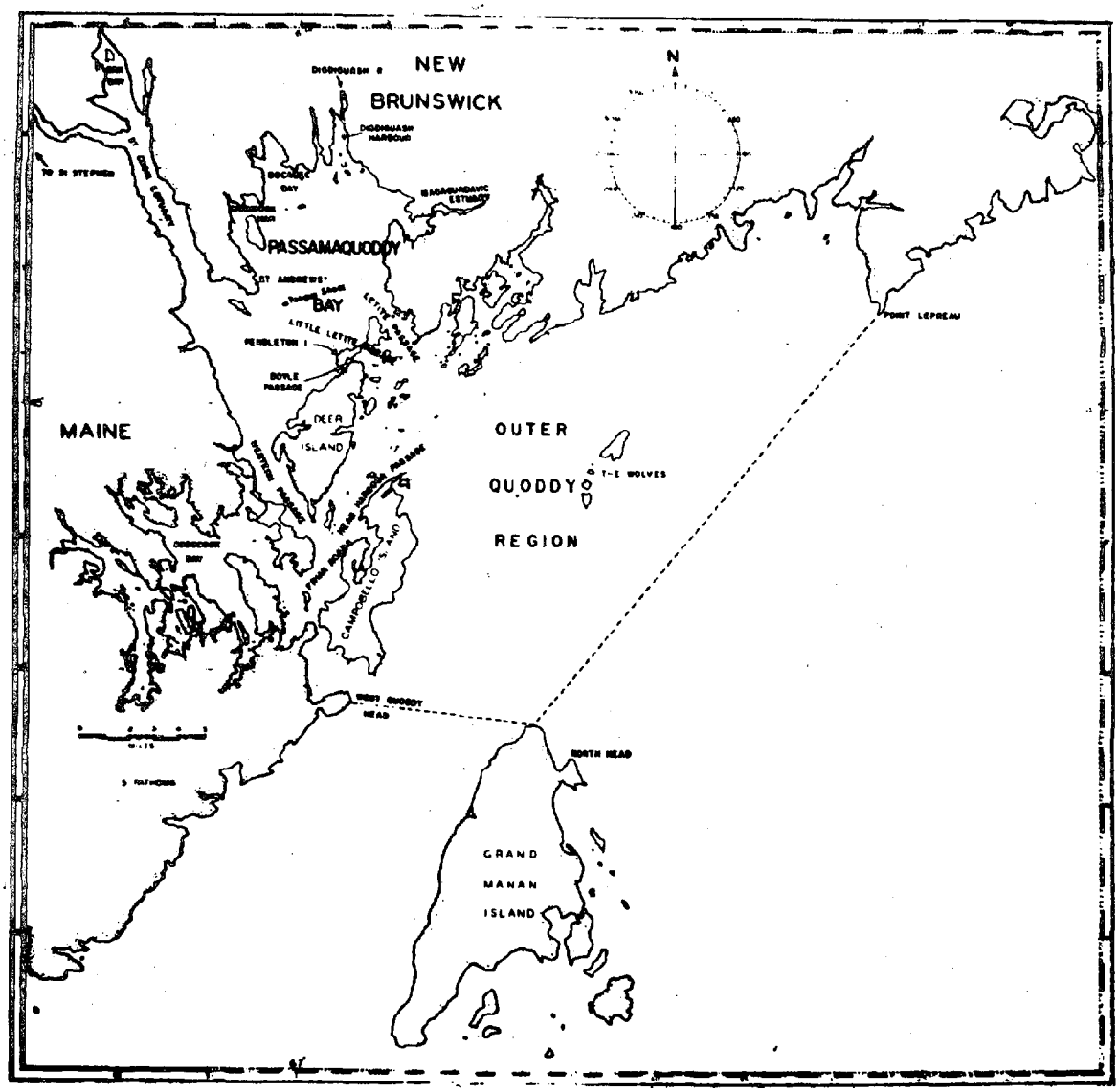
TRIGOM PARC	FIGURE 4-5	Water Content of Salt Marsh Peat-Up Lands to a Main Tidal Creek-Barnstable Harbor (Redfield, 1967)



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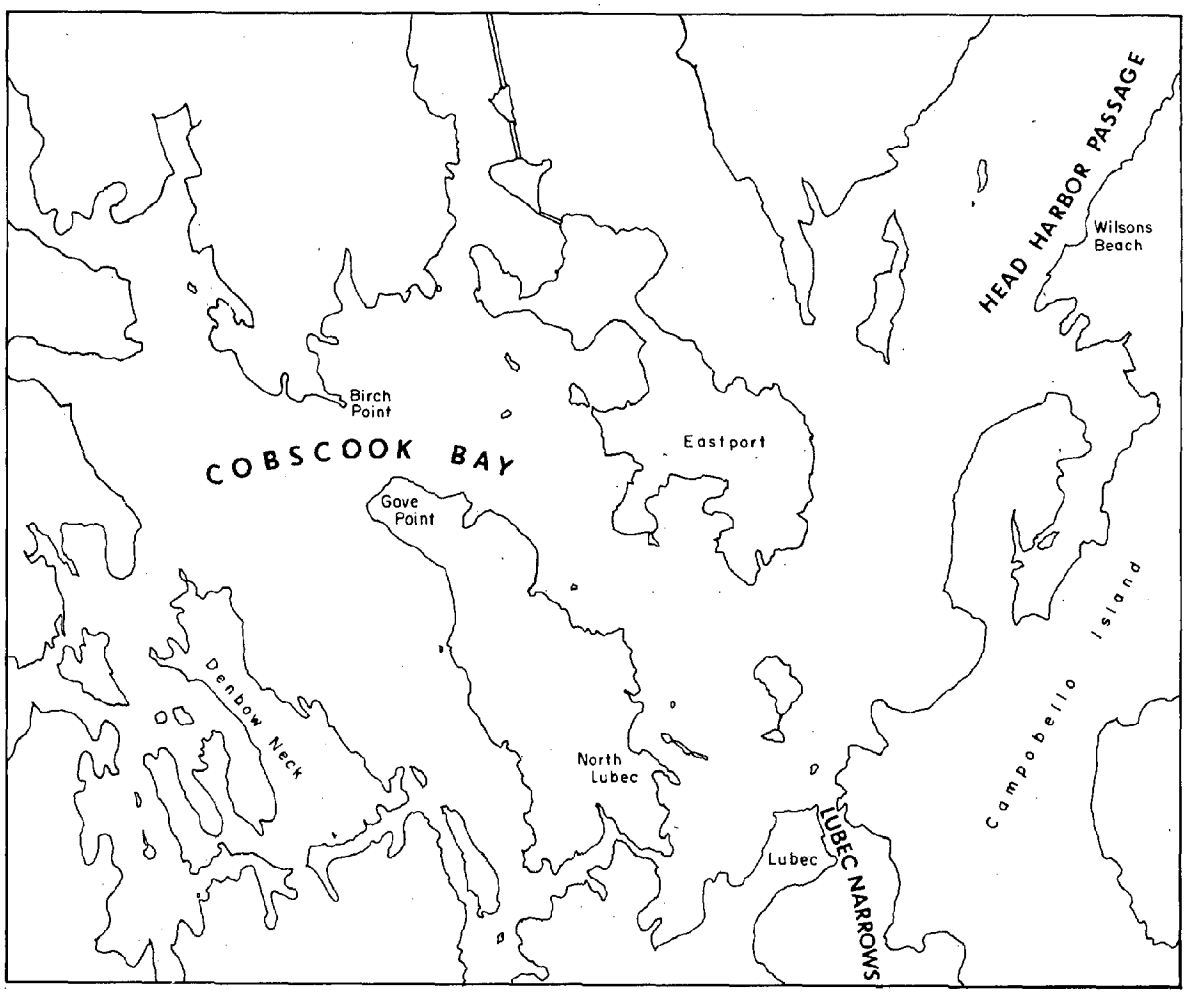
TRIGOM PARC	FIGURE 4-6	St. Croix and Cobscook Bay Estuaries (Forgeron, 1959)



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TRIGOM PARC	FIGURE 4-7	Cobscook Bay

MAINE

Penobscot River Estuary

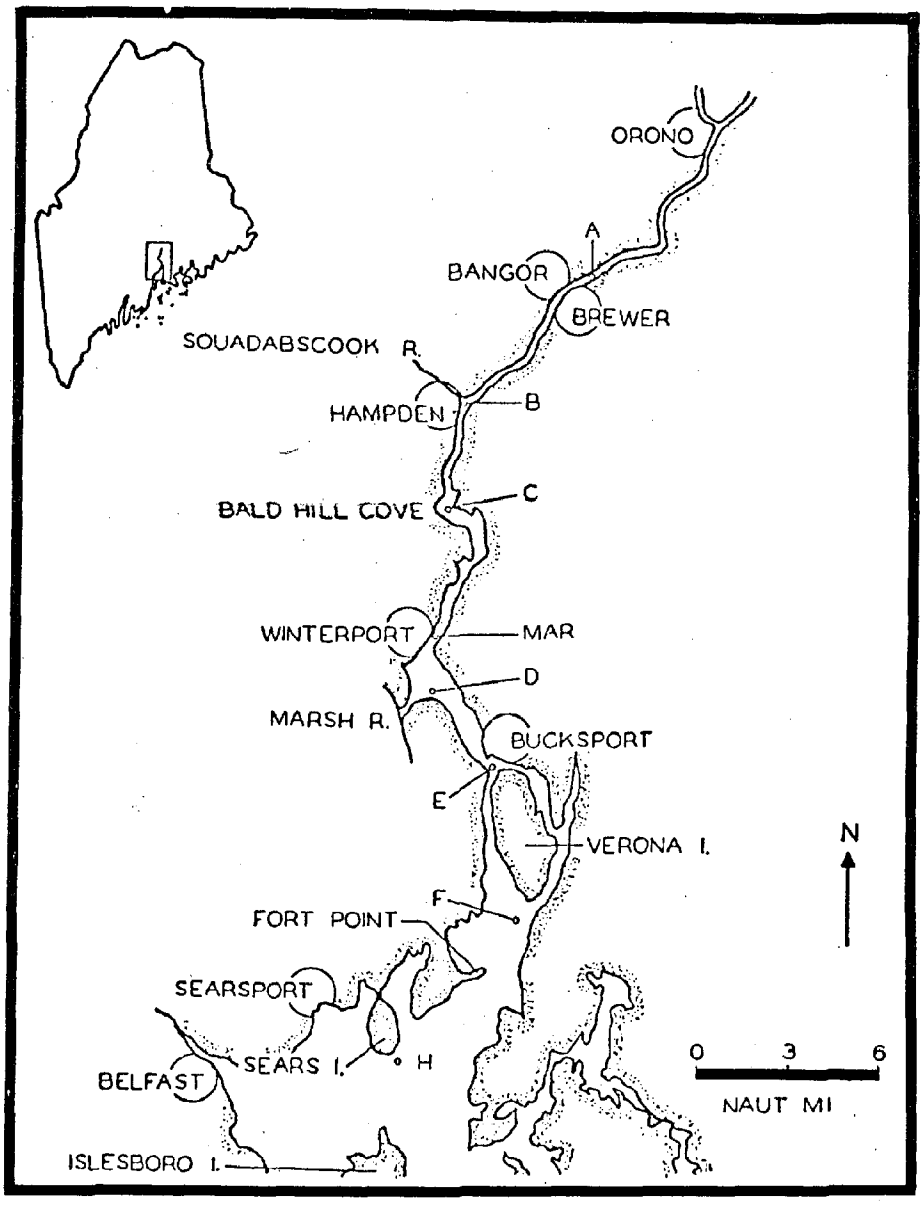
The Penobscot River is the largest river in Maine, draining 12,196 square kilometers of terrain. The River flows southerly into Penobscot Bay, a funnel-shaped reentrant with numerous islands in the middle and to the margins of the basin. (Figure 4-8) The estuarine portion of the Penobscot is 52 nautical miles in length extending from the head of tide at the Bangor hydroelectric dam to Searsport. The estuary can be divided into two portions, a narrow basin with the width averaging nearly two nautical kilometers from Bangor to Bucksport and the lower, funnel-shaped estuary which opens to a width of 15 nautical kilometers from Bucksport to Rockland. The basin has a mean depth of 10 meters with a maximum depth of 33 meters and a surface area of 23,600 acres with a low water volume of 30 billion feet ^{3} (Haefner, 1967).

The sediments of the lower Penobscot estuary have been studied by Ostericher (1965), Hathaway (1972), and Folger (1972 a & b). Folger (1972 a) characterizes the basin as one of high tidal range and relatively small sediment input coupled with high current velocities throughout most of the estuary (100 cm/sec) and vigorous wave action. The resultant of these conditions is a sediment distribution which coarsens from the basin channel laterally to the upland margins and down estuary. Clays occur throughout the deeper portions of the upper lower estuary and coarsens to silt between Rockland and Vinalhaven. Medium to fine sand covers the bay bottom south of Rockland. Coarse sand and gravels exist close to the shoreline and at the mouths of small bays off Penobscot Bay (Figure 4-9).

Cores penetrating surface sediments indicate that in the upper regions of the lower Bay, clay grades down to sand; the mid-portions, clay predominates from the surface to at least depths of three meters; silt or fine sands to fine silts at depths in the lower Bay (Ostericher, 1965)(Figure 4-10a and b).

Organic carbon content decreases with increasing grain-size. Maximum values of 2.1 percent organic content were found by Folger (1972 a) in the estuarine clays, while values of 0.5 percent were found in sand-sized sediments.

Ross (1967) has delineated the areal distribution of sediments delivered to the shallow inshore by the Penobscot River on the basis of the presence and abundance of amphiboles in the sand fraction of the sediments. Sediment is dispersed in a fan-like pattern from the mouth of the river. The dispersed fan extends as far south as Isle au Haut and as far east as Mount Desert Island (Figure 4-11). Ross (1967) illustrates this dispersal in Figure 4-11 , based on heavy mineral analysis. Although



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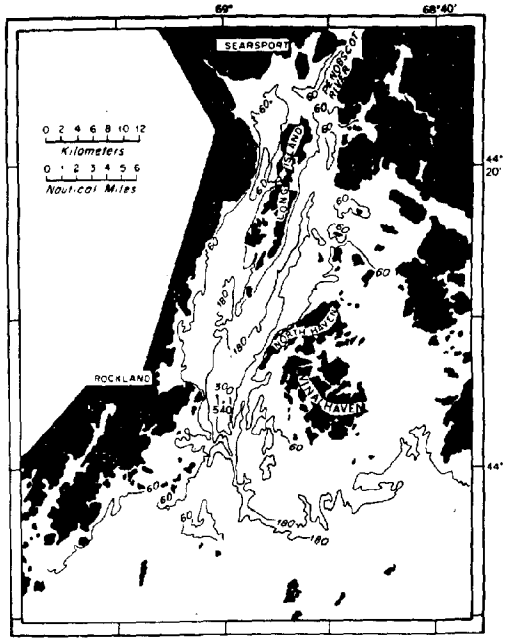
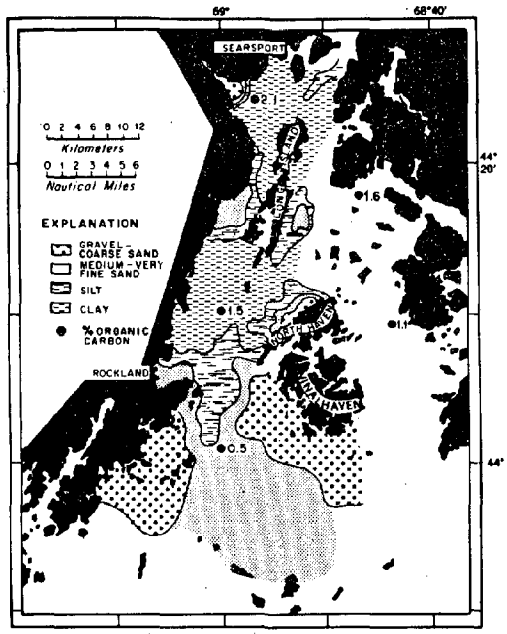
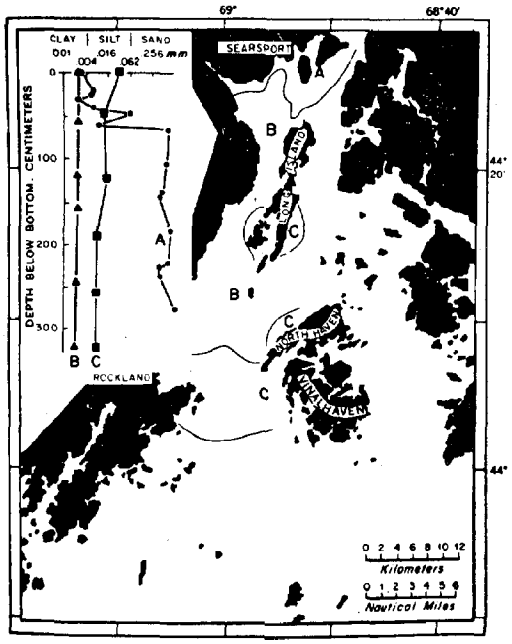
TRIGOM PARC	FIGURE 4-8	Penobscot River Estuary



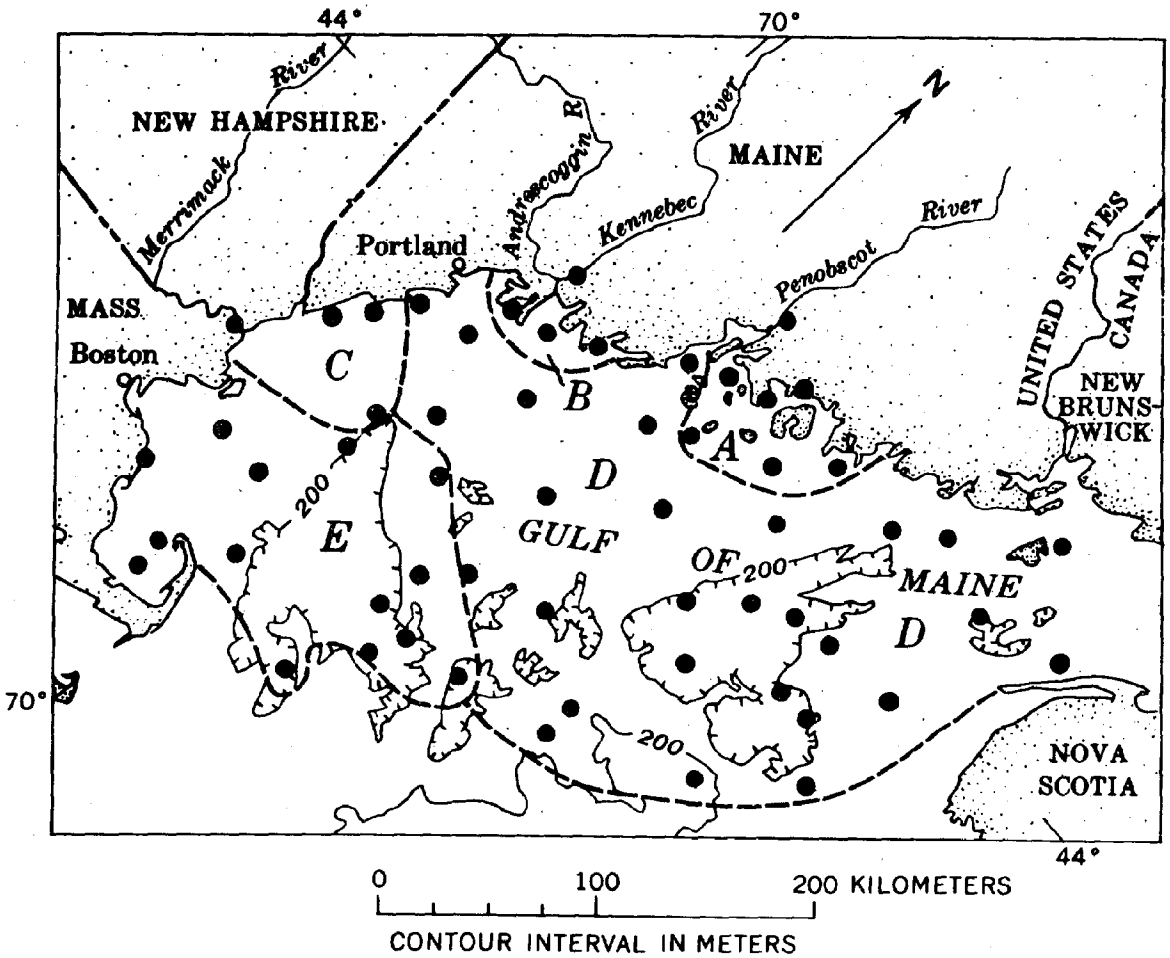
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-9	Bathymetry of Lower Penobscot River Estuary (Folger, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-10a	Sediment Texture of Lower Penobscot River (Folger, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-10b	Sediment-Size Variation with Depth (Folger, 1972)



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

TRIGOM PARC	FIGURE 4-11	Sediment Dispersal Seaward of the Penobscot River Estuary (Ross, 1967)

this dispersal pattern contradicts a southwest drift flow along the Maine coast, no reason for the anomalous distribution has been offered.

SOUTHERN MAINE COAST

Saco River Estuary

The Saco River drains 3470 square kilometers of New Hampshire and Maine uplands and flows into the southern end of the Saco Bay, Maine, area as seen in Figure 4-12.

Jetty construction, dam-building, and dredging have altered the natural sedimentation conditions in the Saco River estuary. Prior to jetty construction both a large flood-tidal delta and ebb-tidal delta existed at the mouth of the estuary. Only a diminutive flood-tidal spit remains within the estuary composed of 0.3 mm coarse, feldspathic sand with flood-oriented mega-ripples on the upper portions of the spit. The lower portions of the spit toward the estuary channel are also covered by mega-ripples which orient themselves to the ambient current direction.

Elsewhere in Saco River estuary, coarse to medium sand occurs on the channel bottom in the lower reaches, whereas fine to medium sand covers the flats on channel bottoms in the upper estuary (Farrell, 1970).

NEW HAMPSHIRE-MAINE BORDER

Great Bay - Piscataqua River Estuary Embayment

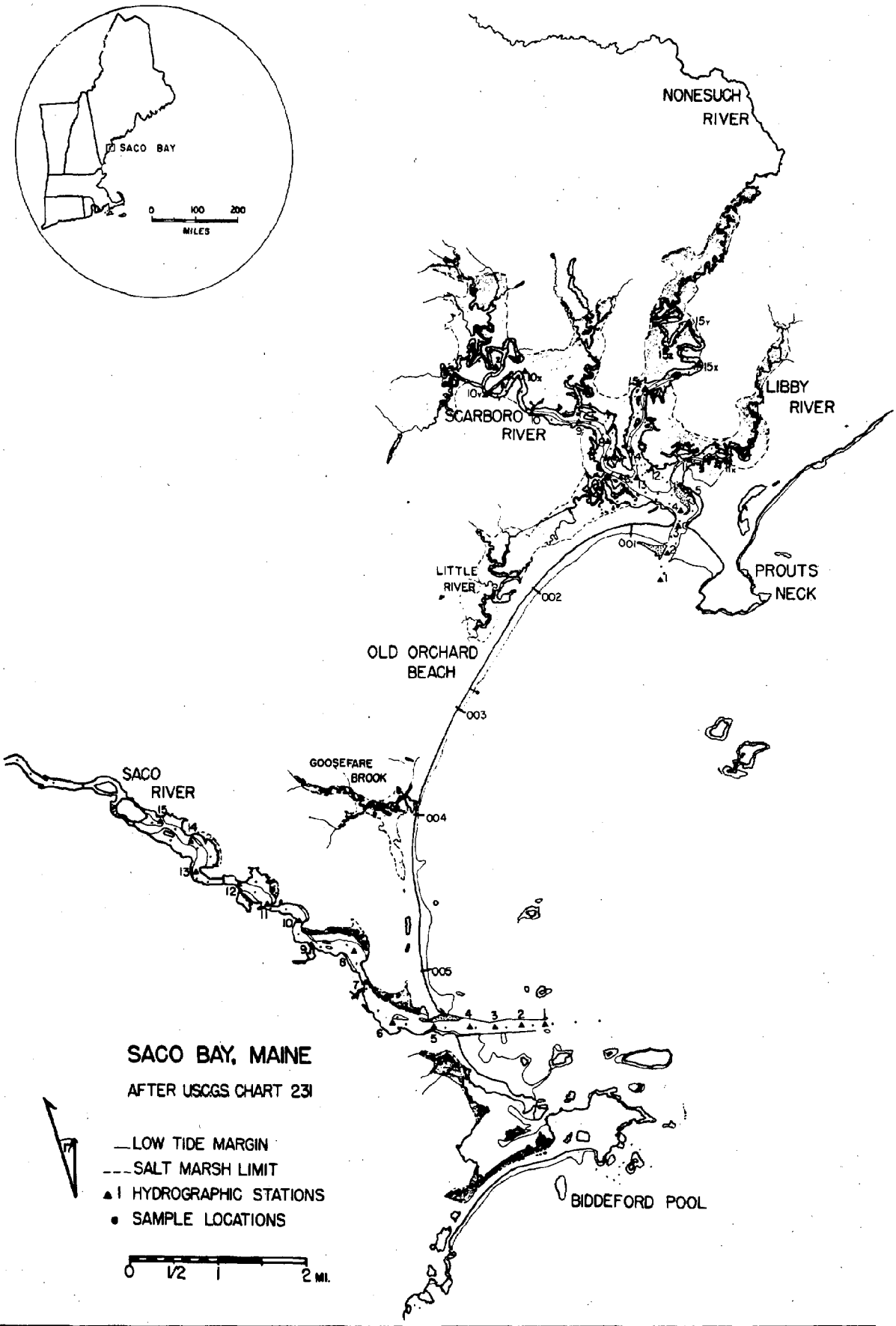
The Great Bay embayment is a complex basin composed of three elements: Little Bay, Great Bay, and the Piscataqua River estuary.

The Piscataqua forms the western margin of the bay complex, flowing from the north-northwest to the southeast in a confined channel. The estuary flows into Portsmouth Harbor, a funnel-shaped basin holding eight islands. Portsmouth Harbor opens directly into the Gulf of Maine.

Little Bay is an elbow-shaped basin which empties into the Piscataqua estuary 9 km from the ocean. The arms of the elbow basin are oriented north-south and east-west. The Bellamy River flows into the upper reaches of the east-west arm, and the Oyster River flows into the upper portions of the north-south arm.

The north-south arm of Little Bay opens south into Great Bay, a large estuarine basin characterized by extensive intertidal mud flats. The Lamprey River flows southeast into the eastern arm of Great Bay, while the Squamscott and Winnicut Rivers flow north into the southern portions of the Bay.

The Little Bay - Great Bay complex encompasses about 5700 acres at mean high water and about 2700 acres at mean low water; inter-tidal flats and marsh tracts make up over 2500 acres of estuarine area



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

TRIGOM PARC	FIGURE 4-12	Saco River Estuary (Farrel, 1970)

(U.S. Army Corps of Engineers, 1972). The entire area of the tidal portion of the Piscataqua River Embayment is 15,407 acres (N.H. Water Supply and Poll. Control Comm., 1971).

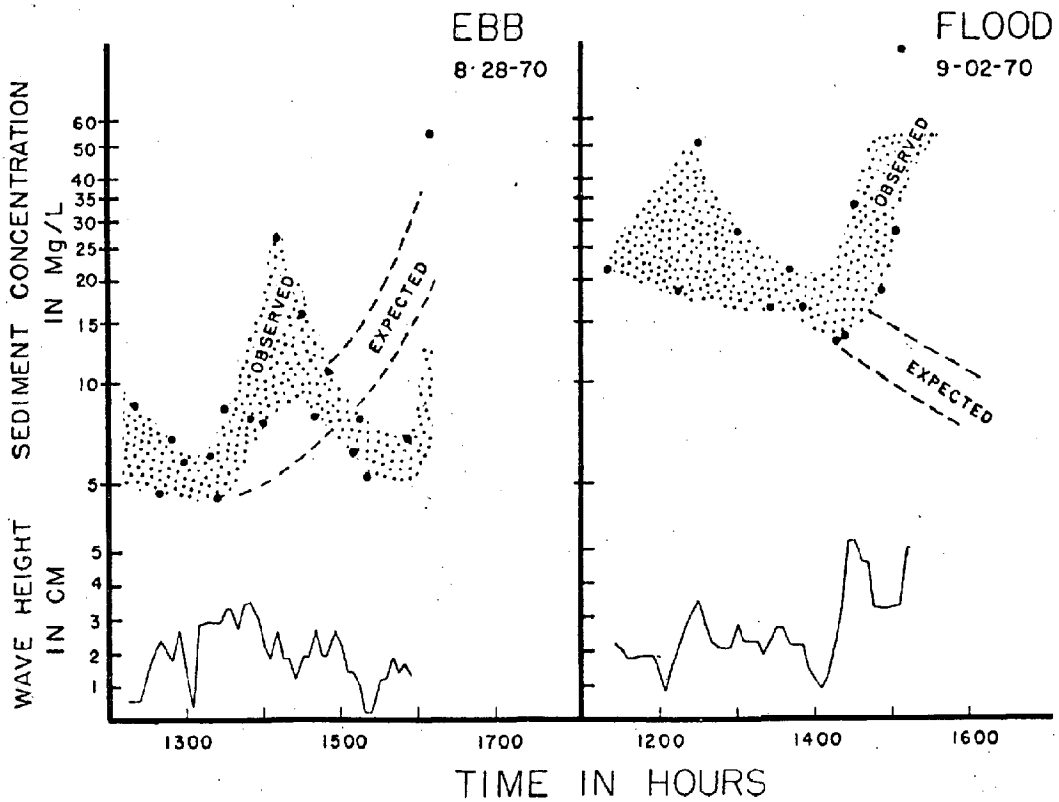
Secchi disk measurements in the estuary indicate that during May and June the turbidity of the waters are high due to river water suspensates, decreasing and stabilizing in July, varying only over the tidal cycle. Anderson (1972) has shown that suspended sediment concentrates reach a maximum at high-water slack when concentration may reach 70 mg/L over the mud flats in Great Bay (Figure 4-13). Suspended sediment concentration varies linearly with wave-chop height in estuarine waters. Wave heights can reach a maximum with increased water depth, hence maximum suspension during high tide. A plot of wave height variation with suspended sediments is shown in Figure 4-14. During all seasons of the year, turbidity readings increase with distance from the harbor mouth.

NEWBURYPORT, MASSACHUSETTS

Merrimack River Estuary

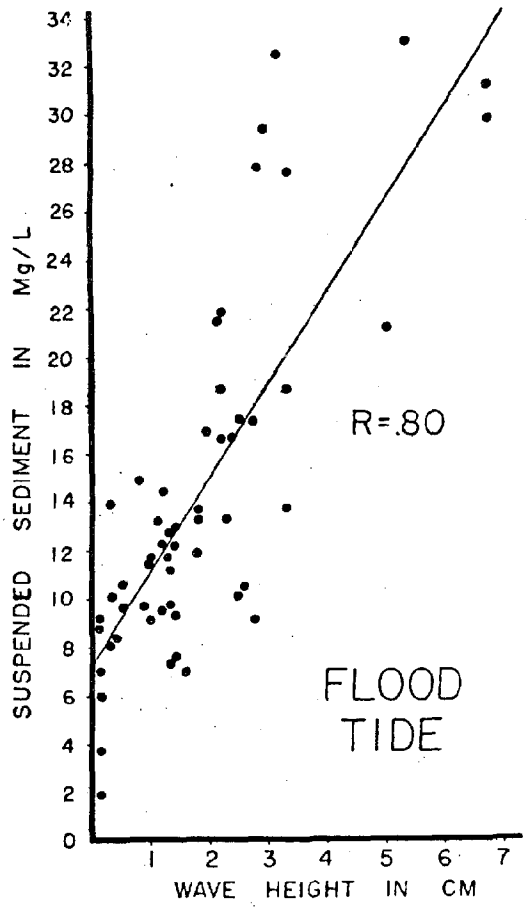
The estuary of the Merrimack has received much attention as the subject of hydrographic and geologic investigations. Hartwell (1969, 1970) has studied the hydrologic characteristics, sedimentology and marsh stratigraphy of the embayment. Other studies include geological studies by Hayes and McCormick (1967), Hayes (1971) McCormick (1968), Rhodes (1971) and Sammel (1962). Jerome, Chesmore, Anderson and Grise (1965) have looked at the morphometry of the basin as a prelude to a marine resources investigation, while Wiesnet and Cotton (1967) defined the circulation patterns using infrared imagery. The sedimentary environments are shown in Figure 4-15, while the flood-tide stratification appears in Figure 4-16.

Suspended sediment concentrations vary with river discharge. During a discharge of 1900 cfs, Hartwell (1970) found concentration of up to 19 mg/l in fresh waters, but concentrations of only up to 5 mg/l in marine waters. When the estuarine waters are mixed, maximum sediment concentration may occur anywhere in the estuary over a tidal cycle, but are generally higher during ebb stage when the river influence is greatest. Figure 4-17 illustrates the changes in suspended sediment concentration during a complete tidal cycle. Suspended sediment loads of 2,590,000 kg /day are found in April and 36,300 kg /day in the fall. (U.S. Geological Survey, 1968). Much of the river sediment is deposited on Joppa Flats, a wide intertidal mudflat expanse along the southern margin of the embayment during high discharge conditions and flood tide stages when the river water is ponded over this area.

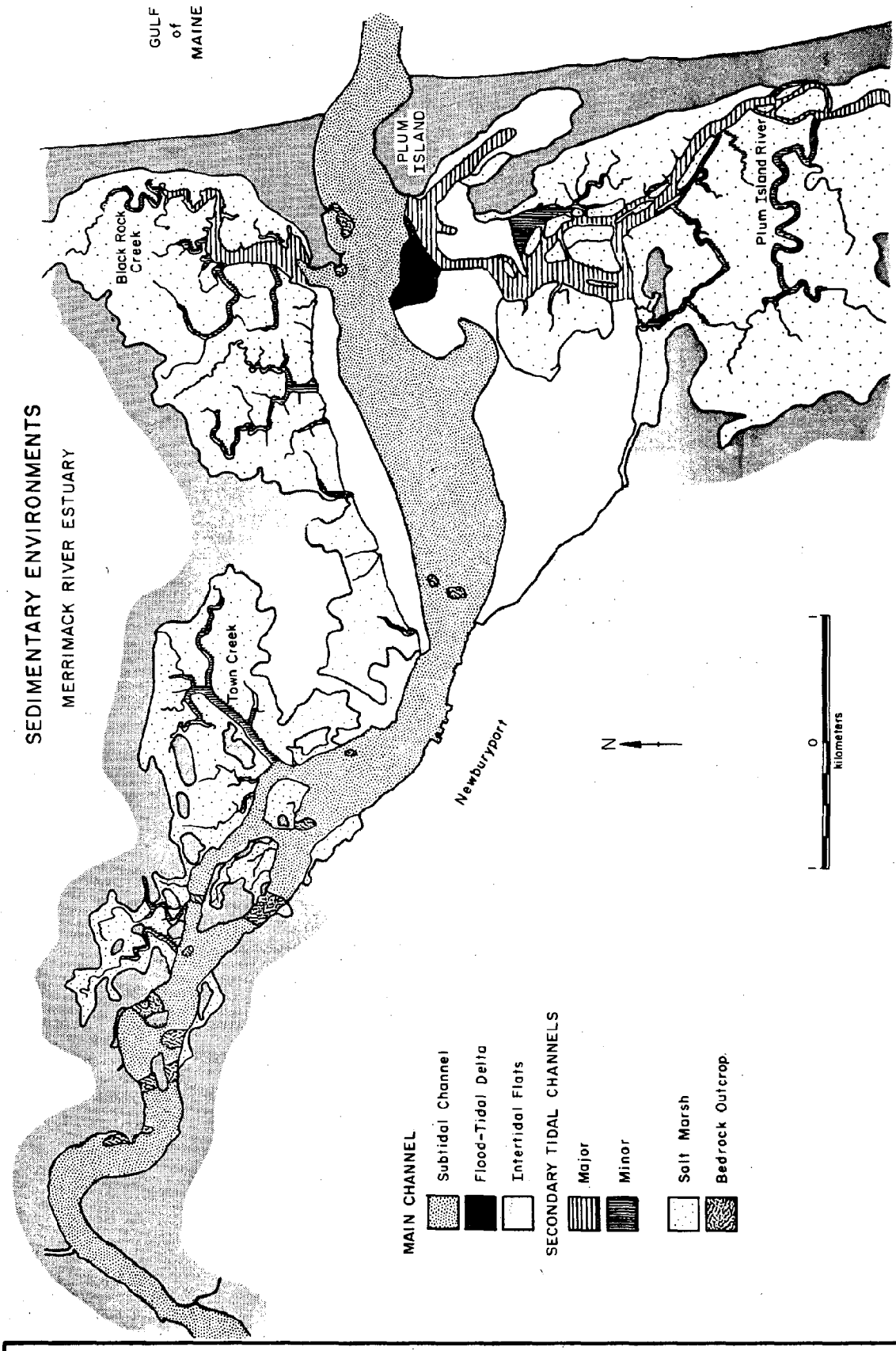


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-13	Suspended Sediment Concentration over Mudflats in Great Bay-Ebb & Flood Tides (Anderson, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-14	Suspended Sediment Concentration Versus Wave Height in Great Bay (Anderson, 1972)

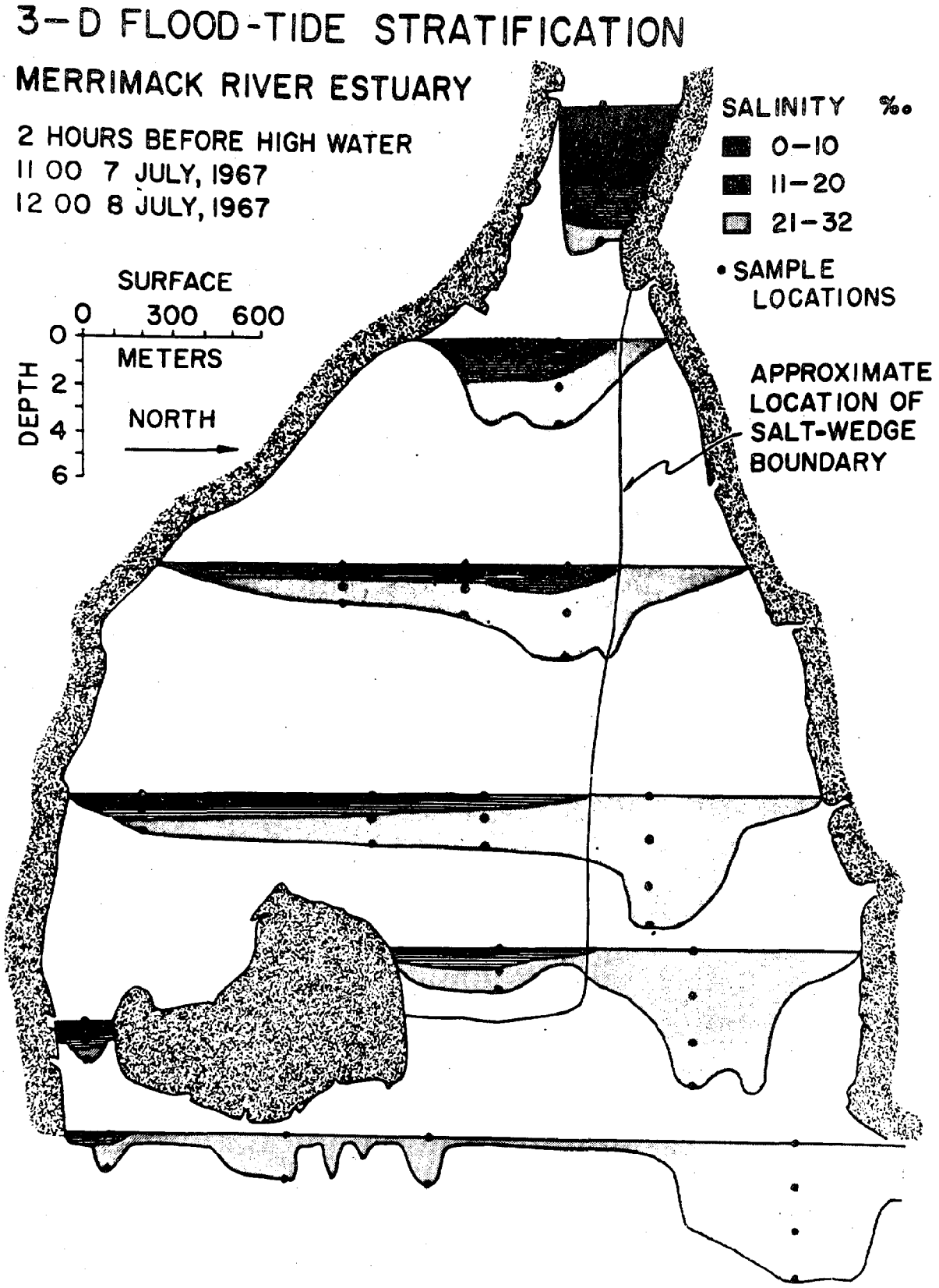


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

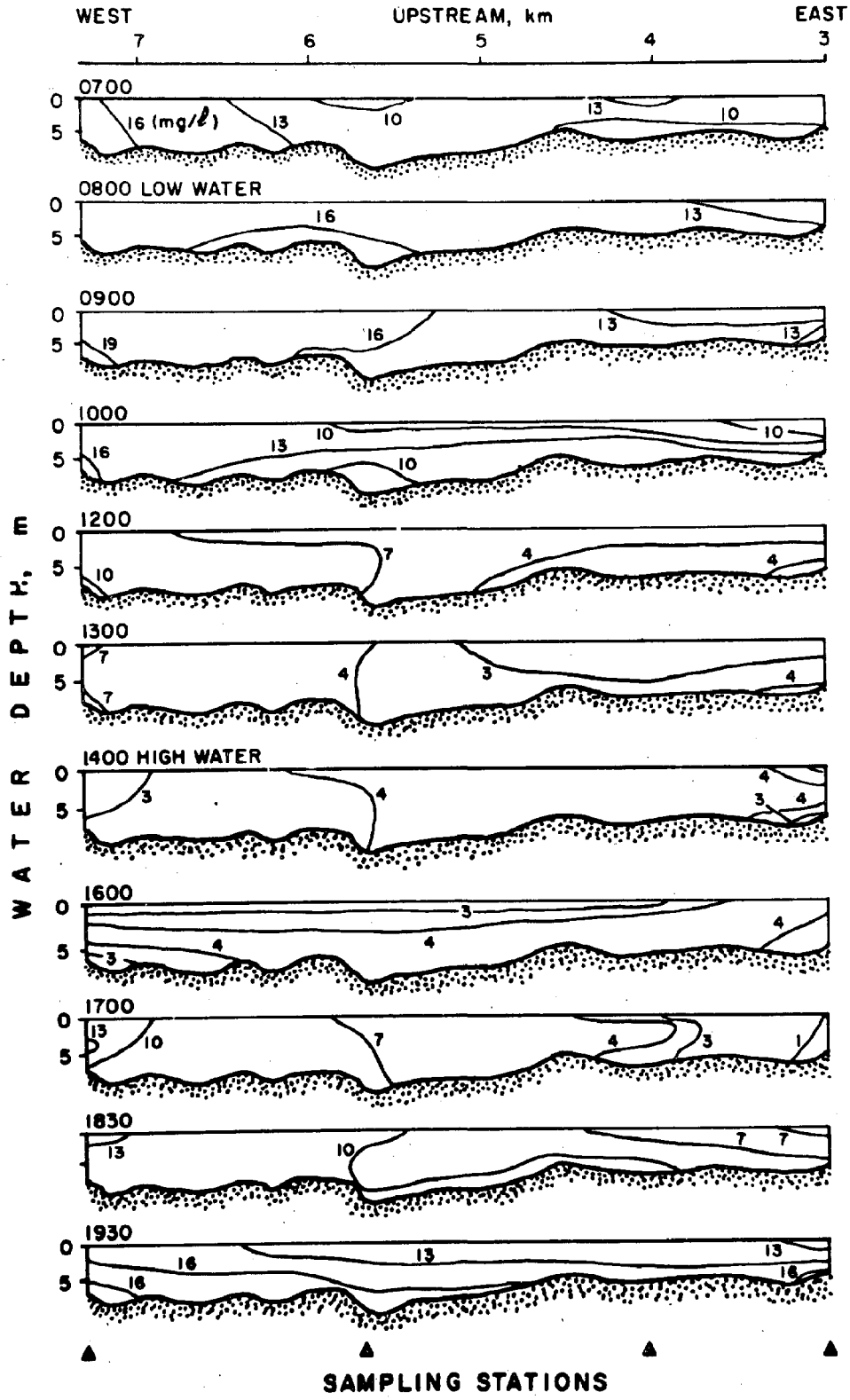
FIGURE 4-15

Sedimentary Environments and Geography of the Merrimack River (Hartwell, 1970)



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

TRIGOM PARC	FIGURE 4-16	Flood-Tide Stratification in the Merrimack River Estuary (Hartwell, 1970)



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

TRIGOM PARC	FIGURE 4-17	Changes in Suspended Sediment Concentrations during a Complete Tidal Cycle-Merrimack Estuary (Hartwell, 1970)

Sediment types and textural parameters of sediments are correlated with the hydrographic circulation pattern of the estuary. Generally, sediments are coarse in the tidal channels and at the mouth of the estuary where sand-sized sediment is transported into the estuary from adjacent barrier beaches.

Sediment in the main channel is gravelly to slightly gravelly sand - moderately sorted to well-sorted. Muddy sand to mud sediments are found on the intertidal flats where tidal currents are weaker. These sediments are poorly sorted to very poorly sorted. Smaller tidal channels are generally fine-grained and poorly sorted. Mean grain-size and sorting for the river are shown on Figure 4-18 and 4-19.

The mouth of the Merrimack River estuary is characterized, from estuary to ocean, by a flood-tidal delta, stabilized inlet, and a large, arcuate ebb-tidal delta.

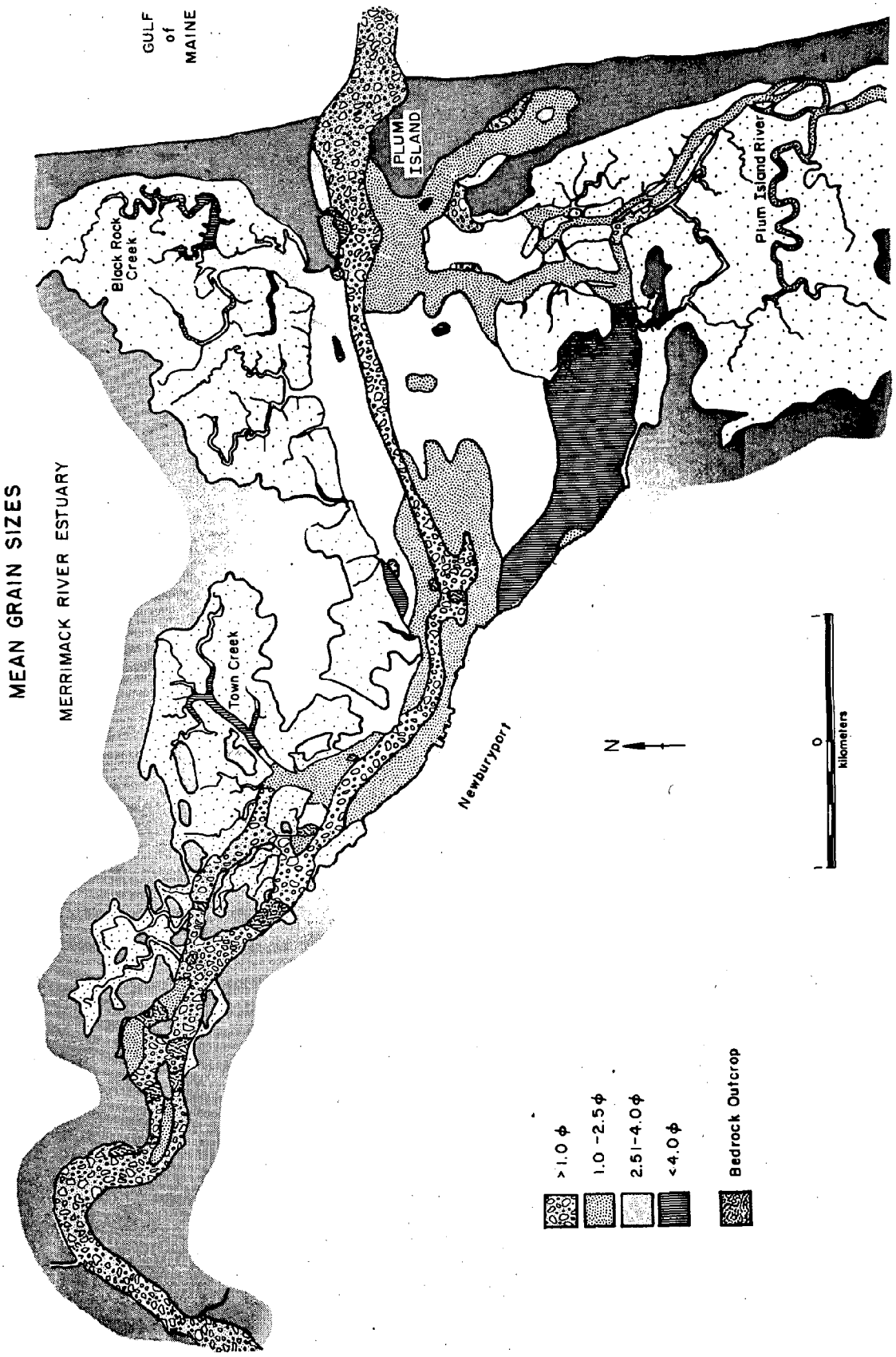
The flood-tidal delta is composed of well-sorted sand and gravelly sand and covered by flood-oriented bedforms in the central and southern portions and ebb-oriented bedforms on the northern margin. During low river flow conditions, flood-oriented bedforms dominate. Bedform migration rates and scales are greatest during spring tides. (Figure 4-20).

The tidal inlet has been stabilized by the Army Corps of Engineers along the outer margins of the channel, but strong currents and storm erosion has altered the inner channel, eroding back the southern portion of the inlet and building a spit into the channel just to the east.

The ebb-tidal delta has a central channel dominated by estuarine currents, flanked by wave-generated swash bars to the north and south to form a broad sand body arc (Hayes, Owens, Hubbard and Abele, 1973).

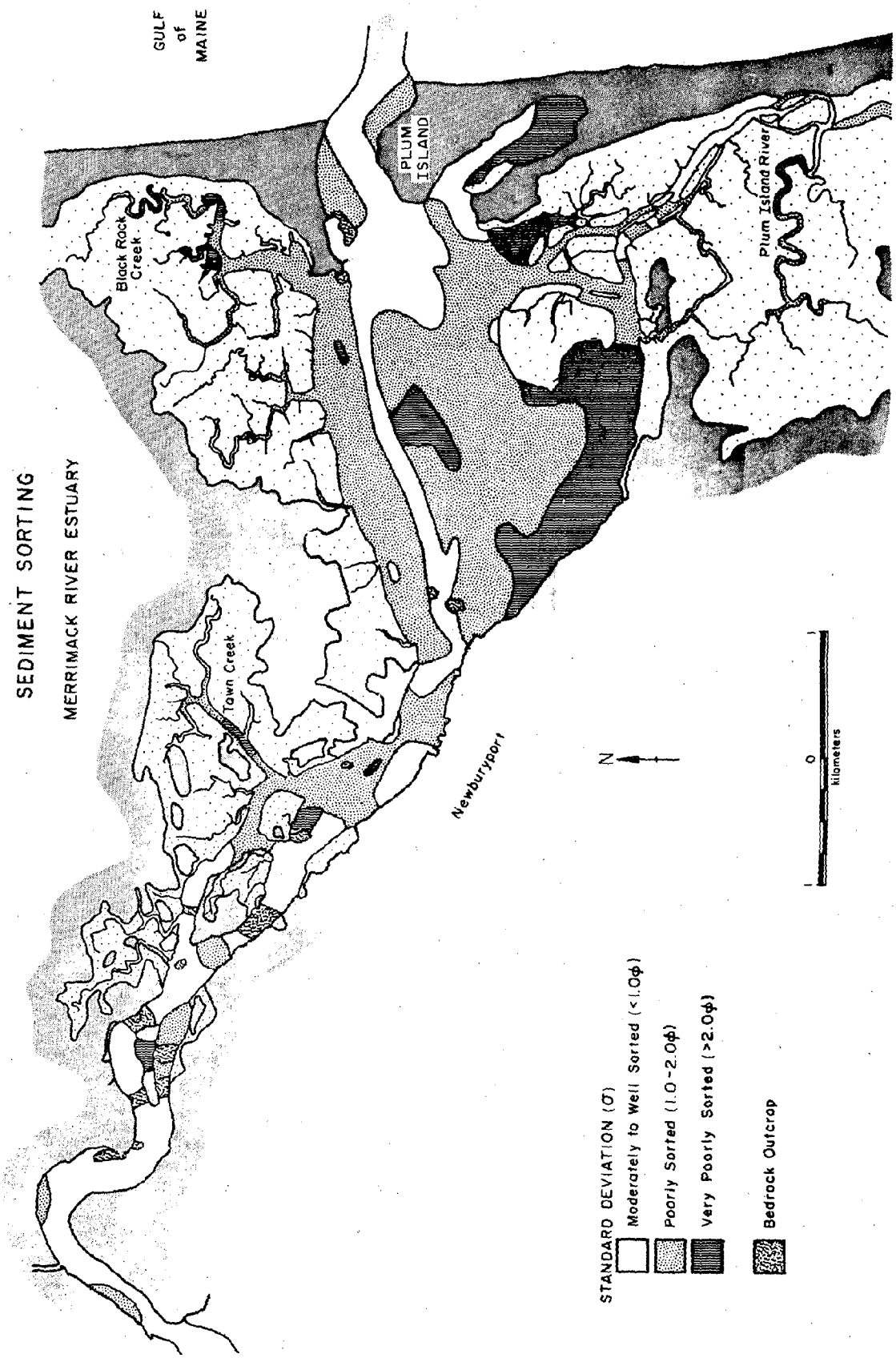
Two distinct large salt marsh tracts occur in the lowest reaches of the estuary. The Salisbury Marsh lies just north of the Merrimack River and contains peat to thicknesses of up to four meters. The salt marsh peat is thickest on the eastern side of the tract where it is drained by Black Rock Creek: Spartina patens and S. alterniflora peat lie directly on estuarine silts and sands throughout most of the marsh tract, but Hartwell (1970) found fresh-water peat in depressions attesting to a marsh origin of submergence of the Merrimack River flood plain. (Figures 4-21 and 4-22).

The Plum Island River Marsh occurs along the southern margin of the estuarine embayment, and extends south, behind Plum Island, to join with the extensive marshlands of the Parker River estuary. Average peat thickness in this marsh tract is only from one to two meters, but an isolated basin containing four meters of peat occurs between the Plum Island River and Plum Island (Figure 4-23). Peat thicknesses



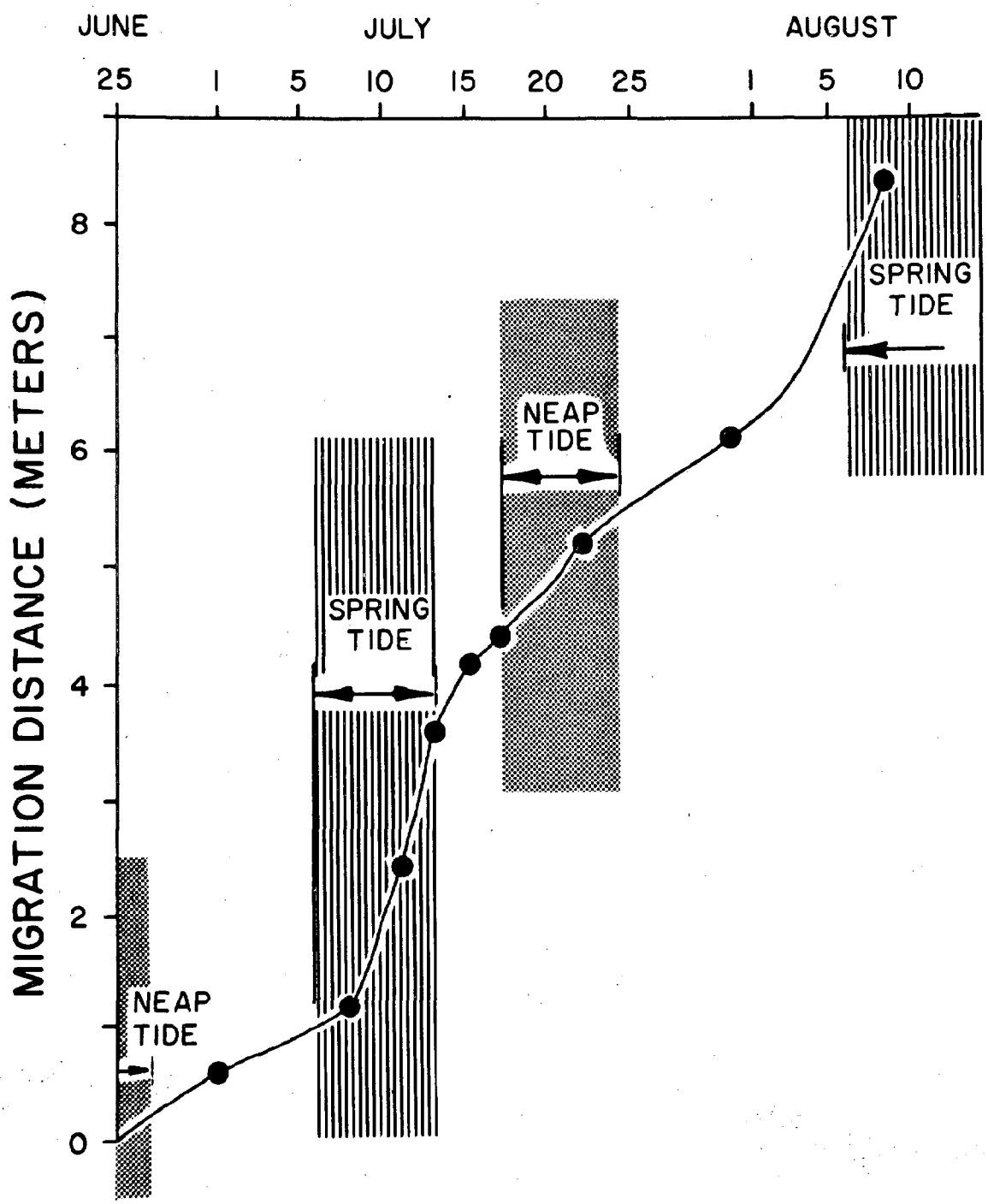
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-18	Mean Grain Size-Merrimack River Estuary (Hartwell, 1970)



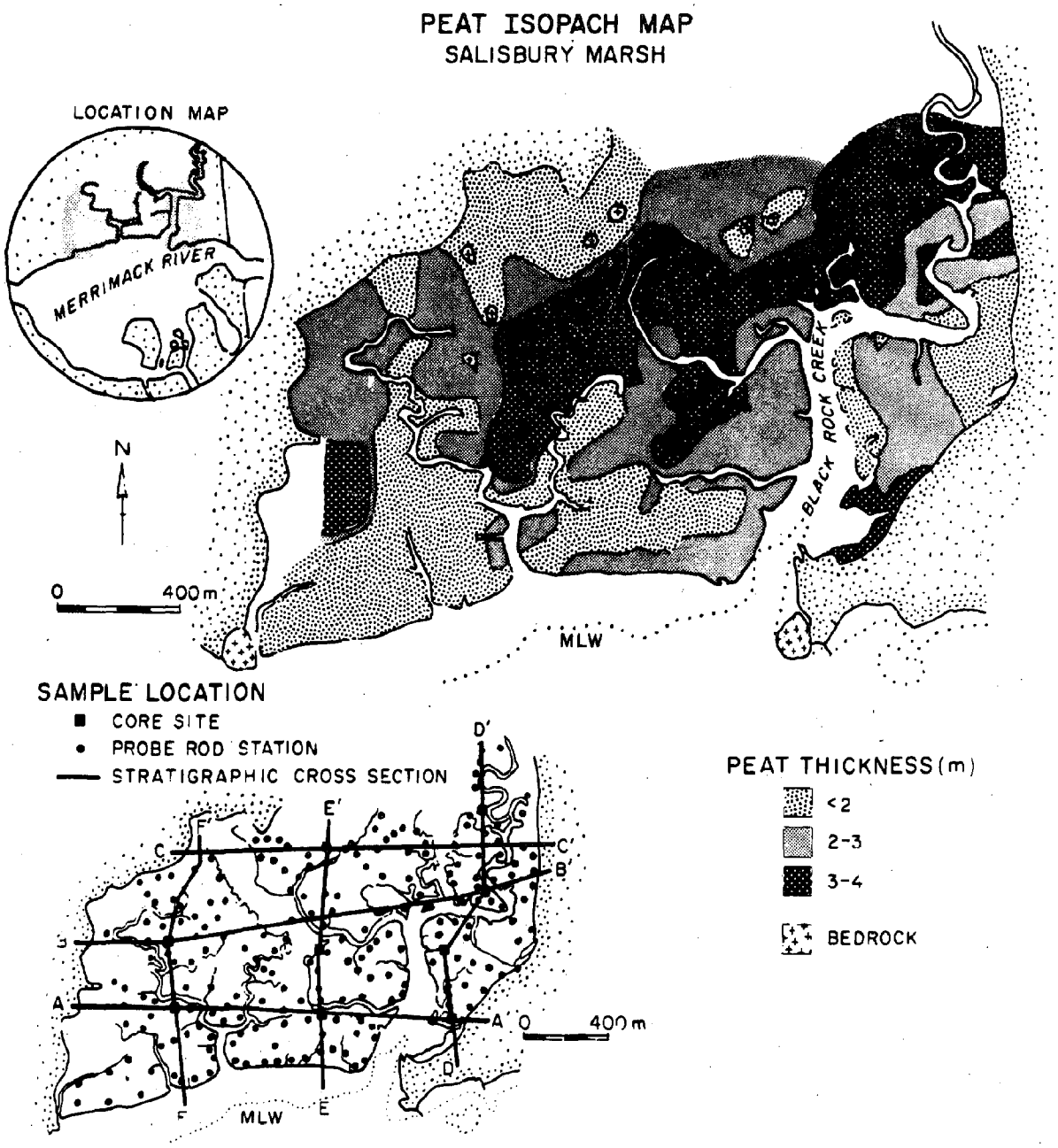
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-19	Sediment Sorting-Merrimack River Estuary (Hartwell, 1970)



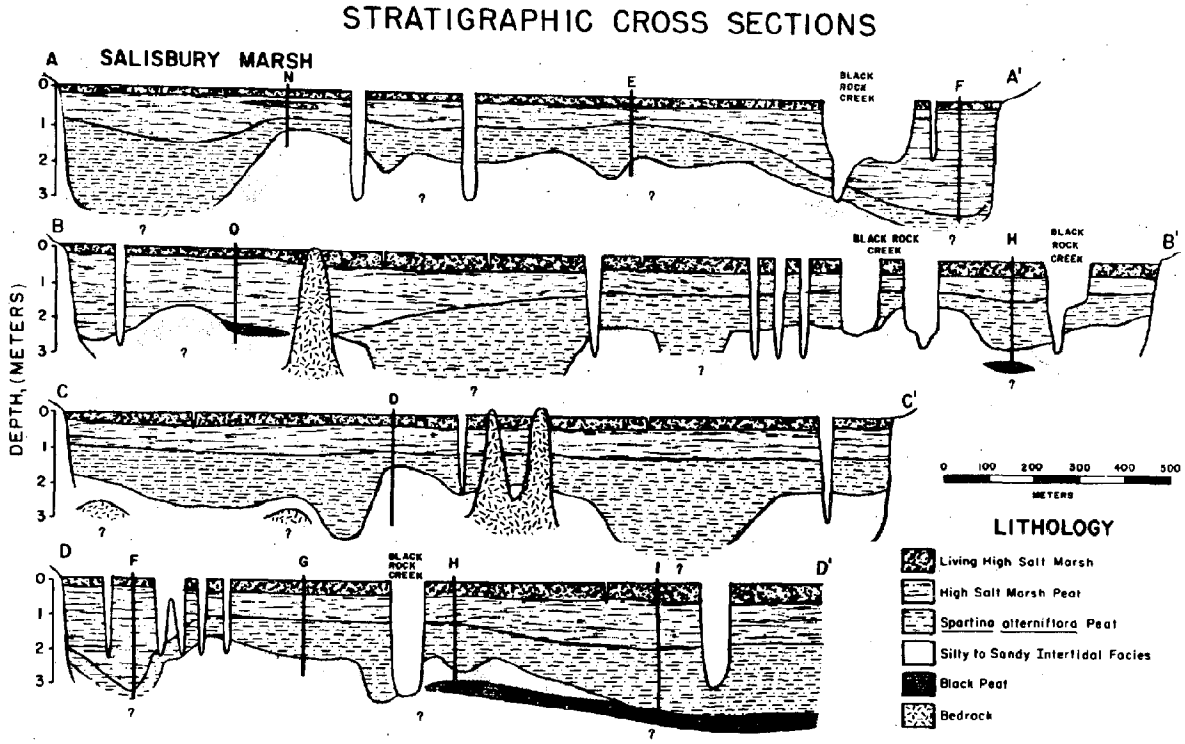
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-20	Sand-Wave Slip-Face Migration on Flood-Tidal Delta of the Merrimack River (Hartwell, 1970)



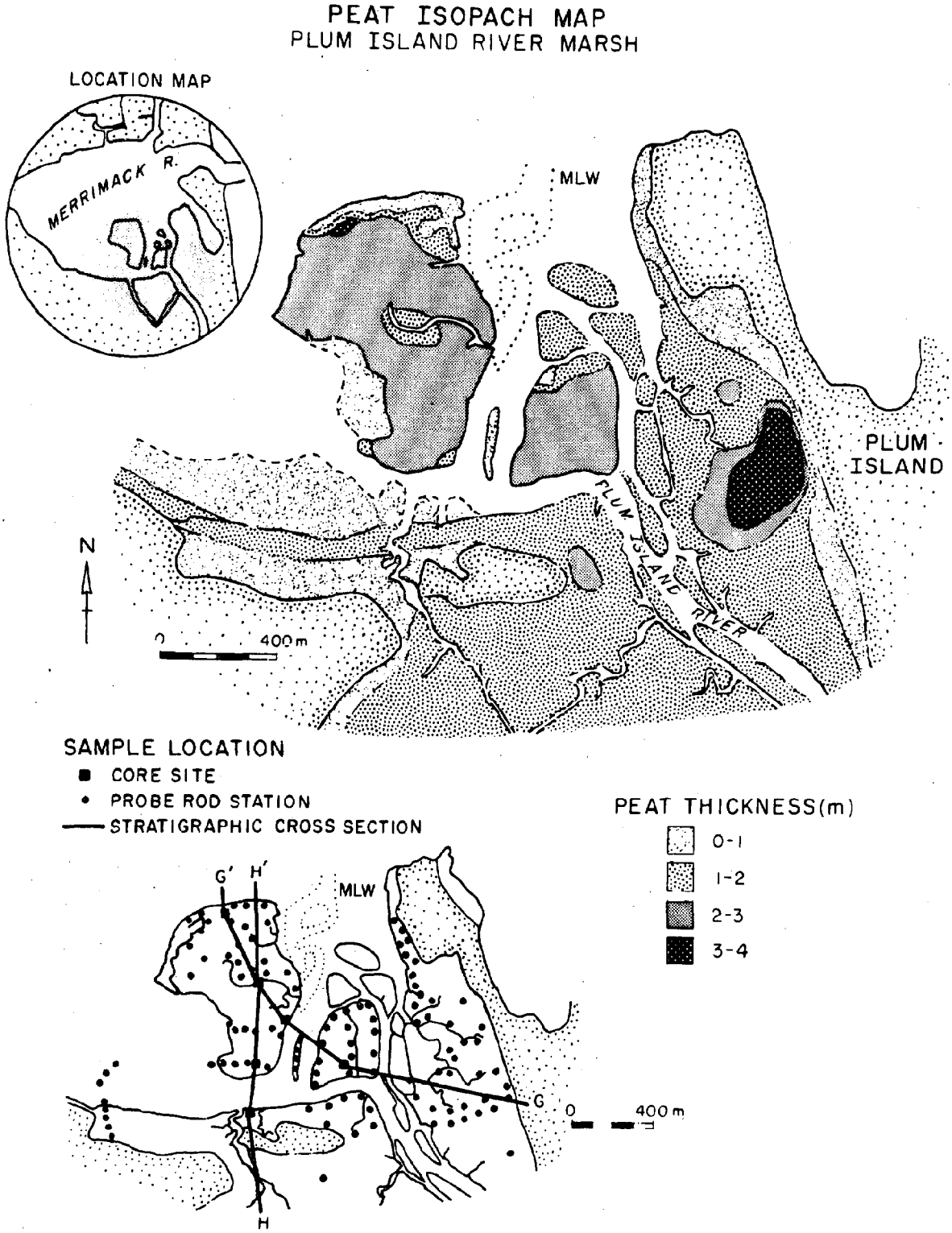
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-21	Peat Isopach Map of the Salisbury Marsh (Hartwell, 1970)



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

TRIGOM PARC	FIGURE 4-22	Cross Sections Across Selected Traverses in the Salisbury Marsh (Hartwell, 1970)



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

TRIGOM PARC	FIGURE 4-23	Peat Isopach Map of the Plum Island River Marsh (Hartwell, 1970)

are less here than in the Salisbury Marsh because of the high rates of inorganic suspended sediment setting on this side of the estuary, as well as the possibility of much of the area being underlain by relict flood-tidal delta bodies. Salt marsh overlies estuarine sands and silts in the Plum Island River Marsh (Figure 4-24).

BOSTON, MASSACHUSETTS

Boston Harbor

Boston Harbor comprises over 20 square miles - an embayment characterized by numerous islands and tombolos. The embayment opens directly east as a U-shaped funnel with the metropolis of Boston at the spout. The Mystic, Chelsea, and Charles River estuaries enter into the northwestern margins of the Harbor and the Neponset River estuary enters the western side of the bay (Figure 4-25).

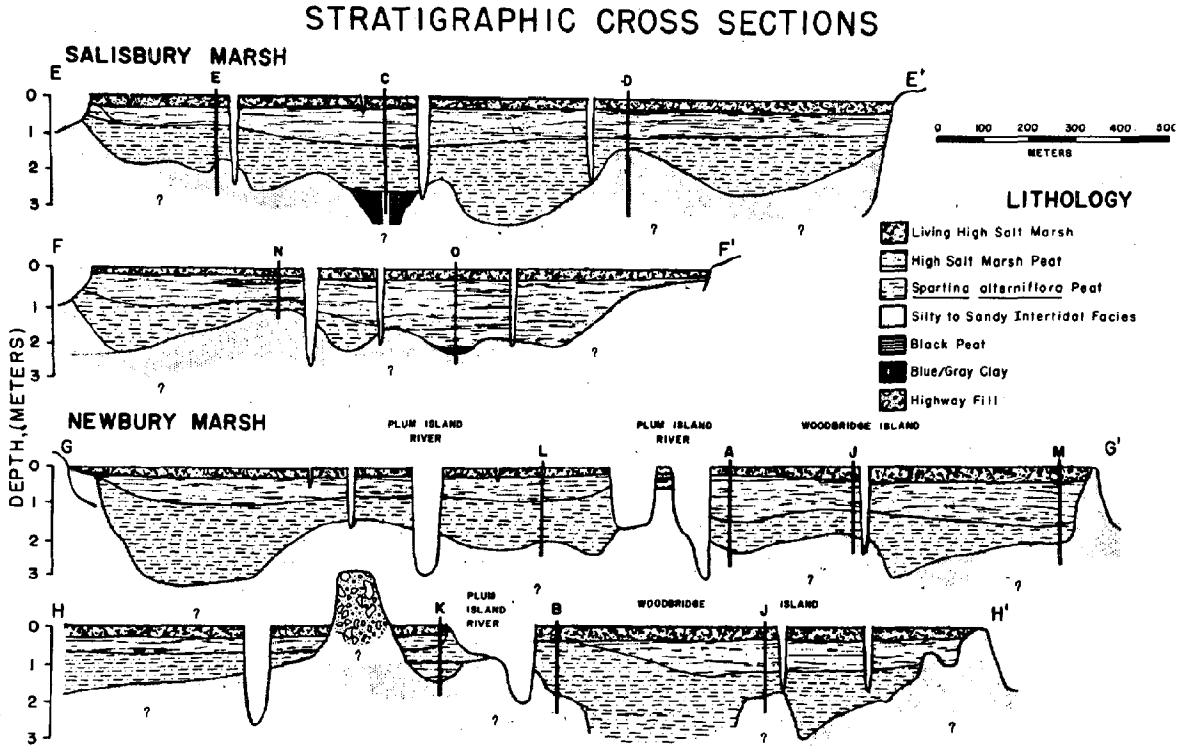
The main channel of the embayment is President Roads, extending easterly and northeasterly from the mouth of the Mystic River to Massachusetts Bay between Deer Island and Long Island. A 20-foot deep channel extends in a southwesterly direction from the southern margins of President Roads to the mouth of the Neponset River. The remainder of the Harbor is characterized by shallow, subtidal flats and channels. Several high-velocity channels exist between the islands where spits or tombolos have not cut them off.

The Charles River is the largest river emptying into Boston Harbor. The Charles drains 590 kilometers and has an annual average discharge of 374 cfs with a recorded maximum of 2,540 cfs and a minimum of 0.1 cfs (U. S. Department of the Interior, 1969).

Current velocities within Boston Harbor reach a maximum of two knots between Deer Island Light and Long Island Head. Mencher, Copeland and Payson (1968) have summarized the currents of Boston Harbor,

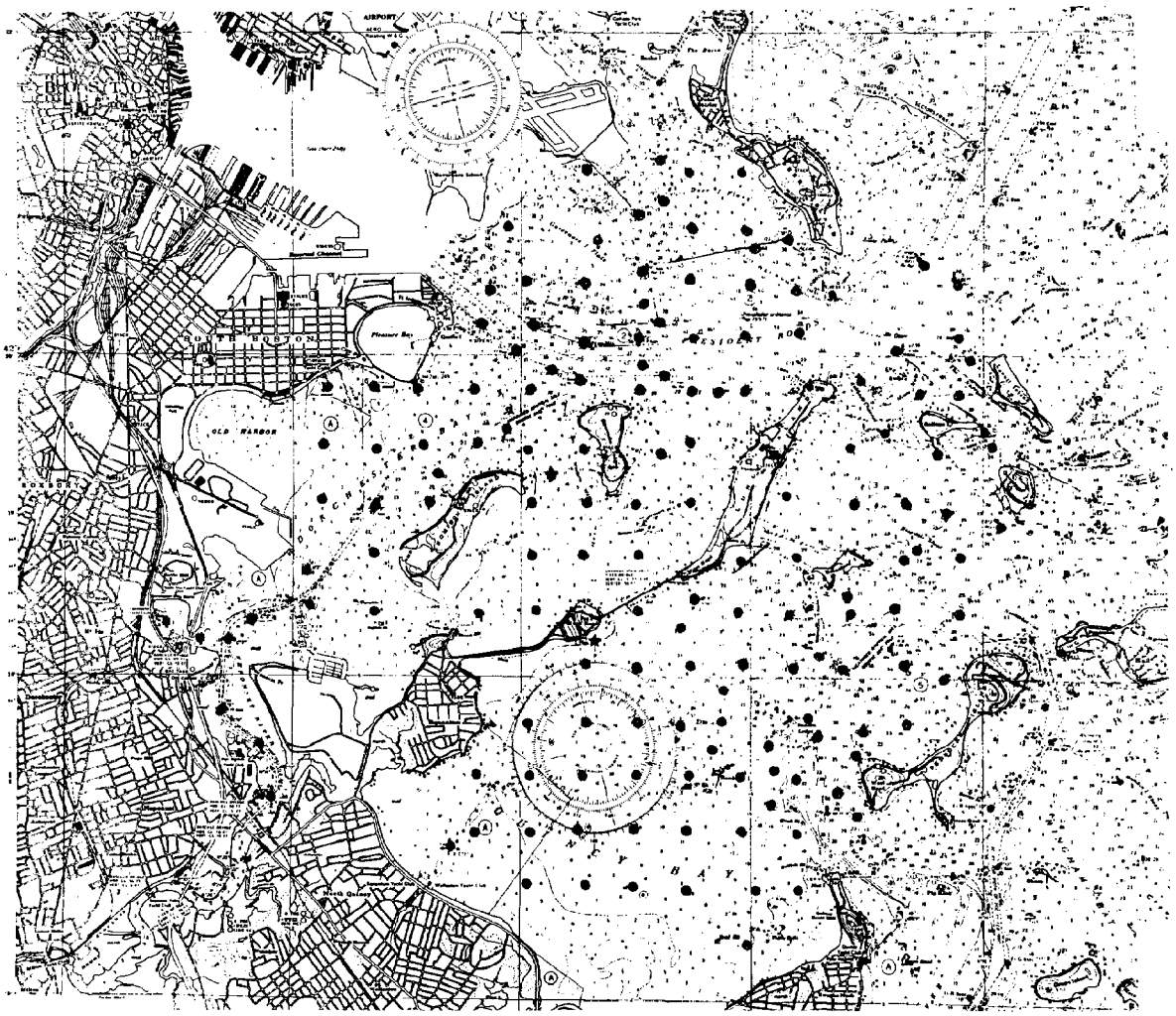
> "Around the southwestern end of Long Island, the current is rotary, counterclockwise, with average velocity at strength of about 0.2 kts. Usually, the flood sets southwesterly; the ebb, easterly. Between Thompson and Spectacle Islands, the velocity reaches a maximum of 0.5 knots, the flood setting northwesterly and the ebb southeasterly. In the main channel between Spectacle Island and the Navy Yard, the maximum velocity varies from 0.5 to 1.0 knots."

The sediments of Boston Harbor are characterized by black to brown muds lying unconformally on bedrock, glacial till, or blue clay. The muddy sediments are about 4.5 m thick throughout the Harbor, but may reach depths of 12 m where old river channels have been filled by marine



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

TRIGOM PARC	FIGURE 4-24	Cross Sections Across Salisbury and Plum Island River Marshes (Hartwell, 1970)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-25	Geographic Features of Boston Harbor (Mencher et. al., 1968)

deposition (Boston Society of Civil Engineers, 1961). Crosby (1903) estimates that deposition rates within the Harbor are slow, averaging at best, a few meters per thousand years.

Mencher, Copeland and Payson (1968) have studied sediment composition, sediment distribution, and organic content of the sediments.

Sand fractions of the sandy muds are composed mostly of quartz grains and coke, coal, and burnt wood shards - "Boston fallout." Minor amounts of feldspar, rock fragments, micas and organic matter are also present. Silt fractions are composed almost entirely of quartz, while the clay fractions are dominated by a chlorite-illite-muscovite-feldspar-particulate organic matter assemblage.

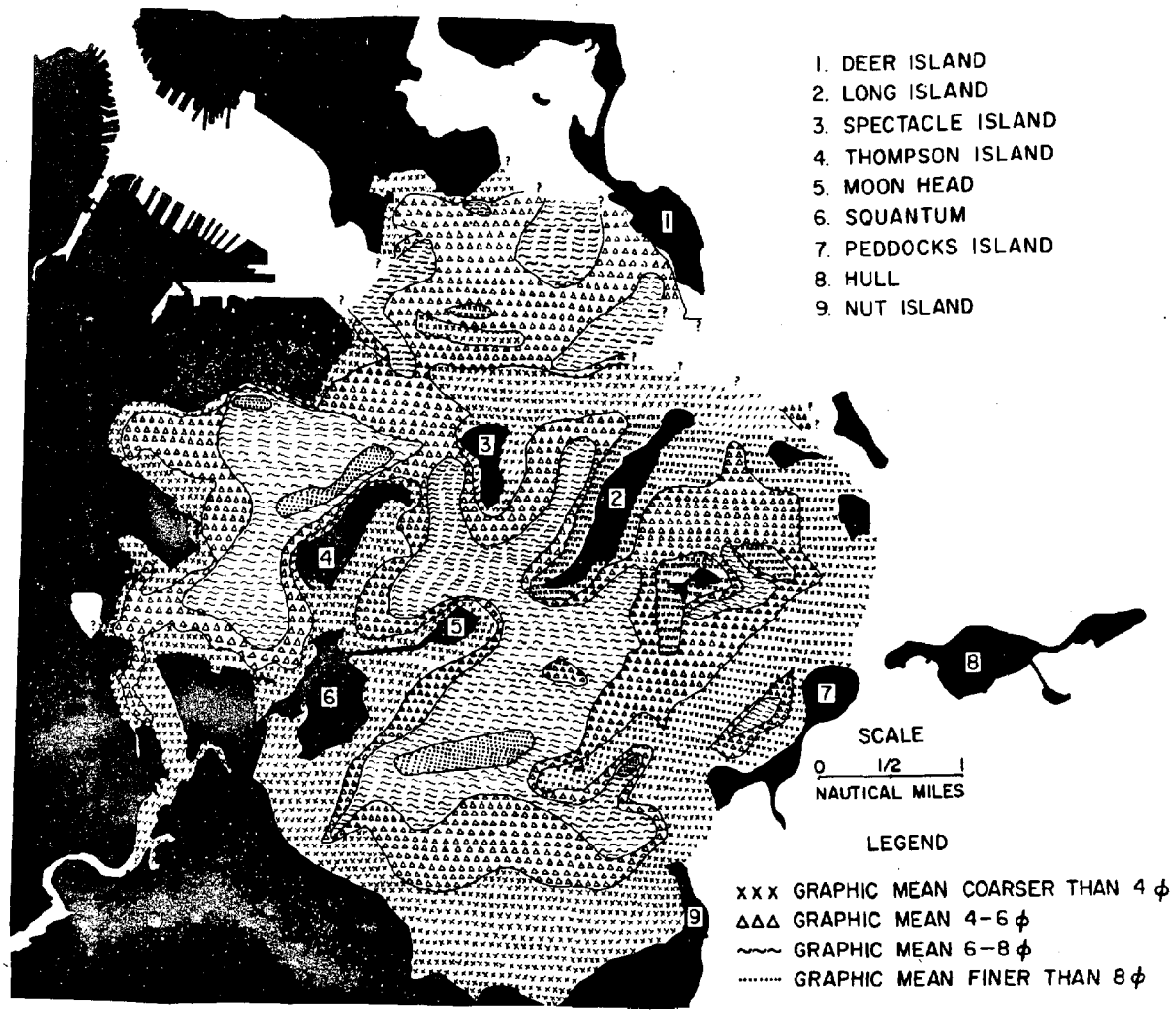
Sediment distribution within Boston Harbor indicates depositional control by current activity. Sand and gravel is present in the main channels and at the margins of the islands. Sediment elsewhere grades from coarse silts to clays toward basin centers from the margins where current velocities are low throughout the tidal cycle (Figure 4-26). Most of the inorganic sediments are derived from erosion of glacial sediments mantling the islands, and very little is delivered to the Harbor from rivers as they are all extensively dammed.

Organic carbon concentrations range from less than one percent to greater than 15 percent. The coarser organic fraction originates as windblown coke and coal particles, whereas the finer organic matter is derived from sewer outfalls located in the Harbor. The highest organic carbon concentrations are found to the northwest and southeast of Moon Island and Long Island (Figure 4-27) and are a consequence of the hydrographic conditions directing sediment dispersal from major sewer outfalls (Figure 4-28).

4.1.4 MINOR EMBAYMENTS BORDERING THE GULF OF MAINE

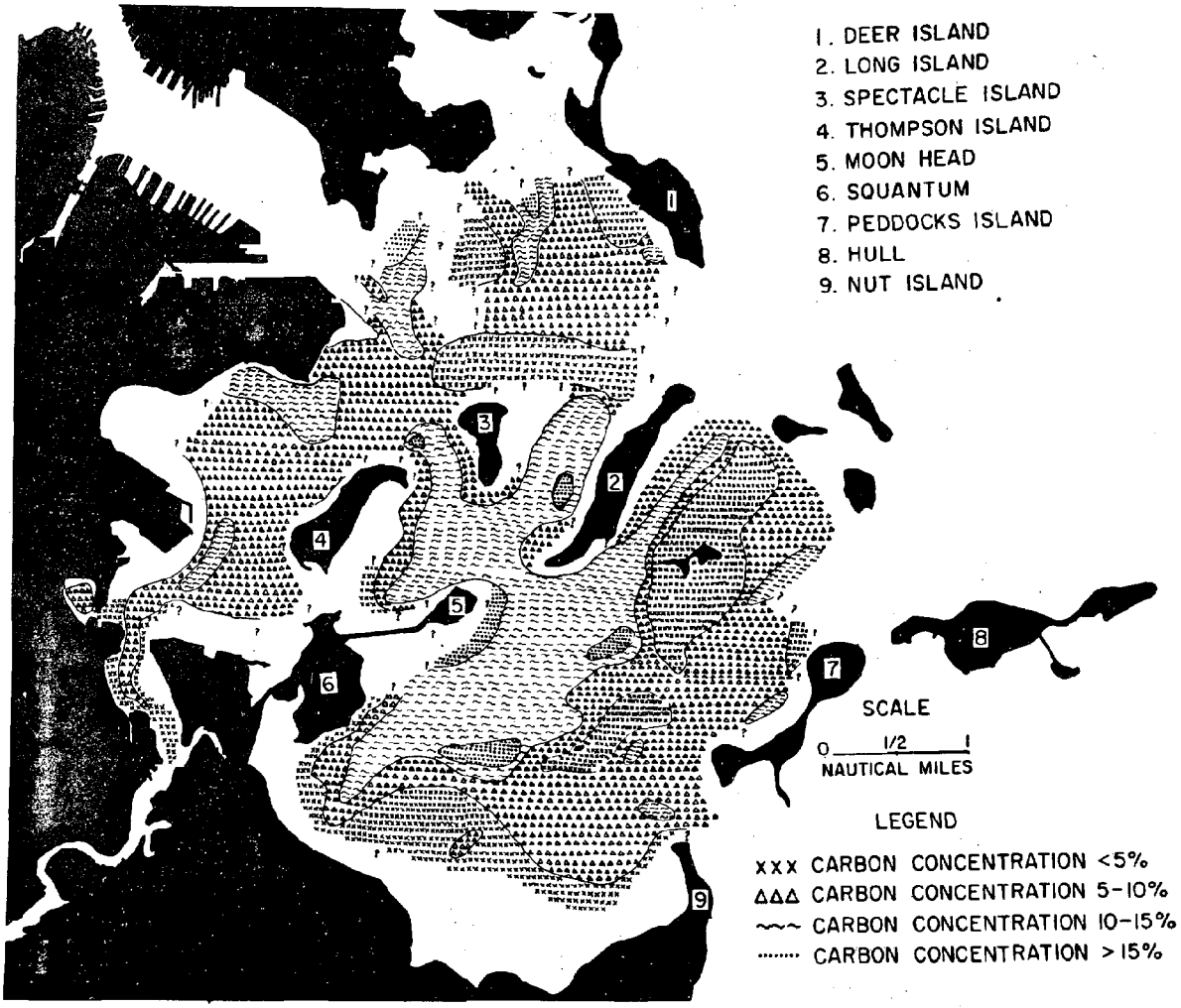
Numerous smaller estuaries empty into the Gulf of Maine, and they have been studied by various investigators. Generally, the estuaries which have been studied are of two types: 1) Relatively long, linear, narrow estuaries characterized by fine-grained sediments throughout and hydrographic patterns marked by stratified waters at their heads and well-mixed waters in the lower estuary; 2) Coarse-grained estuaries usually formed by barrier spit restriction and characterized by extensive marsh deposits and well-mixed estuarine waters except at the heads of small tidal creeks or channels.

A third, anomolous type occurs on Mt. Desert Island, Somes Sound. This estuary is a fjord type estuary and has been studied by Folger (1972b) who concentrated on studies of the estuarine sediments and circulation patterns.



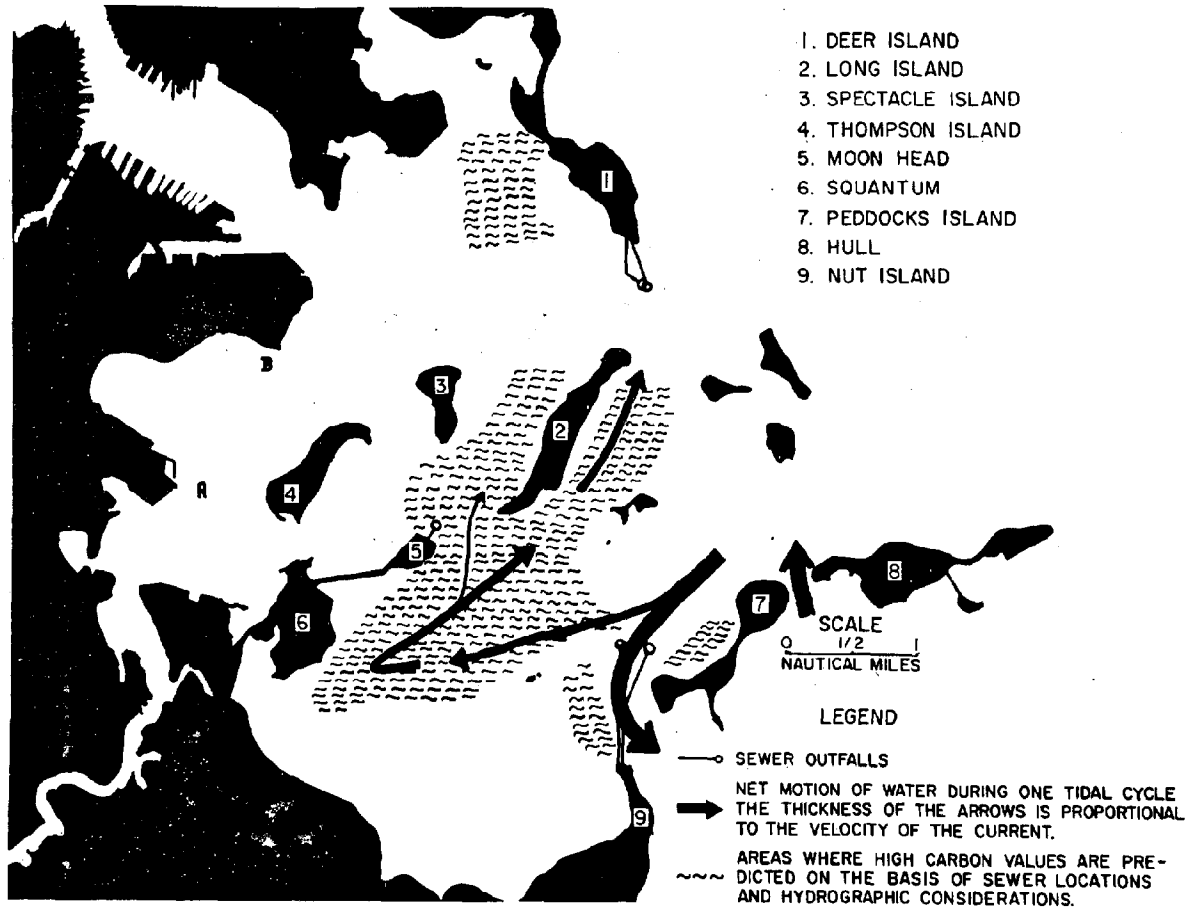
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-26	Mean Grain Size of Boston Harbor Sediments (Mencher et al., 1968)



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

TRIGOM PARC	FIGURE 4-27	Organic Carbon Concentrations of Boston Harbor Sediments (Mencher et al., 1968)



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

TRIGOM PARC	FIGURE 4-28	Sewer Outfalls, Water Movements, and Predicted High Organic Carbon Content (Mencher et al., 1968)

The fine-grained minor estuaries are limited to the Maine Coast. The hydrography of the St. George River estuary has been studied by the U. S. Department of Public Health (1967) and Timson (unpublished data).

The Medomak River estuary in Waldoboro, Maine, has been studied, hydrographically, by the U. S. Department of Public Health (1968).

The Damariscotta River estuary circulation and surface sediments have been investigated by McAlice (1970b, in press).

The Sheepscot River estuary has been the subject of intense study with the advent of the location of an atomic power plant in a cove off the lower estuary. Stickney (1959) published an ecological study of the Sheepscot which included a hydrographic study and a survey of the depositional environments. Hydrographic and sediment studies collected environmental background data for the atomic plant at Bailey Point on the Lower Sheepscot. These studies have been conducted under the auspices of the Maine Yankee Power Company (1969-1972). Schnitker (1972) has studied sedimentation rates and suspended sediment transport in Back Cove, the site of effluent discharge from the power plant. Graham and Boyar (1965) have studied temperature and salinity seasonal distributions in the lower portions of the estuaries of the Boothbay Region. The coarse-grained estuaries are limited to the southern Maine, New Hampshire, and Massachusetts coastlines.

Farrell (1970, 1972) has studied the sediments, marshes, and hydrography of Scarboro River estuary.

The Hampton River estuary has been investigated by Greer (1969 a & b) and Normandeau Associates (1972).

Daboll (1969 a & b) studied the sediments and hydrography of the Parker River estuary; McCormick (1968, 1969) studied the marshes of the Parker River; and Boothroyd and Hubbard (1971) and Hubbard (1971) studied bedforms in the lower Parker River estuary.

Boothroyd (1969) has studied the sand body morphology and sedimentology of the Essex River estuary. This area has also been investigated by Chesmore, Brown and Anderson (1973) for the Massachusetts Department of Marine Resources.

Jerome, Chesmore and Anderson (1969) have investigated the hydrography of the Annisquam River estuary as well as its morphometry.

The smaller estuaries entering Boston Harbor have been studied by Chesmore, Brown and Anderson (1972) and Jerome, Chesmore and Anderson (1966).

Fiske, Watson and Coates (1966) have studied the marine resources of the North River estuary.

The geology of Barnstable Harbor has been studied by Redfield (1959, 1967) and Hobbs (1972). Ayers (1959) has studied the hydrography of the area.

Curley, Lawton, Whittaker and Hickey (1972) and Nilsson (1972) have studied the morphometry and currents of Wellfleet Harbor, respectively.

Hine (1973) has studied the sedimentology and hydrography of Pleasant Bay, Chatham.

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4.1.6 INTRODUCTION - CAPE COD TO SANDY HOOK

Most of the embayments south of Boston can be separated into two categories on the basis of size. Long Island Sound, Narragansett Bay, Buzzards Bay and Cape Cod Bay all are relatively large in size, each being greater than 380 square km in area. Many smaller embayments and coastal marshes, however, lie both within and between these larger systems. Most of the following discussion will involve the large systems.

MASSACHUSETTS

Cape Cod Bay

Cape Cod Bay is roughly circular in outline, being surrounded by Cape Cod to the west, south and east, and by the Massachusetts south shore (Plymouth area) to the northwest. Depths generally increase seaward, and are greater than 48 m seaward of Provincetown (Figure 4-29). In area, Cape Cod exceeds 500 square km.

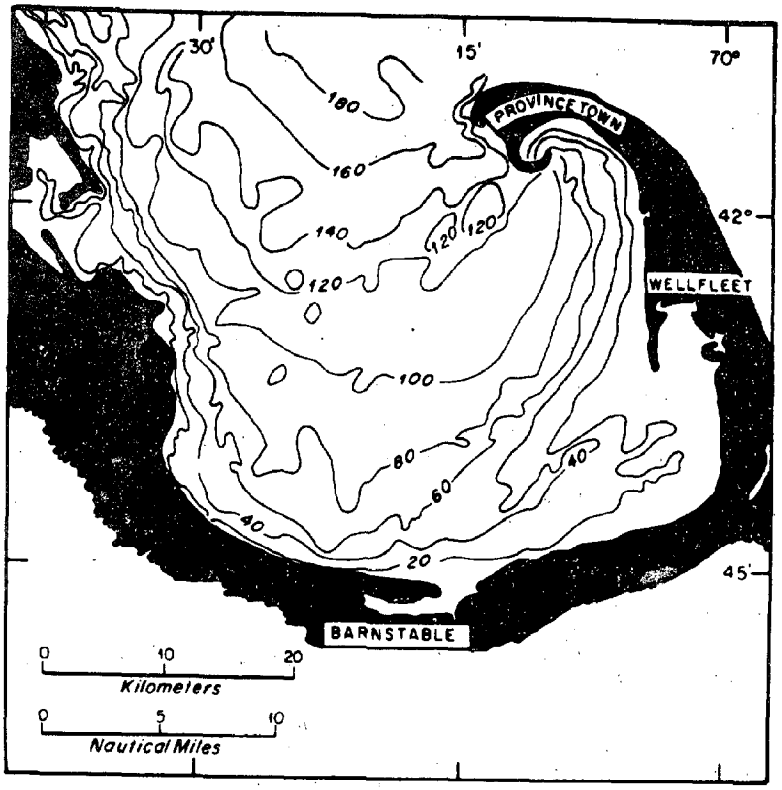
In contrast to the other major embayments, Cape Cod has essentially no freshwater influx, with the result that salinities are typically marine. Sediment influx, therefore, is considered to be minor and most of the sediment is reworked from older deposits.

Nearshore sediments tend to be coarse in size nearshore and finer grained in the deeper portions of the bay (Figure 4-30) (Hough, 1942; Folger, 1972). Organic contents vary inversely with sediment size, although the number of reported values at present are too few to plot significant trends.

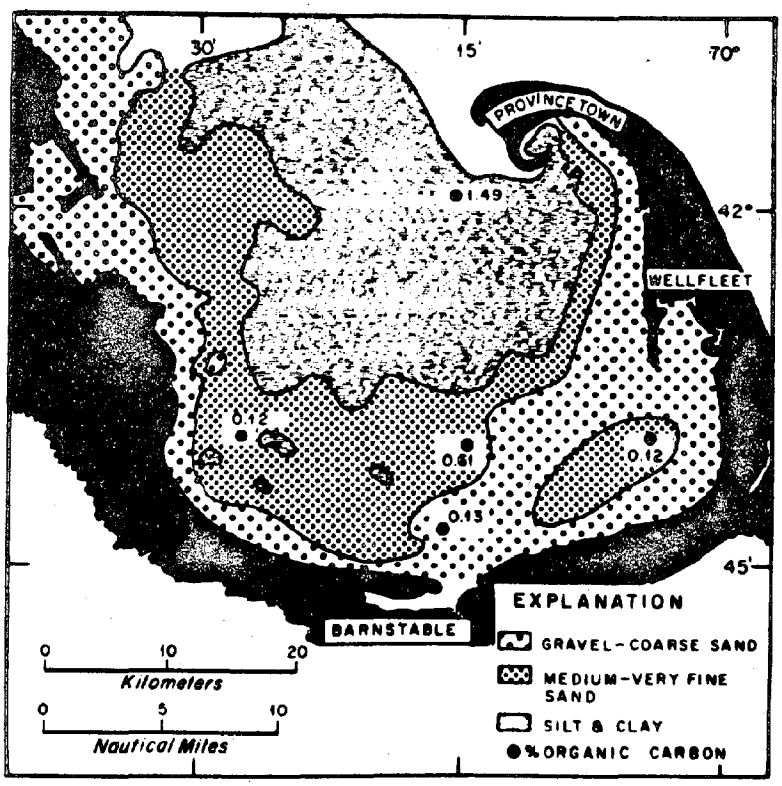
Buzzards Bay

Buzzards Bay lies along the coast of southeastern Massachusetts, bounded on its seaward side by Cape Cod and the Elizabeth Islands. It is approximately 37 km long and 15 to 18 km across, with water depths in the central portions ranging from 12 to 18 m (Figure 4-31). The north side of the bay is generally rough but with a gentle gradient, while the south side is steep nearshore, but with smoother topography. Geophysical profiles in the area indicate that the bay sediments overlie between 9 and 61 m of crystalline basement (Oldale,1969; Folger, 1972).

Sediments within Buzzards Bay are sandy around the edges and muddy in the central portions of the bay (Figure 4-32) (Hough, 1940; Moore, 1963; Rhoads, 1967; Rhoads and Young, 1970). As a result, organic carbon values tend to be high in the muddy central areas (generally greater

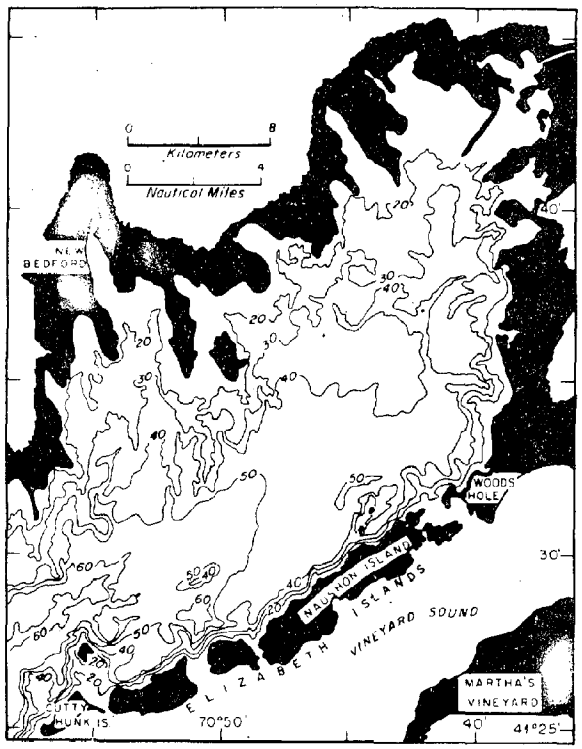


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-29	Topography of Cape Cod Bay (Hough, 1942)



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

TRIGOM PARC	FIGURE 4-30	Bottom Sediments of Cape Cod Bay (Hough, 1942 and Hathaway, 1971)



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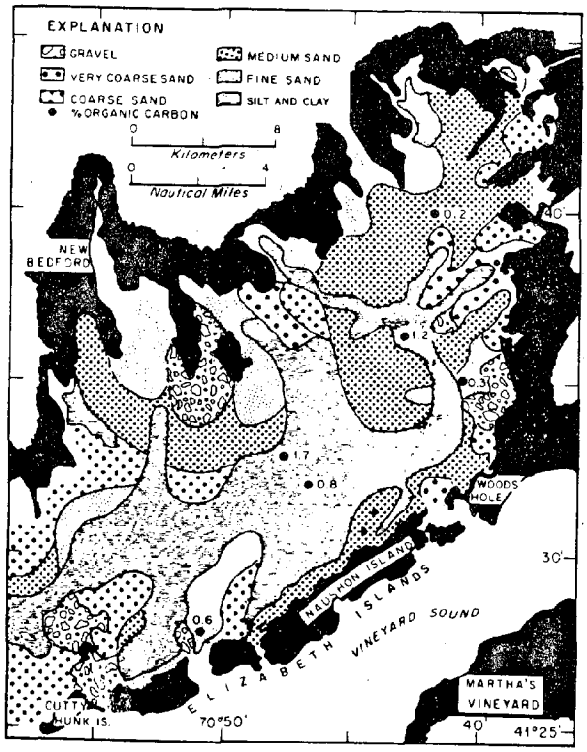
TRIGOM PARC	FIGURE 4-31	Topography of Buzzards Bay (Moore, 1963)



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

TRIGOM PARC	FIGURE 4-32	Bottom Sediments of Buzzards Bay (Moore, 1963 and Hathaway, 1971)

than one percent) and lower around the edges. Presumably most of the surficial sediment has been derived from the reworking of glacial sediments; little is thought to be modern.

RHODE ISLAND

Narragansett Bay

Narragansett Bay occupies the entire eastern shoreline of Rhode Island, and has a total area in excess of 380 square km, although much of it is occupied by islands, the largest being Aquidneck Island (Figure 4-33). The shape and bathymetry of the bay is defined by three main channels (Taunton River, Providence River and Greenwich Bay) cutting into a bedrock valley within a structural depression (Berg, 1963; Upson and Spencer, 1964). Test borings show 18 to 48 m of unconsolidated glacial sediment overlying a consolidated sedimentary (Carboniferous) cover (See Folger, 1972; McMaster, 1960).

Most of the bay is shallower than 6 m (particularly in the northern half of the bay). In the south, depths within East Passage are greater than 18 m, but substantially shallower at Sakonnet Passage and West Passage (Figure 4-33).

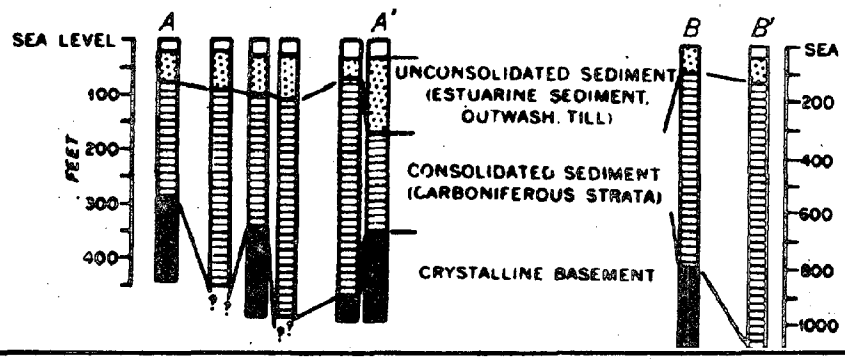
The amount of fresh water flowing into Narragansett Bay is not great. Wilson and others (1967) state that the mean flow rate of the Taunton River, for example is 29 m^3/sec. The inflowing suspended sediment, therefore, is also small in quantity, meaning that much of the material in suspension is eroded from surrounding shoreline or consists of resuspended bottom sediments. Morton (1972) has estimated that only ten percent of the suspended sediments escape into Rhode Island Sound.

The surface sediments within Narragansett Bay are sandy nearshore and muddy in the center (McMaster, 1960). Sand is particularly abundant in and near the three passages (Figure 4-34). The few available analyses suggest that the sediment near populated (polluted) areas is highly polluted, with organic carbon values greater than 2.0 percent.

CONNECTICUT-NEW YORK

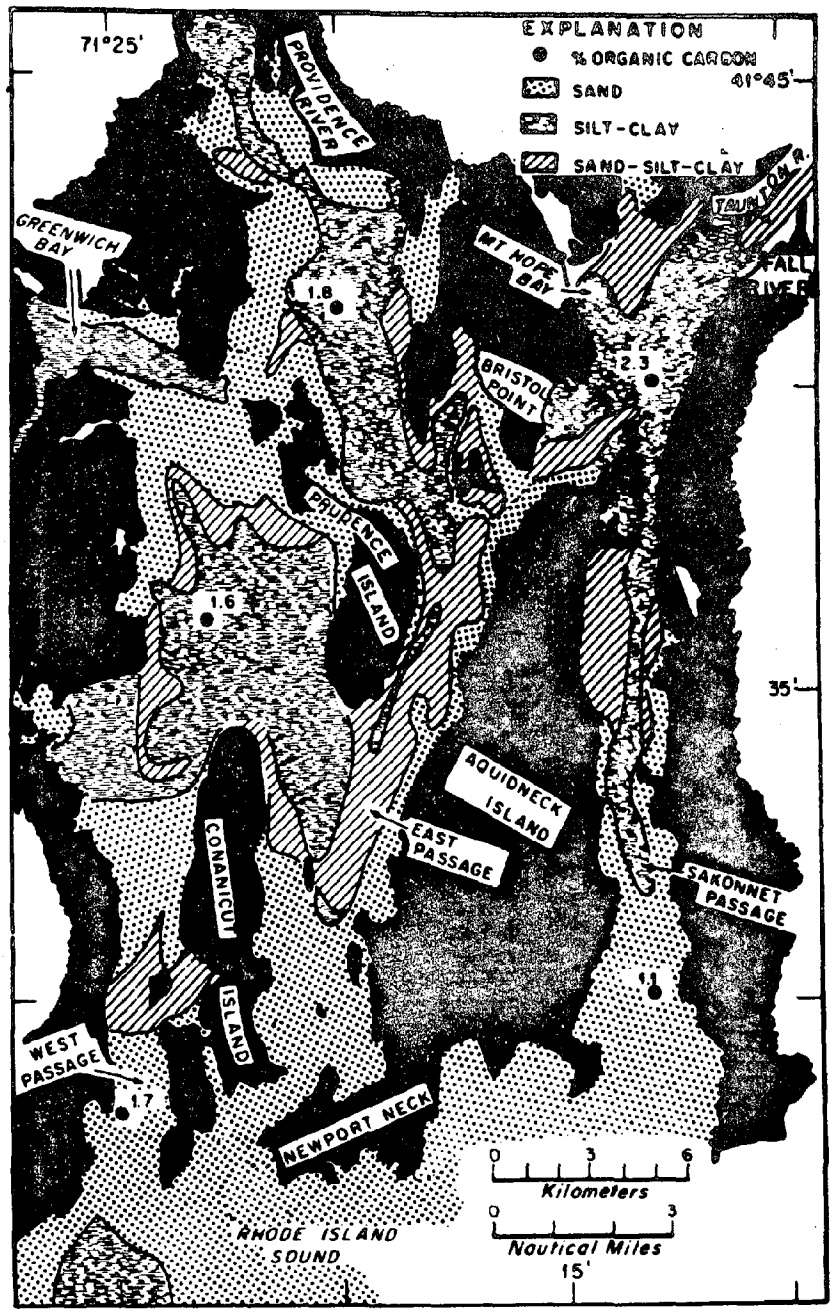
Long Island Sound

The longest estuary in the northeastern United States is Long Island Sound, which is more than 148 km long and between 18 and 45 km wide. It is delineated by the New England Upland to the north and the Long Island - Block Island glacial moraines to the south. Depths within the sound are generally greater than 18 m but less than 37 m. Seismic profiles show a profusion of buried channels throughout the entire sound (Tagg and Uchupi, 1967; Grim, Drake and Heirtzler, 1970). Apparently these are relict stream channels which cut into pre-Pleistocene rocks, perhaps Coastal Plain strata.



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

TRIGOM PARC	FIGURE 4-33	Topography of Narragansett Bay (McMaster, 1960; Hathaway, 1971)



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

TRIGOM PARC	FIGURE 4-34	Bottom Sediments of Narragansett Bay (McMaster, 1960; Hathaway, 1971)

The major river flowing into this estuary is the Connecticut River, which has an average discharge of 606 m^3/sec and a suspended load of 81 x 10^3 tons per year (Dole and Stabler, 1909; Wilson and others, 1967). The river is navigable for 96 km (to Hartford) with depths greater than 4.5 m. The major sediment input, however, is not from the Connecticut River, but from dredge spoil dumpage, which accounts for 0.8 x 10^6 tons per year in the western part of the south (Gross, 1972). The influence of the extensive duck farms along northwestern Long Island must also have a heavy effect upon the sediments, as does the heavy urbanization along much of the Connecticut and New York shoreline.

The sediments within Long Island Sound have not been studied in the detail of the other estuaries mentioned in this review, in spite of (or perhaps because of) the degree of urbanization of the area. Sediments tend to contain more than 75 percent mud in the western central portions and 50 to 75 percent in the eastern part, with shoreline areas often containing mostly sand. The mud is mostly illitic, with smaller amounts of chlorite (Hathaway, 1972). Organic content in western Long Island Sound exceeds one percent and locally is much greater than two percent, although the sparsity of samples prohibits complete delineation of these organic-rich areas. The influence of the wastes from industrial and dredge spoilage as well as the duck farms (Nichols, 1964) is tremendous, although the impact is not well documented.

OTHER AREAS

Studies of smaller areas both within these four large bays and also in intervening areas are numerous. Much of the floristic data are summarized by Halvorson and Dawson (1974) while coastal utilization has been discussed by Ducsik (1974). In many instances these studies have concentrated on marshes or small saline ponds (lagoons) trapped behind the barrier beaches. For instance, marsh studies from southern New England include those by Taylor (1938), Chapman (1940), Miller and Egler (1950), Sears (1963) and Bloom (1964).

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Chapter 4 Major Sounds and Embayments

			Page
Chapter 4.2	Physical Oceanography		
	4.2.1	Introduction to Region North of Cape Cod	4-63
	4.2.2	Characteristics of Currents	4-63
		Coastal Shelf	4-63
		Inshore	4-66
		Major Estuarine Embayments	4-67
	4.2.3	Tides	4-70
	4.2.4	Fresh Water Input	4-74
		General Description of Freshwater Discharge of Major Basins	4-74
		Temperature and Salinity of the Coastal Shelf	4-77
	4.2.5	Characteristics of Circulation	4-89
		Salt Wedge Estuary	4-91
		Partially Mixed Estuary	4-91
		Vertically Homogeneous Estuary	4-91
		Sectionally Homogeneous Estuary	4-92
	4.2.6	Misfits and Variations	4-92
	4.2.7	Sea Ice Conditions - Eastport to Cape Cod	4-94
	4.2.8	References	4-96
	4.2.9	Circulation and Currents - Region South of Cape Cod Introduction	4-200

		Page
4.2.10	Tides	4-216
4.2.11	Sea Ice Conditions - Cape Cod to New York	4-218
4.2.12	References	4-220

4.2 PHYSICAL OCEANOGRAPHY - MAJOR SOUNDS AND EMBAYMENTS

4.2.1 INTRODUCTION TO REGION NORTH OF CAPE COD

The North Atlantic Estuarine Zone (U.S. Fish and Wildlife Service, 1970) extends from the Canadian border in the east (45°N., 67°W.) to Cape Cod in the south (42°N., 70°W.). The general shoreline traverses three states; Massachusetts, New Hampshire, and Maine (Figure 4-35). Each has a relatively large city on its coast; Boston, Portsmouth, and Portland respectively. The shoreline extends in an arc northward from Cape Cod to Portland and then eastward to the Canadian border. The southern shoreline partially encloses Massachusetts and Cape Cod Bays between the northern tip of Cape Cod and Cape Ann. From Cape Ann to Cape Small, the Bigelow Bight partially encloses Ipswich and Casco Bays. From Cape Small to the Canadian border the shoreline is interrupted by the largest estuary of the coast, Penobscot River Estuary and Bay. A second large bay, Passamaquoddy Bay, is dissected (Figure 4-35) by the U.S. Canadian border and opens into the Bay of Fundy. The narrow Bay of Fundy opens onto the Gulf of Maine through two channels on the western and eastern sides of Grand Manan Island.

The coastal shelf zone extends offshore to about 27 km from the headlands and to a depth of about 91 meters. Beyond this distance and depth, the water deepens rapidly only to shoal again in some areas producing banks and ledges such as Jeffreys Ledge, Cashes Ledge, Platts Bank, and Grand Manan Banks. The progression of seasonal events in this shelf water is less conservative than events within the adjacent Gulf of Maine and more conservative than the waters of the estuaries and embayments.

4.2.2 CHARACTERISTICS OF CURRENTS

COASTAL SHELF

The non-tidal drift characteristic to the coastal zone begins at approximately 27 km from shore, near the 90 m isobath. The circulation is complex reflecting both inshore and offshore events although the forces causing non-tidal drift and the direction of drift are the same as those encountered offshore. Sources and movements of water along the western coast of the Gulf of Maine are summarized in Table 4-1 and Figure 4-36.

Water enters the coastal shelf from three sources; 1) the Bay of Fundy, 2) the western basin of the Gulf of Maine and 3) the discharge of estuaries. Water departs the Bay of Fundy on its eastern side and may join the Gulf of Maine eddy to proceed to the coast. In addition, water may at times depart the Bay on the eastern side through Grand Manan Channel to move directly onto the coastal shelf.

Table 4-1 Movements of coastal water.

Initial location			Destination	
Area	Depth	Movement	Area	Depth
1. Bay of Fundy	Surface	West of Grand Manan Island to Maine coast, or to east side of the Island and then west to the coast of Maine. Primarily in spring, autumn, and winter (Chevier and Trites 1960)	Eastern sector of coast	Surface
2. Western Basin off the eastern sector of the coast	Surface	Inshore during winter	Inshore	Surface
3. Eastern sector of the coast	Surface	Westward along the coast, then offshore near Penobscot Bay, and parallel to the western sector of the coast, finally inshore as a compensatory current or a current diverted by bottom topography. During autumn, spring, and summer	Inshore	Surface
4. Western Basin off eastern and central coastal sectors	100m and deeper, bottom	Inshore along the bottom. All seasons	Shore	Surface
5. Jefferys and Scantum Basins	100m and deeper, bottom	Inshore along the bottom. All seasons	Shore	Surface
6. Coastal	30-100m, bottom	From east to west along the bottom and then inshore. All seasons. Occasionally eastward into the Bay of Fundy	Shore	Surface
7. Penobscot Bay	Surface	Sinking during winter in a southerly direction to 150 m and deeper (Bigelow 1927). Possible return along the bottom	Offshore Shore	100m Surface

The flow continues westward and then southerly moving offshore in the vicinity of Penobscot Bay and Cape Ann. Although the main flow is from east to west, water moves shoreward in a number of areas along the coast. These shoreward movements have corresponding offshore limbs formed by estuarine discharge. Such eddies are common in the western sector of the coast, especially in the area between Cape Small and Cape Ann, the Bigelow Bight. Once past Cape Ann the alongshore flow may either move offshore in the southern limb of the Gulf of Maine eddy (Figure 4-35) or turn westward into Massachusetts Bay where it continues southward into Cape Cod Bay.

As in the offshore water of the Gulf the major forces causing non-tidal drift are winds and dynamic pressure gradients and the direction of drift is affected by Coriolis force and the contours of the bottom and shore. Wind frequencies in Figure 4-37 are from Portland, Maine, and correspond to frequencies from other areas of the western coast as well as to those usually encountered in the Gulf of Maine. Generally, the straight line drifts of surface drift bottles released at the Portland lightship were correlated with wind direction when the expected deflection of the drift to the right of prevailing winds by Coriolis force was considered. In autumn, winds were from north to west and the drift was southwest. In winter, increased southwest winds increased the offshore component of drift resulting in fewer recoveries. Winds were more variable in the spring. A relative increase in southerly and easterly winds increased the drift to the northeast. In summer, a relatively larger frequency of winds from the southwest to southeast increased the drift to the northeast. Anomalies of dynamic height and the corresponding streamlines indicate the direction and complexity of coastal surface currents (Figure 4-38). The streamlines coincide generally with the major currents of the Gulf while indicating irregularities that agree with the drift bottle atlas of Bumpus and Lauzier (1965). These are 1) the winter convergence shoreward east of Penobscot Bay, 2) the summer counterclockwise eddy east of Casco Bay and 3) the clockwise or counterclockwise eddy south of Casco Bay. The spring eddy and the summer shoreward movement in the vicinity of Ipswich Bay are not found in the atlas. However, some evidence for the eddy is given by Bigelow (1927) and the summer flow shoreward may be explained by the movement of water over the ledges, Old and New Scantum, and into Scantum Basin (Figure 4-39).

The eddies strongly developed in the spring are related to the spacing of river discharges. Each outpouring of estuarine discharge has a compensatory return of more saline water moving shoreward on the eastern side of the discharge (Figure 4-35). Bottom topography has an effect on the deployment of the discharge. The Penobscot estuarine discharge moves from a large bay and then through a complex of ledges, islands, and channels causing the water to mix.

The Penobscot River salinity increases offshore; that of the Kennebec and Sheepscot is constant (Figure 4-40). Because Coriolis force deflects currents to the right of their direction of flow in the northern hemisphere, the discharges bend to the west over the coastal shelf and the discharge from the Penobscot River is located on the western side of its bay. Bottom water moves shoreward along the coast penetrating the bays and estuaries (Graham, 1970a, Bumpus MS). At times the flow parallels that at the surface moving from east to west, then at some distance down the coast the flow may turn shoreward (Figure 4-41). Upwelling is the most prominent feature of the coastal circulation. Surface water is carried parallel to or offshore from the coast with a compensating movement shoreward along the bottom. The average number of days that sea bed drifters are out may vary from 164 to 288 when released along the coast (Graham, 1970a), making it difficult to determine any seasonality in bottom flows. However, surface water flows generally offshore or alongshore on the coastal shelf during all seasons, suggesting that upwelling might be continuous throughout the year. Specific exceptions to upwelling occur when winds, dynamic topography at the surface, and bottom topography move surface water shoreward (Table 4-1, Figure 4-35).

INSHORE

Theoretically, fresh water entering an estuary is mixed with salt water by the tides which is then carried from the estuary. The seaward moving water would be deflected to the right side of the estuary by Coriolis force caused by the rotation of the earth. In compensation for the salt water removed from the estuary more saline coastal water would enter. This water would also be deflected to the right of its direction of flow or to the side of the estuary opposite to that from which the estuarine flow is departing. In addition to this horizontal difference in flows the more dense and heavier coastal water would be expected to enter along the bottom. In practice the size and shape of an estuarine embayment, its degree of openness to the sea, and the locations of entering rivers among other factors may complicate inshore currents along the western coast of the Gulf of Maine.

The distributions of residual currents has received little attention in the coastal embayments and estuaries. Some inferences as to distributions of currents can be obtained from the distributions of salinity. In a few instances, flood and ebb tidal currents are given in the literature; these are reported here.

MAJOR ESTUARINE EMBAYMENTS OF THE GULF OF MAINE

Passamaquoddy Region: St. Croix River Estuary and Cobscook Bay

Current velocities in the lower St. Croix estuary do not exceed 61.1 cm/sec,with flood velocities exceeding ebb velocities slightly. Surface current velocities are also slightly higher than velocities at depth. Current velocities are distributed symmetrically about high and low water slack periods. Highest velocities are attained three hours before high water and three hours before low water. Details of Passamaquoddy region circulation are shown in the report of Forrester (1959), pages 19 to 43.

Flushing time for the St. Croix estuary has been computed for the basin above St. Andrews (Forgeron, 1959). For a discharge of 3150 cfs the flushing times vary from 6.5 to 6.8 days depending upon base salinity used (31.13 o/oo and 29.95 o/oo respectively). Flushing times of 5.7 and 5.8 days were calculated during a discharge rate of 2170 cfs in August of 1958. Ketchum and Keen (1953) found a flushing rate of eight days in August of 1951.

Flushing rates have not been determined for Cobscook Bay, but a residual drift out of the Bay exists. Drift bottle studies indicate, however, that surface transport well into the estuary occurs in at least 14 hours from well within Passamaquoddy Bay during the flood portion of the tidal curve (Chevrier, 1959).

Tidal current velocities have been measured in the lower reaches and passages leading into Cobscook Bay by various investigators. Current velocities attain values of 159.4 cm/sec at the confluence of Western and Head Harbour Passages with shears developing at channel depth (Canadian Department of Environment, 1973), while current velocities in restricted channels of the lower Bay may reach 308.6 cm/sec at times of spring tides (E.G. & G., 1973). Timson (1973) has studied surface drift rates into Cobscook Bay during a period of normal tides and has found that average drift rates are approximately 140.9 cm/sec during flood tides in the central portion of the Bay. Average hourly flood and ebb currents do not exceed 180.0 cm/sec in the restricted, deep channels (Forrester, 1959).

Penobscot Bay

The salinity distribution at the entrance to Penobscot Bay suggests that freshened water departs on the western side of the bay and a compensatory return of coastal water enters on its eastern side (See Section 4.2.5). Apparently this circulation is maintained to the head of the bay by the islands which separate East Penobscot Bay from West Penobscot Bay. Current studies with drogues on the ebb and flood tides were made at the head of Penobscot Bay in relation to flows entering local harbors and coves (Anon., 1967).

The droque tracks are shown in Figures 4-43 and 4-44.

Flushing rates are published monthly by N.O.A.A. for the Penobscot Estuary. High discharge periods are characterized by flushing rates of about 10.6 days from Winterport to the mouth of the estuary. Low runoff periods increase the flushing times to about 14.2 days.

Casco Bay

Currents in Casco Bay are discussed in relation to the distributions of temperature and salinity in Section 4.2.5. Brayton and Campbell (1953) interpreted these data inferring the circulation shown in Figures 4-45, 4-46, and 4-47. The interaction of the intruding flow of coastal shelf water with the seaward flow of lighter bay water is shown for the surface and depths of 7.5 m and 15 m. Tidal effects were not determined but the authors presumed that the entire system fluctuates in relation to tidal advances and retreats.

Saco River Estuary

Current velocities within the Saco River estuary are governed by the relative salt wedge - freshwater surface layer positions and the topographic irregularities of the estuarine channel. Low-water and high-water slacks do not conform to maximum or minimum water levels. At one-quarter flood the river water maintains a high enough head momentum to retain an ebb flow of 25 cm/sec while current velocities in the lower estuary and at depth in mid-estuary average 60 cm/sec in a flood direction as the salt wedge begins to advance up-estuary.

Ninety minutes before flood tide, current velocities may exceed 100 cm/sec in the flood direction. Flood velocities are higher at the surface of the water column at the mouth of the estuary; at the bottom or mid-depth in mid-and lower, upper estuary; and at the surface and in an ebb direction at the very head of the estuary.

Current velocities during ebb tide stages are higher than flood velocities. At one-quarter ebb, surface velocities may reach values exceeding 150 cm/sec. Surface velocities are greater than velocities at depth. All flow is to the mouth of the estuary except in the deep basins where low, flood-directed velocities reveal the landward flow of dense salt water still flowing to the deeper portions of the basins (Farrell, 1970).

At three-quarter ebb, all flow is ebb and velocities attain their highest values. Surface flows throughout the estuary exceed velocities at depth. Maximum velocities occur in the mid-portion of the estuary where the channel is constricted in several locations.

Coastal Shelf - New Hampshire

Data obtained as part of the Seabrook EIS (PSNH, 1972) show the distribution of drift envelopes released at various locations and the paths of seabed drifters in the same area. More recent work of Shevenell and others (Unpublished manuscript, 1974) shows similar distributions of recovered drifters generally occurring to the south and west of release points in and around the New Hampshire shelf.

Merrimack Estuary - Massachusetts

The release of plastic floats in the Merrimack River estuary (Jerome, Chesmore, Andersen, and Grice, 1965) suggested that the flow of water on both the ebb and flood tides followed the main channel of the estuary (Figure 4-48). The dispersion of dye apparently indicated this channel flow for deeper water as well (Figure 4-49). Further, some of the dye which departed the estuary on the ebb flow was returned on the subsequent flood.

Tidal currents in the estuary show a pronounced asymmetry with respect to velocity-tide stage relationships. In tidal channels, ebb currents are nearly twice as strong as flood currents, reaching values of above two meters per second. Peak flood velocities occur three to four hours after low water, but peak ebb velocities do not occur until four to six hours after high water.

Over flat areas, ebb and flood velocities are equal in magnitude and symmetrical with respect to the tide stages. Flood current velocities are stronger at depth, while ebb velocities are higher at the surface of the water column (Hartwell, 1970).

North River

Dye released in the North River estuary on the ebb tide moved back into the estuarine mouth; the dye was carried upstream on the flood. These dye experiments reported by Fiske, Watson, and Coales (1966) are shown in Figure 4-50.

Boston Harbor

Current velocities within Boston Harbor reach a maximum of 102 cm/sec between Deer Island Light and Long Island Head. Mencher, et al. (1968), have summarized the currents of Boston Harbor.

> "Around the southwestern end of Long Island, the current is rotary, counterclockwise, with average velocity at strength of about 102 cm/sec. Usually, the flood sets southwesterly; the ebb, easterly. Between Thompson and Spectacle Islands, the velocity reaches a maximum of 257 cm/sec, the flood setting northwesterly and the ebb southeasterly. In the main

channel between Spectacle Island and the Navy Yard, the maximum velocity varies from 257 to 514 cm/sec. Figure 4-42 below shows the direction of the Flood Currents in Boston Harbor at the time of Maximum Flood Current, generally 3½ hours after Low Water at Boston. Generally speaking the Ebb Currents flow in precisely the opposite direction (note one exception shown by dotted arrow east of Winthrop), and reach these maximum velocities about 4 hours after High Water at Boston.

Basically, the velocities of the Ebb Currents are about the same as those of the Flood Currents. Where the Ebb Current differs by a .2 kt, the velocity of the Ebb is shown in parentheses.

The velocities shown on this Current Diagram are the maximums normally encountered each month at Full Moon and at New Moon. At other times the velocities will be smaller.

As a rule of thumb, the velocities shown are those found on days when High Water at Boston is 11.0 to 11.5 ft. (see Boston High Water Tables). When the height of High Water is 10.5 ft, subtract 10 percent from the velocities shown; at 10.0 ft., subtract 20 percent; at 9.0 ft., 30 percent; at 8.0 ft., 40 percent; below 7.5 ft., 50 percent."

4.2.3 TIDES

Tides are the vertical oscillations of ocean waters; the flood tide culminates in high water and the ebb tide in low water. The difference between high and low water is the tidal range. The tides and their range are caused by the gravitational attraction of ocean waters to the moon and the sun. The moon is the smaller, but it is much closer, therefore it is the dominating force. In combination the moon and the sun generate three classes of tide-producing forces; 1) semidiurnal forces with a period of oscillation of about one half day, 2) diurnal forces with a period of oscillation of about one day and 3) long period forces with a period of about one half month or more. The tide generating forces fluctuate periodically with the constant changes in the position of the moon and the sun, in their respective distances from earth and their eliptical orbits about a common center of gravity with the earth.

In the study area the tides are semidiurnal; that is, there are two high waters alternated with two low waters in one day. However, the lunar or tidal day is 24 hours and 50 minutes (24.84 hours). Thus, at any given locality the high and low water periods are approximately 50 minutes later each day. If one stood at a given

location at the same hour each day, he would have seen all phases of a complete cycle of rising and falling tides in about 15 days. The phase of the moon has a cycle of 29.5 days. When the moon is new and full and the attracting sun and moon are in direct alignment with the earth, the high water is higher and the low water is lower increasing the tidal range. These are known as spring tides. During the first and third quarters when the moon is at right angles to the sun, as seen from the earth, the high water is lower and the low water higher, reducing the tidal range. These are known as the neap tides. The moon changes its distance from the earth during a cycle of 27.5 days. When in apogee, it is farthest from the earth and when in perigee it is nearest the earth. Perigee spring tides are maximal and apogee neap tides are minimal. Figure 4-51 shows the typical semidiurnal tidal cycle for Boston and its change in range with the distance of the moon from earth and its phase. Note that the tidal range between low and high water is not the same for the two cycles on a given day. Table 4-2 gives the astronomical data pertinent to tidal cycles in 1973.

Tidal range varies with geographic locations along the coast and Table 4-12 gives the mean tidal range for other locations. Figure 4-52a gives the tidal ranges in feet while Figure 4-52b is a Co-time map showing position of crest line of high tide at one-hour intervals after the moon's transit of meridian at Greenwich. Figure 4-52c illustrates the Co-range of mean spring tides. Essentially, one of the most striking features of the geographic variation of the tidal range is its increased size in the northeastern part of the coast compared to its southern part. At Boston Light in Massachusetts the mean tidal range is 3 m; at Eastport, Maine, the tidal range is about 6 m, or twice that of Boston. However, tidal range also varies with the confining topography of the coast. Therefore, considerable variation exists from the small 0.5 to 1 m ranges in the open ocean to the extremes of over 6 m in some of the embayments and channels of the northeastern part of the coast.

Times of high and low tides proceed down the coast of Maine from Lubec to Boston down to Monomoy Island. High tide occurs at Lubec, Maine, approximately one hour and 30 minutes before high tide at Monomoy Point on Cape Cod. The difference in times for low tides is one hour-nine minutes. The difference of times with respect to high or low water is caused by the configuration of the bathymetry of the Gulf of Maine (Emery and Uchupi, 1972). When a tidal wave approaches the New England Coast from the east, it must transgress the continental shelf. A wave node will approach the northern coast of Maine over the Scotian shelf faster than over the Georges Banks or Browns Bank. Wave approach distances over the Gulf of

Table 4-2

ASTRONOMICAL DATA, 1973

(National Ocean Survey, 1972)

Greenwich mean time of the moon's phases, apogee, perigee, greatest north and south declination, moon on the Equator, and the solar equinoxes and solstices.

January

	d.	h.	m.
S	2	14	..
●	4	15	42
E	9	19	..
◐	12	05	27
N	16	05	..
P	16	21	..
○	18	21	28
E	22	12	..
◑	26	06	05
A	28	16	..
S	29	21	..

February

	d.	h.	m.
●	3	09	23
E	6	01	..
◐	10	14	05
N	12	13	..
P	13	11	..
○	17	10	07
E	18	23	..
◑	25	03	10
A	25	13	..
S	26	06	..

March

	d.	h.	m.
●	5	00	07
E	5	09	..
P	10	08	..
N	11	19	..
◐	11	21	26
E	18	07	..
○	18	23	33
$\odot_1$	20	18	13
A	25	09	..
S	25	14	..
◑	26	23	46

April

	d.	h.	m.
E	1	12	..
●	3	11	45
P	6	04	..
N	8	00	..
◐	10	04	28
E	14	14	..
○	17	13	51
S	21	21	..
A	22	02	..
◑	25	17	59
E	29	04	..

May

	d.	h.	m.
●	2	20	55
P	4	06	..
N	5	08	..
◐	9	12	07
E	11	19	..
○	17	04	58
S	19	03	..
A	19	14	..
◑	25	08	40
E	26	12	..

June

	d.	h.	m.
●	1	04	34
P	1	14	..
N	1	17	..
◐	7	21	11
E	8	00	..
S	15	08	..
A	15	17	..
○	15	20	35
$\odot_2$	21	13	01
E	22	18	..
◑	23	19	45
N	29	04	..
P	30	00	..
●	30	11	39

July

	d.	h.	m.
E	5	07	..
◐	7	08	26
S	12	14	..
A	12	22	..
○	15	11	56
E	20	00	..
◑	23	03	58
N	26	14	..
P	28	07	..
●	29	18	59

August

	d.	h.	m.
E	1	17	..
◐	5	22	27
S	8	21	..
A	9	10	..
○	14	02	17
E	16	06	..
◑	21	10	22
N	22	21	..
P	25	07	..
●	28	03	25
E	29	03	..

September

	d.	h.	m.
◐	4	15	22
S	5	05	..
A	6	03	..
E	12	14	..
○	12	15	16
N	19	03	..
◑	19	16	11
P	20	22	..
$\odot_3$	23	04	21
E	25	12	..
●	26	13	54

October

	d.	h.	m.
S	2	13	..
A	3	23	..
◐	4	10	32
E	9	22	..
○	12	03	09
P	16	01	..
N	16	08	..
◑	18	22	33
E	22	19	..
●	26	03	17
S	29	20	..
A	31	19	..

November

	d.	h.	m.
◐	3	06	29
E	6	07	..
○	10	14	27
P	12	15	..
N	12	16	..
◑	17	06	34
E	19	00	..
●	24	19	55
S	26	03	..
A	28	13	..

December

	d.	h.	m.
◐	3	01	29
E	3	15	..
○	10	01	54
N	10	02	..
P	10	22	..
E	16	05	..
◑	16	17	13
$\odot_4$	22	00	08
S	23	09	..
●	24	15	07
A	25	22	..
E	30	22	..

●, new moon; ◐, first quarter; ○, full moon; ◑, last quarter; E, moon on the Equator; N, S, moon farthest north or south of the Equator; A, P, moon in apogee or perigee; $\odot_1$, sun at vernal equinox; $\odot_2$, sun at summer solstice; $\odot_3$, sun at autumnal equinox; $\odot_4$, sun at winter solstice.

0^h is midnight. 12^h is noon. The times may be adapted to any other time meridian than Greenwich by adding the longitude in time when it is east and subtracting it when west. (15° of longitude equals 1 hour of time).

This table was compiled from the American Ephemeris and Nautical Almanac.

Maine to the New Hampshire coast are greater than that to Monomoy Island, but tides approach the lower Cape from the southwest as well as from the east; wave interference over Georges Banks probably delays the tidal wave passage so that tides on Monomoy lag those of Boston or Portsmouth by 50 minutes.

Tidal currents are the horizontal movements that accompany the vertical rise and fall of the tides. In the coastal waters where the tidal currents are confined by topography such as narrow embayments, channels and estuaries, the currents are reversing. Generally, they move shoreward on the flood and seaward on the ebb. Theoretically, there is an approximate constancy between the times of the current and the tide; especially when the difference in the range between the two tidal cycles (diurnal inequality) in a given day is small (see Figure 4-51). The strongest tidal flow would be expected one hour before the times of high and low water. Essentially, the greater the range in the tides the stronger the currents. Usually strong currents occur with the spring tides and weak currents with the neap tides.

The velocity of the tidal current increases where the volume of water that may be passed is reduced by the constriction of a channel or the shoaling of an offshore bank. In such cases the velocity is independent of the advance of the tide. In the rocky inshore areas of coastal Maine, narrow interconnecting channels called "guts" may be located between embayments. Some guts may still have ebbing water within them while water in the embayment receiving its flow may already have begun to flood. Lower Hell Gate is a portion of one such interconnecting channel between the Kennebec and Sheepscot estuaries. Velocities average 154 cm/sec there and up to 463 cm/sec has been recorded. Figure 4-53 shows the mean flood and ebb velocities for selected locations along the coast. In open coastal waters velocities are about 30 cm/sec. Table 4-13 gives velocities for other coastal locations. Figure 4-83 shows the location of tidal datum points (bench marks) and Table 4-11 gives the station names for all New England stations.

Slack water or the period of zero velocity is momentary in inshore water and nonexistent in offshore water where the tides are rotary. Without the inshore restricting topography, the offshore tidal current changes direction continually in a clockwise manner. Haight (1942) illustrates this characteristic for the Nantucket Shoals Lightship located slightly south and west of the area (Figure 4-54). The pattern of flow for the two tidal cycles is that of an ellipse with two maxima and two minima (Figure 4-55). Rotary tidal currents are subject to the same astronomical effects as the inshore reversing currents.

Also, where the volume of water passed at a given point is reduced by shoals such as Georges Bank the tidal velocities are considerably increased compared to the weak velocities over the adjacent deeper water. Table 4-3 lists the direction of flow and mean velocity for rotary tides over Georges Bank.

An object suspended in the surface layer would be carried downstream for a given distance and then upstream for the same distance on a reversing tide, assuming that the tidal velocities and duration of the ebb and flood tidal currents were the same. However, non-tidal currents have a decided effect upon the tidal currents. Within the inshore channels the addition of fresh water lengthens the distance that a particle of surface water is carried on the ebb flow. Winds blowing up the channel will lengthen the distance traveled on the flood and reduce that traveled on the ebb. Non-tidal currents offshore essentially distort the ellipse characteristic of the rotary currents. If the non-tidal currents are sufficiently strong they may at a given time mask the tidal currents.

However, the latter will be apparent when current measurements are taken hourly thus indicating the clockwise change in current direction and velocity.

4.2.4 FRESH WATER INPUT

Between Passamaquoddy Bay in the east and Cape Cod Bay in the south, rivers drain seventeen major basins and discharge their effluents into the ocean. Near the river mouths the discharges enter estuaries and then after mixing with salt water usually the mixed water flows into an embayment. The Kennebec-Androscoggin, Mousam, Piscataqua, and Merrimack estuaries flow into the open coastal shelf. Discharges are evenly spaced along the coast. Large rivers (St. Croix, Penobscot, Kennebec-Androscoggin, Saco, and Merrimack) are separated by one or more small rivers. Only the St. Croix and Dennys rivers enter the same major embayment, Passamaquoddy Bay (Figure 4-35).

Mean discharges during a water year usually vary from 77.5 c.f.s. for the small Mousam River to 12,396 c.f.s. for the large Penobscot River (Table 4-4). On the average, peak discharge occurs in April and reaches a low in August or September (Figure 4-56). A smaller increase may occur in autumn to early winter. Additional data on fresh water inputs may be found in Chapter 2.3, Hydrology.

GENERAL DESCRIPTION OF FRESH WATER DISCHARGE OF MAJOR BASINS

Discharge of the St. Croix River into the estuary is a mean annual rate of 4,000 cfs. The river peaks in April during spring freshets with an average monthly maximum of 4,461 cfs and a monthly minimum

Table 4-3

ROTARY TIDAL CURRENTS (National Ocean Survey, 1972)

Georges Bank
Lat. 41°50′ N., long. 66°37′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	285	0.9
1	304	1.1
2	324	1.2
3	341	1.1
4	10	1.0
5	43	0.9
6	89	1.0
7	127	1.3
8	147	1.6
9	172	1.4
10	197	0.9
11	232	0.8

Georges Bank
Lat. 41°54′ N., long. 67°08′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	298	1.1
1	325	1.4
2	344	1.5
3	0	1.2
4	33	0.7
5	82	0.8
6	118	1.1
7	138	1.5
8	153	1.2
9	178	1.1
10	208	0.9
11	236	0.8

Georges Bank
Lat. 41°48′ N., long. 67°34′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	325	1.5
1	332	2.1
2	342	2.0
3	358	1.3
4	35	0.7
5	99	0.8
6	126	1.3
7	150	2.0
8	159	1.9
9	169	1.7
10	197	1.2
11	275	0.9

Georges Bank
Lat. 41°42′ N., long. 67°37′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	316	1.1
1	341	1.3
2	356	1.0
3	16	0.8
4	43	0.6
5	92	0.8
6	122	1.0
7	146	1.1
8	170	1.1
9	195	1.0
10	215	1.0
11	272	0.9

Georges Bank
Lat. 41°41′ N., long. 67°49′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	318	1.6
1	320	1.8
2	325	1.4
3	330	0.8
4	67	0.3
5	111	0.9
6	117	1.5
7	126	1.7
8	144	1.7
9	160	1.1
10	242	0.8
11	292	1.2

Georges Bank
Lat. 41°30′ N., long. 68°07′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	312	1.5
1	338	1.7
2	346	1.5
3	14	1.1
4	59	0.9
5	99	0.9
6	123	1.3
7	144	1.7
8	160	1.6
9	187	1.3
10	244	1.0
11	274	1.1

Georges Bank
Lat. 41°29′ N., long. 67°04′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	277	1.0
1	302	1.2
2	329	1.4
3	348	1.3
4	15	1.2
5	48	1.1
6	85	1.2
7	122	1.4
8	145	1.5
9	166	1.3
10	194	1.2
11	223	1.1

Georges Bank
Lat. 41°14′ N., long. 67°38′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	305	1.4
1	332	1.6
2	355	1.6
3	15	1.4
4	38	1.1
5	77	0.9
6	112	1.2
7	141	1.6
8	162	1.6
9	187	1.5
10	214	1.4
11	252	1.2

Georges Bank
Lat. 41°13′ N., long. 65°20′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	319	1.5
1	332	2.0
2	345	1.4
3	9	0.8
4	42	0.6
5	80	0.7
6	118	1.0
7	138	1.3
8	154	1.4
9	169	1.5
10	188	1.3
11	236	0.9

Georges Bank
Lat. 40°48′ N., long. 67°40′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	304	0.9
1	340	0.9
2	353	0.8
3	29	0.6
4	56	0.6
5	83	0.6
6	107	0.9
7	140	1.0
8	156	1.0
9	175	0.9
10	202	0.8
11	245	0.8

Georges Bank
Lat. 40°49′ N., long. 68°34′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	301	1.2
1	326	1.5
2	345	1.4
3	8	1.1
4	36	0.8
5	69	0.8
6	106	1.0
7	139	1.4
8	153	1.5
9	175	1.4
10	201	1.1
11	237	0.9

Great South Channel, Georges Bank
Lat. 40°31′ N., long. 68°47′ W.

Time	Direction (true)	Velocity
	Degrees	*Knots*
Hours after maximum flood at Pollock Rip Channel, see page 34: 0	320	0.7
1	331	0.9
2	342	1.1
3	3	1.0
4	23	0.8
5	63	0.4
6	129	0.7
7	140	0.9
8	164	1.0
9	179	1.0
10	190	0.8
11	221	0.6

Portland Lightship, off Cape Elizabeth, Maine: Tidal current is reversing type with velocity averaging only 0.1 knot. See table 2.
Boston Lightship, off Boston Harbor entrance, Mass.: Tidal current is reversing type with velocity averaging only 0.1 knot. See table 2.

Table 4-4 River basins and their annual discharges by water year into coastal waters. Only the most seaward gauging stations at localities draining over 100 sq mi are listed. Data are from records of the U.S. Department of Interior Geological Survey (1972, 1973).

River Basin	Drainage Area (sq. mi.)	Mean Annual Discharge cfs. Mean	(N yrs.)	Recipient Major Enbayments
St. Croix	1,320	4,000	52	Passamaquoddy Bay
Dennys	92.4	186	16	Passamaquoddy Bay
Machias	457	919	58	Machias Bay
Narraguagus	232	474	23	Narraguagus Bay
Union	148	260	52	Blue Hill Bay
Penobscot	6,670	11,590	69	Penobscot Bay
	299	494	56	Penobscot Bay
	178	312	30	Penobscot Bay
Sheepscot	148	236	33	Sheepscot Bay
Kennebec	2,720	4,321	43	Shelf Proper
	354	694	50	Shelf Proper
	514	928	43	Shelf Proper
	579	920	42	Shelf Proper
Androscoggin	3,257	5,978	43	Shelf Proper
Royal	142	266	22	Casco Bay
Presumpscot	436	656	84	Casco Bay
Saco	1,298	2,655	55	Saco Bay
	161	286	31	Saco Bay
Mousam	105	176	32	Shelf Proper
Piscataqua	108	200	Oct.70-Sept.71	Shelf Proper
Merrimack	4,635	7,055	48	Shelf Proper
Ipswich	124	198	41	Ipswich
Charles	211	374	40	Massachusetts Bay

in September of 1,539 cfs (Figure 8 in Forgeron, 1959). A second, lower discharge peak occurs in November or December.

The Dennys River is the largest of the three rivers entering Cobscook Bay. The average discharge of the Dennys is 186 cfs (U.S.G.S., 1969), with a recorded maximum of 2,700 cfs and a minimum of 8.4 cfs. Forgeron (1959) estimates that the total flow of river water into Cobscook Bay is approximately 300 cfs annually.

The discharge of the Penobscot varies from a maximum of 82,200 cfs to a minimum of 3,360 cfs. The average annual discharge is 11,560 cfs (U.S.G.S., 1969). Peak discharge occurs in late April or early May with magnitude peaks in late October - early November or December.

The Saco River has an average annual discharge of 2,919 cfs. Maximum discharge recorded was 45,000 cfs in 1936, while a minimum discharge of 244 cfs was obtained in 1964.

The average annual discharge from the Piscataqua River (Salmon Falls River) is 237 cfs with a recorded maximum of 5,490 cfs and a minimum of 6.4 cfs. The Oyster River has an average annual discharge of 19.3 cfs and the Lamprey River - 274 cfs with a maximum of 5,490 cfs and a minimum of one cfs (U.S.G.S., 1967).

The Merrimack River is the fourth largest river in New England, draining 12,970 square km of terrain. The average daily discharge of the River is about 7,000 cfs, and ranges from more than 23,000 cfs in the spring to about 1,700 cfs in the fall.

The Charles River is the largest river emptying into Boston Harbor. The Charles drains 590 square km and has an annual average discharge of 374 cfs with a recorded maximum of 2,540 cfs and a minimum of 0.1 cfs (U.S.G.S., 1969).

TEMPERATURE AND SALINITY OF THE COASTAL SHELF

The coastal shelf extends in a narrow band about 27 to 36 km wide from the entrance to the Bay of Fundy to Cape Ann. The major modifiers of salinity and temperature along the shelf are river discharge and the strength of tidal mixing increases in the opposite direction, from west to east.

Salinity

From Penobscot Bay westward larger river discharges intensify salinity gradients both horizontally and vertically (Figures 4-108 through 4-116). The spacing of the plumes of estuarine discharge

also makes the distribution of isohalines more complex west of Penobscot Bay. Essentially, each plume of discharge directed onto the shelf has a corresponding intrusion of more saline coastal water shoreward on its right. Because the discharges are evenly spaced along the coast, there is an alternation of estuarine and shelf waters. This alternation is especially evident from the surface down to 10 meters in the spring (Figures 4-113 and 4-114).

Temperature

Progressively greater tidal mixing distributes heat downward in the summer from west to east. Thus, the difference between the surface and bottom temperatures is small in the east and large in the west where the water is stratified thermally during the summer (Figures 4-126 and 4-127). Consequently, summer surface temperature increases toward the west, but bottom temperature decreases. Water temperature is relatively uniform along the coast at 20 meters in summer. This layer of uniform temperature occurs at 40 meters depth farther offshore (Bigelow, 1927).

Surface temperature gradients are usually perpendicular to the coast, especially in the eastern sector (Figures 4-117 through 4-127). To the west the inflow of estuarine water makes the distribution of isotherms more complex. In addition, in August, temperatures as high as 16 C may extend shoreward from the Gulf between Casco and Ipswich Bays. During the same month, in the eastern sector of the coast, temperatures decrease from inshore to offshore indicating the inshore side of a tongue of cold water existing in summer between the warm inshore and offshore waters (Apollonio and Applin, Jr., 1972; Gran and Braarud, 1935).

Temperature Records

Long term temperature records have been kept at Boothbay Harbor (National Marine Fisheries Service until 1973; and presently operated by Maine Department of Marine Resources) and at St. Andrews, New Brunswick (at the Biological Station, Fish Research Board of Canada). The Boothbay Harbor station records begin in 1905 and St. Andrews also began about the same time. Figure 4-57 shows the Boothbay Harbor average temperature from 1905 to 1964 along with the annual deviation 1940-1959. A tabular summary of the St. Andrews station from 1921-1972 is presented on Table 4-5 and Figure 4-58 shows the annual deviation for the same area. Finally, a summary of Boothbay Harbor, Eastport, Portland, and Boston from 1923 to 1946 shows an overall comparison (Table 4-6). Table 4-7 summarizes mean surface water temperatures and densities at major coastal areas from Eastport to Sandy Hook.

Table 4-5

Summary of Temperatures at St. Andrews, N.B. (1921-72) (Lauzier, L. M. and J. H. Hull, 1969)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1921	1.8	0.3	1.8	4.2	7.7	9.6	12.0	12.9	13.0	11.2	6.8	3.2	7.0
1922	-0.2	-0.5	0.5	3.2	6.3	9.1	12.2	12.6	12.2	9.4	5.7	1.7	6.0
1923	-1.2	-1.7	-1.7	1.0	5.7	7.6	10.2	10.9	11.4	10.0	7.5	5.3	5.4
1924	1.6	-0.3	1.2	3.5	6.4	8.2	11.1	12.2	11.9	10.3	7.3	3.3	6.4
1925	0.1	0.0	1.5	3.7	6.9	8.9	11.4	12.3	11.7	8.6	6.3	3.1	6.2
1926	0.5	-1.1	-0.3	1.6	5.3	8.0	11.2	12.2	12.1	10.4	7.4	3.0	5.9
1927	1.6	0.3	1.3	3.4	6.2	9.1	11.4	12.4	11.8	10.8	8.6	5.0	6.8
1928	2.7	1.4	1.8	3.8	6.8	9.9	13.0	13.5	12.4	10.6	7.0	4.9	7.3
1929	2.2	1.3	1.7	3.1	6.8	9.4	11.7	12.6	12.5	10.2	7.1	2.3	6.7
1930	1.3	-0.3	0.7	3.3	6.8	10.2	12.3	13.2	13.2	11.3	8.4	4.6	7.1
1931	2.9	1.0	1.7	3.8	6.6	9.3	12.4	13.4	12.7	10.8	8.6	4.7	7.3
1932	3.0	0.7	0.7	3.3	6.3	9.0	11.4	13.1	12.9	11.4	7.6	4.3	7.0
1933	2.6	1.5	1.4	3.7	6.9	9.6	11.8	12.7	12.3	10.5	6.0	1.6	6.7
1934	-0.4	-1.4	-0.5	3.4	6.5	9.1	11.6	12.7	13.1	10.4	7.6	3.3	6.3
1935	0.0	-0.8	-0.4	2.5	5.3	9.3	12.0	13.1	12.0	10.1	8.0	3.7	6.2
1936	1.4	-0.2	1.9	3.6	6.5	10.4	11.3	12.8	12.2	10.4	7.0	3.7	6.8
1937	2.6	1.3	1.5	4.1	8.1	10.3	12.6	14.4	13.5	10.8	8.0	4.6	7.7
1938	1.7	0.7	0.9	3.8	6.7	9.7	12.2	13.6	12.4	10.9	8.5	4.8	7.1
1939	2.3	0.6	0.6	2.5	6.2	8.7	11.9	13.2	12.4	10.4	6.7	3.9	6.6
1940	0.7	-0.2	0.3	2.3	5.8	8.6	11.5	12.4	11.8	9.4	7.0	3.5	6.1
1941	1.2	0.4	0.4	3.4	6.2	8.8	11.4	12.1	11.5	9.9	7.4	4.0	6.4
1942	1.6	0.0	1.3	3.6	6.5	9.7	11.2	12.5	12.2	10.4	7.5	2.8	6.6
1943	-0.1	-0.4	-0.1	2.1	6.0	8.5	11.5	12.9	12.3	10.7	8.0	4.2	6.3
1944	1.9	0.0	0.3	2.8	6.8	9.1	12.0	13.4	13.3	10.8	7.7	4.5	6.9
1945	0.8	0.3	2.1	5.1	7.6	9.9	12.8	13.8	12.2	10.6	7.5	3.5	7.3
1946	1.0	0.5	1.5	3.6	7.0	9.0	12.1	13.3	12.9	11.8	8.8	4.9	7.2
1947	1.6	1.2	2.1	3.6	6.7	9.9	13.7	14.8	14.2	12.0	8.8	4.3	7.8
1948	1.0	-0.6	0.4	2.4	6.3	8.3	11.3	12.9	12.1	10.4	8.6	5.6	6.5
1949	2.9	1.4	2.0	5.0	8.0	11.0	13.4	14.7	14.3	12.5	8.9	5.7	8.3

Table 4-5 (Continued)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1950	3.8	1.6	1.5	4.0	6.8	10.0	12.4	13.6	12.8	10.8	8.8	5.9	7.7
1951	3.9	2.4	3.1	5.3	8.1	11.1	13.8	14.9	14.2	11.8	8.7	5.2	8.5
1952	2.6	1.9	2.1	4.5	6.9	10.7	13.2	14.2	13.3	11.3	8.3	5.2	7.9
1953	2.9	1.9	2.8	5.8	7.1	10.5	13.7	14.0	14.0	11.7	9.5	7.0	8.4
1954	3.3	2.2	2.9	4.8	8.1	10.9	12.5	13.8	13.4	12.2	8.6	5.4	8.2
1955	3.4	1.9	2.3	4.7	7.7	10.0	12.9	13.8	12.7	11.2	8.3	3.4	7.7
1956	1.8	1.3	1.3	3.5	5.9	9.0	11.0	12.3	12.0	10.3	8.2	4.8	6.8
1957	1.2	0.9	2.0	3.9	7.2	10.1	12.0	13.3	13.0	11.3	8.9	5.4	7.4
1958	3.5	2.1	2.7	4.8	7.3	9.4	12.2	13.4	12.6	10.5	7.8	3.4	7.5
1959	1.1	-0.1	0.4	3.2	6.3	9.1	12.0	13.0	12.3	10.4	7.6	4.5	6.6
1960	2.1	1.7	1.7	3.7	8.2	9.9	12.2	13.3	12.8	10.6	8.3	4.5	7.4
1961	1.5	0.3	0.8	2.6	6.0	9.3	10.9	12.4	12.9	10.9	8.3	5.1	6.8
1962	2.6	0.4	1.4	3.9	6.1	9.3	10.8	12.4	12.2	10.4	7.4	4.7	6.8
1963	2.5	0.7	1.7	4.0	7.1	10.2	12.3	13.0	12.5	10.8	8.5	3.9	7.3
1964	1.8	1.3	1.7	3.4	6.7	8.5	10.8	11.7	11.4	10.1	7.2	3.3	6.5
1965	1.1	0.5	1.2	3.2	6.2	8.7	10.9	12.1	11.7	9.5	6.4	3.8	6.3
1966	1.8	0.9	1.9	3.8	6.1	9.1	11.2	12.3	11.9	9.9	7.9	5.1	6.8
1967	2.5	0.3	0.2	2.3	5.0	8.5	10.6	11.8	11.8	10.4	7.7	3.9	6.3
1968	0.3	-0.2	0.8	3.8	6.5	9.4	12.3	12.7	13.1	11.7	7.9	4.6	6.9
1969	2.3	1.8	1.9	4.2	6.8	9.9	12.1	13.9	13.3	10.8	8.7	5.5	7.6
1970	2.5	1.5	2.1	4.1	8.2	10.1	13.9	13.9	12.6	11.3	8.7	3.8	7.6
1971	0.9	-0.1	1.5	4.0	7.5	10.5	13.4	14.0	13.6	12.0	9.0	4.7	7.6
1972	1.9	0.3	-0.1	2.1	7.1	10.2	12.0	13.3	12.9	10.6			
Long-term average 1921-1967	1.8	0.6	1.2	3.5	6.7	9.4	11.9	13.0	12.6	10.7	7.8	4.2	7.0
Max.	3.9	2.4	3.1	5.8	8.2	11.1	13.8	14.9	14.3	12.5	9.5	7.0	8.5
Min.	-1.2	-1.7	-1.7	1.0	5.0	7.6	10.2	10.9	11.4	8.6	5.7	1.6	5.4
Std.Dev.	1.15	0.96	0.97	0.94	0.75	0.80	0.85	0.83	0.73	0.75	0.84	1.08	0.69
Std.Error	0.17	0.14	0.14	0.14	0.11	0.12	0.12	0.12	0.11	0.11	0.12	0.16	0.10

Table 4-6

Annual Mean Temperatures for Maine Coast
(Source: Maine Department of Sea and Shore Fisheries.)

YEAR	BBH	EASTPORT	PORTLAND	PORTSMOUTH	BOSTON	MEAN
1923	45.4		44.7		48.0	46.0
1924	45.9		45.1		47.8	46.3
1925	45.5		45.8		49.0	46.8
1926	44.8		45.2		48.0	46.0
1927	46.2		46.1		48.8	47.0
1928	47.0		-		49.3	48.2
1929	45.0		-		48.9	47.0
1930	46.6	44.4	-		50.0	47.0
1931	48.4	43.8	47.6		50.4	47.6
1932	46.8	43.8	47.2		49.5	46.8
1933	47.5	-	47.6		49.9	48.3
1934	45.6	42.5	-		48.5	45.5
1935	46.7	42.3	-		48.6	45.9
1936	45.5	43.6	-		48.6	45.9
1937	48.2	44.5	47.1		50.1	47.5
1938	45.2	43.5	46.8		49.5	46.3
1939	43.5	42.9	44.7		49.3	45.1
1940	44.6	41.8	44.4		48.2	44.8
1941	46.1	42.1	45.5		49.7	45.9
1942	46.6	42.2	45.9		50.1	46.2
1943	45.3	42.0	45.4		49.8	45.6
1944	46.4	43.1	45.7	46.7	-	45.5
1945	47.1	43.6	45.7	46.8	51.2	46.9
1946	47.3	43.6	-	47.1	51.9	47.5
MEAN	46.1	43.1	46.1	46.9	49.4	46.3

Table 4-7 MEAN SURFACE WATER TEMPERATURES (T) AND DENSITIES (D)

Stations	Years	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec		Mean	
		(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}	(T) °C	(D) σ_{15}
Eastport, Maine 44°54'N., 66°59'W.	40	3.3	23.8	1.7	23.7	1.7	23.6	2.9	23.3	4.7	23.2	6.8	23.5	9.2	23.8	10.7	24.0	11.0	24.1	10.3	24.2	8.6	24.0	5.9	23.8	6.4	23.8
Bar Harbor, Maine 44°23'N., 68°12'W.	23	1.4	23.7	0.4	23.7	1.7	23.5	4.6	23.2	7.8	23.2	11.3	23.3	13.7	23.5	14.2	23.6	13.1	23.8	11.1	24.0	8.3	23.9	4.3	23.7	7.6	23.6
Portland, Maine 43°40'N., 70°15'W.	37	0.7	22.3	0.1	22.1	1.5	21.3	4.6	20.5	8.8	20.8	12.7	21.6	15.2	22.3	15.6	22.5	14.4	22.5	11.2	22.5	7.3	22.2	3.1	22.0	7.9	21.9
Portsmouth, N.H. 43°05'N., 70°45'W.	26	2.1	21.7	1.3	21.5	2.3	19.7	5.6	18.1	9.2	19.7	12.7	21.4	15.0	22.5	15.8	22.9	14.6	23.0	11.3	23.0	8.2	22.1	4.5	21.2	8.6	21.4
Boston, Mass. 42°21'N., 71°03'W.	48	1.8	21.0	1.2	20.9	3.4	19.1	7.4	18.8	11.9	19.8	16.0	20.9	18.3	21.8	18.8	22.0	17.5	21.8	13.5	22.0	9.1	21.5	4.3	21.3	10.3	20.9

F (Fahrenheit) = 1.8C (Celsius) + 32

Density as used in this table is the specific gravity of the sea water or the ratio between the weight of a sea-water sample and the weight of an equal volume of distilled water at 15°C (59°F). These figures representing density at 15°C (ρ_{15}) are expressed in terms of sigma-t (σ_t) where t = 15°C and σ_{15} = (ρ_{15} − 1) 1000. Thus, for ρ_{15} = 1.0238, σ_{15} = 23.8. Obtain the pamphlet, "Surface Water Temperature and Density, Atlantic Coast, North and South America, C&GS Publication 31-1", for greater detail; for sale by Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, price $1.00.

(National Ocean Survey, 1972)

Temperature and Salinity

Variations in temperature and salinity (Figure 4-59) are characterized by 1) a reduction in the seasonal range of T-S relations from west to east which is associated with decreasing stratification, and 2) differences in the configuration of the T-S diagrams which show a downward retardation of seasonal changes by vertical stratification during the spring and summer.

Because there are few gradients in temperature and salinity east of Penobscot Bay a pycnocline, an area of rapid vertical change in density is barely evident in the spring and summer (Figure 4-60). In contrast the bottom of the pronounced pycnocline occurs at approximately 20 m west of Penobscot Bay and water is least dense at the surface after the spring discharge. In autumn the pycnocline is destroyed and the lighter water mixed downward as indicated by the gentle gradient in the west. The water column is homogeneous in the east in the autumn and during winter in the west. The slight increase in density at the surface in the east may be caused by winter cooling in the surface water.

St. Croix - Passamaquoddy Bay - Cobscook Bay

Temperature - Salinity. Salinity and temperature measurements in the lower St. Croix estuary indicate that the lower estuarine portions are moderately stratified with a salinity difference of 8 o/oo between surface and bottom during spring freshets. The upper portions of the estuary are probably well-stratified during the same periods of high discharge. During periods of lower discharge the top and bottom salinities differ by no more than 3 o/oo with salinities rarely dipping below 28 o/oo in the lower estuary.

Temperatures in the lower estuary vary from 1 C in February to 15 C in July or August. Temperature stratification is present throughout the year except during the fall months. During the winter months the bottom water within the estuary is from 1 to 2 C warmer than surface waters. Temperature inversions occur in May and for the summer months the surface waters may exceed bottom water temperatures by as much as four degrees.

Cobscook Bay adjoining Passamaquoddy Bay is an irregular basin of probable river valley submergence origin. The entire bay is a complex of eight northwest-southeast trending irregular arms. The three largest arms have rivers entering their heads. These rivers are the Dennys, Pennamaquan, and Whiting Rivers; they empty into bay arms named after their respective rivers.

Salinities within Cobscook Bay are generally high year round with

measurements always exceeding 30 o/oo and, in general, remaining constant throughout the water column. Salinities vary from 30.2 o/oo in winter months to 32.3 o/oo in late summer. Water temperatures are also constant with depth and vary from as low as 0.6 C in winter to 14 C in the fall months. Surface waters are slightly colder during the winter months than bottom water temperatures, but are homogeneous throughout the rest of the year.

Penobscot Bay

Temperature and Salinity. The temperature of the estuarine waters of the Penobscot varies seasonally with winter freezing of the upper estuary from December to March.

Temperatures are uniformly 4-5 C throughout the estuary in April. Warm freshwater inflow and surface warming generate temperature stratification in the lower estuary, from Bucksport south, during the spring and early summer months. The head of the estuary is characterized by uniformly warm (19-20 C) water, while partial horizontal stratification exists in the mid-estuary. Bottom waters in the lower estuary are about 5 C.

Temperatures reach a maximum of 20 - 22 C in August and intensify lower estuary thermal stratification even though bottom waters may be as high as 10 C.

Surface water cooling in the fall months create uniform (10 - 12 C) temperatures throughout the entire estuary (Haefner, 1967).

Salinity and density distribution within the Penobscot River estuary define three different zones of stratification and salinity zonation (Haefner, 1967). The upper estuary is a freshwater and oligohaline section (0-0.5 o/oo, 0.5-3 o/oo) (Hedgpeth, 1951) characterized by thorough mixing. During spring freshets, this section extends 17 - 20 km down estuary from Bangor, almost to Winterport. As river discharges decrease, the length of the freshwater section decreases to only about two nautical miles from Bangor.

The oligohaline portion of the upper estuary exists just down estuary from the freshwater section and varies in length from six nautical miles during high discharge to two nautical miles during low-flow conditions.

The mesohaline section (3.1 - 17 o/oo) extends from Winterport to Bucksport and varies in length depending upon fluvial discharge, tidal flow, and mixing conditions. Over most of the length of this region the waters are partially mixed to moderately stratified,

but the lower part of the mid-portion extends into the lower, deeper portions of the estuary during spring freshets producing high stratification below Bucksport.

The polyhaline section (17.1 - 30 o/oo) incorporates up to 50 percent of the estuarine basin and exhibits high stratification throughout the year because of the deep nature of the embayment at its lower reaches. Because of the widths of the lower basin and the existence of an island complex dividing the lower estuary into two separate but wide channels, strong lateral variation in salinity distribution occurs year round. Lower salinities exist on the west side of the Islesboro Islands due to the Coriolis effect. This condition prevails both during high and low river flow stages.

Haefner (1967) found that bottom waters in the lower estuary attained a maximum salinity value of 32.2 o/oo during spring freshets as far north as Bucksport. Surface salinities of greater than 30 o/oo are limited areas south of Belfast during low flow conditions (Sewell, 1932) and just south of the Islesboro islands during maximum fluvial discharge.

Casco Bay

Casco Bay is a moderately large embayment opening onto the coastal shelf between Cape Small and Cape Elizabeth. Many islands and ledges split the upper bay from northeast to southwest forming shallow reaches about 10 to 12 m deep. The lower bay is deeper, about 60 m, and although it is somewhat free of islands the bottom is rugged. The Royal and Presumpscot Rivers flow into the bay; the latter is thoroughly polluted. Smaller streams, such as the New Meadows River, also contribute freshened water to the bay.

Salinity and temperature. Profiles of summer salinity and temperature are given by Brayton and Campbell (1953) for the lower portion of the bay and by Hulbert (1968) for portions of both the upper and lower bays (Figures 4-61 through 4-73). Data from the upper bay during autumn and winter are given by Eayrs and Banerjee (1970); note the freshened water at station 1 (Figure 4-74 and Table 4-8). The study of the lower bay in 1953 by Brayton and Campbell suggested that the salinity regime and to some extent the temperature regime of the lower bay is controlled by)1 fresh water mixed in the upper bay flowing southward toward the coastal shelf and)2 the northward intrusion of shelf water into the bay. Essentially, the intrusion of more saline and colder shelf water is bracketed to the northeast and southwest by less saline and warmer water. The source of this less saline water is the freshened water that is split as it flows southward from the upper bay. The water split to the east is reinforced by additional freshened water from another source. This additional water apparently comes from the Kennebec River estuarine

Table 4-8 Upper Casco Bay, salinity and temperature data (1968) from station in Figure 4-67

Station 1 Brothers Island; 43° 41' 50" N., 70° 12' 07" W., Low water-23-24 ft.

Date	Depth Sampled	Salinity 0/00	Temperature °C
17 Oct.	S	31.7	13.5
	B	31.9	----
21 Oct.	S	32.0	----
	B	31.8	----
7 Nov.	S	32.2	----
13 Nov.	S	31.8	6.0
	B	32.4	----
19 Nov.	S	30.2	6.0
	B	31.5	6.5
3 Dec.	S	30.3	5.0
	B	32.0	6.1
5 Dec.	S	28.9	6.0
	B	28.7	6.0
9 Dec.	S	31.3	3.5
	B	31.4	3.1

S - Surface

M - Mid-depth

B - Bottom

Station 2 Lucksee Sound; 43° 42' 19" N., 70° 06' 28" W., Low water 80-85'

Date	Depth Sampled	Salinity 0/00	Temperature °C
14 Oct.	S	32.1	8.5
17 Oct.	S	32.0	14.0
5 Nov.	S	32.4	----
7 Nov.	S	32.5	----
	B	32.4	----
14 Nov.	S	32.5	8.5
	M	32.0	7.0
3 Dec.	S	32.3	6.1
	B	32.4	6.7
9 Dec.	S	32.0	-1.5
	B	32.8	4.1

Station 3 Richmond Island 43° 30' N., 70° 12' W. Low water 125'

Date	Depth Sampled	Salinity 0/00	Temperature °C
22 Oct.	S	32.1	14.0
	M	32.8	12.5
	B	33.0	12.0
15 Nov.	S	32.6	8.0
	M	32.0	6.9
	B	33.0	7.0
11 Dec.	S	32.2	4.6
	B	32.3	----

Station 4 Lucksee Sound 43° 39' 25" N., 70° 08' 07" W., Low water 100'

Date	Depth Sampled	Salinity 0/00	Temperature °C
22 Oct	S	32.6	----
	B	32.5	----

Station G Portland Lightship 43° 31' 37" N., 70° 05' 30" W, Low water 120'

Date	Depth Sampled	Salinity 0/00	Temperature °C
4 Nov.	S	33.0	----
	B	33.0	----

Station G Pomeroy Rock 43° 40' 09" N., 70° 13' 40" W, Low water 30'

Date	Depth Sampled	Salinity 0/00	Temperature °C
15 Oct.	S	30.9	9.0
	B	32.0	----

outflow. Although it is not indicated in the distribution of isohalines shown by Brayton and Campbell (1953), the water split to the west could at times be reinforced or extended southward by estuarine water entering the adjacent Saco Bay from the estuarine outflow of the Saco River. The intrusion of shelf water into Casco Bay in July can be traced onto the coastal shelf where it is bracketed by the freshened water from the Saco and Kennebec estuaries (Figures 4-108, 4-113, and 4-115).

Detailed profiles of salinity and temperature are not available for other seasons although tables of data for the same stations covered by Brayton and Campbell are given in allied reports by the Narragansett Marine Laboratory of the University of Rhode Island (1954a and 1954b). However, profiles of temperature and measures of surface and bottom salinity (Figures 4-75 and 4-76) summarize the progression of seasonal events for these indentities in Casco Bay (Day, 1959a and 1959b). Thermal stratification is encompassed by the 12 C isotherm which departs the surface in June and returns to the surface during September. The autumnal overturn and the transition to winter thermal homogeneity is also evident. Similarily, there is little difference between surface and bottom salinity and the lowest salinity at both depths occur in the spring.

The tongue of colder more saline water that intrudes from offshore is indicated by the distribution of density at all depths down to 15 m and is especially marked at 8 m (Figures 4-77, 78, and 79). In general, density increases from inshore to offshore.

Great Bay - Piscataqua River

Temperature and Salinity. Estuarine water temperatures vary seasonally and from one portion of the estuary to another, but do not vary with depth which attests to the effectiveness of mixing in the basin.

Estuarine waters are warmer than marine waters from April to October. Water temperatures increase to about 22 C in mid-August to well below 5 C in the winter. Temperatures equilibrate with marine waters in April and October, while the estuary becomes colder than marine waters in the winter months.

Within the estuary itself, the temperatures of the waters well up in the estuary are 3 - 4 degrees higher than those at the mouth of the estuary. Much of this inner-estuary warming is due to insolation from the shallow intertidal flats. Water warmed by insolation over the flats and the warmer river water then is removed on ebb tides. During the summer months ebb-tidal water is about four degrees warmer than flood-tidal water.

Maximum temperature differences with depth are 2 C in Portsmouth

Harbor at the entrance of the estuary. Temperatures within the estuary never vary more than 1 C with depth (U.S. Army Corps of Engineers, 1972).

Estuarine water salinites also vary seasonally, areally throughout the estuary, and slightly with depth at any one point.

Salinities reach a seasonal low during spring freshets in the upper estuary in April with surface salinities decreasing to about 11-12 o/oo. Lower estuary salinities range from 22 to 27 o/oo during the same period.

Salinity values reach a maximum of from 30-32 o/oo in August and September throughout the entire estuary and vary during the late fall and winter months only during times of increased rainfall in the drainage basin.

Higher salinity values are encountered at depth, but surface to bottom increase averages only one to two parts per thousand. No well-defined salt wedge has been found in this lower estuary.

4.2.5 CHARACTERISTICS OF THE CIRCULATION

Where the river meets the sea an estuary is formed; the manner in which this meeting takes place varies according to river flow, tidal velocities, and the shape of the estuarine basin. The classification used here is based on the physical circulation of estuaries. Its features were proposed by Stommel (1951 unpublished, 1953), adopted by Pritchard (1952, 1955), Pritchard and Carter (1971), and Ketchum (1953), and reviewed recently by Bowden (1967). Essentially, the circulation is determined by the relative role between tidal flows and river discharge. Tables 4-9 and 4-10 indicate the major types of estuaries, the physical processes that dominate in them and the factors or forces that retain them in equilibrium to the extent that they may be classified. Pritchard's classification is indicated by letters A through D within the classification of Bowden to suggest that opinions may vary among experts.

Estuarine basins in the study area (northern) are drowned river valleys with the sea entering at one end and the river at the other. As the river enters the basin the river water mixes with the salt water and carries it into the ocean and away from the coast. Because the estuarine system must maintain a salt balance, salt water moves into the basin to replace that transported to sea. The amount of salt removed and the amount entering in compensation is determined largely by mixing. The entering sea water is more dense and sinks below the departing brackish water of the estuary; it flows inward near the bottom. The volume of such density currents depends upon

Table 4-9

Type	Physical processes	Salt balance factors
A. Salt wedge	River input	horizontal & vertical advection
B. Partially mixed	Neither River input of tidal flow dominates	horiz.advection, vert. advec.& vert.diffusion
C. Vertically homogeneous	Tidal flow dominates	long.advec.,lat.advec. & lateral diffusion
D. Sectionally homogeneous	Tidal flow dominates	longitudinal diffusion

Table 4-10

Type	Physical processes	Forces
1. Salt wedge (A)	River flow dominant	Pressure gradients,field accelerations,Coriolis effect,interfacial action
2. Two layer flow with entrainment inc. fjords	River flow modified by tidal currents	Pressure gradients,field accelerations,Coriolis effect entrainment
3. Two layer flow with vert. mixing (B)	River flow and tidal mixing	Pressure gradients,Coriolis effect,entrainment, turb.shear stresses
4. Vertically homogeneous a. With lat. variation (C) b. Laterally homogeneous(D)	Tidal currents predominating	Pressure gradients,entrainment

the degree of mixing in the estuary. Tidal currents provide the energy for such mixing, increasing the movement or advection of portions of the sea water into the freshened water and furthering its diffusion or transfer of salt. Where the mixing is very vigorous such vertically stratified density currents may not exist since the entire water column may be homogeneous. Drowned river valleys narrow at their head and widen at their mouth where Coriolis effect may occur. Because the earth is rotating, currents are deflected to the right of their intended direction of flow in the Northern Hemisphere. Looking down the estuary, the less saline outgoing water leaves primarily on the left. This Coriolis effect may continue into the narrower portions of the estuarine basin, but it is difficult to detect and may in fact be absent from narrow completely mixed estuaries.

SALT WEDGE ESTUARY

In this type of estuary the river flow dominates all other factors. The fresh water flows out and over the salt water forming two layers with a sharp discontinuity at their interface. The resulting steep density gradient reduces turbulence and mixing (Figure 4-80). The Coriolis effect causes more fresh water to depart on the right side of the estuary looking seaward and the interface of fresh and saltwater slopes downward toward the right. The movement of salt water shoreward tends to be slow since the amount of salt water mixed with fresh water carried to sea is reduced by the discontinuity layer. The Mississippi River estuary is usually cited as an example of a sale wedge estuary. In view of the vigorous tides in the study region, salt wedge estuaries do not occur.

PARTIALLY MIXED ESTUARY

Tidal currents in relatively shallow estuaries mix fresh water downward and salt water upward destroying any possibility of a salt wedge. The interface is gradual with its maximum gradient in density occurring near the level of no-net-motion. This level exists at the depth where the net residual flow of the flood and ebb tides is zero and above it the net flow is seaward and below it the net flow is landward (Figure 4-81). Because the amount of salt mixed and carried out of the estuary is great the flow into and out of the estuary is considerably larger than the flow of river water entering. Many estuaries in the subject region are of the partially mixed type. The Sheepscot estuary in central Maine is a good example (Figure 4-82a) as well as the Kennebec estuary (Stommel, 1953). The Coriolis effect can be detected within the estuarine mouth of the Sheepscot (Graham, unpublished data).

VERTICALLY HOMOGENEOUS ESTUARY

According to Pritchard and Carter (1971) if the estuary is sufficiently

wide and the mixing vigorous, the estuary might become entirely mixed, destroying the vertical density gradient found in the partially mixed estuary. The flow of less saline water to the sea is on the right at all depths and the incoming more saline water on the left. The wider reaches of the Delaware and Raritan estuaries are of this type, but are not any such estuaries in the study region.

SECTIONALLY HOMOGENEOUS ESTUARY

When the tidal mixing completely dominates relative to river flow, the interface is obliterated and salinity is homogeneous both vertically and laterally. The movement of salt upstream may be by diffusion in spite of the absence of large salinity gradients (Pritchard and Carter, 1971).

4.2.6 MISFITS AND VARIATIONS

Although the relation of river inflow to tidal flows permits a useful classification of estuaries, the characteristics of their circulations may be obscured by other factors. Somes Sound is a fjord-type of embayment located in the eastern sector of the coast (Figure 4-35). A small stream enters at the head of its U-shaped glaciated valley and a sill 153 feet in depth is at the entrance to its basin. The circulation in its deeper waters is very likely slow with little exchange causing the accumulation of hydrogen sulfide. In the upper water, especially above the depth of the sill, the circulation is like that of a partically mixed estuary in which the bottom has been replaced by a basin of undiluted sea water.

Seasonal changes in river flow can also change an estuarine circulation sufficiently to alter its classification. The Hampton Harbor estuary in New Hampshire is usually homogeneous vertically with tidal currents dominating. But during spring rains it may become partially mixed (PSNH, Seabrook Station, 1972). During some seasons winds may alter the circulation. Southern winds blowing up the Sheepscot may change the vertical profile of tidal excursions shifting the depth at which the level of no-net-motion usually occurs (Figure 4-82b).

Along the coast of Maine, abrupt changes in the shape of an estuarine basin may either alter the character of its circulation or in some of its sections, its classification. The Kennebec estuary is connected to the Sheepscot estuary by a narrow and rough channel called the Sassanoah River. The currents through this channel are fast and it is likely that the water column is homogeneous in some of its sectors. Stommel (1953) describes the effect of water emerging from a narrow sector of the Kennebec estuary into the wider sector near the mouth. Essentially, as the less dense water moves into the widened sector it loses its velocity because of the sector's increased volume. The less dense water spreads over the

surface because it cannot push before it the denser water of the widened sector. As more water moves downstream stratification increases between the two layers.

With reversal of the tide both waters move upstream where they are mixed by turbulence and back eddies in the narrow channel. Narrow channels or constrictions in channels are common in the high rocky area of the coast and occur in the southern lower coastal area where the mouths of estuaries are often narrowed by bars. In some instances channel constrictions cause tidal falls which thoroughly mix the water; e.g. Sheepscot Falls and Sullivan Falls. Narrow channels with broad areas of shallow water at their borders may have circulations that differ within the channel and above the channel sides. In the channel occupying Sullivan Harbor it is possible that in some places a vertical level of no-net-motion does not exist (Graham, preliminary data) because the route taken through the harbor by the flood tide may in part differ from that of the ebb tide.

4.2.7 SEA-ICE CONDITIONS-EASTPORT TO CAPE COD FROM: NOAA (1972) U.S. COAST PILOT

Ice. The extent to which the harbors of Maine are closed to navigation by ice varies greatly in different years. During some winters most of the harbors are open, while in others the only harbors available for anchorages are Quoddy Narrows, Eastport, Little River, Machias Bay (above Avery Rock Light), Mistake Harbor (not much used), Winter Harbor, and Boothbay Harbor. Portland Harbor generally has an open channel in winter, kept so by steamers and tugs. The mouths of the rivers are generally avoided for anchorage in winter and early spring on account of running ice. In the bays and Harbors the ice formation is mostly local; beginning at the head, in sheltered places along the shore, it extends outward. During a calm or light winds from northward the local formations rapidly increase, while strong winds break them up and force them as drift ice onto the lee shore. The tidal currents do not prevent the formation of ice or influence its movements in strong winds except in the larger rivers.

In severe winters some of the harbors south of Cape Ann are closed to navigation by ice, and there is more or less drift ice in all the harbors, in Cape Cod Bay, and on Monomoy and Nantucket Shoals. In the principal harbors, steamers and tugs usually keep a channel open. See Ice under the different headings in the text.

During some winter months or when threatened by icing conditions, lighted buoys may be removed from station or replaced by unlighted buoys; unlighted buoys, and day beacons and lights on marine sites also may be removed; see LIGHT LIST.

The International Ice Patrol is conducted by the U.S. Coast Guard whenever the presence of ice begins to threaten steamship traffic in the North Atlantic Ocean, which usually begins in February and extends to about July. The patrol guards the southeastern, southwestern, and southern limits of the regions of icebergs in the vicinity of the Grand Banks of Newfoundland for the purpose of informing passing ships of the extent of this dangerous area.

Reports of ice in this area are collected from passing ships and from flights by Ice Patrol aircraft. Should severe ice conditions be encountered, the Coast Guard deploys a surface patrol ship to conduct ice observations. Information on ice conditions are disseminated by Ice Patrol Bulletins which are broadcast by radio and landline circuits. A list of the radio stations, frequencies, and times of broadcast are published annually in Local Notices of Mariners of the First and Third Coast Guard Districts and in the Notice to Mariners issued by the U.S. Naval Oceanographic Office.

All shipping is requested to assist in the operation of the Inter-

national Ice Patrol by radio reporting all sightings of ice at once to the Commander, International Ice Patrol (COMINTICEPAT), Governors Island, New York. The report can usually be made via the nearest Coast Guard station.

4.2.8 References (Section 4.2 North)

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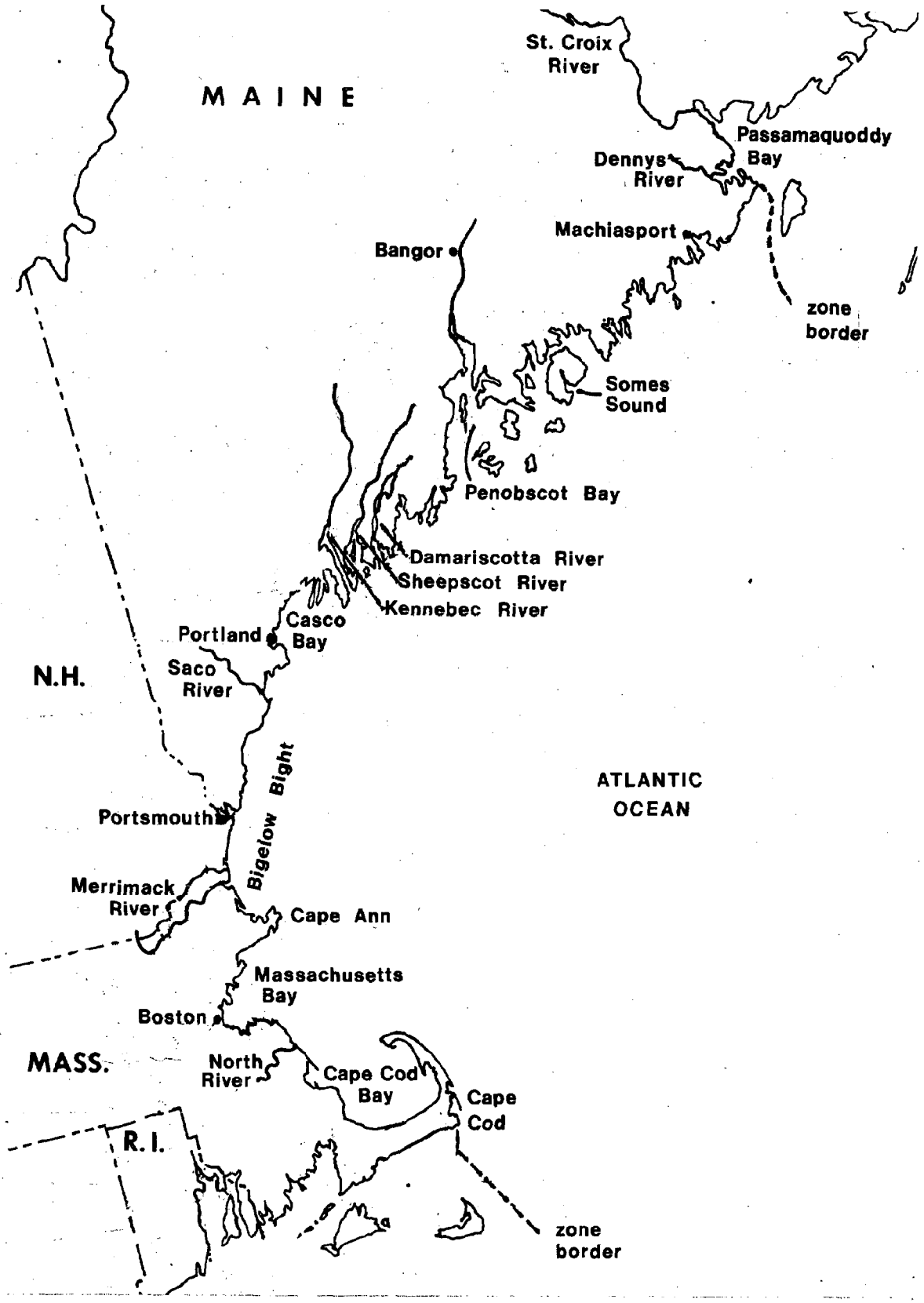
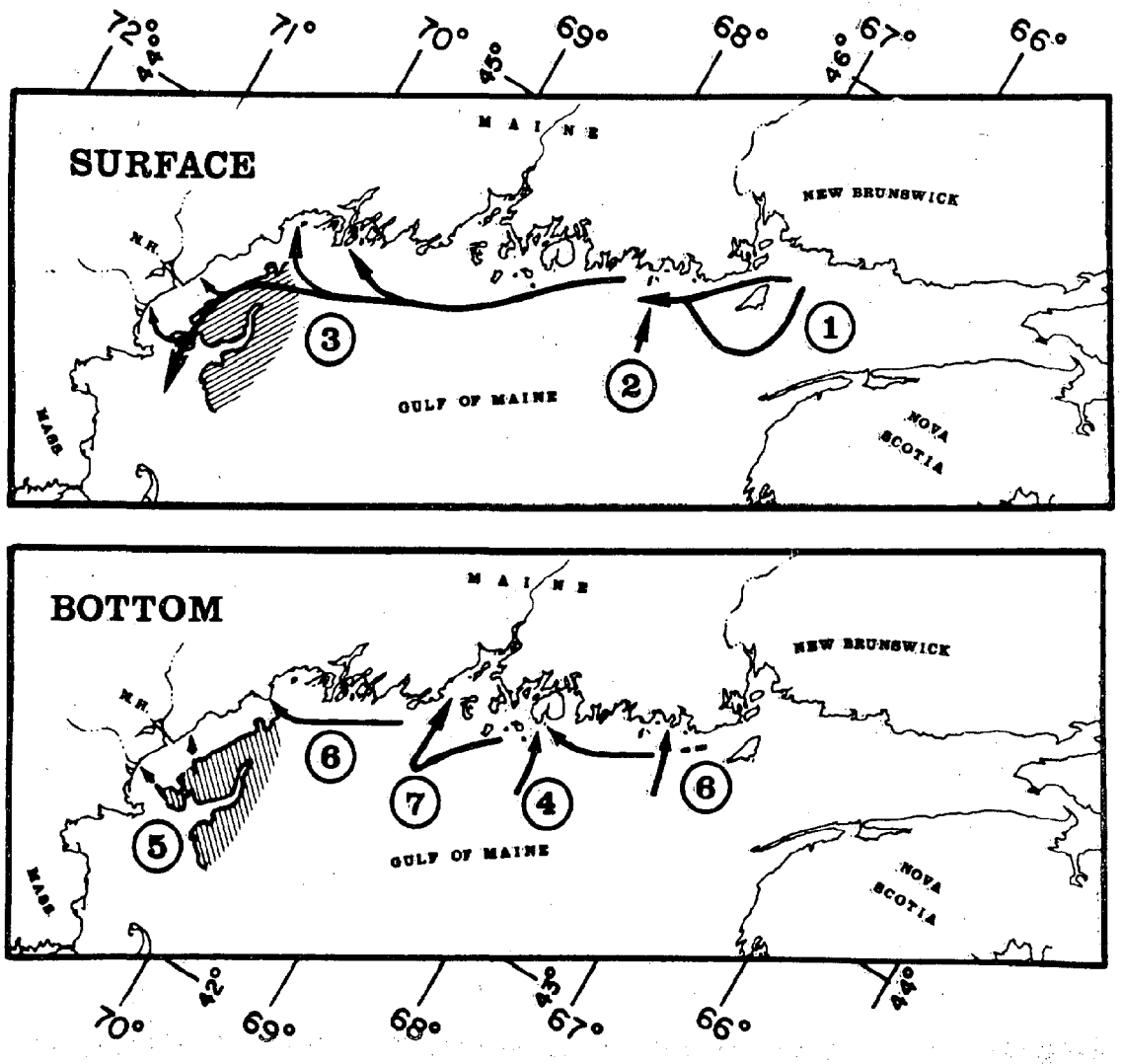


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-35	North Atlantic Estuarine Zone



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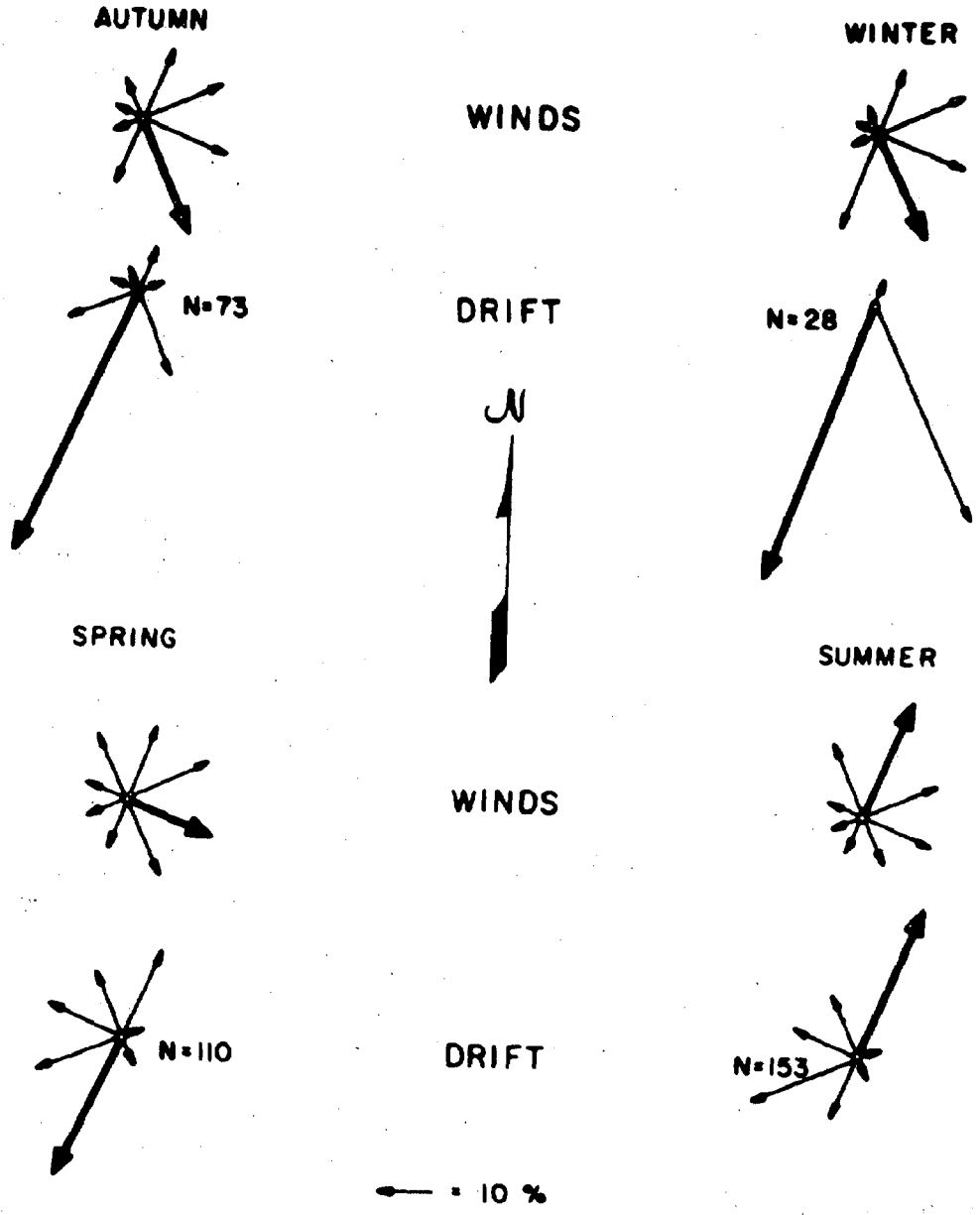
TRIGOM PARC	FIGURE 4-36	Inferred Routes of Travel of a Particle of Water - Source to Coastal Shelf (Graham, 1970a)



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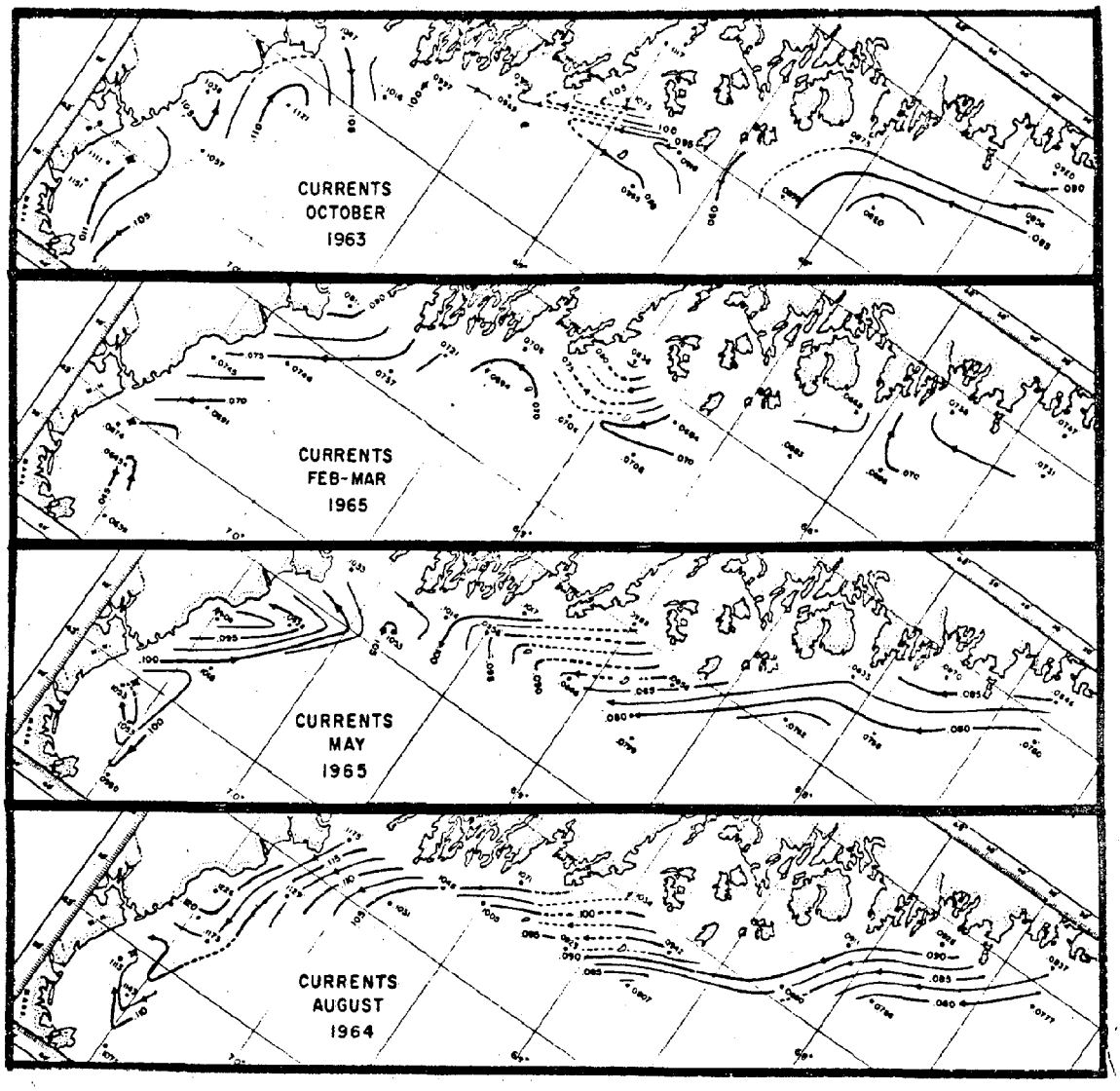
TRIGOM PARC	FIGURE 4-37	Frequencies of Prevailing Direction of Winds and Bottle Drift (Haight, 1942)



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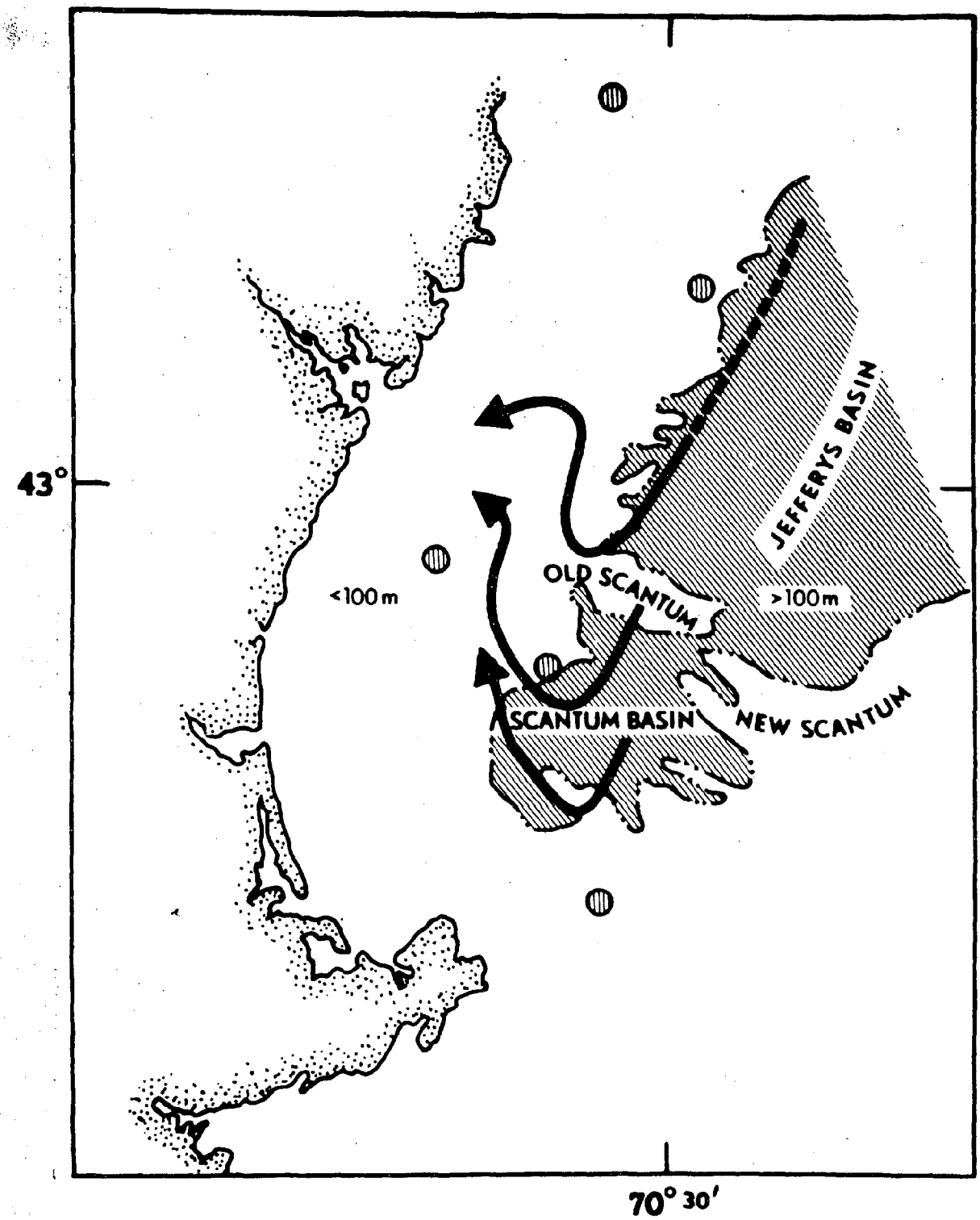
TRIGOM PARC	FIGURE 4-38	Dynamic Topography at the Surface Relative to 30M. (Graham, 1970b)



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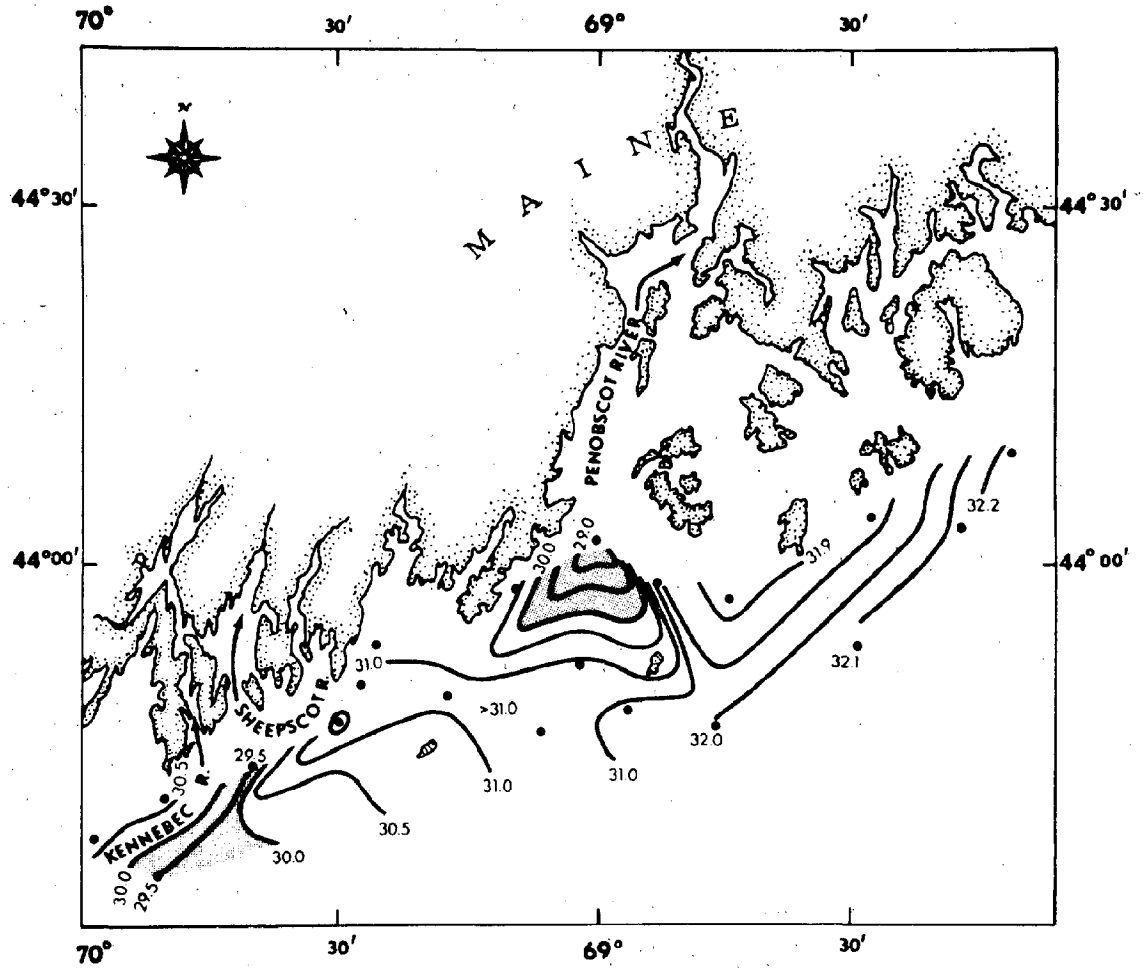
TRIGOM PARC	FIGURE 4-39	Effect of Bottom Irregularities on the Dynamic Topography (Graham, 1970b)



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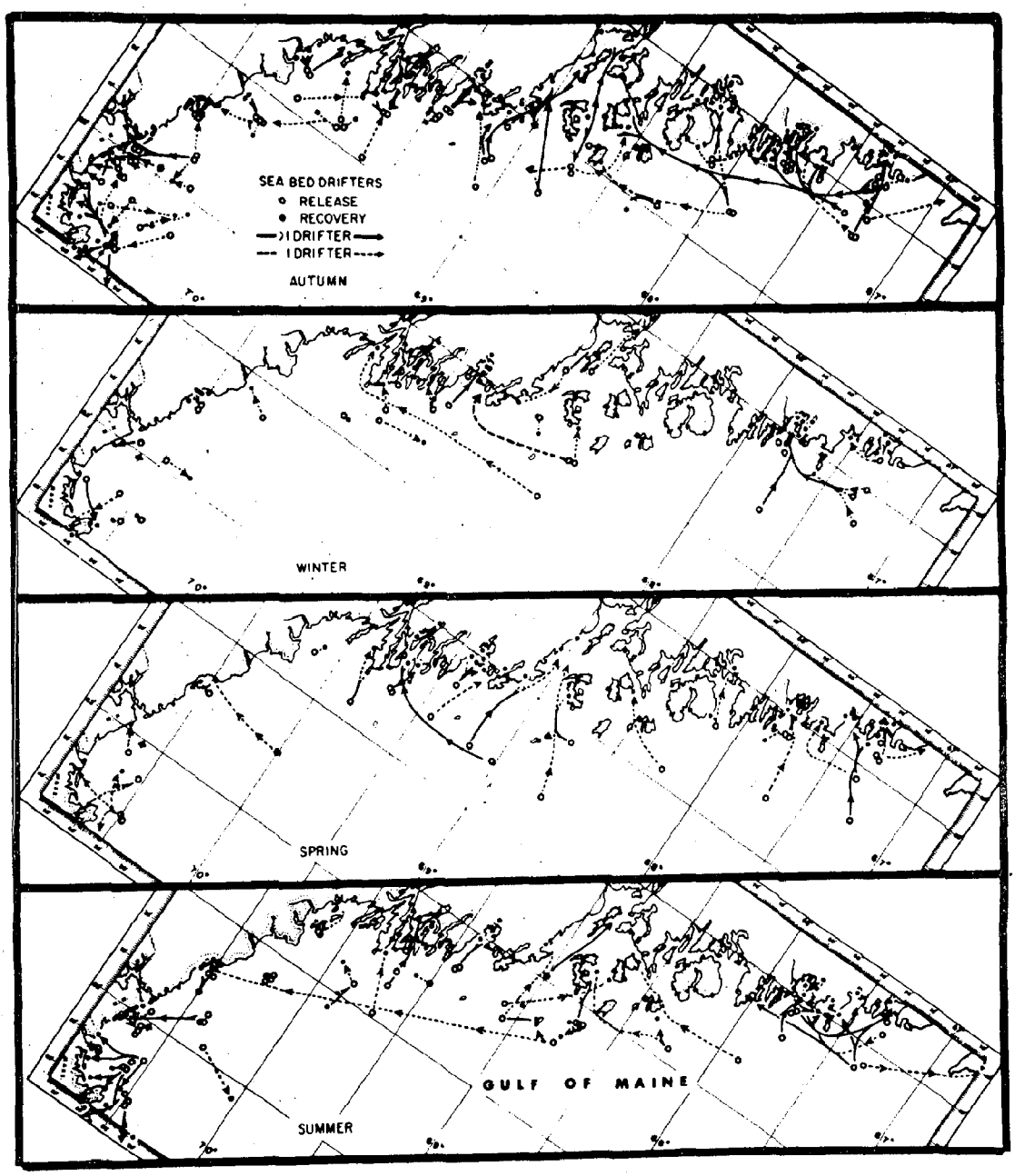
TRIGOM PARC	FIGURE 4-40	Effect of Discharge form Penobscot, Kennebec, and Sheepscot Rivers as shown by salinity distribution - May 1965 (Graham, 1970a)



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TRIGOM PARC	FIGURE 4-41	Release, Routes, and Recovery of Sea Bed Drifters (Gorham, 1970a)

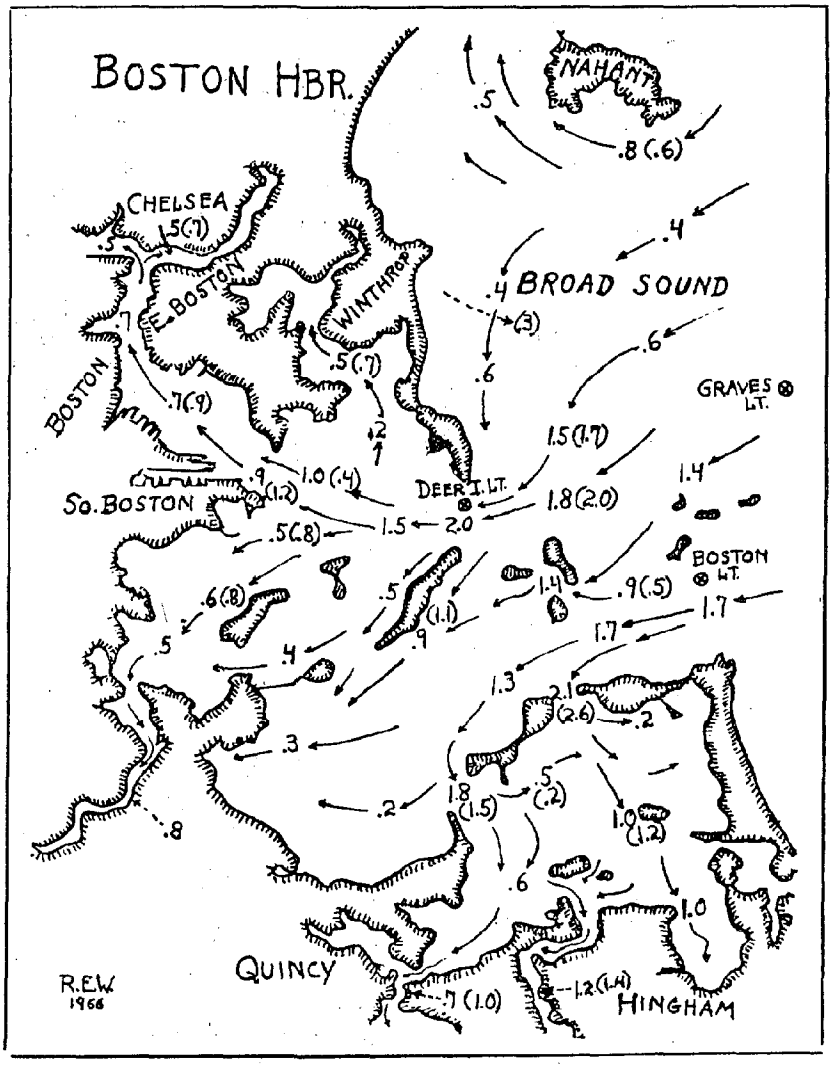
BOSTON HARBOR CURRENTS

The diagram below shows the direction of the Flood Currents in Boston Harbor at the time of Maximum Flood Current, generally 3½hrs. after Low Water at Boston. Generally speaking the Ebb Currents flow in precisely the opposite direction (note one exception, shown by dotted arrow east of Winthrop), and reach these maximum velocities about 4 hrs. after High Water at Boston.

Basically, the velocities of the Ebb Currents are about the same as those of the Flood Currents. Where the Ebb Current differs by a .2 kt, the velocity of the Ebb is shown in parentheses.

The Velocities shown on this Current Diagram are the maximums normally encountered each month at Full Moon and at New Moon. At other times the velocities will be smaller.

As a rule of thumb, the velocities shown are those found on days when High Water at Boston is 11.0 to 11.5 ft. (see Boston High Water Tables pp. 10-15). When the height of High Water is 10.5', subtract 10% from the velocities shown; at 10.0', subtract 20%; at 9.0', 30%; at 8.0', 40%; below 7.5', 50%.



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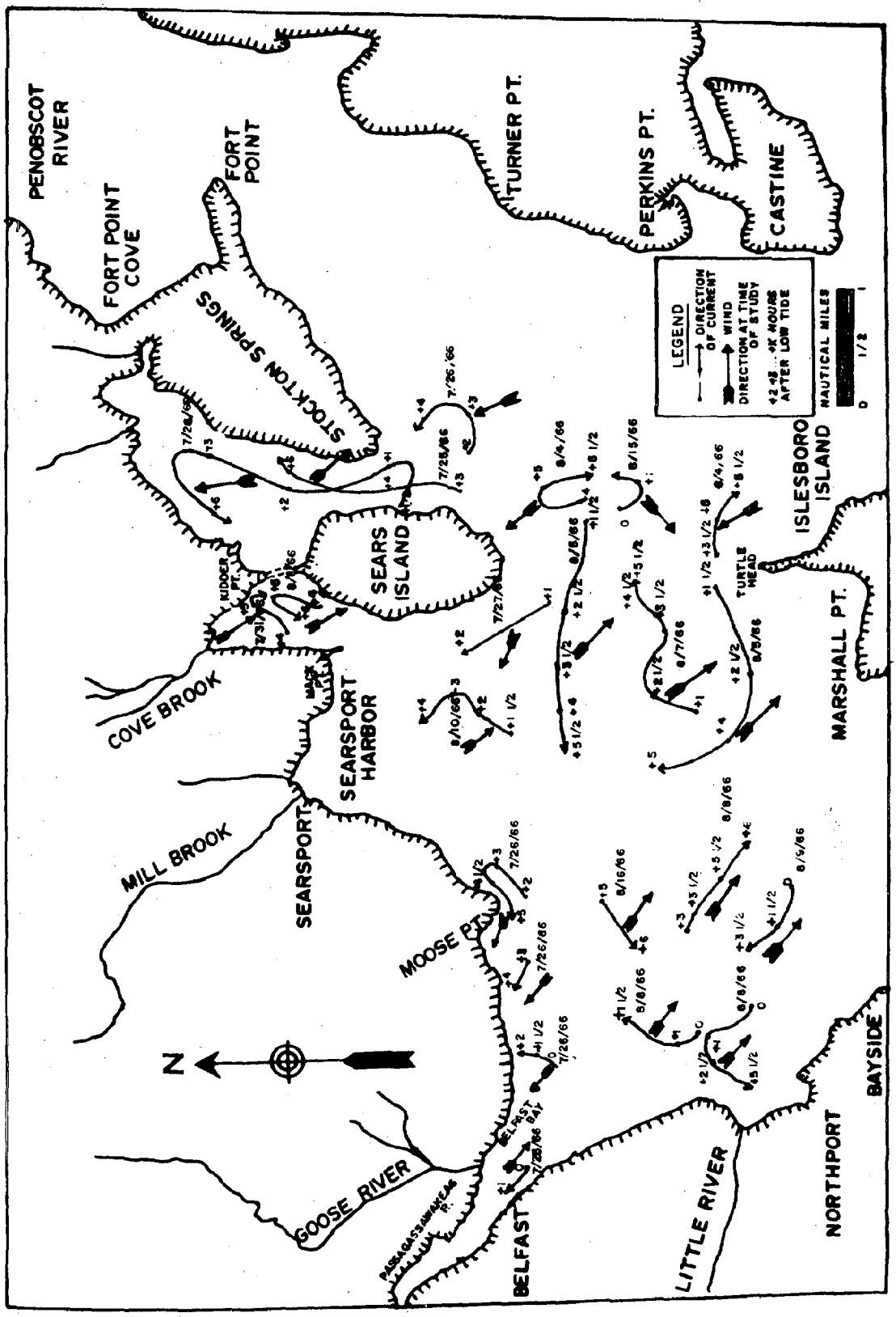
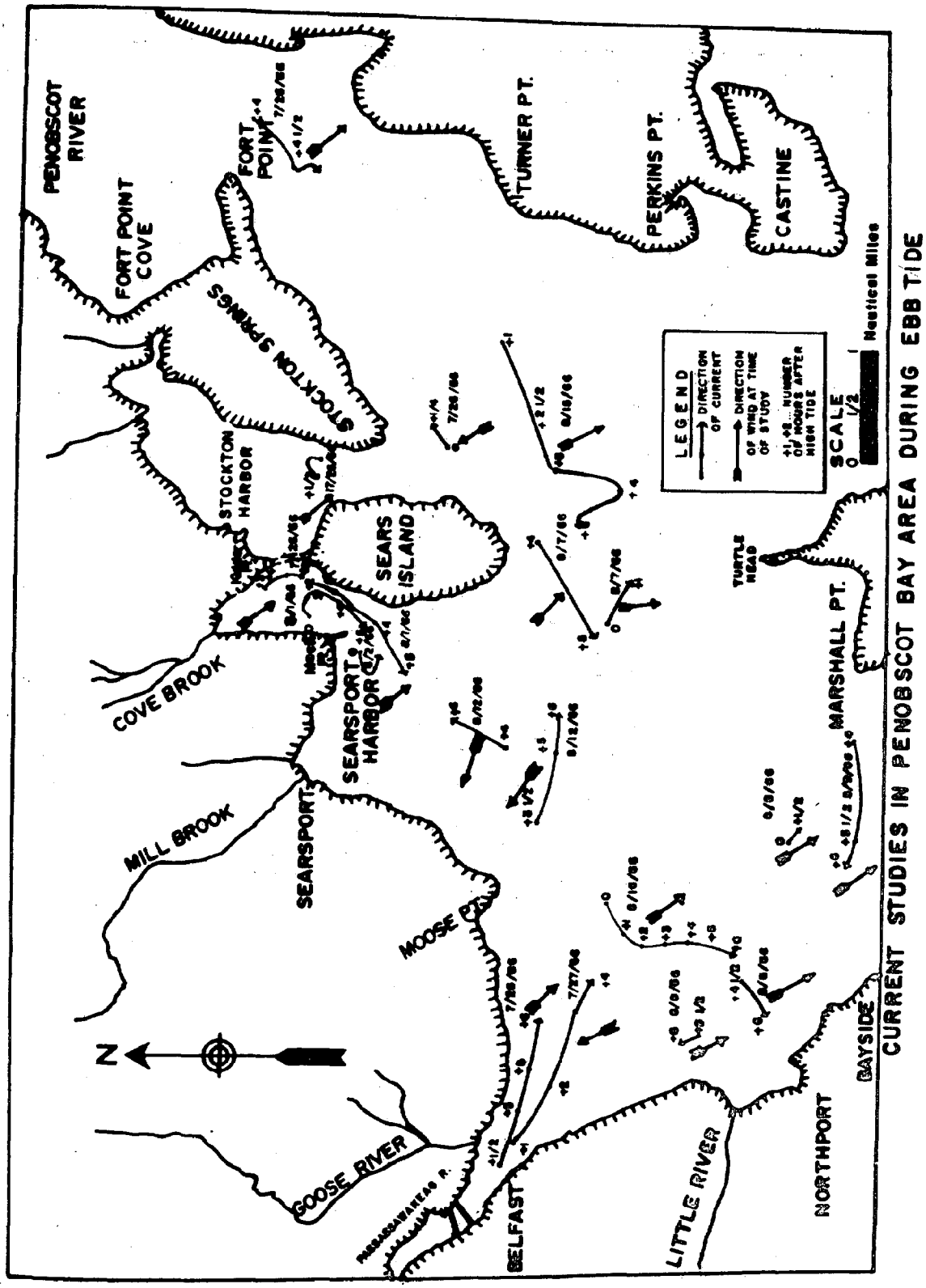
TRIGOM PARC	FIGURE 4-42	Boston Harbor Currents (Eldridge, 1973)



CURRENT STUDIES IN PENOBSCOT BAY AREA DURING FLOOD TIDE

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

TRIGOM PARC	FIGURE 4-43	Current Studies in Penobscot Bay During Flood Tide (Anonymous, 1967)



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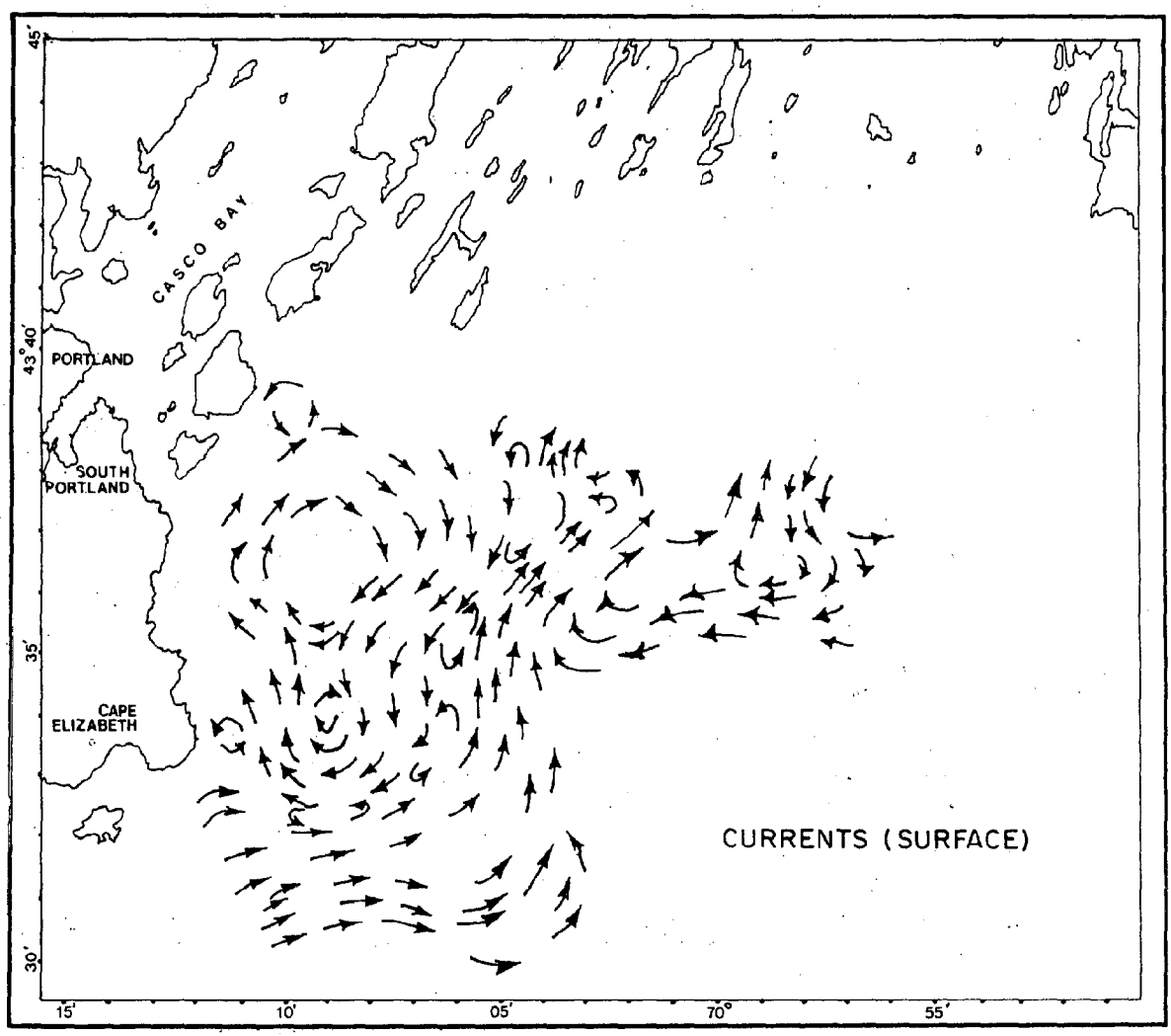
TRIGOM PARC	FIGURE 4-44	Current Studies in Penobscot Bay During Ebb Tide (Anonymous, 1967)



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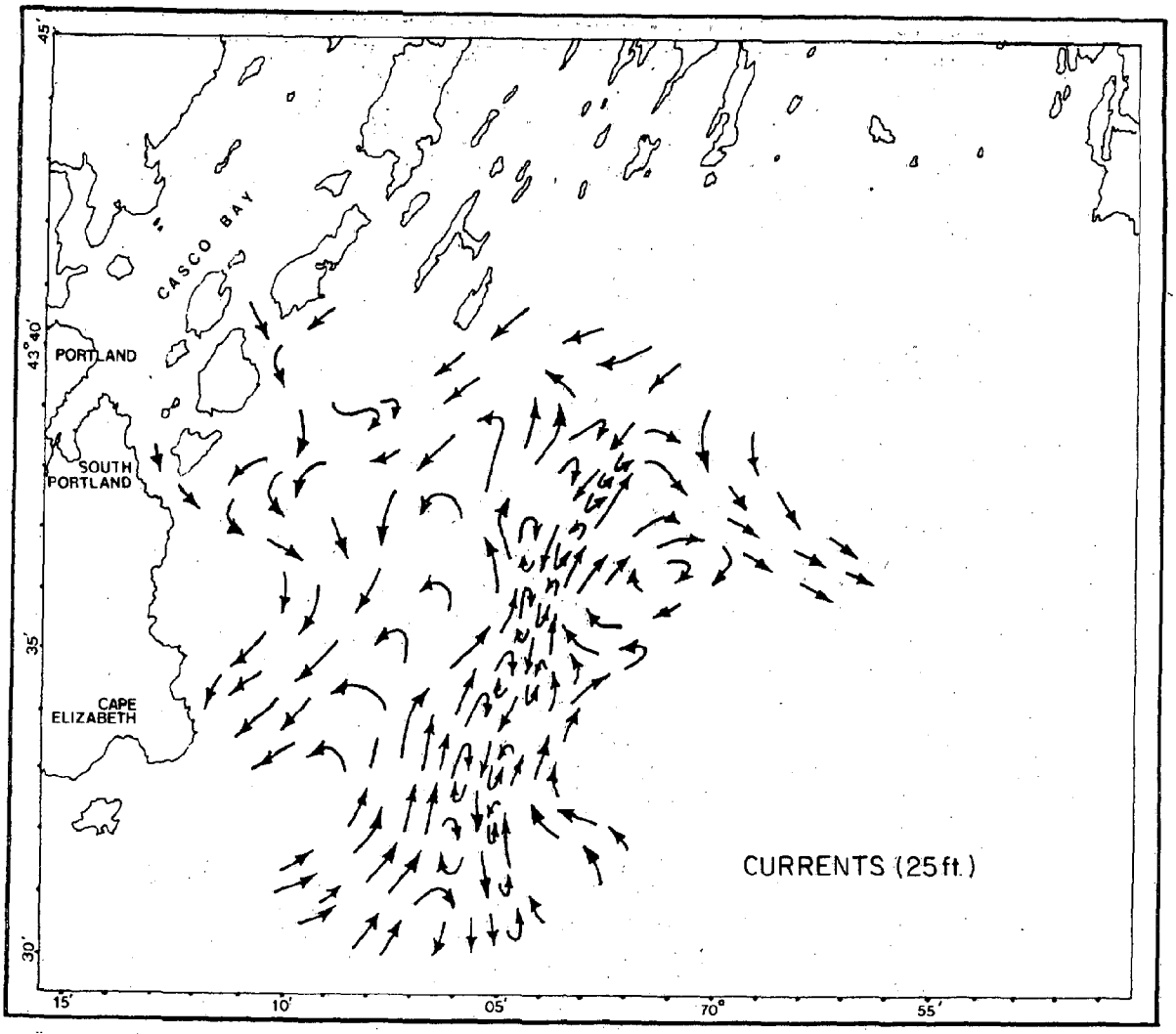
TRIGOM PARC	FIGURE 4-45	Casco Bay Currents at the Surface (Brayton and Campbell, 1953)



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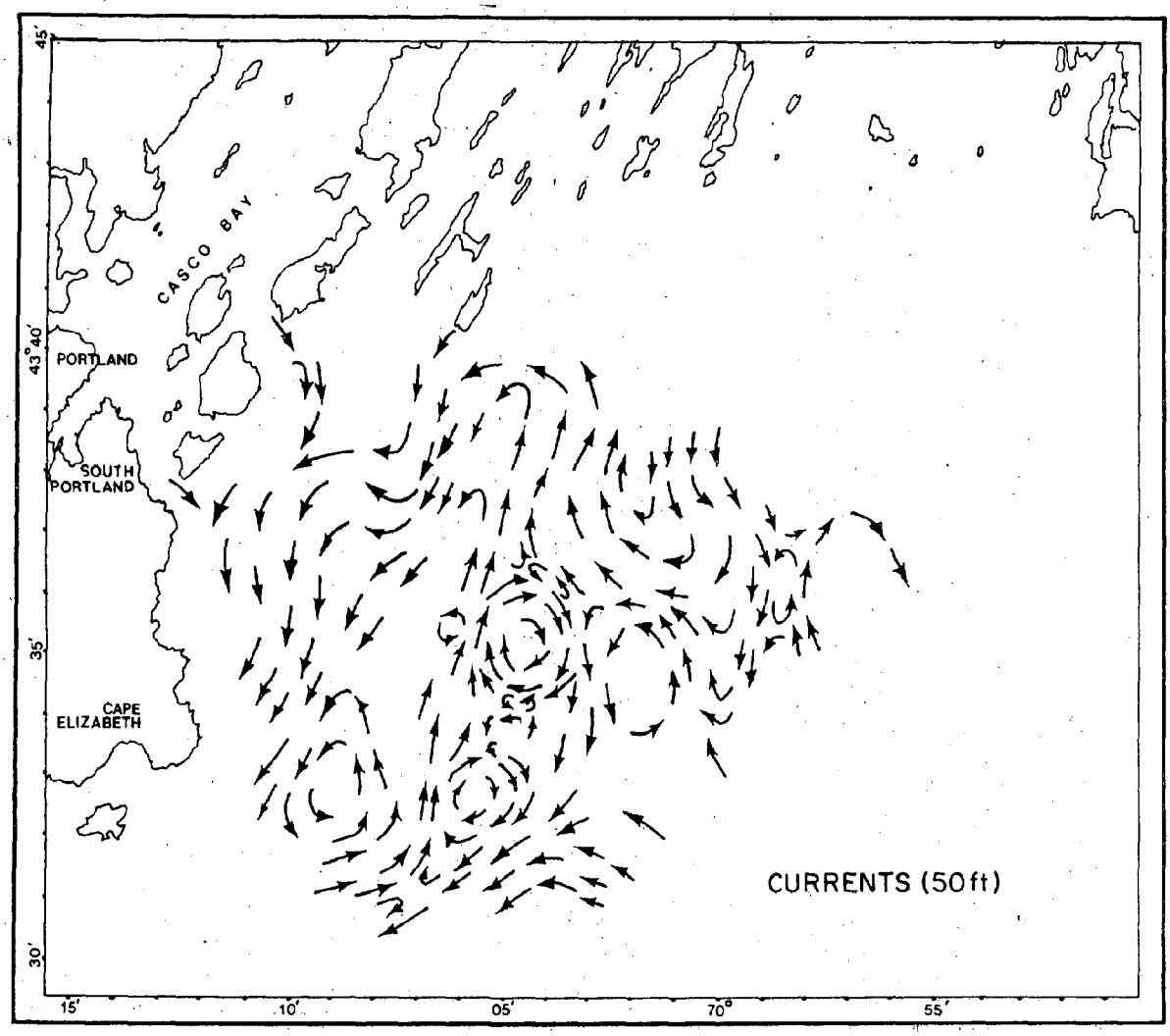
TRIGOM PARC	FIGURE 4-46	Casco Bay Currents at 25 Feet (Brayton and Campbell, 1953)



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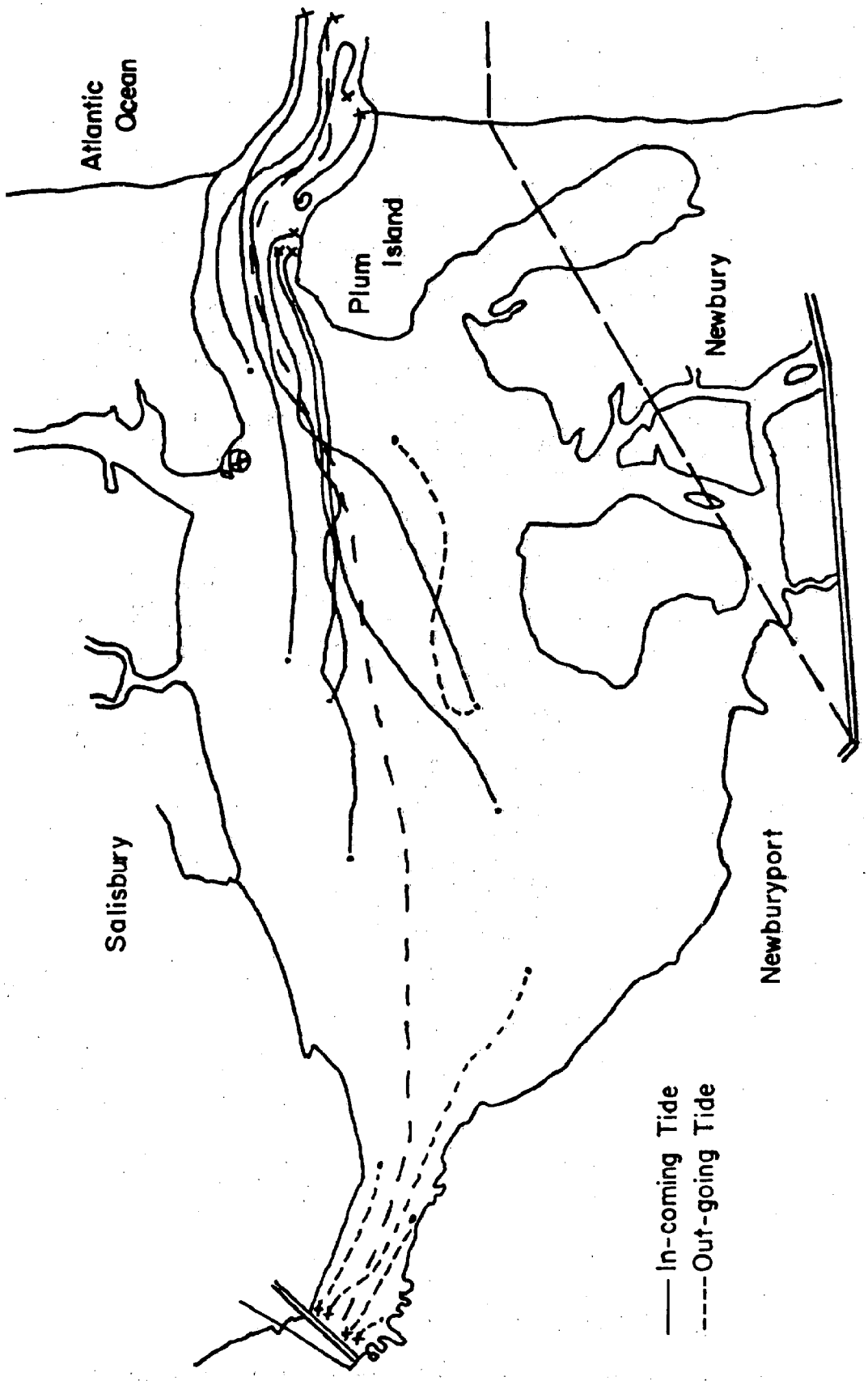
TRIGOM PARC	FIGURE 4-47	Casco Bay Currents at 50 Feet (Brayton and Campbell, 1953)



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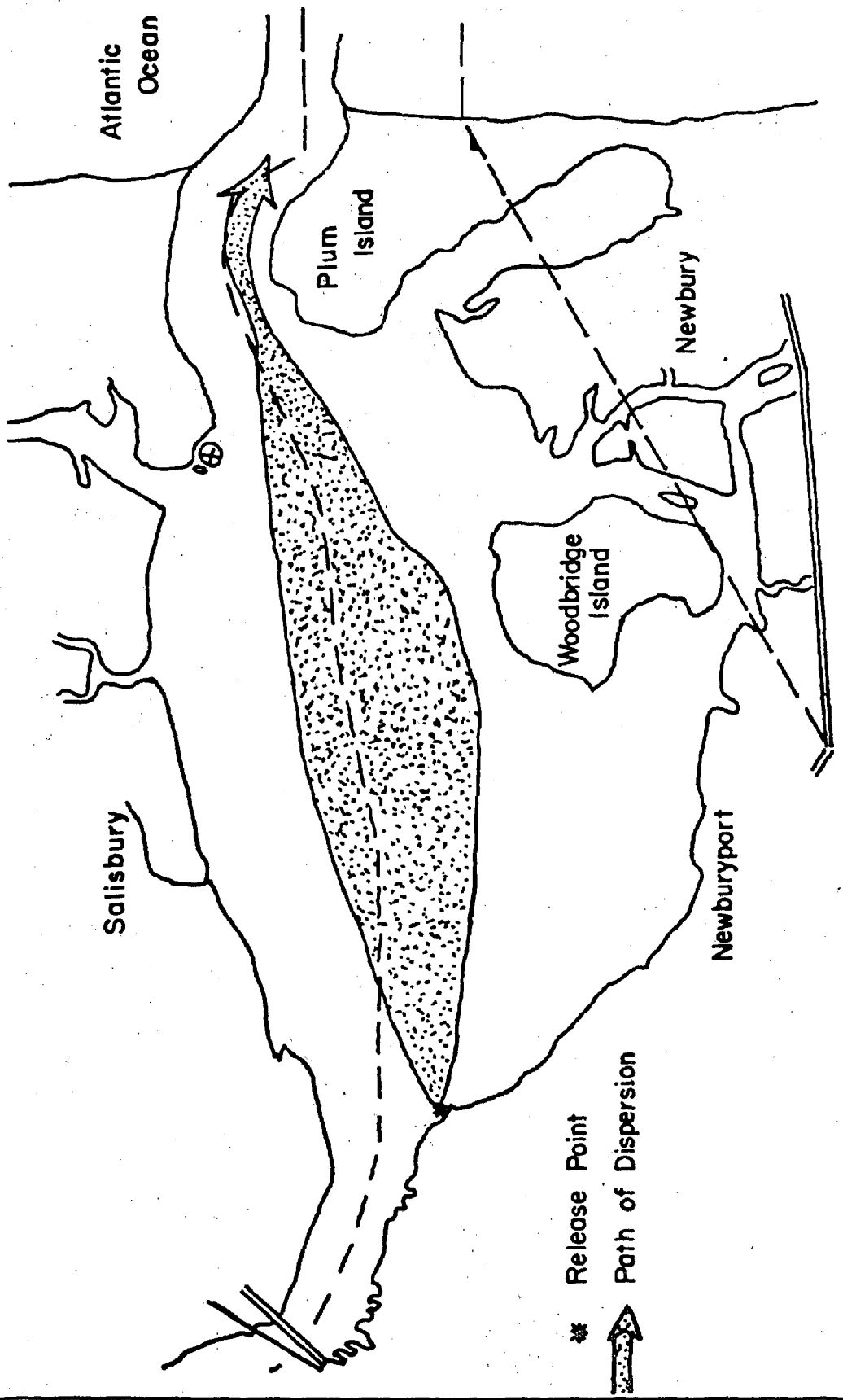
TRIGOM PARC	FIGURE 4-48	Paths Taken by Plastic Floats-Merrimack River Incoming and Outgoing Tides (Jerome et al., 1965)



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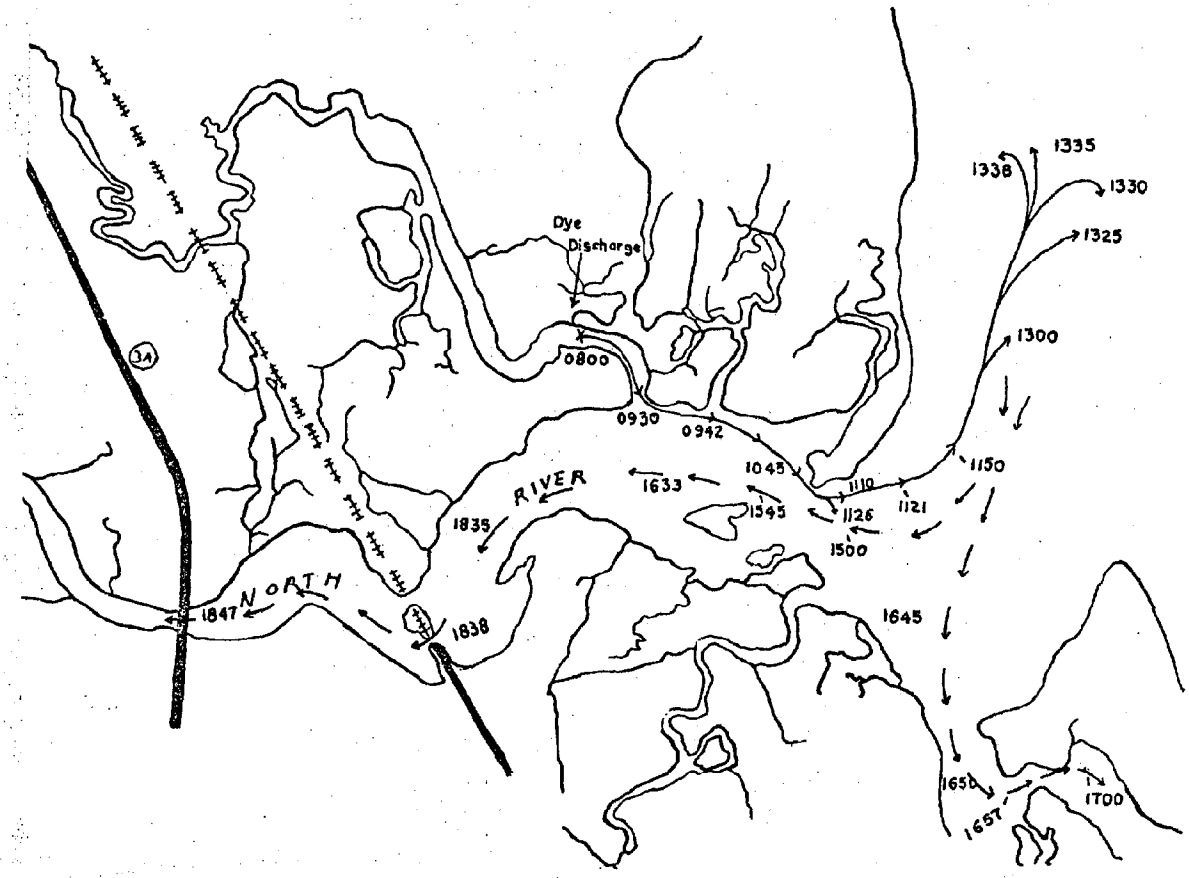
TRIGOM PARC	FIGURE 4-49	Dispersal of Rhodamine B Dye Released at Newburyport Sewage Treatment Plant (Jerome et. al., 1965)



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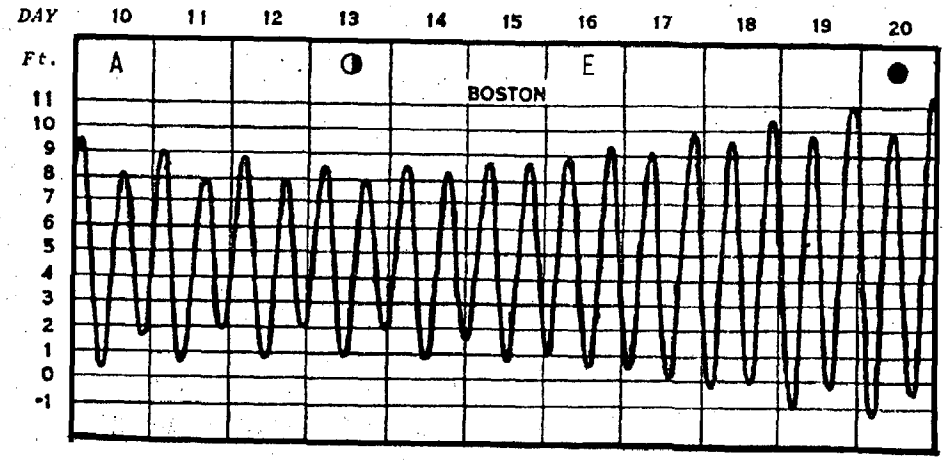
TRIGOM PARC	FIGURE 4-50	Summary of Dye Movement on Tidal Action (Fiske et al., 1966)



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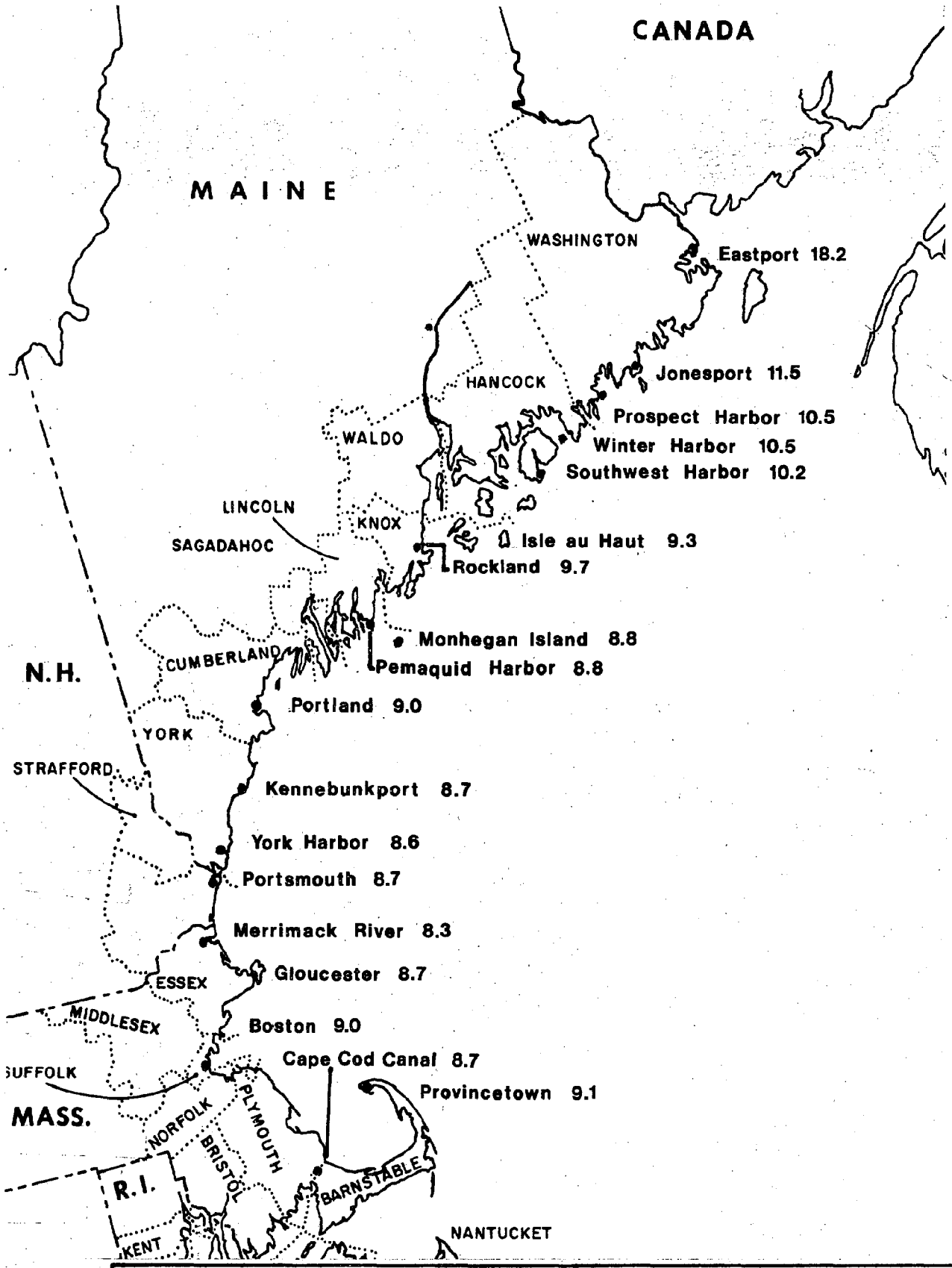
TRIGOM PARC	FIGURE 4-51	Typical Tide Curves for Boston (NOS/NOAA, 1972



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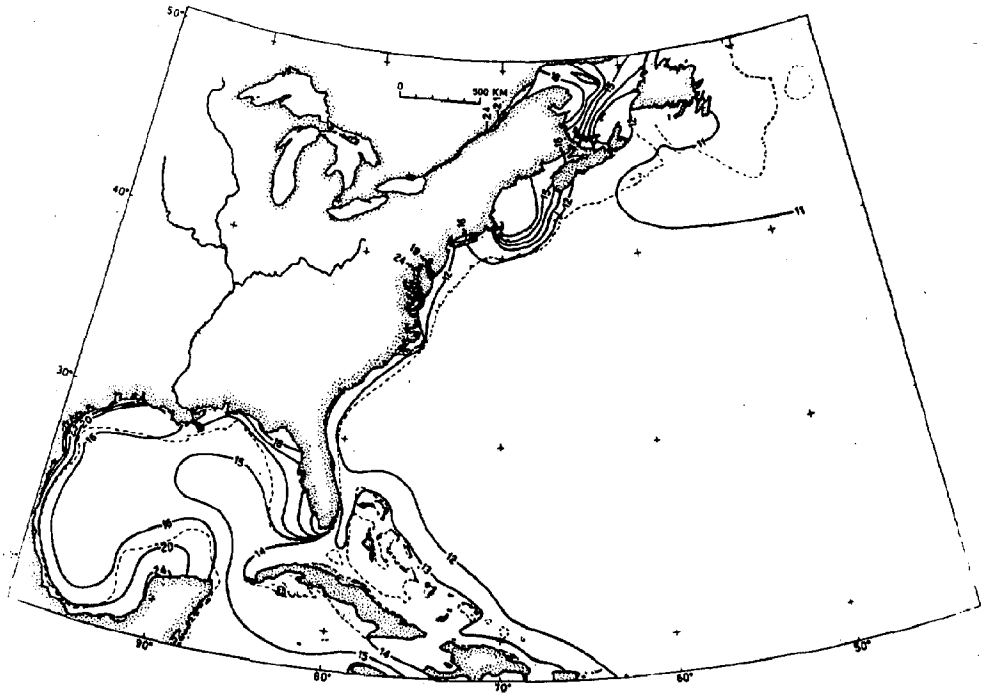
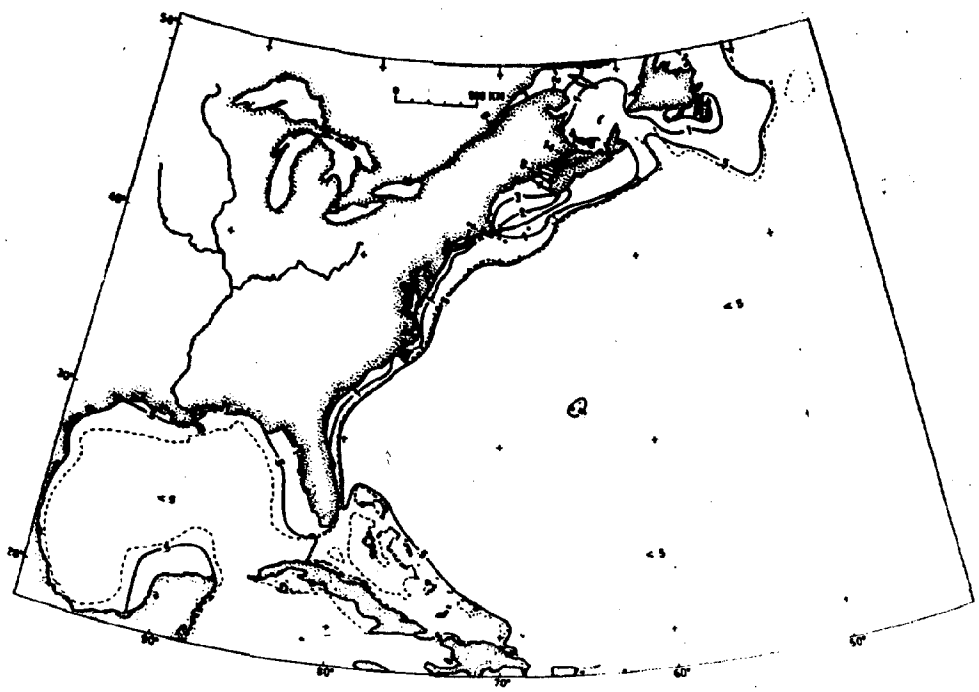
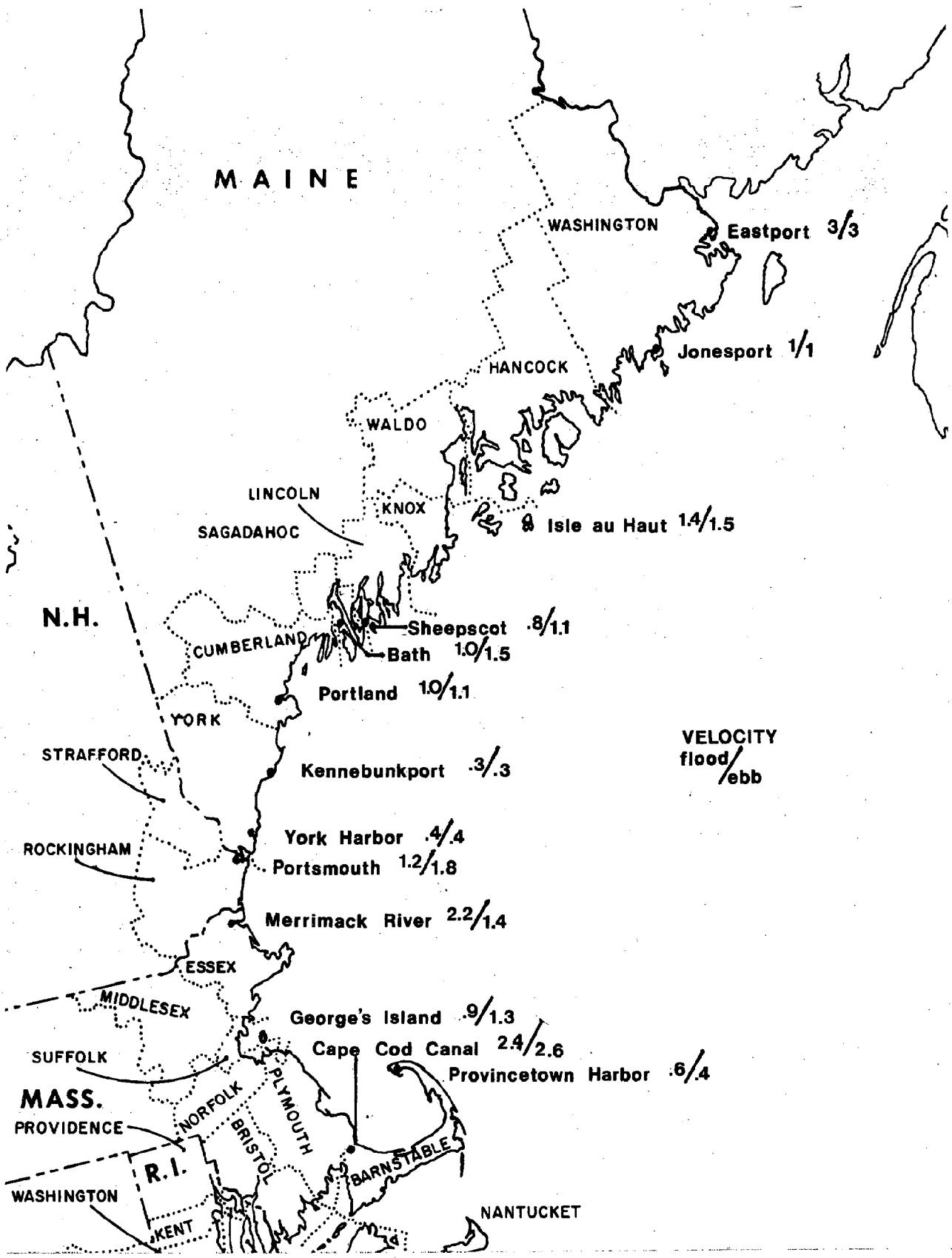
TRIGOM PARC	FIGURE 4-52a	Mean Tidal Range in Feet for Selected Areas Along the Coast



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-52b	Co-Time Map Showing Position of High Tide at One Hour Intervals (Emery and Uchupi, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-52c	Co-Range Map of Mean Spring Tides (Emery and Uchupi, 1972)



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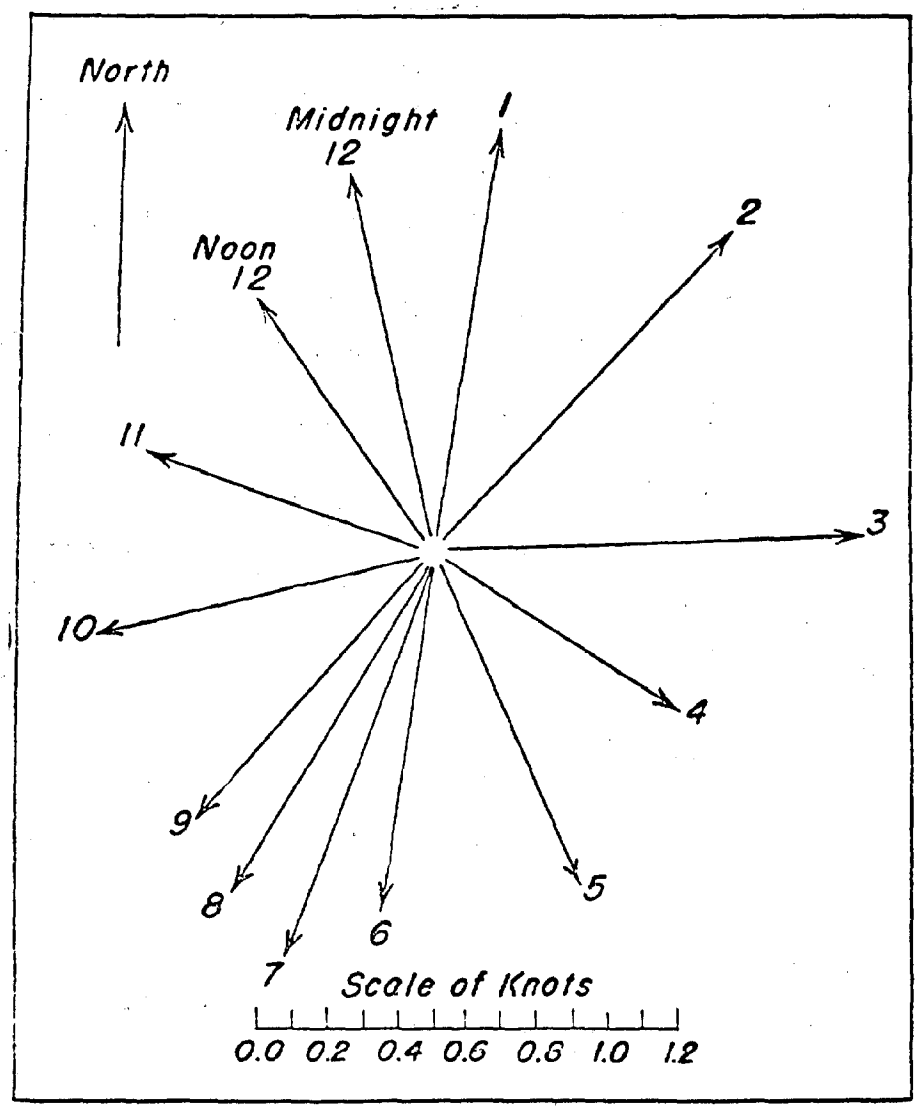
TRIGOM PARC	FIGURE 4-53	Mean Flood and Ebb Velocities for Selected Coastal Locations



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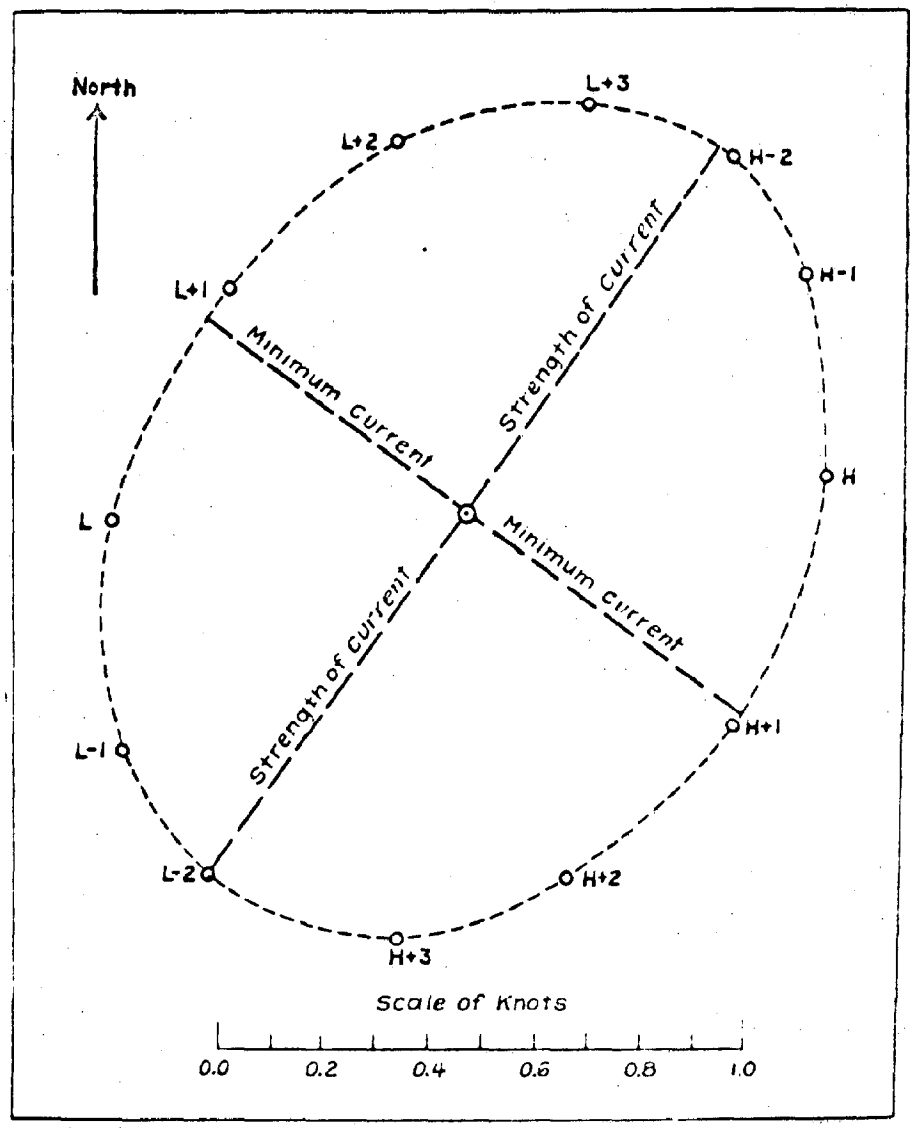
TRIGOM PARC	FIGURE 4-54	Rotary Current - Nantucket Shoals Lightship (Haight, 1942)



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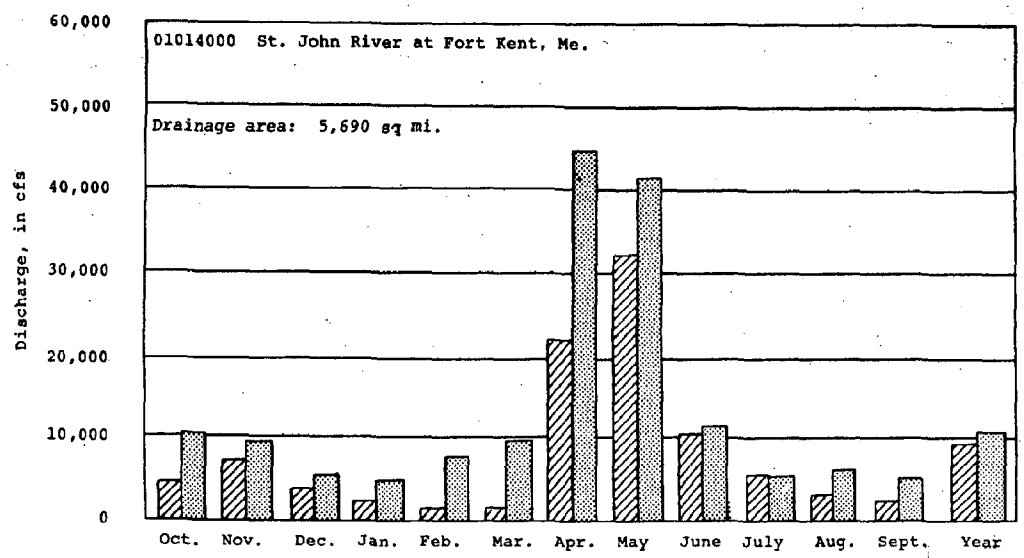
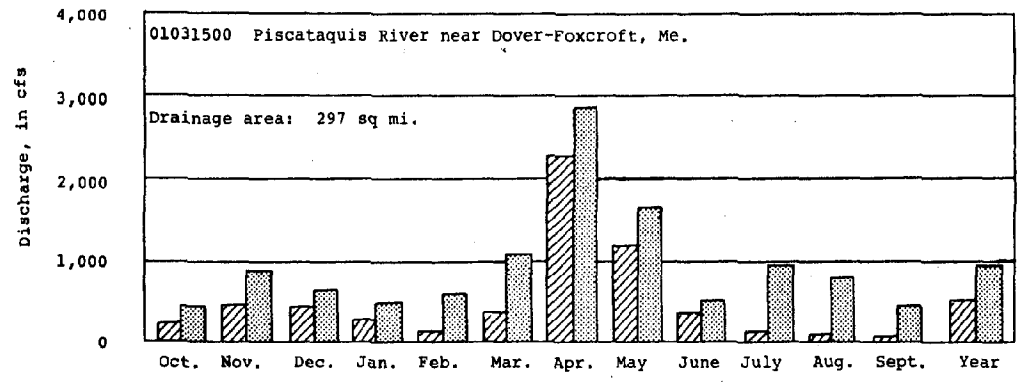
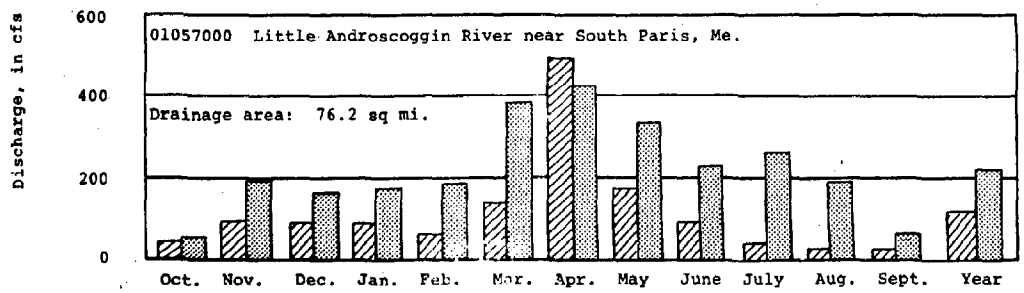
TRIGOM PARC	FIGURE 4-55	Mean Current Curve - Nantucket Shoals Lightship (Haight, 1942)







Explanation

Median of monthly and yearly mean discharges for water years 1931-60.

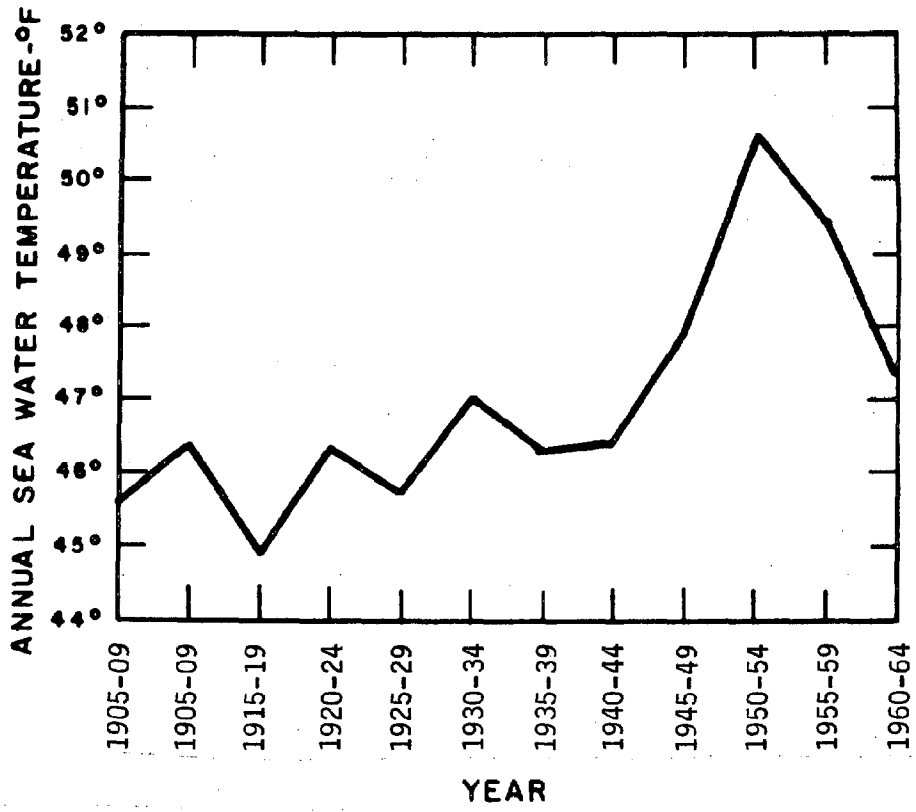
Monthly and yearly mean discharges during 1973 water year.

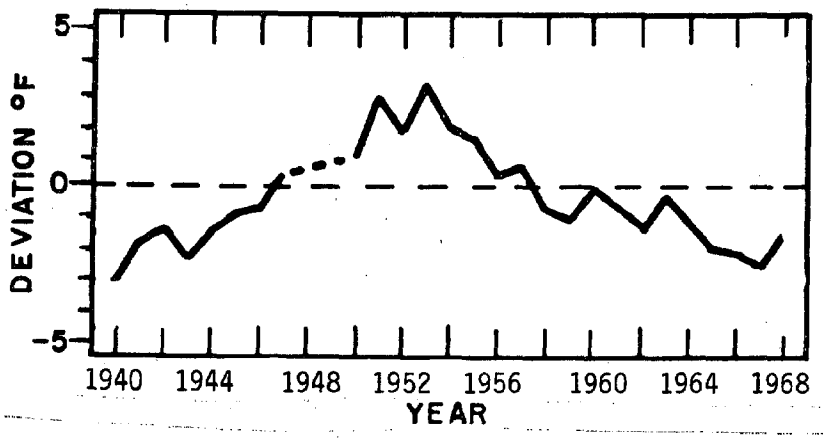
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 4-56

Runoff Comparison at Two Long-Term Index Guaging Stations During 1971 (U.S. Geological Survey, 1972)





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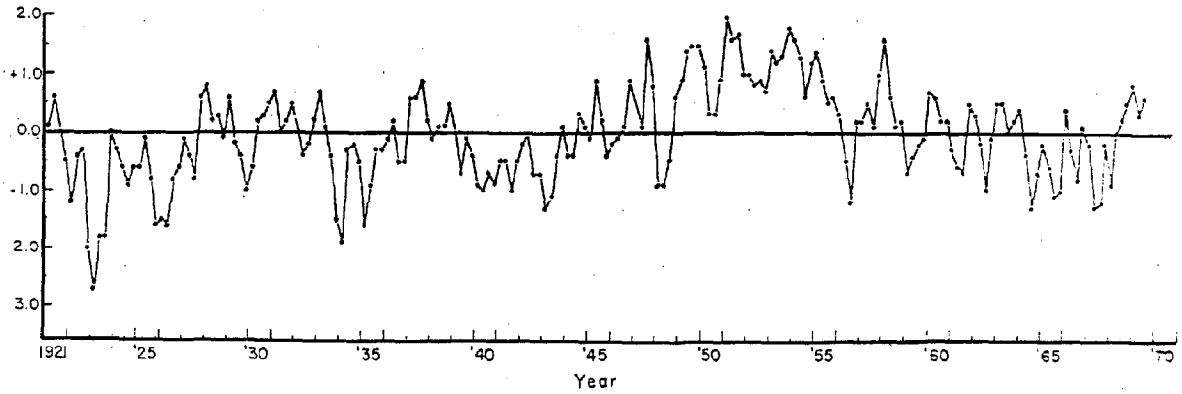
TRIGOM PARC

FIGURE 4-57

Annual Deviations from the 1940-1959 Mean Sea-Surface Temperature at Boothbay Harbor (P.S.N.H., 1972)



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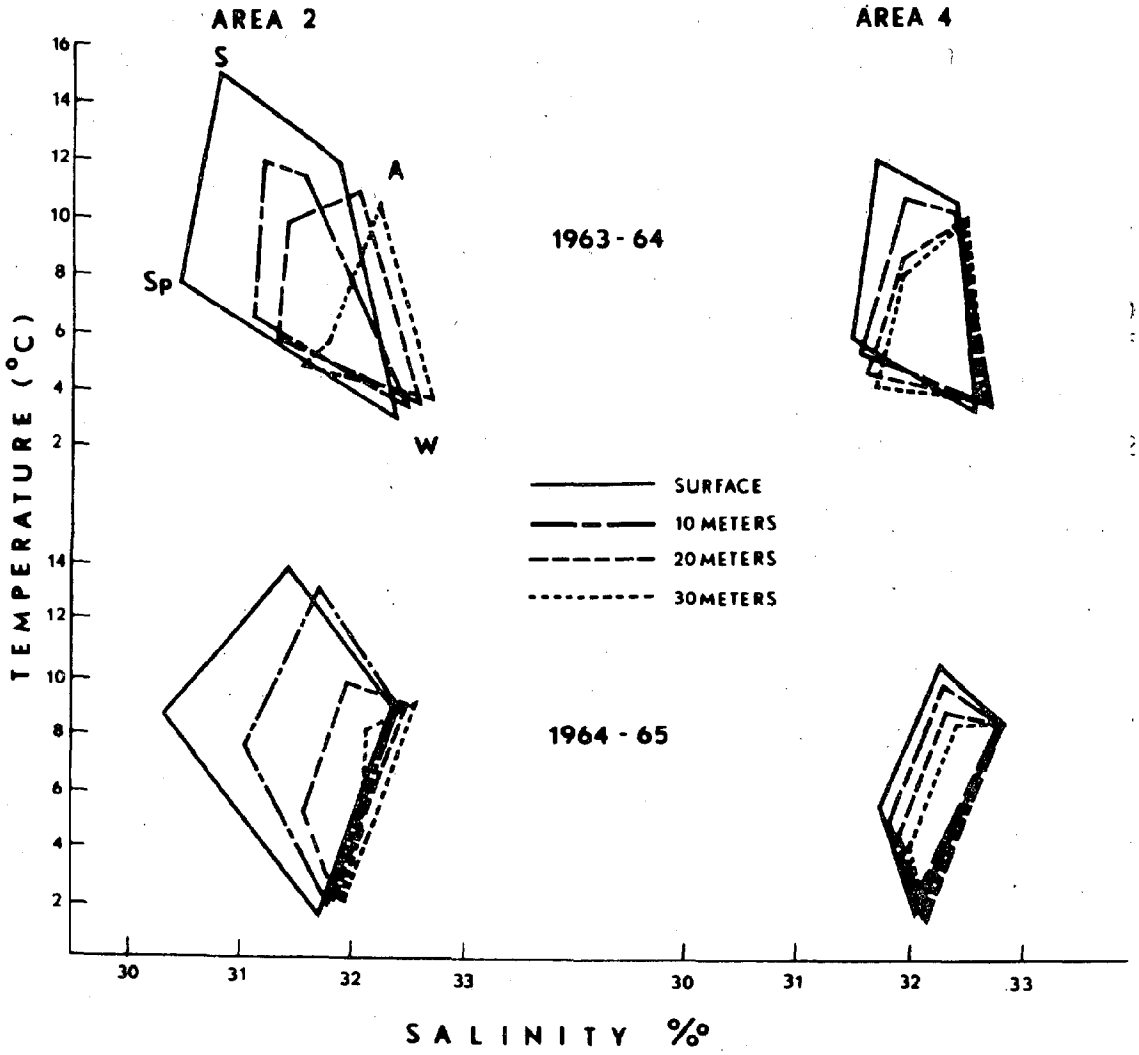
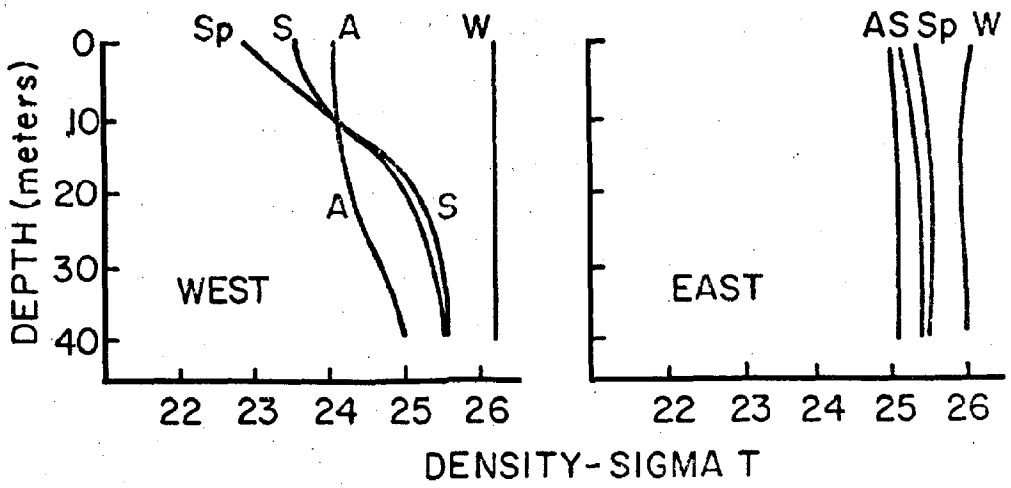
TRIGOM PARC	FIGURE 4-58	Quarterly Devations of Surface Water Temperature at St. Andrews, N.B. (Lauzier and Hull, 1969)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-59	Seasonal Temperature Salinity Relationships (Graham, 1970b)



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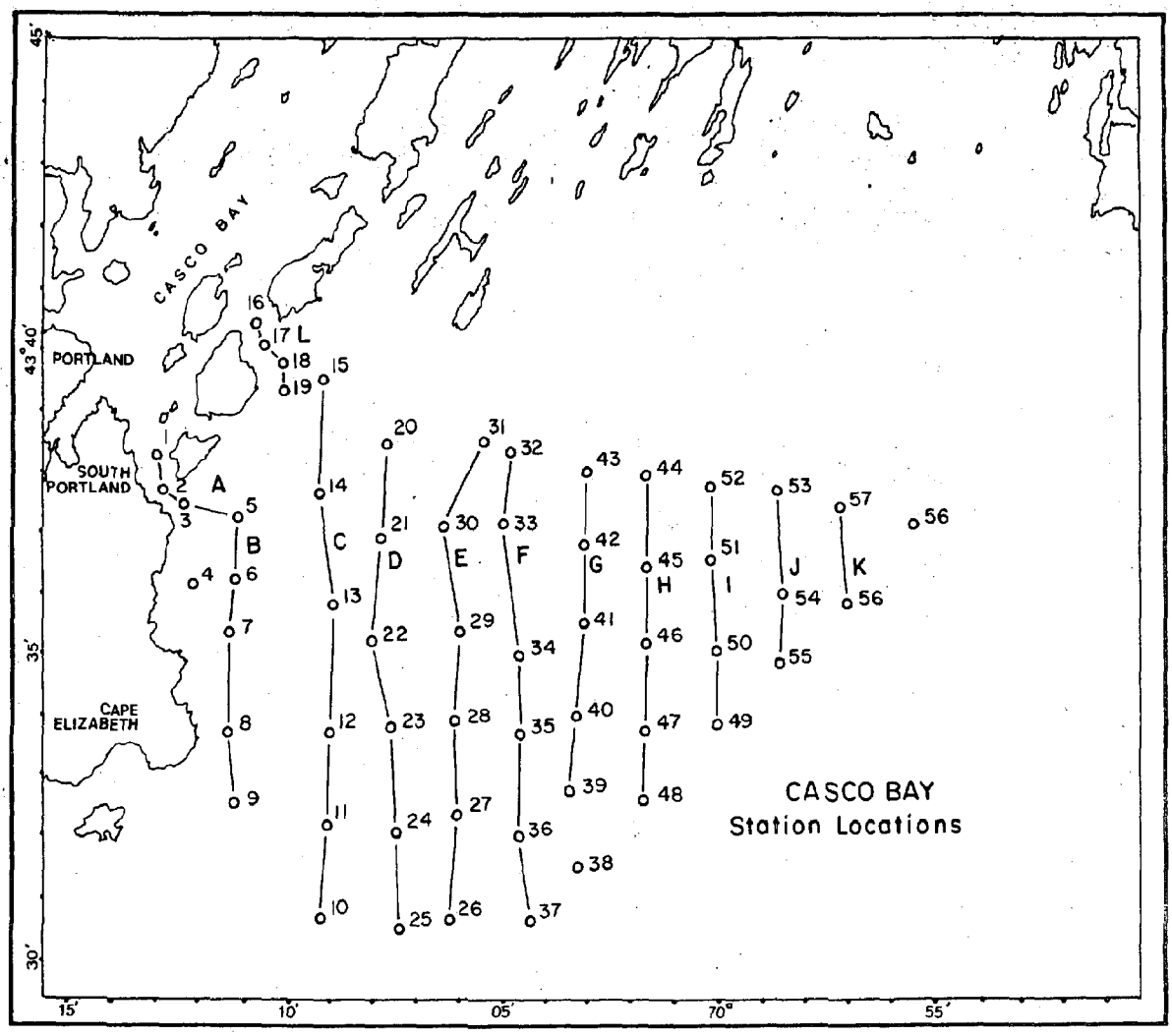
TRIGOM PARC	FIGURE 4-60	Vertical Distribution of Density East and West of Penobscot Bay (Graham, 1970b)



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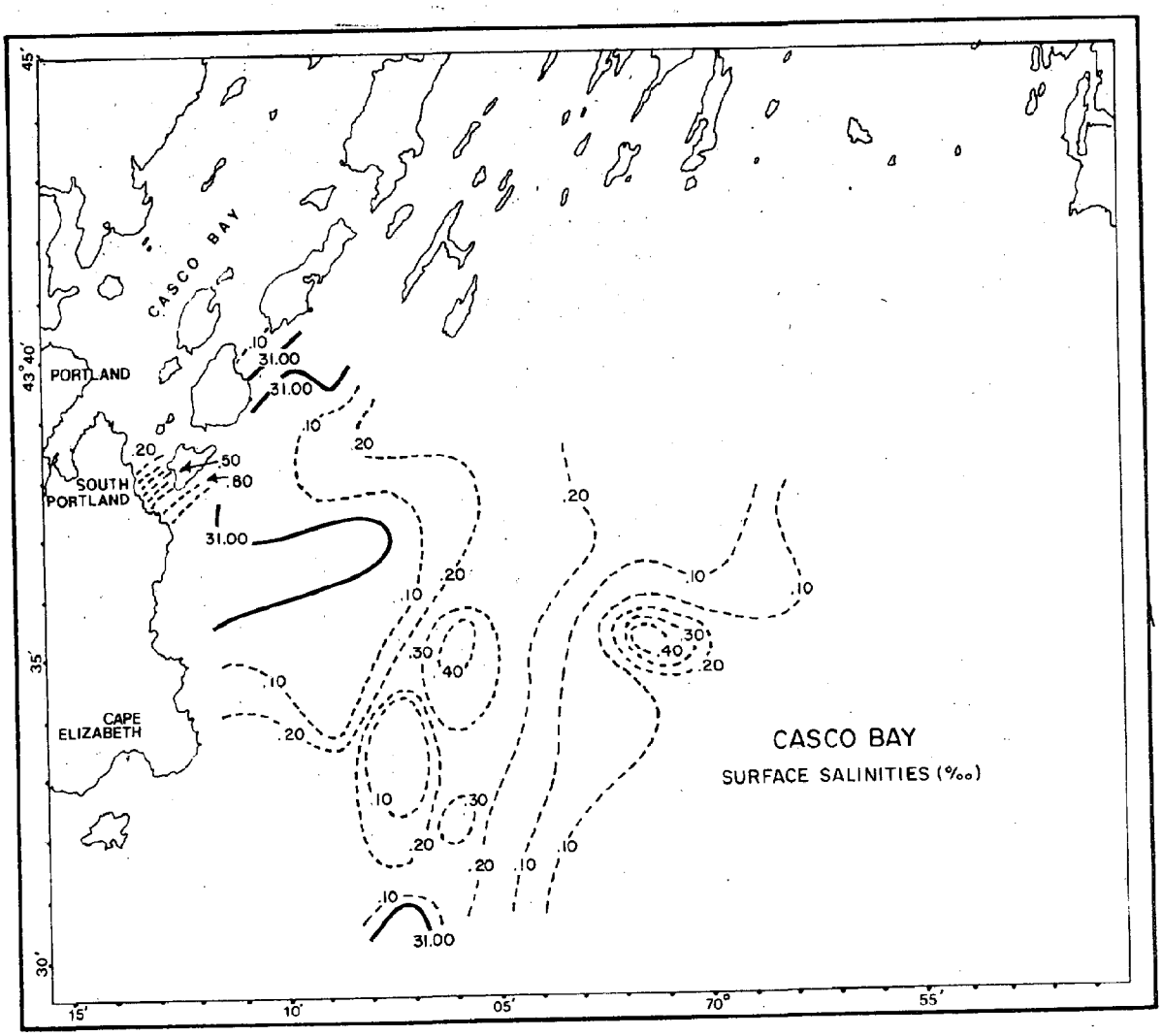
TRIGOM PARC	FIGURE 4-61	Lower Casco Bay Station Locations (Graham, 1970b)



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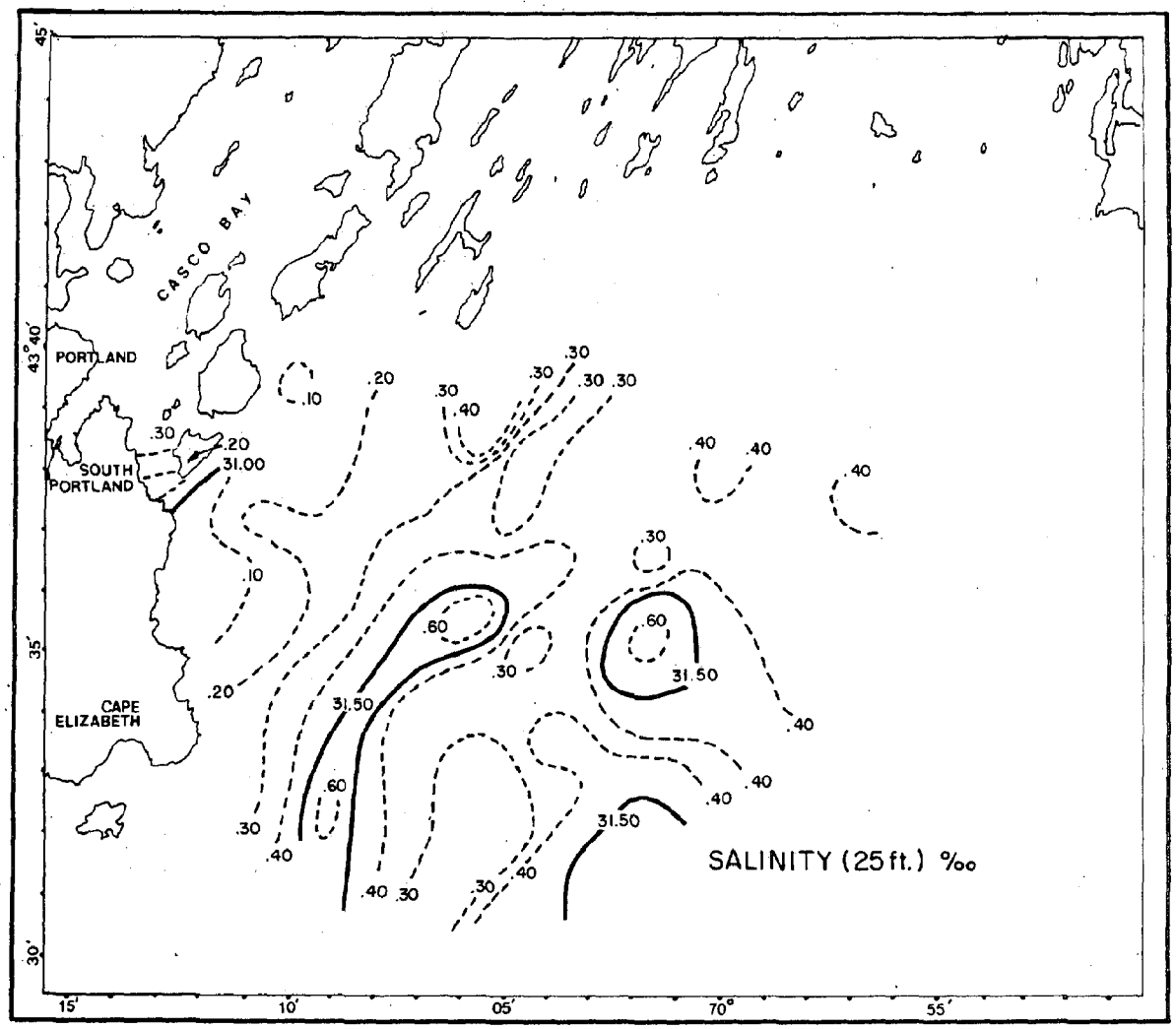
TRIGOM PARC	FIGURE 4-62	Lower Casco Bay Surface Salinity (Graham, 1970b)



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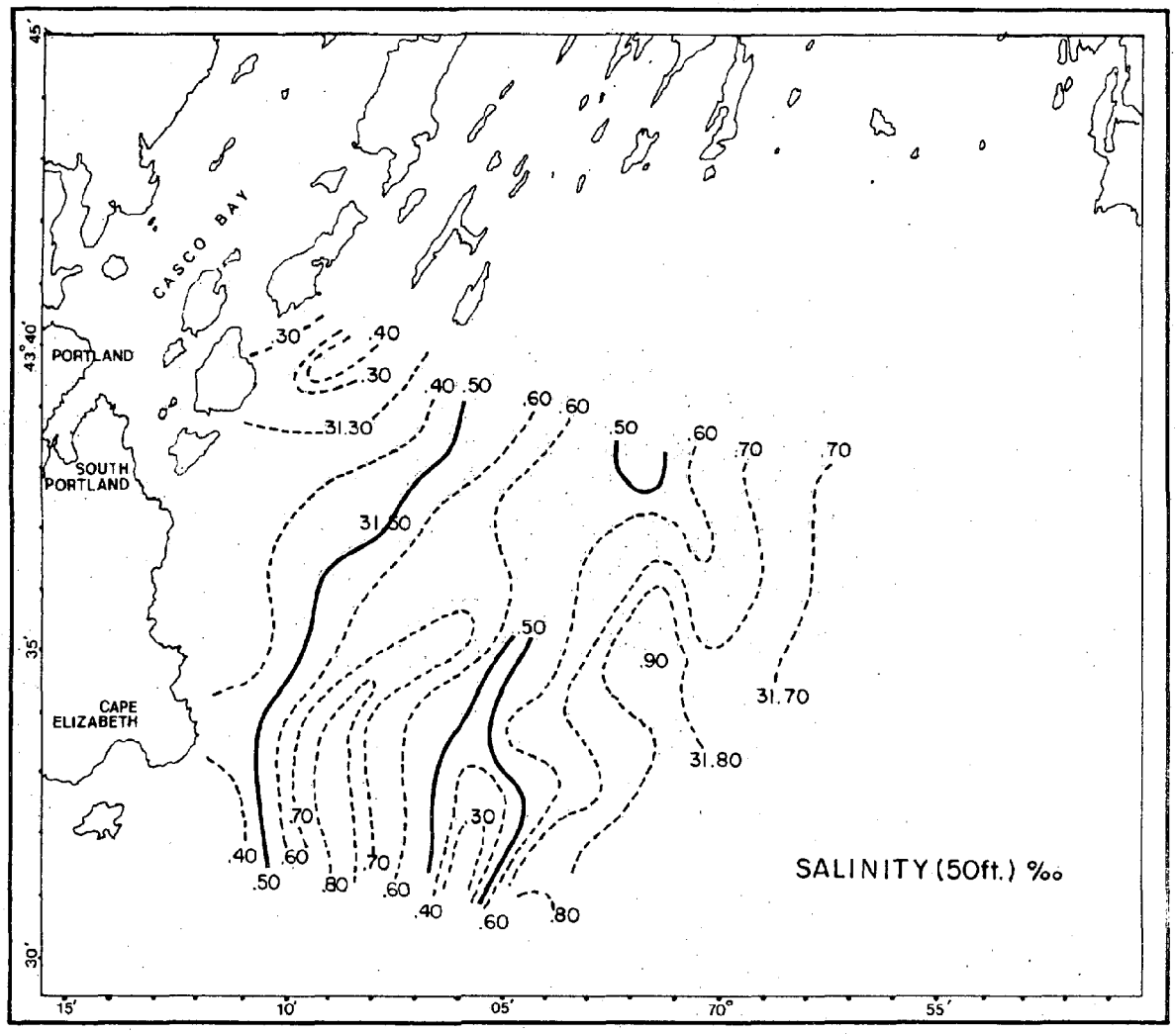
TRIGOM PARC	FIGURE 4-63	Lower Casco Bay Salinity - 25 Feet (Graham, 1970b)



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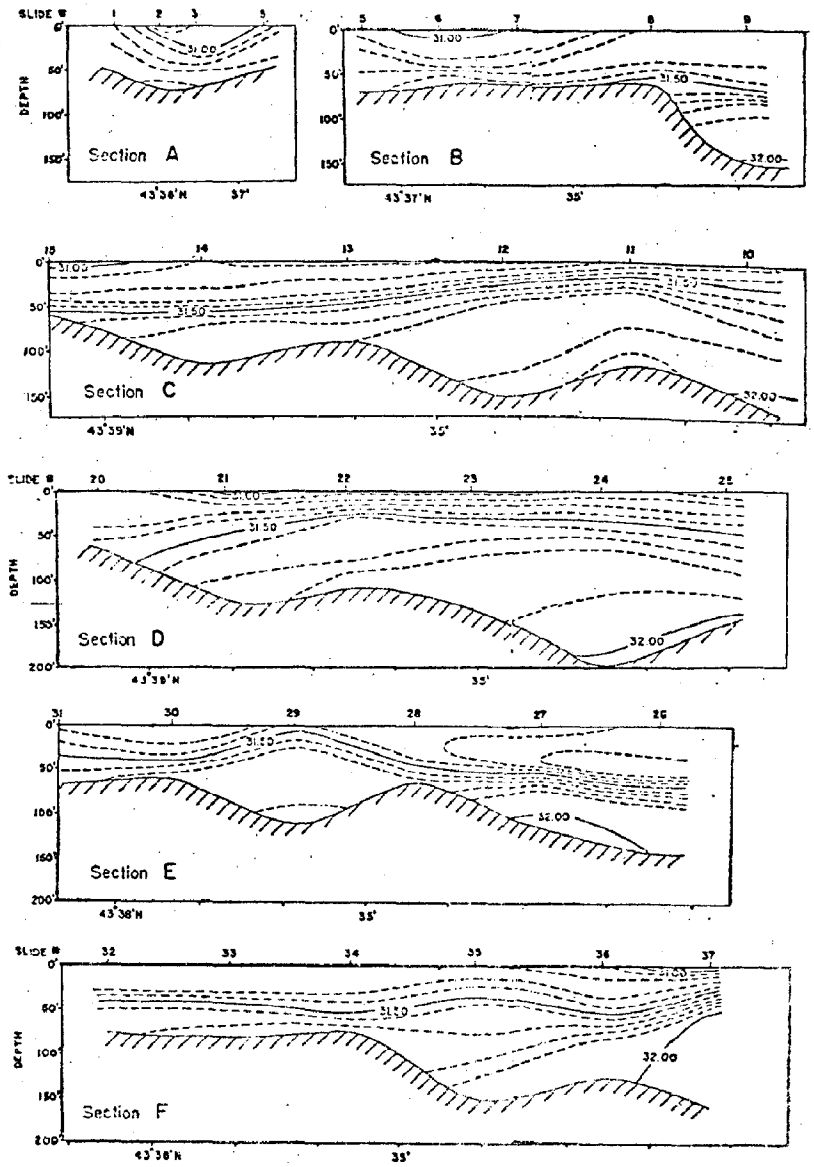
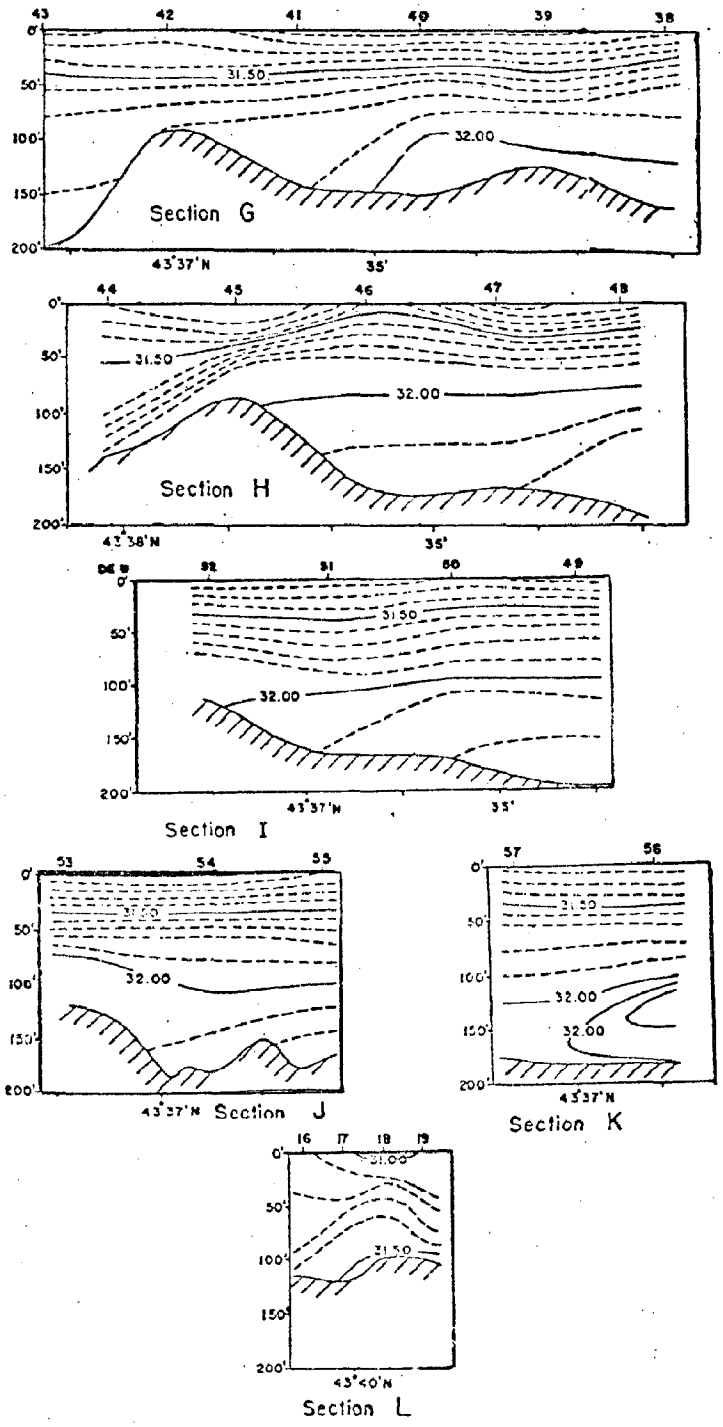
TRIGOM PARC	FIGURE 4-64	Lower Casco Bay Salinity - 50 Feet (Graham, 1970b)



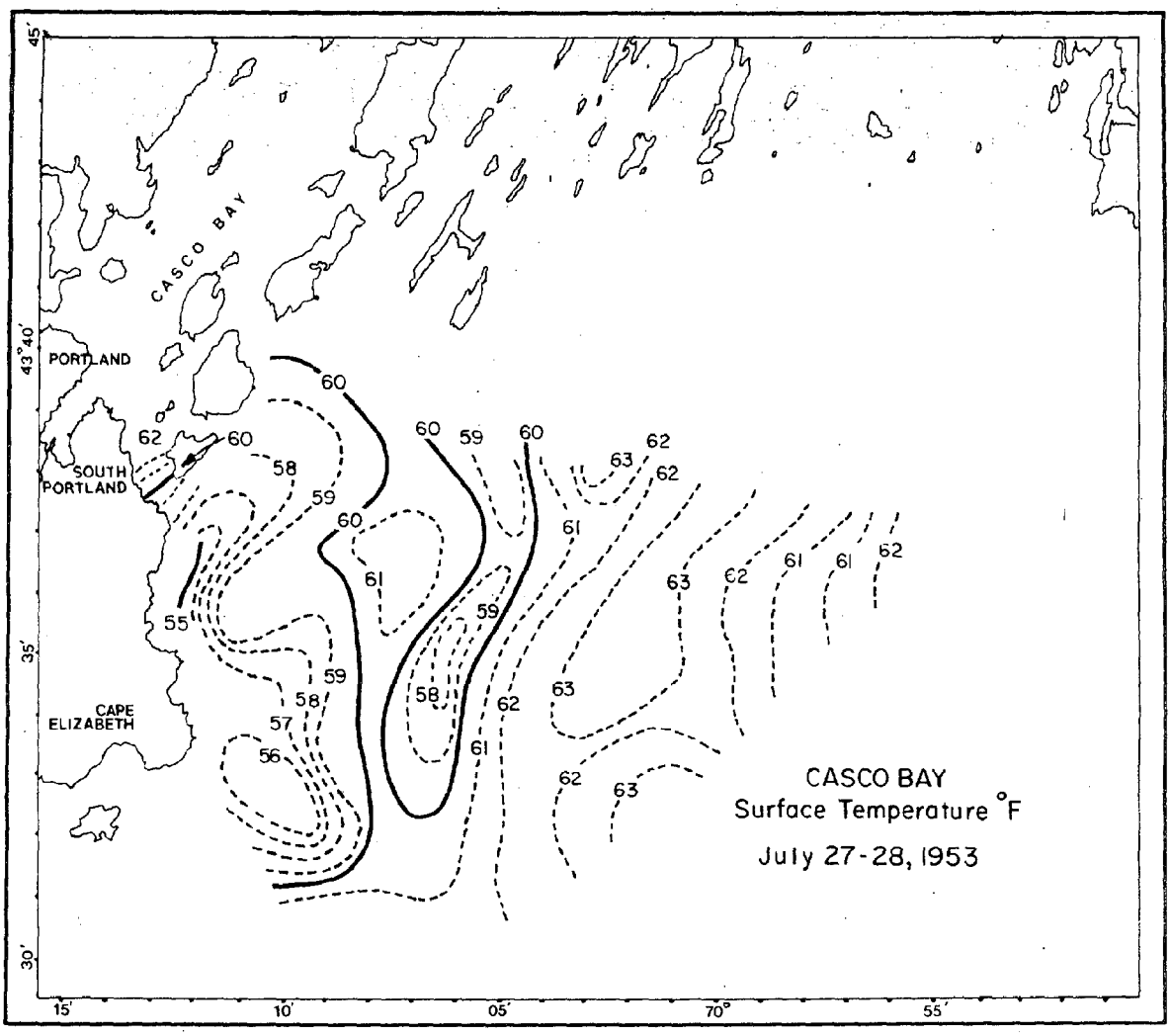
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-65a	Lower Casco Bay - Vertical Salinity Section (Brayton and Campbell, 1953)



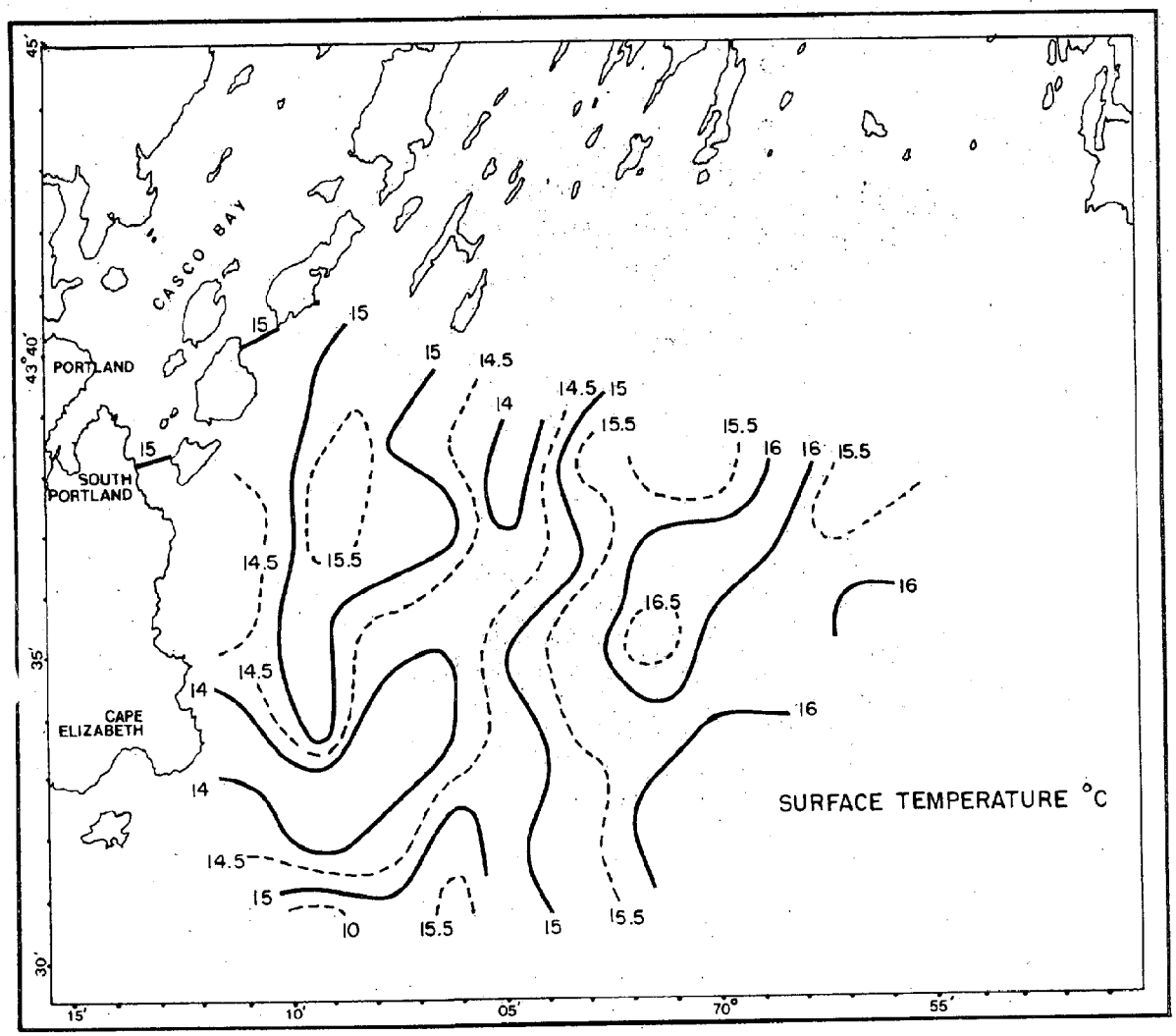
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-65b	Lower Casco Bay - Vertical Salinity Section (Brayton and Campbell, 1953)



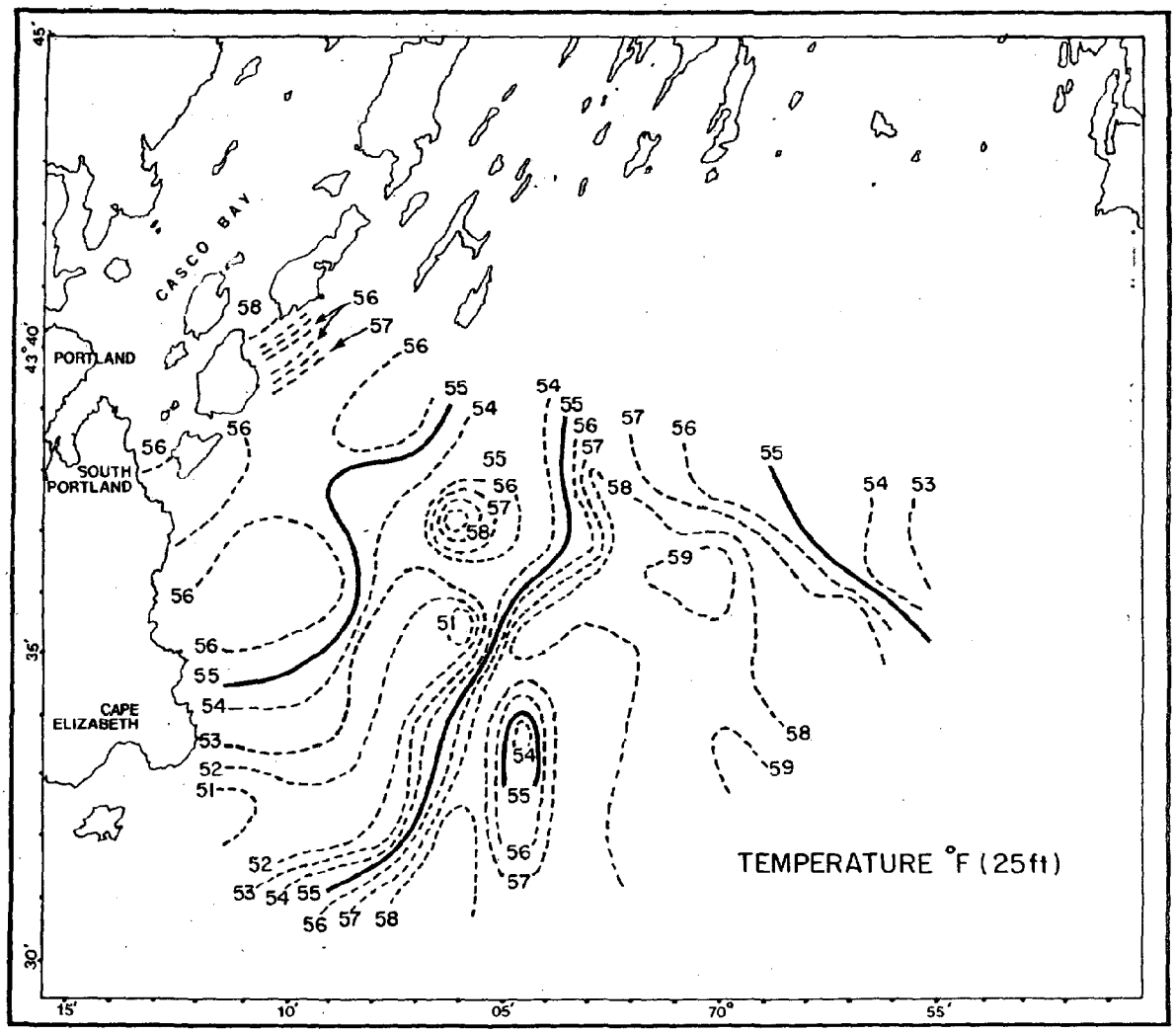
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-66	Lower Casco Bay Temperature - °F, Surface (Brayton and Campbell, 1953)

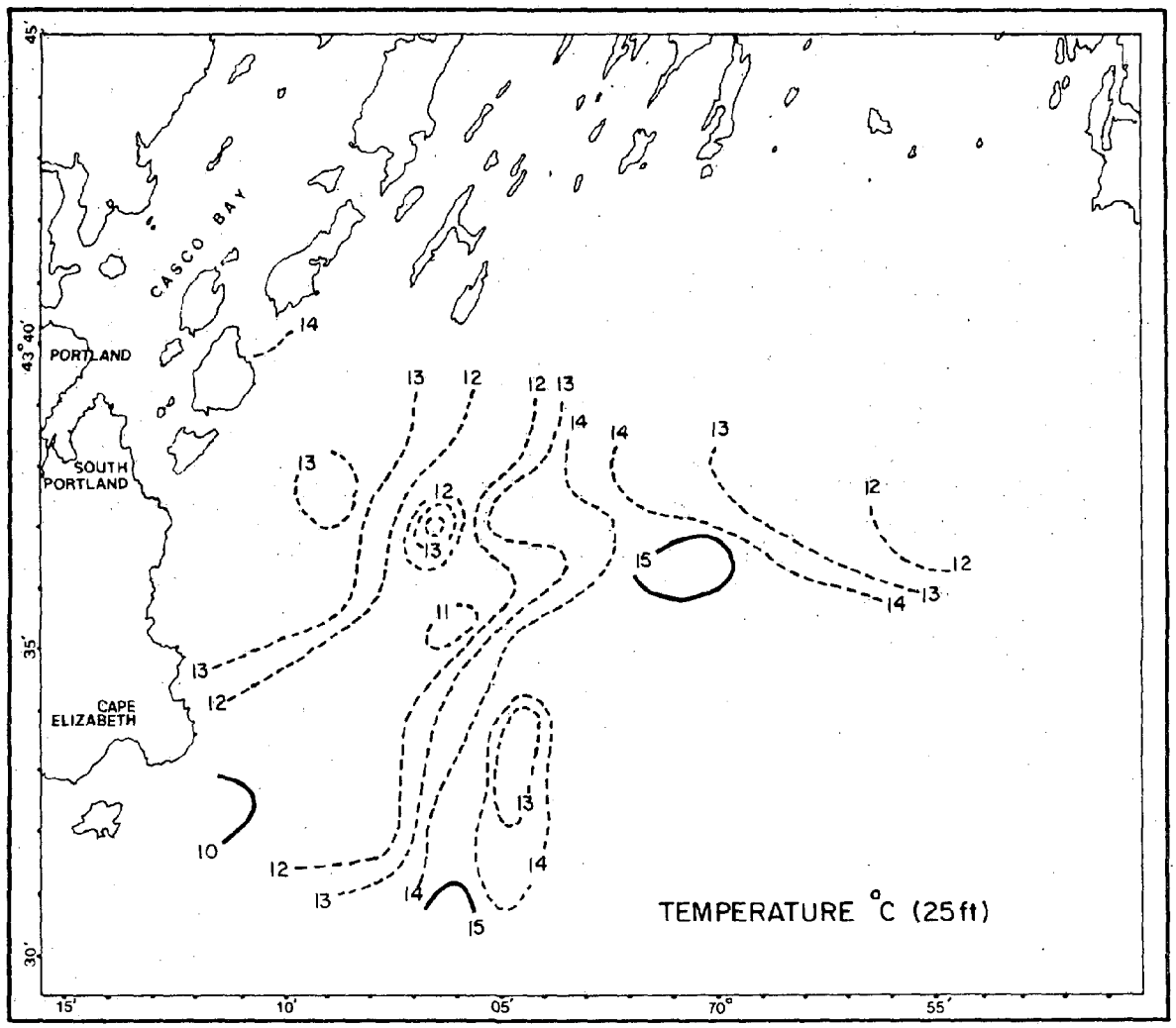


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-67	Lower Casco Bay Temperature - °C, Surface (Brayton and Campbell, 1953)

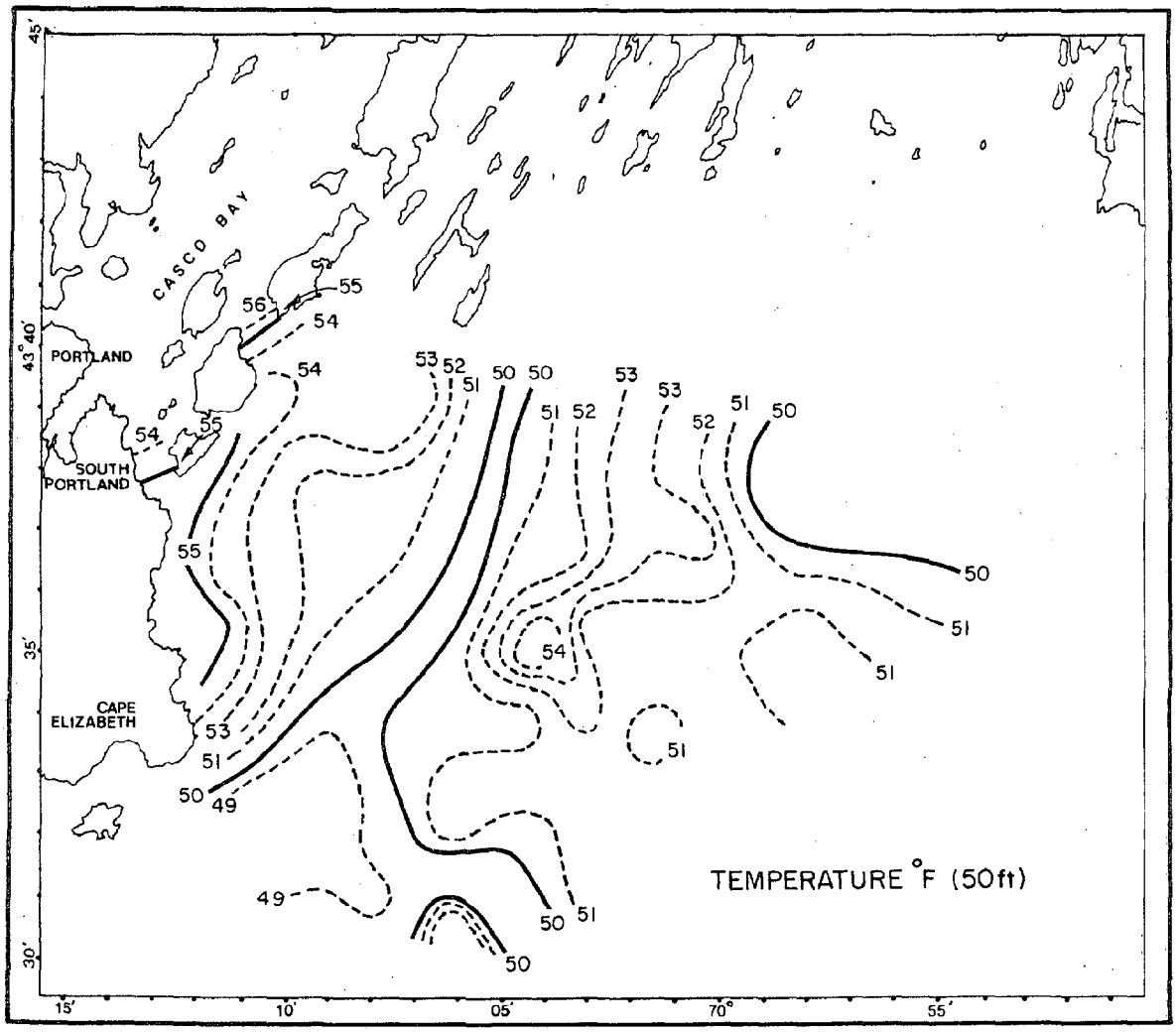


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-68	Lower Casco Bay Temperature - °F, 25 Feet (Brayton and Campbell, 1953)



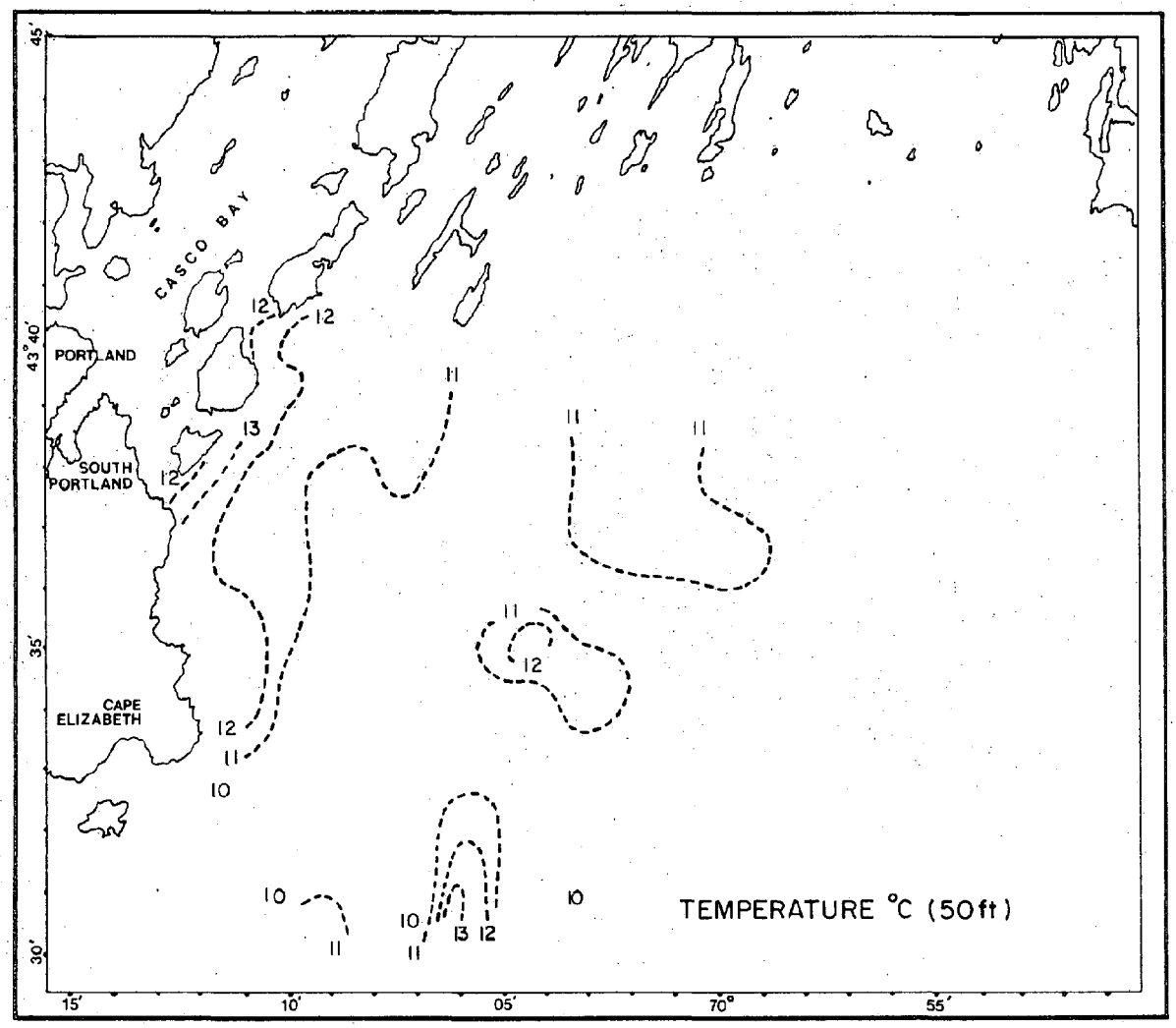
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-69	Lower Casco Bay Temperature - oC, 25 Feet (Brayton and Campbell, 1953)



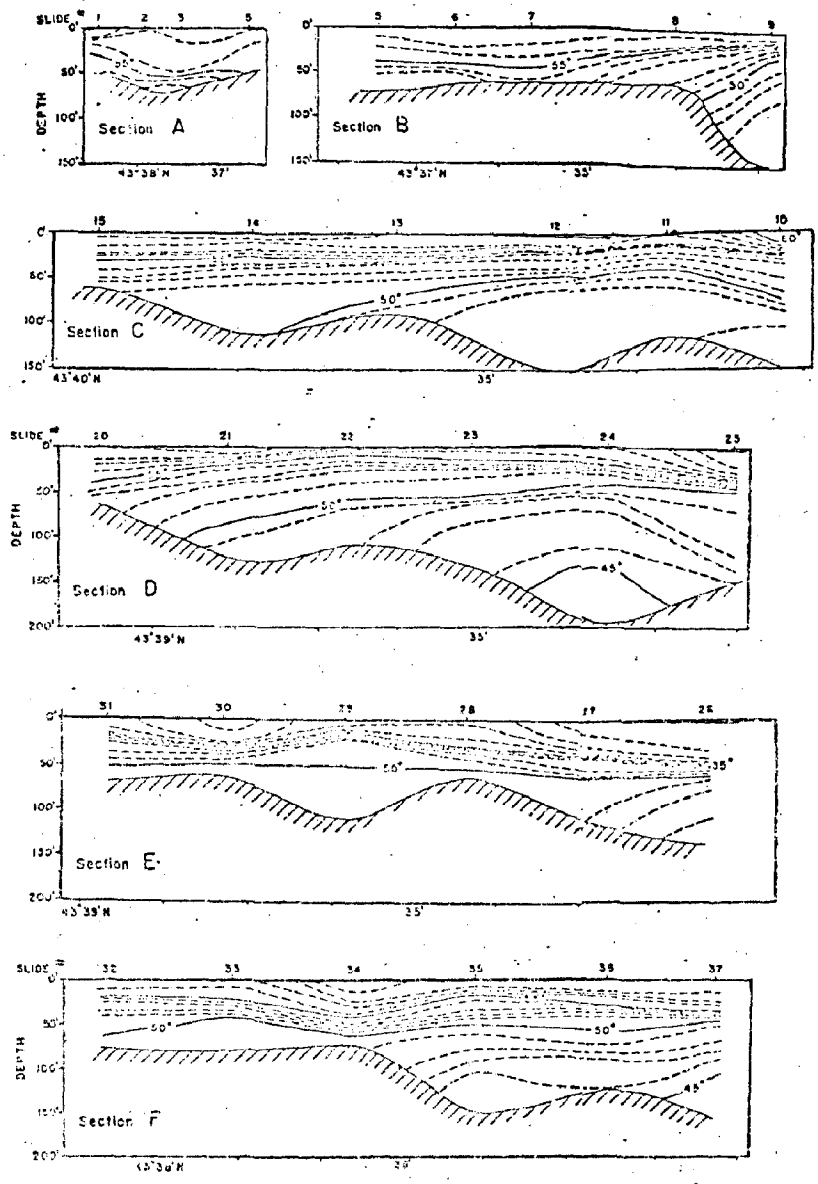
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-70	Lower Casco Bay Temperature - F°, 50 Feet (Brayton and Campbell, 1953)



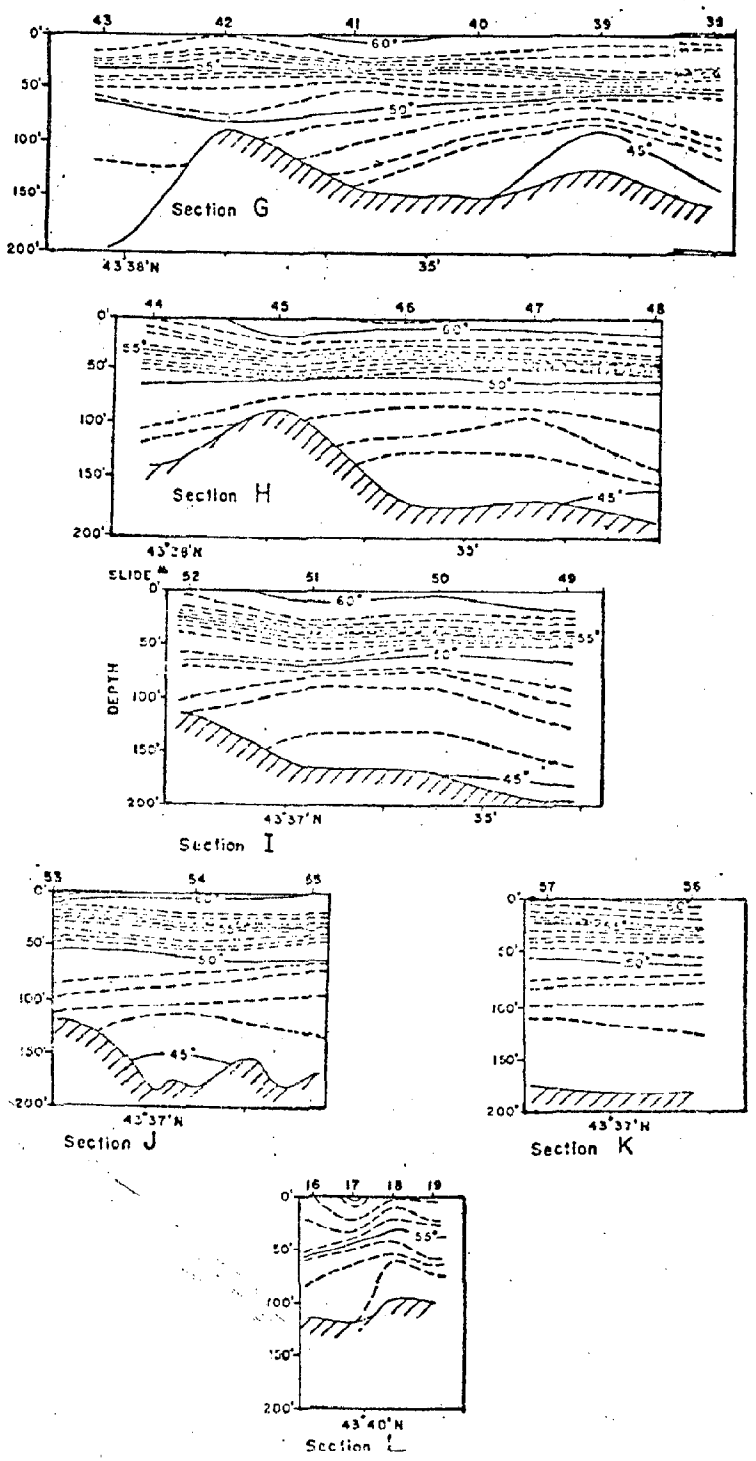
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-71	Lower Casco Bay Temperature - C°, 50 Feet (Brayton and Campbell, 1953)



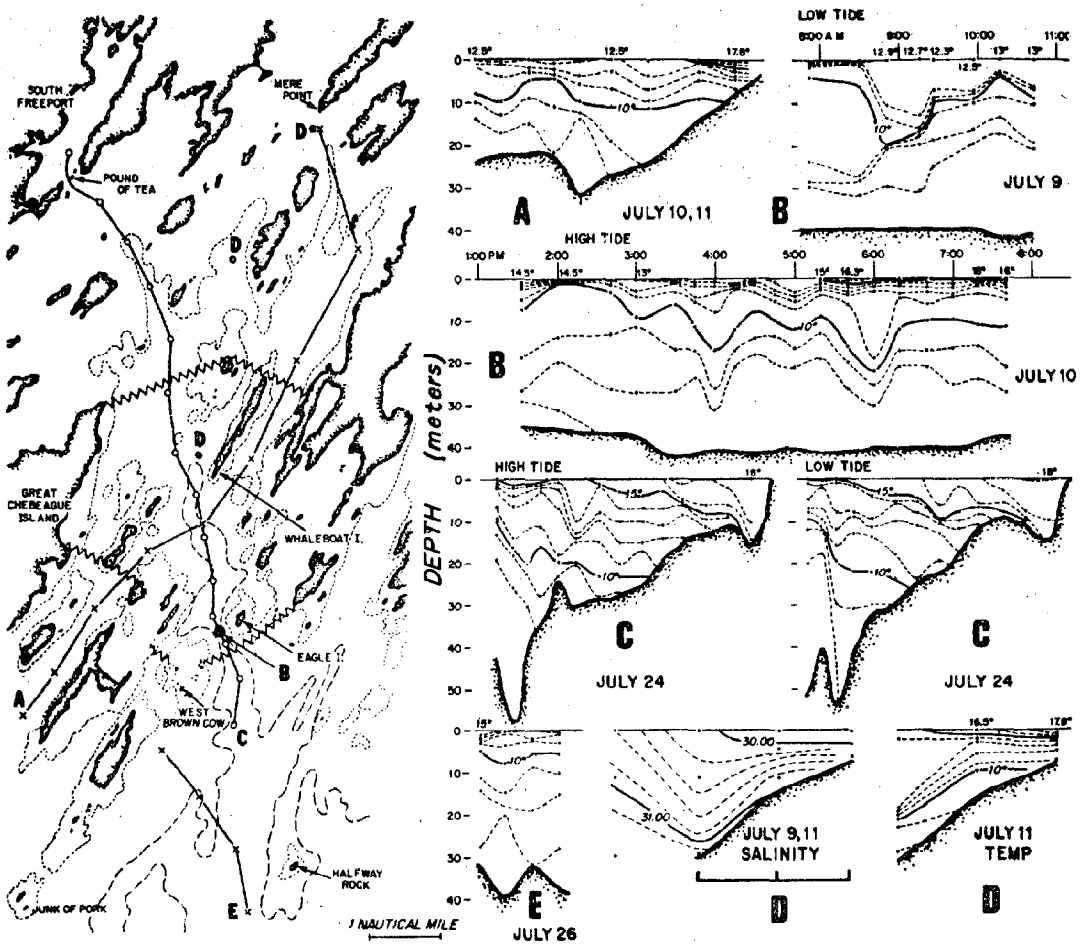
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-72a	Lower Casco Bay Vertical Temperature Sections (Brayton and Campbell, 1953)



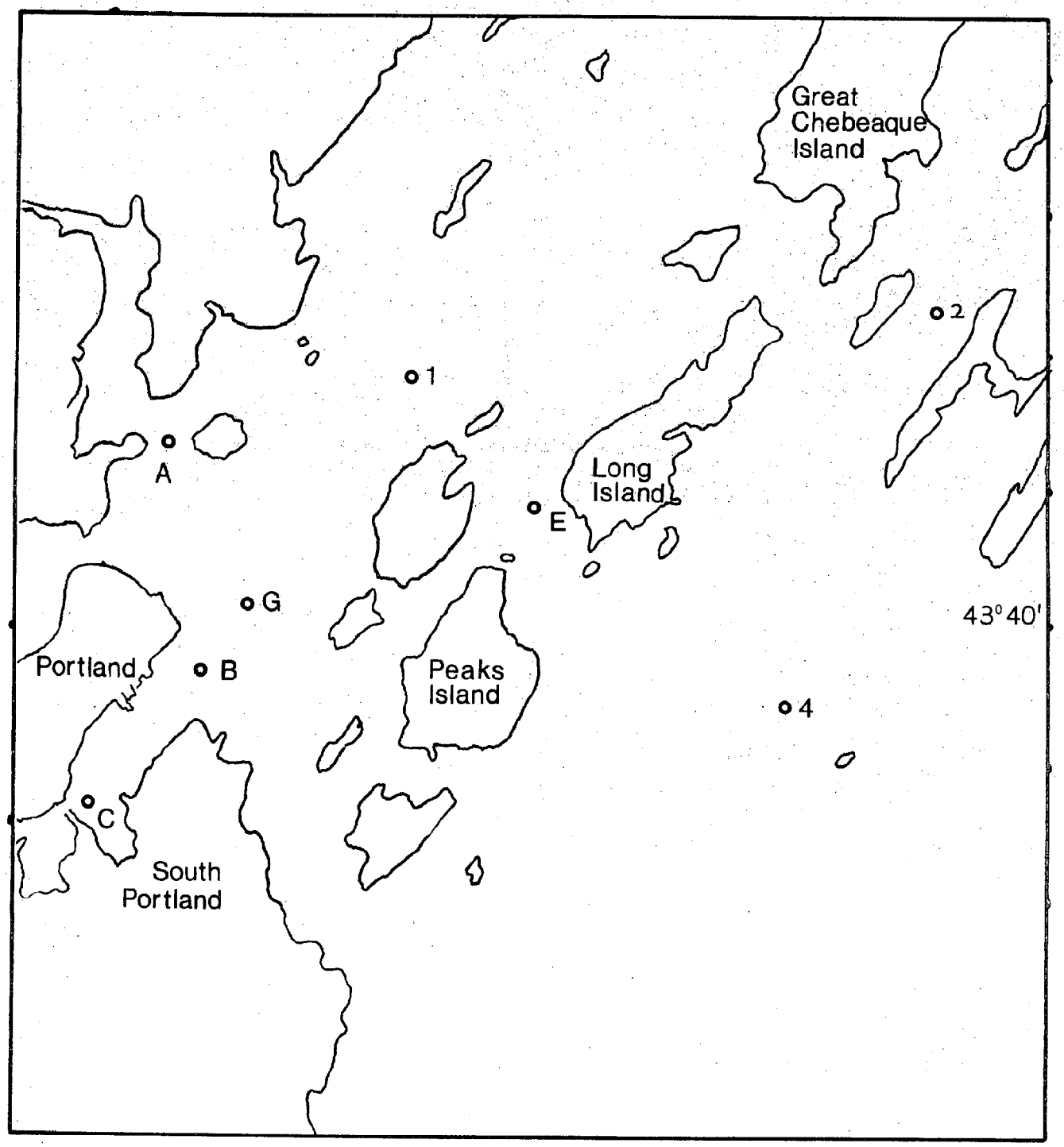
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-72b	Lower Casco Bay Vertical Temperature Sections (Brayton and Campbell, 1953)



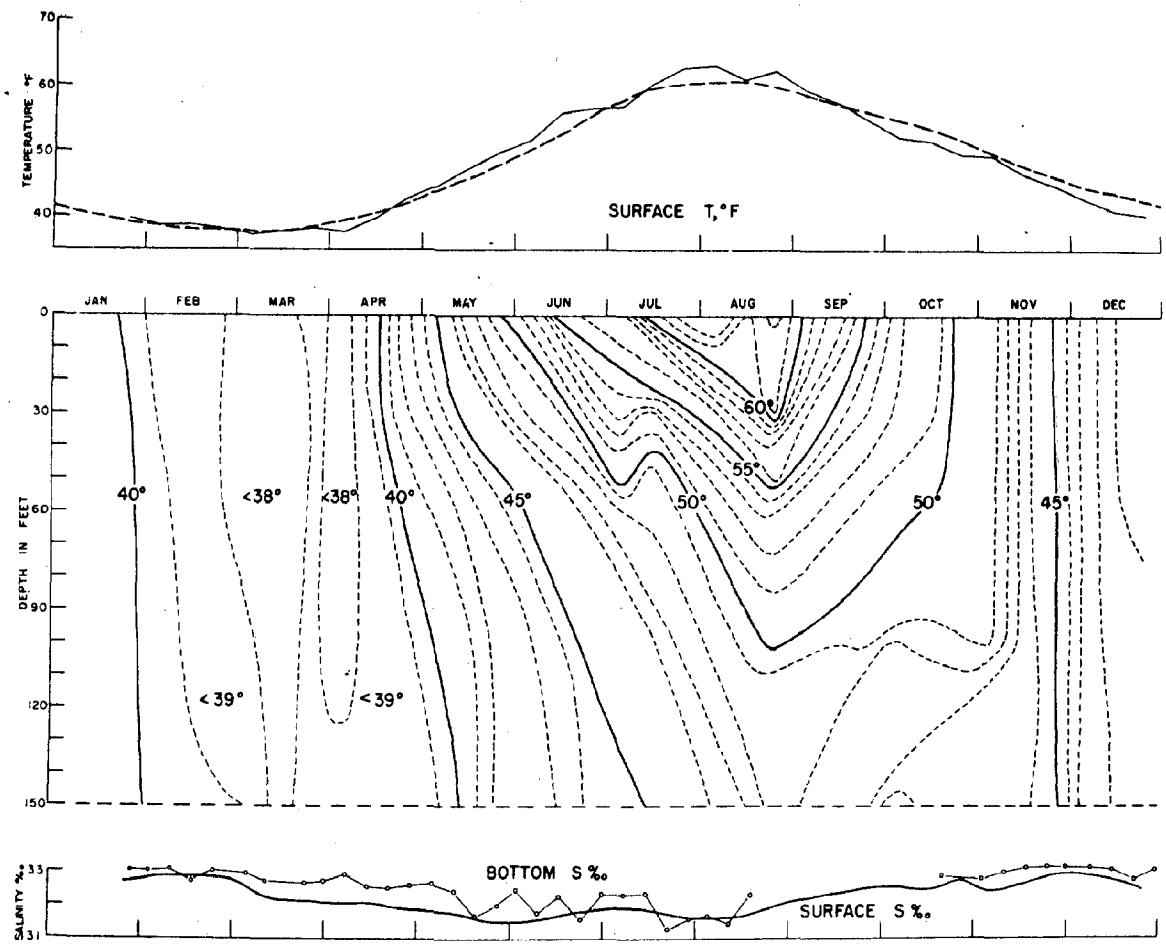
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-73	Central Casco Bay-Vertical Temperature Sections (Hulbert, 1968)



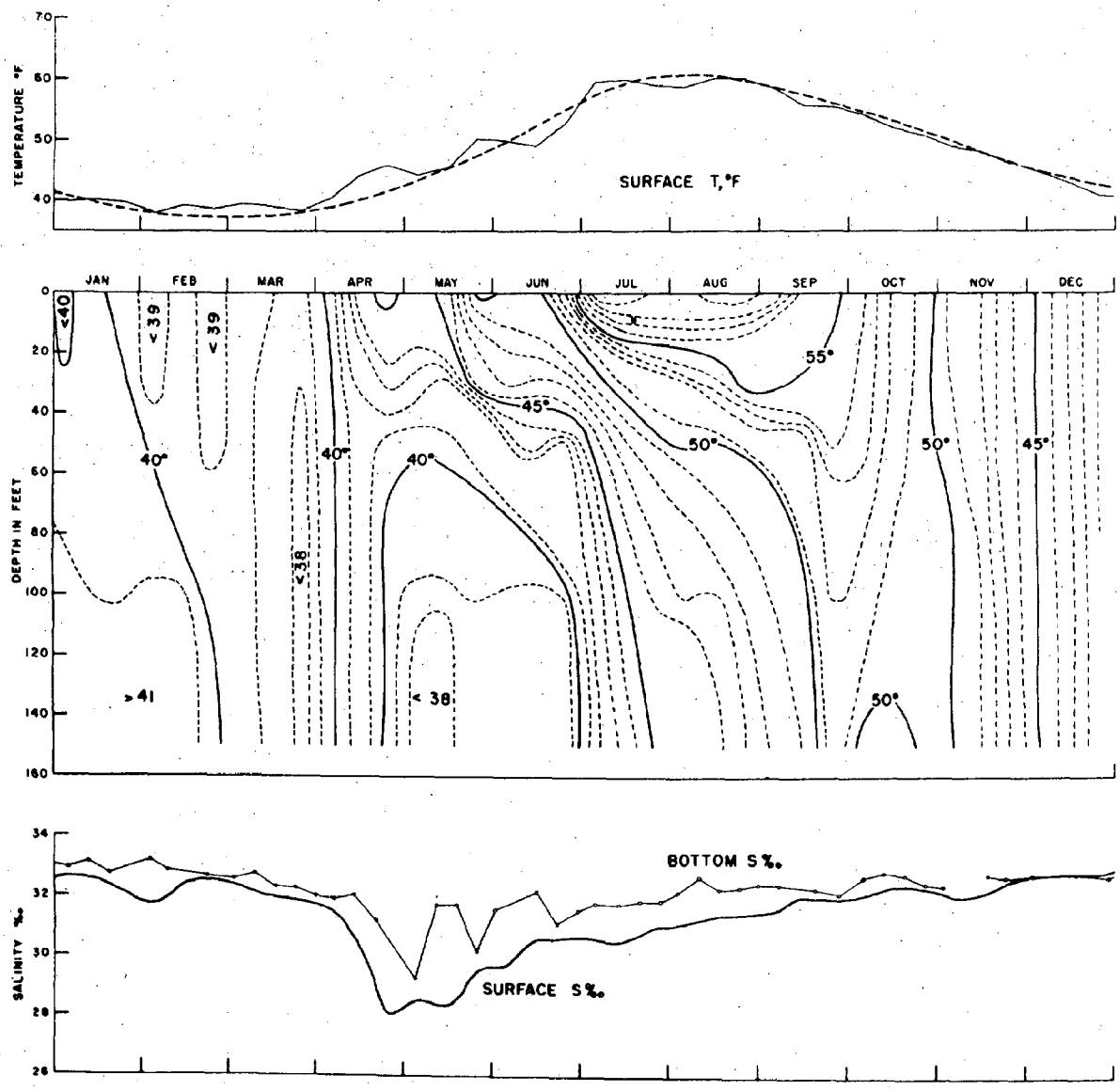
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-74	Upper Casco Bay-Salinity and Temperature Stations



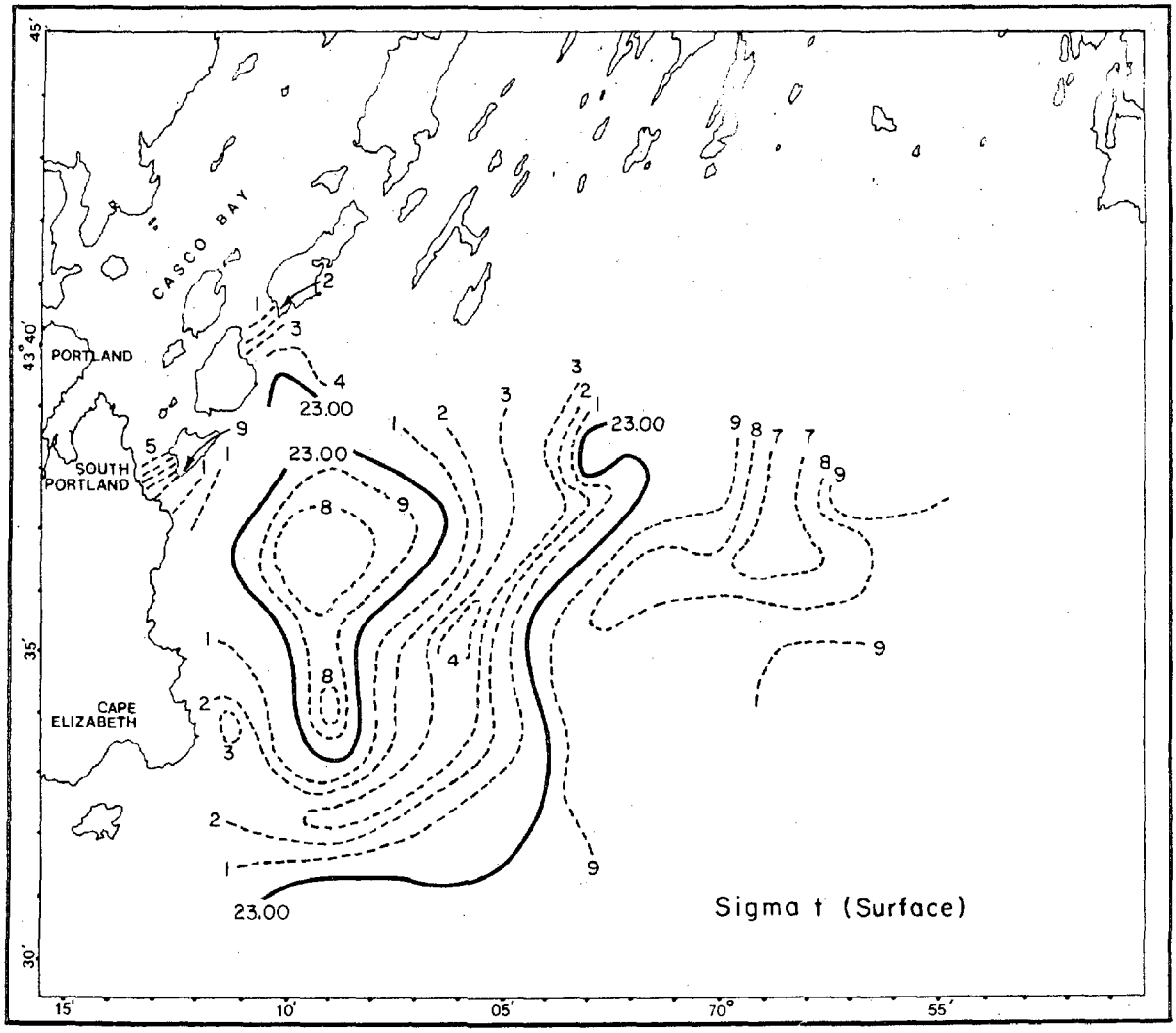
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-75	Portland Lightship-Salinity and Temperature Data (Day, 1959a)



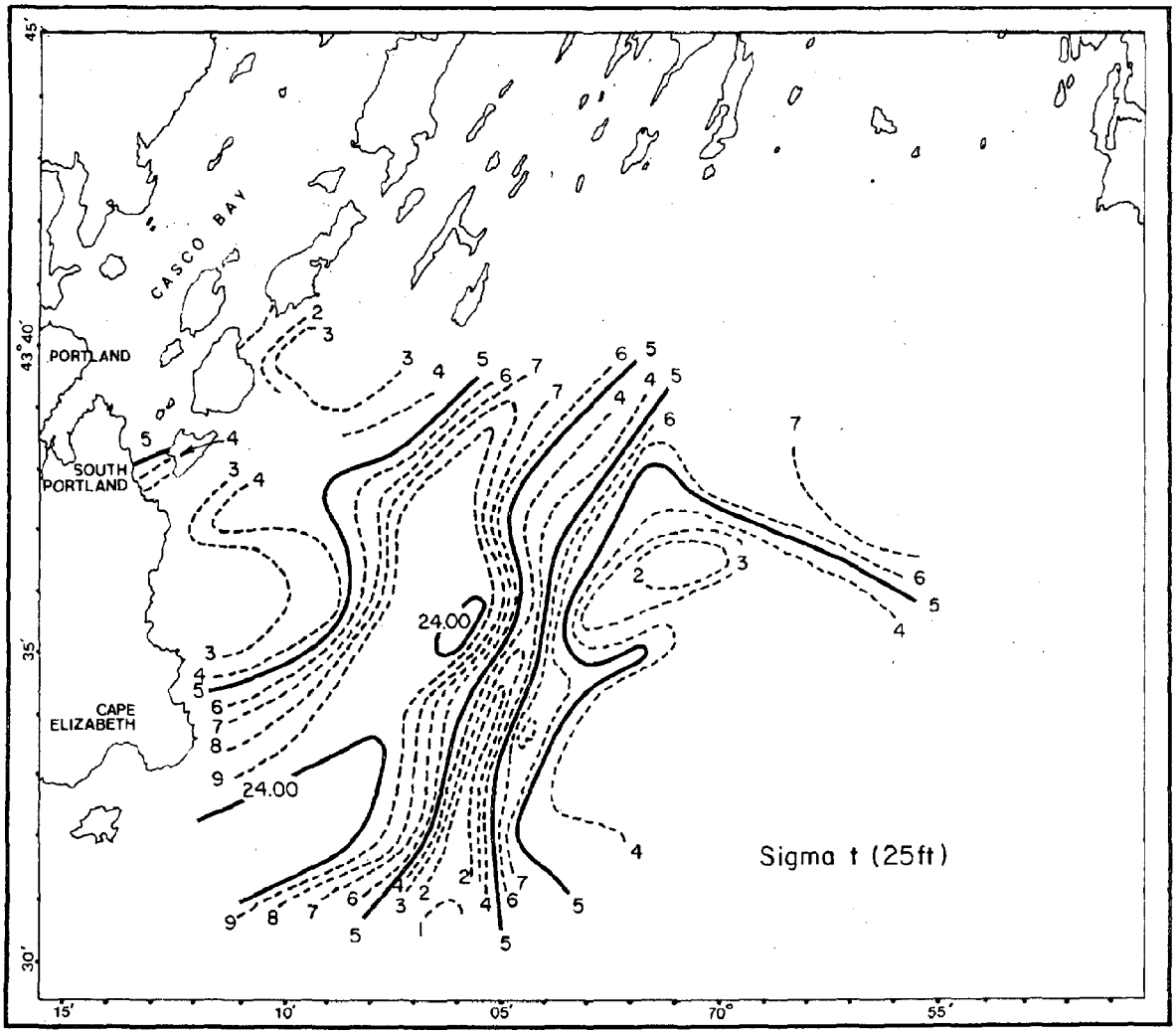
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-76	Portland Lightship-Salinity and Temperature Data (Day, 1959b)



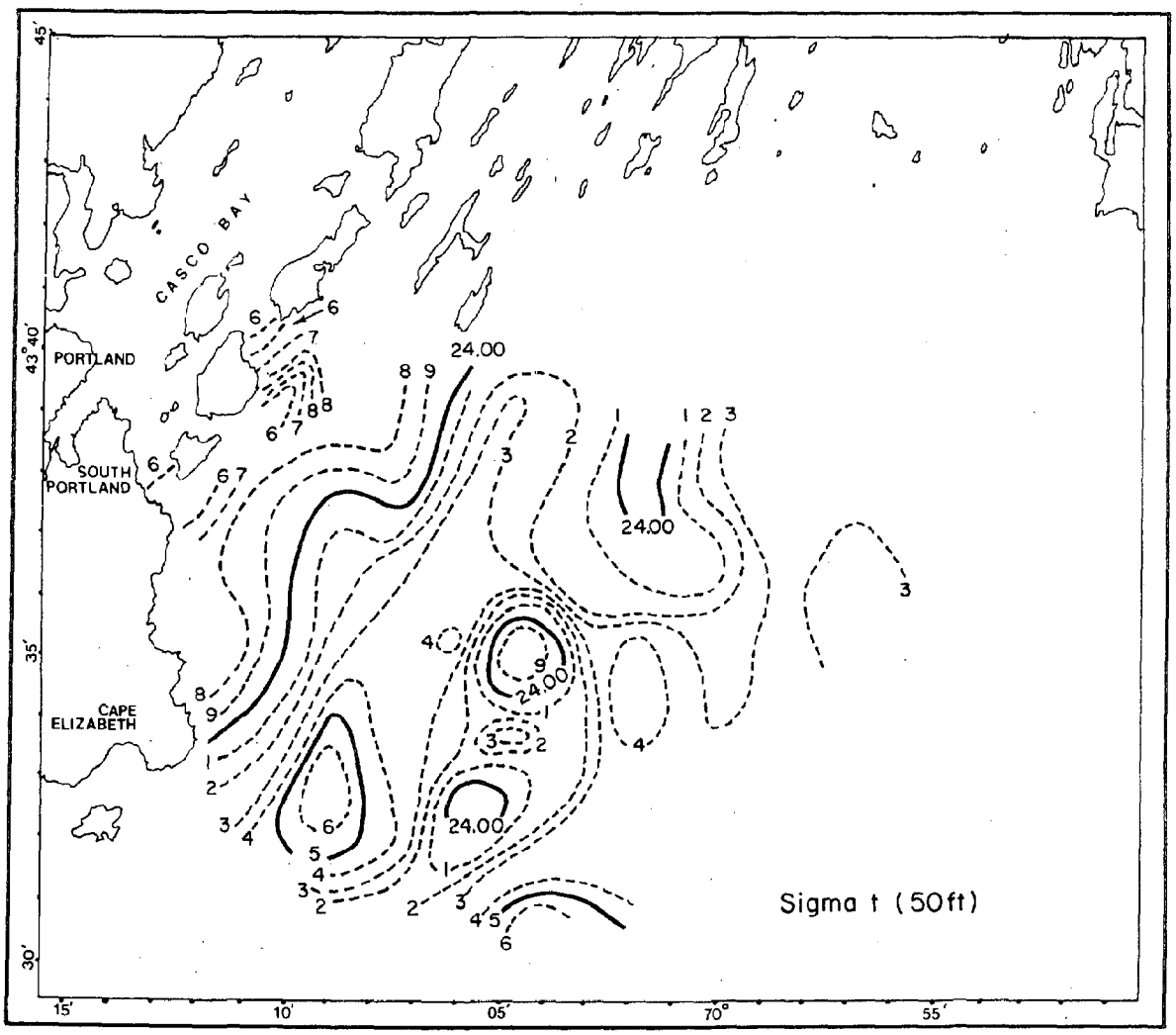
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-77	Distribution of Density (Sigma t) in Lower Casco Bay - Surface (Brayton and Campbell, 1953)

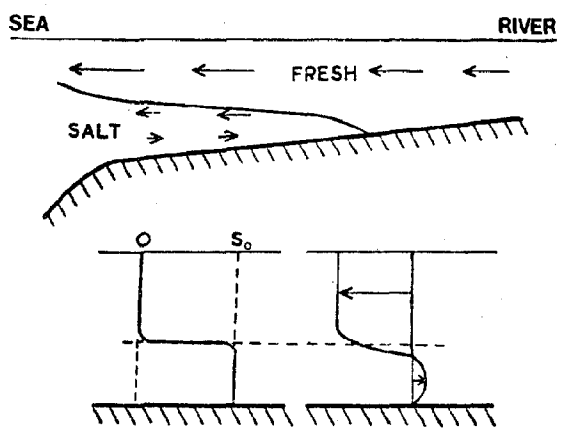


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

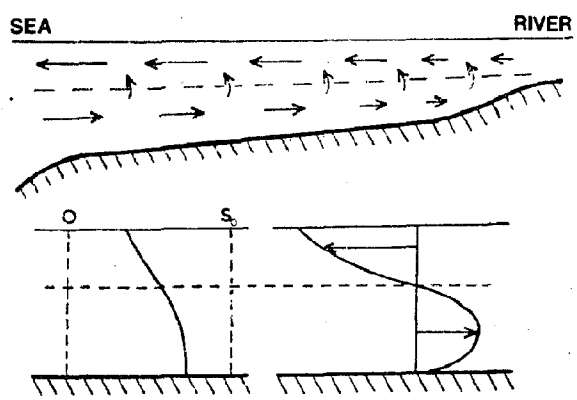
TRIGOM PARC	FIGURE 4-78	Distribution of Density (Sigma t) in Lower Casco Bay - 25 Feet (Brayton and Campbell, 1953).



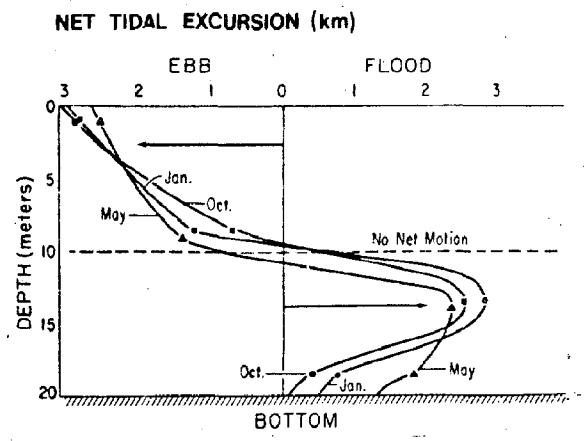
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-79	Distribution of Density (Sigma t) in Lower Casco Bay - 50 Feet (Brayton and Campbell, 1953)



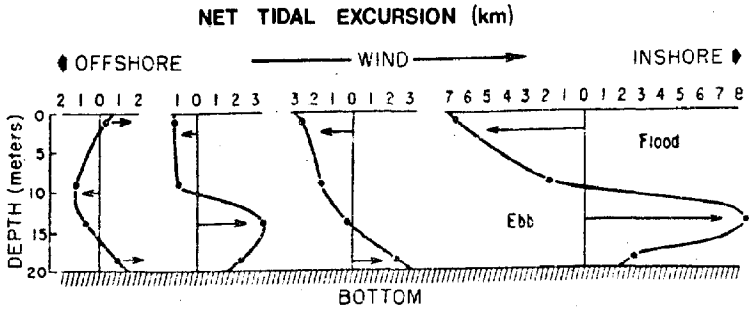
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-80	Salinity and Velocity Profiles of a Salt Wedge Estuary (Bowden, 1967)



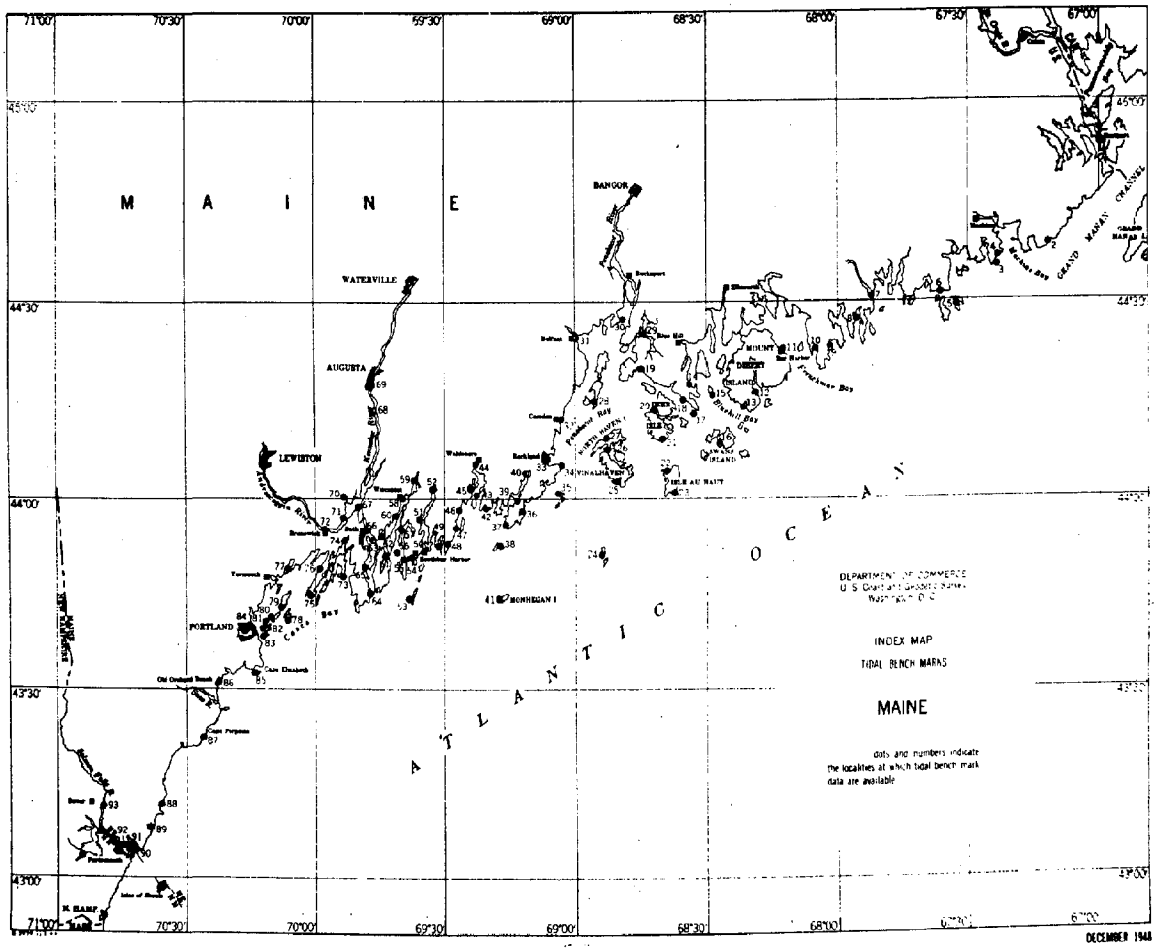
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-81	Salinity and Velocity Profiles of a Partially Mixed Estuary (Bowden, 1967)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-82 a	Vertical Profiles of Mean Tidal Excursions in the Sheepscot Estuary (Graham, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-82b	An Effect of Offshore Winds in the Net Tidal Excursions Along the Channel of the Sheepscot Estuary (Graham, 1972)



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

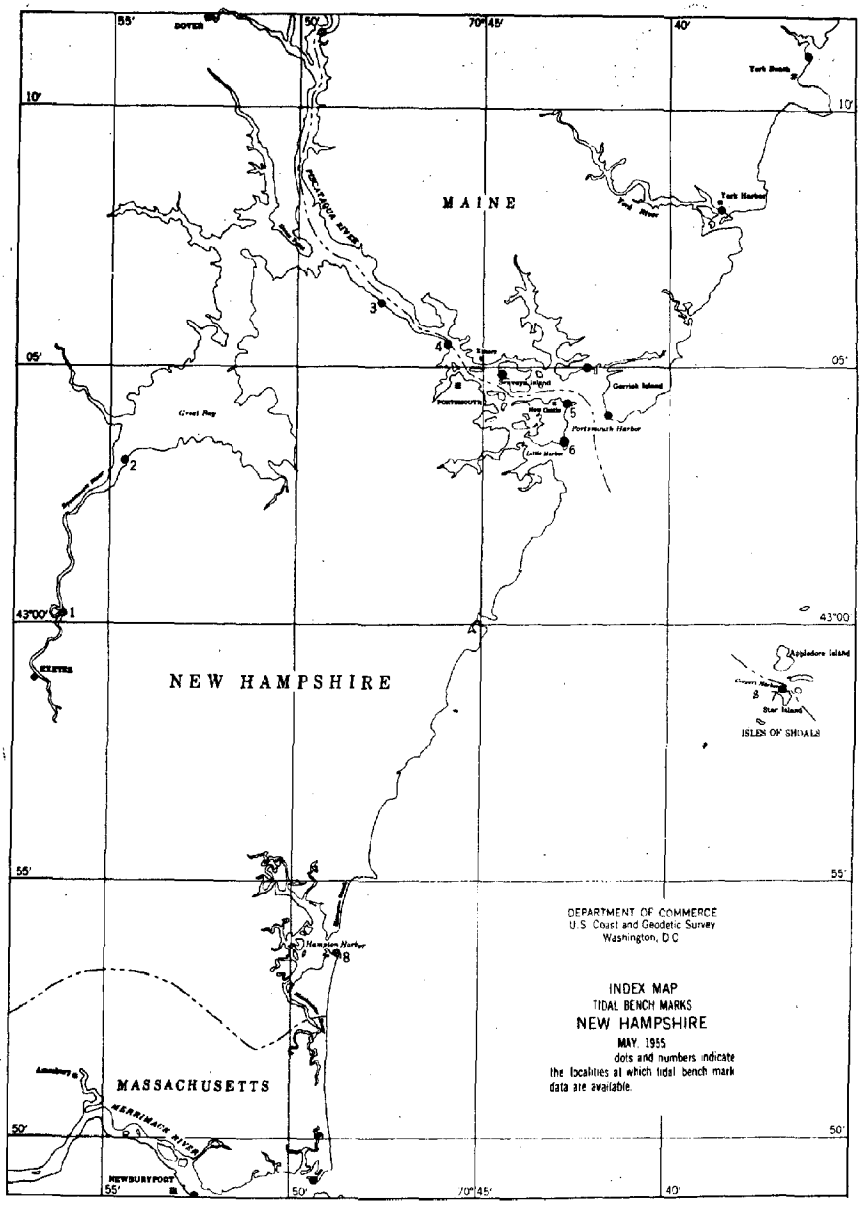
TRIGOM PARC	FIGURE 4-83a	Index Map - Tidal Bench Marks - Maine (U.S. Dept. of Commerce, 1948)

Table 4-11a Tidal Bench Mark Locations - * Maine

Index Map Number	Name
1	Eastport
2	Cutler, Little River
2A	Stone Island, Machias Bay
3	Starboard Island, Machias Bay
3A	Machiasport
4A	Shoppee Point, Englishman Bay
5	Steel Harbor Island
6	Jonesport, Moosabec Reach
7	Marraguagus River Entrance
7A	Green Island, Petit Manen Bar
8	Fish Island, Pinkham Bay
8A	Sand Cove, Gouldsboro Bay
8B	Couldsboro Bay (North End)
9	Prospect Harbor
10	Winter Harbor, Frenchman Bay
11	Bar Harbor, Mount Desert Island
12	Southwest Harbor, Mount Desert Island
13	Bernard, Bass Harbor, Mount Desert Island
14A	Blue Hill Harbor, Blue Hill Bay
16	Burnt Coat Harbor, Swans Island
15A	Mackerel Cove, Swans Island
22A	Isle Au Haut (NE end)
22B	Isle Au Haut (Thorofare)
24	Matinicus (Wheaton Island)
25	Vinalhaven, Vinalhaven Island
27	Pulpit Harbor, North Haven Island
30A	Winterport, Penobscot River
31	Belfast, Penobscot Bay
33	Rockland, Penobscot Bay
37	Port Clyde
38	Burnt Island, Georges Islands
39	Otis Cove, St. George River
40	Thomaston, St. George River
41	Monhegan Island
42	Jameson Point, Friendship Harbor
43	Jones Neck, Medomak River
44	Waldoboro, Medomak River
46	Muscongus Harbor
47	Moxie Cove, Muscongus Sound
48	New Harbor, Muscongus Sound
49	Fort Point, Johns Bay
50	East Boothbay, Damariscotta River

Table 4-11a (continued)

Index Map Number	Name
51	East Edgecomb, Damariscotta River
52	Newcastle, Damariscotta River
53	Damariscove Harbor
54	Boothbay Harbor
55	Southport, Townsend Gut
56	Isle of Springs, Sheepscot River
57	Cross River (N. end Barter's I.)
58	Wiscasset, Sheepscot River
59	Sheepscot, Sheepscot River
60	Back R. Ferry, Westport I.
61	Robinhood Riggs Cove
62	Phipps Point, Hockomock Bay
63	Palace Cove, Sassanoa River
64	Hunniwell Pt. (Fort Popham)
65	Phippsburg, Kennebec River
66	Bath, Kennebec River
67	Sturgeon I., Merrymeeting Bay
71	Androscoggin River Entrance
72	Brunswick, Androscoggin River
73	Cundy Harbor, New Meadows River
74	Howard Point, New Meadows River
75	South Harpswell, Potts Harbor
76	Wilson Cove, Harpswell Neck
78	Jewell Island, Casco Bay
79	Great Chebeague I., Casco Bay
80	Long Island, Casco Bay
81	Great Diamond I., Casco Bay
82	Peak's Island, Casco Bay
83	Cushing Island, Casco Bay
84	Portland
85	Richmond Island
87	Cape Porpoise (Bickford I.)
89	York
90	Gerrish I., Whf., Portsmouth Harbor
91	Kittery Point, Pepperell Cove
92	Portsmouth Navy Yard, Seavy I.
93	Salmon Falls River Bridge



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

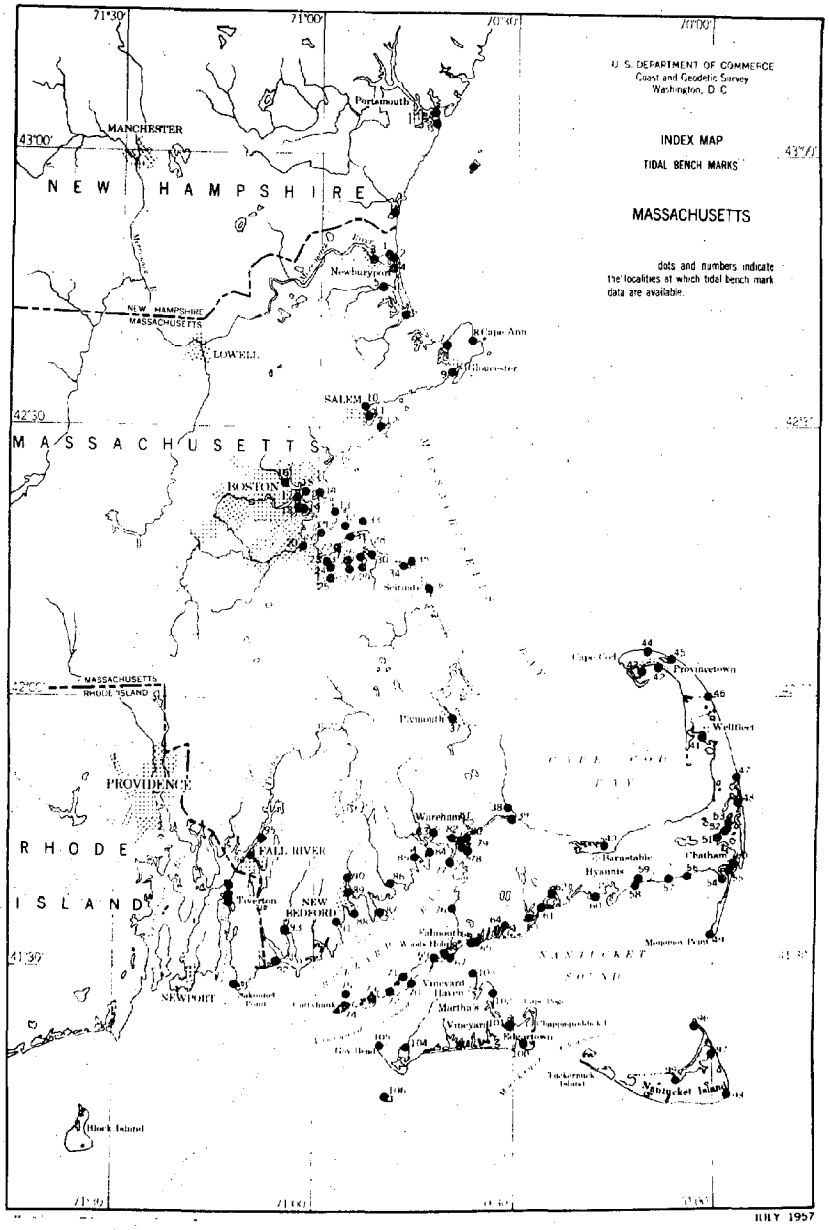
TRIGOM PARC

FIGURE 4-83b

Index Map - Tidal Bench Marks - New Hampshire (U.S. Dept. of Commerce, 1955)

Table 4-11b New Hampshire

Index Map Number	Name
2	Squamscott River Railroad Bridge
3	Newington, Piscataqua River
4	Atlantic Heights (National Gypsum Co.), Piscataqua River
5	Fort Point (Fort Constitution), New Castle Island
6	Jaffrey Point (Fort Stark), New Castle Island
7	Gosport Harbor, Star Island, Isles of Shoals
8	Hampton River Entrance



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

TRIGOM PARC	FIGURE 4-83c	Index Map - Tidal Bench Marks - Massachusetts (U.S. Dept. of Commerce, 1955)

Table 4-11c Massachusetts

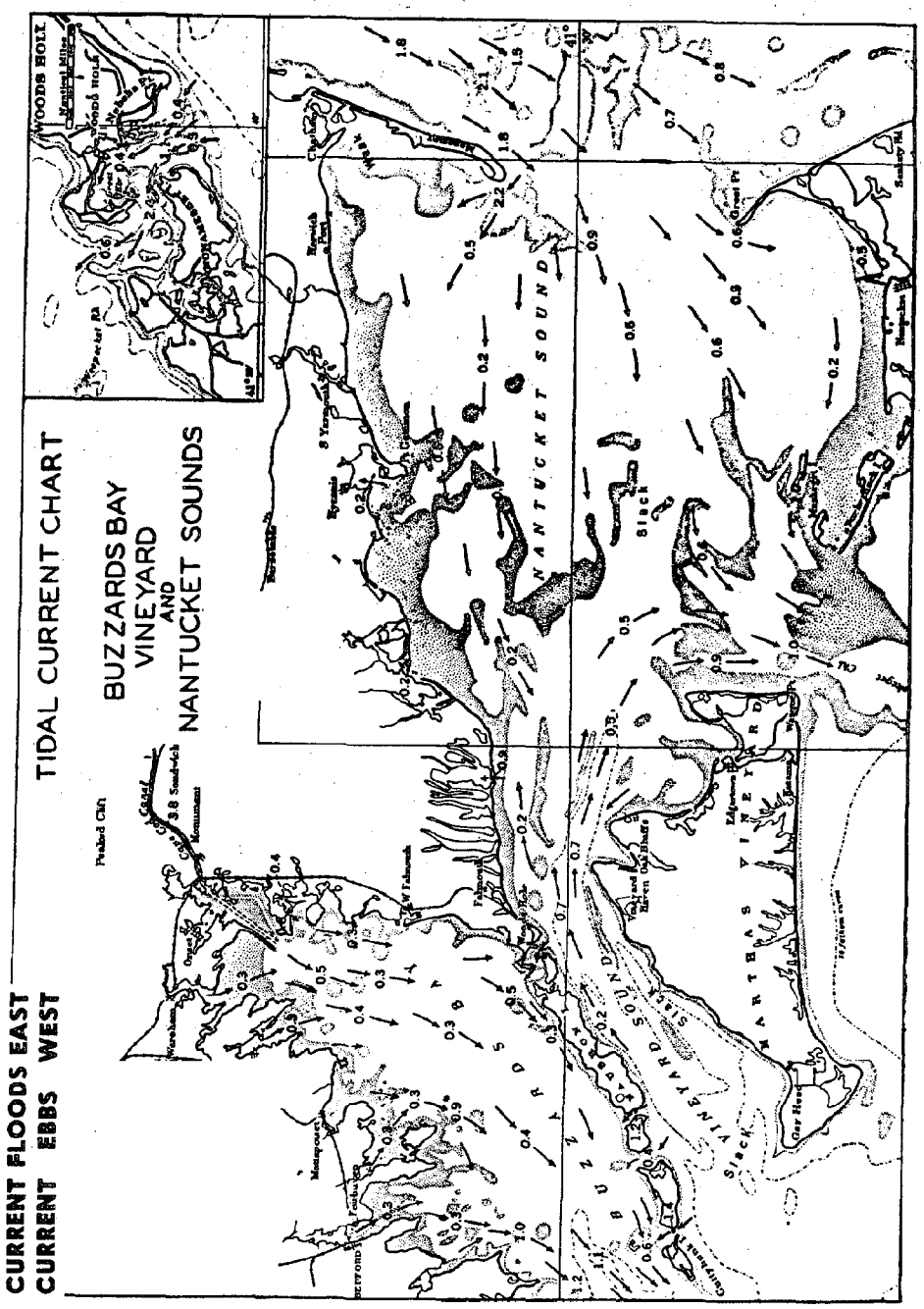
Index Map Number Fig. 4.3-18c	Name
1	Salisbury Beach, Merrimack River Entr.
2	Plum Island (North End), Merrimack River Entr.
3	Newburyport, Merrimack River
4	Plum Island Highway Bridge, Plum I. River
5	Newbury Old Town, Parker River
6	Plum Island (South End), Plum I. Sound
7	Annisquam, Annisquam River
8	Rockport Harbor
9	Ten Pound Island, Gloucester Harbor
11	Salem
13	Fort Dawes, Deer I., Boston Harbor
14	Belle Isle Inlet, Winthrop
15	Chelsea St. Bridge, Chelsea R., E. Boston
16	Wellington Memorial Bridge, Mystic River
17	Boston Naval Shipyard, Charlestown
18	Boston (Appraisers Stores)
19	South Boston and Vincinity
20	Neponset R., Highway Bridge, Boston Harbor
21	Moonhead
22	Nut Island, Quincy
23	Town River Yacht Club, Town River Bay
24	Weymouth, Fore River Bridge
25	Weymouth, Weymouth Fore River
26	Eastern Neck, Weymouth Back River
27	Hingham (Naval Ammunition Depot), Weymouth Back River
28	Crow Point, Hingham Harbor Entrance
29	Hingham, Hingham Harbor
30	Nantasket, Weir R., Hingham Bay
31	Hull (Windmill Pt.), Hingham Bay
33	Boston Lt. Lighthouse I., Boston Harbor
34	White Head, Cohasset Harbor
36	Scituate
36A	Damons Point, North River
37	Plymouth, Plymouth Harbor
39	Cape Cod Canal Entrance, Cape Cod Bay
40	Barnstable Harbor (Beach Point), Cape Cod
43	Provincetown and Vicinity, Cape Cod
44	Peaked Hill Bar, Outer Coast Cape Cod
46	Little America (Head of Pamet River), Cape Cod
49	Powder Hole, Monomoy Point
50	Chatham, Lydia Cove
51	Pleasant Bay (Quanset Pond)
52	Little Pleasant Bay (Southwest End)

Table 4-11c (continued)

Index Map Number Fig. 4.3-18c	Name
53	Little Pleasant Bay (Northwest End)
55	Chatham Stage Harbor
56	Wychmere Harbor, Harwichport
57	Herring River Entrance
59	South Yarmouth, Bass River
60	Hyannisport
62	Cotuit, Great Bay
63	Poponesset Island, Poponesset Bay
64	Waquoit Bay (Yacht Club)
65	Falmouth Heights, Vineyard Sound
67	Little Harbor and Nobska Point, Woods Hole
68	Woods Hole (Oceanographic Institute)
69	Uncatena I., Elizabeth Is., Woods Hole
70	Tarpaulin Cove, Naushon I., Elizabeth Is.
71	Kettle Cove, Naushon I., Elizabeth Is.
73	Quicks Hole, Nashawena I., Elizabeth Is.
74	Cuttyhunk Pond Entr., Cuttyhunk I.
75	Penikese Island, Elizabeth Islands
76	Chappaquoit Point, W. Falmouth Harbor Entr.
77	Stony Point Dike, Buzzards Bay
78	Monument Beach and Back R. Harbor, Buzzards Bay
79	West Mooring Basin (Hog Island), Buzzards Bay
80	Buzzards Bay, Cape Cod Canal
81	Sears Point, Buzzards Bay
82	Onset, Onset Bay, Buzzards Bay
83	Wareham, Wareham R., Buzzards Bay
84	Great Hill (1 mile north of Great Hill Pt.), Buzzards Bay
85	Marion, Sippican Harbor, Buzzards Bay
86	Mattapoisett, Mattapoisett Harbor, Buzzards Bay
87	West Island (W. Side), Buzzards Bay
88	New Bedford (Clark Pt.), Buzzards Bay
89	New Bedfore (New Bedford-Fairhaven Bridge)
90	New Bedford (Nashawena Mills), Acushnet R.
91	South Dartmouth, Apponaganset R. Entr.
92	Westport Harbor Entr., (Charlton Wharf)
93	Hix Bridge, Westport R. (East Branch)
94	Fall River (State Pier)
95	Fall River, Taunton River
96	Great Point, Nantucket Island
99	Nantucket, Nantucket Island
99A	Eel Point
99B	Smith Point
99C	Muskeget Island

Table 4-11c (continued)

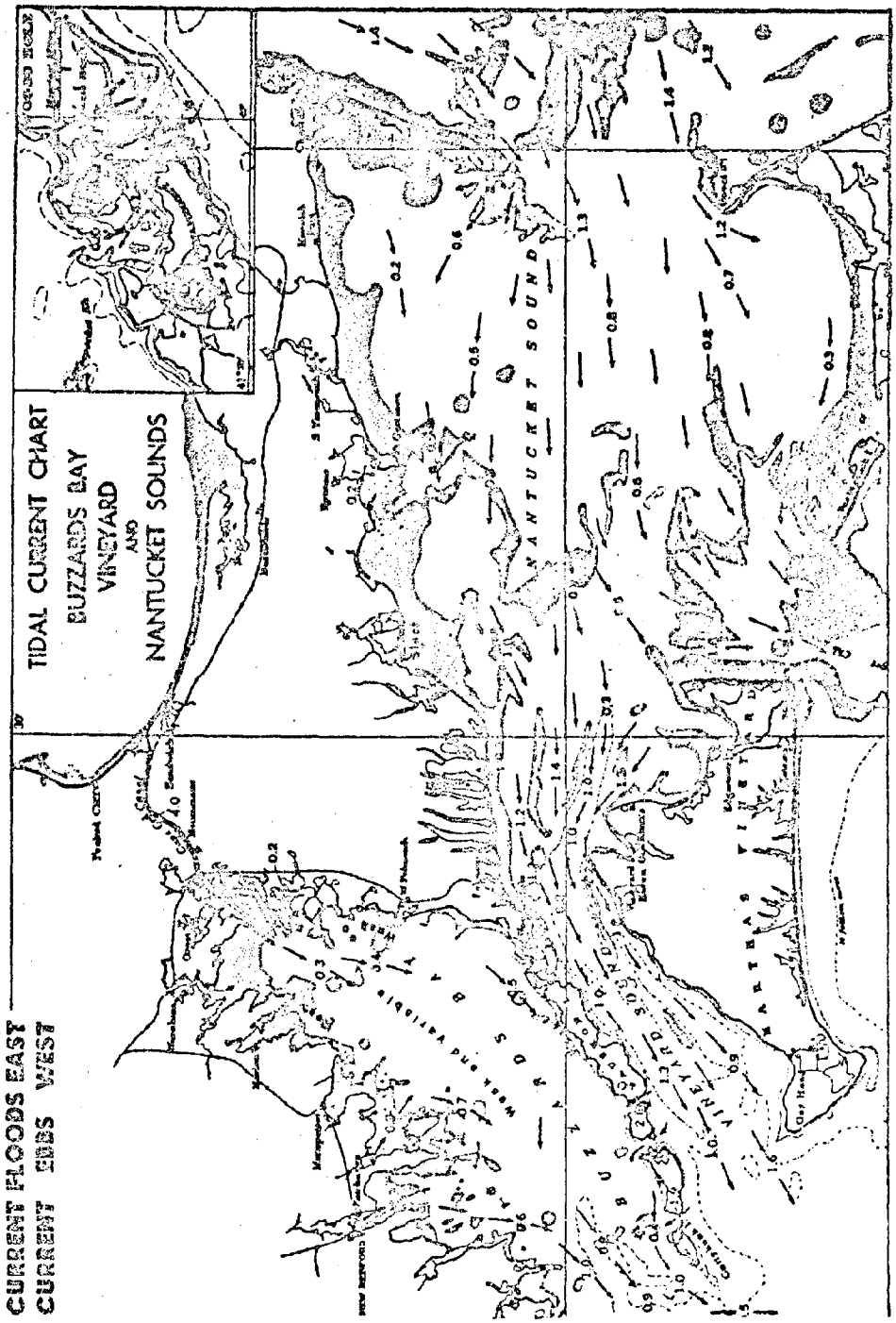
Index Map Number Fig. 4.3-18c	Name
100	Chappaquiddick I. (Southwest Side)
100A	Katama Bay, Chappaquiddick, Is.
101	Edgartown, Martha's Vineyard
102	Oak Bluffs, Martha's Vineyard
103	West Chop, Martha's Vineyard
103A	Cedar Tree Neck, Martha's Vineyard
105	Gay Head and Vicinity, Martha's Vineyard
105A	Squibnockett Point
106	No Mans Land Island



HIGH WATER AT BOSTON

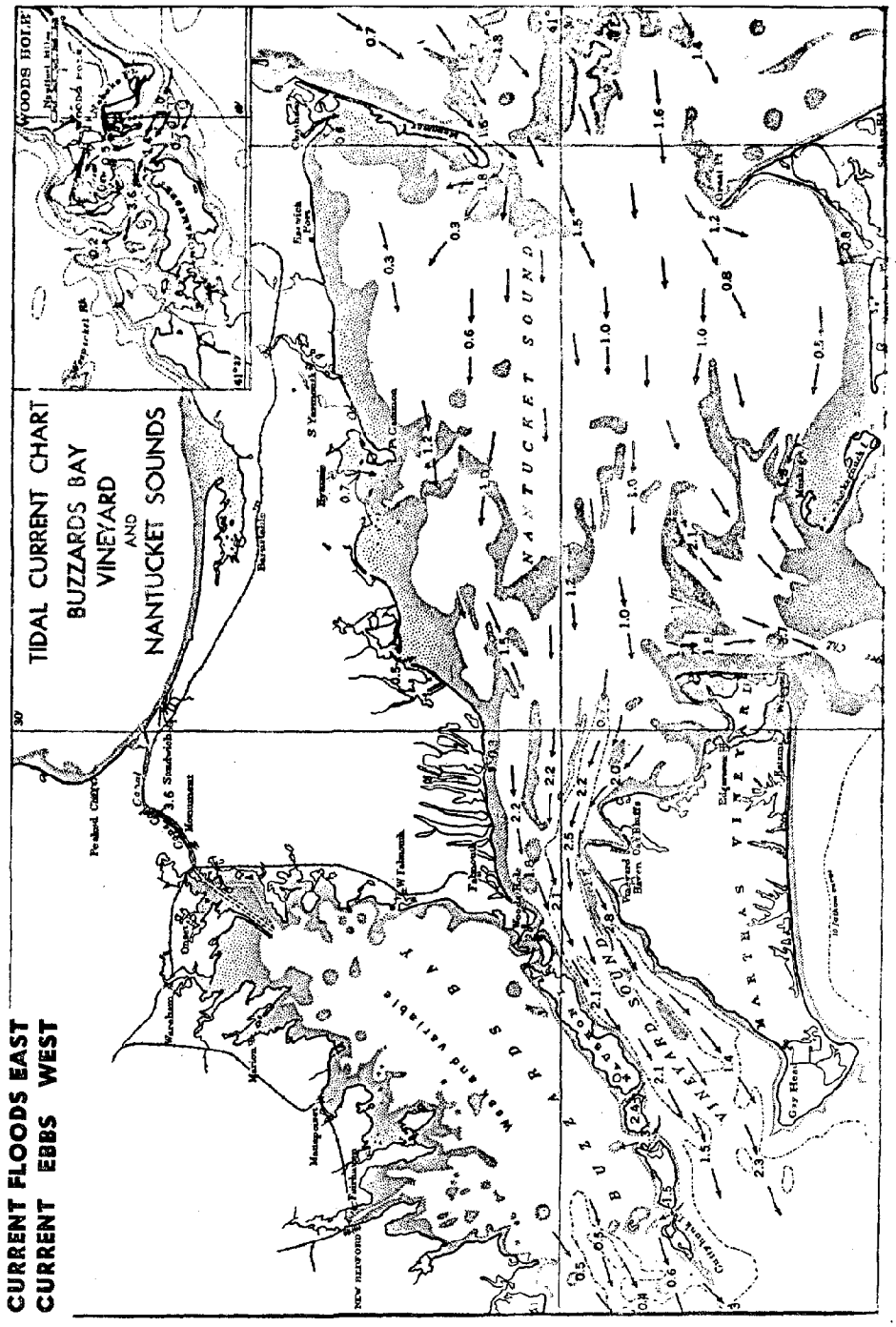
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-96a	High Water at Boston (Eldridge, 1973)



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

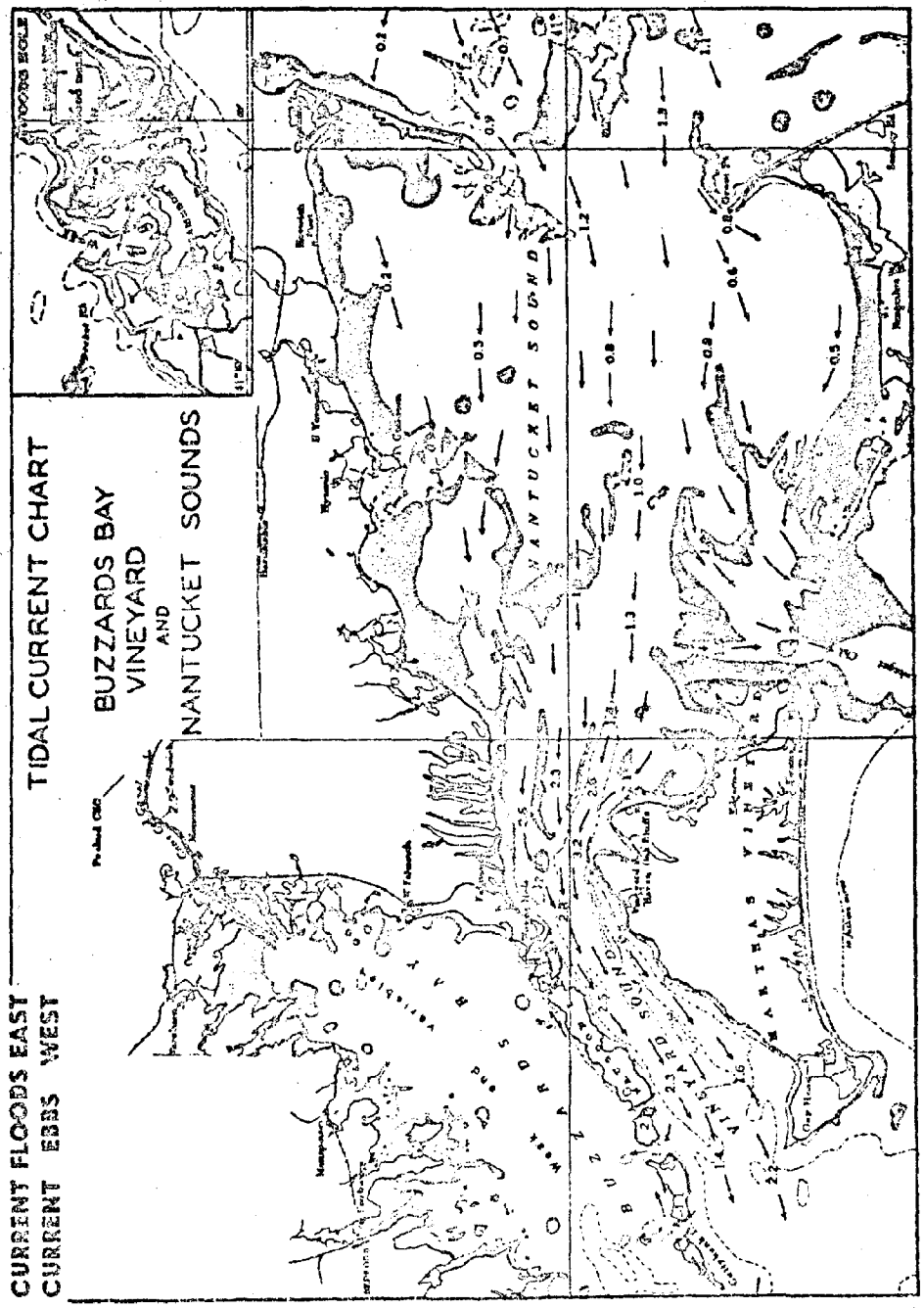
TRIGOM PARC	FIGURE 4-96b	1 Hour After High Water at Boston (Eldridge, 1973)



2 HOURS **AFTER** HIGH WATER AT BOSTON

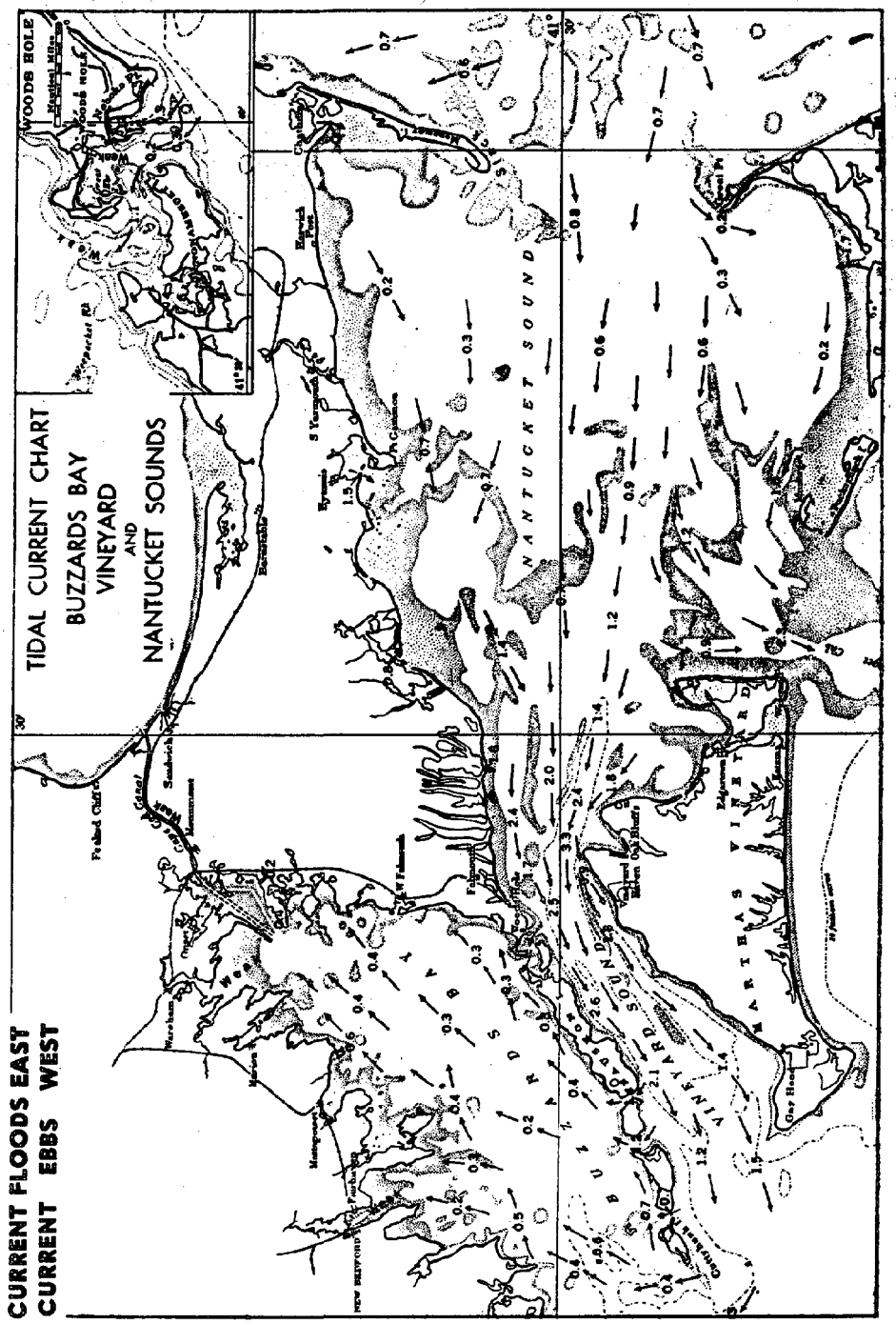
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-96c	2 Hours After High Water at Boston (Eldridge, 1973)



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

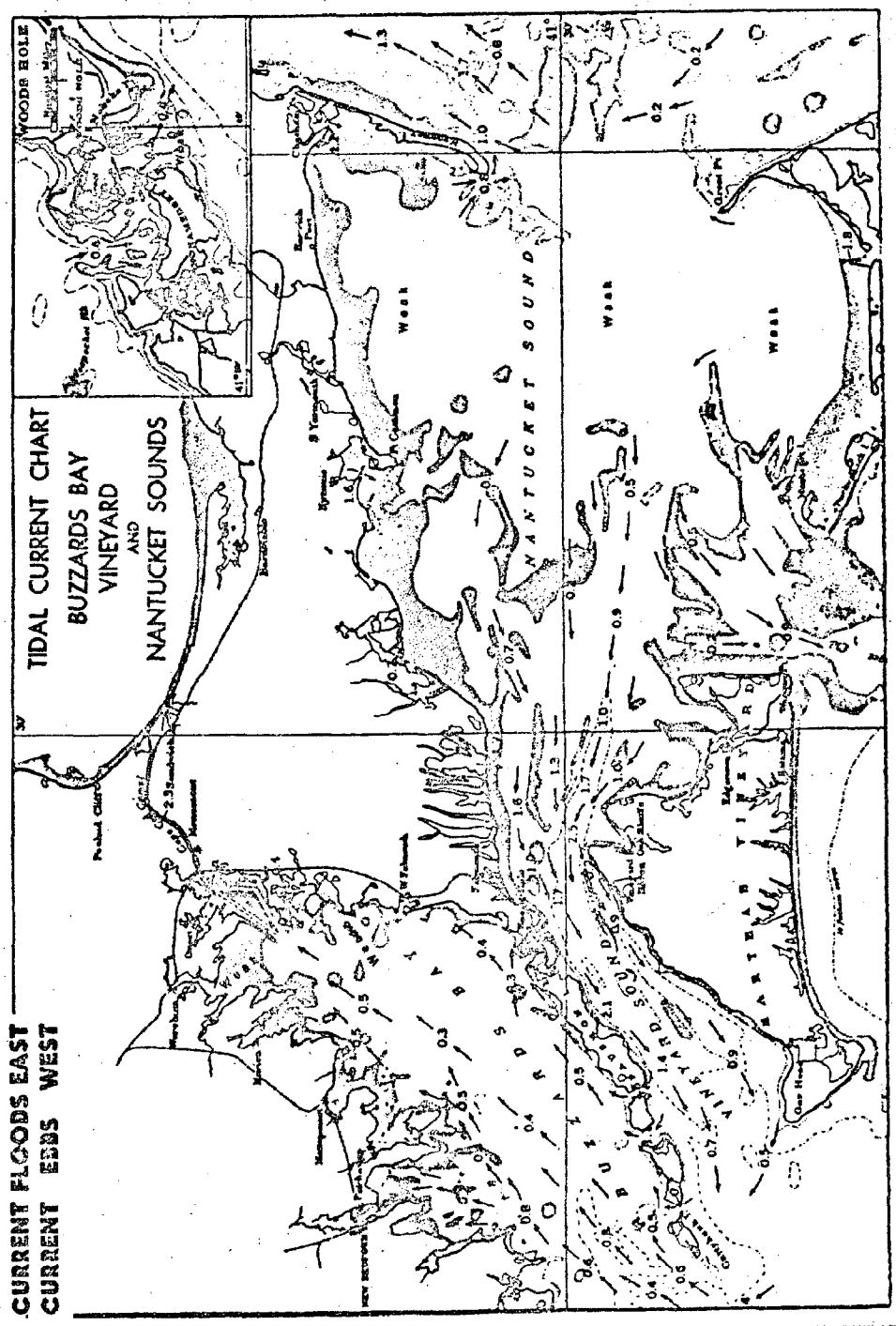
TRIGOM PARC	FIGURE 4-96d	Maximum Current - 3 Hours After High Water at Boston (Eldridge, 1973)



4 HOURS AFTER HIGH WATER AT BOSTON

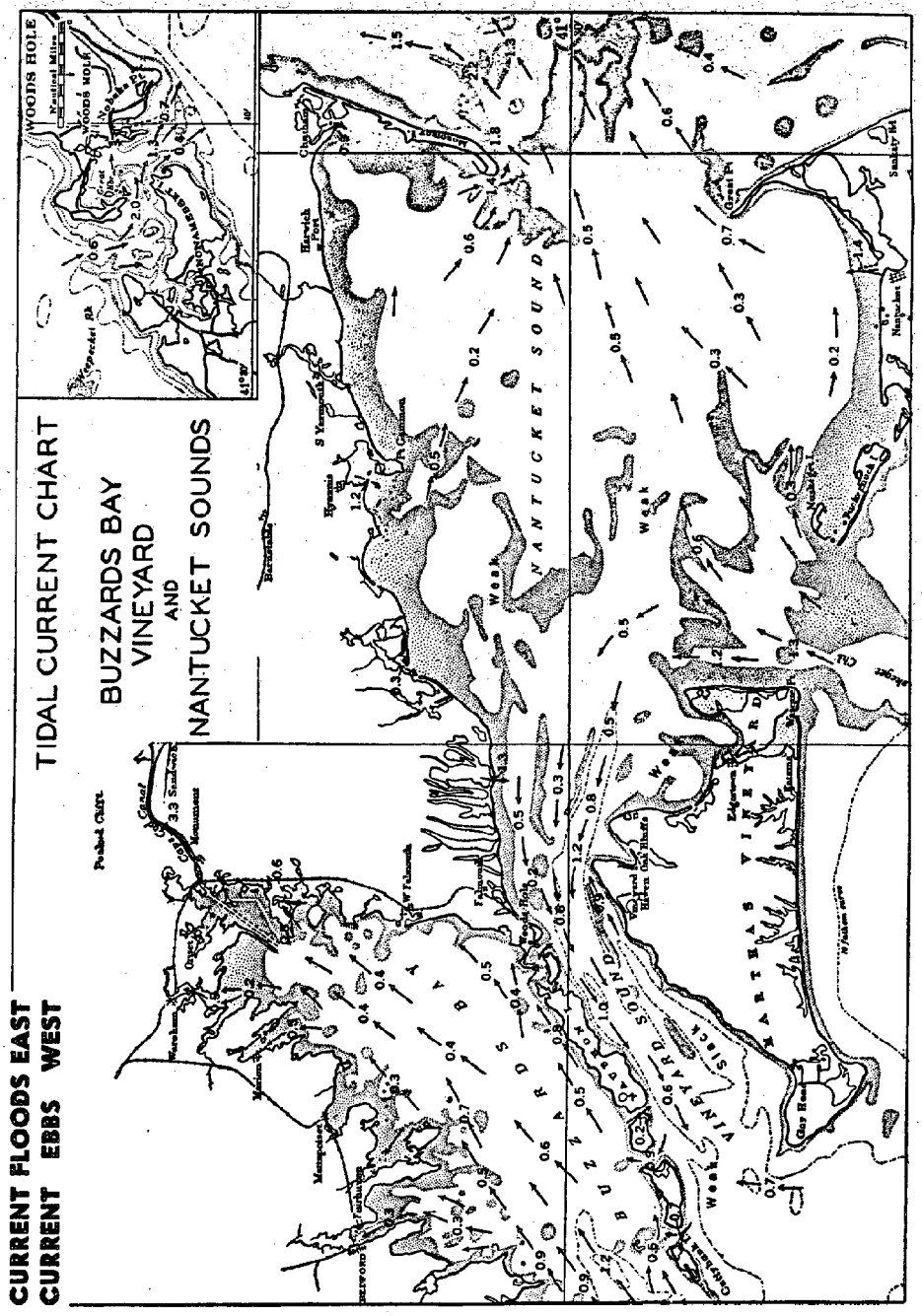
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-96e	4 Hours After High Water at Boston (Eldridge, 1973)



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

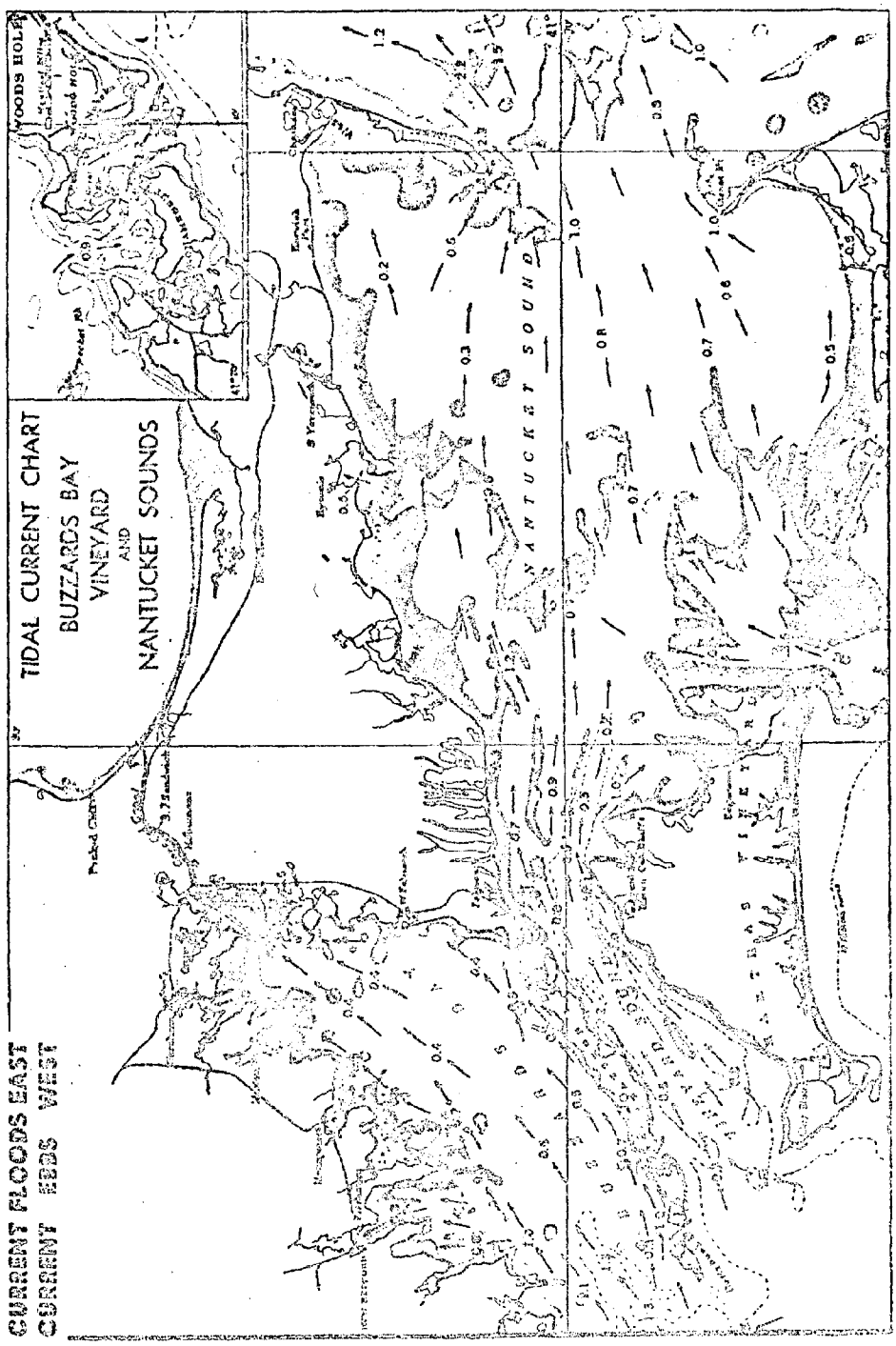
TRIGOM PARC	FIGURE 4-96f	5 Hours After High Water at Boston (Eldridge, 1973)



LOW WATER AT BOSTON

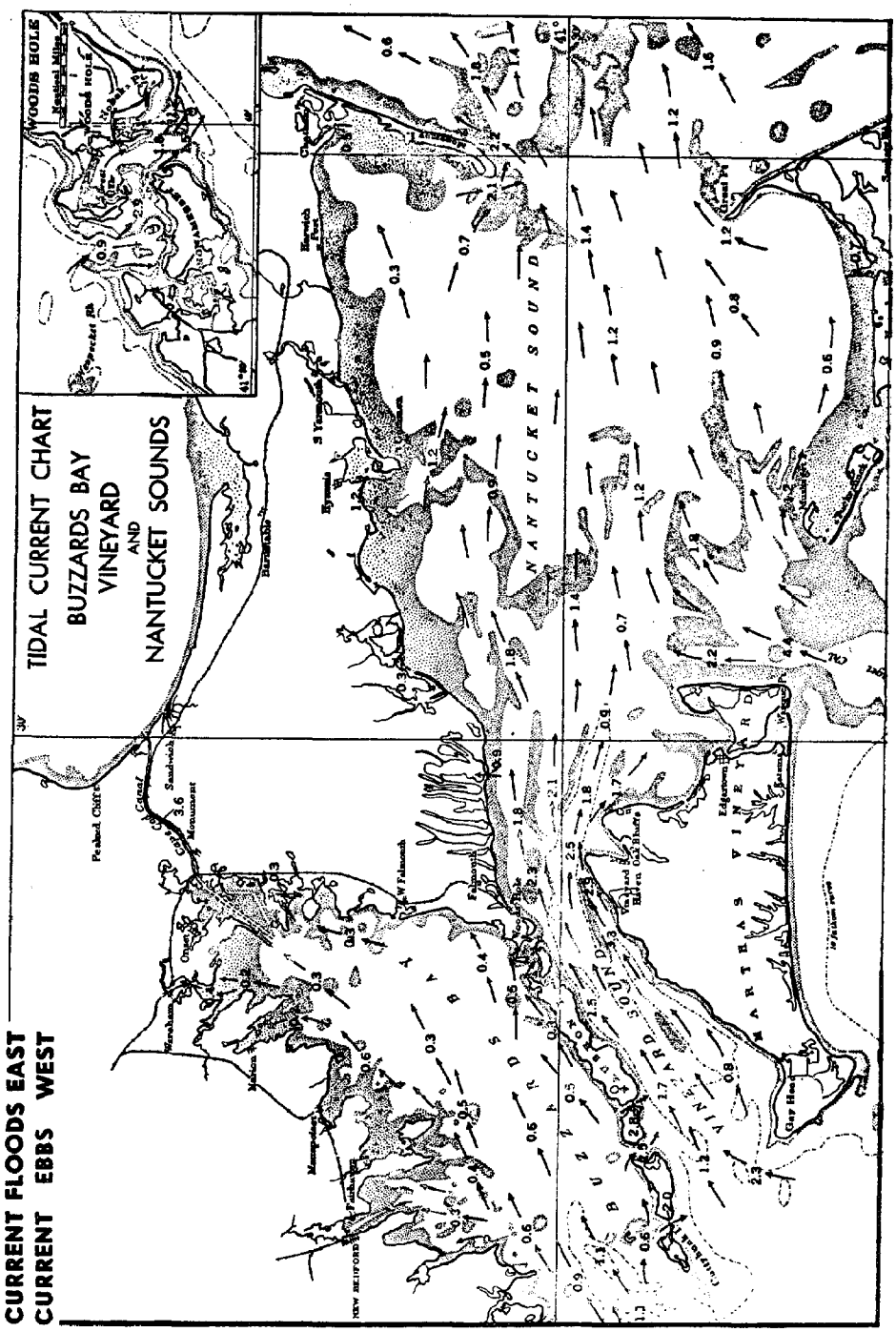
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-96g	Low Water at Boston (Eldridge, 1973)



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

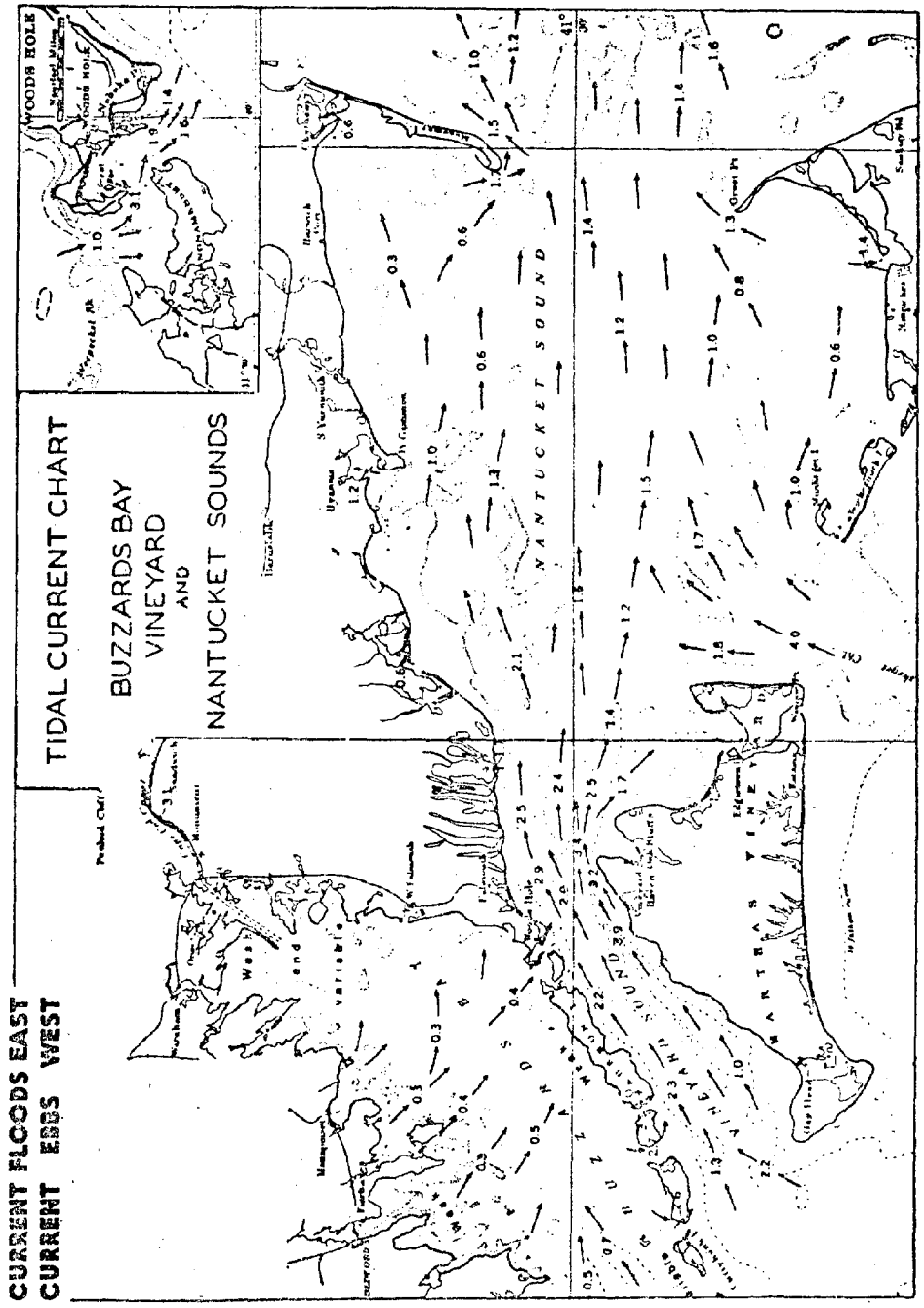
TRIGOM PARC	FIGURE 4-96h	1 Hour After Low Water at Boston (Eldridge, 1973)



2 HOURS **AFTER** LOW WATER AT BOSTON

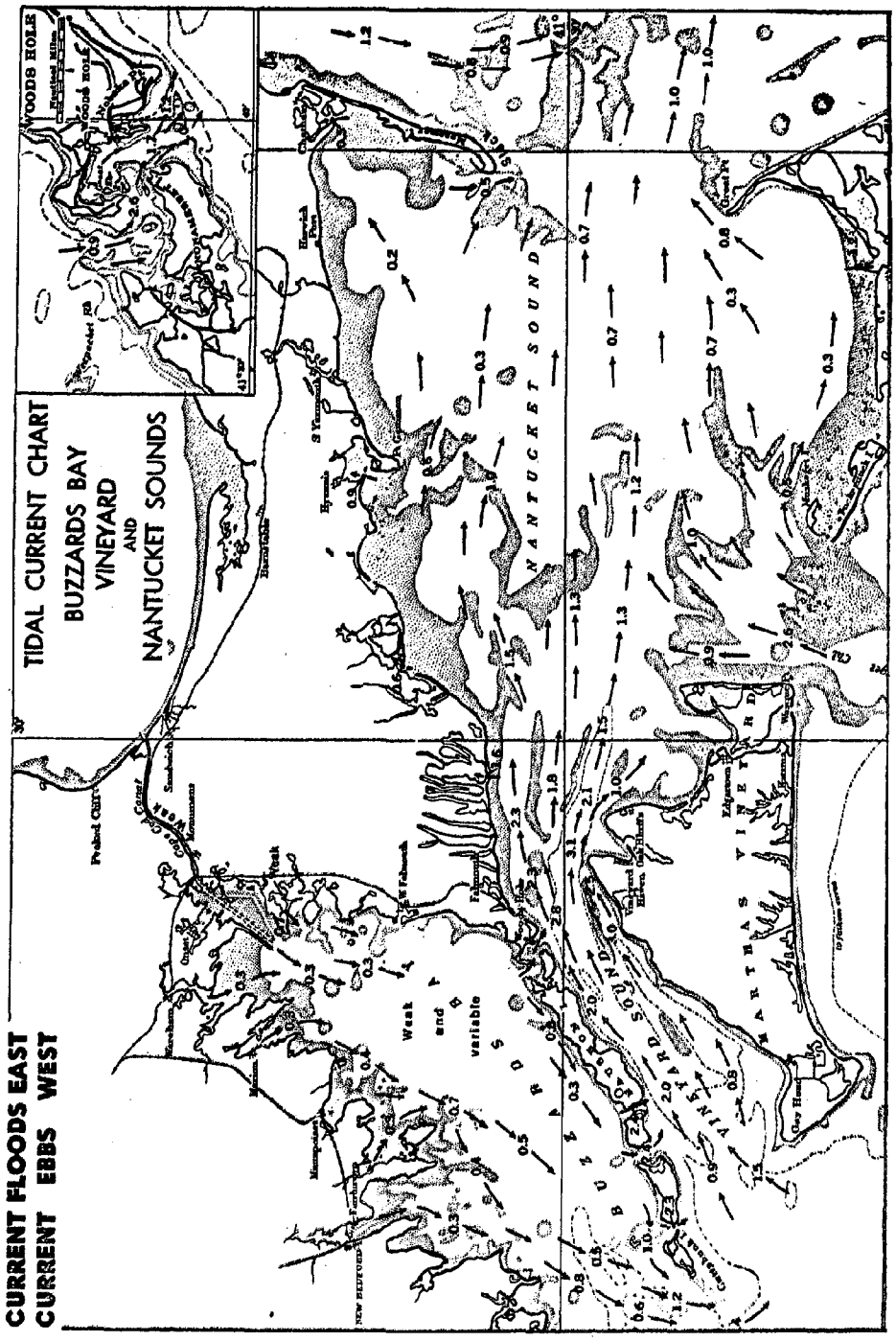
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-96i	2 Hours After Low Water at Boston (Eldridge, 1973)



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

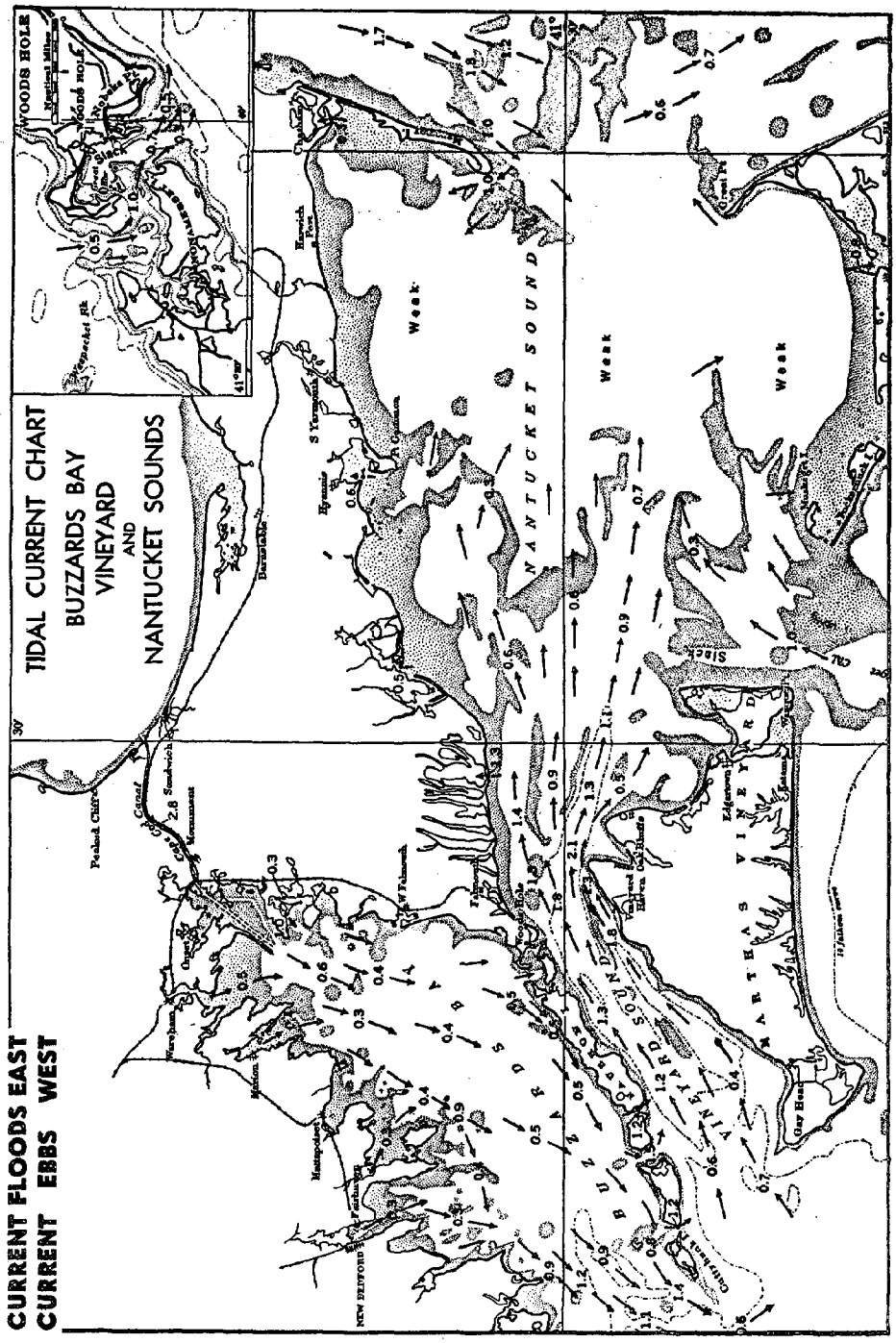
TRIGOM PARC	FIGURE 4-96j	Maximum Current - 3 Hours After Low Water at Boston (Eldridge, 1973)



4 HOURS AFTER LOW WATER AT BOSTON

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

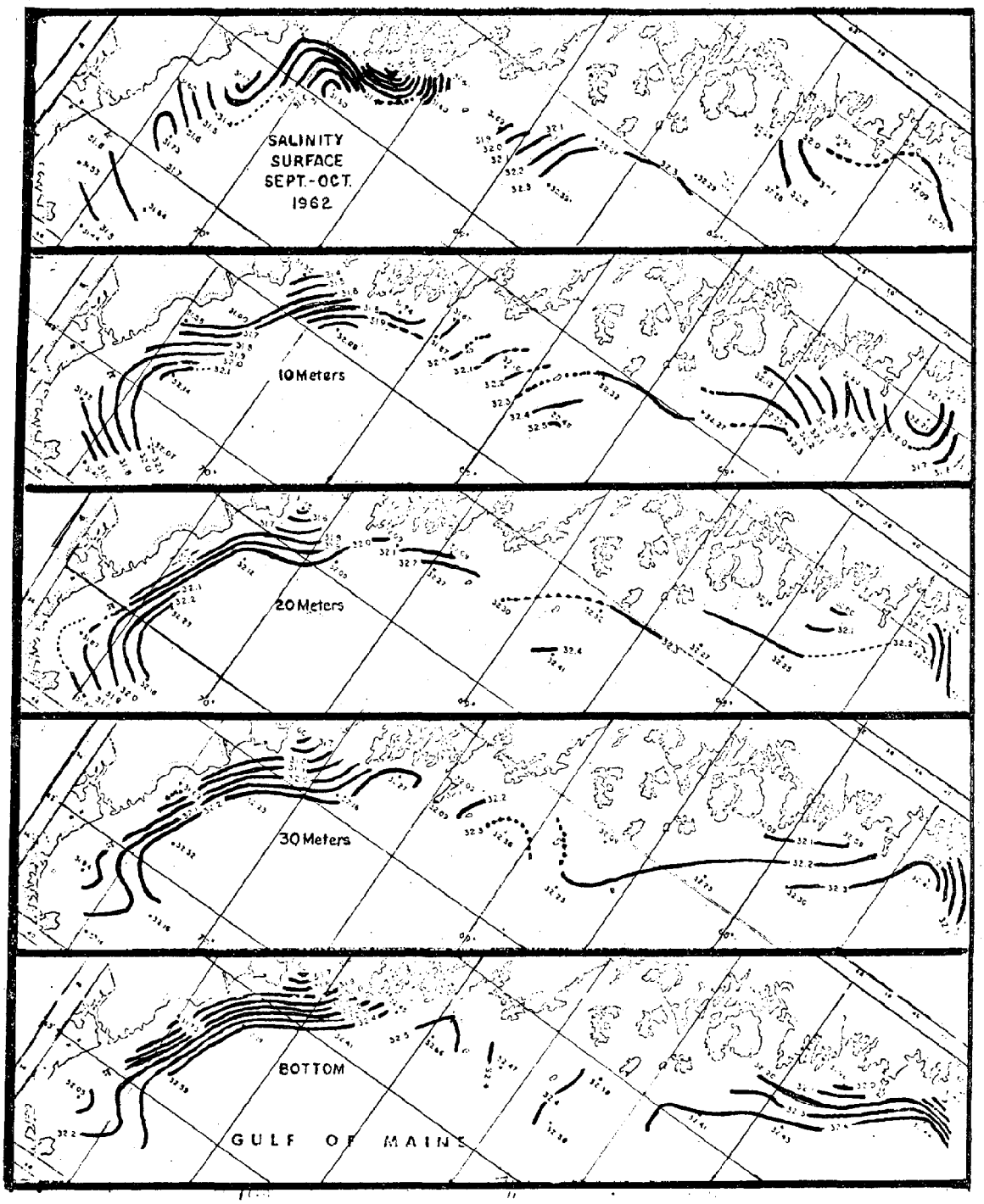
TRIGOM PARC	FIGURE 4-96k	4 Hours After Low Water at Boston (Eldridge, 1973)



5 HOURS AFTER LOW WATER AT BOSTON

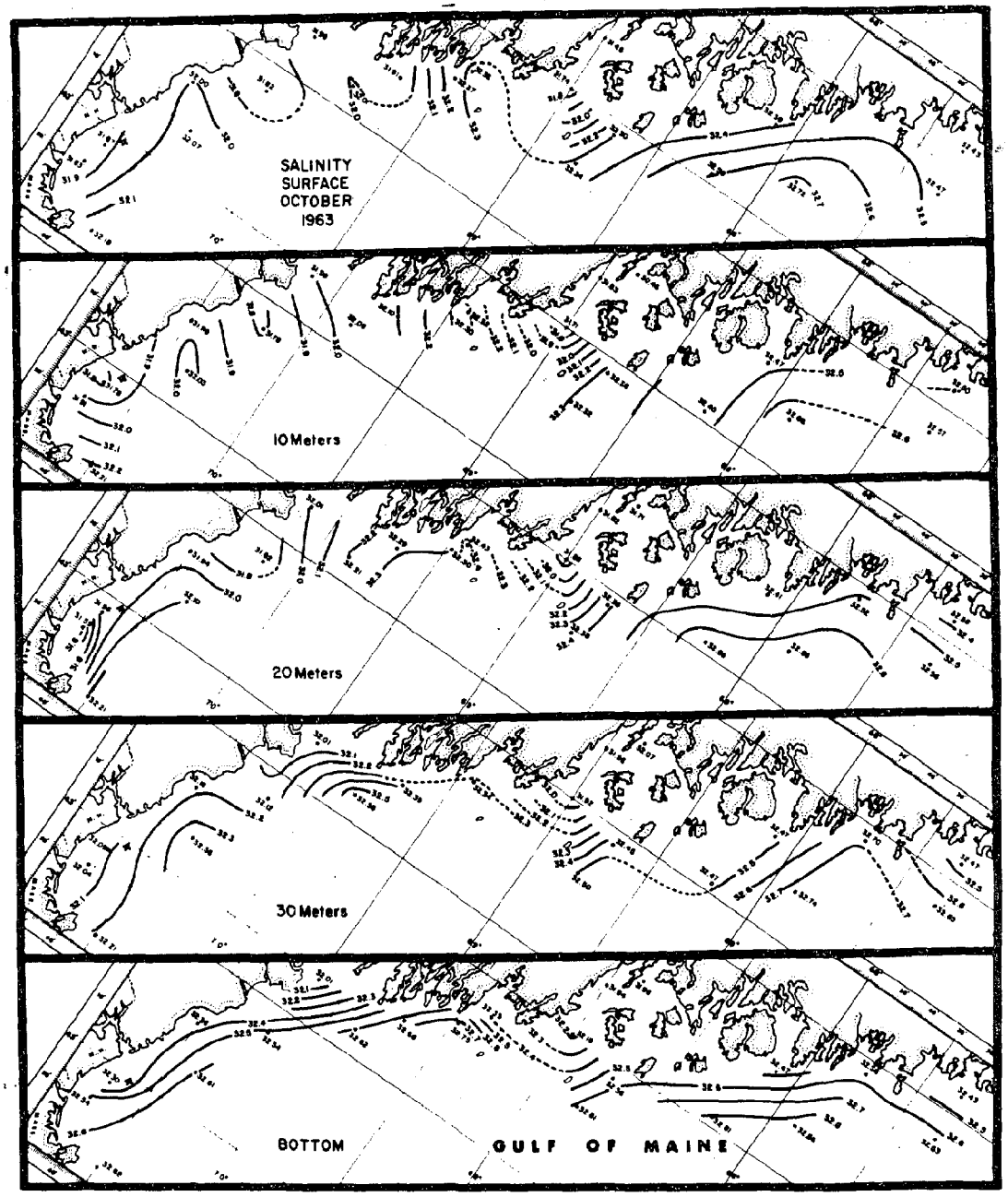
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-961	5 Hours After Low Water at Boston (Eldridge, 1973)



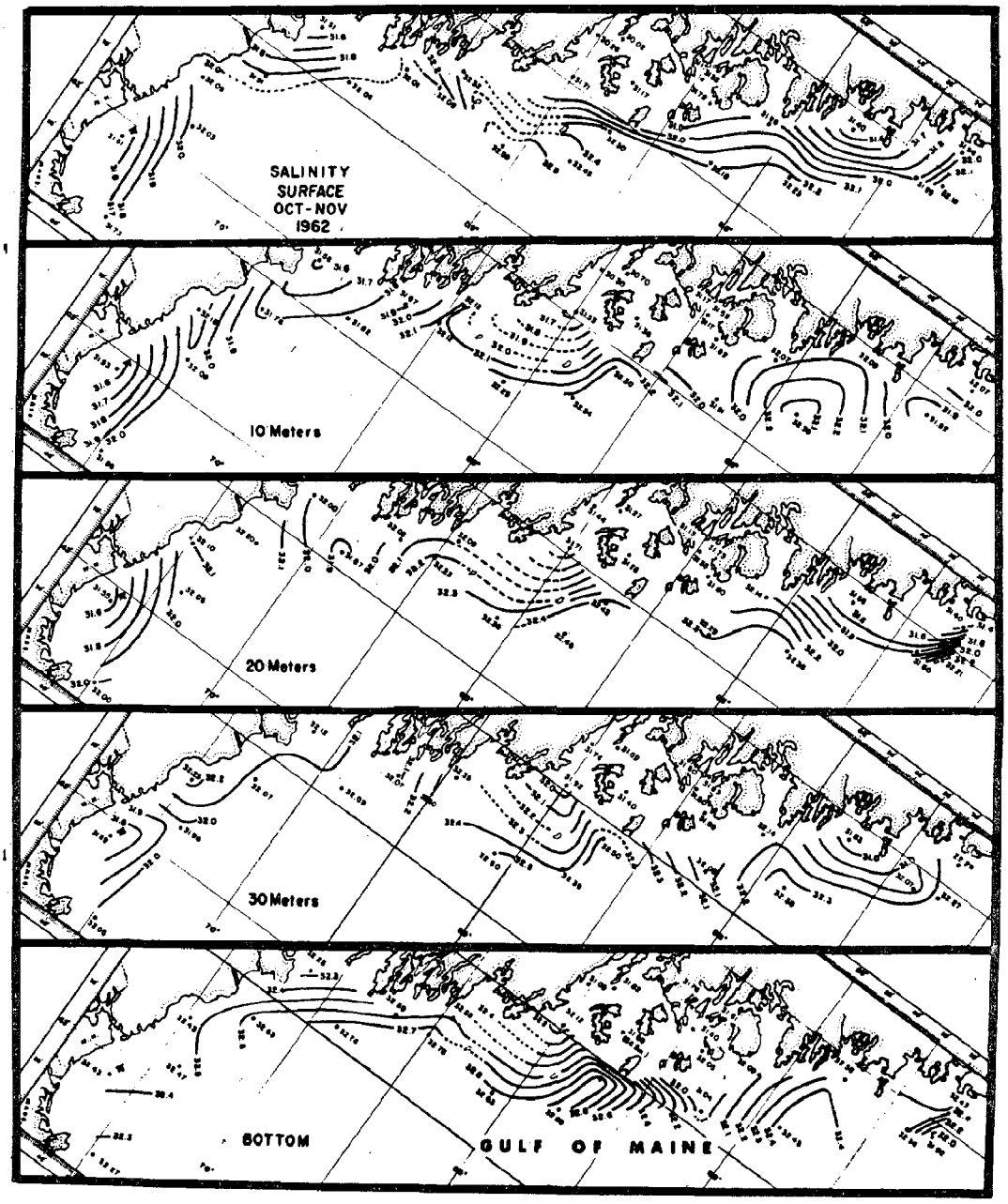
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-108	Distribution of Isohalines September-October 1962 (Graham, 1970b)

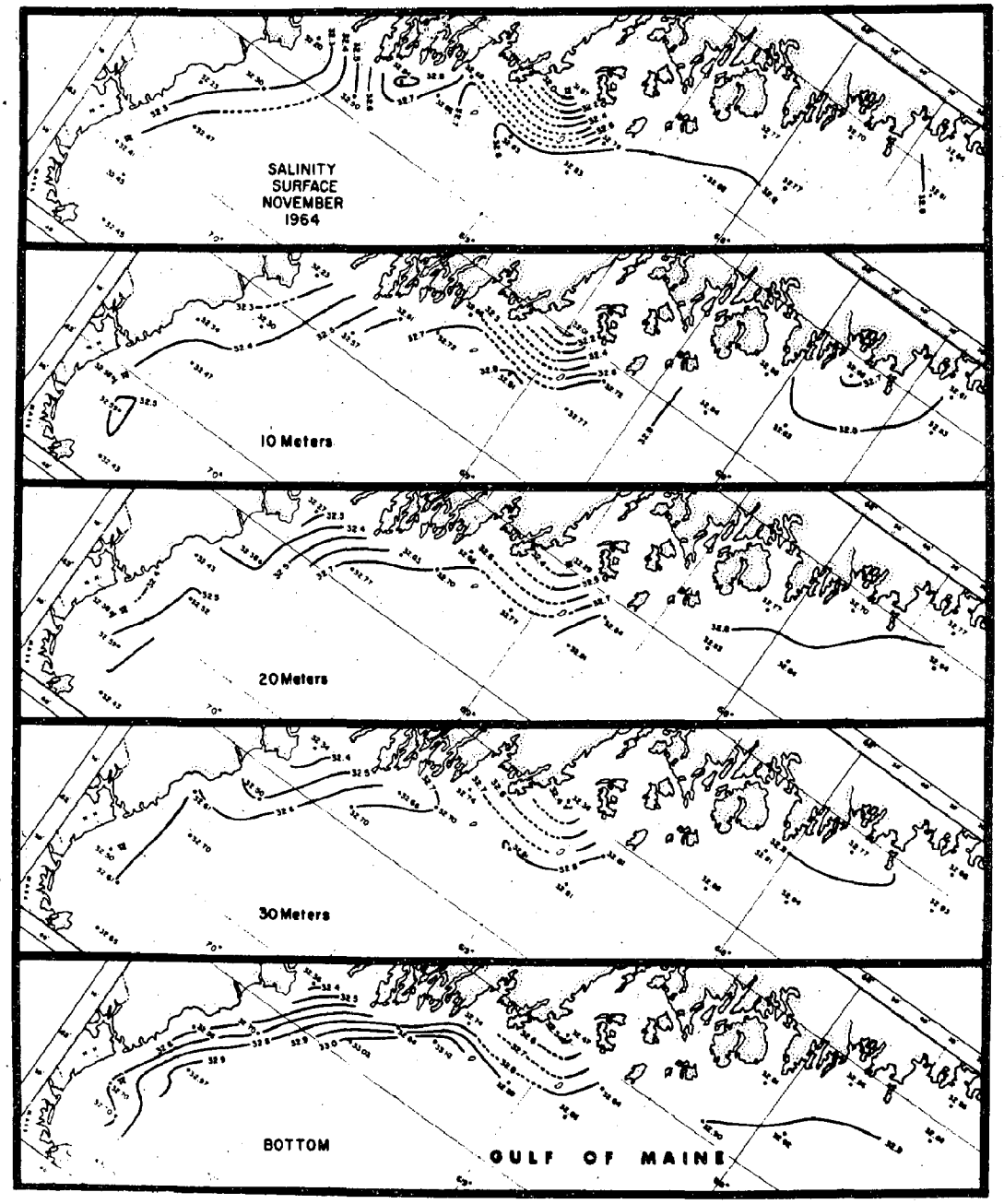


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-109	Distribution of Isohalines October 1963 (Graham, 1970b)

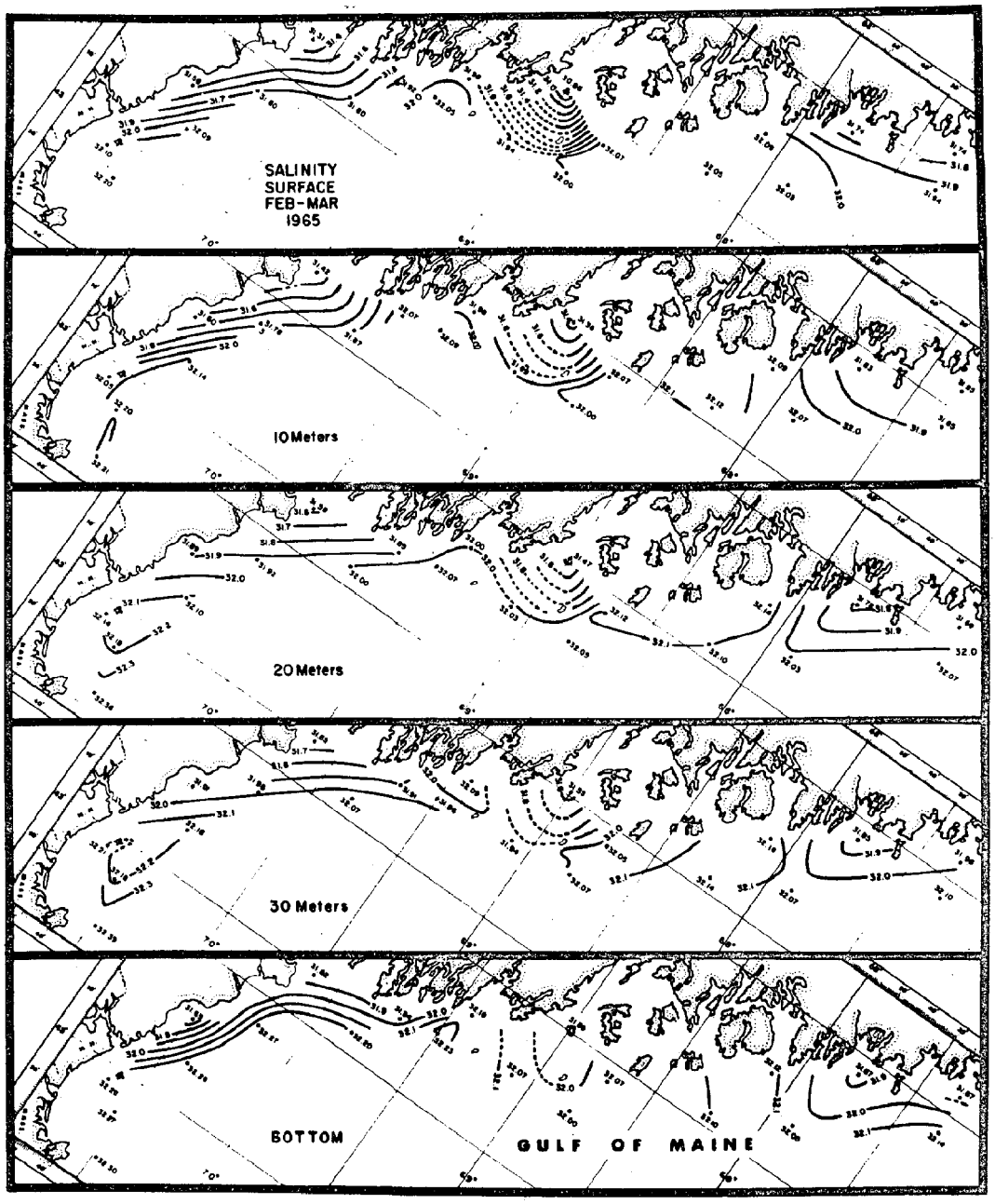


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-110	Distribution of Isohalines October-November 1962 (Graham, 1970b)



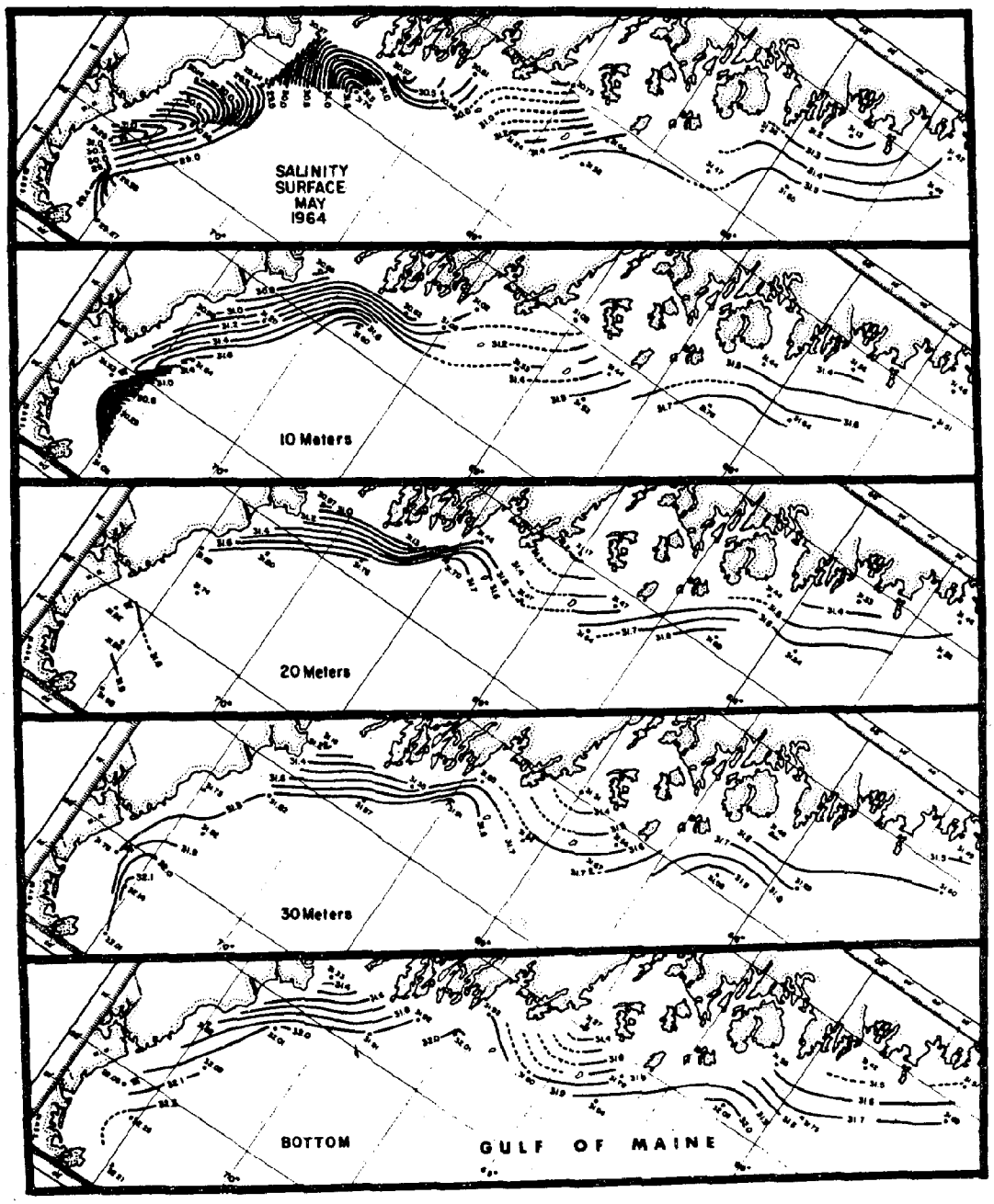
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-111	Distribution of Isohalines October-November 1964 (Graham, 1970b)



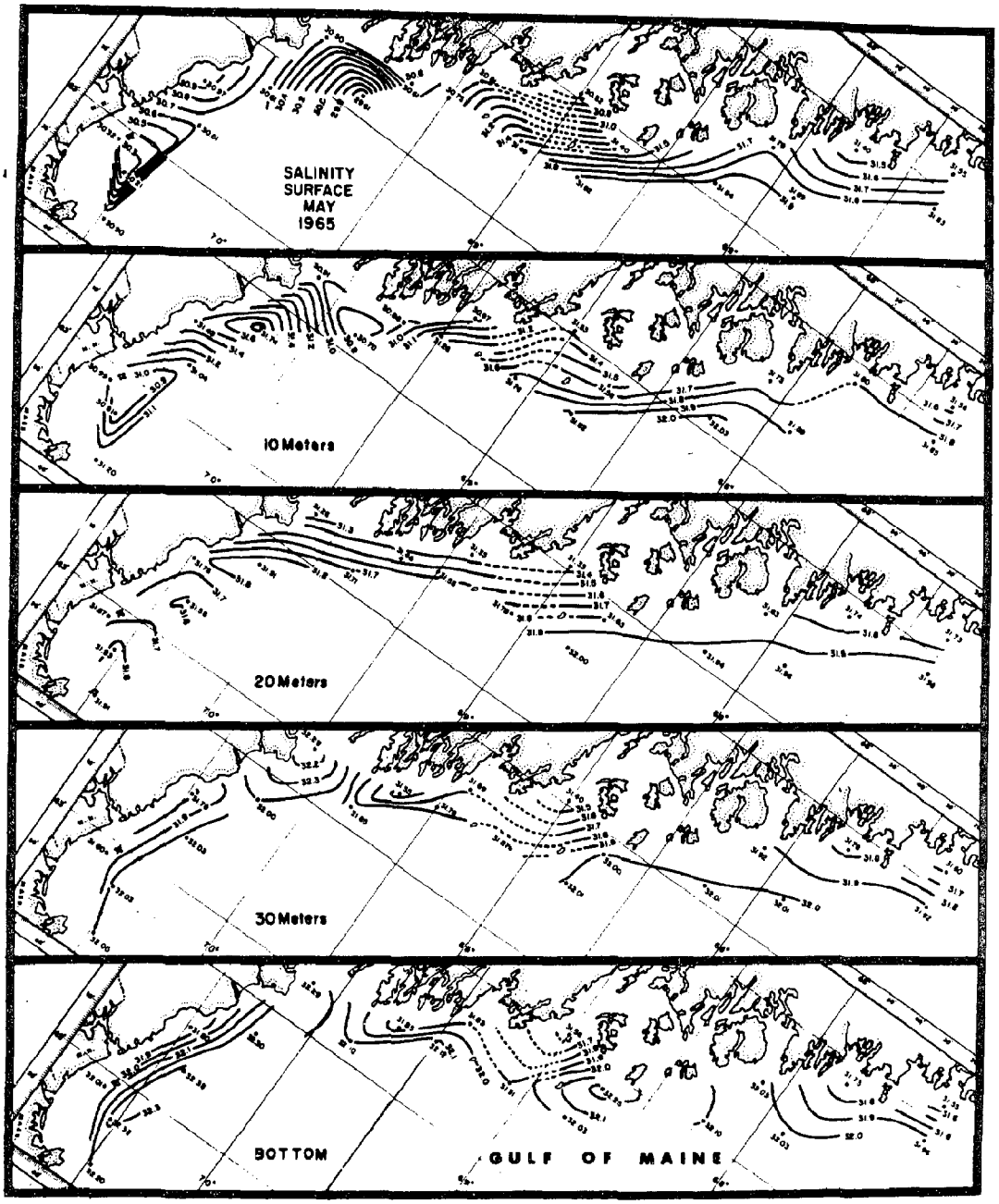
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-112	Distribution of Isohalines February-March 1965 (Graham, 1970b)



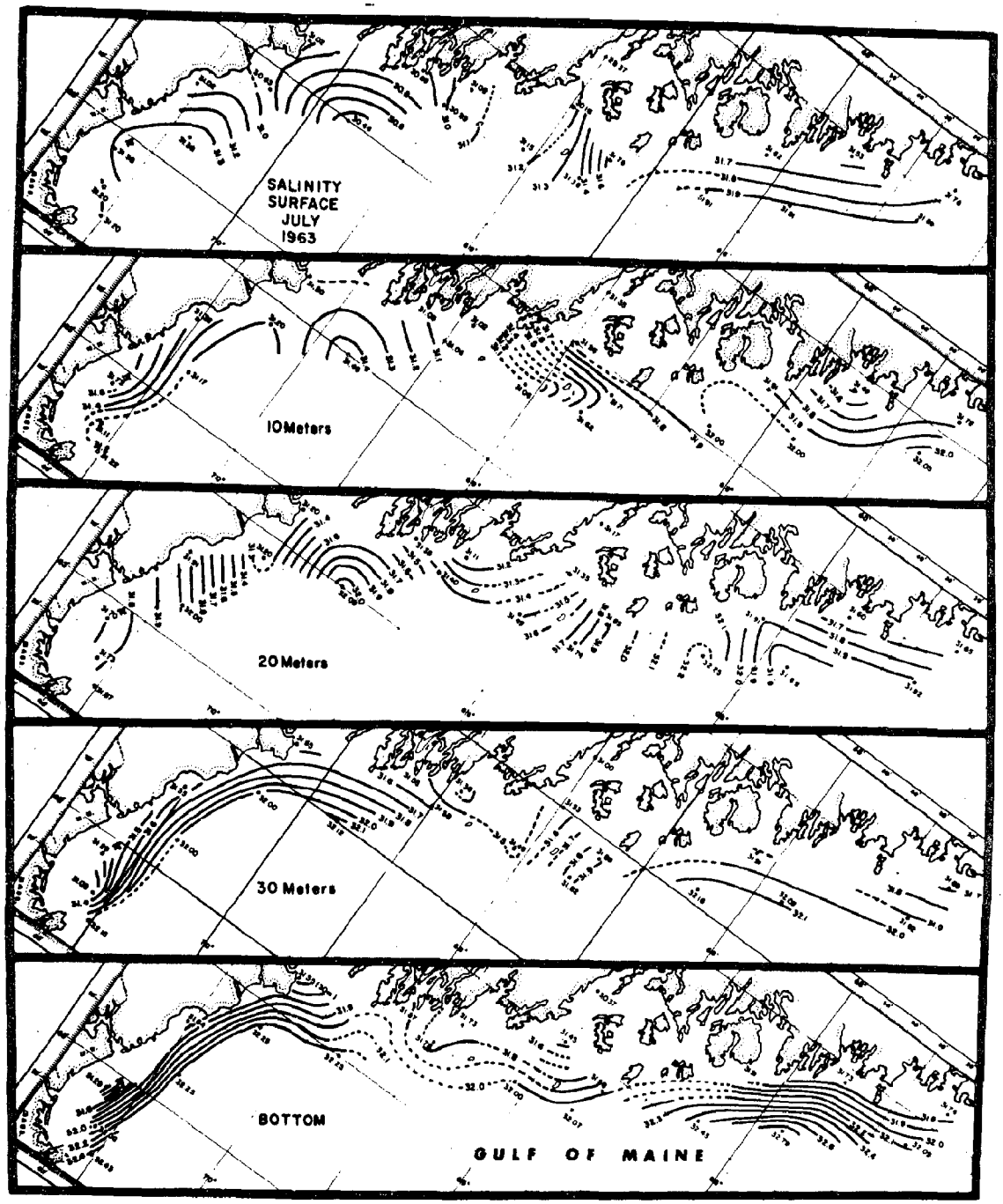
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-113	Distribution of Isohalines May 1964 (Graham, 1970b)



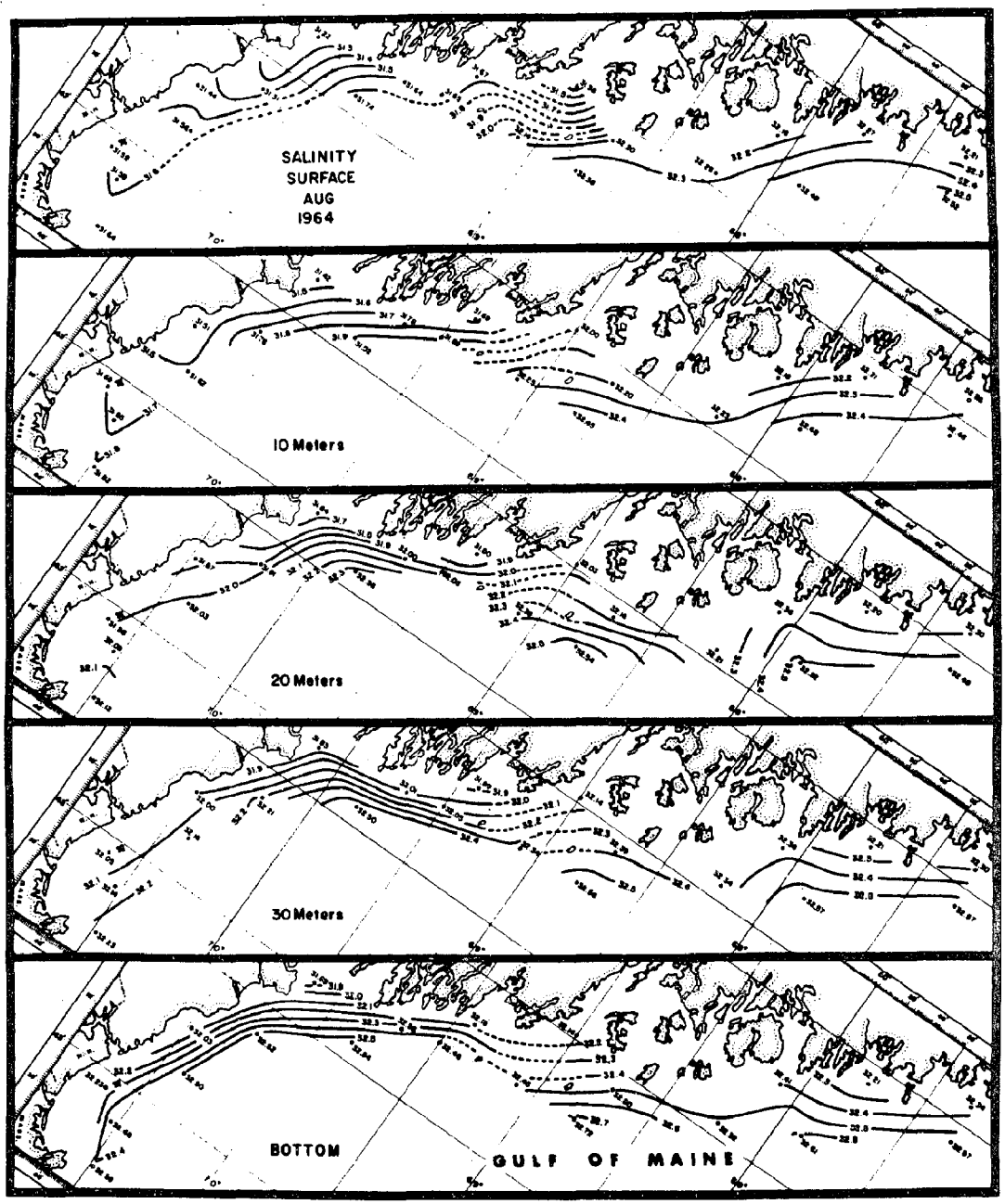
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-114	Distribution of Isohalines May 1965 (Graham, 1970b)



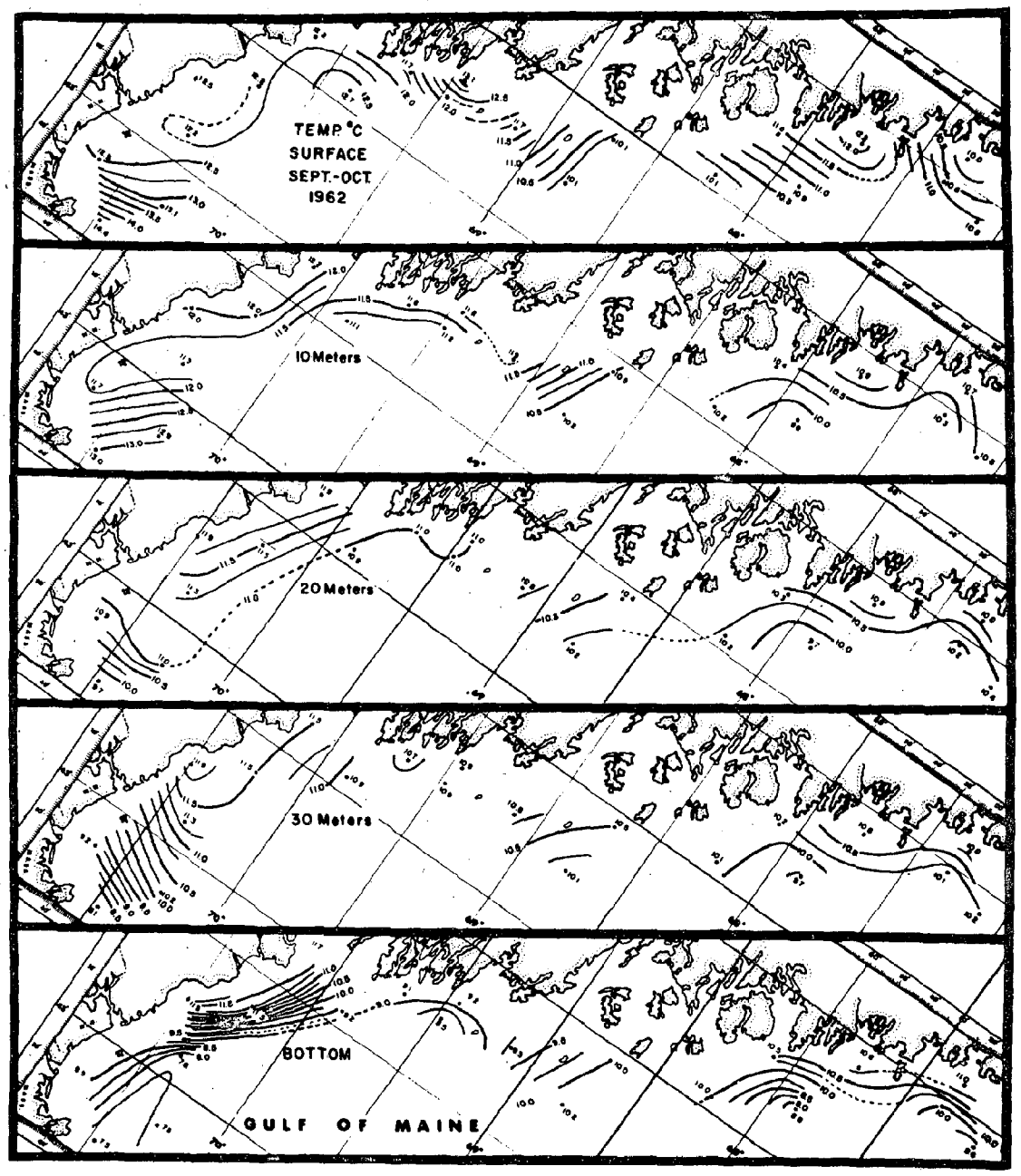
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-115	Distribution of Isohalines July 1963 (Graham, 1970b)



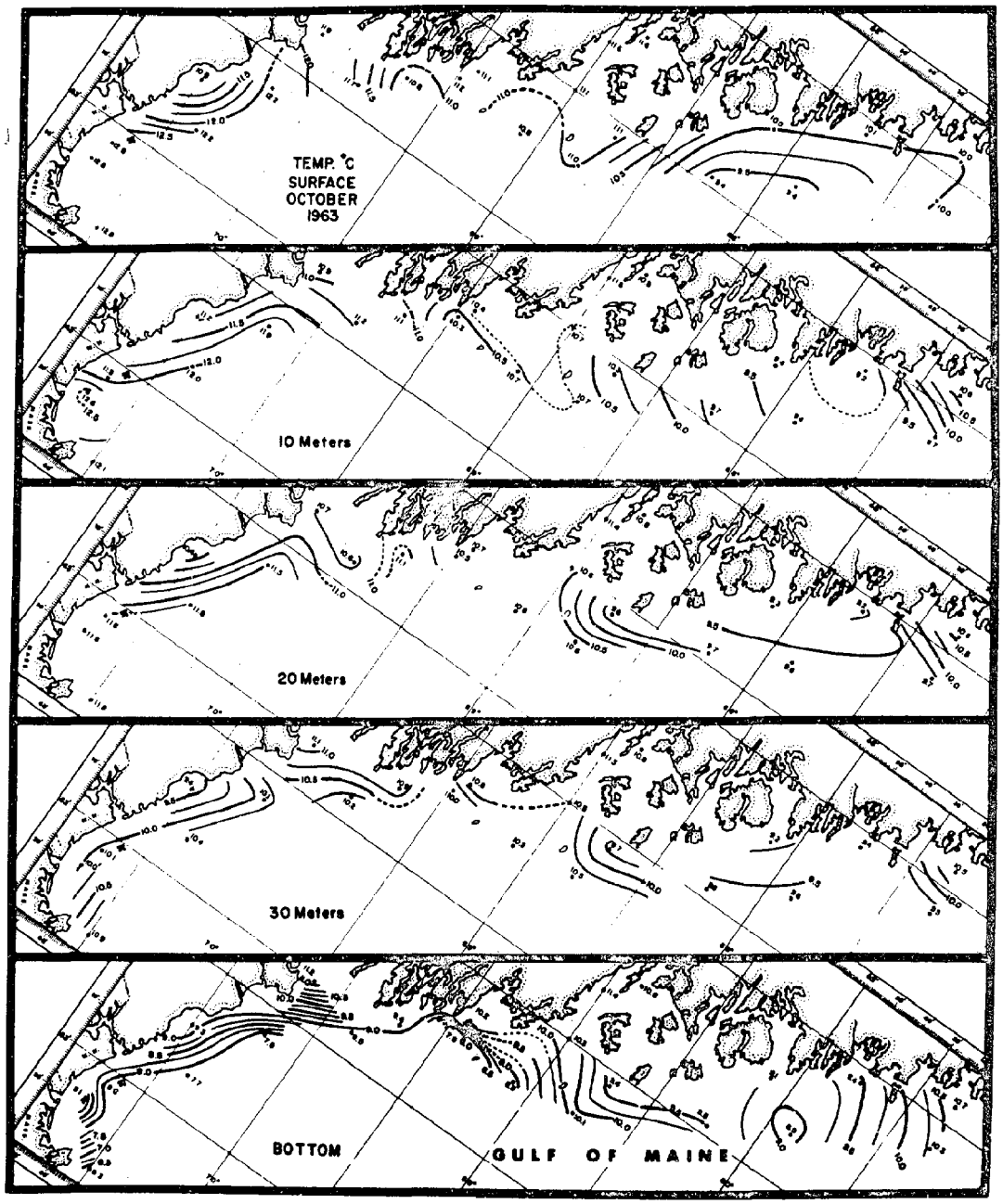
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-116	Distribution of Isohalines August 1964 (Graham, 1970b)



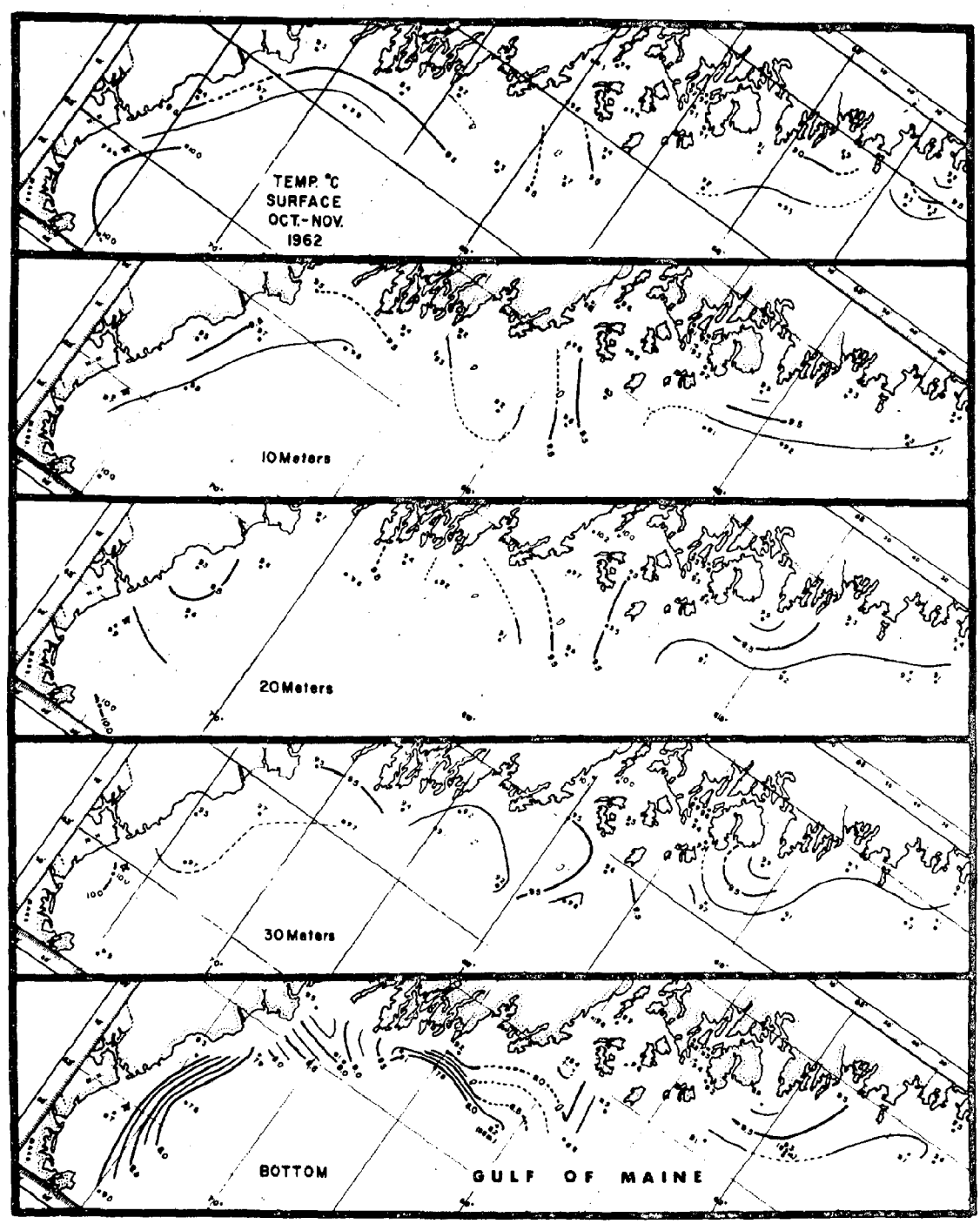
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-117	Distribution of Isotherms September-October 1962 (Graham, 1970b)



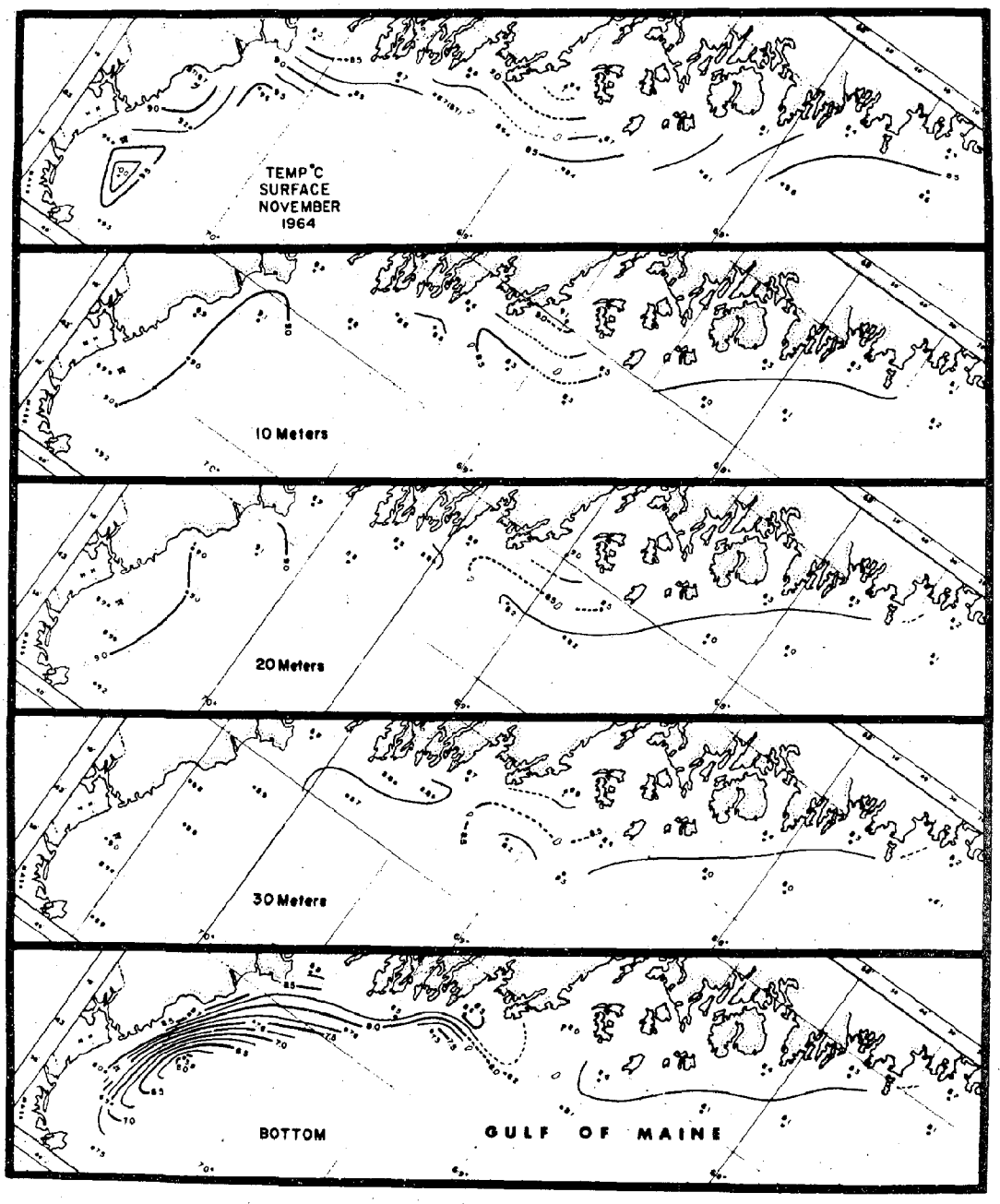
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-118	Distribution of Isotherms October 1963 (Graham, 1970b)



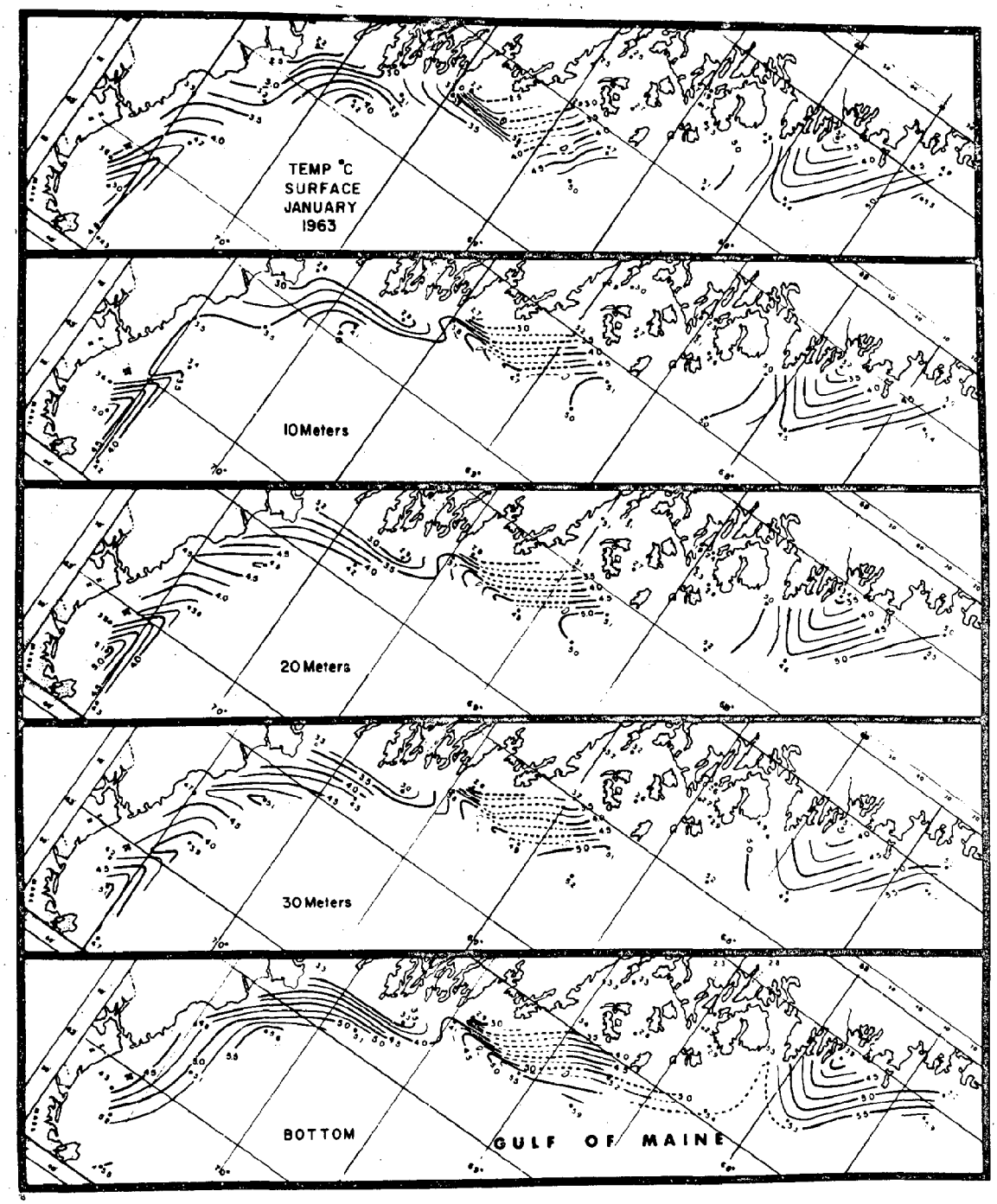
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-119	Distribution of Isotherms October-November 1962 (Graham, 1970b)



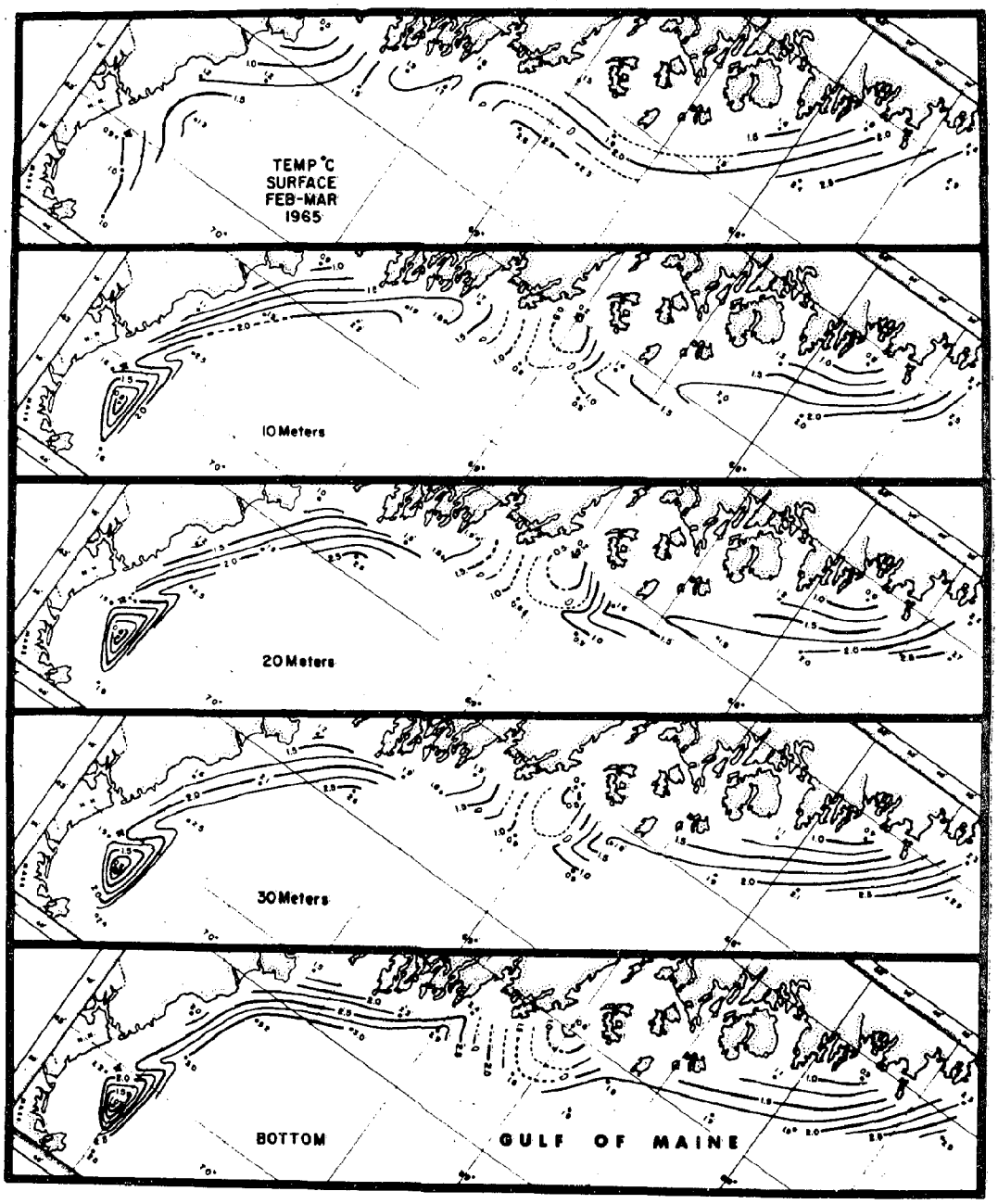
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-120	Distribution of Isotherms November 1964 (Graham, 1970b)



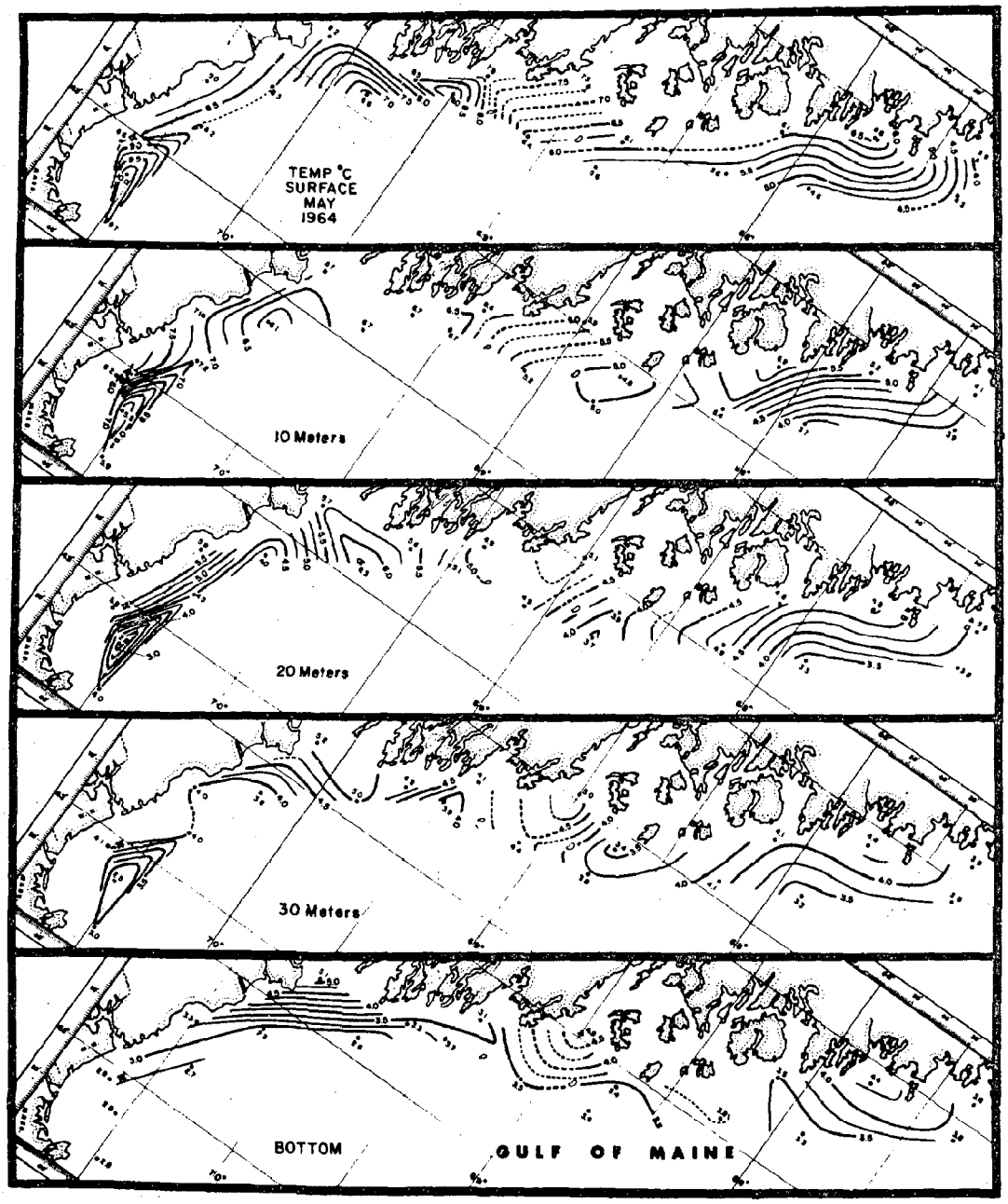
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-121	Distribution of Isotherms January 1963 (Graham, 1970b)



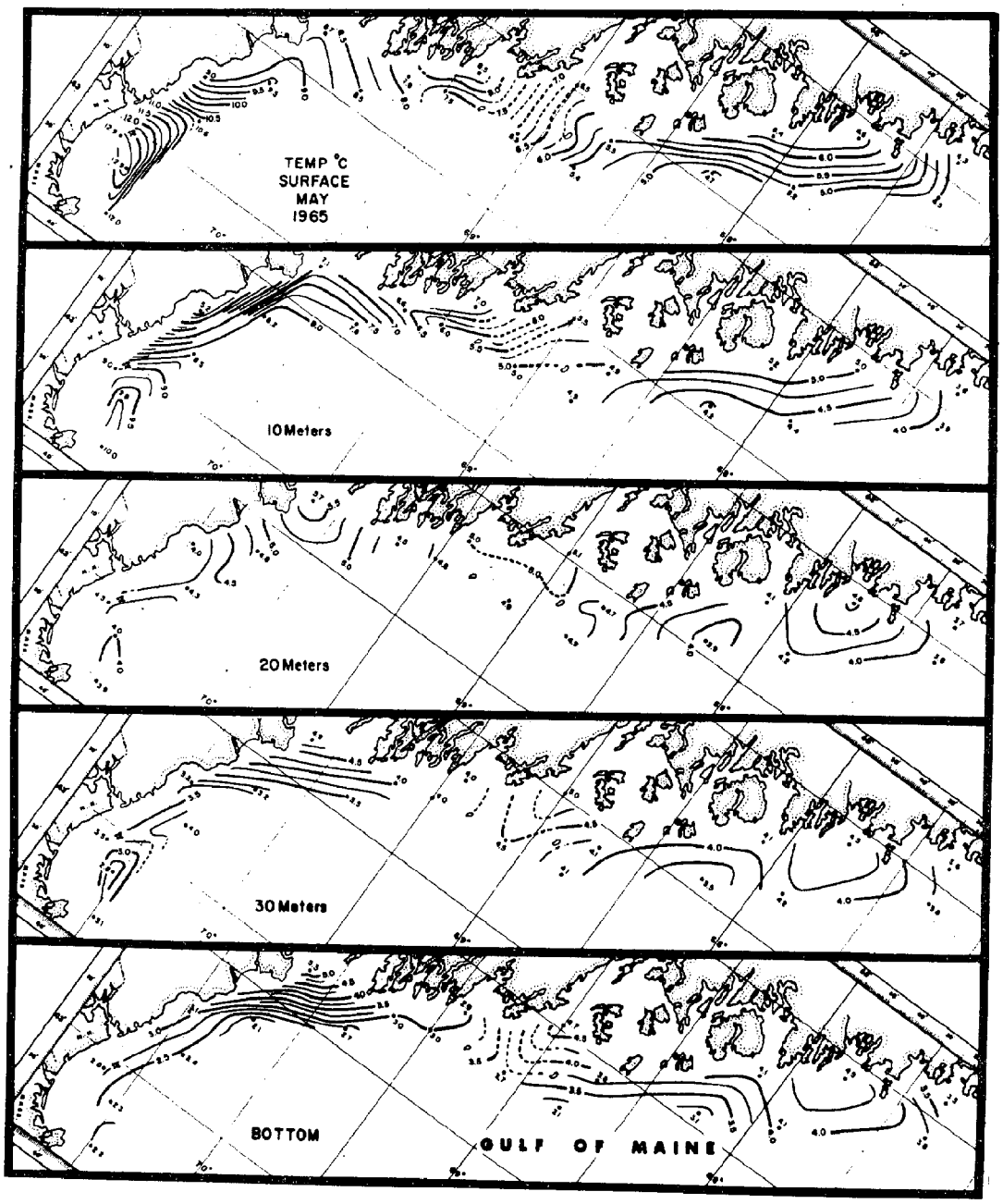
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-122	Distribution of Isotherms February-March 1965 (Graham, 1970b)



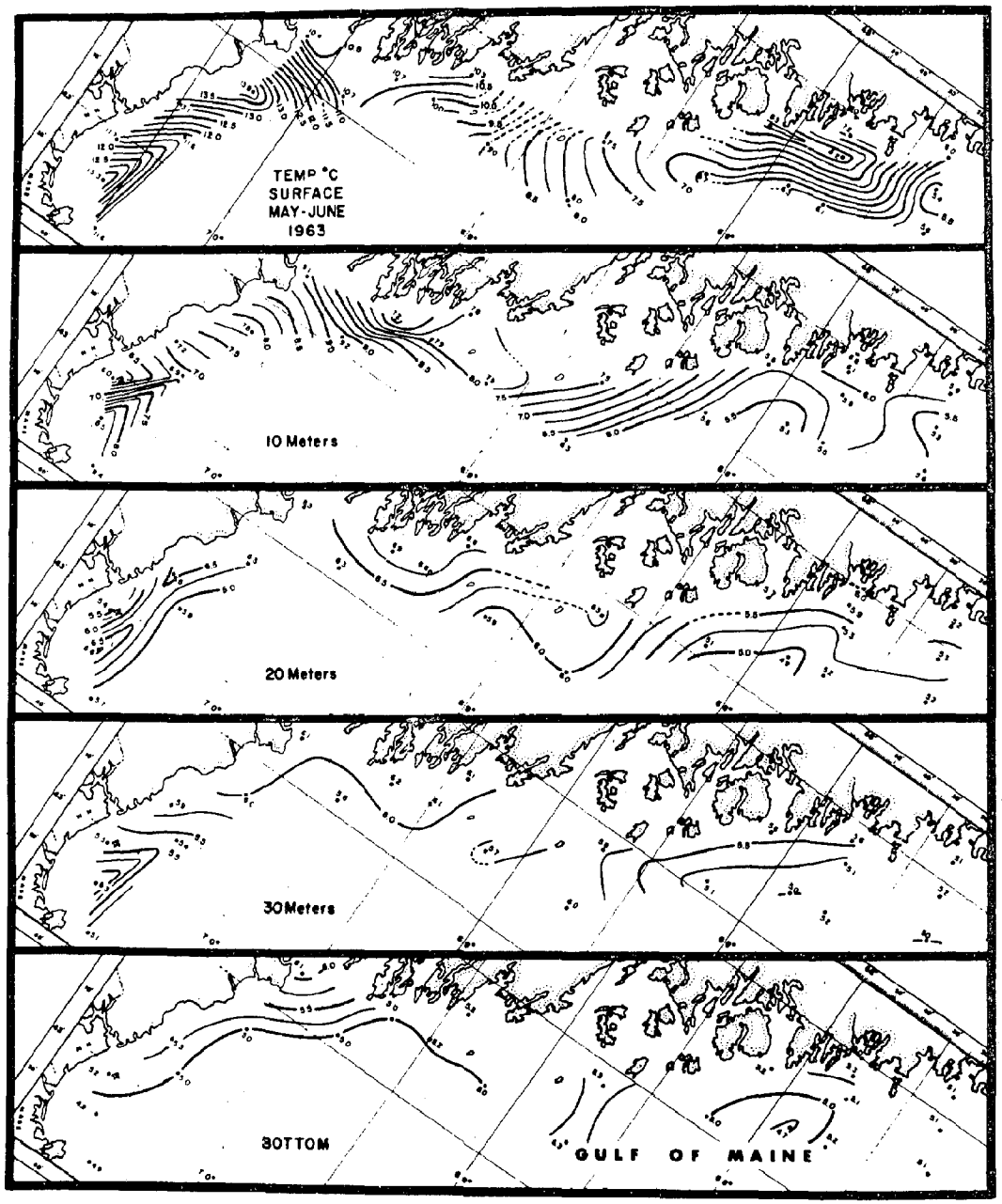
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-123	Distribution of Isotherms May 1964 (Graham, 1970b)



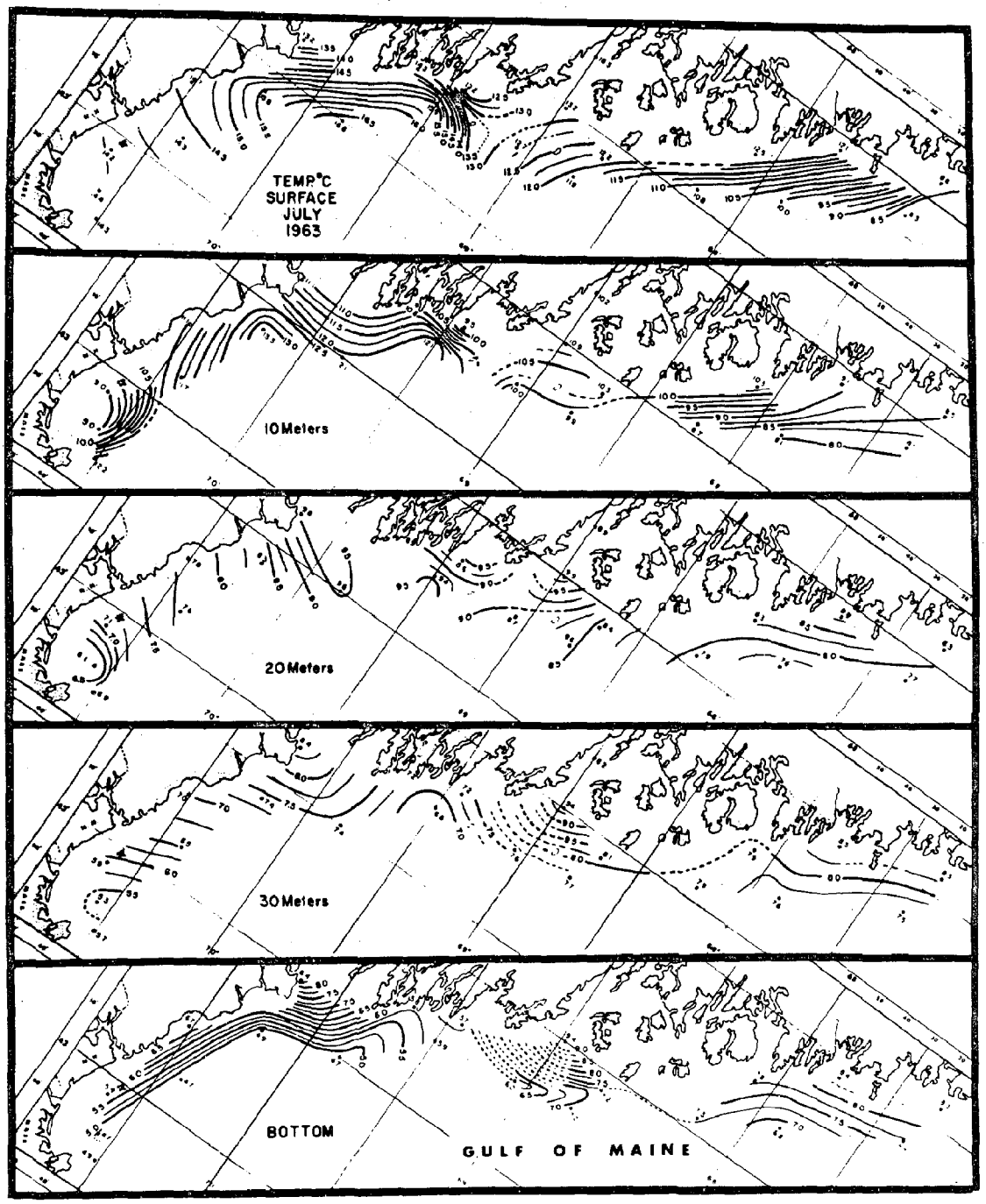
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-124	Distribution of Isotherms May 1965 (Graham, 1970b)



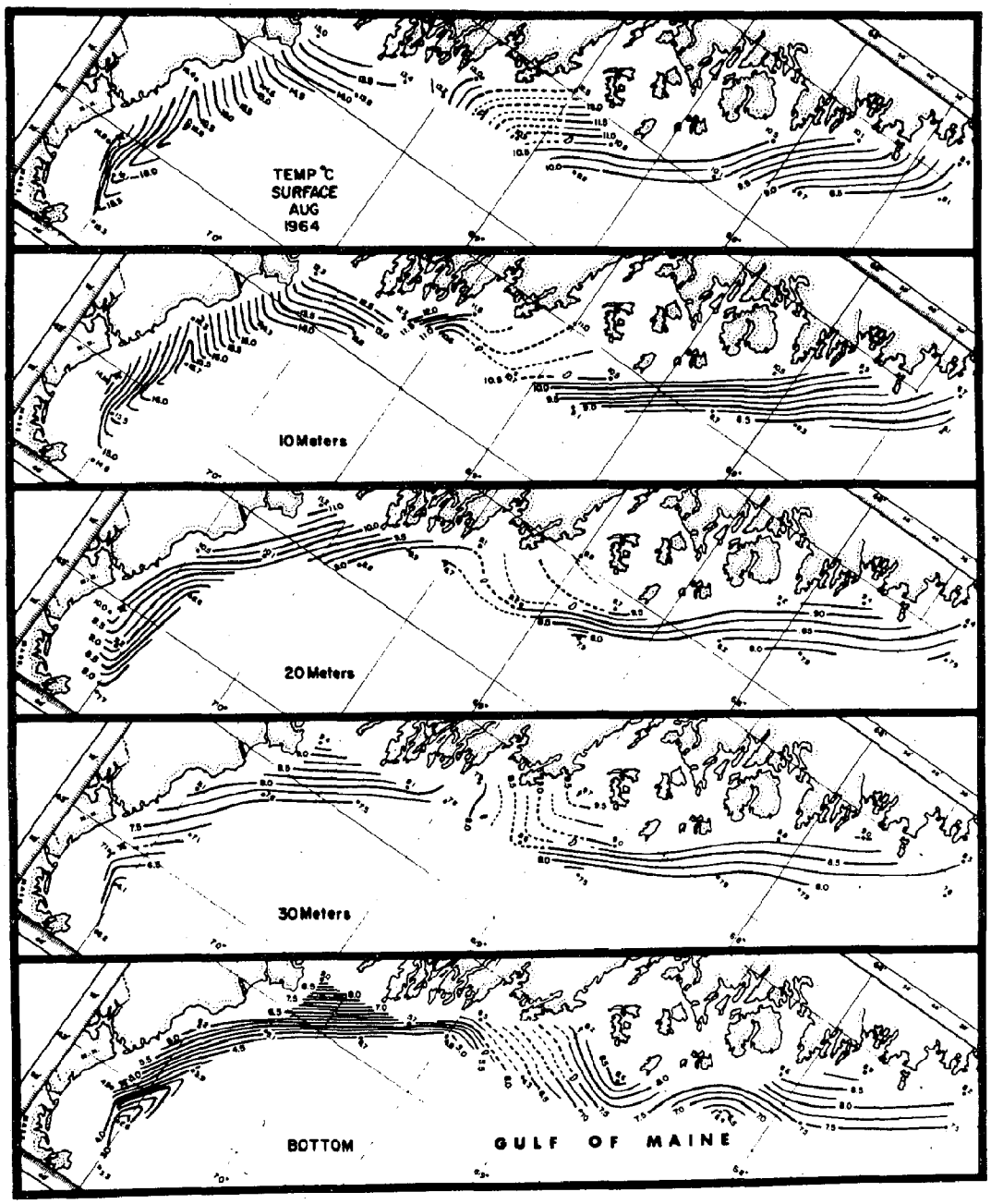
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-125	Distribution of Isotherms May-June 1963 (Graham, 1970b)



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

TRIGOM PARC	FIGURE 4-126	Distribution of Isotherms July 1963 (Graham, 1970b)



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

TRIGOM PARC	FIGURE 4-127	Distribution of Isotherms August 1964 (Graham, 1970b)

Table- 4-12 Tidal Range of Selected Locations (NOS, 1972)

No.	PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level
		Lat.	Long.	Time		Height		Mean	Spring	
				High water	Low water	High water	Low water			
	MAINE									
	Time meridian, 75°W.									
627	EASTPORT	44 54	66 59					18.2	20.7	9.1
629	Gleason Cove, Western Passage	44 58	67 03					18.4	20.9	9.2
	St. Croix River									
631	Robbinston	45 05	67 06					19.2	21.8	9.6
633	St. Croix Island	45 08	67 08					19.6	22.3	9.8
637	Calais	45 11	67 17					20.0	22.8	10.0
	Cobscook Bay									
639	Deep Cove, Moose Island	44 54	67 01					18.7	21.3	9.3
641	East Bay	44 56	67 07					19.1	21.8	9.5
643	Coffins Point	44 52	67 07					18.3	20.8	9.1
645	Birch Islands	44 52	67 09					17.6	20.0	8.8
647	Horan Head, South Bay	44 52	67 04					19.2	21.9	9.5
649	Lubec	44 52	66 59					17.5	20.0	8.7
651	West Quoddy Head	44 49	66 59					15.7	17.9	7.8
653	Moose Cove	44 44	67 06					14.8	16.9	7.4
655	Cutler, Little River	44 39	67 13					13.6	15.5	6.8
657	Stone Island, Machias Bay	44 36	67 22					12.4	14.1	6.2
659	Machiasport, Machias River	44 42	67 24					12.5	14.4	6.3
661	Shoppee Point, Englishman Bay	44 37	67 30					12.1	13.8	6.1
663	Roque I. Harbor, Englishman Bay	44 34	67 31					12.3	14.0	6.1

*Ratio. †Wharves dry at low water.

‡There is a bore in the Petitcodiac River. It arrives at Moncton about 2h 30m before high water at St. John and its height is about 3 to 3½ feet on average spring tides but it sometimes exceeds 5 feet on highest tides. On small tides it is not much more than a large ripple.

§The Reversing Falls at St. John.--The most turbulence in the gorge occurs on days when the tides are largest. On largest tides the outward fall is between 13 and 16½ feet and is accompanied by a greater turbulence than the inward fall which is between 11 and 12½ feet. The outward fall is at its best between 2 hours before and 1 hour after low water at St. John; the inward fall is best just before the time of high water.

*For Eastern Standard time subtract one hour from the predictions obtained using these differences.

Table 4-12 (cont.)

No.	PLACE	POSITION Lat.	POSITION Long.	RANGES Mean	RANGES Spring	Mean Tide Level
		° ′ N.	° ′ W.	feet	feet	feet
	MAINE — Continued *Time meridian, 75°W.*					
665	Steele Harbor Island	44 30	67 33	11.6	13.3	5.2
667	Jonesport, Moosabec Reach	44 32	67 36	11.5	13.2	5.2
669	Gibbs Island, Pleasant River	44 33	67 46	11.3	13.0	5.6
671	Addison, Pleasant River	44 37	67 45	11.8	13.6	5.5
673	Trafton Island, Narraguagus Bay	44 29	67 50	11.1	12.8	5.5
675	Milbridge, Narraguagus River	44 32	67 53	11.3	13.0	5.6
677	Pigeon Hill Bay	44 27	67 52	11.1	12.8	5.6
678	Green Island, Petit Manan Bar	44 22	67 52	10.6	12.2	5.3
679	Pinkham Bay, Dyer Bay	44 28	67 55	10.9	12.5	5.4
681	Garden Point, Gouldsboro Bay	44 28	67 59	10.8	12.4	5.4
683	Corea Harbor	44 24	67 58	10.5	12.1	5.2
685	Prospect Harbor	44 24	68 01	10.5	12.1	5.2
	Frenchman Bay					
701	Winter Harbor	44 23	68 05	10.1	11.6	5.0
703	Eastern Point Harbor	44 28	68 10	10.5	12.1	5.2
705	Sullivan	44 31	68 12	10.5	12.1	5.2
707	Mount Desert Narrows	44 26	68 22	10.5	12.1	5.3
	Mount Desert Island					
709	Salsbury Cove	44 26	68 17	10.6	12.2	5.3
711	Bar Harbor	44 23	68 12	10.5	12.1	5.2
713	Southwest Harbor	44 16	68 19	10.2	11.7	5.1
715	Mount Desert	44 22	68 20	10.6	12.2	5.3
717	Bass Harbor	44 14	68 21	9.9	11.3	5.0
719	Pretty Marsh Harbor	44 20	68 25	10.2	11.7	5.1
	Blue Hill Bay					
721	Union River	44 30	68 26	10.4	11.9	5.2
723	Blue Hill Harbor	44 24	68 34	10.1	11.6	5.0
725	Allen Cove	44 18	68 33	10.3	11.8	5.1
727	Mackerel Cove	44 10	68 26	10.0	11.5	5.0
729	Burnt Coat Harbor, Swans Island	44 09	68 27	9.5	10.8	4.7
	MAINE, Penobscot Bay					
	Eggemoggin Reach					
731	Naskeag Harbor	44 14	68 33	10.2	11.6	5.1
733	Center Harbor	44 16	68 35	10.1	11.5	5.0
735	Sedgwick	44 18	68 38	10.2	11.7	5.1
736	Isle Au Haut	44 04	68 38	9.3	10.7	4.7
737	Head Harbor, Isle Au Haut	44 01	68 37	9.1	10.4	4.6
739	Kimball Island	44 04	68 39	9.6	10.9	4.8
741	Oceanville, Deer Isle	44 12	68 38	10.1	11.5	5.0
743	Stonington, Deer Isle	44 09	68 40	9.7	11.0	4.8
745	Northwest Harbor, Deer Isle	44 14	68 41	10.1	11.5	5.0
747	Matinicus Harbor	43 52	68 53	9.0	10.4	4.5
749	Vinalhaven, Vinalhaven Island	44 03	68 50	9.3	10.7	4.6
751	Iron Point, North Haven Island	44 08	68 52	9.5	10.8	4.8
753	Pulpit Harbor, North Haven Island	44 09	68 53	9.8	11.1	4.9
755	Castine	44 23	68 48	9.7	11.1	4.8
757	Pumpkin Island, South Bay	44 25	68 44	10.3	11.7	5.1
	Penobscot River					
759	Fort Point	44 28	68 49	10.3	11.8	5.1
761	Bucksport	44 34	68 48	11.0	12.5	5.5
763	South Orrington	44 42	68 49	12.3	14.0	6.1
765	Hampden	44 45	68 50	12.8	14.6	6.4
767	Bangor	44 48	68 46	13.1	14.9	6.5
769	Belfast	44 26	69 00	10.0	11.5	5.0
771	Camden	44 12	69 03	9.6	10.9	4.8
773	Rockland	44 06	69 06	9.7	11.2	4.8
775	Owls Head	44 06	69 03	9.4	10.7	4.7
777	Dyer Point, Weskeag River	44 02	69 07	9.6	10.9	4.8

Table 4-12 (cont.)

No.	PLACE	POSITION Lat.	POSITION Long.	RANGES Mean	RANGES Spring	Mean Tide Level
		° ′ N.	° ′ W.	feet	feet	feet
	MAINE, Outer Coast *Time meridian, 75°W.*					
779	Tenants Harbor	43 58	69 12	9.3	10.6	4.6
781	Monhegan Island	43 46	69 19	8.8	10.1	4.4
783	Burnt Island, Georges Islands	43 52	69 18	8.9	10.2	4.4
	St. George River					
785	Port Clyde	43 56	69 16	8.9	10.2	4.4
787	Otis Cove	43 59	69 14	9.1	10.5	4.5
789	Thomaston	44 04	69 11	9.4	10.8	4.7
791	New Harbor, Muscongus Bay	43 52	69 29	8.8	10.1	4.4
793	Muscongus Harbor, Muscongus Sound	43 58	69 27	9.0	10.4	4.5
795	Friendship Harbor	43 58	69 20	9.0	10.4	4.5
	Medomak River					
797	Jones Neck	44 01	69 23	9.1	10.5	4.5
799	Waldoboro	44 06	69 23	9.5	10.9	4.8
801	Pemaquid Harbor, Johns Bay	43 53	69 32	8.8	10.1	4.4
	Damariscotta River					
803	East Boothbay	43 52	69 35	8.9	10.2	4.4
805	Newcastle	44 02	69 32	9.3	10.7	4.6
807	Damariscove Harbor, Damariscove I	43 46	69 37	8.8	10.1	4.4
809	Boothbay Harbor	43 51	69 38	8.8	10.1	4.4
811	Southport, Townsend Gut	43 51	69 40	8.9	10.2	4.4
	Sheepscot River					
813	Isle of Springs	43 52	69 41	8.9	10.3	4.4
815	Cross River entrance	43 56	69 40	9.1	10.5	4.5
817	Wiscasset	44 00	69 40	9.4	10.8	4.7
819	Sheepscot (below rapids)	44 03	69 37	9.6	11.0	4.8
821	Back River	43 57	69 41	9.1	10.5	4.5
823	Robinhood, Sasanoa River	43 51	69 44	8.8	10.1	4.4
825	Mill Point, Sasanoa River	43 53	69 46	8.8	10.1	4.4
827	Upper Hell Gate, Sasanoa River	43 54	69 47	7.0	8.0	3.5
	MAINE, Kennebec River					
829	Fort Popham	43 45	69 47	8.4	9.7	4.2
831	Phippsburg	43 49	69 49	8.0	9.2	4.0
833	Bath	43 55	69 49	6.4	7.4	3.2
835	Sturgeon Island, Merrymeeting Bay	43 59	69 50	5.3	6.1	2.6
837	Androscoggin River entrance	43 57	69 53	4.7	5.4	2.3
839	Brunswick, Androscoggin River	43 55	69 58	3.8	4.4	1.9
841	Bowdoinham, Cathance River	44 00	69 54	5.7	6.6	2.8
843	Richmond	44 05	69 48	5.3	6.0	2.6
845	Nehumkeag Island	44 10	69 45	5.3	6.0	2.6
847	Gardiner	44 14	69 46	5.0	5.7	2.5
849	Hallowell	44 17	69 47	4.3	4.9	2.1
851	Augusta	44 19	69 46	4.1	4.6	2.0
	MAINE, Casco Bay					
853	Small Point Harbor	43 44	69 51	8.8	10.1	4.4
855	Cundy Harbor, New Meadows River	43 47	69 54	8.9	10.2	4.4
857	Howard Point, New Meadows River	43 53	69 53	9.0	10.3	4.5
859	Lowell Cove, Orrs Island	43 45	69 59	8.8	10.1	4.4
861	Harpswell Harbor	43 46	70 00	9.0	10.4	4.5
863	South Harpswell, Potts Harbor	43 44	70 01	8.9	10.2	4.4
865	Wilson Cove, Middle Bay	43 49	69 59	9.1	10.5	4.5
867	Little Flying Point, Maquoit Bay	43 50	70 03	9.0	10.3	4.5
869	South Freeport	43 49	70 06	9.0	10.3	4.5
871	Chebeague Point, Great Chebeague I	43 46	70 06	9.0	10.4	4.5
873	Prince Point	43 46	70 10	9.0	10.4	4.5
875	Peaks Island	43 39	70 12	9.0	10.4	4.5
877	PORTLAND	43 40	70 15	9.0	10.4	4.5

*Ratio.

Table 4-12 (cont.)

No.	PLACE	POSITION Lat.	POSITION Long.	RANGES Mean	RANGES Spring	Mean Tide Level
		° ′ N.	° ′ W.	feet	feet	feet
	MAINE, Outer Coast—Continued					
879	Richmond Island	43 33	70 14	8.9	10.1	4.4
881	Old Orchard Beach	43 31	70 22	8.8	10.1	4.4
883	Wood Island Harbor	43 27	70 21	8.7	9.9	4.3
885	Cape Porpoise	43 22	70 26	8.7	9.9	4.3
887	Kennebunkport	43 21	70 28	8.6	9.9	4.3
889	York Harbor	43 08	70 38	8.6	9.9	4.3
	MAINE and NEW HAMPSHIRE					
	Portsmouth Harbor					
891	Jaffrey Point	43 03	70 43	8.7	10.0	4.4
893	Gerrish Island Wharf	43 04	70 42	8.7	10.0	4.4
895	Fort Point	43 04	70 43	8.6	9.9	4.3
897	Kittery Point	43 05	70 42	8.7	10.0	4.4
899	Seavey Island	43 05	70 45	8.1	9.3	4.0
901	Portsmouth	43 05	70 45	7.8	9.0	3.9
	Piscataqua River					
903	Atlantic Heights	43 05	70 46	7.5	8.6	3.7
905	Dover Point	43 07	70 50	6.4	7.4	3.2
907	Salmon Falls River entrance	43 11	70 50	6.8	7.8	3.4
909	Squamscott River RR Bridge	43 03	70 55	6.8	7.8	3.4
911	Gosport Harbor, Isles of Shoals	42 59	70 37	8.5	9.8	4.2
913	Hampton Harbor	42 54	70 49	8.3	9.5	4.1
	MASSACHUSETTS, Outer Coast					
915	Merrimack River entrance	42 49	70 49	8.3	9.5	4.1
917	Newburyport, Merrimack River	42 49	70 52	7.8	9.0	3.9
919	Plum Island Sound (south end)	42 43	70 47	8.6	9.9	4.3
921	Annisquam	42 39	70 41	8.7	10.1	4.4
923	Rockport	42 40	70 37	8.6	10.0	4.3
925	Gloucester	42 36	70 40	8.7	10.1	4.3
927	Manchester Harbor	42 34	70 47	8.8	10.2	4.4
929	Beverly	42 32	70 53	9.0	10.4	4.5
931	Salem	42 31	70 53	8.8	10.2	4.4
933	Marblehead	42 30	70 51	9.1	10.6	4.5
	Broad Sound					
935	Nahant	42 25	70 55	9.0	10.4	4.5
937	Lynn Harbor	42 27	70 58	9.2	10.7	4.6
	Boston Harbor					
939	Boston Light	42 20	70 53	9.0	10.4	4.5
941	Lovell Island, The Narrows	42 20	70 56	9.1	10.6	4.5
943	Deer Island (south end)	42 21	70 58	9.3	10.8	4.6
945	Belle Isle Inlet entrance	42 23	71 00	9.5	11.0	4.7
947	Castle Island	42 20	71 01	9.4	10.9	4.7
949	BOSTON	42 21	71 03	9.5	11.0	4.7
951	Dover St. Bridge, Fort Point Channel	42 21	71 04	9.6	11.0	4.8
	Charles River					
953	Charlestown Bridge	42 22	71 04	9.5	11.0	4.7
955	Charles River Dam	42 22	71 04	9.5	11.0	4.7
957	Charlestown	42 22	71 03	9.5	11.0	4.7
959	Chelsea St. Bridge, Chelsea River	42 23	71 01	9.6	11.1	4.8
	Mystic River					
961	Wellington Bridge	42 24	71 05	9.6	11.1	4.8
963	Medford Bridge	42 25	71 07	9.3	10.8	4.6
965	Neponset, Neponset River	42 17	71 02	9.5	11.0	4.7
967	Moon Head	42 19	70 59	9.4	10.9	4.7
969	Rainsford Island, Nantasket Roads	42 19	70 57	9.1	10.6	4.5

Table 4-12 (cont.)

No.	PLACE	POSITION Lat.	POSITION Long.	RANGES Mean	RANGES Spring	Mean Tide Level
		° ′	° ′	feet	feet	feet
	MASSACHUSETTS, Outer Coast — Con. Hingham Bay *Time meridian, 75°W.*	N.	W.			
971	Nut Island	42 17	70 57	9.2	10.7	4.6
973	Sheep Island	42 17	70 55	9.5	11.0	4.7
975	Weymouth Fore River Bridge	42 15	70 55	9.5	11.0	4.7
977	Weymouth Back River Bridge	42 15	70 53	9.5	11.0	4.7
979	Crow Point, Hingham Harbor entrance	42 16	70 54	9.4	10.9	4.7
981	Hingham	42 15	70 53	9.5	11.0	4.7
983	Nantasket Beach, Weir River	42 16	70 52	9.4	10.9	4.7
985	Strawberry Hill	42 17	70 53	9.5	11.0	4.7
987	Hull	42 18	70 55	9.3	10.8	4.7
	Cohasset Harbor to Davis Bank					
989	Cohasset Harbor (White Head)	42 15	70 47	8.8	10.2	4.4
991	Scituate	42 12	70 43	8.8	10.2	4.4
992	Damons Point, North River	42 10	70 44	8.5	9.9	4.2
	Cape Cod Bay					
993	Gurnet Point	42 00	70 36	9.2	10.7	4.6
995	Plymouth	41 58	70 40	9.5	11.0	4.7
997	Cape Cod Canal, east entrance	41 46	70 30	8.7	10.1	4.3
999	Barnstable Harbor, Beach Point	41 43	70 17	9.5	11.0	4.7
1001	Wellfleet	41 55	70 02	10.0	11.6	5.0
1003	Provincetown	42 03	70 11	9.1	10.6	4.5
1005	Race Point	42 04	70 15	9.0	10.4	4.5
	Cape Cod					
1007	Cape Cod Lighthouse, SE. of	42 00	70 01	7.6	8.8	3.8
1009	Nauset Harbor	41 48	69 56	6.0	7.0	3.0
1011	Chatham (outer coast)	41 40	69 56	6.7	7.8	3.3
1013	Chatham (inside)	41 41	69 57	3.6	4.2	1.8
1015	Pleasant Bay	41 44	69 59	3.2	3.7	1.6
1017	Monomoy Point	41 33	70 00	3.7	4.3	1.8
1019	Georges Shoal	41 42	67 46	4.2	4.8	2.1
1021	Davis Bank, Nantucket Shoals	41 08	69 39	1.3	1.5	0.6

Table 4-13

No.	PLACE	POSITION Lat.	POSITION Long.	MAXIMUM CURRENTS Flood Direction (true)	Flood Average velocity	Ebb Direction (true)	Ebb Average velocity
		° ′	° ′	deg.	knots	deg.	knots
	BAY OF FUNDY	N.	W.				
1	Brazil Rock, 6 miles east of----------	43 22	65 18	275	1.0	50	1.0
5	Cape Sable, 3 miles south of----------	43 20	65 38	275	2.2	95	2.0
10	Cape Sable, 12 miles south of----------	43 11	65 37	285	1.7	90	1.6
15	Blonde Rock, 5 miles south of----------	43 15	65 59	310	2.0	125	2.0
20	Seal Island, 13 miles southwest of----	43 16	66 15	325	2.6	140	1.6
25	Cape Fourchu, 17 miles southwest of---	43 34	66 24	355	1.2	145	1.2
30	Cape Fourchu, 4 miles west of----------	43 47	66 15	0	2.0	175	1.7
35	Lurcher Shoal, 6 miles east of----------	43 52	66 21	355	2.0	175	1.9
40	Lurcher Shoal, 10 miles west of--------	43 46	66 42	0	1.4	160	1.6
45	Lurcher Shoal, 10 miles northwest of--	43 59	66 37	5	1.8	175	1.2
50	Brier Island, 5 miles west of----------	44 13	66 30	5	2.7	185	2.5
55	Brier Island, 15 miles west of----------	44 17	66 44	60	1.4	250	1.2
60	Gannet Rock, 5 miles southeast of------	44 29	66 41	40	2.6	230	3.9
65	Bears Head, 10 miles northwest of------	44 31	66 23	20	1.9	205	2.0
70	Prim Point, 20 miles west of----------	44 44	66 15	40	1.6	235	1.4
75	Cape Spencer, 14 miles south of--------	44 58	65 57	50	1.7	245	1.6
80	BAY OF FUNDY ENTRANCE----------	44 45	66 56	30	2.3	210	2.4
	MAINE COAST						
85	Eastport, Friar Roads----------	44 54	66 59	210	3.0	40	3.0
90	Western Passage, off Kendall Head------	44 56	67 00	320	3.2	140	3.1
95	Western Passage, off Frost Ledge--------	44 58	67 02	330	2.1	150	1.7
100	Pond Point, 7.6 miles SSE. of----------	44 20	67 30	15	0.5	215	1.2
105	Moosabec Reach, east end----------	44 32	67 34	110	1.0	260	1.0
110	Moosabec Reach, west end----------	44 31	67 39	90	1.0	255	1.2
115	Bar Harbor, 1.2 miles east of----------	44 23	68 10	330	0.2	150	0.7
120	Casco Passage, E. end, Blue Hill Bay--	44 12	68 28	85	0.7	285	0.7
125	Hat Island, SE. of, Jericho Bay--------	44 08	68 30	320	0.9	125	1.3
130	Isle Au Haut, 0.8 mi. E. of Richs Pt--	44 05	68 35	335	1.4	140	1.5
135	West Penobscot Bay, off Monroe I-------	44 05	69 00	5	0.3	160	0.6
140	Muscongus Sound----------	43 56	69 27	----	----	----	----
145	Damariscotta River, off Cavis Point---	43 53	69 35	350	0.6	215	1.0
150	Sheepscot River, off Barter Island----	43 54	69 41	5	0.8	200	1.1
155	Lowe Pt., NE. of, Sasanoa River--------	43 51	69 43	325	1.7	150	1.8
160	Lower Hell Gate, Knubble Bay[4] --------	43 53	69 44	290	3.0	155	3.5
165	Upper Hell Gate, Sasanoa River--------	43 54	69 46	305	1.0	140	0.8
	KENNEBEC RIVER						
170	Hunniwell Point, northeast of----------	43 45	69 47	330	2.4	150	2.9
175	Bald Head, 0.3 mile southwest of------	43 48	69 48	320	1.6	155	2.3
180	Bluff Head, west of----------	43 51	69 48	15	2.3	185	3.4
185	Fiddler Ledge, north of----------	43 53	69 48	265	1.9	115	2.6
190	Doubling Point, south of----------	43 53	69 48	300	2.6	125	3.0
195	Lincoln Ledge, east of----------	43 54	69 49	0	1.9	175	2.8
200	Bath, 0.2 mile south of bridge*--------	43 55	69 48	5	1.0	175	1.5

[1]Flood begins, +0h 15m; ebb begins, -1h 35m.
[2]Times of slack are indefinite.
[3]Current too weak and variable to be predicted.
[4]Velocities up to 9.0 knots have been observed in the vicinity of The Boilers.
[5]Flood begins, +3h 30m; maximum flood, +2h 50m; ebb begins, +1h 20m; maximum ebb, +2h 05m.
*Current turns westward just before the end of the flood.

(Cont) Table 4-13 CURRENT DIFFERENCES AND OTHER CONSTANTS

No.	PLACE	POSITION Lat.	POSITION Long.	MAXIMUM CURRENTS Flood Direction (true)	Flood Average velocity	Ebb Direction (true)	Ebb Average velocity
		° ′ N.	° ′ W.	deg.	knots	deg.	knots
	CASCO BAY		on	16			
205	Broad Sound, west of Eagle Island	43 43	70 04	10	0.9	170	1.3
210	Hussey Sound, 0.2 mile SE. of Crow I	43 41	70 11	0	1.1	175	0.8
215	Hussey Sound, 0.5 mile S. of Overset I	43 40	70 10	340	1.1	130	1.4
220	Portland Hbr. ent., SW. of Cushing I	43 38	70 13	320	1.0	155	1.1
225	Diamond I. Ledge, midchannel SW. of	43 40	70 14	300	0.9	150	0.9
230	Portland Breakwater Lt., 0.3 mi. NW. of	43 40	70 15	(2)	0.4	50	0.5
235	Grand Trunk Wharves, off ends	43 40	70 15	250	0.6	40	0.4
240	Portland Bridge, center of draw	43 39	70 16	225	0.9	50	1.0
	MAINE COAST—Continued						
245	Portland Lightship	43 32	70 06	----	----	----	----
250	Cape Elizabeth	43 34	70 11	340	0.3	160	0.3
255	Cape Porpoise	43 22	70 24	35	0.3	215	0.3
260	Cape Neddick	43 10	70 35	25	0.4	205	0.4
265	York Harbor ent., 3 miles south of	43 08	70 33	25	0.4	205	0.4
	PORTSMOUTH HARBOR						
270	Kitts Rocks, 0.2 mile west of	43 03	70 42	325	0.8	175	1.6
275	Little Harbor entrance	43 03	70 43	310	0.7	130	1.1
280	PORTSMOUTH HARBOR ENT. (off Wood I.)	43 04	70 42	355	1.2	195	1.8
285	Fort Point	43 04	70 42	350	1.5	130	2.0
290	Salamander Point	43 05	70 43	260	1.3	85	1.3
295	Between Hick Rocks and Clarks I	43 05	70 43	335	0.9	195	0.8
300	Kittery Point Bridge	43 05	70 43	20	0.8	200	1.1
305	Jamaica Island, NE. of	43 05	70 43	315	1.0	135	1.0
310	Seavey Island, north of	43 05	70 44	260	1.4	80	1.8
315	Between Clarks I. and Seavey I	43 05	70 44	200	1.8	(4)	(4)
320	Clarks Island, south of	43 04	70 44	260	2.1	80	3.1
325	Seavey Island, south of	43 04	70 44	260	3.0	90	3.8
330	Between Marvin I. and Goat I	43 04	70 44	160	1.2	340	0.8
335	Henderson Point, west of	43 05	70 44	340	2.6	170	2.3
340	Off Gangway Rock	43 05	70 45	280	2.1	110	3.0
345	Badgers Island, east of	43 05	70 45	240	1.1	50	0.4
350	Badgers Island, SW. of	43 05	70 45	330	3.3	125	3.7
	PISCATAQUA RIVER and TRIBUTARIES						
355	NW. of Nobles Island (RR. bridge)	43 05	70 46	50	1.6	200	0.9
360	Nobles Island, north of	43 06	70 46	305	3.6	140	4.4
365	Frankfort Island, south of	43 07	70 48	310	2.6	130	2.9
370	Little Bay entrance, Dover Point	43 07	70 50	270	3.8	95	4.2
375	Furber Strait	43 05	70 52	185	2.0	10	2.1
	MASSACHUSETTS COAST						
380	Gunboat Shoal	43 01	70 42	340	0.5	160	0.5
385	Isles of Shoals Light, White Island	42 58	70 37	20	0.3	200	0.3

[1]Times of slack are indefinite.
[2]Current tends to rotate counterclockwise, flood direction swinging from westward to southward.
[3]Current too weak and variable to be predicted.
[4]Observations indicate that current floods about 11 hours and ebbs about 1½ hours. Slack before flood occurs about 4½ hours earlier, maximum flood about 1 hour later, slack before ebb about ½ hour later, and maximum ebb about 1½ hours earlier than corresponding predictions at Portsmouth Harbor Entrance. Average ebb velocity is less than ½ knot.

Table 4-13 (Cont.) 2.—CURRENT DIFFERENCES AND OTHER CONSTANTS

No.	PLACE	POSITION Lat.	POSITION Long.	MAXIMUM CURRENTS Flood Direction (true)	Flood Average velocity	Ebb Direction (true)	Ebb Average velocity
		° ′ N.	° ′ W.	deg.	knots	deg.	knots
	MASSACHUSETTS COAST—Continued						
390	Merrimack River entrance	42 49	70 49	285	2.2	105	1.4
395	Newburyport, Merrimack River	42 49	70 52	290	1.5	100	1.4
400	Plum Island Sound entrance	42 42	70 47	315	1.6	185	1.5
405	Annisquam Harbor Light	42 40	70 41	200	1.0	15	1.3
410	Gloucester Harbor entrance	42 35	70 40	----	----	----	----
415	Blynman Canal ent., Gloucester Hbr	42 37	70 40	310	3.0	130	3.3
420	Marblehead Channel	42 30	70 49	285	0.4	105	0.4
425	Nahant, off East Point	42 25	70 54	235	0.8	85	0.7
430	Lynn Harbor entrance	42 25	70 57	325	0.5	170	0.5
435	Winthrop Beach, 1.2 miles east of	42 23	70 57	195	0.4	95	0.2
	BOSTON HARBOR APPROACHES						
440	Stellwagen Bank	42 24	70 24	----	----	----	----
445	Boston Lightship	42 20	70 45	----	----	----	----
450	North Channel, off Great Faun	42 21	70 56	200	1.2	25	1.4
455	Hypocrite Channel	42 21	70 54	255	1.2	70	1.0
460	Nantasket Roads entrance	42 19	70 53	260	1.4	85	1.5
465	Black Rock Channel	42 19	70 55	220	1.2	35	1.2
	BOSTON HARBOR						
470	The Narrows, off Georges Island	42 19	70 56	280	0.9	110	1.3
475	The Narrows, off Gallups Island	42 20	70 56	125	0.6	315	0.2
480	Between Gallups I. and Georges I	42 19	70 56	205	0.6	40	0.8
485	Nubble Channel	42 20	70 57	195	0.8	15	0.8
490	BOSTON HARBOR (Deer Island Light)	42 20	70 57	260	1.7	85	1.3
495	Point Shirley, 0.5 mile SW. of	42 21	70 59	----	----	----	----
500	Main Ship Chan., off Ft. Independence	42 21	71 01	300	0.6	110	0.6
505	Fort Point Channel entrance	42 21	71 03	210	0.2	25	0.4
510	Between Boston and East Boston	42 22	71 03	340	0.4	160	0.6
515	Charles River entrance	42 22	71 04	----	----	----	----
520	Between Charlestown and East Boston	42 22	71 03	25	0.4	200	0.6
525	Chelsea River entrance	42 23	71 02	100	0.5	290	0.6
530	Mystic River entrance	42 23	71 03	270	0.4	90	0.5
535	Between Spectacle I. and Castle I	42 20	71 00	250	0.6	70	0.6
540	Between Spectacle I. and Thompson I	42 19	71 00	310	0.5	120	0.5
545	Dorchester Bay, off Thimble Island	42 18	71 02	230	0.8	65	0.9
550	Neponset River (railroad bridge)	42 17	71 02	230	0.6	50	0.7
555	Between Long I. and Spectacle I	42 19	70 58	185	0.4	25	0.5
560	Between Thompson I. and Moon Head	42 18	71 00	260	0.4	55	0.5
565	Between Moon Head and Long Island	42 19	70 59	----	----	----	----
570	Between Long I. and Rainsford I	42 19	70 58	225	0.8	45	1.0
575	Nantasket Roads, off Georges Island	42 19	70 55	250	1.3	40	1.9
580	Nantasket Roads, off Rainsford I	42 18	70 57	240	1.1	60	1.0
585	Squantum, 0.3 mile SE. of	42 17	71 00	----	----	----	----
590	Nut Island, 0.8 mile West of	42 17	70 58	275	0.3	55	0.2
595	Hull Gut	42 18	70 55	155	2.0	350	2.4
600	Between Peddocks I. and Nut I	42 17	70 57	125	1.6	315	1.4
605	Between Peddocks I. and Sheep I	42 17	70 56	40	0.5	220	0.4
610	Between Raccoon I. and Grape I	42 16	70 56	185	0.5	30	0.4

[1]Current too weak and variable to be predicted.
[2]For flood and slack before ebb, -1^h 20^m. For ebb and slack before flood, -0^h 25^m.
[3]For flood and slack before ebb, -2^h 00^m. For ebb and slack before flood, -0^h 20^m.
[4]For flood, $+0^h$ 35^m. For ebb, -0^h 50^m.
†Current weak and rotary, turning counterclockwise.

Table 4-13 (Cont) —CURRENT DIFFERENCES AND OTHER CONSTANTS

No.	PLACE	POSITION Lat.	POSITION Long.	MAXIMUM CURRENTS Flood Direction (true)	Flood Average velocity	Ebb Direction (true)	Ebb Average velocity
		° ′	° ′	deg.	knots	deg.	knots
	BOSTON HARBOR—Continued	N.	W.				
620	Weymouth Fore River, Quincy Point	42 15	70 58	225	0.6	45	0.9
625	Weymouth Back River, bridge	42 15	70 56	165	1.2	345	1.2
630	Hull, Channel SE. of	42 18	70 54	60	0.2	215	0.3
635	Strawberry Hill, 0.5 mile west of	42 17	70 54	----	----	----	----
640	Off Bumkin Island	42 16	70 54	130	0.9	325	1.1
645	Worlds End, North of	42 16	70 53	85	1.0	275	1.2
650	Off Crow Point	42 16	70 54	150	0.9	335	1.0
	CAPE COD BAY						
655	Race Point, 7 miles north of	42 11	70 16	290	1.5	----	1.5
660	Race Point, 1 mile northwest of	42 05	70 15	225	1.0	60	0.9
665	Provincetown Harbor	42 03	70 10	315	0.6	135	0.4
670	Wellfleet Harbor	41 54	70 03	20	0.7	200	0.5
675	Barnstable Harbor	41 44	70 16	190	1.2	5	1.4
680	Sandwich Harbor	41 46	70 29	----	----	----	----
	Cape Cod Canal (see page 144)	-----	-----	----	----	----	----
685	Sagamore Beach	41 48	70 31	----	----	----	----
690	Ellisville Harbor, 1 mile east of	41 51	70 30	200	0.3	20	0.3
695	Manomet Point	41 56	70 32	155	1.1	10	0.9
700	Gurnet Point, 1 mile east of	42 00	70 35	250	1.4	----	1.0
705	Plymouth Harbor	41 58	70 39	245	0.5	10	0.4
710	Farnham Rock, 1 mile east of	42 06	70 35	180	1.1	10	0.9

4.2.9 CIRCULATION AND CURRENTS - REGION SOUTH OF CAPE COD

INTRODUCTION

The components of circulation discussed in the preceding chapter on the offshore area are greatly modified in coastal areas by both emergent and submergent geomorphology. Confined to narrow passages at their entrances, the tidal motion becomes a reversing oscillation rather than a rotary one within the coastal waters, and the currents increase sharply in amplitude (Fig. 4-84). The elevation of the land immediately adjacent to these waters sharply increases the hydrostatic head of the freshwater runoff, and both diurnal and seasonal oscillations in temperature are much sharper. These factors, operating directly upon the shallower waters over short distances, produce steeper pressure gradients and hence stronger currents than those of offshore areas. Just as the emergent shore and underwater topography act as barriers and channels to modify the course of these currents, so does the moving water act upon the shifting coastlines, building bars, and wearing away headlands; in general, acting together with the historical tectonic processes to produce the three major types of coastal embayments found in this area; sounds, drowned estuaries, and inlets behind bar-built beaches.

Vineyard and Nantucket Sounds

These two areas form essentially a single body of relatively shallow water 75 nautical km long, 28 nautical km wide in the Nantucket portion and 7 nautical km wide in the Vineyard portion. Bumpus, Lynde, and Shaw (1973) classifies them as Prichard Type D estuaries. River runoff is relatively low, and tidal currents of up to 35 km/hr dominate. The residual drift is characterized by an eddy of Gulf of Maine waters around Nantucket Island and into the sound, then a net easterly flow of about 5 percent of the tidal volume (200 m^3 per tidal cycle) out of Nantucket Sound between Monomoy and Nantucket Islands (Figs. 4-84 and 4-85), given off from the southern side of currents within Nantucket Sound (Bigelow, 1924). Drift bottles, released in Rhode Island Sound to the west, confirmed strong easterly drift into Vineyard and Nantucket Sounds, as well as the clockwise gyre around Nantucket Island (Cook, 1966). There appears to be an onshore set from the northern sections of Vineyard and Nantucket Sounds as well as movement south between Nantucket and Martha's Vineyard.

Rhode Island Sound

This area is much more open than the sounds to the east and the west (Fig. 4-84). It receives a large amount of water from Buzzards Bay and Narragansett Bay, which comprise virtually its total northern

boundary. The fresh water discharge from Narragansett Bay persists year-round and its effect can be seen in the salinity profiles in Figures 4-129 to 4-155. A definite salt-wedging effect from the outer shelf can be seen in both the salinity and the density profiles of Figures 4-129 to 4-155 except in January when it appeared essentially homogeneous.

The temperature structure approaches vertical homogeneity between October and April (Fig. 4-134 and 4-135), then becomes stratified over the summer (Fig. 4-152 to 4-155), developing a sharp thermocline (4-132, 4-133). The usual onshore-offshore gradient persists, with summer and winter reversals (Morton, 1967).

The general circulation pattern in Rhode Island Sound consists of a clockwise gyre centered off the Sakonnet River (Cook, 1966). The shelf water moving inshore from south of Martha's Vineyard moves north along the eastern portion of the Sound, giving off water to Vineyard Sound and the southeastern shores of Buzzards Bay. The eddy entrains water from the northern shores of Buzzards Bay, from the Sakonnet River, and from Narragansett Bay as it flows west along the coast of Rhode Island. It circles south, and receives water from between Block Island and Point Judith, except in the summer (Table 4-15), when it gives off water to the west. Prevailing winds drive a portion of this water to the east between Block Island and Martha's Vineyard, and from there it flows north to complete the cycle (Fig. 4-84).

Cook ascribes the general circulation pattern to estuarine outflow and non-estuarine advective processes, modified seasonally by prevailing winds and seasonal changes in runoff. He does not discuss the geomorphology of the area, which undoubtedly interacts with the dynamic gradients. Rhode Island Sound is naturally bounded on the south by subsurface remnants of the Ronkonkoma moraine, producing an elevated area between Block Island and Martha's Vineyard, broken only by a 9 km gap off Block Island (McMaster, 1960). The Harbor Hill moraine is manifested by a discontinuous belt of hummocky relief from Point Judith to the Elizabeth Islands, cut by the submerged valley of Buzzards Bay. These features undoubtedly contribute to the location of the gyre, and must be responsible in part for the cyclonic nature of water movement. In this same area there is the phenomenon of a tidal current reversal well known to local sailors, such that the ebb currents to the east of Narragansett Bay flow eastward into Nantucket Sound; those to the west flow westward into Block Island Sound, drawing water inward from the south. The currents to the westward (interacting with the Block Island Sound Area) are much stronger than those to the eastward off Buzzards Bay (Eldridge, 1974). Bumpus also described a larger gyre enveloping Block Island which was discussed in an earlier section.

Table 4-15 Circulation in Rhode Island Sound. Changes in the seasonal pattern. Data compiled from Cook, 1966.

Season	Depth	East. RIS	Pt. Judith-Block Is.	Prevail. Wind	Surface Runoff
Spring	Surface	N. and E. weak W. components	East	S & SW	decr. fr.
Apr, May, June	Bottom	N. and W.	West		March Max.
Summer	Surface	N. with weaker E. & W. components	NW and SW	SW & S	minimum
Jul, Aug, Sept	Bottom	North	West		
Fall & Winter	Surface	E. or SE offshore	E & S	NW	no data
Oct - Apr	Bottom	onshore	North		

Block Island Sound

This area comprises 1,040 square km west of Rhode Island Sound. Its average depth is 40 m, with a maximum of 100 m (Williams, 1969). It opens to the Atlantic Ocean through Southern Channel between Montauk Point and Block Island, and to the west it exchanges water with Long Island Sound through the Race and Plum Gut.

Block Island Sound is somewhat more protected than Rhode Island Sound. It receives only a small amount of river discharge. The eastern sector is a broad flat plain with a mean depth of 33.5 m. The western topography is rough, dissected by many holes, ridges, and submerged valleys reaching 51.5 m. The greatest depth in Block Island Sound is a closed basin 98.5 m, deep lying 7 km south of East Point on Fishers Island. A sill runs from Valiant Rock across The Race to Fishers Island (Fig. 4-156), the junction of Block Island and Long Island Sounds. This sill and an extensive shoal area restrict the free exchange of water between the two sounds (Gallagher and Nalwalk, 1971).

The temperature structure in Block Island Sound is nearly homogeneous spring and fall. Temperatures decrease with depth in summer but no distinct thermocline develops. Bottom temperatures are slightly warmer in winter. In summer the warmest temperatures occur near shore along the Rhode Island coast while the coldest are on the bottom in Block Island Channel (about 13 C).

In summer there are typically cells of warm or cold water a few kilometers in extent. These indicate a thermal front between Block Island Sound and Rhode Island Sound. A cold eddy persists off Montauk Point in June and July. During June, July, and August the surface temperatures in western Block Island Sound are about 1 C warmer than Central Block Island Sound, probably from mixing with Long Island Sound water. Weather conditions such as clouds and fog affect surface temperatures. During this time a tongue of cold saline water wedged along the bottom into Block Island Sound from the shelf and cold water from the shelf floods through Block Island Channel and ebbs again through there and between Block Island and the mainland, keeping onshore-offshore gradients high.

In early fall, the temperatures are warmer inshore, the water column becomes homogeneous, and the horizontal gradient reverses, placing the warmer temperatures offshore. The rate of cooling is a function of the autumn storms. The winter gradients are all very weak. The largest vertical gradient is 0.4 C at 20 m. Vernal warming takes place first inshore, following no definite pattern. Differential heating results in thermal eddy development. A more complete description of the seasonal dynamics of the temperature structure is given in Williams, Lamoureaux, and Azarovitz, 1971).

The lowest salinities in Block Island Sound are about 30 $^{o}/oo$ at the surface near Montauk Point while highest of 31 $^{o}/oo$ occur on the bottom in Block Island Channel. Diurnal fluctuations in temperature and salinity are shown in Figure 4-176. They mainly reflect tidal variations.

The circulation pattern in Block Island Sound shows some features typical of estuaries and others typical of a strait between two seas (Williams, et al., 1971). Few current data exist for non-tidal flow, but with those available there appears to be a cyclonic gyre similar to Rhode Island Sound (Figure 4-84), with some seasonal changes in pattern.

Water flows westward into Block Island Sound between Point Judith and Block Island (Riley, 1952). It crosses the Sound and joins the southeast flow of water from Long Island Sound out past Montauk Point. The subsurface water from Block Island Sound continues into Long Island Sound, but the water flowing out of Long Island Sound stays close to Montauk Point and has little effect on the hydrography of the central and eastern portions of Block Island Sound. During summer, there is no eastward transport through the central portion of the sound. Both the outflow from Long Island Sound and the freshwater drainage from the Rhode Island coast are at a minimum, and offshore water is prevalent throughout Block Island Sound, bearing shelf-type plankton rather than species from coastal waters.

By winter the Long Island Sound flow increases, influencing to some extent the subsurface pattern in the central portion of Block Island Sound in the form of a diffuse eddy. Williams (1969) reports onshore bottom drift and offshore surface drift along the boundary between Block Island Sound and the Atlantic Ocean, as well as some bottom drift into Long Island Sound at the Race.

Long Island Sound

To the west of Block Island Sound, Long Island Sound stretches 185 km down the Connecticut coast, comprising an area of about 2,300 square km (Riley, 1959). The maximum depth is 100 m near the eastern end, but elsewhere depths rarely exceed 30 m. Water from Long Island Sound is exchanged with Block Island Sound through the eastern end. There is a limited exchange with New York Harbor through the East River at the western end. The drainage basin comprises 13 times the area of the Sound itself; greater than 75 percent of the runoff is accounted for by the Thames and Connecticut Rivers at the eastern end which does not appreciably affect the hydrography of the central and western portions.

Some estimates of annual stream discharge are given in Figure 4-178,

4-179, and 4-180. In 1973 the greatest discharge occurred in April and the Connecticut River accounted for a large percentage of the runoff. The effect of Connecicut River discharge on the salinity of the outer shelf has already been discussed.

The water temperatures for central Long Island Sound (Figure 4-178 and 4-179) range annually from close to 0 C (Jan.-Feb.) to 22 C (Jul.-Aug.). Bottom temperatures lag the surface slightly during both heating and cooling so that a slight negative gradient develops in summer and a slight positive gradient in winter. Both surface and bottom follow the air temperatures with a slight lag.

Temperatures are generally higher in the Western Sound in summer and lower there in winter, reflecting the seasonal onshore-offshore gradient. A similar seasonal gradient exists between the Long Island and Connecticut shores (Figure 4-180 and 4-182). Shorter-term fluctuations occur in both the eastern and western Sound following the tidal cycle (Figure 4-168 to 4-171).

Salinity increases from surface to bottom (Figure 4-178 and 4-179) and is generally higher in the eastern end where it is flushed with shelf water. Off the mouths of rivers such as the Connecticut, the fresh water flow may significantly lower salinities all the way to Plum Gut during periods of heavy flow (Figure 4-176, Table 4-37). Salinity also tends to be lower along the Connecticut shore because river water tends to be pushed back along that shore. Seasonal variations follow the runoff pattern.

Riley states that the Sound has a two-layered transport system, with a relatively fresh surface layer moving eastward out of the Sound as saline bottom water moves inward to the west. He tentatively suggests that the Sound changes 30 percent of its volume each month.

The non-tidal surface circulation appears to involve net drift eastward into the Sound from the East River, joining a counterclockwise current in the western third of the Sound. This gyre trades off with a weak clockwise gyre in the central portion. Another small clockwise eddy exists between the Connecticut River and Long Island Shoal. To the east of these eddies, there is an eastward drift out through the passages into Block Island Sound, where the water merges with the western portion of the Block Island Sound circulation as mentioned above.

Riley attributed the circulation within the Sound to the Coriolis effect upon tidal flow, and the horizontal density gradients. He did not discuss seasonal changes in drift patterns, except to state that Long Island Sound outflow increased in midwinter and decreased in midsummer.

More recent studies in the eastern Sound (Hollman and Sandberg, 1972, Dehlinger, Fitzgerald, Feng, Paskowsky, Garvine and Bohlen, 1973) confirm net inflow at the surface through the Race and net outflow at the surface through Plum Gut (Figure 4-157 through 4-161) and a salt-wedging effect into the Sound on the bottom resulting in two-layered flow (Figure 4-163 and 4-164). Hollman and Sandberg (1972) also showed a greater amount of exchange between Block Island Sound and Long Island Sound than was indicated by Riley (1952), involving both surface and bottom water, probably influenced to a great extent by wind conditions (Figure 4-162 through 4-166).

Tidal current velocities are greater in the eastern passages than in the western passages (Figure 4-167), except in the confines of the East River. Tidal amplitudes increase from 1 m in the eastern Sound to 2 m in the western Sound (see section on tides). Tidal currents are essentially reversing with small rotational components (Figures 4-157 through 4-161).

Buzzards Bay Buzzards Bay is a wedge-shaped estuary averaging about 13 km in width and 43 km along its NE-SW axis (Figure 4-85). It is bounded to the east by the mainland shoulder of Cape Cod, and then by the Elizabeth Islands, a slender archipelago separating the Bay from Vineyard Sound to the east. Water is exchanged between these two larger bodies through a series of narrow passages, Woods Hole, Robinsons Hole, Quicks Hole, and Canapitsit Channel, resulting in extremely swift tidal currents, especially through Woods Hole (180 cm/sec average maximum) and Quicks Hole (128 cm/sec average maximum). Tidal currents in the Bay itself are relatively weak (67 cm/sec average maximum), semi-diurnal, reversing type.

At its NE apex, Buzzards Bay exchanges water with Cape Cod Bay through the Cape Cod Canal, a man-made connector 12 km long and 145 m wide, where tidal currents reach 232 cm/sec during the ebb and 206 cm/sec on the flood (Fairbanks, Randall, Collings and Sicles, 1971). The mean tidal range is 1 m at the Bay entrance (Bumpus, et al., 1973), and is variously recorded at 1.4 m (Bumpus, ibid.) and 3 m (Fairbanks, et al., 1971) at the western entrance to the canal. The discrepancy for the canal probably depends upon the location of measurement, since the canal would be expected to significantly amplify the tidal range. A later section gives fuller treatment of tidal regimes.

There is a small net influx of water from Cape Cod Bay (Fairbanks, et al., 1971), and an apparent net counterclockwise drift around Buzzards Bay (Bumpus, et al., 1973). Bumpus classifies the area as a Type C, vertically homogeneous estuary.

The water temperature ranges annually from -1 C to 24 C at the canal

entrance, from -1.7 C to 31 C at Woods Hole, and from -0.5 C to 18 C at the mouth (Figs. 4-86, 87; Tables 4-16 and 17). Temperatures minima occur in January and February; maxima occur in July and August at Woods Hole and the Canal, but may be as late as September at the light station which is under direct influence of the shelf waters. Only at the entrance is there any vertical stratification (2-3 C). Light Station records indicate a progressive long-term warming of summer surface water which is consistent with trends along the shelf as a whole. At the head of the Bay, water from Cape Cod Bay, which may be as much as 5.5 C colder in summer, enters during the last 2 1/2 hour of the flood tide, but most of this is flushed back out again when the cycle reverses (Fairbanks, et al., 1971).

There is little variation in salinity either with season or with distance along the axis of the estuary, reflecting the low freshwater runoff (1,000 cfs annual average). The range is greater at the Light Station (29.18-32.49 o/oo) than at Woods Hole (30.84-31.87 o/oo) or the Canal (30.41-32.72 o/oo), probably because most of the runoff occurs from small rivers along the NW shore (Tables 4-16, 17, 18).

Narragansett Bay

Narragansett Bay is a complex estuary 28 km long (along its major axis) and 18.5 km at its maximum width. It is made up of 3 major N-S systems; from east to west the Sakonnet River-Mount Hope Bay-Taunton River system, the East Passage-Providence River System, and the West Passage (Figure 4-88). The total area of the Bay is $3.24 \times 10^9 m^2$ and its volume is $2.8 \times 10^9 m^3$ at MLW. The tidal volume is $4 \times 10^8 m^3$ or 15 percent of the total volume. Overall mean depth is 8.8 m, however the Sakonnet River and West Passage Systems are relatively shallower (average depth 7.5 m) than East Passage, a deep, narrow area of irregular submarine topography, where the average depth is 17.8 m and maximum depths reach 62 m (Morton, 1967).

Tides in the Bay are semidiurnal with an amplitude of 1.12 m at the mouth, increasing to 1.4 m in the upper reaches. The area is vulnerable to storm surges so that tidal flood barriers have been built at Providence (Bumpus, et al., 1973). Tidal currents show standing wave characteristics. Thus, a current maximum is reached midway between upper bay and lower bay minima, coincident with high and low water. Currents are usually less than 50 cm/sec, but maxima of 140 cm/sec occur near Tiverton, Rhode Island, where the Sakonnet River is greatly restricted (Morton, 1967). Swifter currents typically occur in the constrictions of the passages (Figure 4-89).

Narragansett Bay is classified as a Type B, moderately stratified

Table 4-16. Monthly temperature and salinity at Woods Hole.

	TEMPERATURE C°		SALINITY 0/00	
	Mean	Range	Mean	Range
January	-0.4	-1.7 to 1.4	31.08	29.39 - 31.61
February	-0.5	-1.7 to 0.8	31.16	30.44 - 31.77
March	2.1	0.7 to 3.2	30.86	30.28 - 31.16
April	5.6	3.5 to 7.7	30.88	30.28 - 31.13
May	10.3	7.6 to 13.7	30.86	30.03 - 31.08
June	16.8	13.2 to 19.1	30.84	30.50 - 31.08
July	20.7	19.2 to 21.6	31.15	30.79 - 31.86
August	21.8	20.8 to 31.0	30.99	29.88 - 31.36
September	20.6	19.2 to 21.4	31.46	30.94 - 31.70
October	17.4	16.1 to 19.4	31.78	31.48 - 31.96
November	11.0	7.6 to 16.6	31.87	31.54 - 32.05
December	5.6	3.9 to 7.6	31.64	29.70 - 31.98

Table 4-17. Temperatures and salinities at Buzzards Bay Lightship.

	TEMPERATURE C°		SALINITY 0/00	
	Mean	Range	Mean	Range
January	1.6	-0.4 to 2.8	31.79	31.18 - 32.13
February	0.7	-0.5 to 2.2	31.70	29.15 - 32.02
March	1.8	1.0 to 2.9	31.73	31.26 - 32.16
April	4.4	2.5 to 5.8	31.80	31.45 - 32.25
May	8.9	6.2 to 11.5	31.58	30.81 - 32.44
June	14.2	11.6 to 16.9	31.50	31.28 - 31.82
July	----	----------	-----	----------
August	16.3	14.2 to 17.9	31.56	31.31 - 32.12
September	16.4	15.0 to 18.0	31.79	31.67 - 32.12
October	16.2	15.0 to 17.5	31.98	31.88 - 32.07
November	12.5	9.5 to 16.0	32.22	32.04 - 32.32
December	7.1	5.9 to 8.5	32.21	31.71 - 32.49

Table 4-18

AVERAGE MONTHLY SALINITIES (0/00) AT HIGH AND LOW TIDE
IN THE CAPE COD CANAL, JUNE 1966 - DEC. 1969

	1966		1967		1968		1969	
	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide	High Tide	Low Tide
January	-	-	31.48	31.45	30.71	31.29	31.53	31.95
February	-	-	31.04	31.59	30.87	31.39	31.26	32.28
March	-	-	30.77	31.50	30.41	31.44	31.60	32.19
April	-	-	31.02	31.55	30.46	31.65	30.70	32.07
May	-	-	30.53	30.91	31.00	31.48	31.23	31.59
June	31.53	31.64	30.67	31.11	31.28	31.18	31.72	31.75
July	32.58	31.75	30.89	31.49	31.74	31.47	32.11	31.86
August	32.72	32.06	31.29	31.67	31.81	31.81	32.02	31.97
September	31.74	31.80	31.48	31.63	32.16	32.06	32.28	32.22
October	31.81	31.99	31.46	31.73	32.31	32.20	31.72	31.86
November	31.42	31.81	31.25	31.42	31.79	31.90	31.46	31.76
December	31.53	31.45	30.63	31.61	31.16	31.43	31.14	31.88

estuary, with net outward flow of fresh water above a net inward flow of salt (Bumpus, et al., 1973). Streamflow into the combined areas is 2,709 cfs annually, and there is a definite increasing salinity gradient from head to mouth and from surface to bottom throughout the year. The salt wedge moves up-estuary in summer and down-estuary in winter (Fig. 4-90). This seasonal fluctuation is small in West Passage, but significantly greater in the other two passages, reaching a minimum salinity in February (Hicks, 1963).

The Bay is isothermal from surface to bottom most of the year, but becomes stratified from May through July, corresponding to maximum surface temperatures. In summer the water is warmer up-estuary; the reverse is true in winter (Fig. 4-90).

Diurnal variations in physical parameters were measured for a single station in West Passage by Morton (1967). These data, taken over 36 hours in November, showed bottom temperatures slightly higher than surface temperatures, as opposed to the generally isothermal characterization of this time of hear by Hicks (1963). Bottom temperatures were more stable than surface temperatures, which were affected by a storm which came up about 6 hours after the sampling began (Fig. 4-91), lowering the surface temperatures and, after a delay, affecting the bottom. Tidal influence was greater on a short-term basis, causing temperature maxima at high tide with the inflow of warmer Sound water, and minima at low tide. Nevertheless, the total diurnal fluctuation was only about 1 C, while air fluctuations were more than 11 C, and affected the overall trend of the water temperature. Data are given in Figure 4-128 to 4-129.

Salinities agreed with the generalized picture (higher on the bottom) with a maximum variation of only 0.5 o/oo away from the mean (Fig. 4-90). Density variations closely followed salinity (Table 4-24). The combination of temperature and salinity produced a low vertical density gradient, and there was a great deal of mixing between surface and bottom waters.

Raritan Bay - Hudson River (New York Harbor)

New York Harbor is a complex estuarine system of 390 square kilometers, formed by the drowned lower valleys of the Raritan and Hudson Rivers (Figure 4-92). The Outer Harbor is a triangular area made up of Raritan Bay on the west and south, Lower Bay as the largest portion on the north, and Sandy Hook Bay in the southeast. It opens to the eastward into New York Bight.

The Inner Harbor is made up of the Hudson River, Upper Bay, Newark Bay and their various connectors; the Arthur Kill, a tidal strait linking the western end of Raritan Bay with Newark Bay; Kill Van Kull which connects Newark and Upper Bays; the East River which

joins Upper Bay to Long Island Sound; and the Harlem River which connects the East River to the Hudson above Manhatten Island. Upper Bay empties directly into Lower Bay through The Narrows between Staten Island and Long Island.

The Outer Harbor averages 23 nautical kilometers along its E-W axis and 22 nautical kilometers on its N-S axis, for a combined aerial exttent of (1,670 x 10^6 ft^2). of this, the Raritan Bay-Arthur Kill portion forms 242 square kilometers, with 77 km of shoreline (sea cliffs, wide beaches, tidal marshes) on the Bay and 65 km on the Kill. In Raritan Bay the average depth is 7 m, natural depths reach 9 m, and a channel is dredged to 12 m. Lower Bay is deeper, averaging 9 m with dredged depths of 13 m. Arthur Kill has a mean depth of 5.4 with a narrow channel dredged to 11 m. The channel of the Raritan River is 7.5 m up to Perth Amboy and 2.7 m to New Brunswick, forming 3.6 m of channel (Publ. Health Serv., 1963). Data are summarized in Table 4-20.

The combined area receives an average of 26,400 cfs of river discharge (Bue, 1970). The natural freshwater drainage area of Raritan Bay and Arthur Kill is approximately 3,380 square kilometers. Its major tributary streams are the Raritan and Shrewsbury Rivers; those to the Kill are the Elizabeth and Rahway Rivers. Of the total runoff (2,000 cfs), more than 80 percent is from the Raritan River, which flows 38 km from its junction with the Millstone River eastward into the Bay.

Water also enters the Bay from the Hudson River system, with a net discharge of 6.0 billion ft^3 per tidal cycle flowing through the Narrows into the Lower Bay from the Upper Bay. Of this, 0.7 billion ft^3 is fresh water, making the Hudson River system a major source of water to Raritan Bay. In addition to river inputs, raw and municipal sewage wastes add 650 cfs to the Arthur Kill and 105 cfs to Raritan Bay, which exceeds natural runoff from the Raritan River 55 percent of the time according to the discharge rates in Figure 4-93.

The mean tidal range in the combined system is 1.7 m.Heights increase up the bay. Mean heights of 1.3 m at the Narrows and 1.6 m at Staten Island reach 1.6 and 1.9 m respectively over spring tides. The tidal prism is 9200 x $10^6 ft^3$, which is 300 times the river discharge. Flushing times vary from 15 to 30 days depending on the river flow (Bumpus et al., 1973). Tidal currents reach 52 cm/sec in Raritan Bay and 26 cm/sec in Lower Bay. Upstream bottom currents transport water at a rate of 17,000 cfs between Sandy Hook and Rockaway Point, and have been detected as far upstream as Governors Island (22 km) and Riverdale (49 km) and about 25 percent of the time at West Point (101 km) in the Hudson River

The net circulation pattern in the Bay is a slow, counterclockwise

Table 4-19

PHYSICAL DATA FOR RARITAN AND LOWER BAYS AND ARTHUR KILL

Area	Volume (Billion cubic feet) (Low Water)	Volume (Billion cubic feet) (High Water*)	Surface Area (Square Miles) (Low Water)	Mean Depth (Feet) (Vol. ÷ Surf. Area)	Shore Line (Miles) Staten Is.	Shore Line (Miles) New Jersey	Shore Line (Miles) Total
Raritan Bay	10.4	14.8	31.82	11.75	11.18	13.00	24.18
Lower Bay (Inc. Sandy Hook Bay)	25.4	33.2	56.39	16.18	5.98	13.00	18.98
Raritan, Lower and Sandy Hook Bays combined	35.8	48.1	88.24	14.55	17.16	26.00	43.16
Arthur Kill	2.23	2.83	4.36	18.38	17.78	18.59	36.37
Total Study Area **	38.03	50.93	92.60	-	34.94	44.59	79.53

*Taking mean tidal range as 5 feet

**Excluding Raritan River

TABLE 4-20

SUMMARY OF USGS STREAM GAGING STATION RECORDS,
RARITAN BAY STUDY AREA STREAMS

Gaging Station Location	Drainage Area, mi^2	Average Discharge, cfs	Average Runoff Rate, $cfsm^2$
Raritan River Basin			
Raritan River, Bound Brook, N.J.	779	1,220	1.57
Green Brook, Plainfield, N.J.	9.8	12.1	1.24
Lawrence Brook, Farrington Dam, N.J.	34.4	38.5	1.12
South River, Old Bridge, N.J.	94.6	137	1.45
TOTALS	917.8	1,407.6	
Extrapolated total average discharge:	1,072	1,650	
Arthur Kill Drainage Area			
Elizabeth River, Elizabeth, N.J.	20.2	23.8	1.18
Rahway River, Rahway, N.J.	40.9	44.8	1.10
Robinson's Branch, Rahway River, Rahway, N.J.	21.6	23.5	1.09
TOTALS	82.7	92.1	
Extrapolated total average discharge:		136	
Extrapolated total average discharge for total Arthur Kill drainage area:		160	

TABLE 4-20 (Cont'd)

SUMMARY OF USGS STREAM GAGING STATION RECORDS,
RARITAN BAY STUDY AREA STREAMS

Gaging Station Location	Drainage Area, mi^2	Average Discharge, cfs	Average Runoff Rate, $cfsm^2$
Navesink-Shrewsbury River Basin			
Swimming River (head of Navesink River) near Red Bank, N.J.	48.5	77.2	1.59
New Jersey Shore Drainage Area	69	-	1.50*
Extrapolated total average discharge:		110	
Staten Island Shore Drainage Area	24	-	1.10*
Extrapolated total average discharge:		25	

* Estimated

gyre (Fig. 4-94) in which salt waters inflowing from the Lower Bay and fresh waters inflowing from the Raritan River each tend to keep to the right, so that salinities are higher on the north side of the Bay than the south side. The mean annual gradient in 1.27 o/oo, with some variations according to river flow. Waters on the flood tide thrust southward at the head of the Bay, bisecting the Raritan River discharge and tending to accelerate it. The river discharge, on the other hand, tends to dam up the high salinity water at the head of the Bay (Jeffries, 1962).

Current dispersion studies show a net seaward movement from the mouth of the Raritan River of about 0.2 km tidal cycle, and the Arthur Kill a net seaward movement of about 1.8 km/tidal cycle. Currents flowing seaward through the Narrows are displaced westward, thus adding to the western portion of the Bay some waters originating in the Upper Bay (Public Health Service, 1963).

Bumpus, et al., 1973, classifies the Raritan Bay portion as a Type C, vertically homogeneous estuary, whereas the Hudson River portion is partially mixed. Salinity and temperature regimes follow river inflow. Annual ranges are given in Fig. 4-184. Salinities in terms of chloride concentration patterns are given in Section 4.3.11. In general, a mass of high chlorinity water extends from Seguine Point to Sandy Hook, while relatively low salinities prevail along the Southeast portions of the Bay. There is an intermediate zone between the two masses which extends to the Highlands inside of Sandy Hook. The same general pattern persists to the bottom. A smaller second lobe of high chlorinity water extends southward into Sandy Hook Bay, and a smaller third lobe pushes northward toward New Dorp Beach on Staten Island. Deep water chlorinities corresponded closely, giving the estuary its Type C character.

Westerly winds apparently displace the high chlorinity lobes toward the Staten Island Shore, while easterly winds favor its central position within the Bay. Changes in freshwater runoff may also change the position of these lobes. River discharge is from 6 to 50 times greater in January through March when lobes are well developed than in summer and autumn when they tend to disappear. The predominant wave regime at the entrance is from the east and northeast.

Water temperatures may vary from 0 C to 26 C. The highs occur in July and the lows in January or February. There is a vernal lag in warming so that downstream areas may be 1.7 C to 3.5 C cooler during flooding tides. The incoming tide pushes warmer water up into Arthur Kill both summer and winter (Figure 4-195).

The Upper and Lower Bays form a mixing zone for waters from the

Hudson River and New York Bight. Temperatures are about 21 C and considerably cooler than those of 27 C in Raritan Bay. During the winter, Lower Bay harbor water is about 2.7 C while Raritan Bay is 10 C and the New York Bight is 6 to 7 C. Two shallow areas, Upper Bay and Lower East River, constitute areas of local warming (Powers and Backus, 1951). Tidal effects are less than expected at The Narrows. Surface water temperatures are slightly higher at slack-before-ebb in winter, reflecting the inflow of warmer flood waters from Lower Bay. In the Hudson River, typical tidal tongues of cooler summer water and warmer winter water extend up-river during slack-before-ebb and downriver during slack-before-flood (Figs. 4-196 and 4-198).

Salinity distributions by season and by tidal stage are given in Figures 4-199 to 4-206. In summer, the surface salinities in The Narrows and Upper Bay are at a minimum of 20 o/oo as expected during slack-before-flood and at a maximum of about 26 o/oo during slack-before-ebb. Winter tidal variations are smaller.

Salinity distributions for the Hudson River, the East River, and the Harlem River complex are predictably higher in summer, reflecting the seasonally low fresh water runoff. During the tidal cycle, the expected salinity minima occur at slack-before-flood and maxima occur at slack-before-ebb for both surface and bottom water in the Hudson. In the Harlem and East Rivers the reverse occurs. This is because the volume of the outflow in the Hudson is so great by comparison that the strong outflow on ebb sucks water out of the Harlem and East Rivers, causing replacement by the higher salinity water from eastern Long Island Sound and salinity variations of up to 2 o/oo during a tidal cycle.

4.2.10 TIDES

As described previously for the Gulf of Maine, tidal currents of the shelf and coastal waters of the Northwestern Atlantic are semidiurnal in nature with a period of 12 h 25 m, and nearly equal in amplitude (Fig. 4-97). The amplitude also manifests long-term periodicities corresponding to phase, parallax, and declination of the moon (Fig. 4-98). The greatest spring tides (high tides corresponding to the full and new moons, i.e. every 14 days) occur during the summer and winter solstices. The lowest low tides occur at night during the winter and in early morning during the summer (Emery and Uchupi, 1972).

The amplitude of the tidal wave is generally less than 0.5 m in the open ocean, but as the wave crosses the shelf it increases between 1.5 and 2 m due to the decreased depth. Drag on the bottom decreases the speed of propagation and shortens the wave lenth, so that although the wave front is essentially parallel to the shelf edge as it

approaches, the timing of its arrival on shore will vary depending upon the width and depth of the shelf (Fig. 4-99). Predictive tables of the times of high and low tides for specific localities are available (NOAA, 1973).

Slowing of the tidal wave propagation becomes more pronounced in broad, shallow estuaries such as Long Island Sound. Refraction of the tidal wave around complex island areas such as those south of Cape Cod may cause tidal waves to approach from several different directions and at different times. It may also result in a damping or amplifying effect on tidal height, depending upon the degree to which the different waves are in phase with each other (Fig. 4-100). Some estuaries also amplify the tidal wave height by confining the water in a narrow passage or from resonance set up within the estuary (Fig. 4-101). Changes in amplitude of this nature can be seen in Table 4-22, by comparing tidal heights from east to west in Long Island Sound or from south to north in Buzzards and Narragansett Bays.

The periodic variations in amplitude of the tidal wave are reflected in the tidal currents, which reach their maximum velocities during spring tides. Predicted values for both heights and current velocities for any given date at specific locations can be found in Tidal Current Tables (Anon., annual). On the outer shelf the currents rotate clockwise through 360°in a single period, with no slack water and almost equal velocities in all directions. Closer to the coast, the currents become more elliptical, with 3 hour of velocity maxima alternating with 3 hour of velocity minima (Fig. 4-102, 4-103, and 4-93. The major directional axis for these shallower shelf currents is shown in Figure 4-104. Within passages and confined bays, the currents become more bi-directional, depending upon their restriction, and take on the character of reversing currents with a period of slack water intervening during the change in direction.

At times, both the velocity and direction may be obscured by wind currents, runoff currents, or the development of a storm surge, but generally the effect of tidal currents exceeds that of all others combined. Some of the highest velocities for the shelf areas (65 cm/sec) are reached over Georges Banks and the entire shallow region between Long Island and Nova Scotia. Some tidal current maxima for both offshore and inshore areas are given in Fig. 3-99. Tidal current velocities at lightships are given in Fig. 102. Typically, tidal velocities are greater in confined passages.

Tidal heights may be greatly affected by wind stress, which may blow water in or out of confined areas. Storm tides or storm surges may be caused by interaction of wind stress, lowered barometric pressure transport by waves, and swell and coastline configuration. The occurrence of storm surges relative to normal tidal phases determines

the overall tidal rise, which may be damped or greatly amplified. Historical data on storm surges for east coast areas have been collected by Harris (1963), some of which are given in Figures 4-105 and 4-106. Data are also available from the U.S. Department of Commerce, and hourly predictive data for velocities and direction of flow in specific areas are available from several sources.

4.2.11 SEA-ICE CONDITIONS-CAPE COD TO NEW YORK FROM: NOAA (1973) U.S. COAST PILOT

Eastern Long Island

Ice. In ordinary winters the floating and pack ice in Long Island Sound, while impeding navigation, does not render it absolutely unsafe, but in exceptionally severe winters the reverse is true; none but powerful steamers can make their way.

Drift ice, which is formed principally along the northern shore of the sound under the influence of the prevailing northerly winds, drifts across to the southern side and accumulates there, massing into large fields, and remains until removed by southerly winds, which drive it back to the northerly shore.

In ordinary winters ice generally forms in the western end of the sound as far as Eatons Neck; in exceptionally severe winters ice may extend to Falkner Island and farther eastward.

Effects of winds on ice. In Long Island Sound northerly winds drive the ice to the southern shore of the sound and southerly winds carry it back to the northern shore. Northeasterly winds force the ice westward and cause formations heavy enough to prevent the passage of vessels of every description until the ice is removed by westerly winds. These winds carry the ice eastward and, if of long duration, drive it through The Race into Block Island Sound, thence it goes to sea and disappears.

In New Haven Harbor the influence of the northerly winds clears the harbor and its approaches unless the local formation is too heavy to be moved. Southerly winds force the drift ice in from the sound and prevent the local formations from leaving the harbor. Tides have little effect upon the ice. Additional information concerning ice conditions in the waters adjoining Long Island Sound is given under the local descriptions.

New York Harbor

Ice. Navigation of the channels in the Port of New York and New Jersey is not restricted by ice. The main channels do not freeze over, and any ice in the smaller waterways is well broken up by tugs and general traffic. Fresh-water ice is brought down the Hudson River

in large floes during periods of thaws or winter freshets. Occasionally there are large accumulations of ice at Spuyten Duyvil where Harlem River joins the Hudson, and at such times it is difficult for low-powered vessels or tows to make much headway. Under conditions of strong winds the slips on the exposed side of the channel become packed with drift ice, causing difficulty when maneuvering in the slip or when berthing. During extremely severe winters navigation is interfered with seriously for only short periods of time.

Western Long Island

Ice. In ordinary winters the floating and pack ice in Long Island Sound, while impeding navigation, does not render it absolutely unsafe, but in exceptionally severe winters the reverse is true; then only the powerful steamers can make their way.

Drift ice, which is formed principally along the northern shore of the sound under the influence of the prevailing northerly winds, drifts across to the southern side and accumulates there, massing into large fields, and remains until removed by southerly winds which drive it back to the northerly shore.

In ordinary winters ice generally forms in the western end of the sound as far as Eatons Neck; in exceptionally severe winters ice may extend to Falkner Island and farther eastward.

Effects of winds on ice. In Long Island Sound northerly winds drive the ice to the southern shore of the sound and southerly winds carry it back to the northern shore. Northeasterly winds force the ice westward and cause formations heavy enough to prevent the passage of vessels of every description until the ice is removed by westerly winds. These winds carry the ice eastward and if of long enough duration, drive it through The Race into Block Island Sound, from where it goes to sea and disappears.

In Bridgeport Harbor winds from north to northwest clear the harbor of drift ice, and those from southeast through south to southwest force the ice into the harbor from the sound. The outer buoys may be carried out of position by heavy ice during severe winters.

Additonal information concerning ice conditions in the waters adjoining Long Island Sound is given under the local descriptions.

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Table 4-22 Range of Tidal Heights in Feet According to Eldridge (1974)

	Spring Tidal Rise	Neap Tidal Rise	Mean Tidal Rise	Variation*
Boston	11.8	7.6	9.5	
Nantucket Island	3.1	1.2	2.2	
Nantucket Sound	3.7	1.5	2.5	1.5 - 3.4
Martha's Vineyard	1.7			1.4 - 2.7
Wood's Hole	1.8		0.9	1.3 - 3.0
Buzzard's Bay				
Mouth	3.6	1.7	2.8	3.4 - 3.8
Canal Entrance			3.5	3.0 - 4.1
Rhode Island Sound	3.8	3.3	3.5	2.4 - 4.9
Narragansett Bay				
Mouth (Newport)			3.5	
Head (Providence)			4.6	
Block Island Sound	3.1	2.5	2.8	
Long Island Sound (Ct. side)				
Eastern	3.5	2.5	3.0	
Middle	6.5	4.9	5.7	
Western	6.6	7.4	7.0	
Long Island Sound (N.Y. side)				
Eastern			2.4	2.0 - 2.8
Middle			6.6	4.0 - 7.3
Western			7.1	6.5 - 7.5
Long Island, South Shore			3.7	
New York Harbor				
Upper Bay			4.5	
Narrows			4.8	
Hudson River			3.7	
Lower Bay			4.7	
East River			6.2	5.3 - 7.1
Raritan Bay			5.0	4.7 - 5.3

*Mean rise variation according to location within the listed area.

Table 4-23 Hourly Tidal Current Velocities at Selected Locations, from Haight (1942)

Hourly Tidal Current Velocities at Selected Locations, from Haight (1942)

Location		Hours after Greenwich transit of the moon												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Nantucket Shoals	Kts.	0.71	0.80	0.84	0.75	0.57	0.61	0.69	0.80	0.83	0.83	0.69	0.42	0.67
40°37.1'N 69°37.1'W	°T	355	015	038	056	086	128	166	193	215	233	260	308	344
Vineyard Sound	Kts.	0.22	0.20	0.16	0.48	0.52	0.42	0.24	0.24	0.26	0.26	0.43	0.42	0.29
41°22.8'N 71°00.0'W	°T	030	097	138	152	163	181	208	245	311	327	344	355	020
U.S.S. Finch	Kts.	0.05	0.10	0.14	0.14	0.13	0.07	0.07	0.12	0.10	0.10	0.11	0.09	0.10
40°04.3'N 72°43.4'W	°T	065	085	104	122	128	152	203	257	295	291	307	345	025
Five Island	Kts.	0.00	0.08	0.11	0.15	0.14	0.11	0.04	0.04	0.11	0.13	0.12	0.10	0.02
40°28.7'N 73°11.4'W	°T	--	073	090	093	098	100	115	255	271	277	280	285	330
U.S.S. Cardinal	Kts.	0.07	0.03	0.09	0.09	0.12	0.12	0.09	0.03	0.03	0.11	0.11	0.11	0.08
40°16.0'N 73°15.5'W	°T	308	045	095	109	112	115	132	--	257	281	292	297	305
Ambrose Channel	Kts.	0.24	0.15	0.02	0.10	0.18	0.24	0.28	0.21	0.06	0.04	0.17	0.24	0.25
40°28.0'N 72°50.0'W	°T	283	260	282	100	093	092	096	101	120	270	272	277	292
Ambrose Channel	Kts.	0.23	0.15	0.06	0.04	0.11	0.17	0.22	0.21	0.16	0.00	0.14	0.26	0.24
40°27.1'N 73°49.4'W	°T	265	295	292	090	090	090	095	106	121	--	262	278	282
Scotland	Kts.	0.41	0.26	0.12	0.21	0.41	0.60	0.65	0.44	0.10	0.24	0.42	0.43	0.43
39°26.6'N 73°55.2'W	°T	312	327	024	079	111	127	133	144	196	287	295	298	308
Barnegat	Kts.	0.03	0.02	0.03	0.05	0.05	0.04	0.02	0.02	0.04	0.05	0.05	0.05	0.04
39°45.8'N 73°56.0'W	°T	020	063	119	130	141	152	271	272	351	321	335	343	001
U.S.S. Falcon	Kts.	0.06	0.06	0.04	0.04	0.05	0.06	0.05	0.04	0.06	0.07	0.04	0.04	0.06
39°04.5'N 73°25.5'W	°T	015	029	059	091	147	146	183	221	240	259	293	302	000
Northeast End	Kts.	0.10	0.06	0.12	0.19	0.22	0.20	0.13	0.07	0.11	0.25	0.23	0.20	0.13
38°57.8'N 74°09.6'W	°T	329	039	086	102	110	119	140	197	241	280	290	303	317
Five Fathom Bank	Kts.	0.22	0.06	0.11	0.23	0.29	0.30	0.26	0.15	0.16	0.20	0.29	0.32	0.26
38°47.3'N 74°34.6'W	°T	304	005	073	099	103	112	125	158	217	268	284	295	301
Overfalls	Kts.	1.37	0.85	0.38	0.32	1.21	1.40	1.23	0.48	0.44	0.25	0.92	1.38	1.41
38°47.9'N 75°01.4'W	°T	306	317	015	087	117	126	131	136	173	252	297	300	303
Fenwick Is. Shoal	Kts.	0.24	0.18	0.08	0.10	0.19	0.27	0.27	0.22	0.14	0.09	0.16	0.23	0.25
38°27.4'N 74°46.7'W	°T	345	354	025	088	126	145	158	176	208	259	308	329	343
Winter Qtr Shoal	Kts.	0.07	0.06	0.06	0.06	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
37°55.4'N 74°56.4'W	°T	060	030	062	090	121	154	185	206	215	266	290	323	350
U.S.S. Brant	Kts.	0.08	0.11	0.16	0.19	0.19	0.15	0.11	0.17	0.15	0.16	0.16	0.17	0.19
37°04.6'N 74°51.1'W	°T	358	042	061	083	106	133	183	237	261	273	292	326	335
Cape Charles	Kts.	0.30	0.20	0.10	0.05	0.19	0.27	0.29	0.22	0.10	0.03	0.13	0.24	0.30
37°05.3'N 74°43.5'W	°T	264	265	228	144	090	089	086	060	055	140	245	268	264
Chesapeake	Kts.	0.15	0.13	0.06	0.03	0.10	0.14	0.15	0.13	0.03	0.00	0.06	0.13	0.15
36°58.7'N 75°42.2'W	°T	279	278	271	335	093	095	094	100	106	--	272	281	278
Tail of Horseshoe	Kts.	0.56	0.90	0.95	0.64	0.12	0.50	1.04	1.40	1.50	1.23	0.95	0.21	0.16
36°58.8'N 76°00.4'W	°T	312	312	312	312	312	126	126	126	126	126	126	126	312
Diamond Shoal	Kts.	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
35°05.3'N 75°19.7'W	°T	035	072	116	140	165	205	237	266	293	311	337	341	024

Table 4-24 Results of 36-Hour Time Station

Sample No.	Concentration mg/l	Surface Temperature °C	Bottom Temperature °C	Surface Salinity °/oo	Bottom Salinity °/oo	Surface Density σ_t	Bottom Density σ_t
TS-1-S	2.14						
TS-2-B	1.64		11.47		31.29		23.83
TS-3-S	2.16		11.37		31.23		23.80
TS-4-B	1.88		11.40		31.28		23.84
TS-5-S	2.01		11.40		31.26		23.82
TS-6-B	2.00		11.44		31.35		23.88
TS-7-S	1.85		11.44		31.26		23.81
TS-8-B	1.69		11.45		31.22		23.78
TS-9-S	1.74		11.36		31.22		23.80
TS-10-B	1.78		11.19		31.11		23.74
TS-11-S	1.73		11.25		30.92		23.58
TS-12-B	1.95		11.14		30.84		23.54
TS-13-S	1.97		11.08		31.03		23.70
TS-14-B	2.37	10.89	11.38	30.86	31.22	23.51	23.79
TS-15-S	2.12	10.96	11.43	30.92	31.27	23.55	23.82
TS-16-B	1.92	10.74	11.41	30.92	31.19	23.56	23.76
TS-17-S	2.22	10.92	11.39	31.03	31.29	23.64	23.84
TS-18-B	2.15	10.99	11.32	31.02	31.43	23.65	23.96
TS-19-S	1.91	10.94	11.32	31.03	31.26	23.66	23.83
TS-20-B	2.32	11.11	11.31	31.18	31.42	23.77	23.96
TS-21-S	1.98	10.97	11.19	31.09	31.35	23.72	23.93
TS-22-B	1.81	10.66	11.12		31.10		23.75
TS-23-S	2.02	10.91	11.00		31.08		23.75
TS-24-B	2.07	10.51	11.06		31.16		23.80
TS-25-S	2.37	10.35	11.03		31.15		23.80
TS-26-B	2.56	10.57	11.13	30.97	31.30	23.64	23.90
TS-27-S	2.17	10.73	11.00	31.05	31.30	23.75	23.92
TS-28-B	2.34	10.54	11.06	31.00	31.33	23.68	23.93
TS-29-S	2.15	10.71	10.92	31.07	31.21	23.76	23.87
TS-30-B	3.72	10.76	11.11	31.13	31.47	23.77	24.03
TS-31-S	2.67	10.54	11.03	31.10	31.48	23.76	24.05
TS-32-B	2.53	10.47	10.97	31.12	31.39	23.79	24.00
TS-33-S	2.93	10.84	11.09	31.45	31.61	24.02	24.15
TS-34-B	2.61	10.88	11.08	31.39	31.48	23.98	24.05
TS-35-S	2.19	10.50	11.13	31.12	31.50	23.76	24.05
TS-36-B	1.93	10.37	10.83	31.09	31.24	23.79	23.90

Table 4-25

Temperature, salinity, current direction and speed at the current stations shown in Figs. 1. (Current magnitudes are relative only).

PLUM GUT 05 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (kts)
1200	SURF	15.3	25.82	150	1.5
	40	13.8	26.57	180	0.7
	80	11.9	27.43	305	1.1
	106	11.7	28.86	295	1.7
1300	SURF	16.1	25.76	280	1.6
	40	14.0	26.24	290	0.8
	80	13.9	26.66	270	1.3
	106	11.8	29.21	265	1.5
1400	SURF	14.6	27.29	285	1.4
	40	14.3	27.57	270	2.0
	80	12.8	28.62	295	2.8
	106	11.9	29.00	295	2.6
1500	SURF	14.9	26.62	295	0.9
	40	14.3	27.64	295	2.8
	80	12.5	28.69	300	3.3
	106	12.2	28.81	295	3.1
1600	SURF	14.4	27.65	305	3.4
	40	12.8	28.20	300	2.9
	80	12.6	28.59	290	2.4
	106	12.5	28.65	305	1.6
1700	SURF	14.2	27.71	265	0.3
	40	12.6	28.67	270	0.9
	80	12.3	28.88	285	0.7
	106	12.2	28.97	310	0.4
1800	SURF	14.8	27.30	120	1.1
	40	12.2	28.80	135	0.6
	80	12.1	29.17	125	0.4
	106	12.0	29.62	090	0.4
1900	SURF	13.9	27.41	145	1.6
	40	12.5	28.39	160	2.2
	80	12.2	29.14	160	2.2
	106	12.2	29.67	150	2.2

Table 4-26

PLUM GUT 05 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
2000	SURF	14.7	26.80	170	3.8
	40	12.2	29.12	145	2.9
	80	11.7	29.74	150	2.8
	106	11.7	29.79	130	2.7
2100	SURF	13.5	27.48	165	3.5
	40	12.3	29.73	165	3.8
	80	11.6	29.54	155	3.3
	106	11.6	29.65	155	2.8
2200	SURF	13.9	26.86	175	3.3
	40	12.7	28.46	185	2.7
	80	11.8	29.14	160	2.5
	106	11.7	29.32	150	2.0
2300	SURF	13.9	25.71	155	3.5
	40	11.7	27.06	160	2.4
	80	11.7	29.04	140	1.3
	106	11.7	29.17	130	1.2
2400	SURF	14.9	25.77	180	0.2
	40	13.5	26.35	180	1.9
	80	12.2	28.04	150	1.1
	106	11.9	28.57	030	0.8
		06 June, 1972			
0100	SURF	14.4	25.81	220	0.0
	40	13.7	26.42	190	1.0
	80	12.8	27.41	290	0.5
	106	11.8	29.22	280	1.2
0200	SURF	14.4	NA	280	0.0
	40	14.9	NA	295	0.8
	80	13.5	NA	295	1.0
	106	11.8	NA	270	1.1

Table 4-27 FISHERS ISLAND SOUND 07 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1200	SURF	13.1	28.24	NA	NA
	25	12.5	29.13	NA	NA
	50	12.3	29.29	NA	NA
	75	12.3	29.30	NA	NA
1300	SURF	13.4	27.65	100	1.00
	25	12.8	28.74	090	1.50
	50	12.3	29.23	120	1.30
	75	12.2	29.49	120	1.10
1353	SURF	13.6	28.01	340	1.10
	25	12.8	28.87	350	1.00
	50	12.4	29.21	045	0.57
	75	12.2	29.55	110	0.57
1500	SURF	13.4	28.17	305	1.40
	25	12.8	28.73	335	1.60
	50	12.5	29.06	325	1.70
	75	12.2	29.31	340	2.00
1600	SURF	13.4	28.73	345	2.40
	25	12.9	28.97	340	2.70
	50	12.7	29.00	330	2.50
	75	12.7	29.02	340	2.90
1655	SURF	12.8	29.11	320	2.60
	25	12.8	29.09	330	2.50
	50	12.8	29.09	340	2.40
	75	12.8	29.09	330	2.30
1805	SURF	13.2	29.07	350	1.80
	25	13.0	29.29	350	1.90
	50	12.8	29.54	335	2.00
	75	12.8	29.65	330	2.40
1900	SURF	13.0	29.37	350	1.20
	25	13.0	29.40	355	1.20
	50	12.9	29.65	340	1.40
	75	12.8	29.76	320	1.30
2000	SURF	12.9	29.07	070	0.54
	25	12.9	29.43	340	0.32
	50	12.9	29.80	340	0.78
	75	12.9	29.93	320	0.58

Table 4-28 FISHERS ISLAND SOUND 07 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
2055	SURF	13.3	27.89	140	1.60
	25	12.9	29.47	130	1.60
	50	12.8	29.74	160	1.10
	75	12.8	29.82	145	0.80
2155	SURF	13.7	25.97	145	2.50
	25	13.2	28.88	135	2.50
	50	12.9	29.27	205	2.20
	75	12.8	29.64	180	1.80
2255	SURF	13.7	26.45	125	2.40
	25	12.9	29.11	125	2.20
	50	12.9	29.27	125	2.20
	75	12.9	29.38	130	2.00
2356	SURF	13.3	26.38	130	2.30
	25	12.8	29.10	140	2.30
	50	12.4	29.20	140	2.10
	75	12.4	29.33	135	1.80
		08 June, 1972			
0100	SURF	12.8	27.14	110	2.00
	25	12.3	29.19	140	1.60
	50	12.2	29.41	140	1.80
	75	12.1	29.56	150	1.90
0200	SURF	12.8	29.59	100	1.10
	25	12.3	29.09	150	0.84
	50	12.2	29.43	135	0.84
	75	12.2	29.54	130	0.74
0240	SURF	12.7	NA	345	0.52
	25	12.4	NA	045	0.58
	50	12.3	NA	045	0.48
	75	12.2	NA	115	0.42

Table 4-29 VALIANT ROCK 27 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1320	SURF	14.2	29.10	NA	NA
	30	13.8	29.17	NA	NA
	60	13.1	29.52	NA	NA
	90	13.0	30.34	NA	NA
1415	SURF	NA	28.87	155	1.40
	30	NA	29.01	150	1.80
	60	NA	29.07	140	1.50
	90	NA	29.54	155	1.00
1535	SURF	NA	29.02	175	1.90
	30	NA	29.04	170	1.60
	60	NA	29.09	160	1.60
	90	NA	29.22	155	1.20
1600	SURF	NA	28.77	175	2.30
	30	NA	28.88	165	1.80
	60	NA	28.96	155	1.90
	90	NA	29.44	140	1.30
1700	SURF	15.0	28.38	175	2.30
	30	14.3	29.76	175	1.90
	60	14.3	28.96	170	1.20
	90	14.3	29.00	180	1.10
1805	SURF	15.8	26.96	165	1.60
	30	15.2	27.74	185	1.20
	60	14.3	29.04	185	0.11
	90	14.3	29.15	181	0.06
1910	SURF	15.2	27.28	190	0.67
	30	15.2	27.71	195	0.53
	60	14.7	28.63	280	0.57
	90	14.4	28.96	230	0.43
2000	SURF	15.3	27.36	205	0.35
	30	14.8	28.17	270	0.60
	60	14.5	28.87	295	1.10
	90	14.1	29.37	285	0.64
2100	SURF	14.8	27.88	325	1.80
	30	14.4	29.01	315	1.70
	60	14.1	29.07	325	1.80
	90	13.8	29.65	325	1.60

Table 4-30 VALIANT ROCK 27 June, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
2200	SURF	14.2	29.18	340	1.60
	30	14.2	29.21	340	1.70
	60	14.2	29.23	330	1.90
	90	13.5	29.89	330	1.90
2300	SURF	14.2	29.15	345	1.60
	30	14.2	29.19	340	1.70
	60	13.6	29.26	345	1.50
	90	13.4	29.88	325	0.65
2400	SURF	14.1	29.25	335	1.10
	30	14.1	29.23	335	1.10
	60	13.5	29.46	345	0.90
	90	13.3	30.04	270	0.66
		28 June, 1972			
0100	SURF	14.2	29.12	045	0.59
	30	14.2	29.15	075	0.58
	60	13.7	29.30	135	0.22
	90	13.2	30.26	190	0.56
0200	SURF	14.5	28.86	135	1.70
	30	14.5	28.97	135	1.80
	60	14.3	29.07	130	1.70
	90	13.5	28.90	140	1.10

Table 4-31 RACE 24 July, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1000	SURF	17.8	30.42	310	1.10
	40	16.2	30.68	320	1.10
	80	15.5	31.15	320	0.80
	120	15.1	31.26	315	0.90
1100	SURF	17.8	30.50	080	0.38
	40	17.2	30.52	310	0.12
	80	17.3	30.66	290	0.20
	120	15.5	30.81	180	0.01
1200	SURF	17.8	29.80	125	0.90
	40	16.2	30.84	115	0.90
	80	14.4	31.49	130	1.40
	120	14.2	31.50	140	1.20
1300	SURF	16.6	30.19	110	1.40
	40	15.7	30.88	130	1.50
	80	15.2	31.13	110	0.60
	120	14.9	31.14	110	0.50
1400	SURF	17.5	29.46	125	1.50
	40	15.2	30.54	110	1.00
	80	14.5	31.30	085	0.15
	120	14.4	31.35	340	0.22
1500	SURF	18.0	29.40	130	1.00
	40	15.6	30.45	350	0.36
	80	15.1	30.92	250	0.46
	120	14.7	31.26	230	0.45
1600	SURF	18.2	29.68	145	0.27
	40	15.0	30.51	310	0.35
	80	15.1	30.93	300	0.90
	120	14.9	31.19	300	0.60
1700	SURF	18.5	29.91	310	0.30
	40	16.7	30.46	320	0.74
	80	15.1	30.57	310	1.40
	120	14.6	31.27	290	1.30
1800	SURF	18.5	29.77	310	0.34
	40	17.2	29.97	330	0.85
	80	16.1	30.46	325	1.80
	120	15.2	31.15	330	2.00

Table 4-32 RACE 24 July, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1900	SURF	17.1	30.69	280	2.30
	40	15.8	30.90	305	2.20
	80	15.8	31.15	330	2.10
	120	15.0	31.42	315	2.10
2000	SURF	17.7	30.18	300	2.30
	40	17.5	30.70	300	2.20
	80	15.7	31.30	310	2.00
	120	15.2	31.39	325	1.90
2100	SURF	17.8	30.43	325	2.10
	40	17.3	30.99	325	2.20
	80	14.8	31.48	335	1.50
	120	14.5	30.46	330	0.50
2200	SURF	17.7	30.42	320	1.10
	40	16.1	31.10	320	1.40
	80	15.7	31.26	335	1.20
	120	14.9	31.53	290	0.75
2300	SURF	17.8	30.11	135	0.75
	40	17.7	30.64	240	0.32
	80	17.1	30.72	210	0.27
	120	16.1	31.15	130	0.65

Table 4-33 RACE 19 October, 1972

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
0815	SURF	14.0	31.53	315	1.10
	64	14.0	31.58	305	0.60
	128	14.0	31.63	305	0.48
	192	14.0	31.65	315	0.24
0900	SURF	13.3	31.25	200	0.72
	64	13.3	31.54	305	0.19
	128	13.3	31.56	325	0.26
	192	13.3	31.61	290	0.40
1000	SURF	14.0	30.72	145	1.40
	64	14.0	31.55	100	0.70
	128	14.0	31.55	105	0.60
	192	14.1	31.61	100	0.90
1100	SURF	13.6	31.03	125	0.80
	64	14.0	31.05	105	0.90
	128	13.9	31.37	100	1.30
	192	13.9	31.69	085	1.30
1200	SURF	13.1	31.04	120	1.30
	64	13.2	31.07	145	1.00
	128	13.3	31.38	170	0.90
	192	13.4	31.52	210	1.00
1300	SURF	14.5	31.14	150	0.70
	64	14.6	31.15	170	0.25
	128	14.7	31.23	090	0.26
	192	14.7	31.34	180	0.20
1400	SURF	14.0	31.19	250	0.90
	64	14.1	31.21	160	1.00
	128	14.1	31.22	240	1.00
	192	14.1	31.29	240	0.80
1500	SURF	13.8	31.15	310	1.00
	64	13.8	31.20	280	0.80
	128	13.8	31.22	280	1.00
	192	13.8	31.25	290	1.10
1600	SURF	14.7	30.95	335	1.60
	64	14.8	31.01	335	2.10
	128	14.9	31.21	320	2.20
	192	14.9	31.25	325	2.10

Table 4-34

RACE 19 October, 1972

TIME	DEPTH (m)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1700	SURF	14.3	31.06	340	1.50
	64	14.3	31.10	330	1.70
	128	14.2	31.21	330	1.70
	192	14.2	31.31	320	2.10
1800	SURF	14.1	31.22	330	2.20
	64	14.3	31.23	315	2.10
	128	14.2	31.51	315	2.20
	192	14.2	31.53	315	2.40
1900	SURF	13.7	31.65	320	2.00
	64	13.8	31.64	315	2.10
	128	13.8	31.65	315	2.10
	192	13.9	31.68	320	1.70
2000	SURF	14.1	31.66	325	1.80
	64	14.3	31.65	320	1.60
	128	14.3	31.68	320	1.60
	192	14.3	31.68	320	1.40
2100	SURF	13.7	31.61	310	0.70
	64	13.8	31.66	285	0.53
	128	13.9	31.73	325	0.58
	192	13.9	31.73	340	0.36

Table 4-35

RACE 17 January, 1973

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
1100	SURF	5.3	30.98	080	0.84
	33	5.4		080	0.63
	67	5.8	31.26	085	0.59
	95	5.7	31.25	100	0.45
1200	SURF	5.1	30.48	080	1.21
	33	5.1	31.02	075	1.12
	67	5.3	31.05	077	0.98
	95	5.3	31.32	079	0.92
1300	SURF	4.8	30.05	078	1.01
	33	5.1	30.11	078	0.94
	67	5.3	31.26	080	0.78
	95	5.3	31.38	083	0.69
1400	SURF	5.0	30.18	078	1.14
	33	5.3	30.44	078	0.98
	67	5.6	30.65	073	0.84
	95	5.7	31.20	075	0.65
1500	SURF	5.0	30.24	050	0.51
	33	5.0	30.35	057	0.45
	67	5.4	30.52	062	0.25
	95	5.6	30.90	315	0.06
1600	SURF	4.9	30.10	055	0.16
	33	5.0	30.25	028	0.25
	67	5.6	30.40	320	0.10
	95	5.6	31.01	235	0.35
1700	SURF	4.6	30.19	233	0.10
	33	4.8	30.36	240	0.29
	67	5.3	30.78	280	0.53
	95	5.4	31.30	278	0.49
1800	SURF	4.3	30.27	290	0.78
	33	4.6	30.43	290	0.76
	67	5.3	30.93	265	0.88
	95	5.4	31.51	278	1.07
1900	SURF	4.8	30.53	255	1.01
	33	5.2	30.95	282	1.27
	67	5.4	31.31	327	1.04
	95	5.4	31.46	310	1.19

Table 4-36 RACE 17 January, 1973

TIME	DEPTH (ft)	TEMP. (°C)	SALINITY (ppt)	CURRENT DIRECTION (Degrees Mag)	CURRENT SPEED (Kts)
2000	SURF	5.3	31.08	290	1.27
	33	5.4	31.39	280	1.35
	67	5.5	31.45	302	1.12
	95	5.6	31.44	290	1.04
2100	SURF	5.4	31.18	310	0.94
	33	5.8	31.39	305	0.88
	67	5.9	31.54	288	0.80
	95	5.9	31.54	278	0.67
2200	SURF	5.2	31.24	320	0.55
	33	5.6	31.24	309	0.47
	67	5.8	31.41	285	0.37
	95	5.8	31.63	225	0.27

Table 4-37 ESTIMATED STREAM DISCHARGE ENTERING LONG ISLAND SOUND

Year	Month	Cubic feet per second				
		A	B	C	D	E
1972	January	15,100	4,630	3,400	1,550	24,700
	February	13,200	3,440	3,360	1,380	21,400
	March	32,200	8,970	10,600	3,130	54,900
	April	49,600	7,220	5,140	3,690	65,700
	May	56,600	6,970	5,580	4,090	73,200
	June	31,500	8,440	5,680	2,790	48,400
	July	20,100	6,300	2,730	1,880	31,000
	August	8,480	1,260	1,040	870	11,600
	September	5,360	760	1,130	680	7,930
	October	7,870	1,580	1,440	880	11,800
	November	25,600	4,760	5,720	2,270	38,400
	December	31,800	7,890	8,240	2,920	50,800
	Mean	24,800	5,190	4,510	2,180	36,700
1973	January	29,800	6,120	5,380	2,550	43,800
	February	33,600	7,330	6,700	2,900	50,500
	March	46,400	5,890	4,200	3,390	59,900
	April	45,900	7,090	5,600	3,500	62,100
	May	36,600	5,600	3,760	2,810	48,800
	June	20,400	2,400	1,890	1,640	26,300
	July	30,900	3,560	2,130	2,290	38,900
	August	8,580	1,080	1,160	910	12,300
	September					
	October					
	November					
	December					
	Mean					

A, Connecticut River; B, Housatonic River; C, Thames River; D, all other surface inflow; E, total surface inflow to Long Island Sound. Total does not include ground-water inflow estimated to average 300-400 cfs.

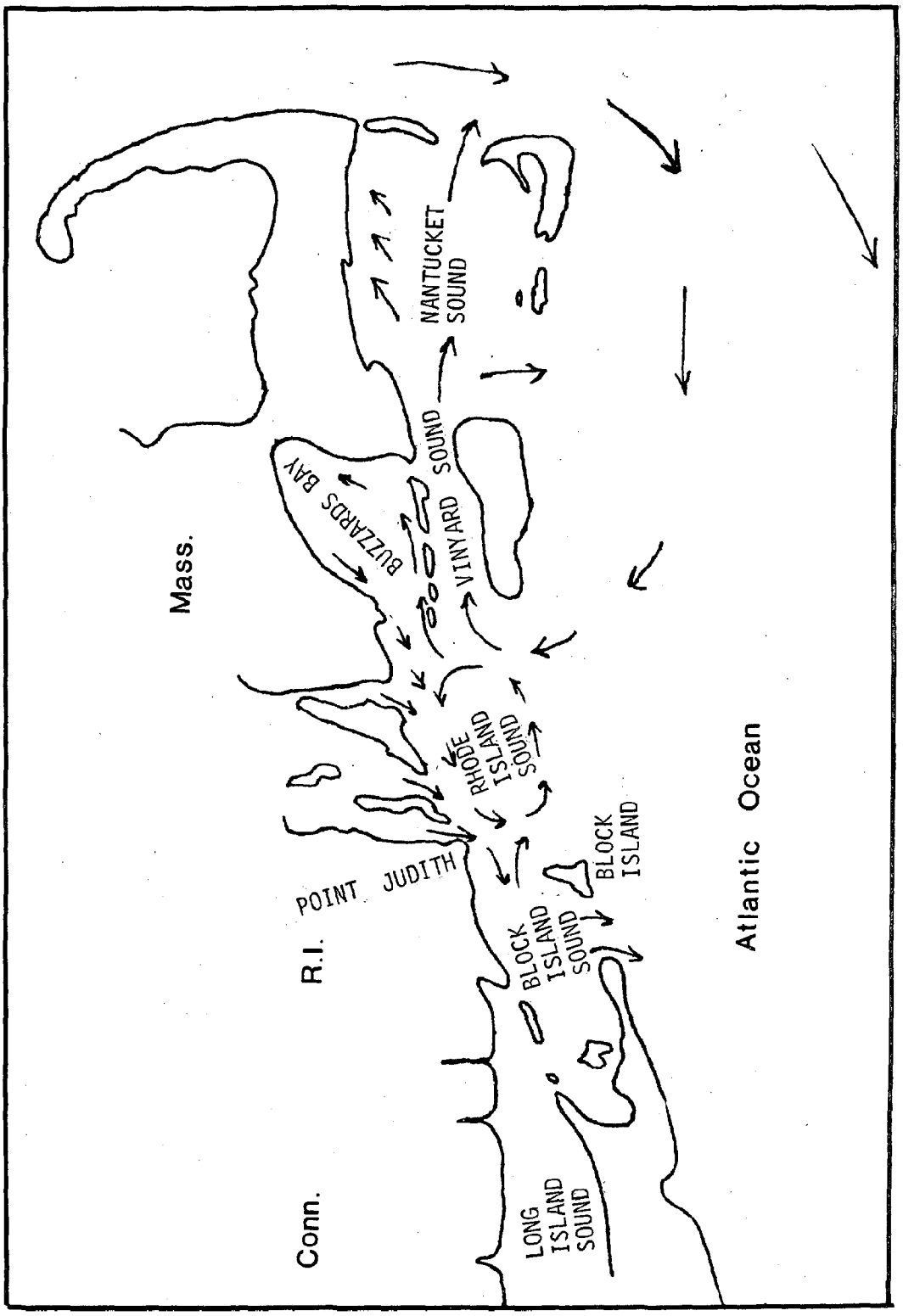
Table 4-38

	Temperature					
	Surface stations			Bottom stations		
	1	5	6	1	5	6
Summer	24.3 ± 0.9	23.0 ± 1.0	23.2 ± 0.9	23.7 ± 0.7	22.1 ± 0.7	21.7 ± 0.8
Fall	11.7 ± 4.5	9.7 ± 4.3	11.1 ± 4.2	11.9 ± 4.0	10.0 ± 4.1	12.1 ± 5.2
Winter	3.4 ± 2.9	2.9 ± 1.6	2.4 ± 1.8	3.0 ± 2.0	3.4 ± 1.8	2.3 ± 1.5
Spring	14.1 ± 6.0	13.6 ± 5.5	12.0 ± 4.5	13.4 ± 5.3	12.4 ± 5.1	11.6 ± 4.9
Summer	24.0 ± 2.8	23.2 ± 3.0	22.8 ± 2.9	23.6 ± 1.2	22.3 ± 2.6	21.6 ± 2.5

	Salinity					
	Surface stations			Bottom stations		
	1	5	6	1	5	6
Summer	24.02 ± 1.14	26.37 ± 0.46	26.91 ± 0.60	24.26 ± 1.12	26.59 ± 0.54	27.10 ± 0.41
Fall	21.77 ± 2.24	26.12 ± 1.20	27.14 ± 0.71	22.71 ± 2.45	26.35 ± 1.22	27.28 ± 0.82
Winter	12.88 ± 6.86	19.55 ± 1.38	23.27 ± 2.17	18.93 ± 4.42	21.46 ± 3.14	22.75 ± 3.26
Spring	11.82 ± 6.91	17.98 ± 4.47	19.13 ± 6.41	16.50 ± 4.07	19.80 ± 4.36	20.69 ± 4.56
Summer	25.09 ± 2.22	26.23 ± 1.42	26.74 ± 0.82	24.95 ± 1.32	26.59 ± 1.72	27.39 ± 0.80

Mean daily discharge rate of Raritan River in ft³/sec, 1957–1958

Month	1957	1958
January	925	2,739
February	1,754	1,854
March	1,578	3,716
April	3,022	3,246
May	648	2,359
June	280	557
July	131	709
August	95	360
September	122	346
October	148	—
November	283	—
December	2,393	—



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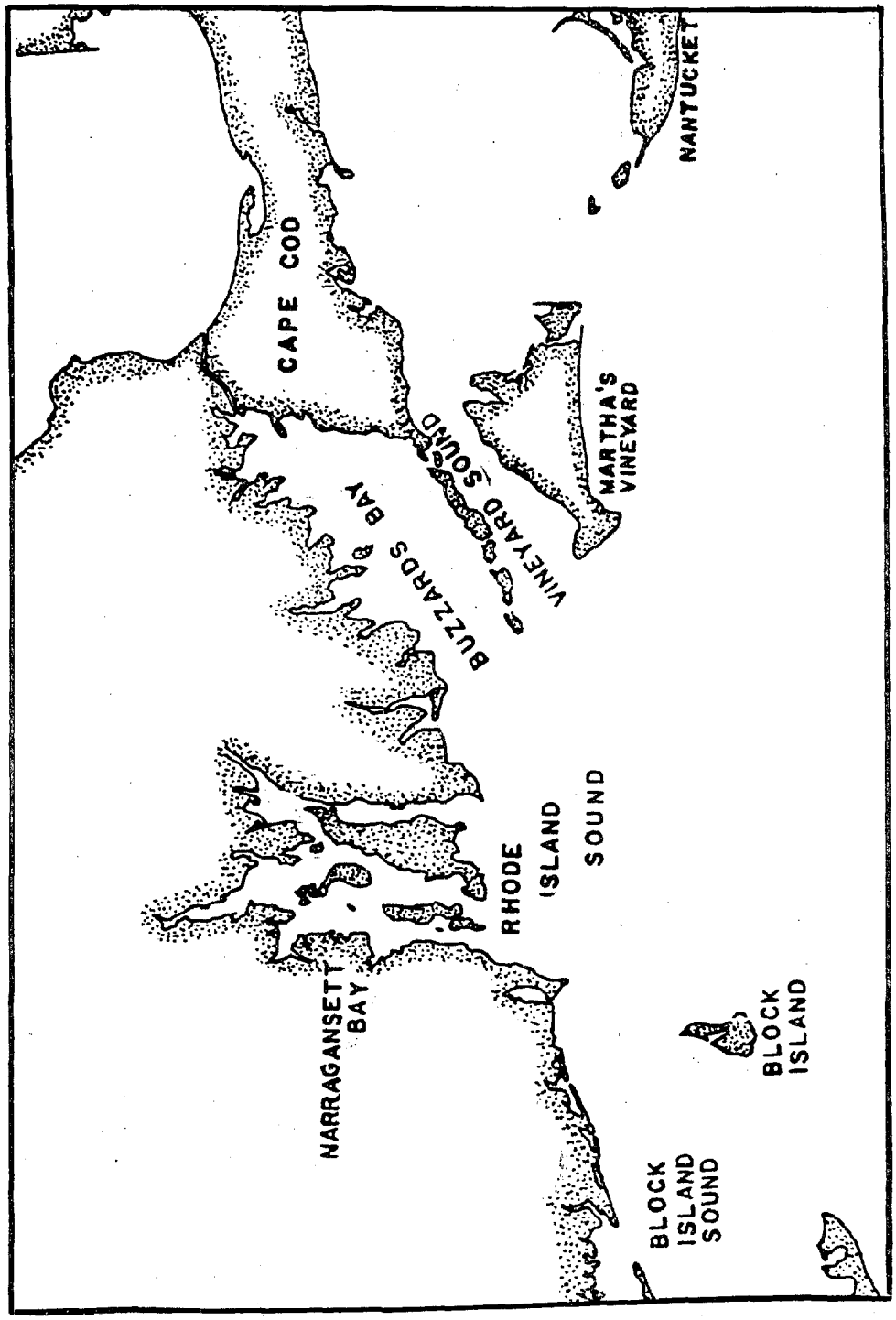
TRIGOM PARC	FIGURE 4-84	Circulation Patterns Off Southern New England



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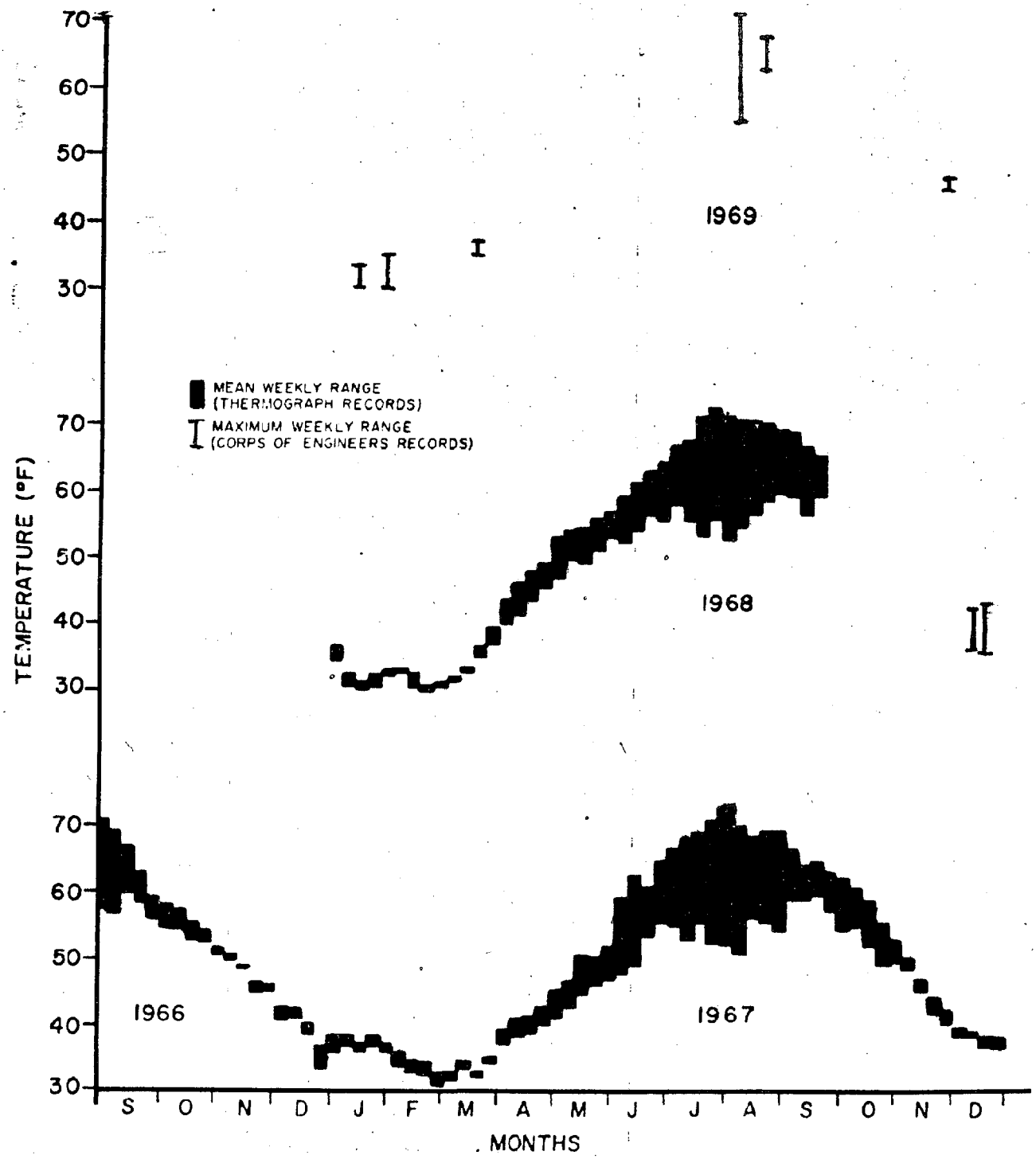
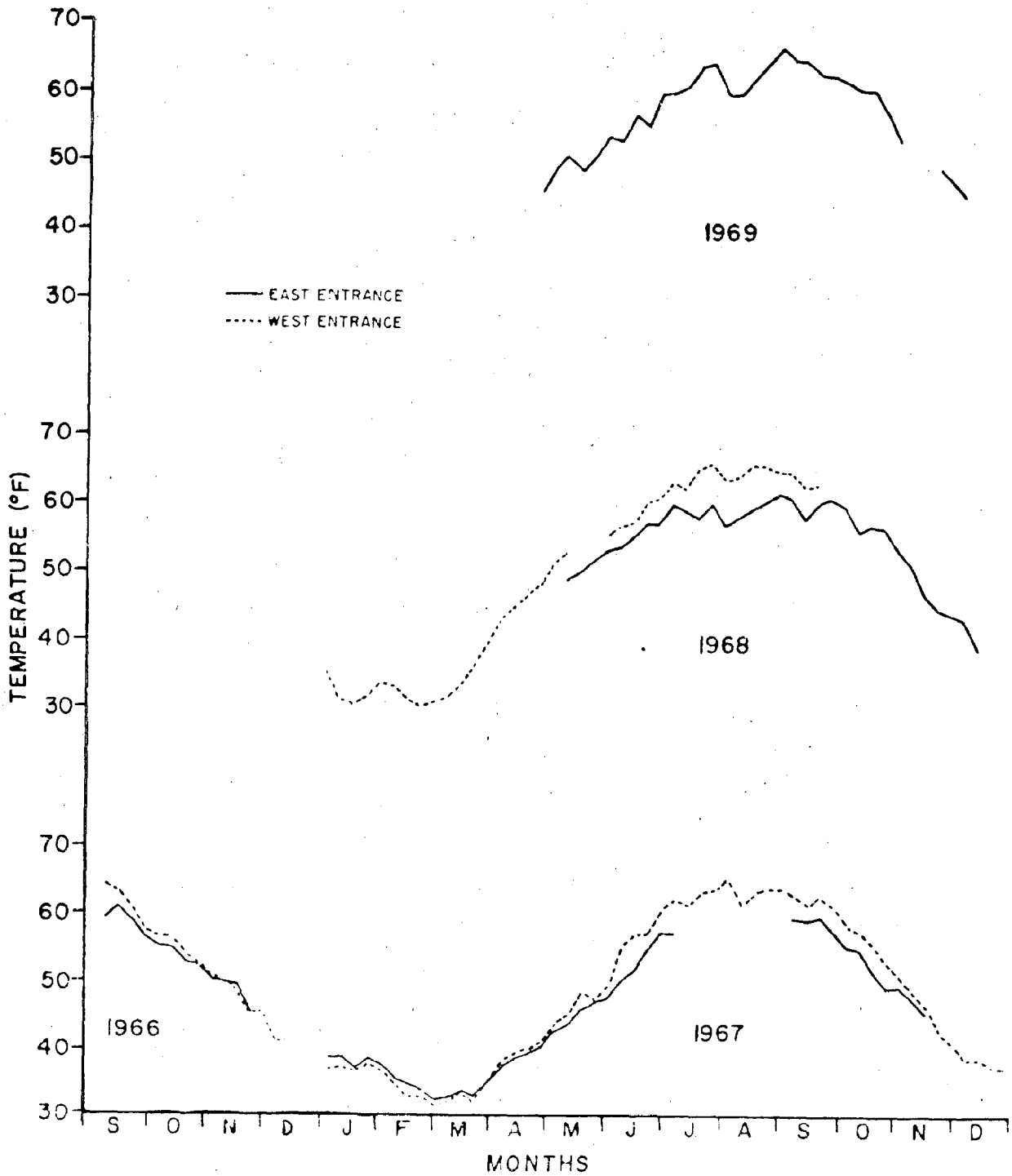
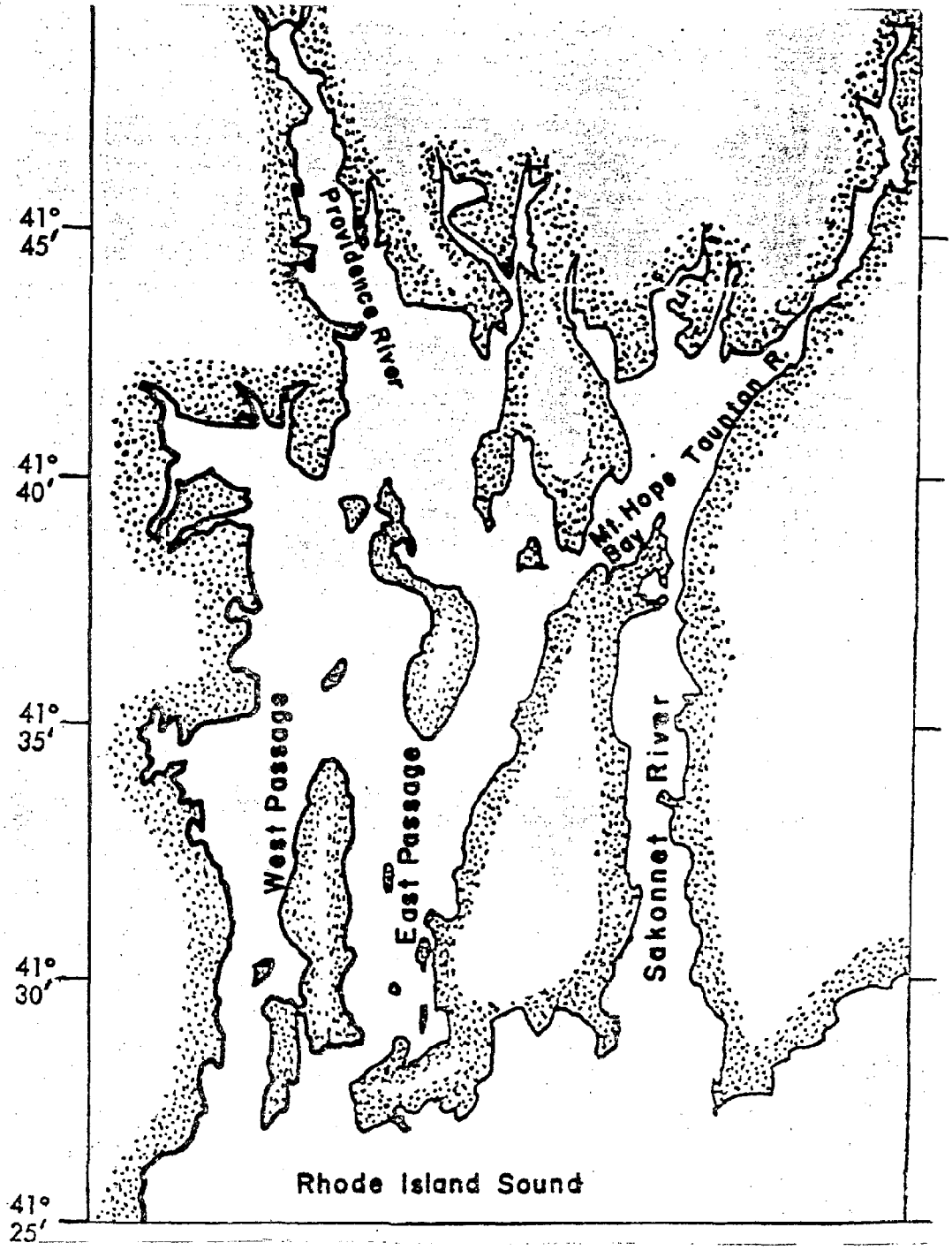
TRIGOM PARC	FIGURE 4-85	Location of Buzzards Bay and Elizabeth Island Archipelago (Norton, 1967)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-86	Weekly Temperature Ranges at West End of Cape Cod Canal



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-87	Weekly Mean Temperature at the East and West Entrance to the Cape Cod Canal (Fairbanks et al., 1971)



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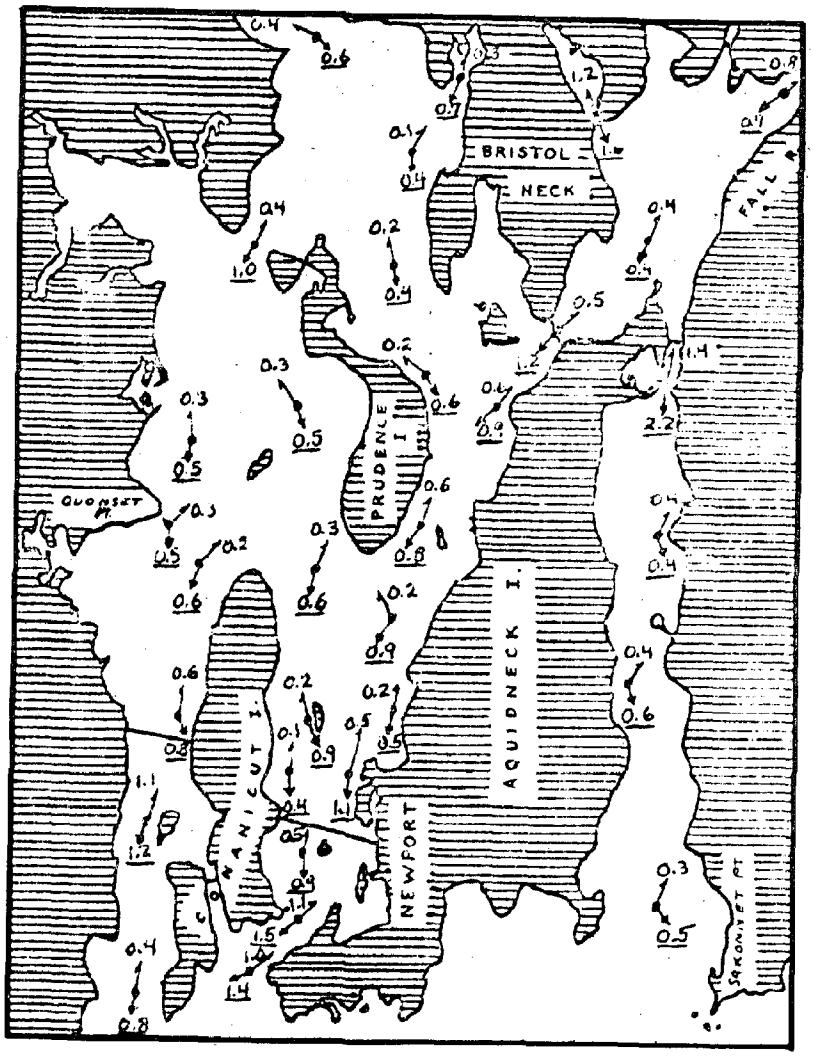
TRIGOM PARC	FIGURE 4-88	Rivers and Passages in the Narragansett Bay System (Morton, 1967)



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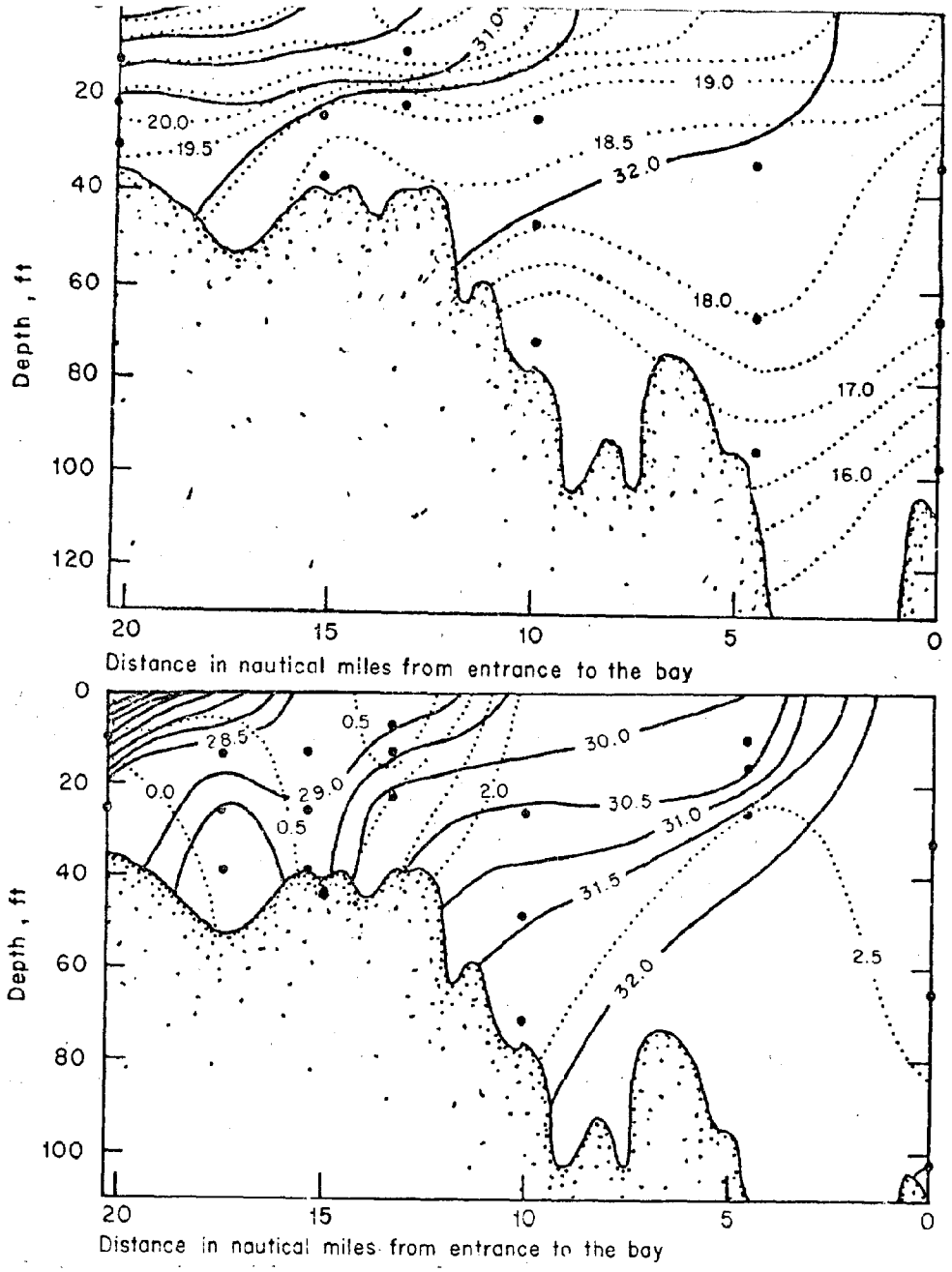
TRIGOM PARC	FIGURE 4-89	Narragansett Bay Currents (Eldridge, annual)



Seasonal Trends and Ranges for Narragansett Bay[1]

	Temperature, °C				Salinity, °/oo			
	winter	spring	summer	autumn	winter	spring	summer	autumn
From Heads to Entrances								
General surface tendency	increase[2]	decrease	decrease	decrease	increase	increase	increase	increase
General surface range	0.0 - 2.0	11.5 - 5.5	23.0 - 18.5	9.0 - 12.0	24.5 - 32.0	20.5 - 31.5	29.5 - 32.5	29.0 - 32.5
General bottom tendency	increase[2]	decrease	decrease	decrease	increase	increase	increase	increase
General bottom range	0.0 - 2.5	8.0 - 5.0	22.0 - 15.5	9.0 - 13.0	29.0 - 32.5	27.0 - 32.0	31.0 - 32.0	30.5 - 32.5
General tendency								
Surface to bottom	increase[3]	decrease	decrease	increase	increase	increase	increase	increase
Vertical stratification	0.3	-0.9	-4.2	1.0	2.2	6.3	1.0	0.1

[1]Based on four cruises in January-February, April, July, and November, 1957.
[2]East and West Passages only.
[3]Except Mt. Hope Bay and Sakonnet River.

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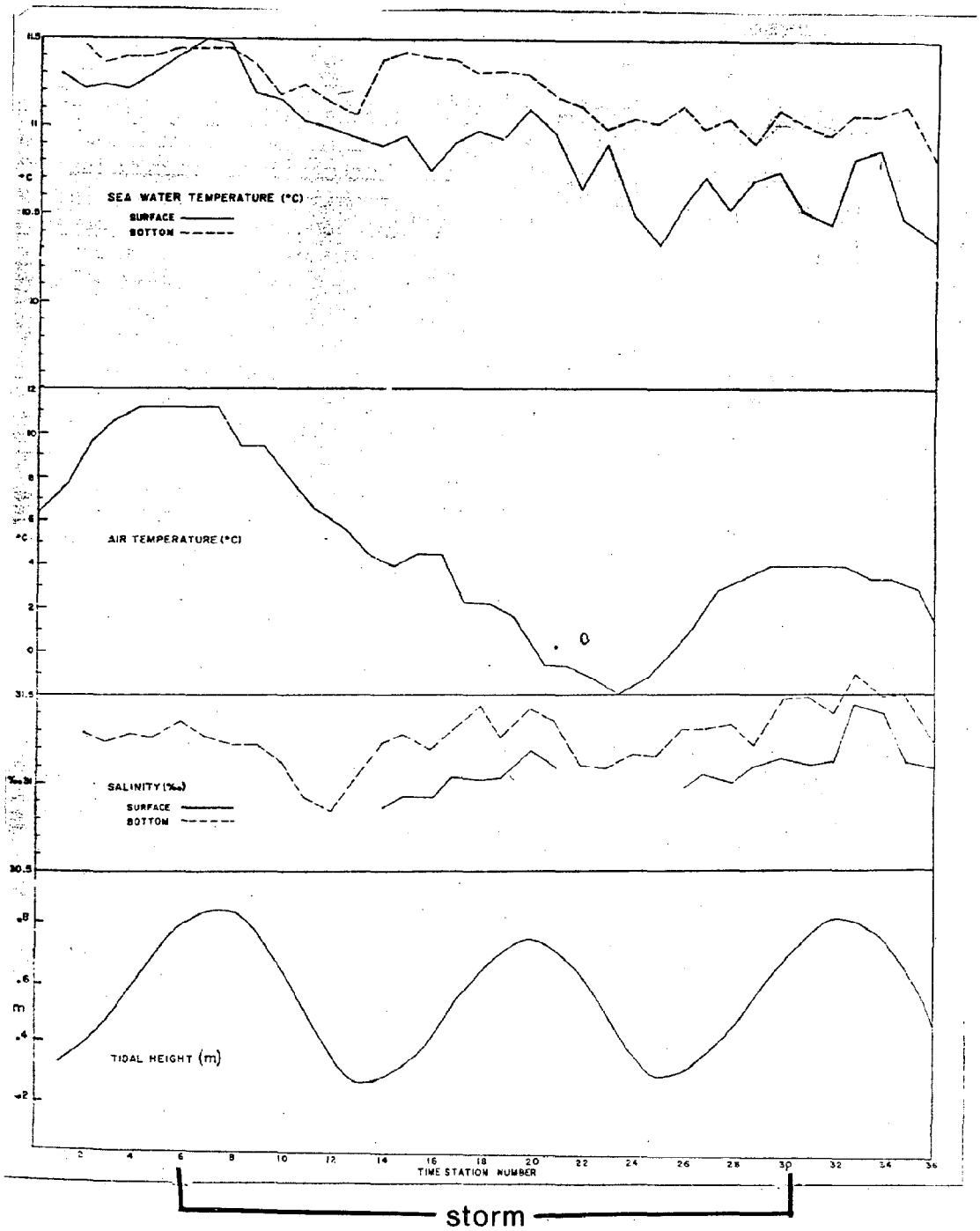
TRIGOM PARC

FIGURE 4-90

Vertical Distribution of Temperature and Salinity in the Providence River and Narragansett Bay (Bumpus et.al., 1973)



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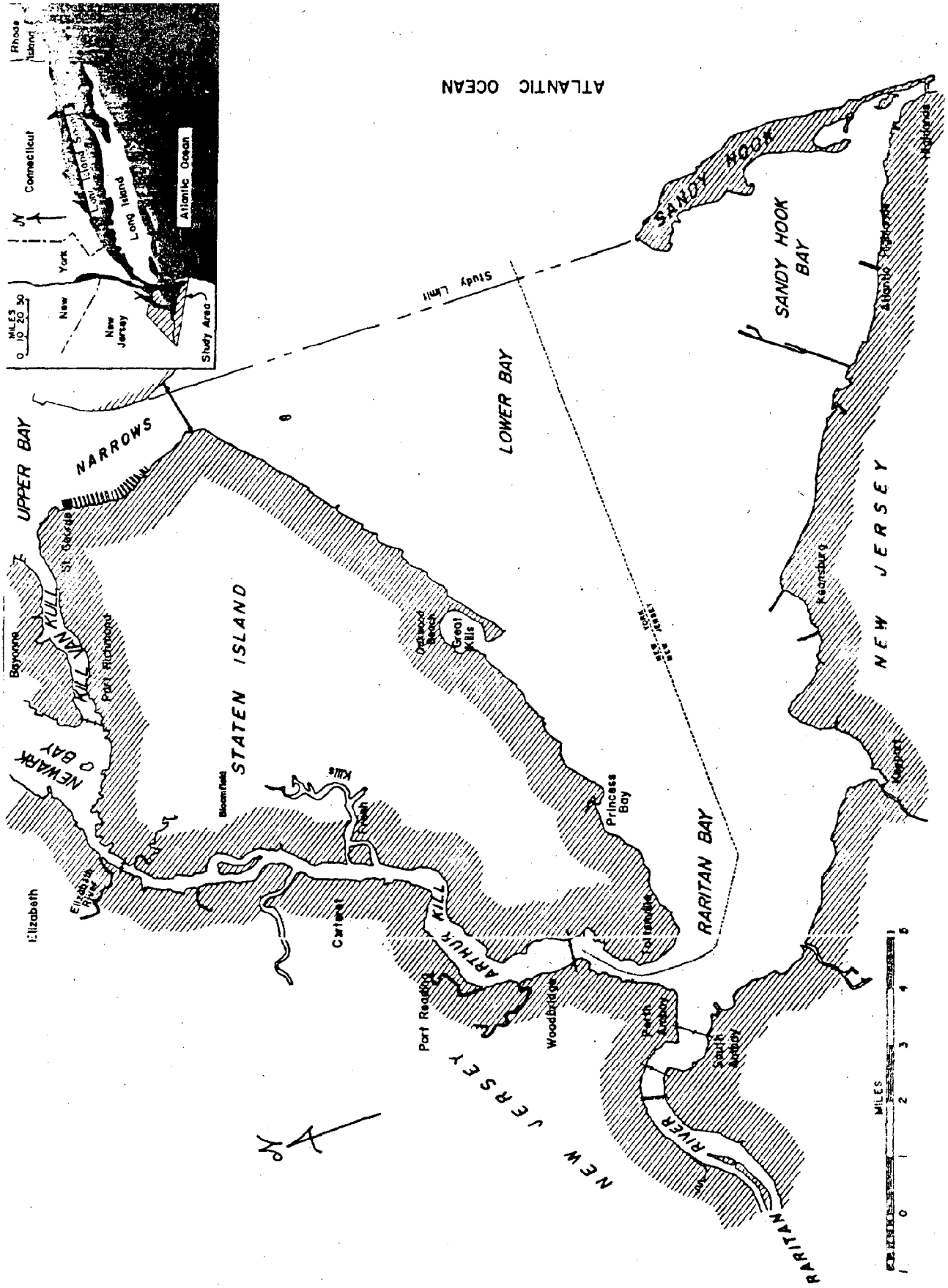
TRIGOM PARC	FIGURE 4-91	Variation of Physical Parameters During Time Station (Morton, 1967)



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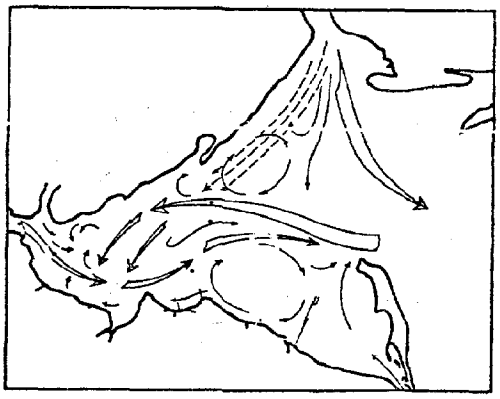
TRIGOM PARC	FIGURE 4-92	New York Outer Harbor (Public Health Service 1963, 1967)



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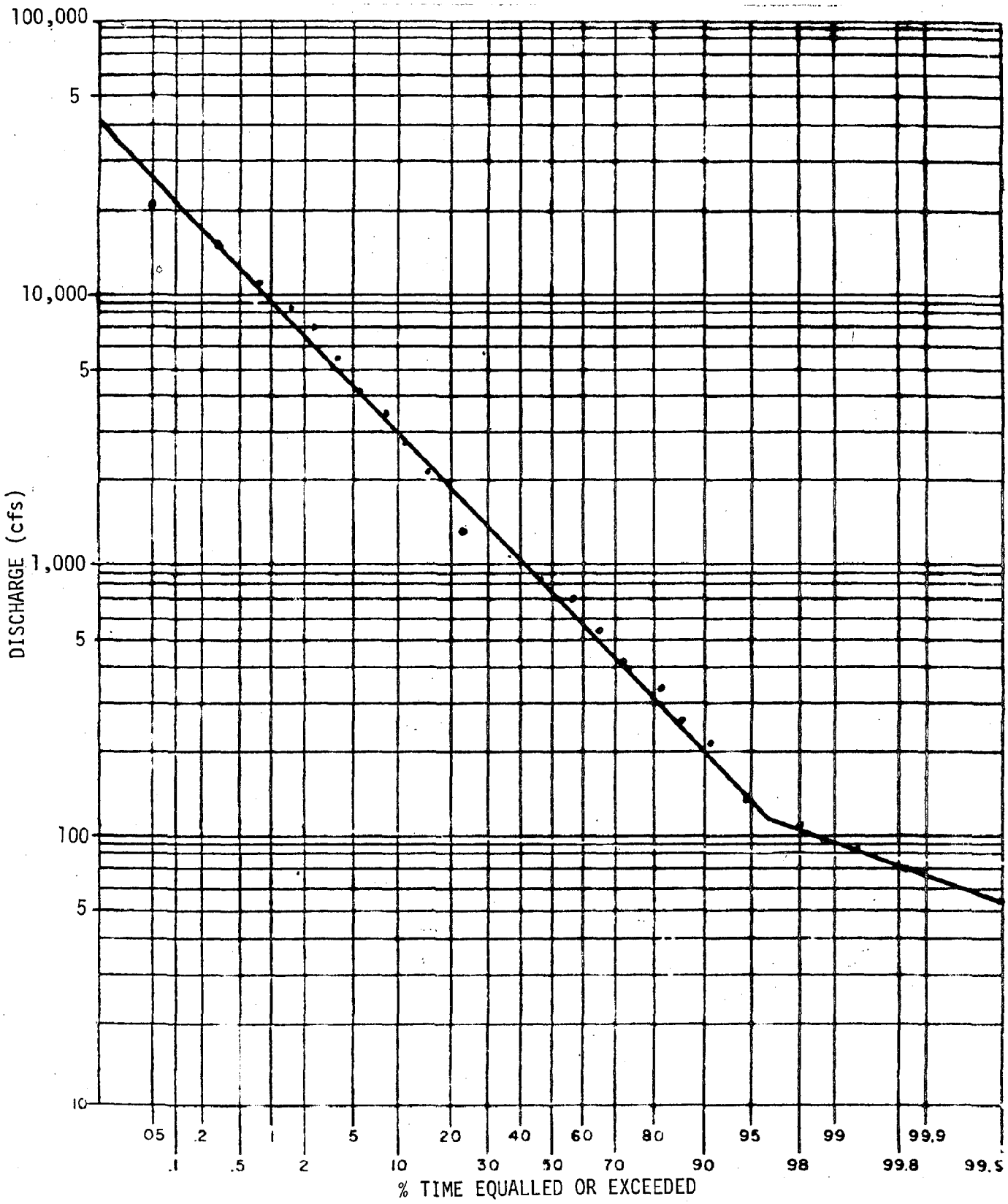
TRIGOM PARC	FIGURE 4-93	Schematic Representation of Net Currents in New York Outer Harbor (Jeffries, 1962)



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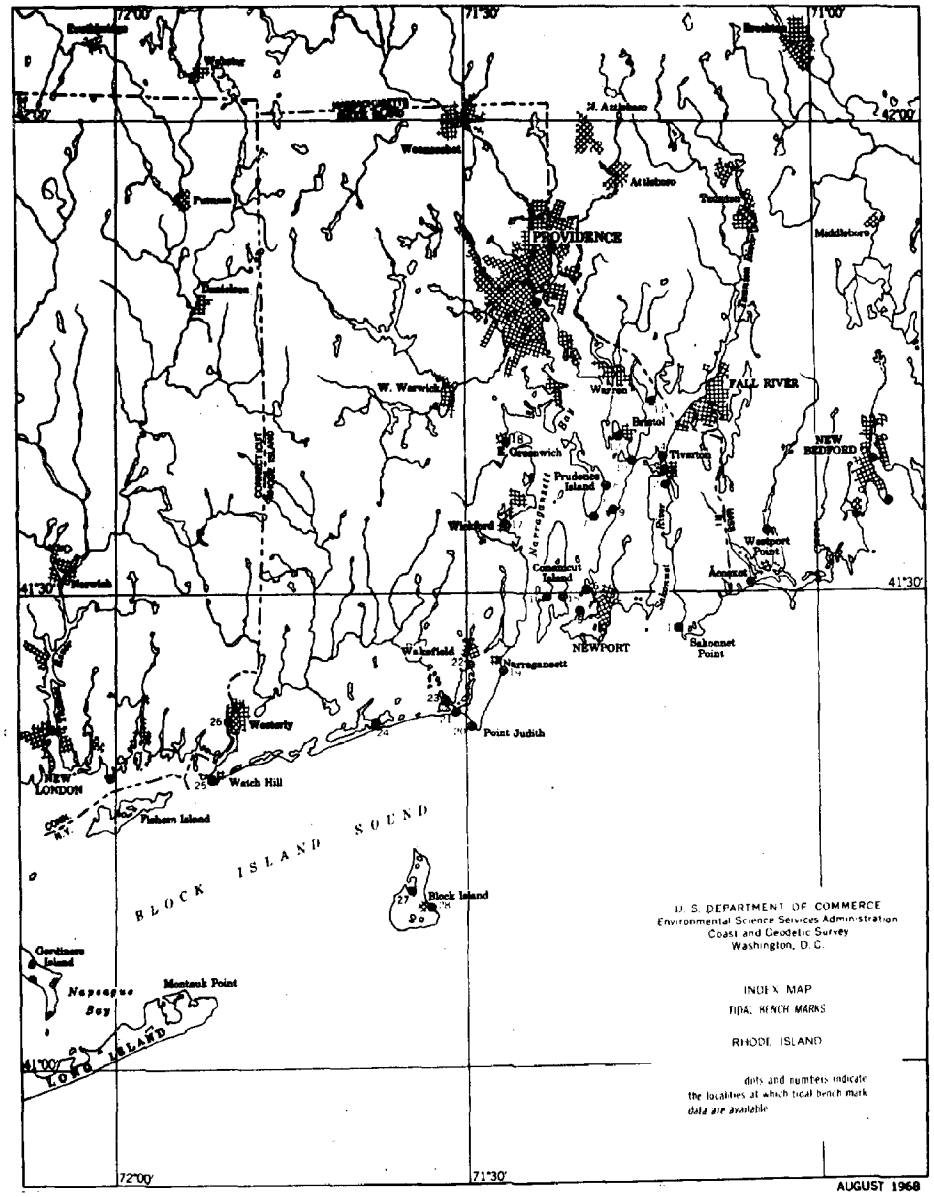
TRIGOM PARC	FIGURE 4-94	Probability Plot of Extrapolated Daily Discharge Data for the Raritan River (Public Health Service, 1967)



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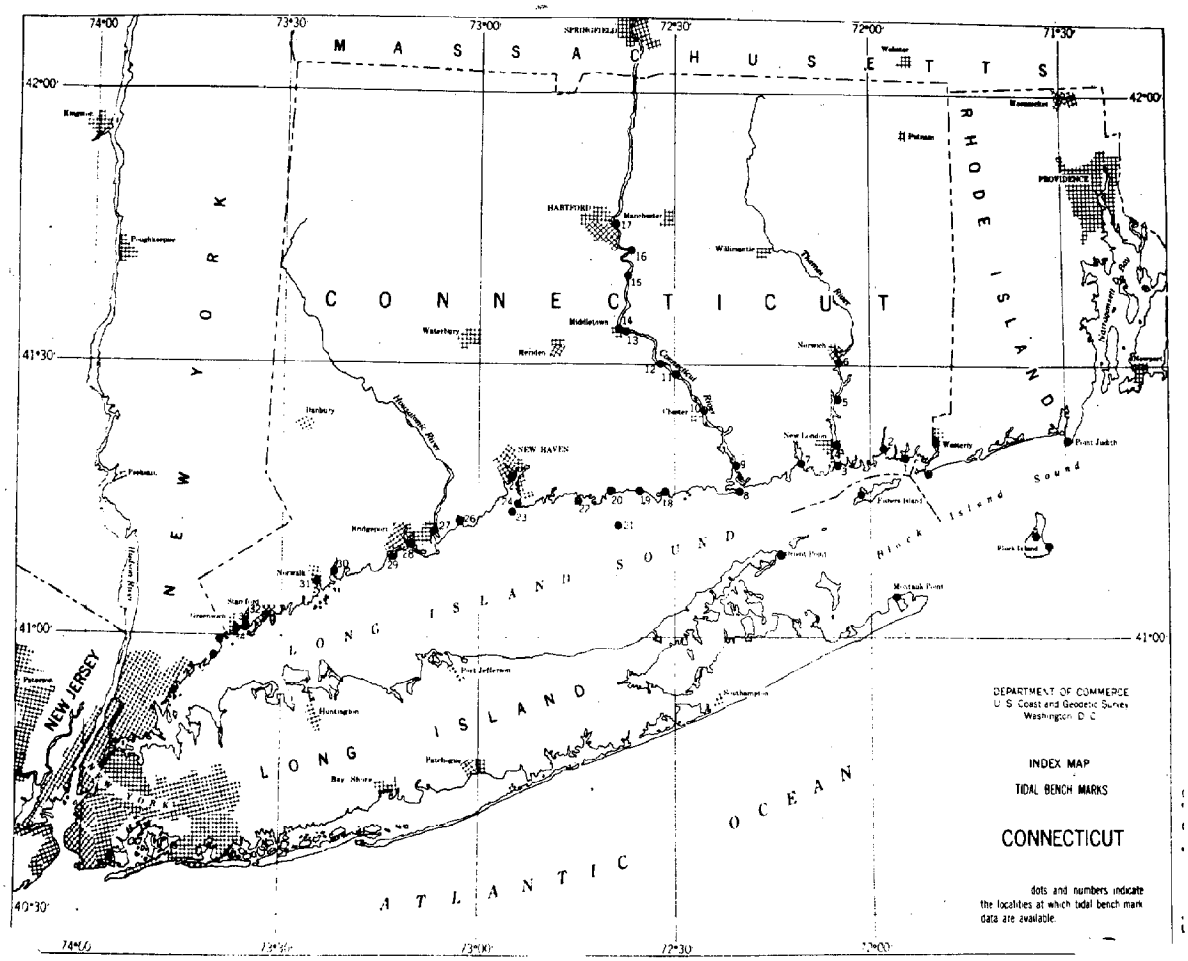
TRIGOM PARC	FIGURE 4-95a	Index Map - Tidal Bench Marks - Rhode Island (U.S. Dept. of Commerce, 1968)

Table 4-21a Tidal Bench Mark Locations - Rhode Island

INDEX MAP NUMBER	NAME
1	Sakonnet, Sakonnet River Entrance
2	Tiverton (Nannaquacket Point, Sakonnet River
3	Tiverton (Near Anthony Point), Sakonnet River
4	Tiverton (Bay Oil Company), Sakonnet River
5	Fort Adams, Narragansett Bay
6	Newport (Naval Training Station)
7	Navy Pier, Prudence Island (Southeast end of)
8	Sandy Point, Prudence Island
9	Melville (Navy Fuel Oil Depot)
10	Bristol Point, Bristol Neck
11	Bristol Narrows, Mt. Hope Bay
12	Bristol, Bristol Harbor
13	Providence (State Pier No. 1)
14	Pawtucket, Seekonk River
17	Wickford, Narragansett Bay
18	East Greenwich, Greenwich Bay
19	Narragansett Pier, Narragansett Bay
20	Point Judith (Eastern Breakwater), Harbor of Refuge
21	Point Judith Pond Entrance (Galilee), Harbor of Refuge
22	Point Judith Pond (North End)
23	Point Judith Pond (Potters Pond)
24	Ninigret Pond, Charleston
25	Watch Hill Point
26	Westerly, Pawcatuck River
27	New Harbor, Great Salt Pond, Block Island
28	Block Island Harbor (Old Harbor), Block Island



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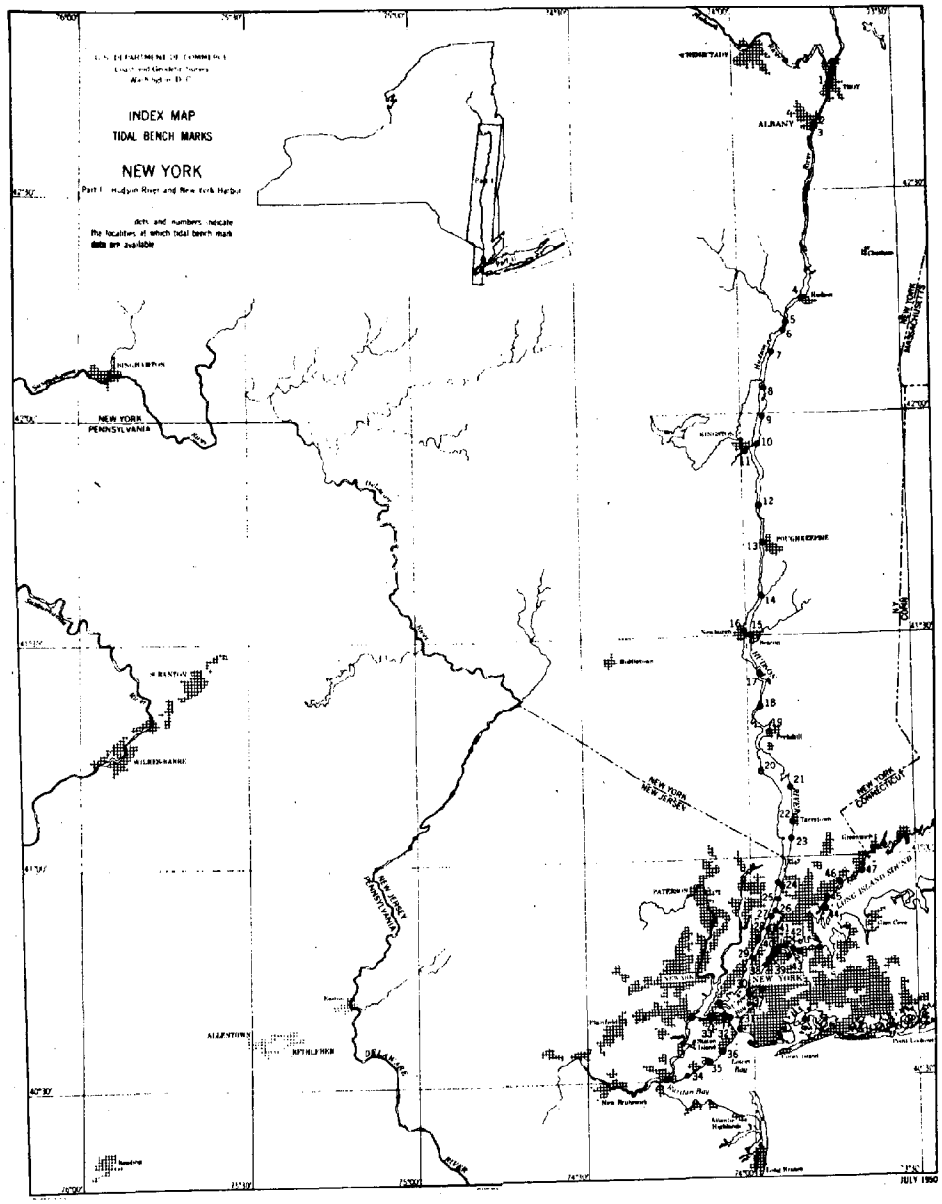
TRIGOM PARC	FIGURE 4-95b	Index Map - Tidal Bench Marks - Connecticut (U.S. Dept. of Commerce, 1948)

Table 4-21b Tidal Bench Mark Locations - Connecticut

INDEX MAP NUMBER	NAME
2A	Noank, Fishers Sound
4	New London, Thames River
6	Norwich, Thames River
8	Saybrook Jetty, Connecticut River Entrance
8A	Old Saybrook Point, Connecticut River
9	Lyme Highway Bridge (West End), Connecticut River
10	Hadlyme, Connecticut River
10A	East Haddam, Connecticut River
12	Higganum, Connecticut River
13	Portland, Connecticut River
15	Rocky Hill, Connecticut River
18A	Dick Island Roads
20A	Sachum Head
25	New Haven, New Haven Harbor
27	Stratford Housatonic River
28	Bridgeport
31	South Norwalk, Norwalk River
32	Stamford, Stamford Harbor
33	Coscob Harbor



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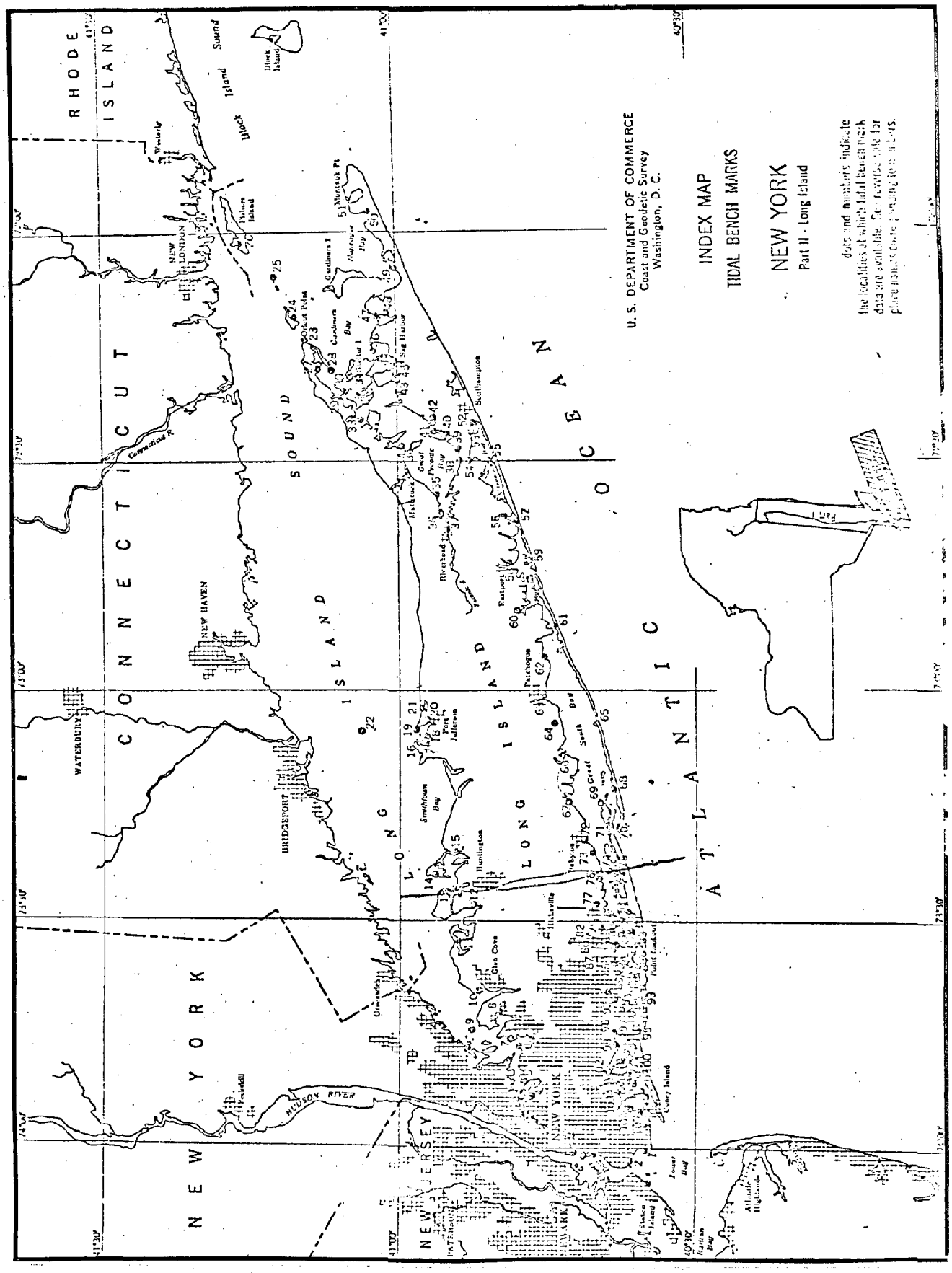
TRIGOM PARC	FIGURE 4-95c	Index Map - Tidal Bench Marks - New York (U.S. Dept. of Commerce and C. & G. S., 1950).

Table 4-21c Tidal Bench Mark Locations - New York

INDEX MAP NUMBER	NAME
1	Norton Point, Coney Island
2	Fort Hamilton
3	Brooklyn Naval Shipyard, East River
3A	Hunters Point
5	College Point, Flushing Bay Entrance
6	Willets Point (Fort Totten)
10	Glen Cove (New York Yacht Club), Hampstead Harbor
11	Bayville Bridge, Oyster Bay
14	Eatons Neck, Huntington Bay
19	Port Jefferson Harbor Entrance
20	Port Jefferson, Port Jefferson Harbor
21A	Herod Point
21B	Northville
23	Orient Point (New London Ferry Company Dock), Gardiners Bay
24	Plum Gut Harbor, Plum Island
25	Little Gull Island
26	Silver Eel Pond (Fort Wright), Fishers Island
27	Orient, Orient Harbor
29	Greenport, Greenport Harbor
31	Coecles Harbor, Shelter Island
33	Southold, Southold Bay
34	New Suffolk, Cutchogue Harbor
35	South Jamesport, Great Paconic Bay
43	Noyack Bay, Shelter Island Sound
44	Sag Harbor, Shelter Island Sound
47	Threemile Harbor Jetty, Threemile Harbor Entrance
49	Promised Land, Napeague Bay
50	Montauk, Fort Pond Bay
51	Montauk Harbor Entrance, Montauk Point
55	Shinnacock Inlet
55A	Moriches Inlet
63	Patchogue, Great South Bay
64	Sayville (Town Dock), Brown Creek, Great South Bay
65	Lone Hill, Fire Island Beach, Great South Bay
65A	Point O'Woods, Great South Bay
66	Great River, Connetquot River, Great South Bay
67	Bay Shore, Watchogue Creek Entrance, Great South Bay
68	Fire Island Lighthouse, Fire Island Beach
68A	West Fire Island, Fire Island, Great South Bat
69	Wa Wa Yanda Yacht Club, Captree Island, Great South Bay

Table 4-21C (continued)

INDEX MAP NUMBER	NAME
70	Democrat Point, Fire Island Inlet
71	Oakbeach
72	Babylon, Sampawam, Creek Entrance, Great South Bay
73	Neguntatogue Creek Entrance, Great South Bay
74	Elder Island, Great South Bay
75	Gilgo Heading, Gilgo Beach, Great South Bay
76	Amityville, Amityville Creek Entrance, Great South Bay
77	Biltmore Shores
78	Green Island Drawbridge, Hempstead Bay
79	Ballmore, Ballmore Creek, Hempstead Bay
80	Cube Island (Southeast End), Hempstead Bay
81	Deep Creek Meadow (Southwest End), Hempstead Bay
82	Neds Creek, False Channel Meadow, Hempstead Bay
84	Point Lookout, Jones Inlet
85	Meadow Island (Bascule Bridge), Hempstead Bay
86	Freeport, Freeport Creek, Hempstead Bay
89	Baldwin, Parsonage Cove, Hempstead Bay
90	Cinder Island (East Side), Hempstead Bay
92	Bay Park, East Rockaway, Hewlett Bay, Hampstead Bay
93	Long Beach
94	Woodmore (Keystone Yacht Club), Brosware Bay
95	Far Rockaway, Atlantic Beach, Reynolds Channel, East Rockaway Inlet
96	Norton Point, Hook Creek, Head of Bay, Jamaica Bay
97	Mott Basin, Jamaica Bay
98	New York International Airport, Jamaica Bay
100	Beach Channel (Cross Bay Bridge), Rockaway Beach, Jamaica Bay
101	Broad Creek Marsh, Jamaica Bay
102	North Channel Bascule Bridge (Cross Bay Boulevard), Grassy Bay, Jamaica Bay
103	Canarsle Beach, Jamaica Bay
104	Mill Basin, Brooklyn, Jamaica Bay
106	Barren Island (Foot of Flatbush Avenue), Marine Parkway Bridge, Jamaica Bay Entrance
107	Plum Island Marina Boat Basin, Plum Beach Channel
107A	Manhattan Beach, Sheepshead Bay



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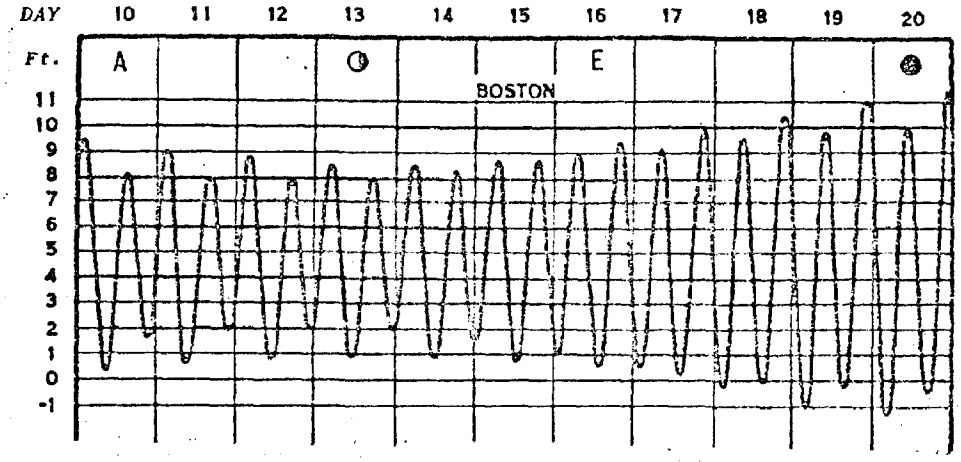
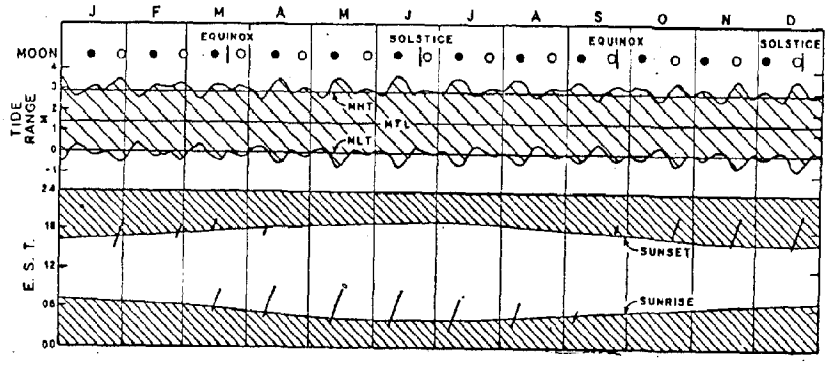
TRIGOM PARC	FIGURE 4-95d	Index Map - Tidal Bench Marks - New York (U.S. Dept. of Commerce and C. & G. S., 1951)

TABLE 4.21d New York

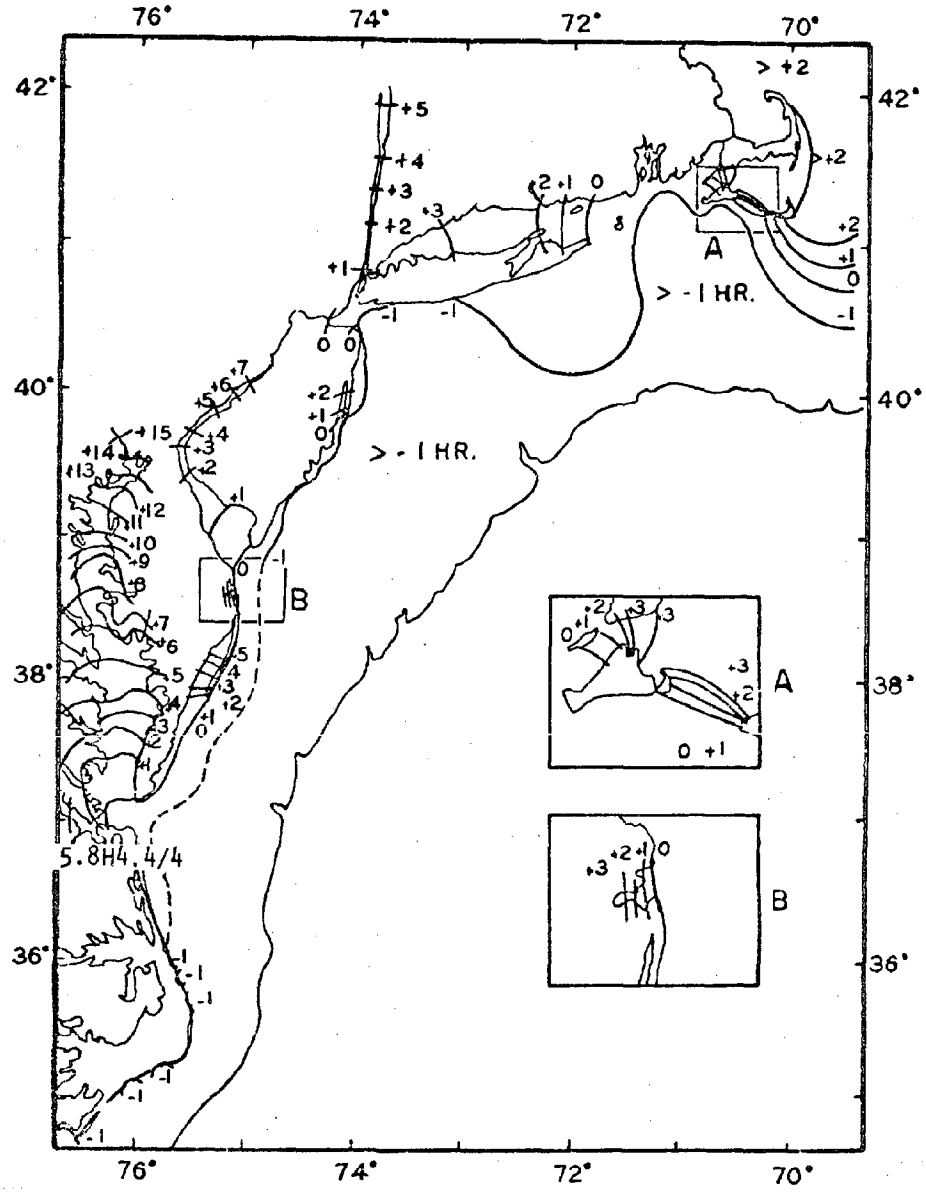
INDEX MAP NUMBER	NAME
11	Kingston, Rondout Creek, Hudson River
20	Haverstraw, Hudson River
22	Tarrytown, Hudson River
23	Irvington, Hudson River
24	Yonkers, Hudson River
25	Riverdale, Hudson River
26	Spuyten Duyvil Creek Entrance, Hudson River
27	New York City (Dyckman Street Ferry Slip, Tubby Hook), Hudson River
28	New York City (West 157th Street, Dock and George Washington Bridge), Hudson River
29	New York City (Pier 92), Hudson River
30	New York City (The Battery)
31	St. George, Staten Island
36	New Dorp Beach, Staten Island
36A	Ft. Wadsworth, The Narrows
37	Governors Island, New York Harbor
39	New York City (Foot of East 90th St), East River
41	Port Morris, East 138th St.
43A	Throgs Neck, Ft. Schuyler
45	New Rochelle, Long Island Sound
47	Rye Beach (Playland) Amusement Park, Long Island Sound



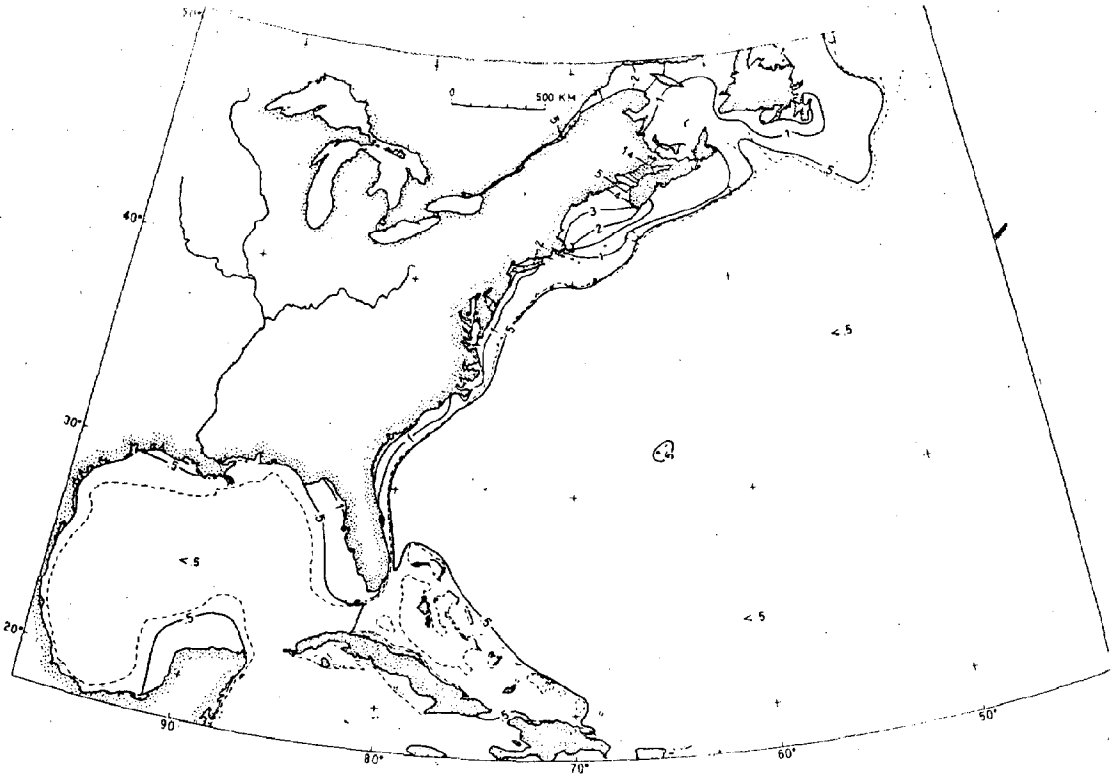
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-97	Typical Tide Curve for North Eastern U.S. Ports (NOS/NOAA, 1972)



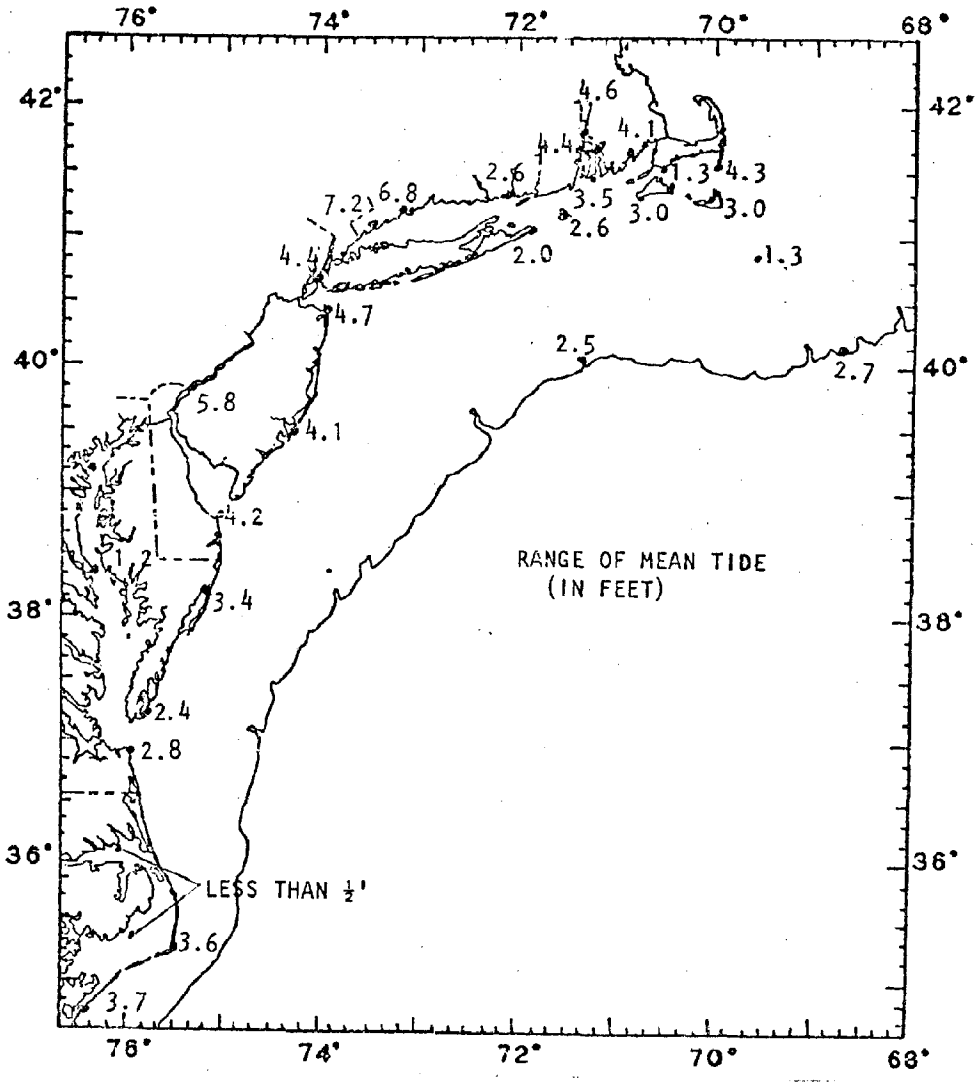
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-98	Relation of Tidal Range to Phases of the Moon (Sverdrup et.al., 1942)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-99	Co-Tidal Chart Showing Approximate Time of High Water Relative to New York Harbor (Bumpus et al., 1973)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-100	Co-Range Chart for Mean Spring Tides (Emery and Uchupi, 1972)



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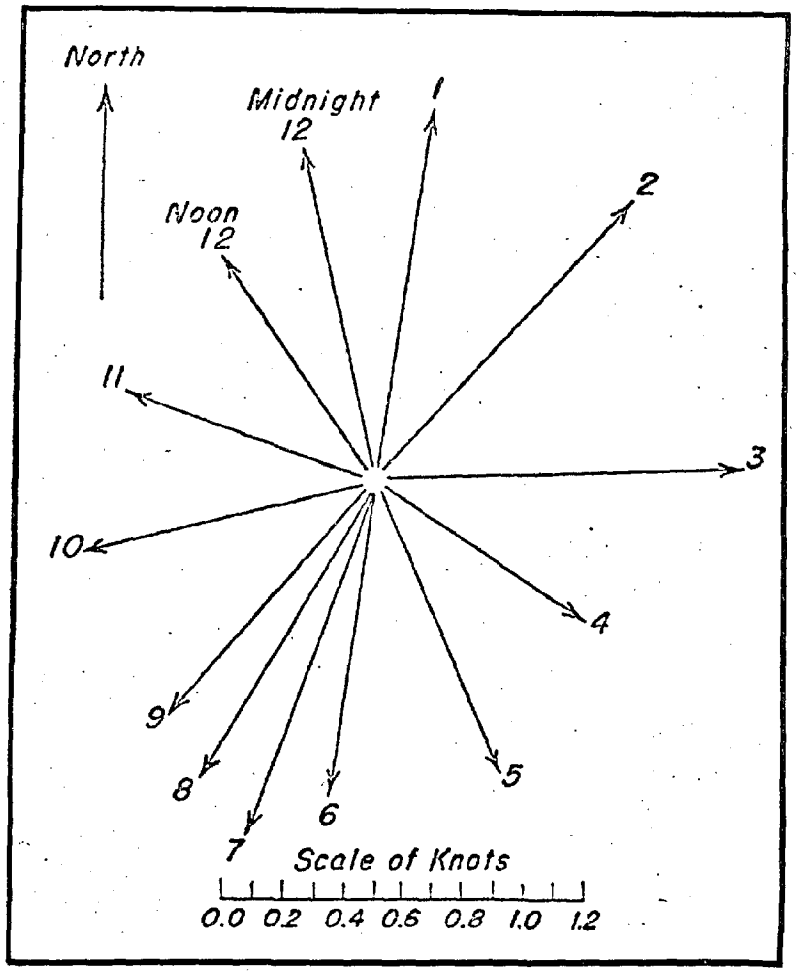
TRIGOM PARC	FIGURE 4-101	Range of Mean Tide (Bumpus et al., 1973)



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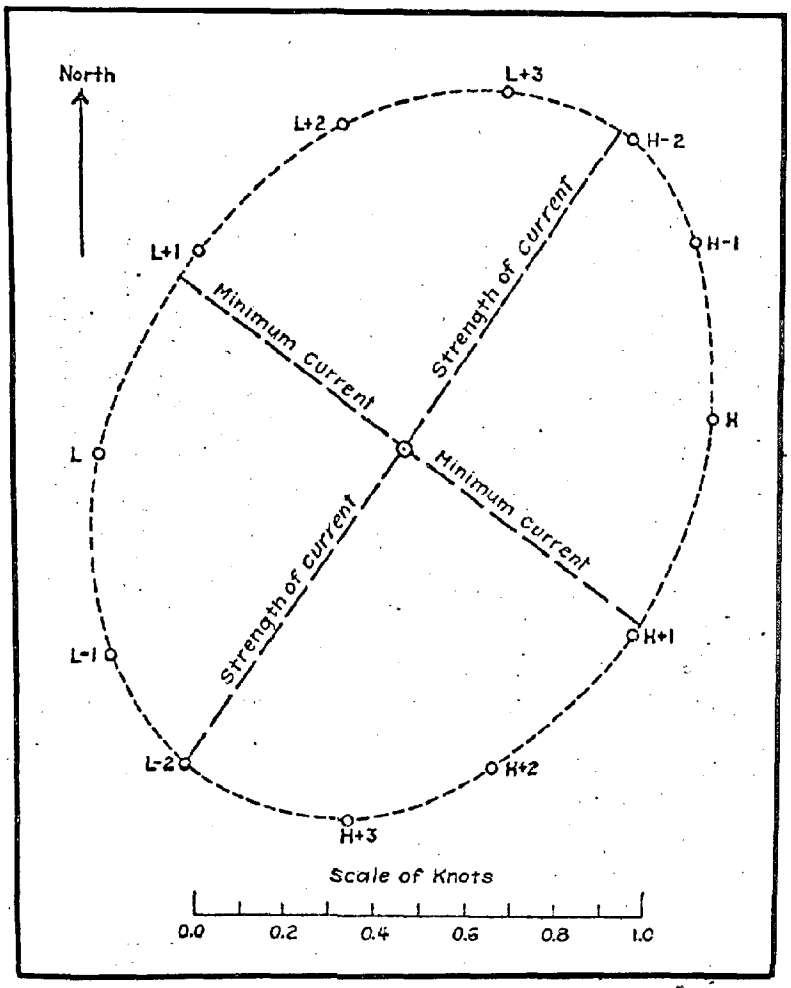
TRIGOM PARC	FIGURE 4-102	Direction and Velocity of Tides at Nantucket Lightship (Haight, 1942)



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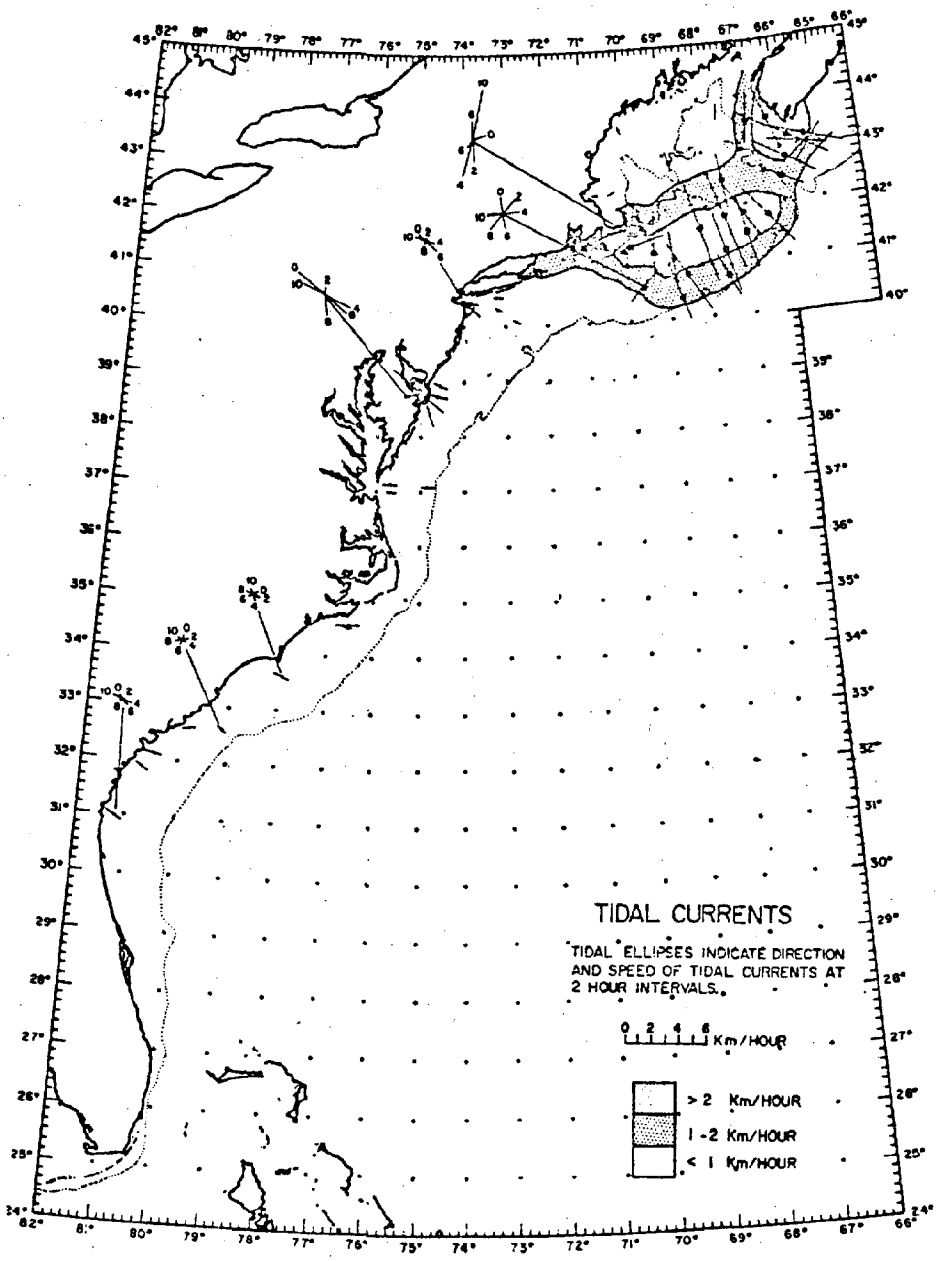
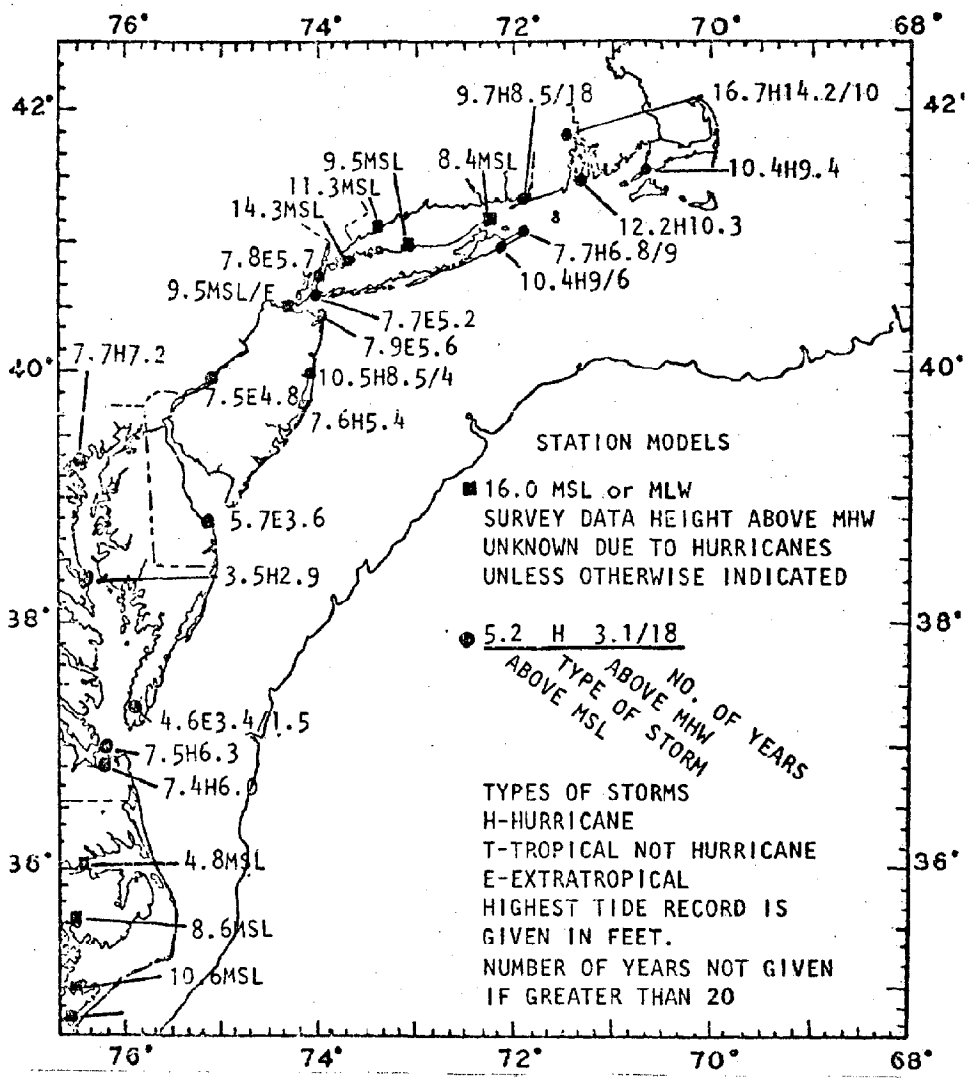
TRIGOM PARC	FIGURE 4-103	Pattern of Tidal Currents at Nantucket Lightship (Haight, 1942)



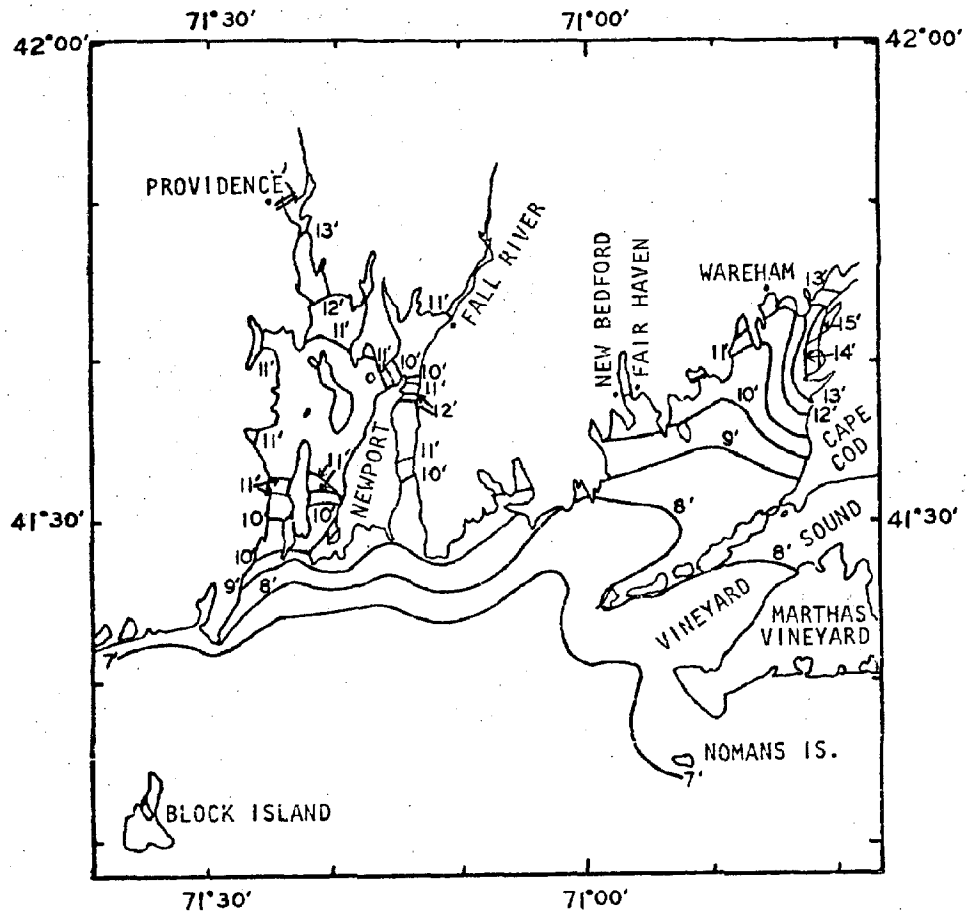
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-104	Surface Tidal Currents Offshore Over the Continental Shelf (Emery and Uchupi, 1972)



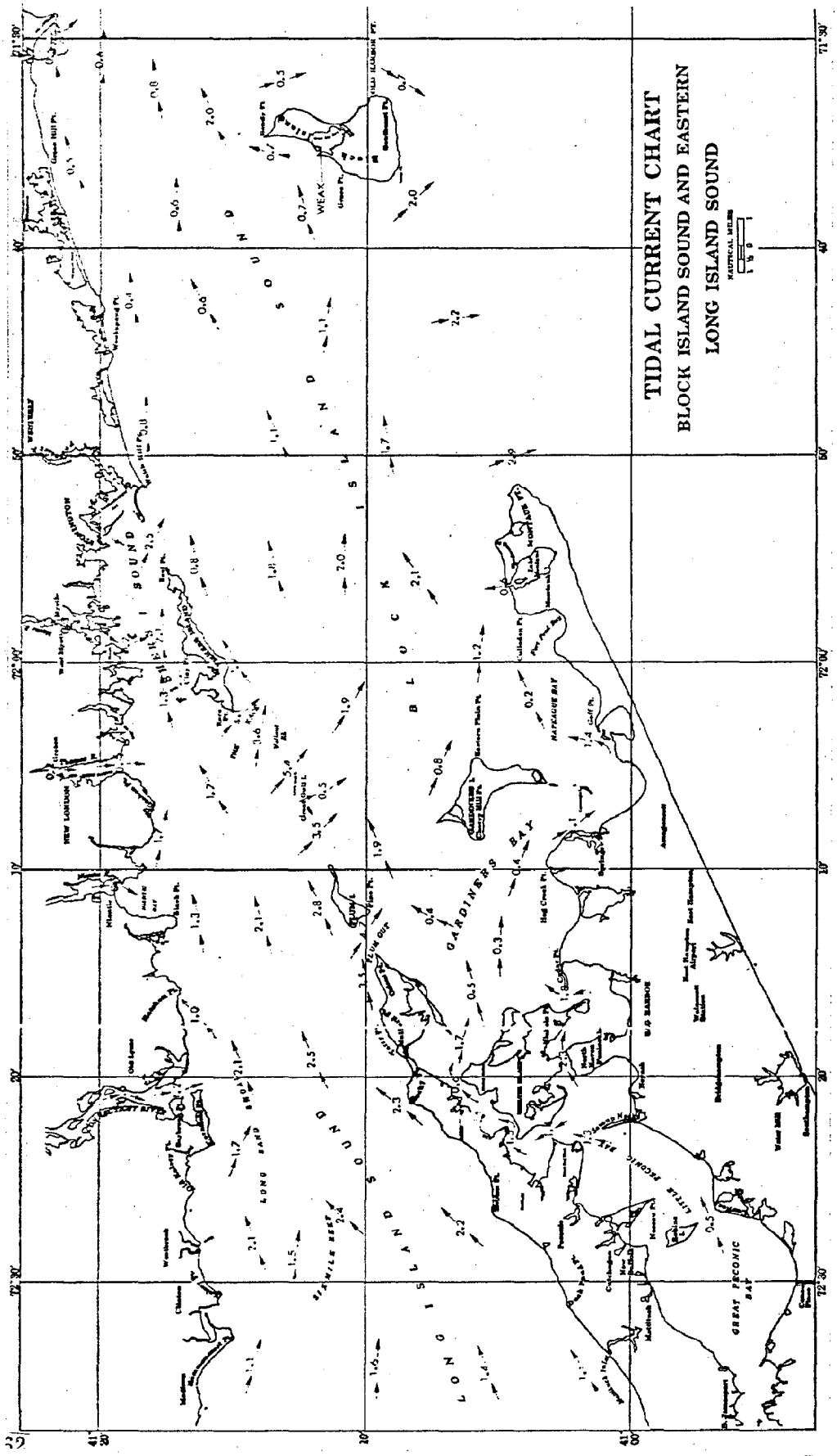
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

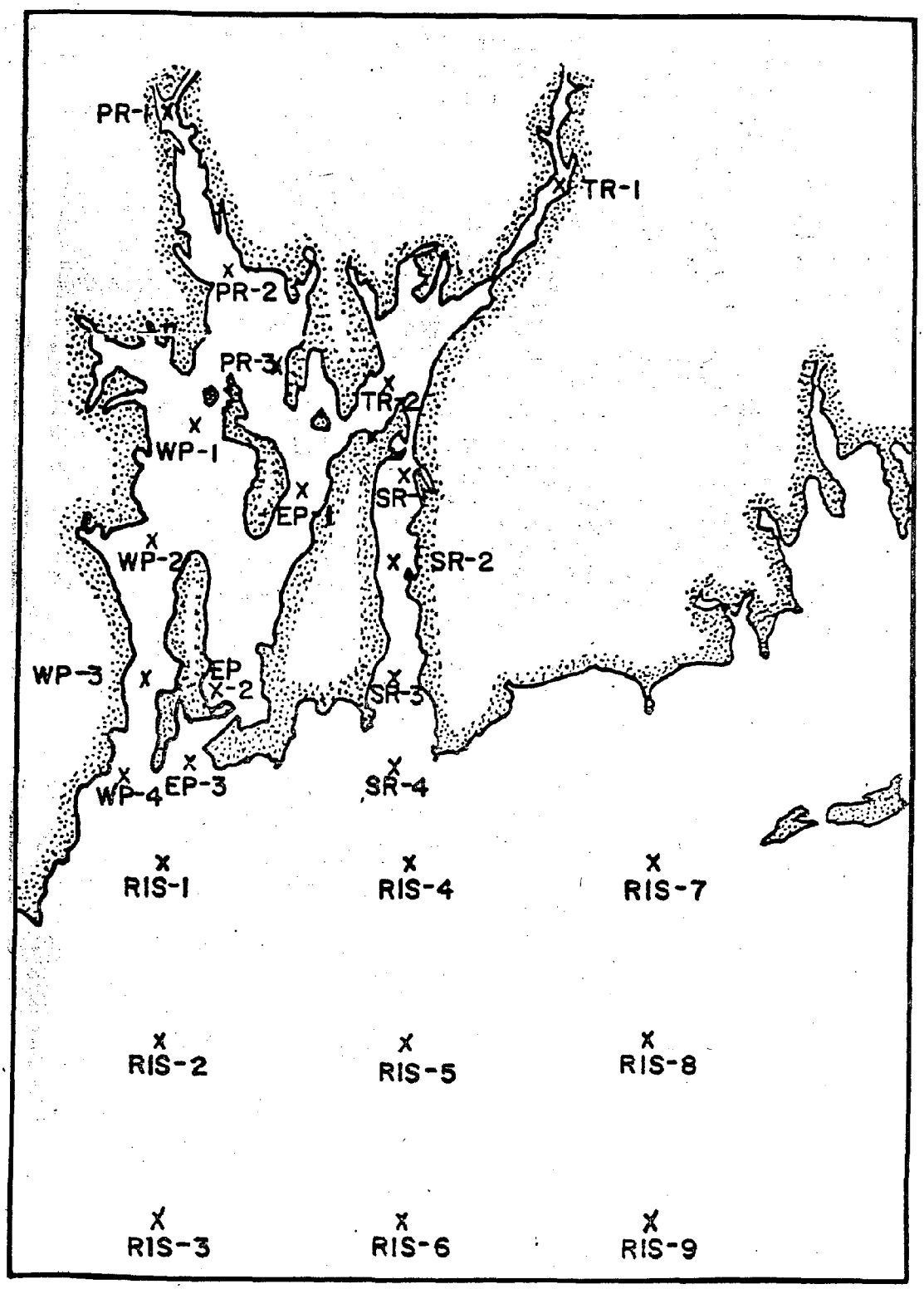
TRIGOM PARC	FIGURE 4-105	Highest Recorded Tide Levels (Bumpus et.al., 1973)



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

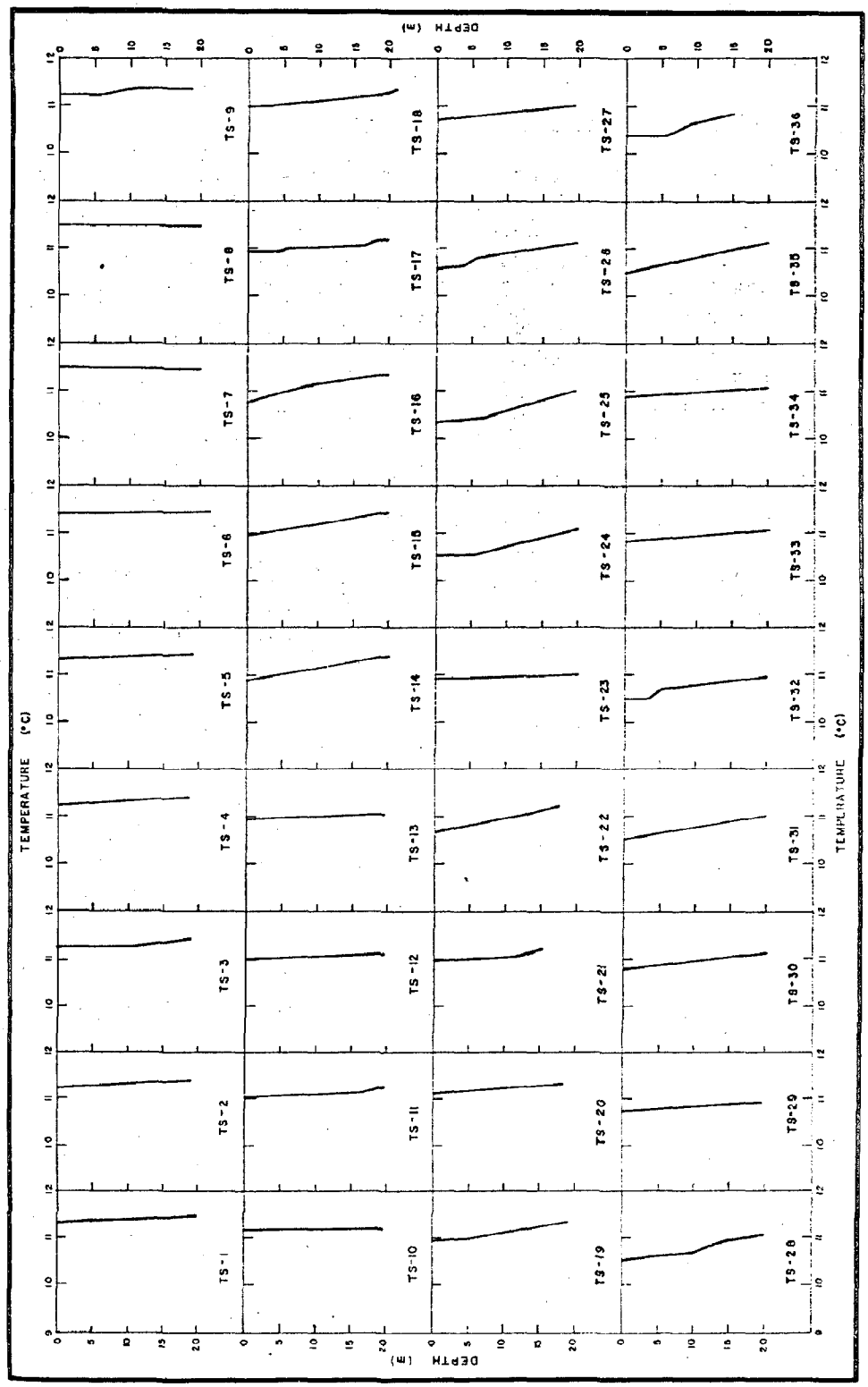
TRIGOM PARC	FIGURE 4-106	Surge Height (in feet) Above Predicted or Astronomical Tide in a Hurricane (Bumpus et al. 1973)


TIDAL CURRENT CHART
BLOCK ISLAND SOUND AND EASTERN
LONG ISLAND SOUND
NAUTICAL MILES
WEAK
BLOCK ISLAND SOUND
LONG ISLAND SOUND
GARDINERS BAY
GREAT PECONIC BAY
LONG SAND
NARRAGANSETT BAY
NEW LONDON
WEST HAVEN
MILFORD
BRIDGEPORT
NEW HAVEN
MATTITUCK
GREENPORT
SHELTER ISLAND
MONTAUK
BIG BARBER
Amagansett
East Hampton
Bridgehampton
Water Mill
Southampton
Sag Harbor
Hog Creek Pt.
Gardiners Pt.
Gardiners Bay
Plum Island
Orient Pt.
Gull Island
Fishers Island
Watch Hill
Block Island
Point Judith
Narragansett Bay
Newport
Sakonnet Pt.
Gay Head
Cuttyhunk
Nantucket Sound
Vineyard Sound
Martha's Vineyard
Nantucket Island
Cape Cod
Cape Cod Canal
Buzzards Bay
Vineyard Haven
Edgartown
Menemsha
Chatham
Monomoy Pt.
Nauset Inlet
Wellfleet
Provincetown
Cape Ann
Gloucester
Rockport
Ipswich
Plum Island
Newburyport
Salisbury
Merrimack R.
Portsmouth
Kittery
Isles of Shoals
Boston
Hull
Scituate
Plymouth
Duxbury
Marshfield
Scituate
Cohasset
Hingham
Weymouth
Quincy
Dorchester
Chelsea
Revere
Winthrop
Lynn
Marblehead
Salem
Beverly
Manchester



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

TRIGOM PARC	FIGURE 4-128	Station Points Sampled for Temperature, Salinity and Density by Morton, 1967 (Morton, 1967)

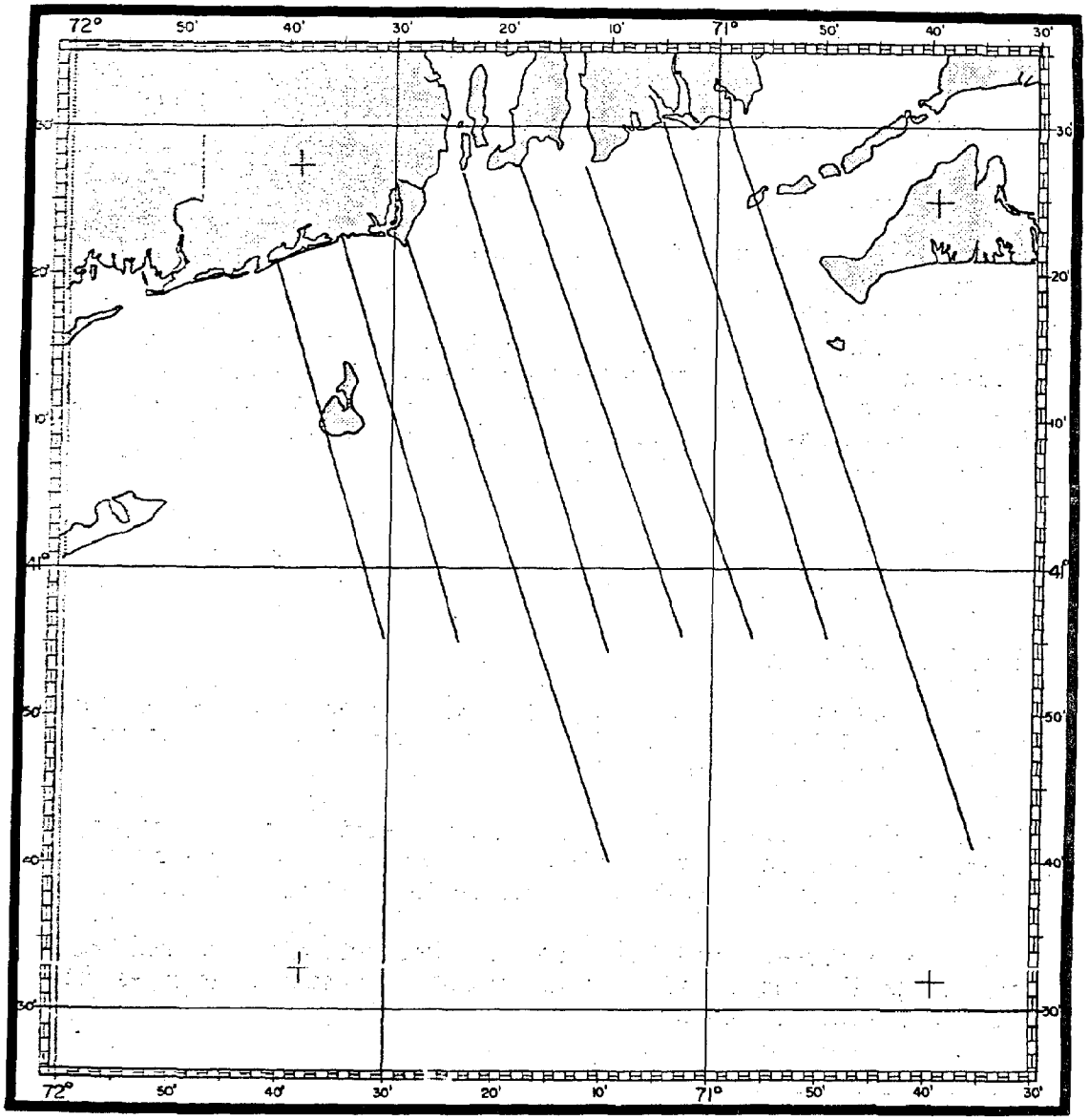


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

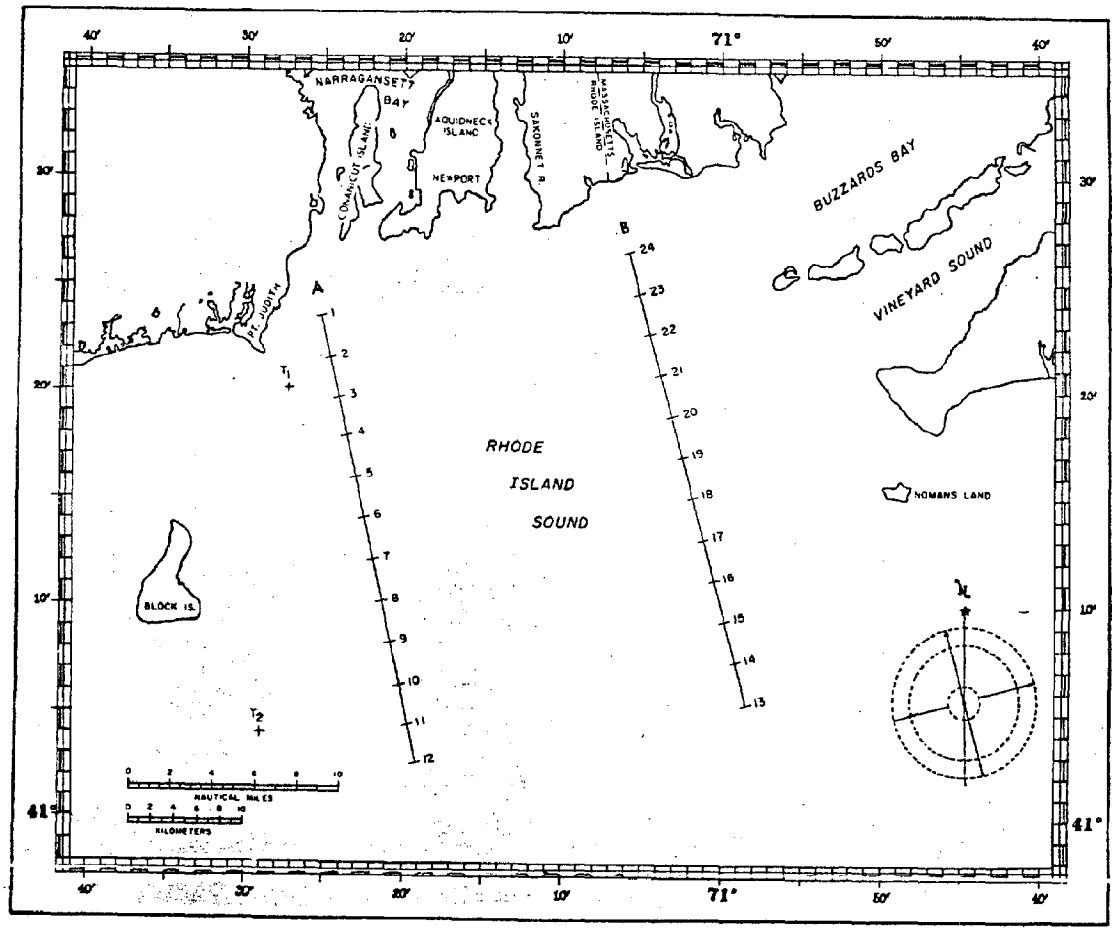
FIGURE 4-129

Hourly Thermal Structure Station EP-1.
0730 Nov. 1 to 1830 Nov. 2, 1965
(Morton, 1967)



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

TRIGOM PARC	FIGURE 4-130	Transects Used in Obtaining Temperature Profiles (Shonting et al., 1966)



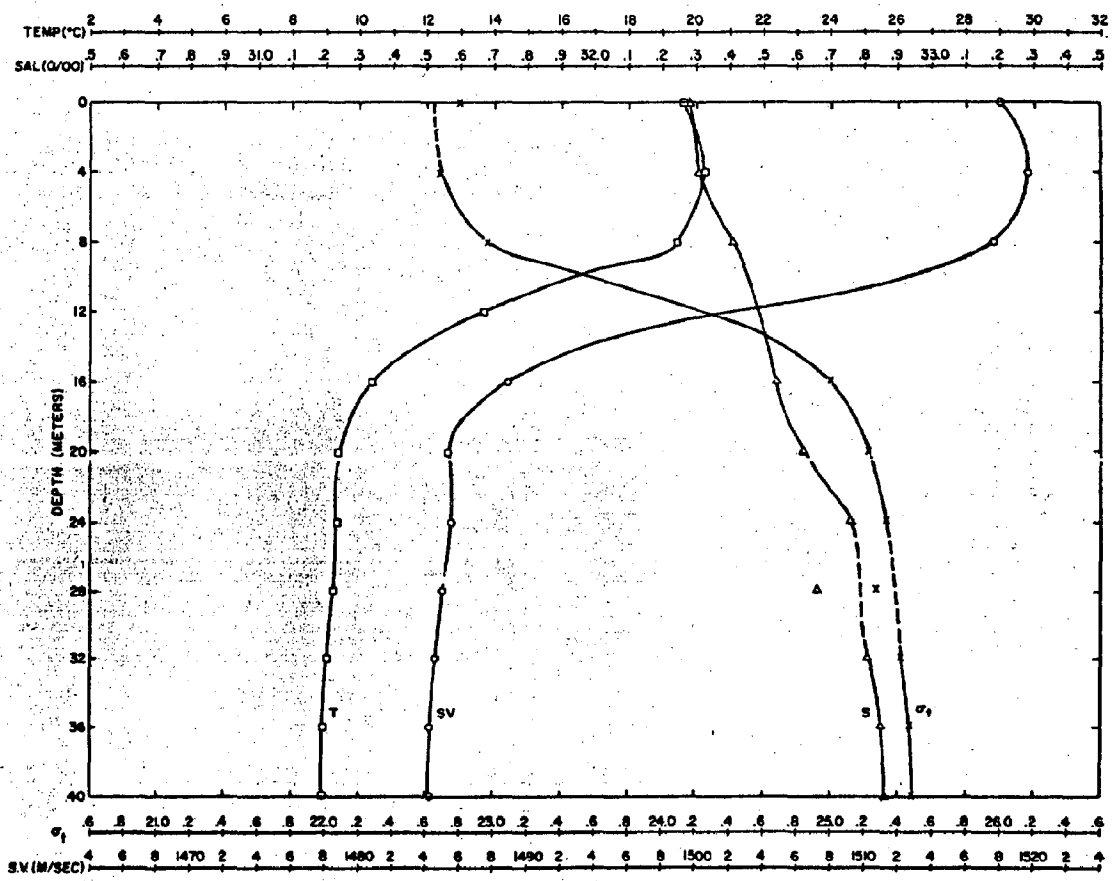
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-131	Hydrographic and Time Stations (Shonting et al., 1966)

SURFACE OBSERVATIONS									
CRUISE NO.	STATION	DATE				POSITION		SONIC DEPTH UNCORRECTED	MAX. SAMPLE DEPTH
		MO.	DAY	YEAR	HOUR	LATITUDE	LONGITUDE		
1	12	7	24	1963	2305				40

WIND		ANEMO. HGT.	AIR PRESS	AIR TEMPERATURE		HUMIDITY	WEATHER	CLOUD		SEA		SWELL		VIS.	WATER	
SPEED	DIR.			DRY	WET			TYPE	AMT.	DIR.	AMT.	DIR.	AMT.		COL.	TRANS.
5.2	22			19.96												

SUBSURFACE OBSERVATIONS						
SAMPLE DEPTH (M)	T°C	S °/oo	σ_t	V_f		
0.00	19.687	32.28	22.799	1518.09		
4.00	20.265	32.31	22.668	1519.78		
4.00	20.207	32.31	22.684	1519.62		
8.00	19.413	32.41	22.966	1517.60		
8.00	19.465	32.41	22.953	1517.74		
12.00	13.676					
16.00	10.365	32.54	25.000	1488.84		
20.00	9.345	32.62	25.230	1485.26		
24.00	9.336	32.76	25.339	1485.47		
28.00	9.221	32.66	25.274	1484.96		
32.00	9.037	32.81	25.423	1484.53		
36.00	8.907	32.85	25.473	1484.16		
40.00	8.897	32.86	25.483	1484.21		



NUOS SWEP CRUISE 1A STATION 12 DATE: 24 JULY 1963

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

TRIGOM PARC

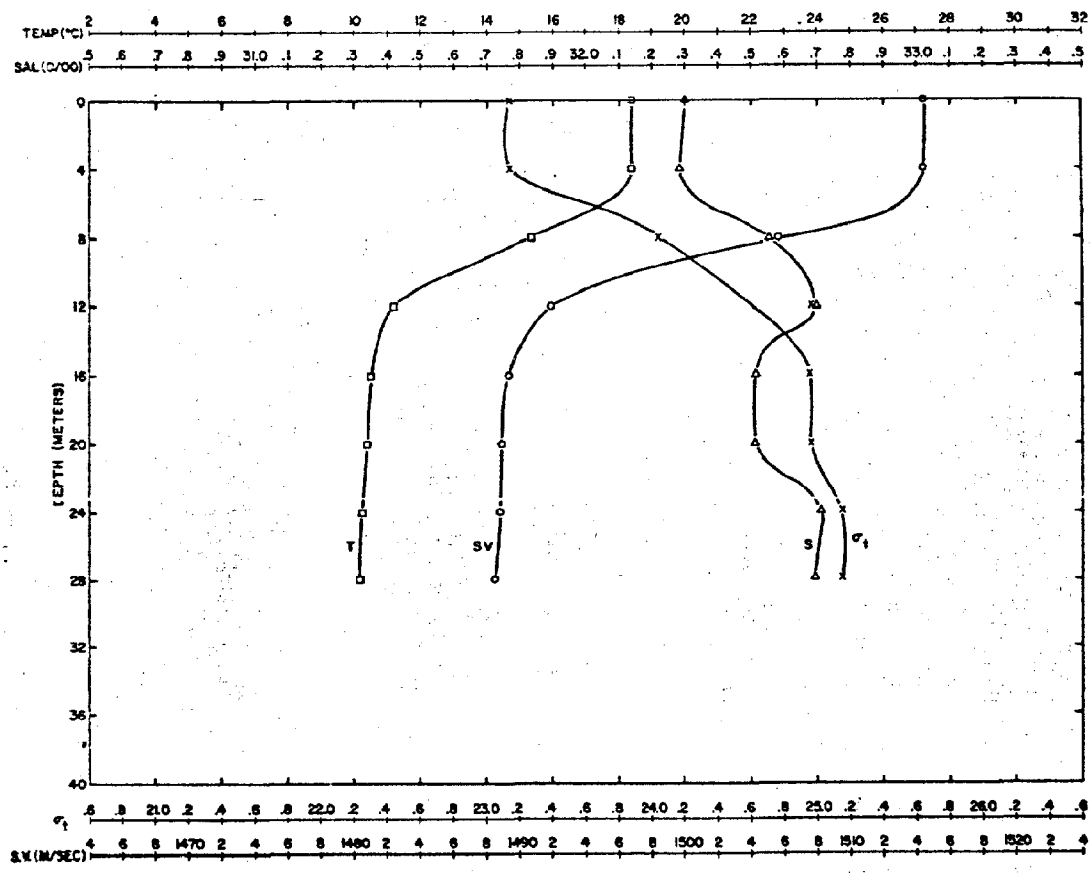
FIGURE 4-132

Monthly Data Sample - Station 12 - July 24, 1963 (Shonting et al., 1966)

SURFACE OBSERVATIONS									
CRUISE NO.	STATION	DATE				POSITION		SONIC DEPTH UNCORRECTED	MAX. SAMPLE DEPTH
		MO.	DAY	YEAR	HOUR	LATITUDE	LONGITUDE		
1	13	7	24	1963	0150				28

WIND		ANEMO. HGT.	AIR PRESS	AIR TEMPERATURE		HUMIDITY	WEATHER	CLOUD		SEA		SWELL		VIS.	WATER	
SPEED	DIR.			DRY	WET			TYPE	AMT.	DIR.	AMT.	DIR.	AMT.		COL.	TRANS.
				19.95												

SUBSURFACE OBSERVATIONS						
SAMPLE DEPTH (M)	T°C	S °/oo	σt	V_f		
0.00	18.385	32.30	23.136	1514.40		
4.00	18.361	32.28	23.132	1514.38		
8.00	15.334	32.55	24.038	1505.59		
12.00	11.173	32.69	24.972	1491.86		
16.00	10.499	32.51	24.953	1489.28		
20.00	10.379	32.51	24.967	1488.91		
24.00	10.256	32.71	25.151	1488.79		
28.00	10.165	32.69	25.151	1488.50		



NUOS SWEP CRUISE 1B STATION 13 DATE: 24 JULY 1963

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

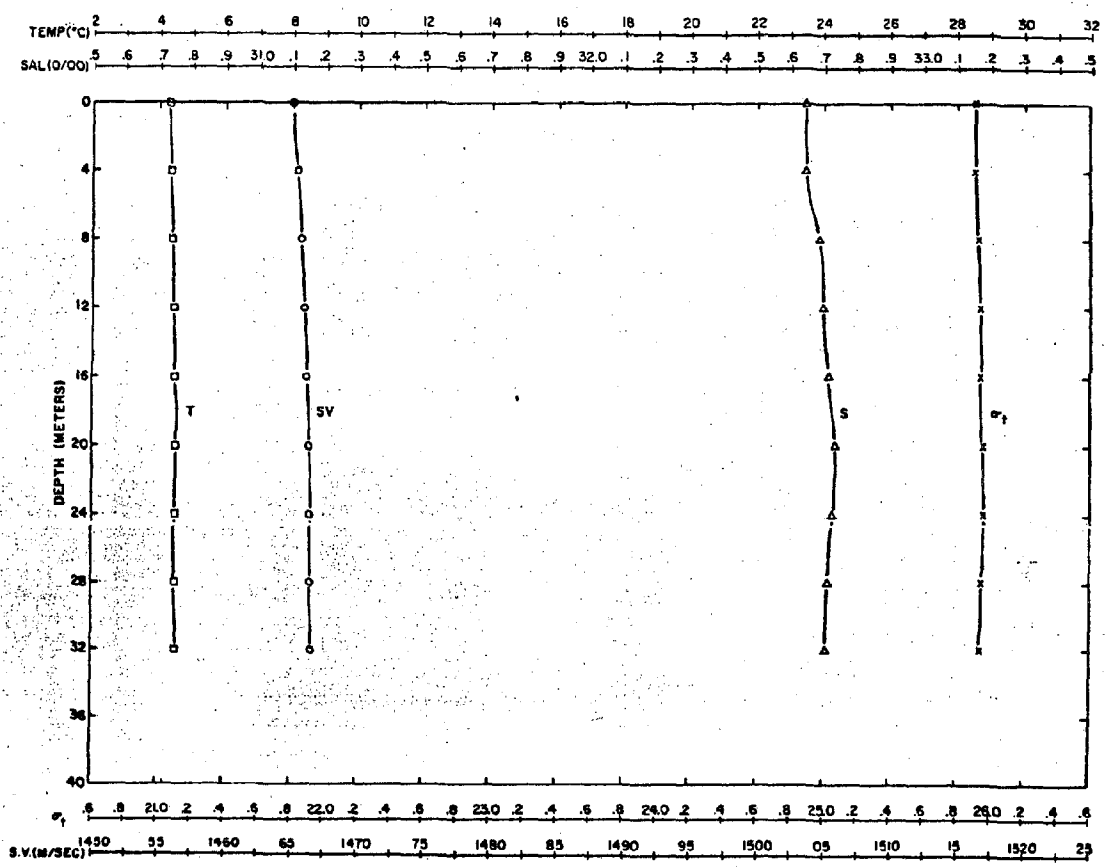
TRIGOM PARC

FIGURE 4-133 Monthly Data Sample - Station 13 - July 24, 1963 (Shonting et al., 1966)

SURFACE OBSERVATIONS									
CRUISE NO.	STATION	DATE				POSITION		SONIC DEPTH UNCORRECTED	MAX. SAMPLE DEPTH
		NO.	DAY	YEAR	HOUR	LATITUDE	LONGITUDE		
4A	11	1	22	1964	1450				32

WIND		ANEMO. HGT.	AIR PRESS	AIR TEMPERATURE		HUMIDITY	WEATHER	CLOUD		SEA		SWELL		VIS.	WATER	
SPEED	DIR.			DRY	WET			TYPE	AMT.	DIR.	AMT.	DIR.	AMT.		COL.	TRANS.
2.1	29			9.00												

SUBSURFACE OBSERVATIONS						
SAMPLE DEPTH (M)	T°C	S ‰	σ_t	V_f		
0.00	4.343	32.64	25.900	1465.13		
4.00	4.396	32.64	25.897	1465.42		
8.00	4.436	32.68	25.922	1465.70		
12.00	4.474	32.69	25.928	1465.94		
16.00	4.502	32.71	25.938	1466.15		
20.00	4.525	32.73	25.954	1466.34		
24.00	4.518	32.72	25.944	1466.36		
28.00	4.530	32.71	25.942	1466.47		
32.00	4.541	32.70	25.929	1466.57		



NUOS SWEP CRUISE 4A STATION 11 DATE: 22 JANUARY 1964

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

TRIGOM PARC

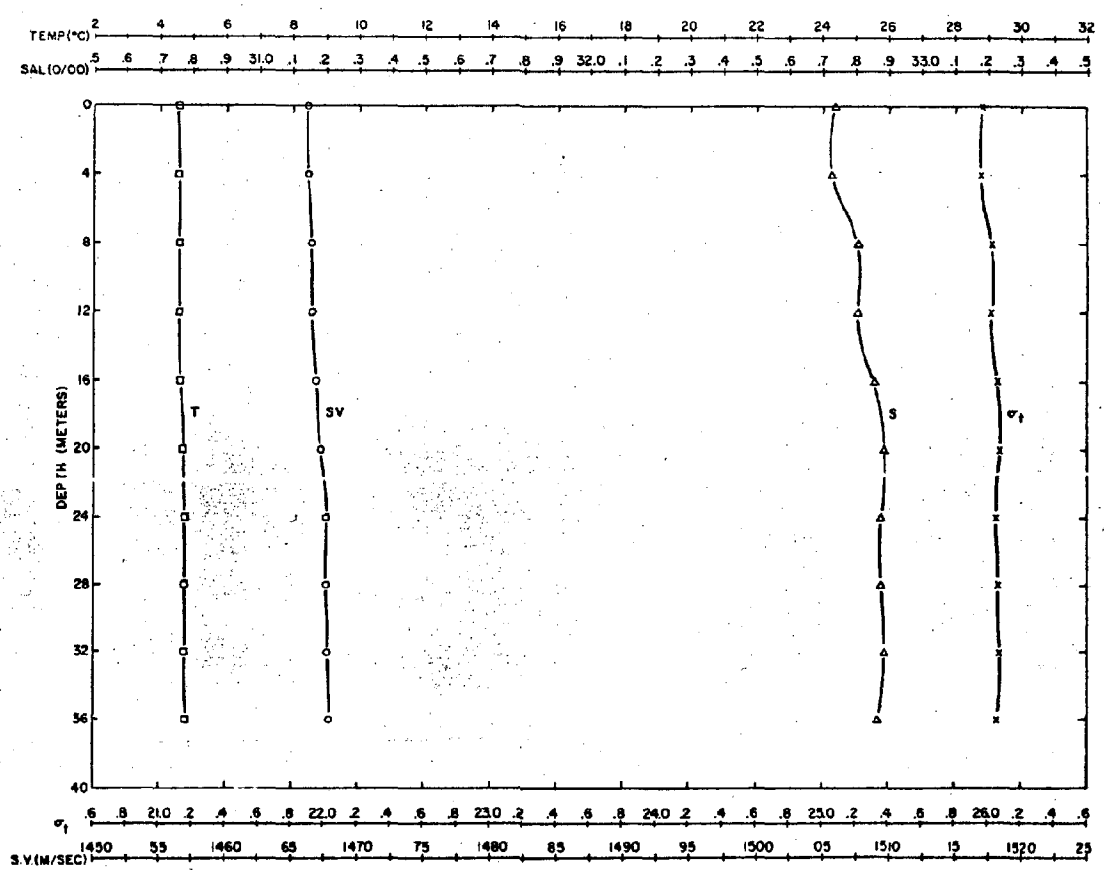
FIGURE 4-134

Monthly Data Sample - Station 11 - January 22, 1964 (Shonting et al., 1966)

SURFACE OBSERVATIONS									
CRUISE NO.	STATION	DATE				POSITION		SONIC DEPTH UNCORRECTED	MAX. SAMPLE DEPTH
		MO.	DAY	YEAR	HOUR	LATITUDE	LONGITUDE		
4A	12	1	22	1964	1525			44	36

WIND		ANEMO. HGT.	AIR PRESS	AIR TEMPERATURE		HUMIDITY	WEATHER	CLOUD		SEA		SWELL		VIS.	WATER	
SPEED	DIR.			DRY	WET			TYPE	AMT.	DIR.	AMT.	DIR.	AMT.		COL.	TRANS.
3.6	29			6.90												

SUBSURFACE OBSERVATIONS						
SAMPLE DEPTH (M)	T°C	S °/oo	σ_t	V_f		
0.00	4.542	32.73	25.951	1466.08		
4.00	4.544	32.72	25.945	1466.15		
8.00	4.561	32.80	26.009	1466.39		
12.00	4.564	32.80	26.006	1466.47		
16.00	4.603	32.85	26.044	1466.77		
20.00	4.665	32.88	26.056	1467.12		
24.00	4.746	32.87	26.039	1467.51		
28.00	4.730	32.87	26.045	1467.52		
32.00	4.724	32.88	26.053	1467.57		
36.00	4.748	32.86	26.038	1467.71		

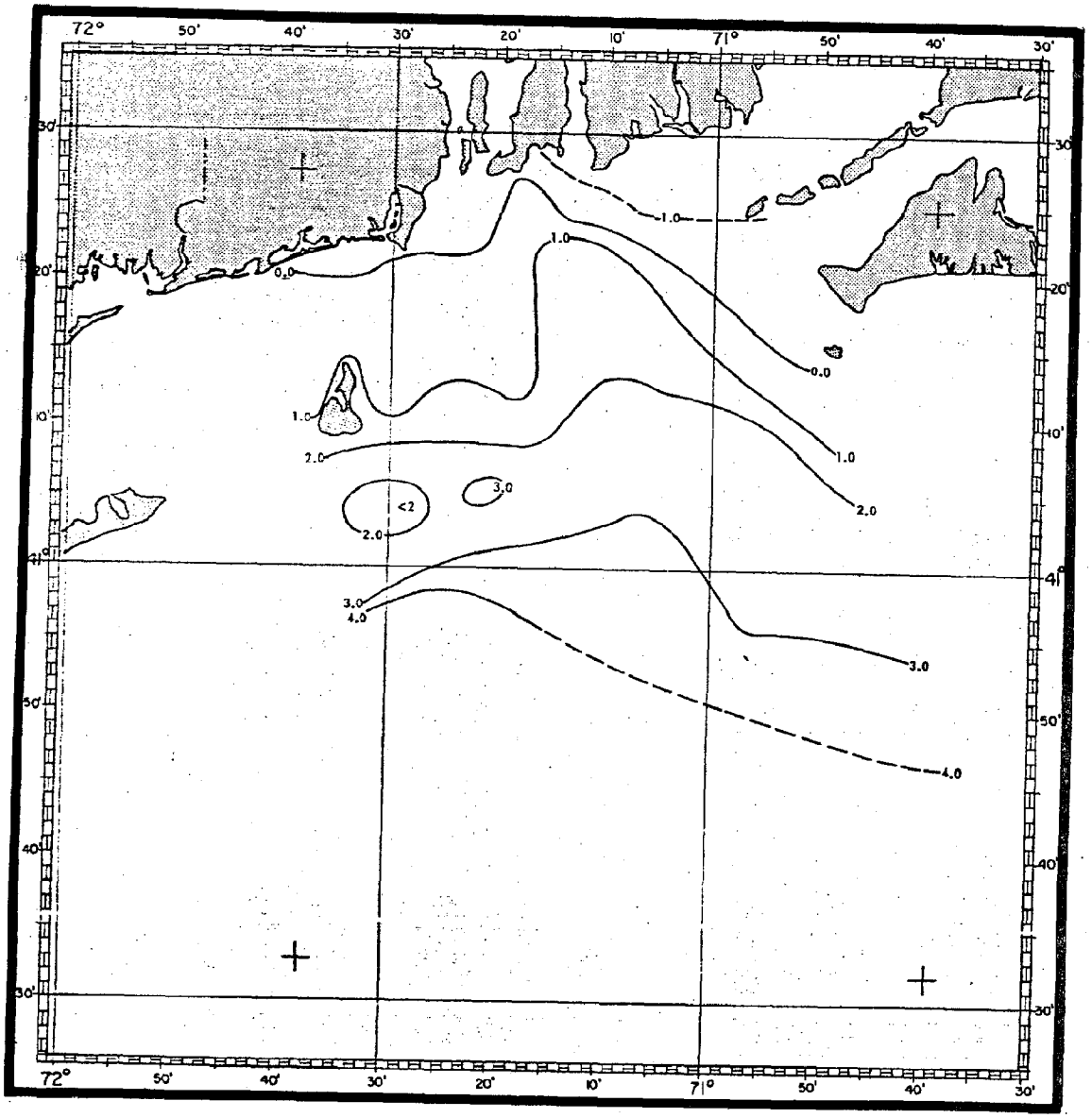


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

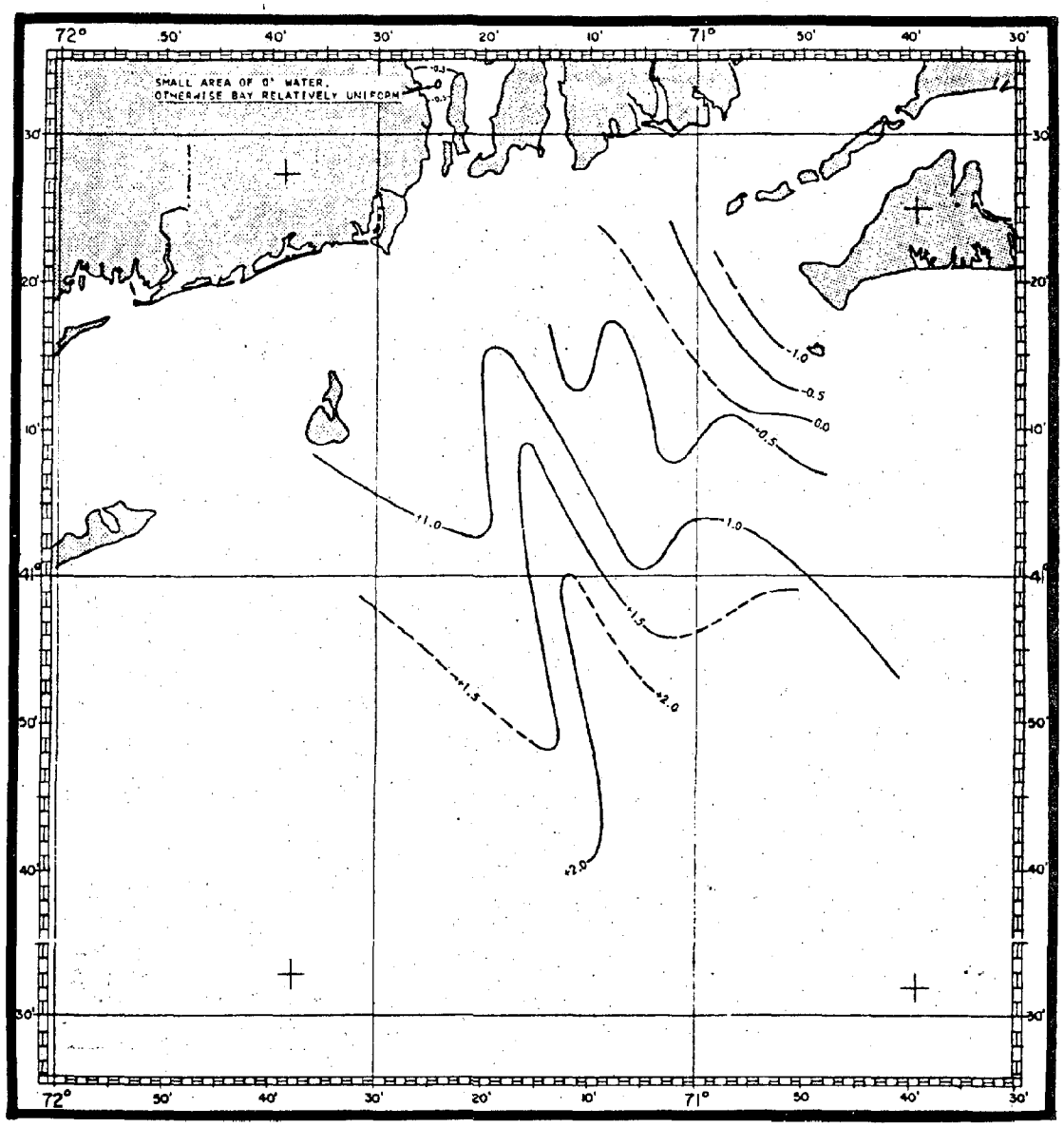
FIGURE 4-135

Monthly Data Sample - Station 12 - January 22, 1964 (Shonting et al., 1966)



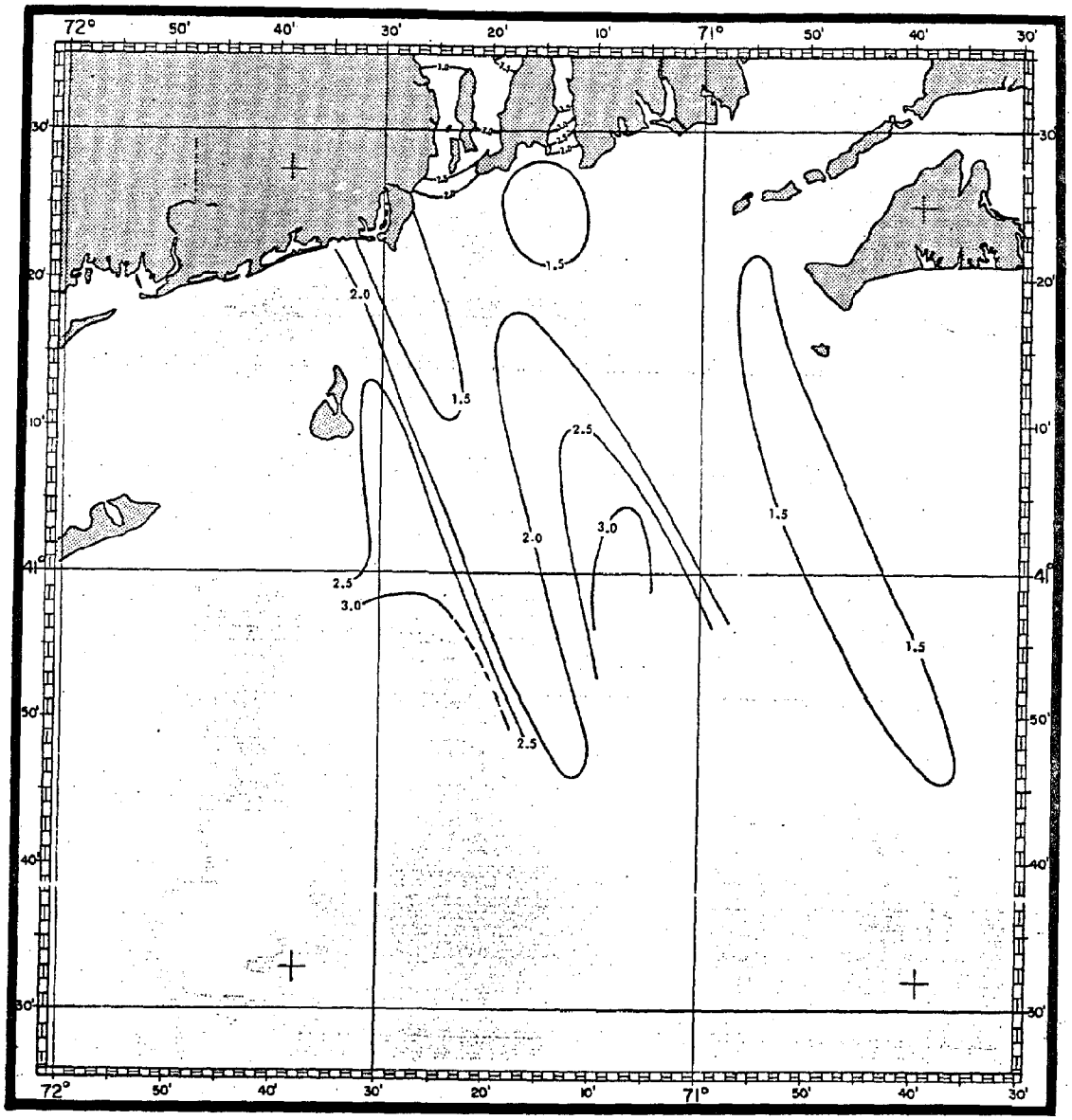
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-136	Surface Isotherms in Rhode Island Sound February 4, 1964 (Shonting et al., 1964)



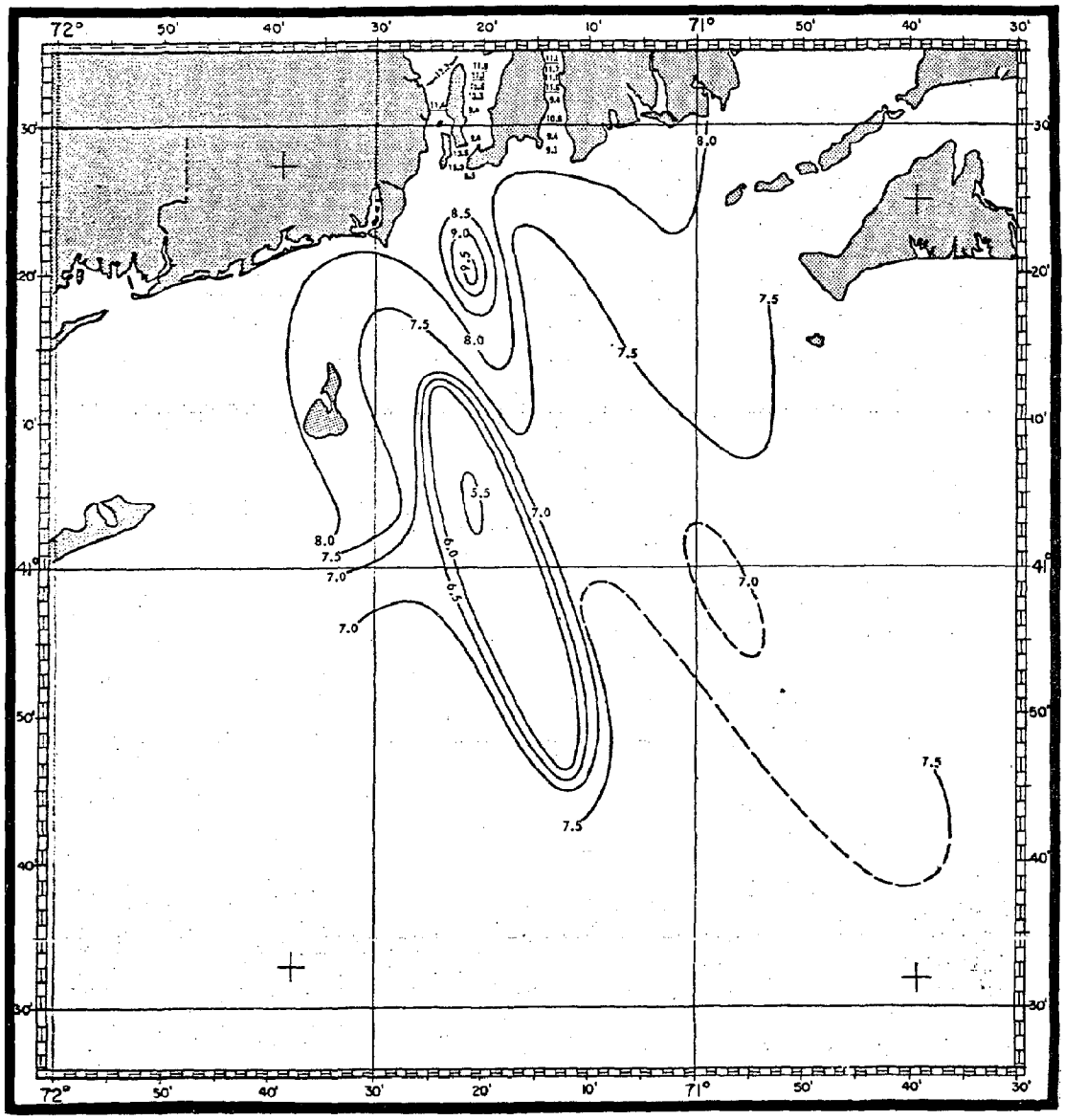
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-137	Surface Isotherms in Rhode Island Sound February 28, 1964 (Shonting et al., 1964)



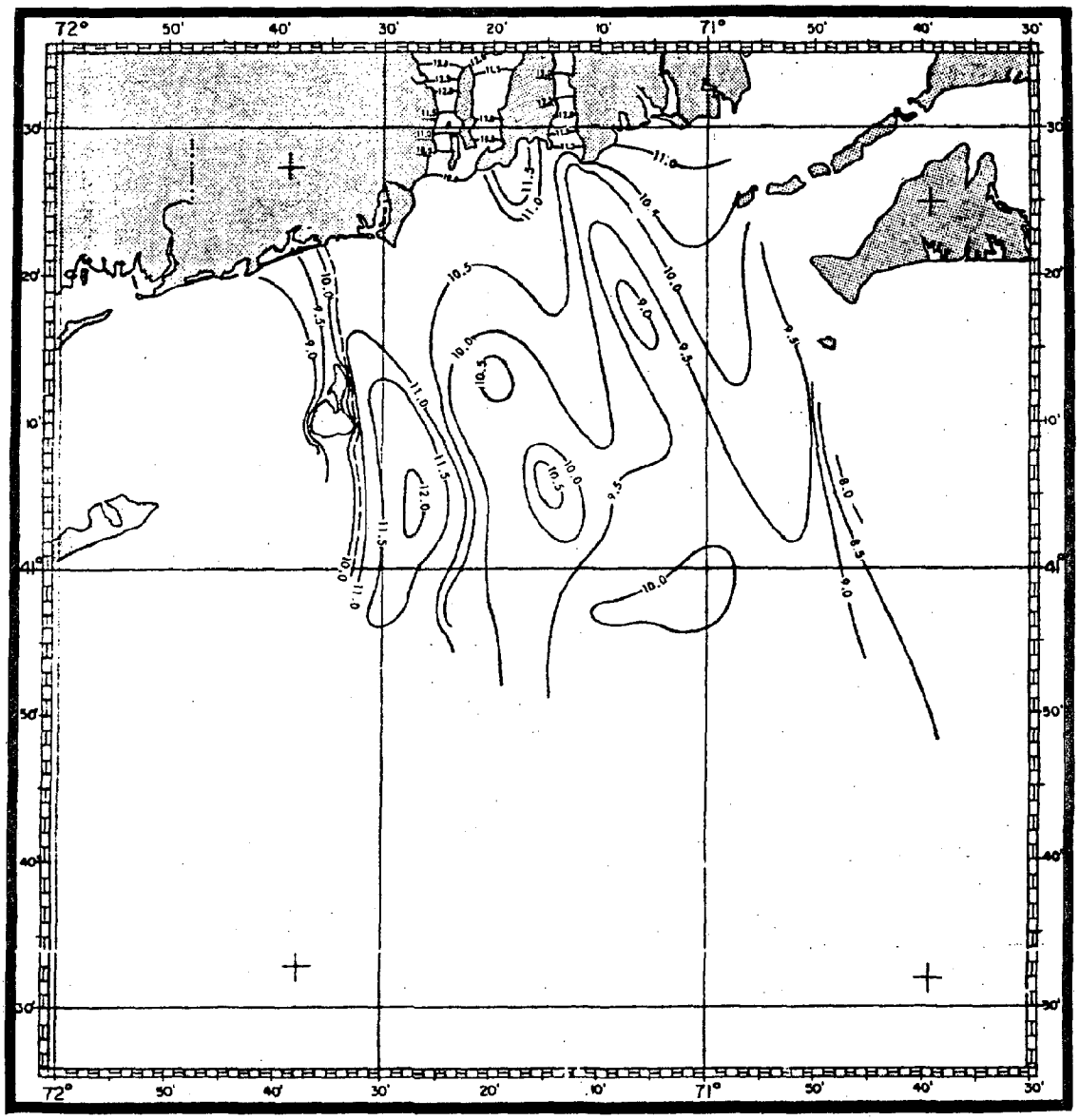
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-138	Surface Isotherms in Rhode Island Sound April 2, 1964 (Shonting et al., 1964)



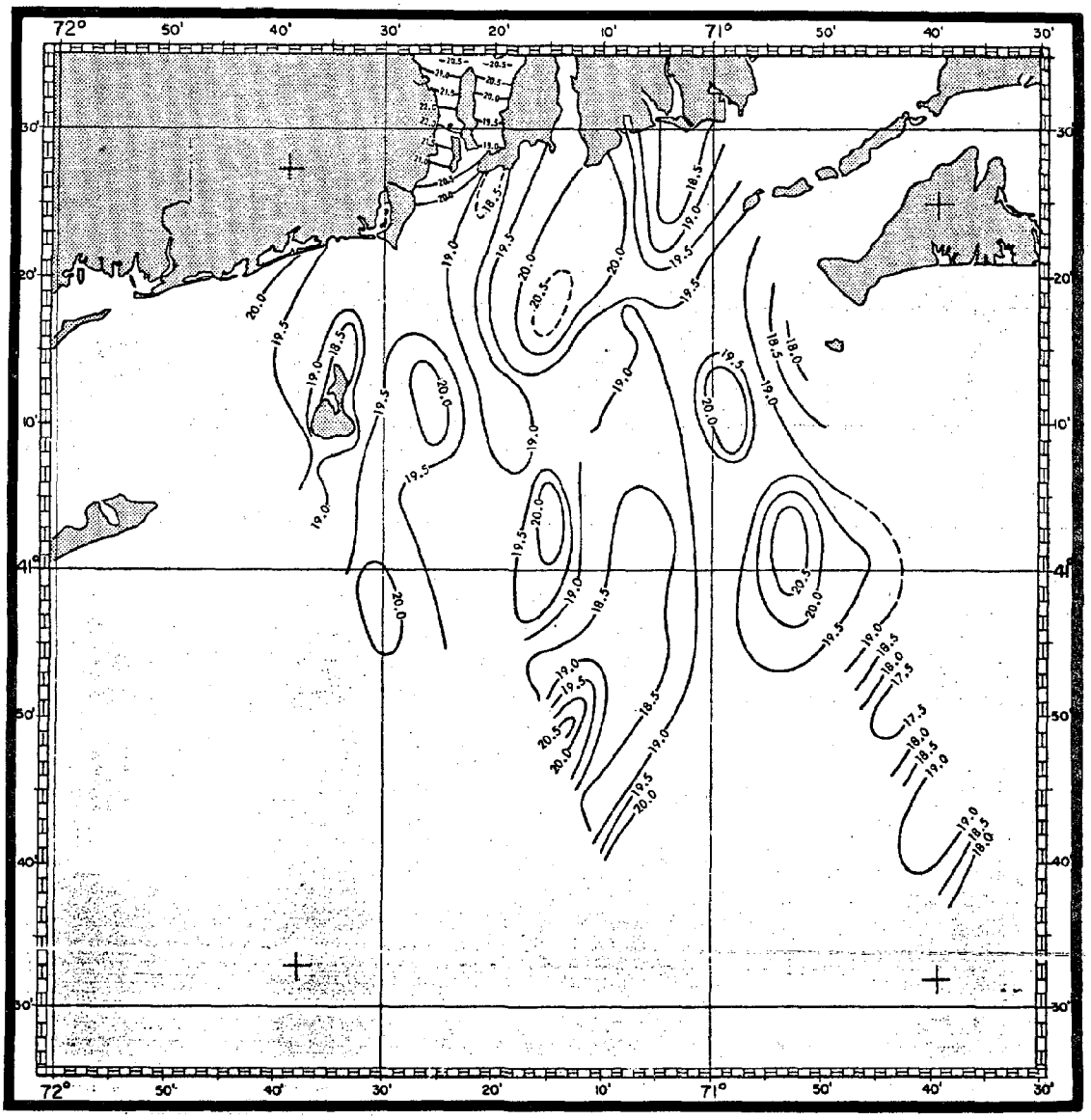
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-139	Surface Isotherms in Rhode Island Sound May 7, 1964 (Shonting et al., 1964)



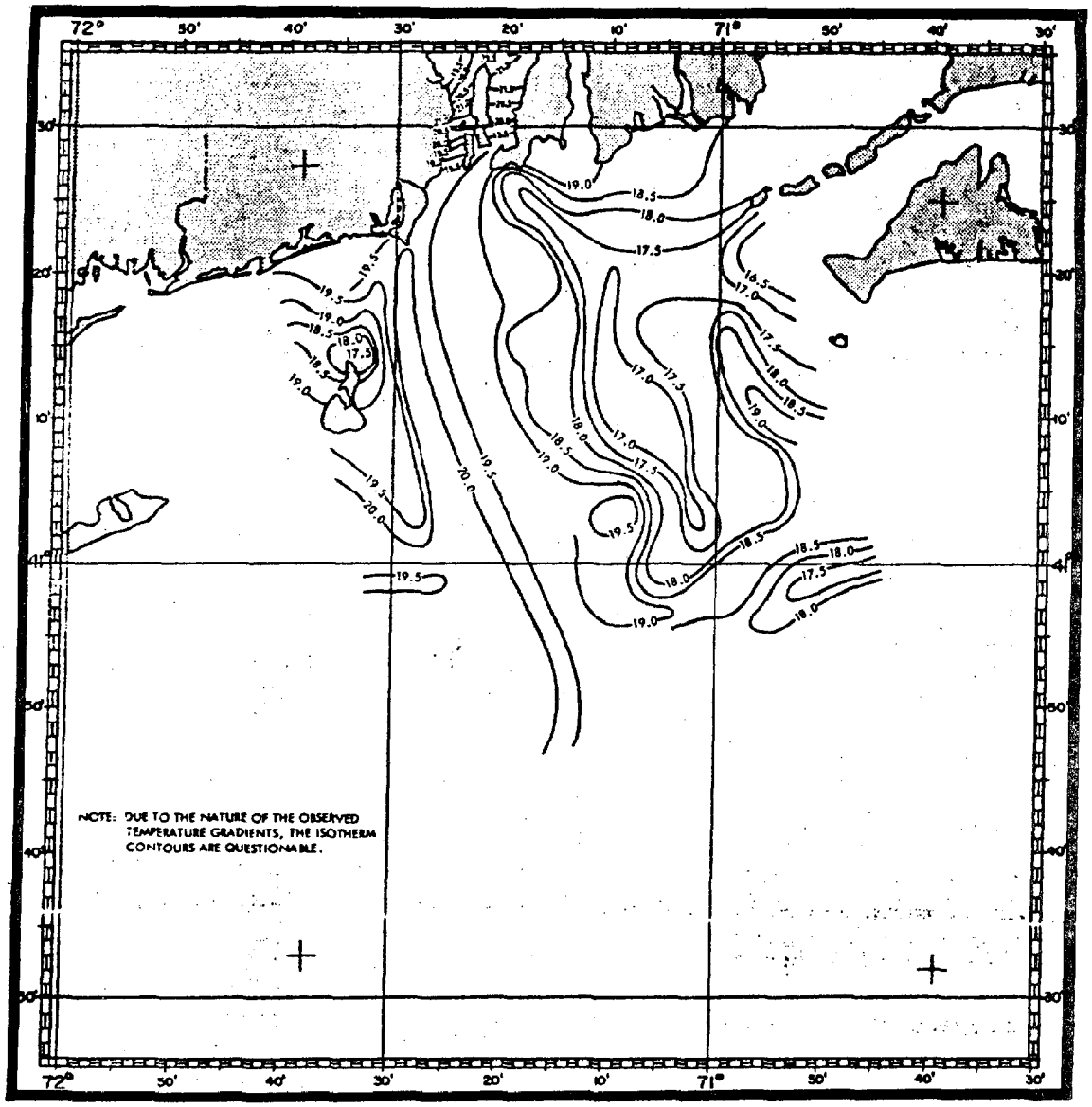
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-140	Surface Isotherms in Rhode Island Sound May 21, 1964 (Shonting et al., 1964)



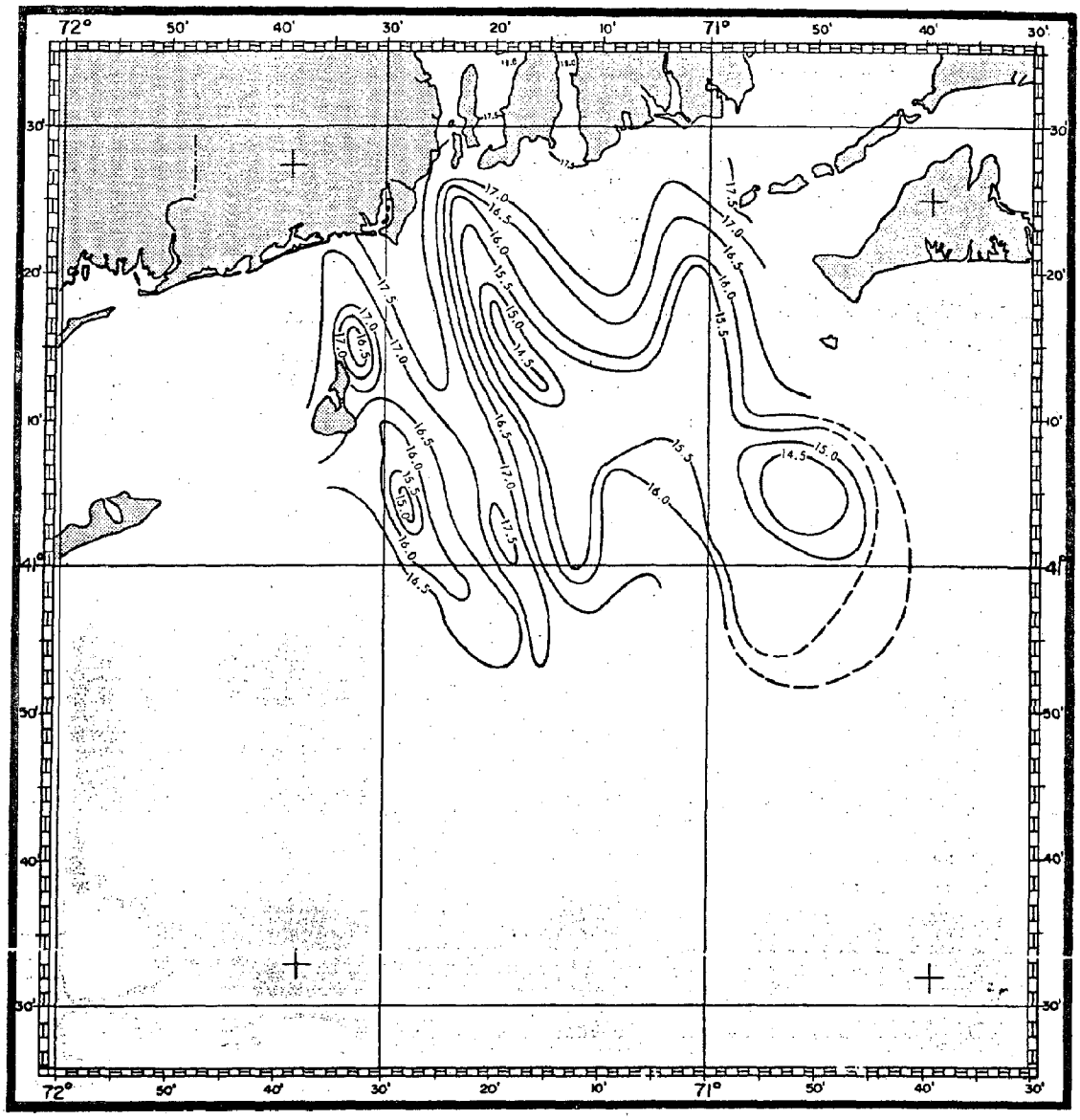
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-141	Surface Isotherms in Rhode Island Sound July 2, 1964 (Shonting et al., 1964)



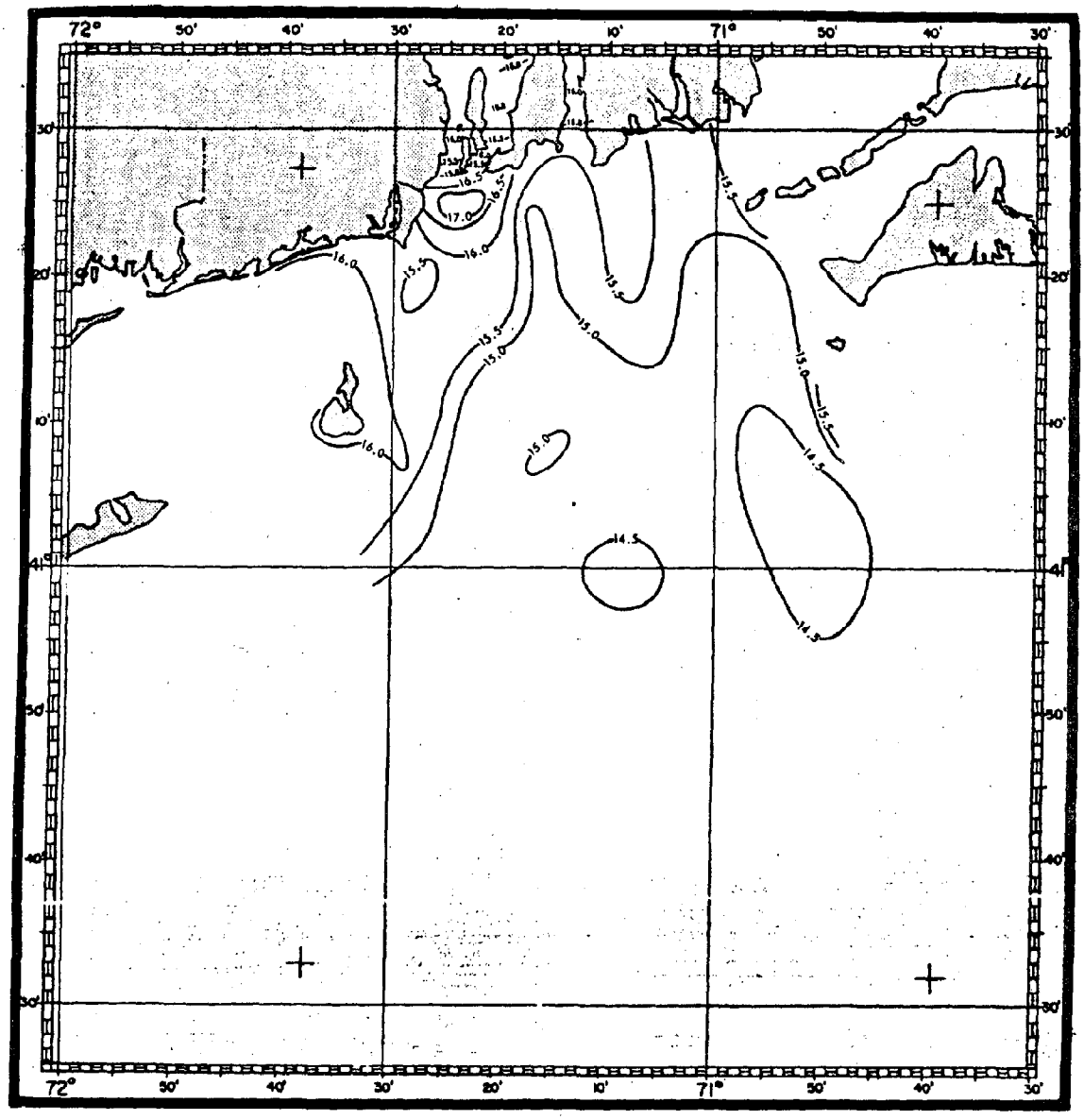
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-142	Surface Isotherms in Rhode Island Sound August 20, 1964 (Shonting et al., 1964)



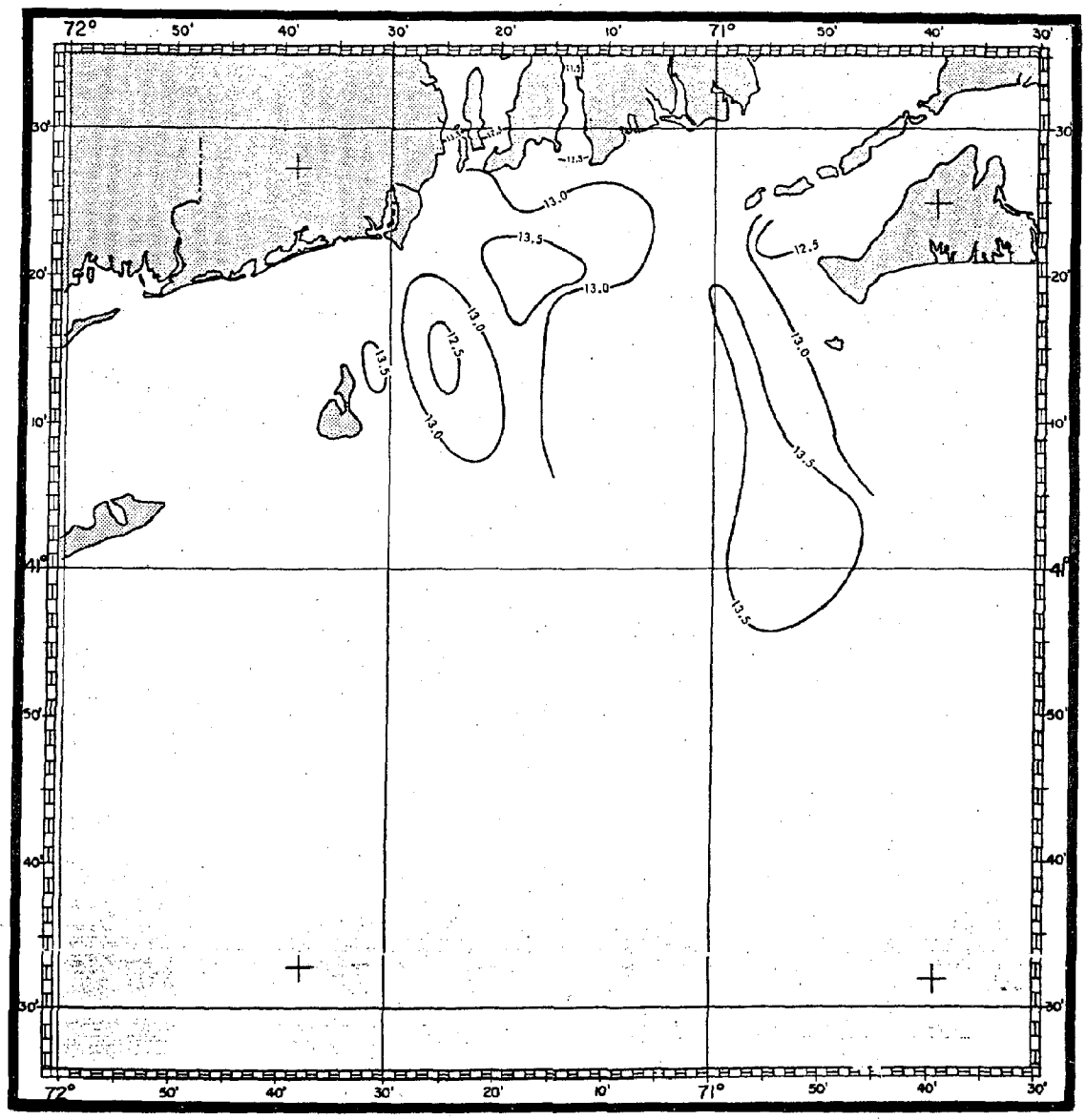
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-143	Surface Isotherms in Rhode Island Sound September 17, 1964 (Shonting et al., 1964)



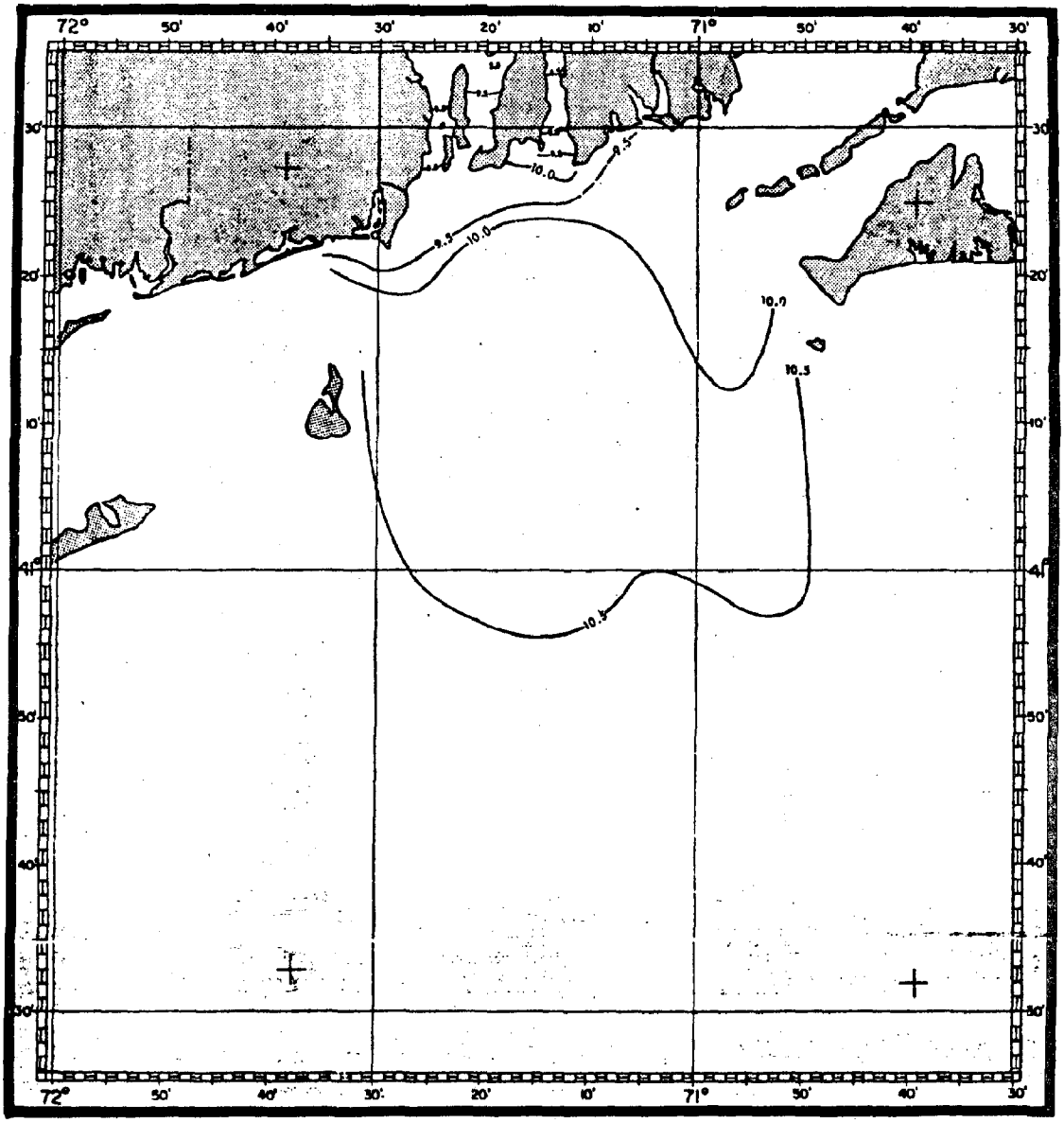
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-144	Surface Isotherms in Rhode Island Sound October 1, 1964 (Shonting et al., 1964)

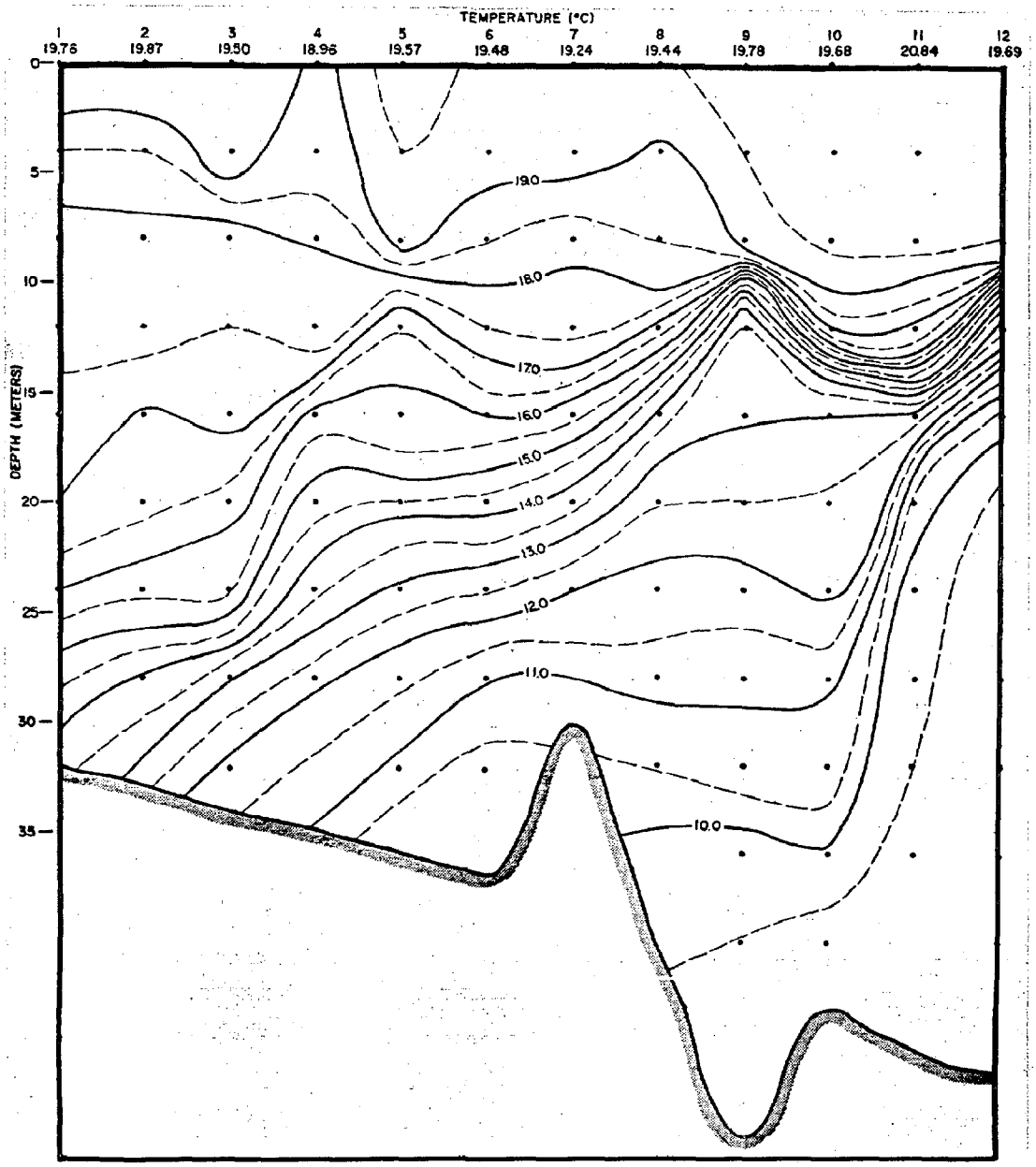


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-145	Surface Isotherms in Rhode Island Sound October 23, 1964 (Shonting et al., 1964)

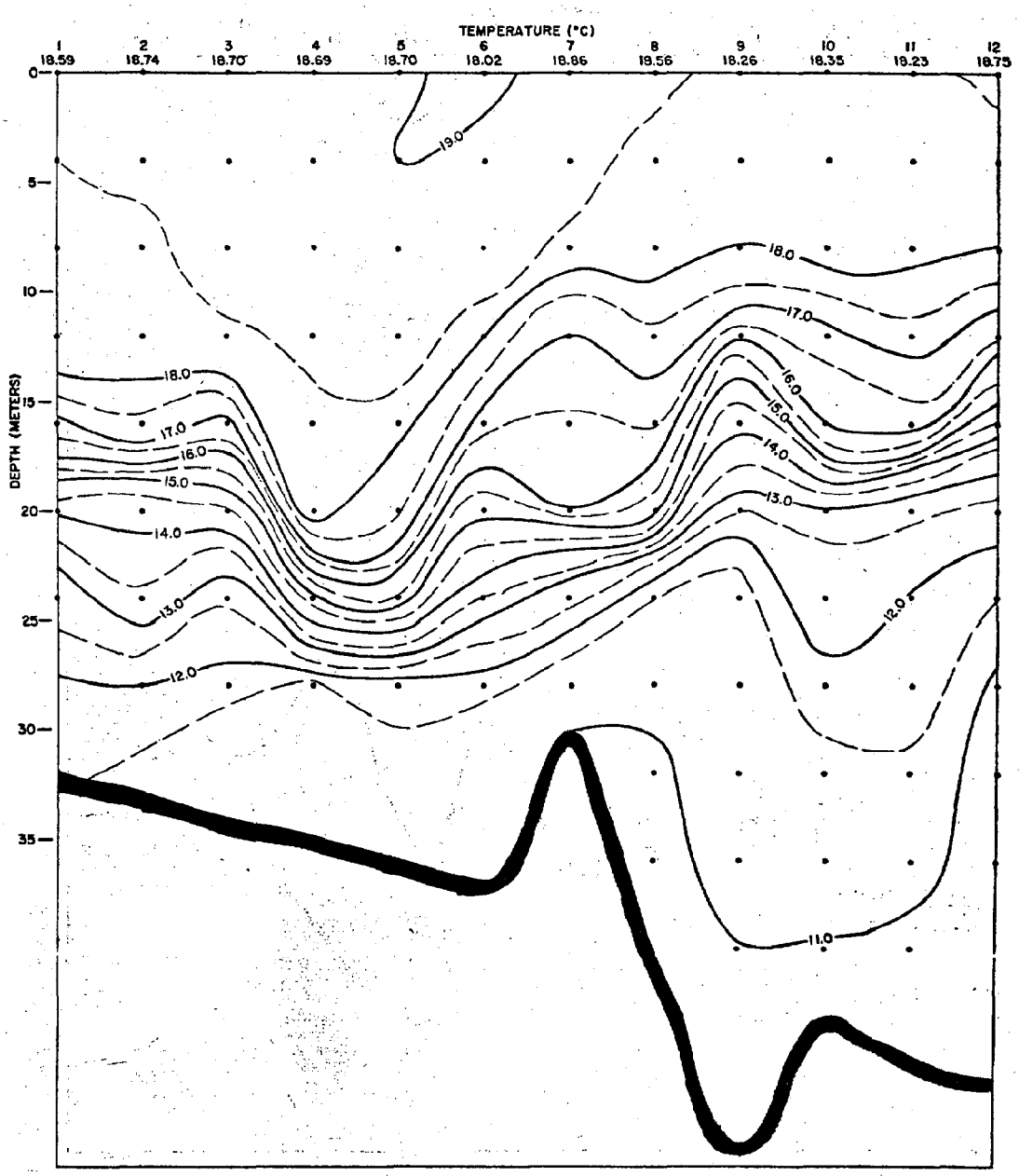


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-146	Surface Isotherms in Rhode Island Sound November 19, 1964 (Shonting et al., 1964)



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

TRIGOM PARC	FIGURE 4-147	Vertical Temperature Profiles in Rhode Island Sound July 1963 (Shonting et al., 1964)

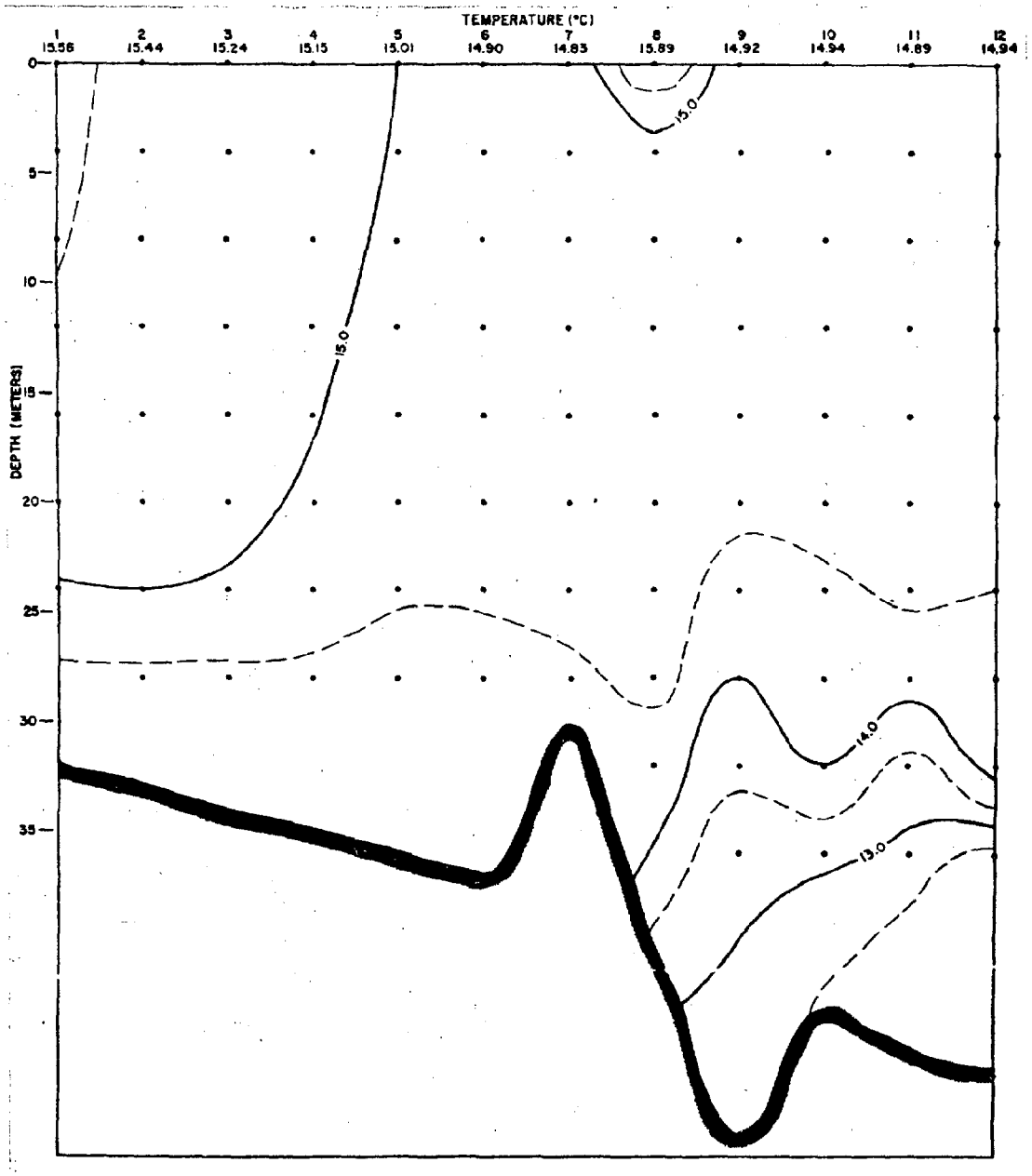


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

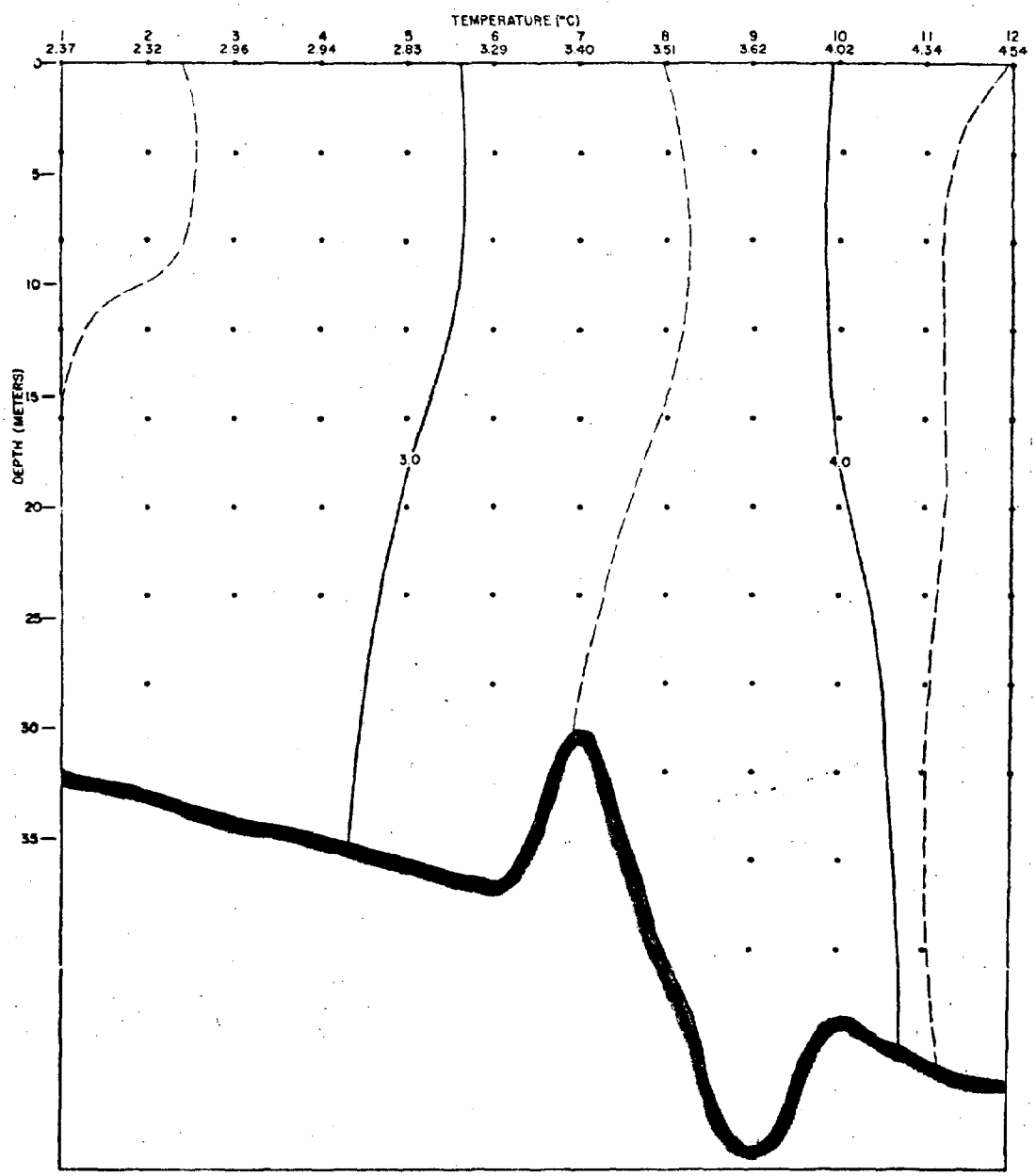
FIGURE 4-148

Vertical Temperature Profiles in Rhode Island Sound August 1963 (Shonting et al., 1964)



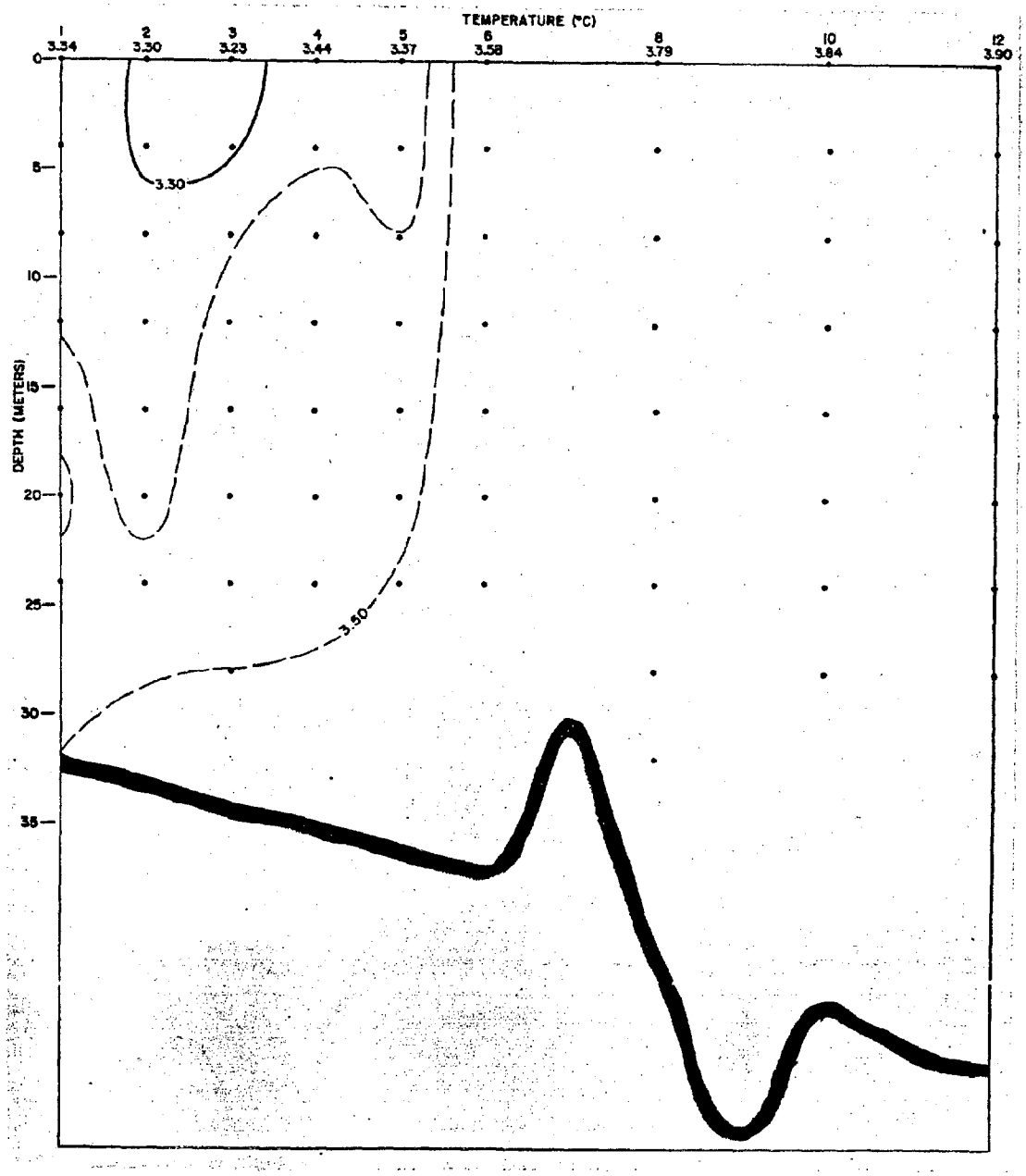
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-149	Vertical Temperature Profiles in Rhode Island Sound October 1963 (Shonting et al., 1964)



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

TRIGOM PARC	FIGURE 4-150	Vertical Temperature Profiles in Rhode Island Sound January 1964 (Shonting et al., 1964)

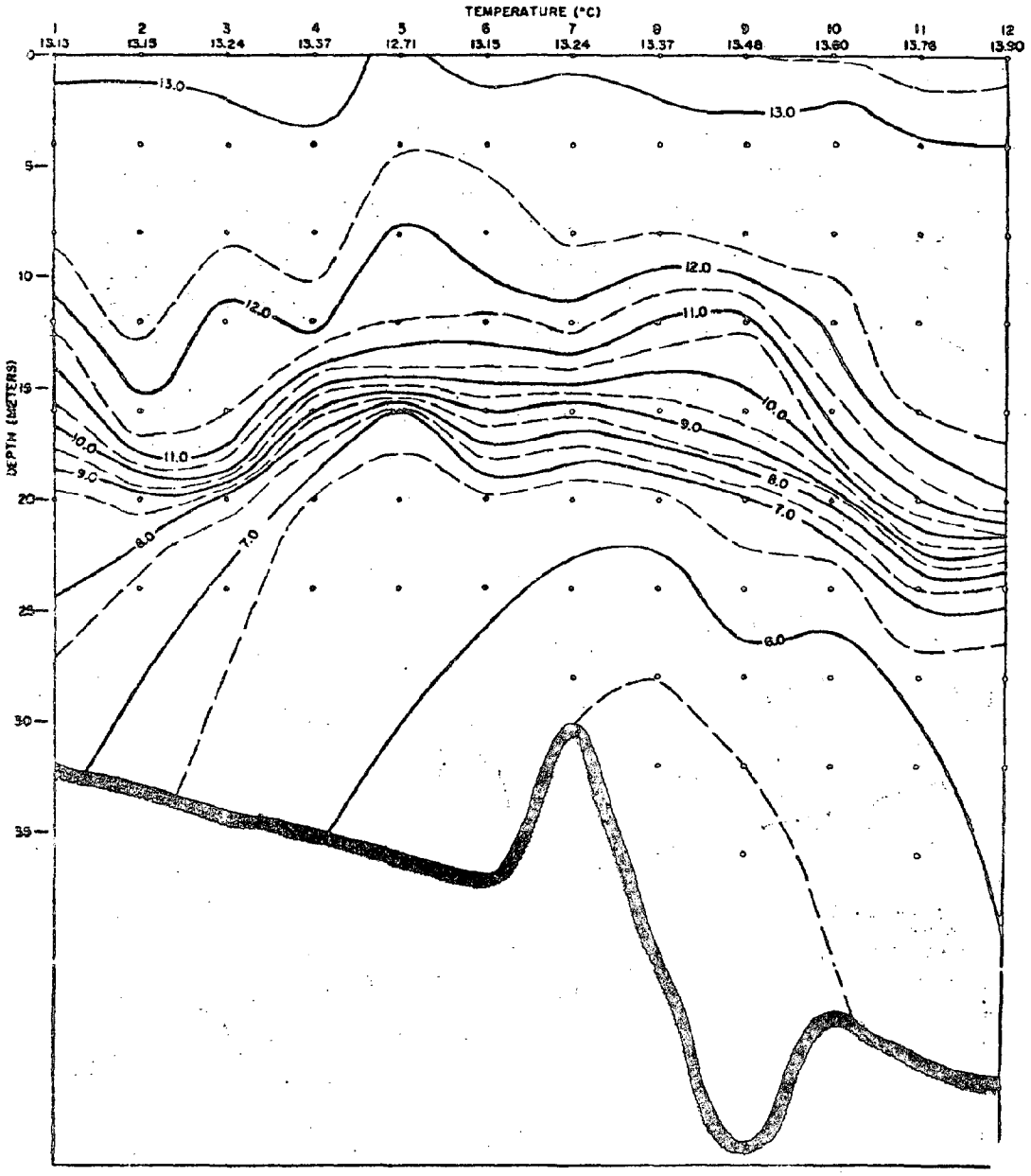


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

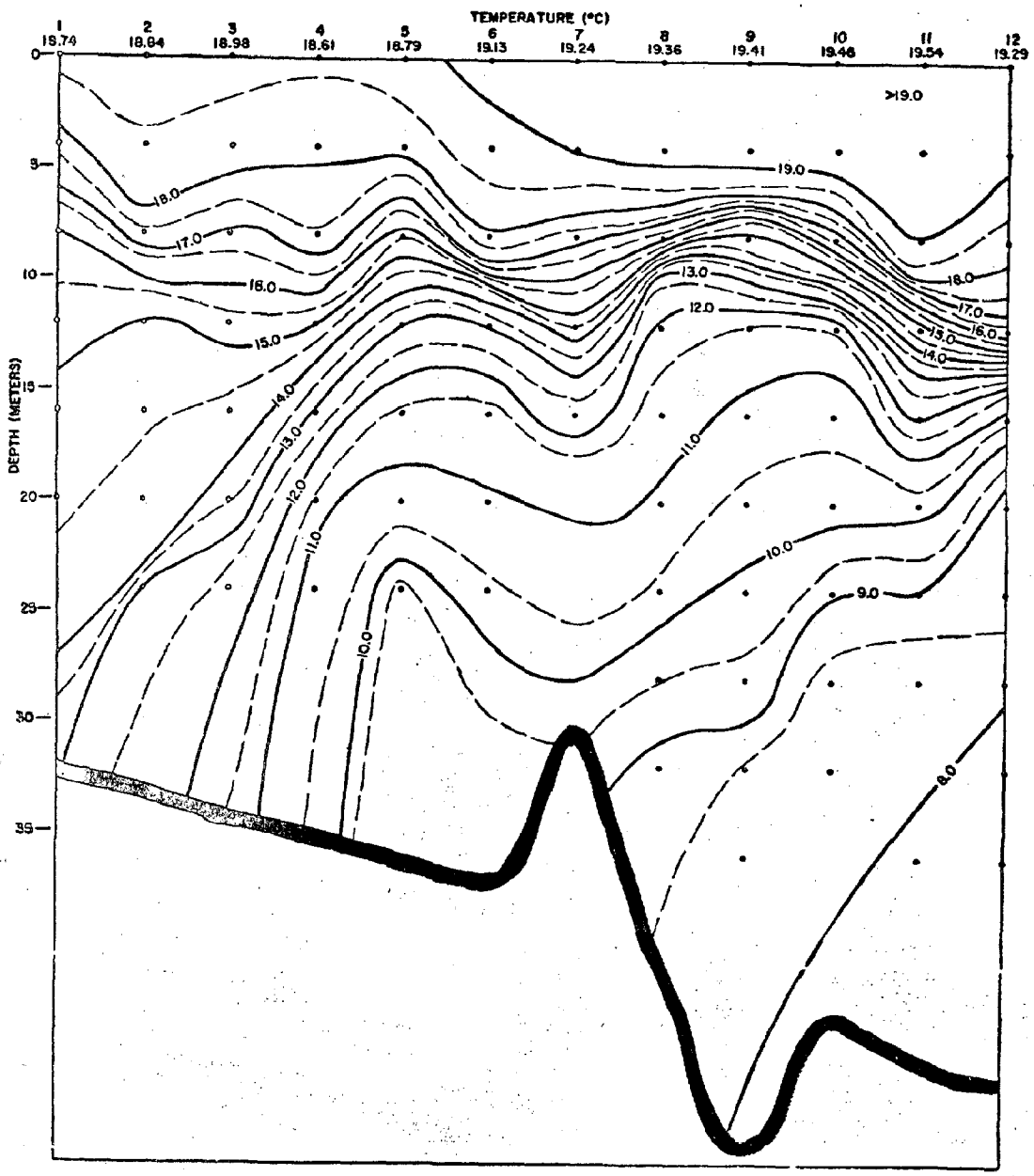
FIGURE 4-151

Vertical Temperature Profiles in Rhode Island Sound March 1964 (Shonting et al., 1964)



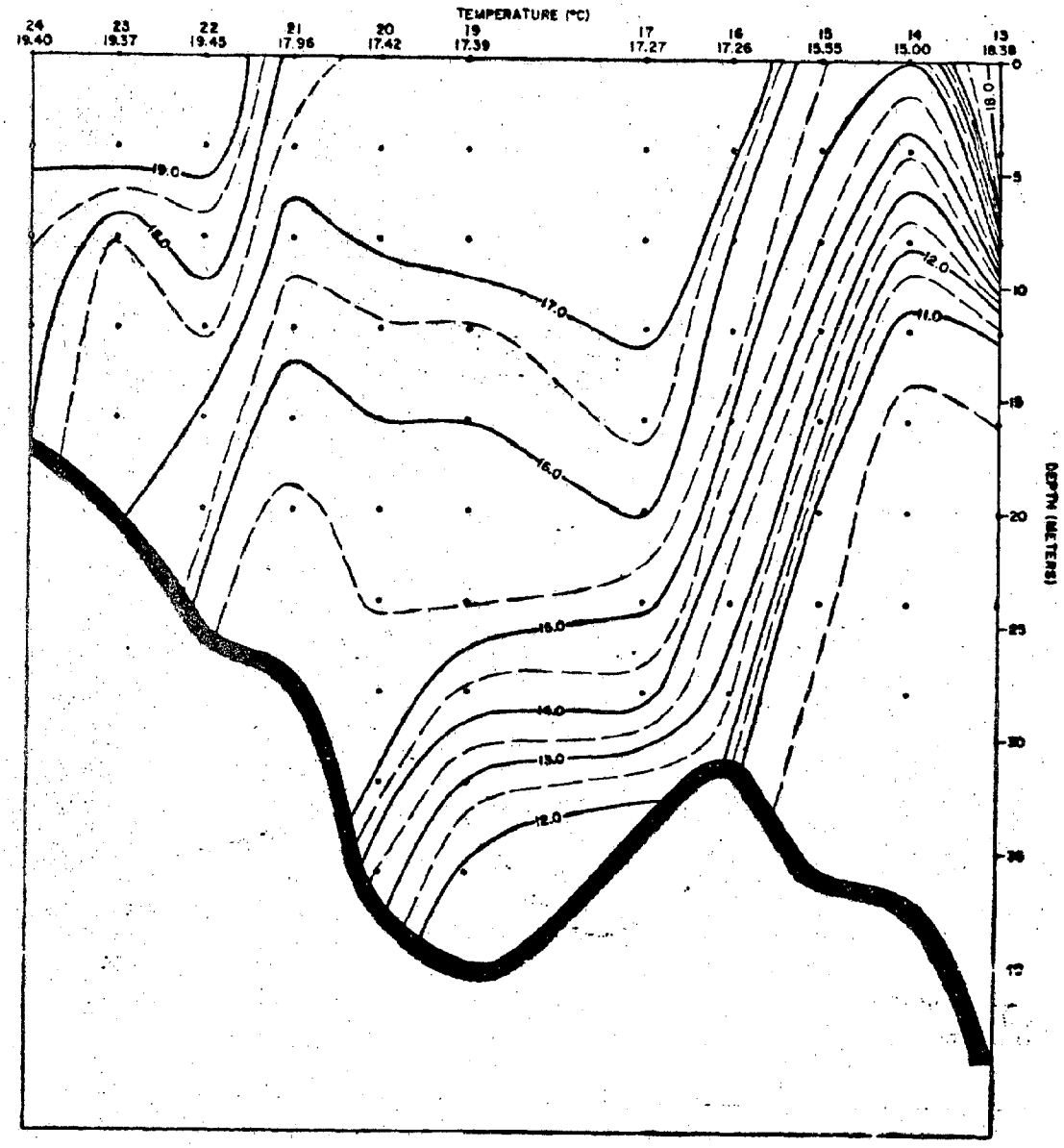
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-152	Vertical Temperature Profiles in Rhode Island Sound June 1964 (Shonting et.al., 1964)

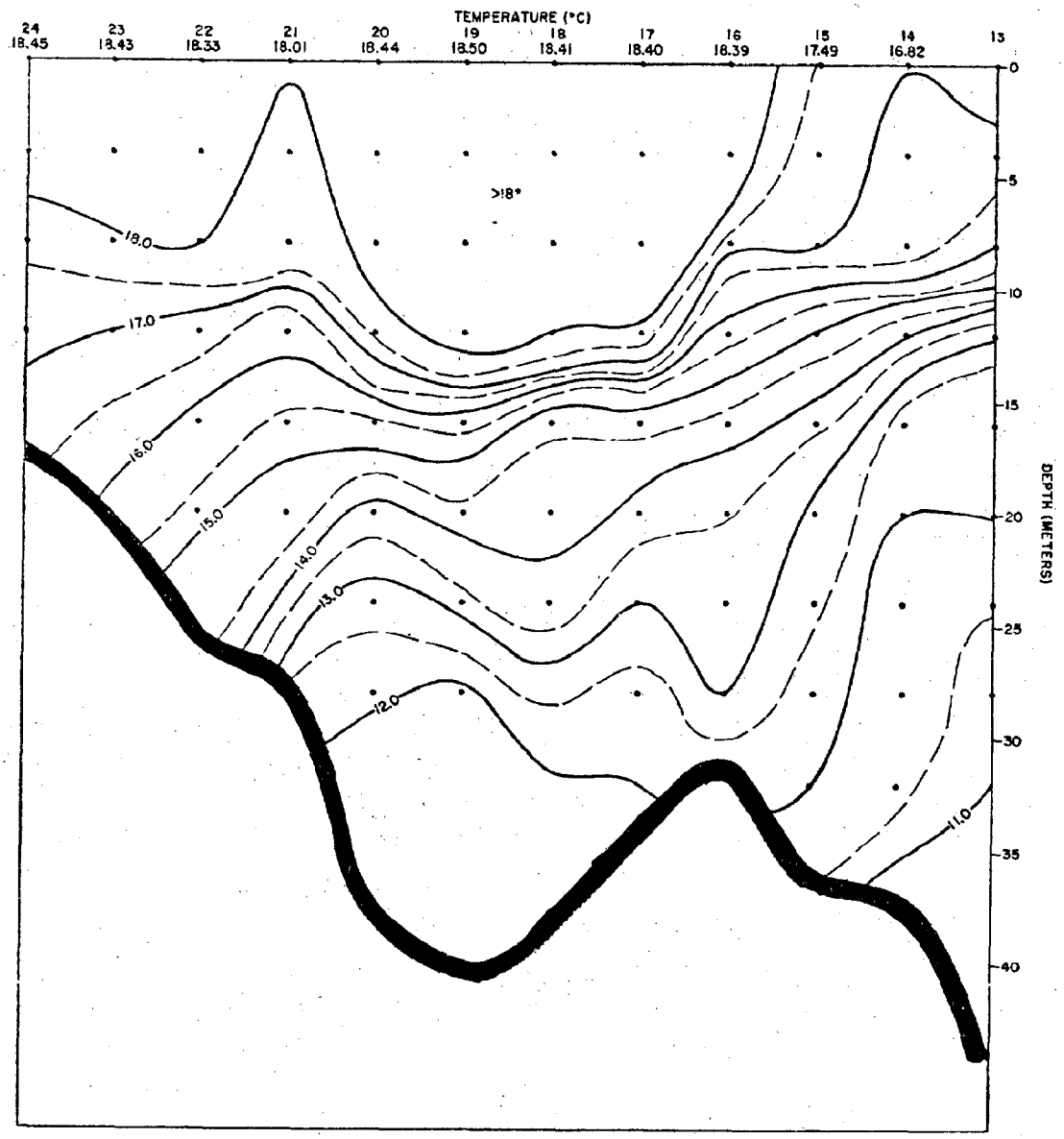


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-153	Vertical Temperature Profiles in Rhode Island Sound July 1964 (Shonting et al., 1964)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-154	Vertical Temperature Profiles in Rhode Island Sound July 1963 (Shonting et al., 1964)



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

TRIGOM PARC

FIGURE 4-155

Vertical Temperature Profiles in Rhode Island Sound August 1963 (Shonting et al., 1964)

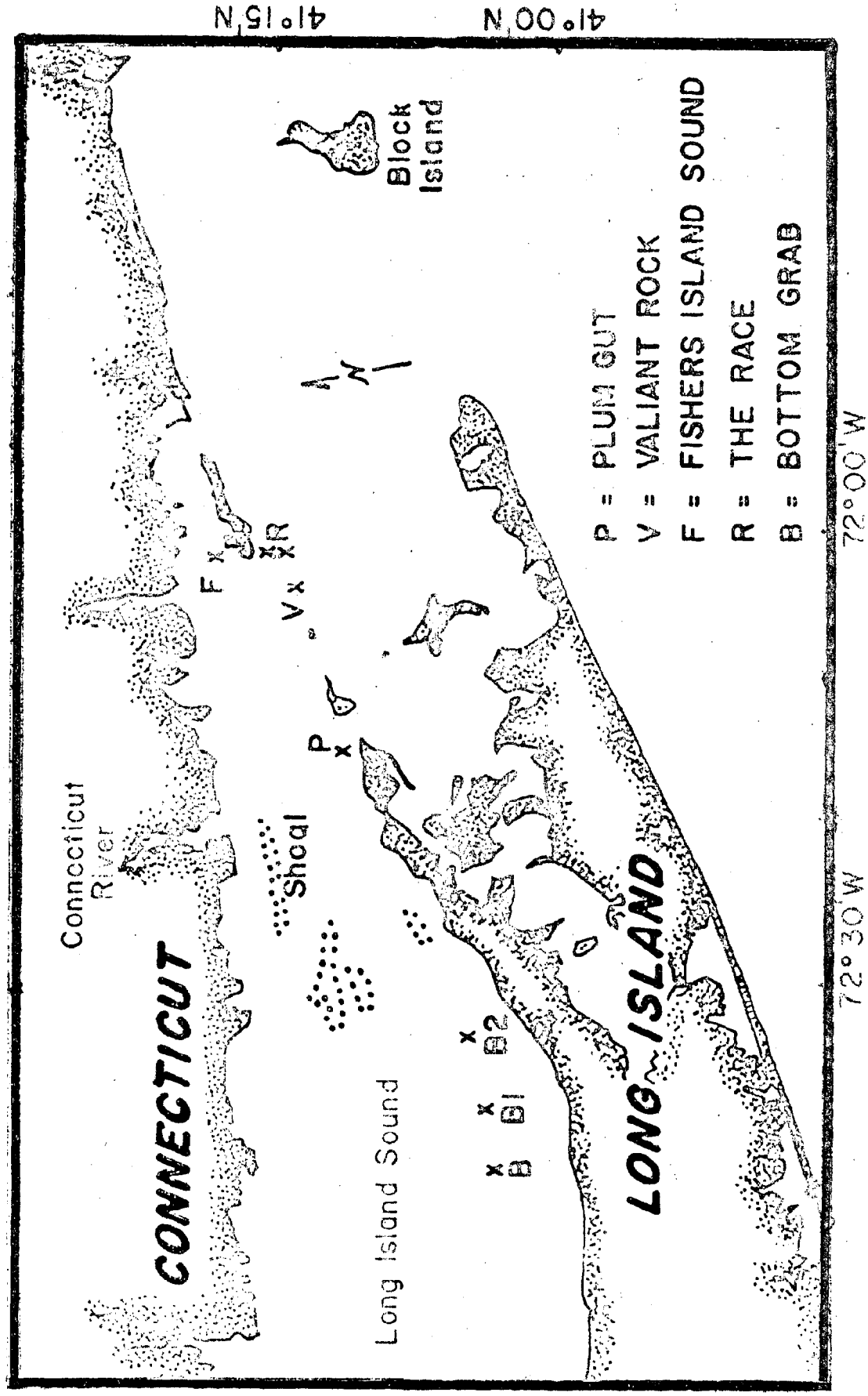


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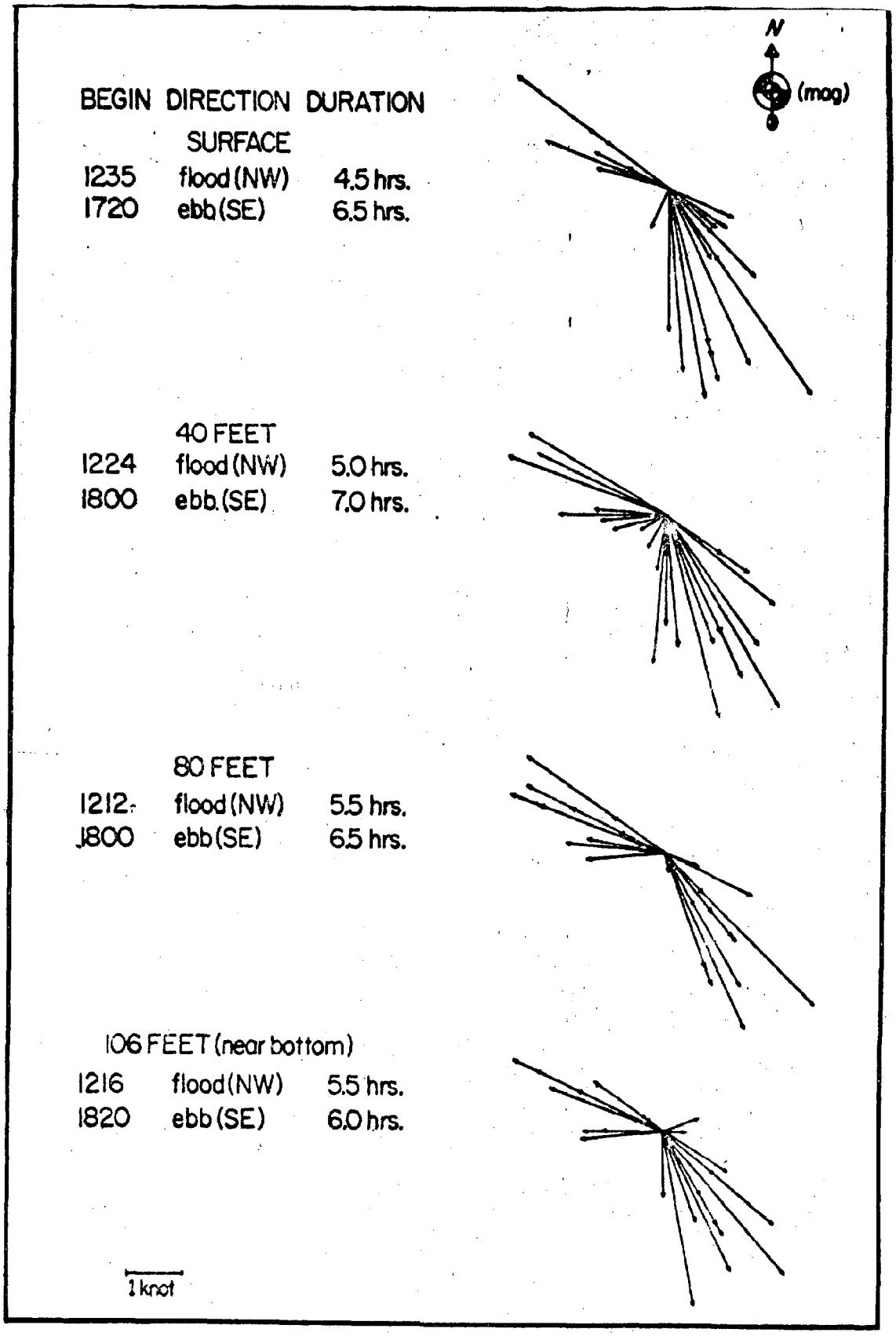
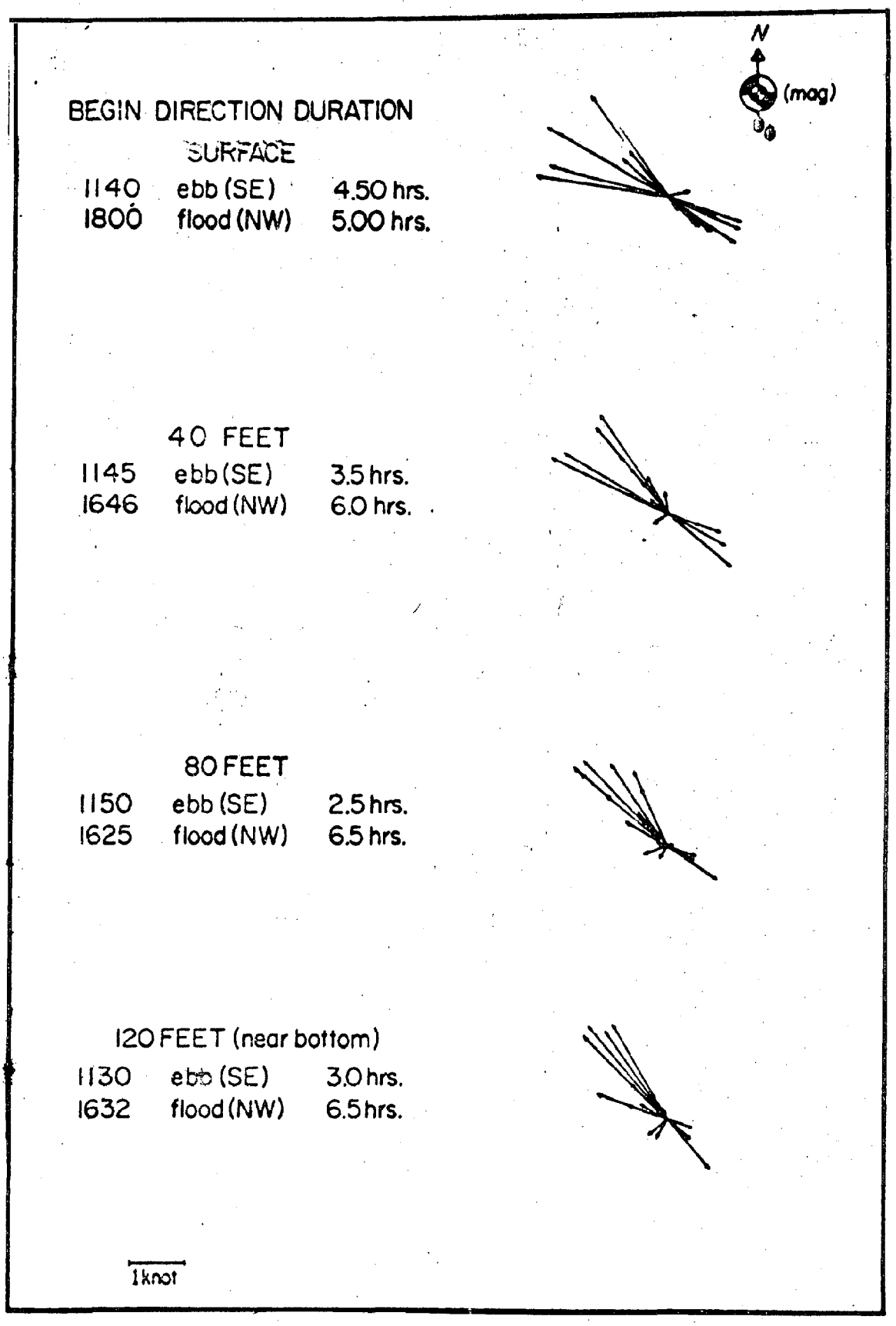
FIGURE 4-156

Current Measurement Stations in Eastern Long Island (Dehlinger et al., 1973)



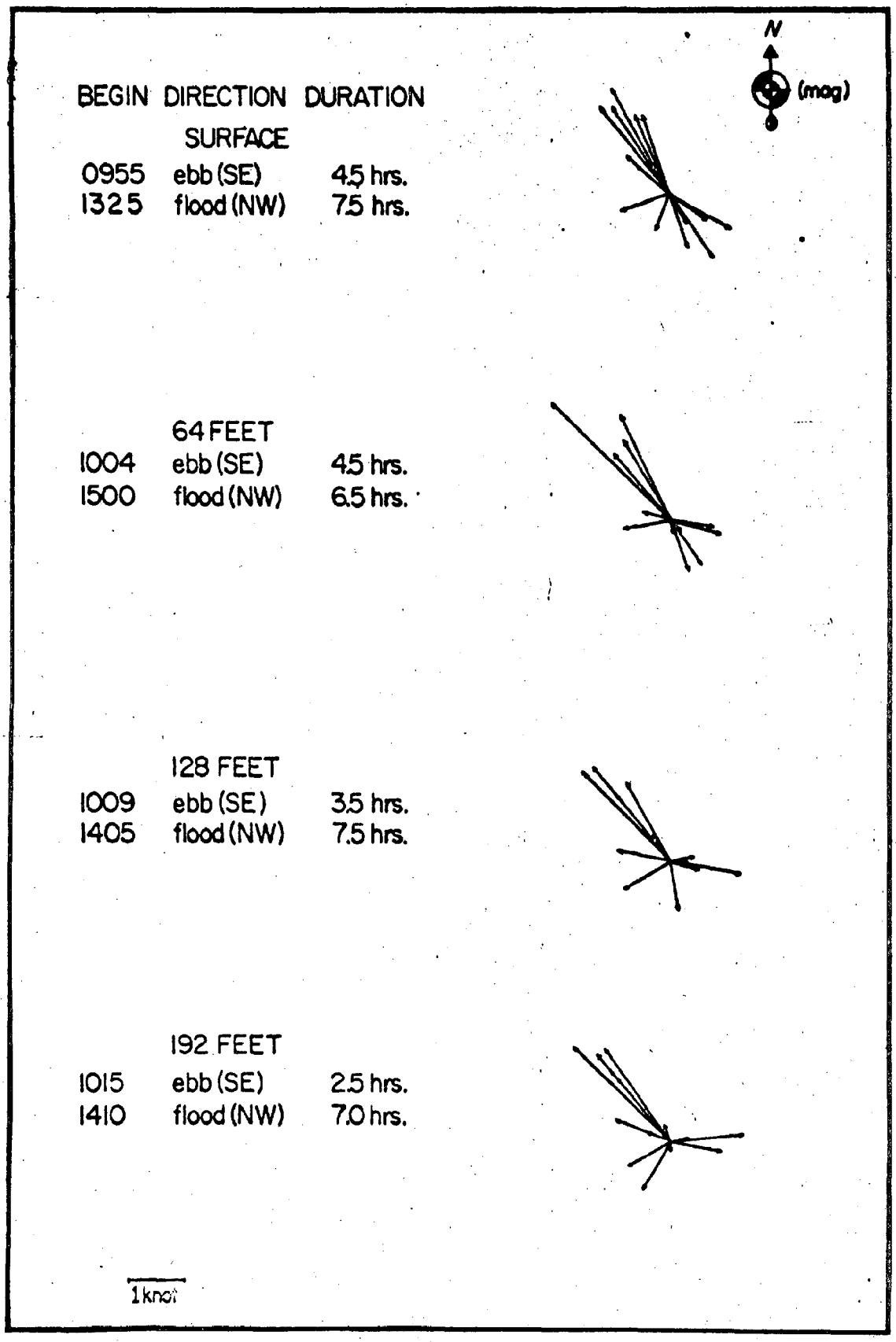
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-157	Reversing Tide Currents - Plum Gut June 5, 1972 (Dehlinger et al., 1973)



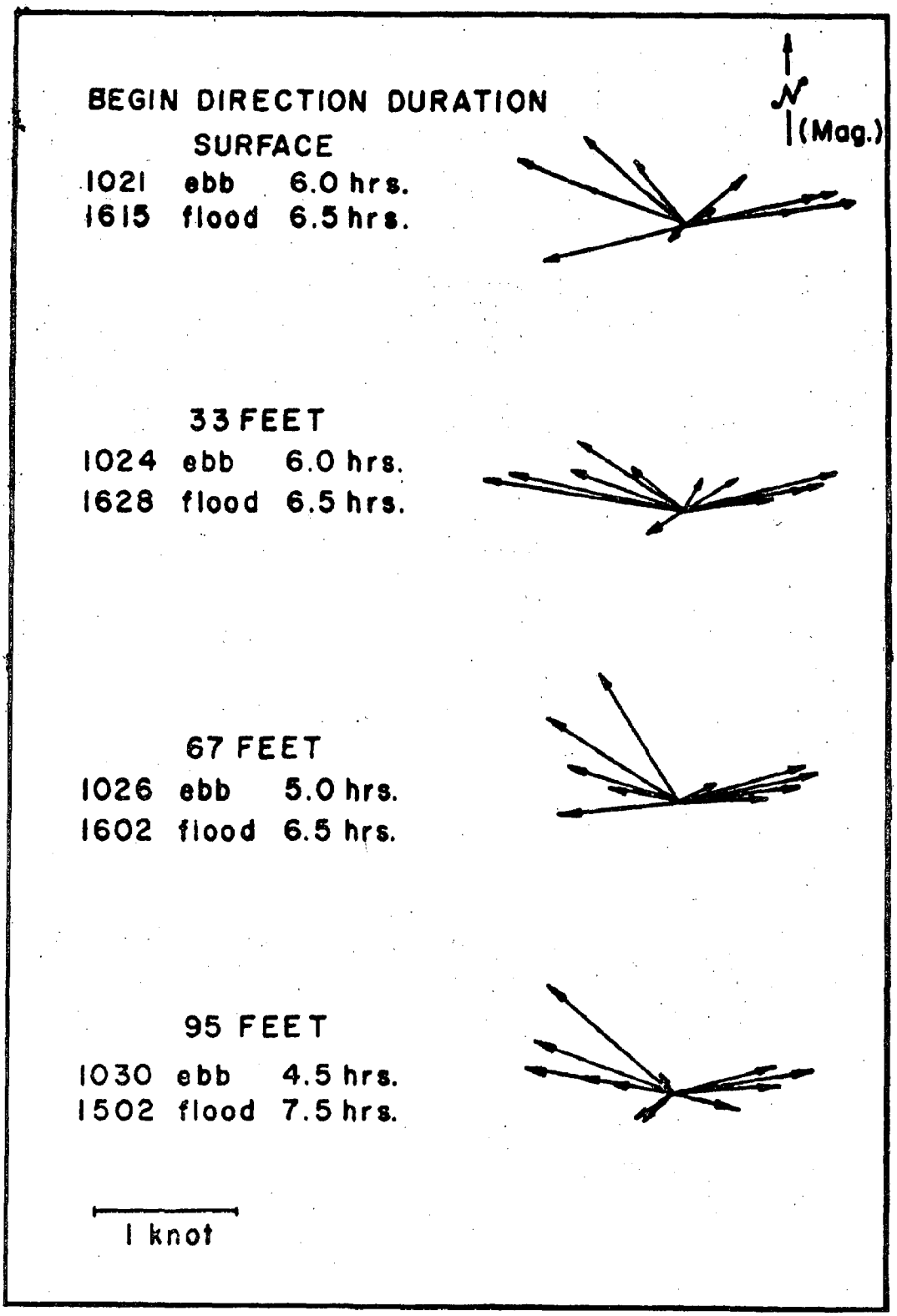
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-158	Reversing Tide Currents-the Race July 24, 1972 (Dehlinger et al., 1973)



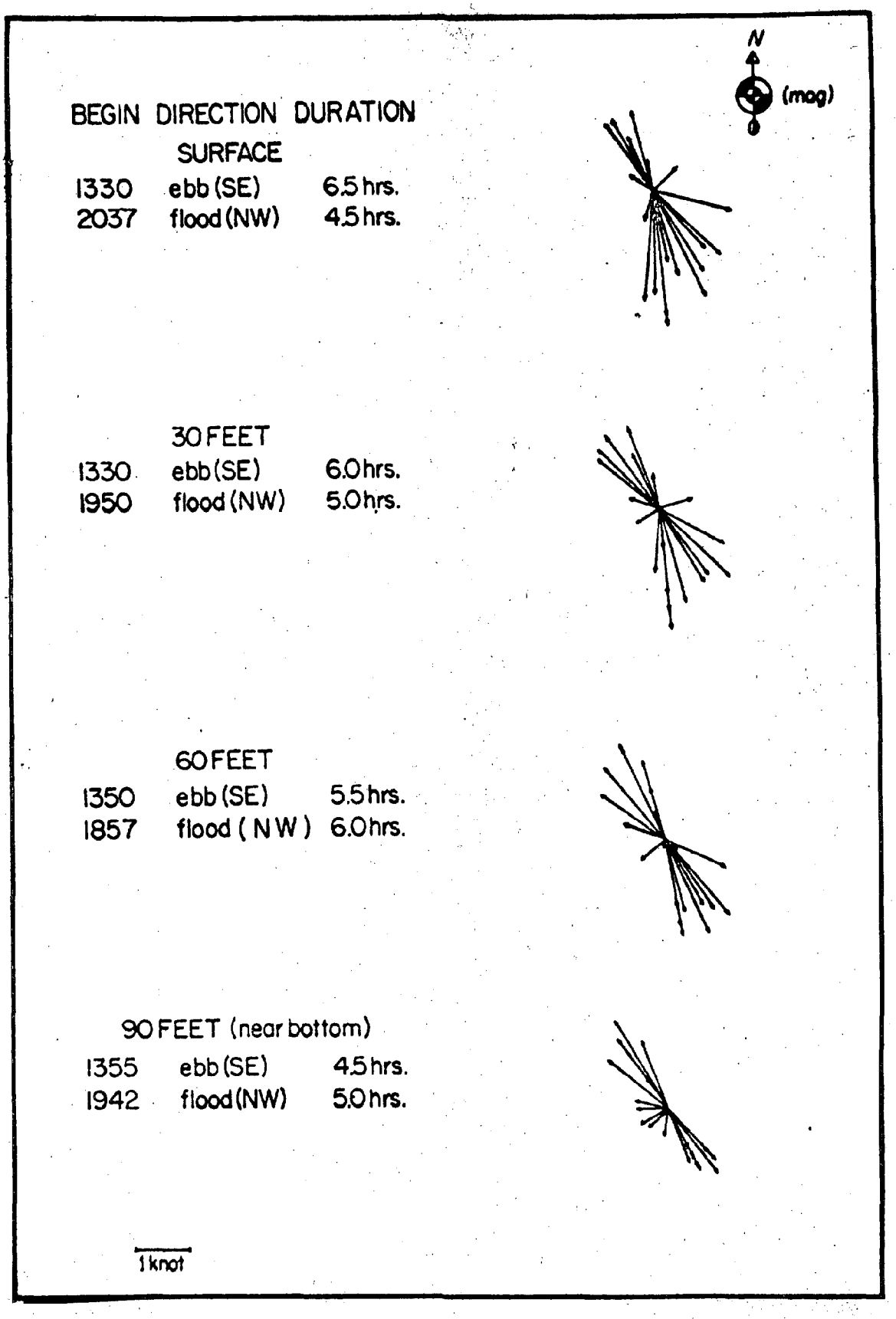
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-159	Reversing Tide Currents-the Race October 19, 1972 (Dehlinger et al., 1973)



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

TRIGOM PARC	FIGURE 4-160	Reversing Tide Currents the Race January 17, 1973 (Dehlinger et al., 1973)



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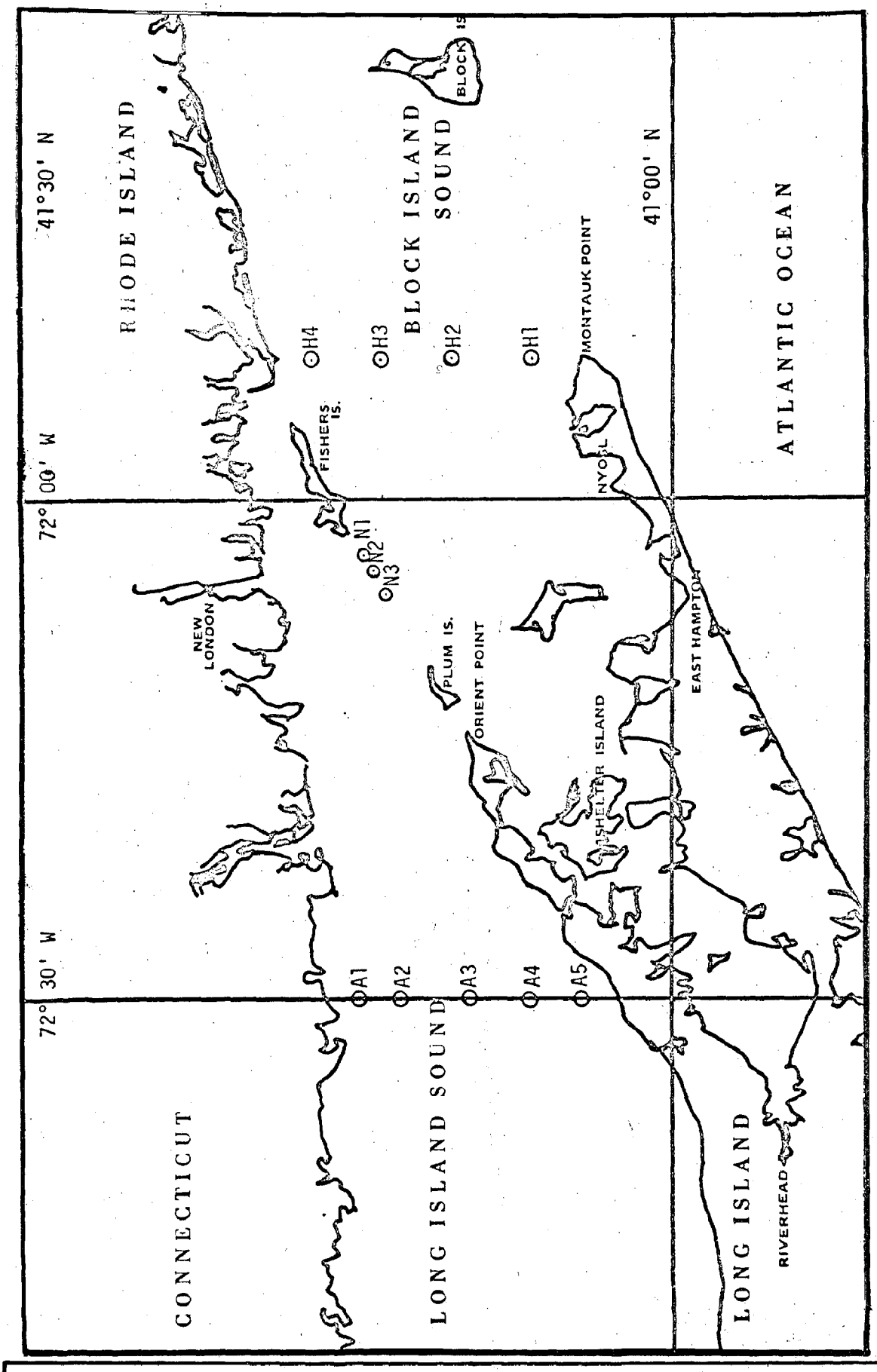
TRIGOM PARC	FIGURE 4-161	Reversing Tide Currents Valiant Rock June 27, 1972 (Dehlinger et al., 1973)



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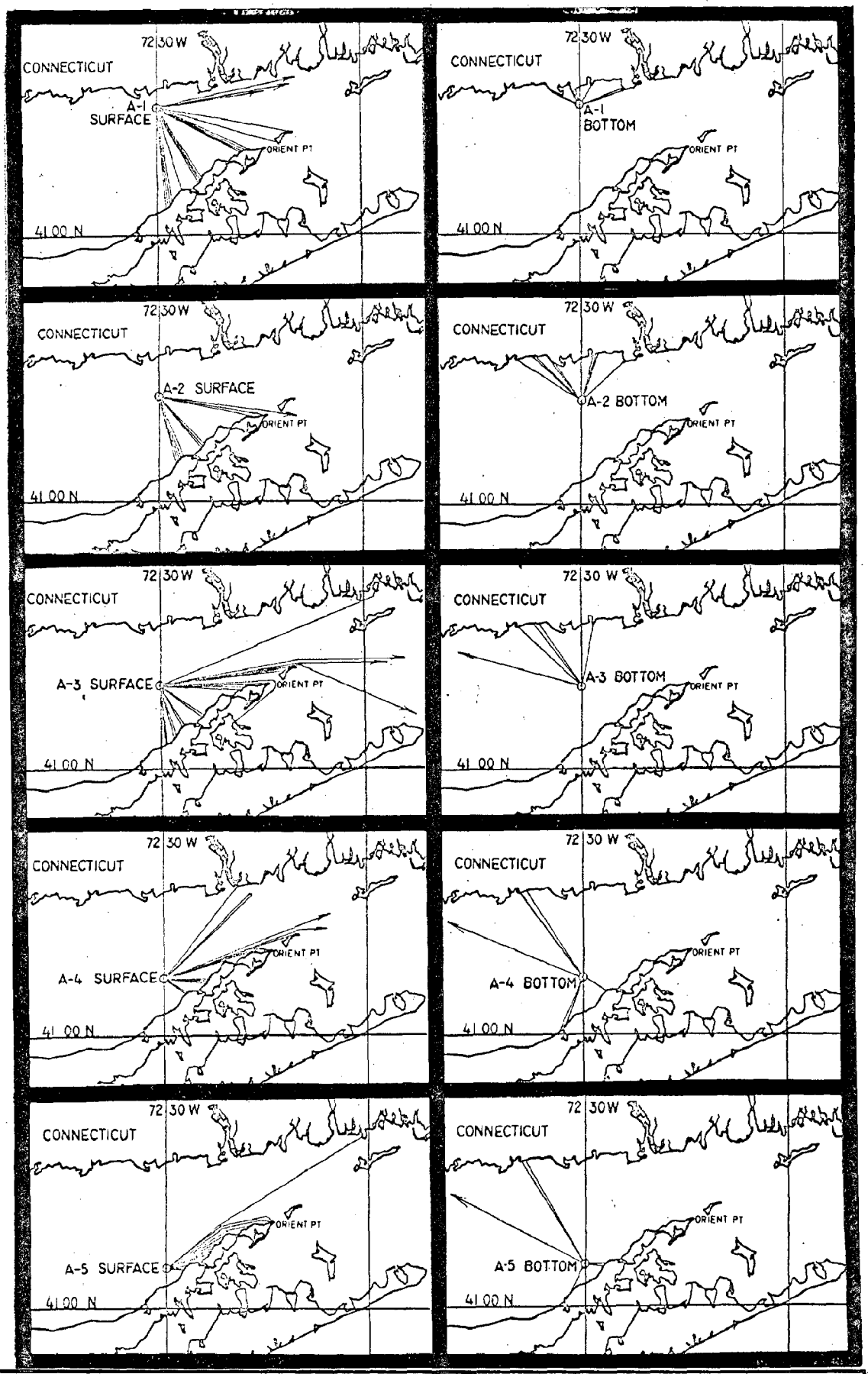
TRIGOM PARC	FIGURE 4-162	Sampling Stations - Eastern Long Island Sound and Block Island (Hollman and Sandberg, 1972)



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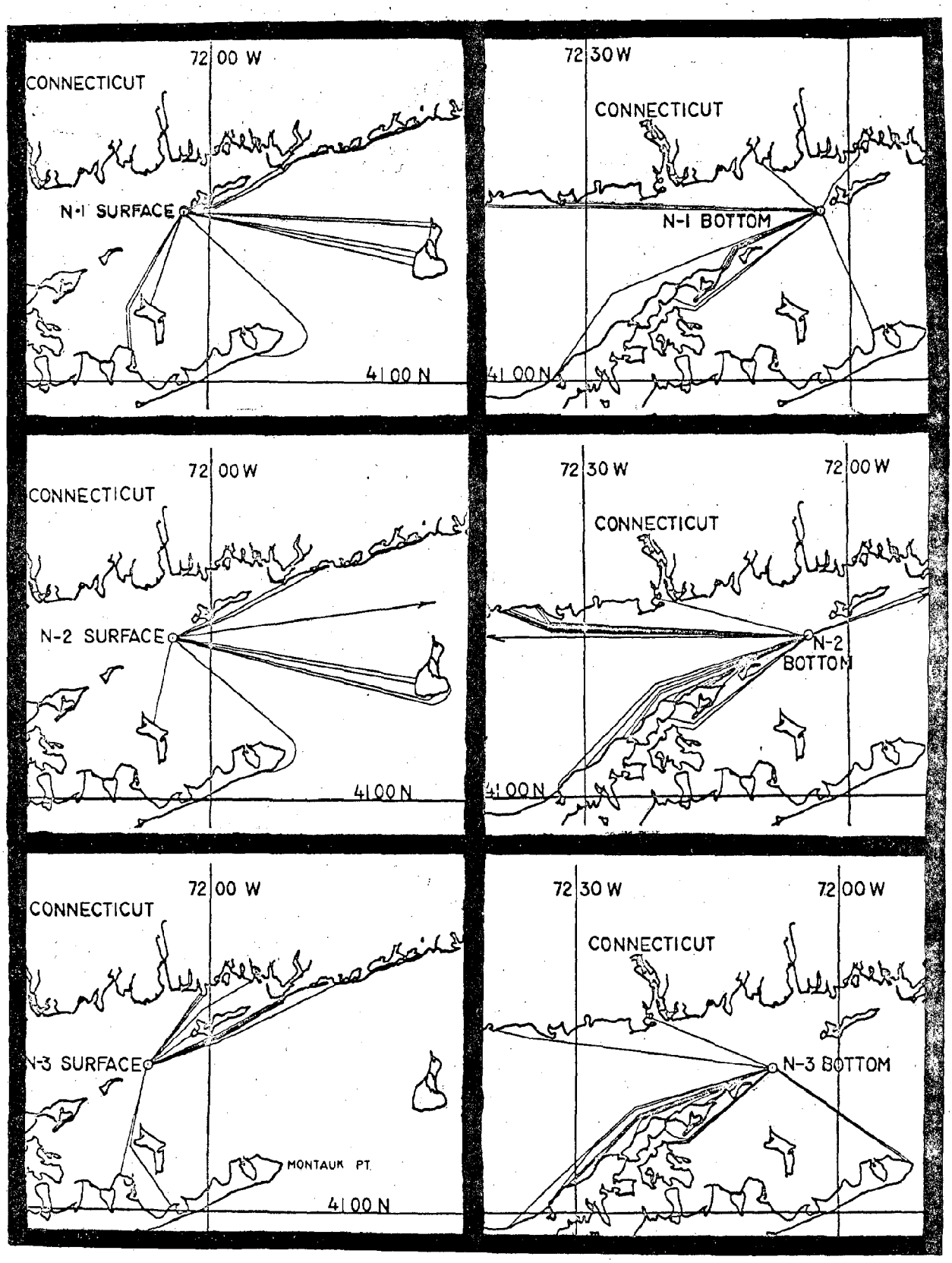
TRIGOM PARC

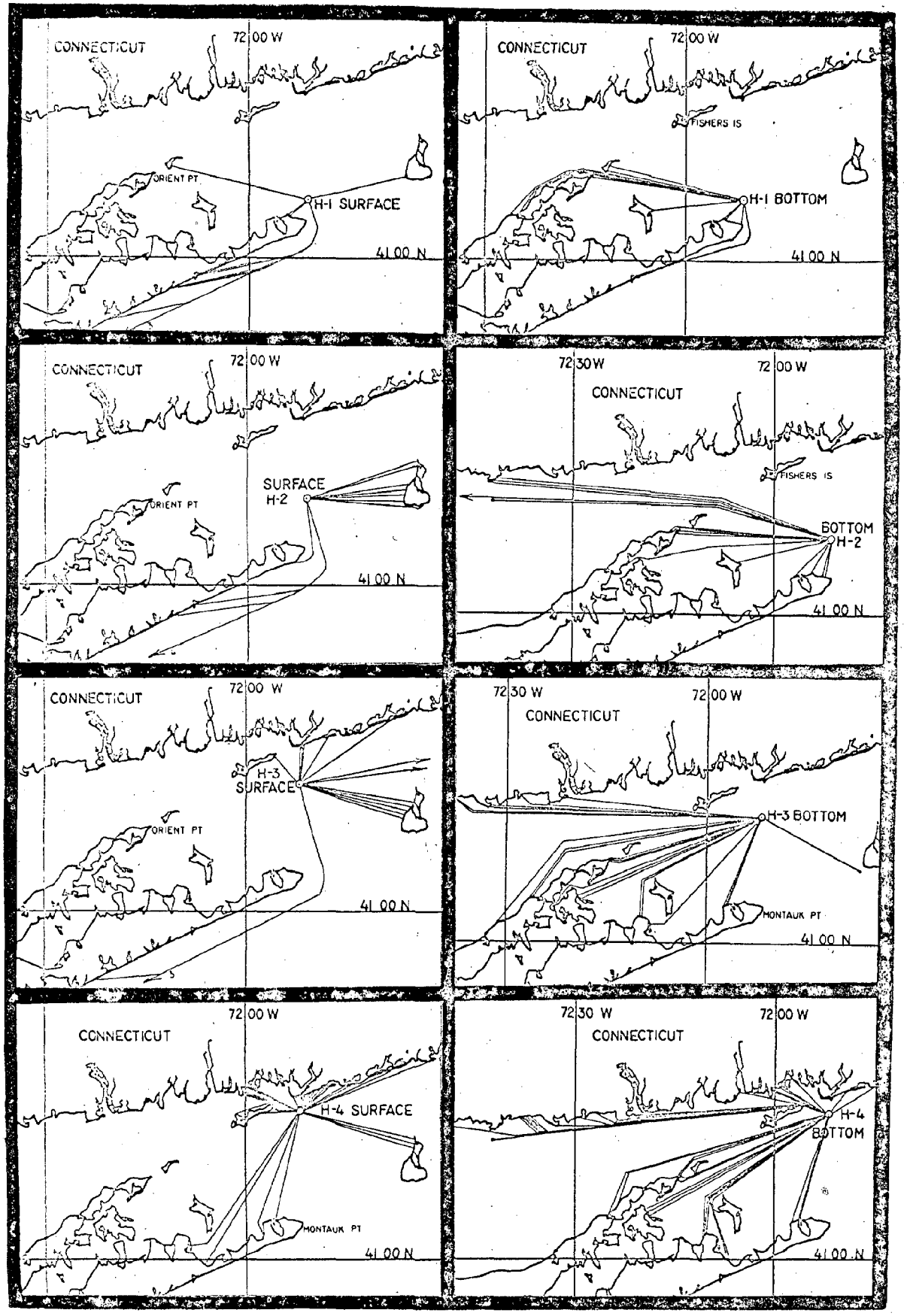
FIGURE 4-163

Surface and Seabed Drifters - "A" Transect (Hollman and Sandberg, 1972)



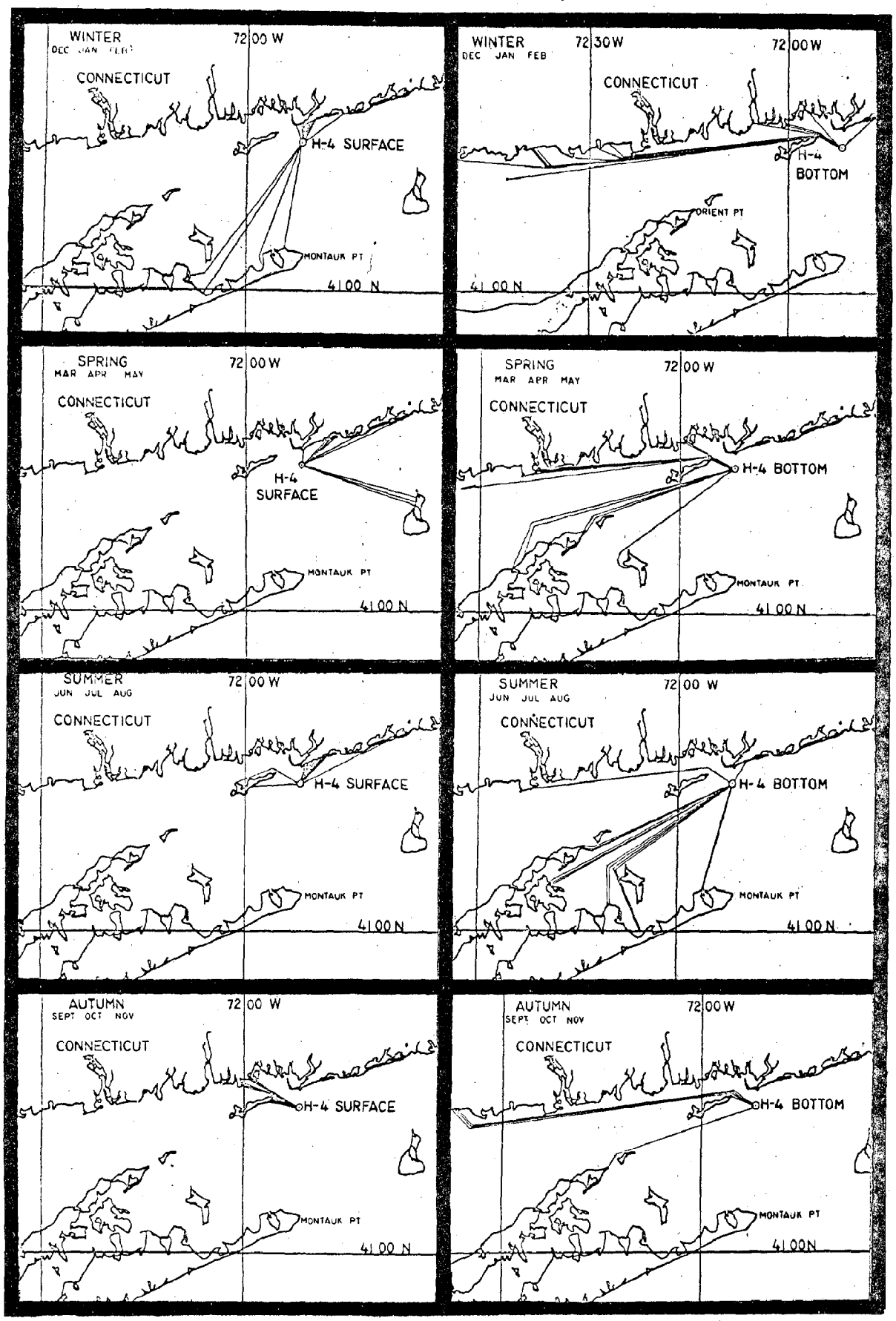
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-164	Surface and Seabed Drifters - "N" Transect (Hollman and Sandberg, 1972)



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

TRIGOM PARC	FIGURE 4-165	Surface and Seabed Drifters - "H" Transect (Hollman and Sandberg, 1972)



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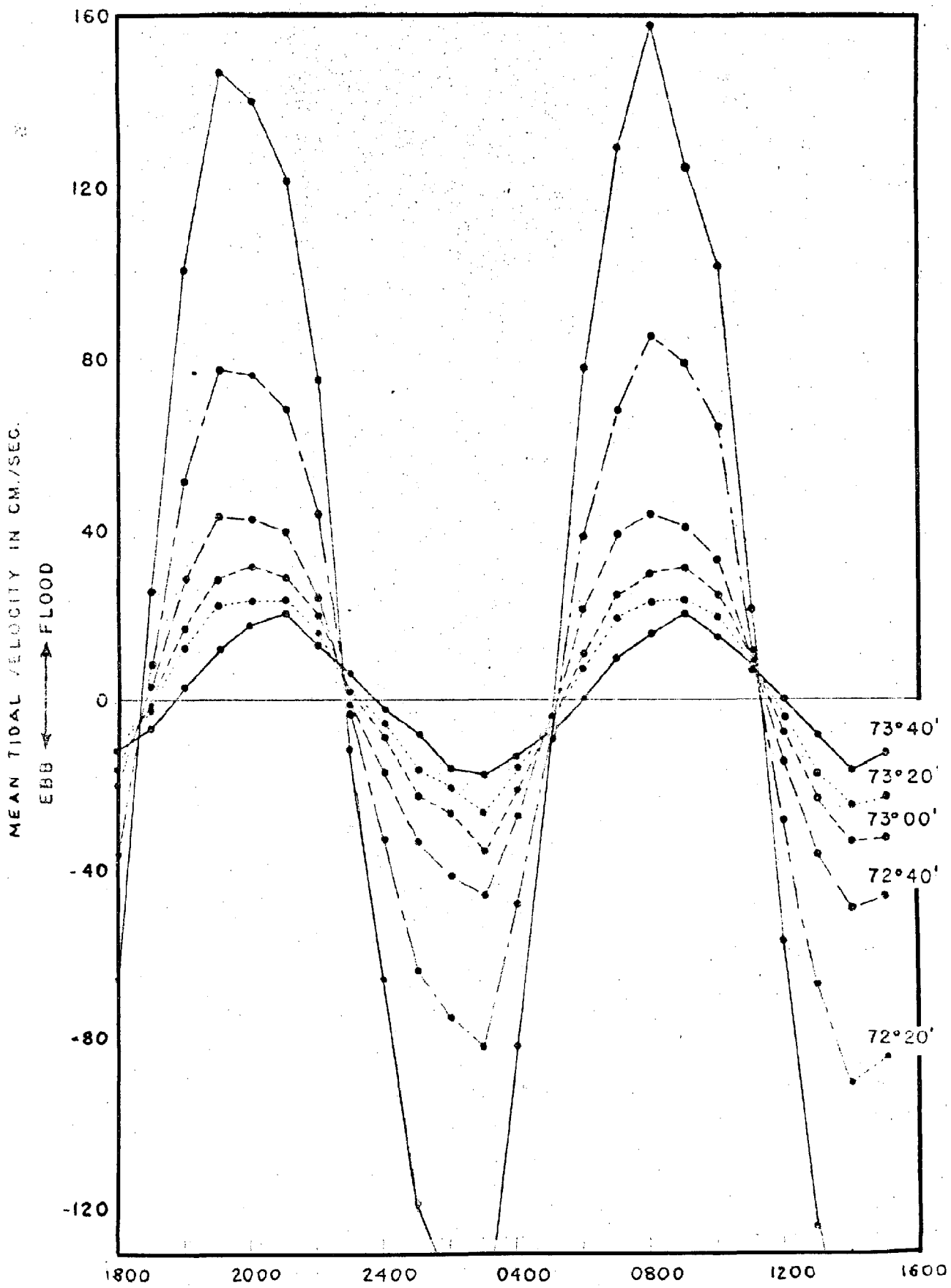
TRIGOM PARC	FIGURE 4-166	Seasonal Changes in Drift Patterns Along the "H" Transect (Hollman and Sandberg, 1972)



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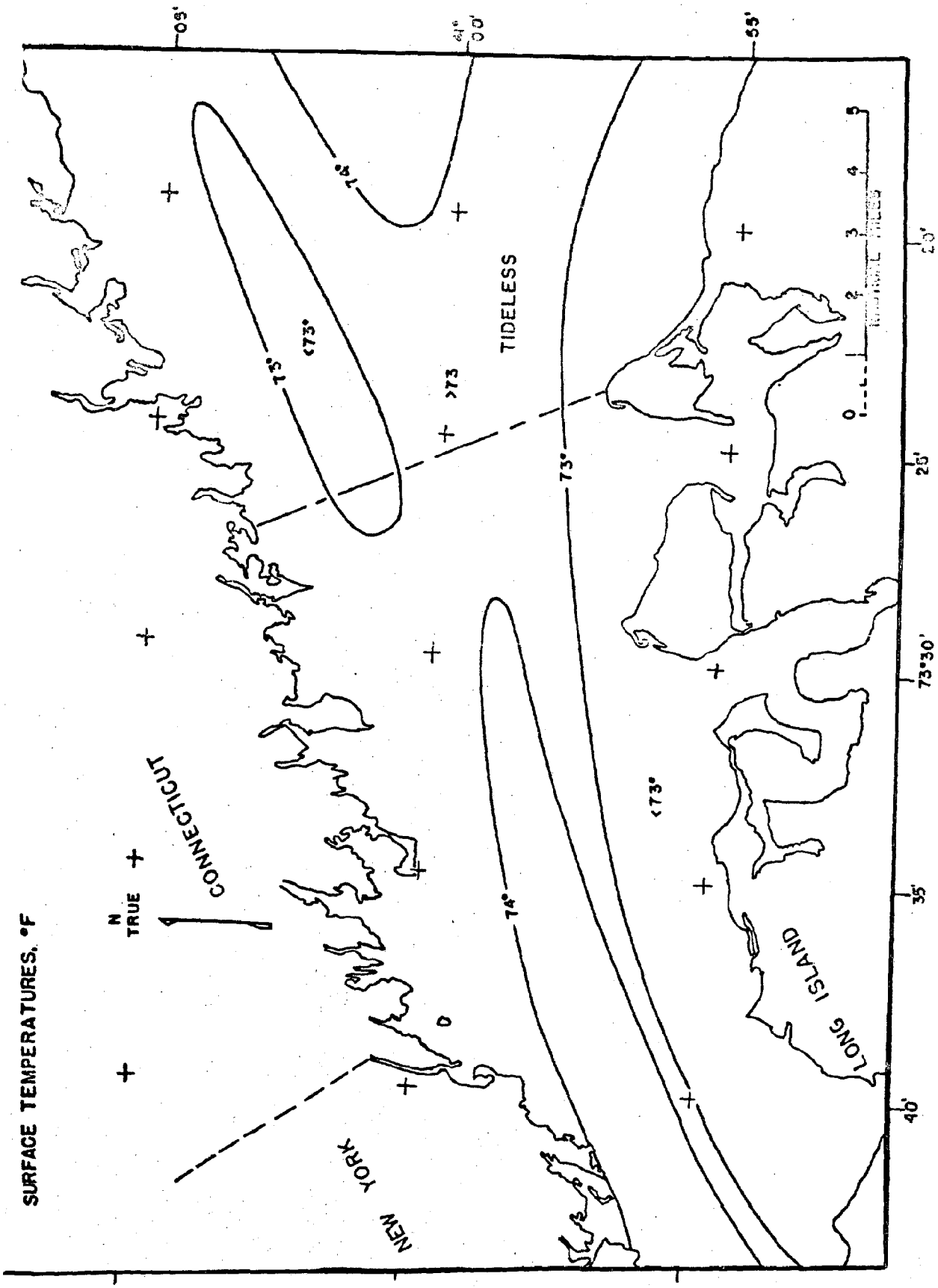
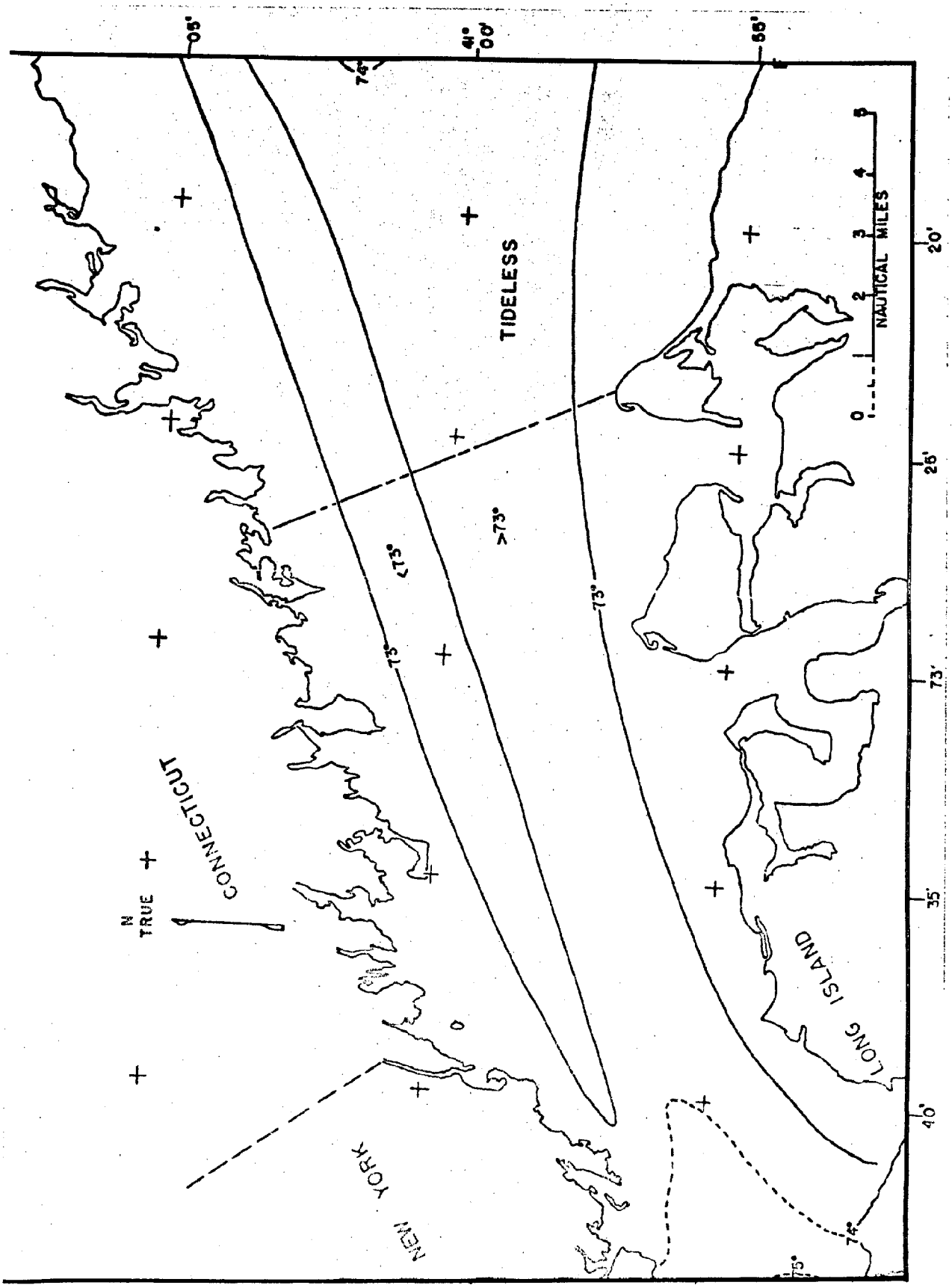
TRIGOM PARC	FIGURE 4-167	Mean Tidal Velocities Tidal Passes from East to West in Long Island Sound (Riley, 1948)



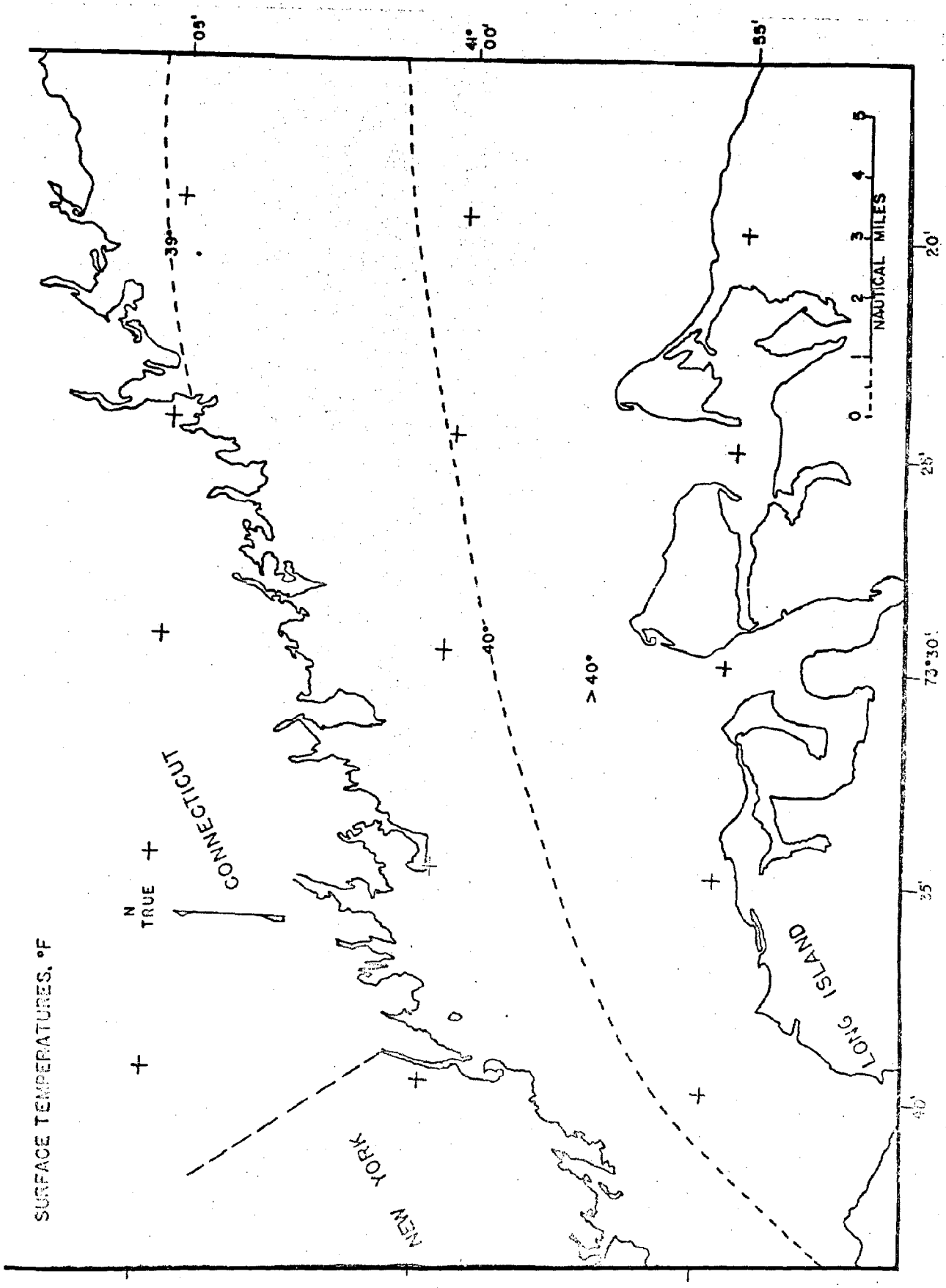
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-168	Surface Temperature Distribution in Western Long Island Sound - Summer - Slack Before Flood (Public Health Service, 1963 & 1967)



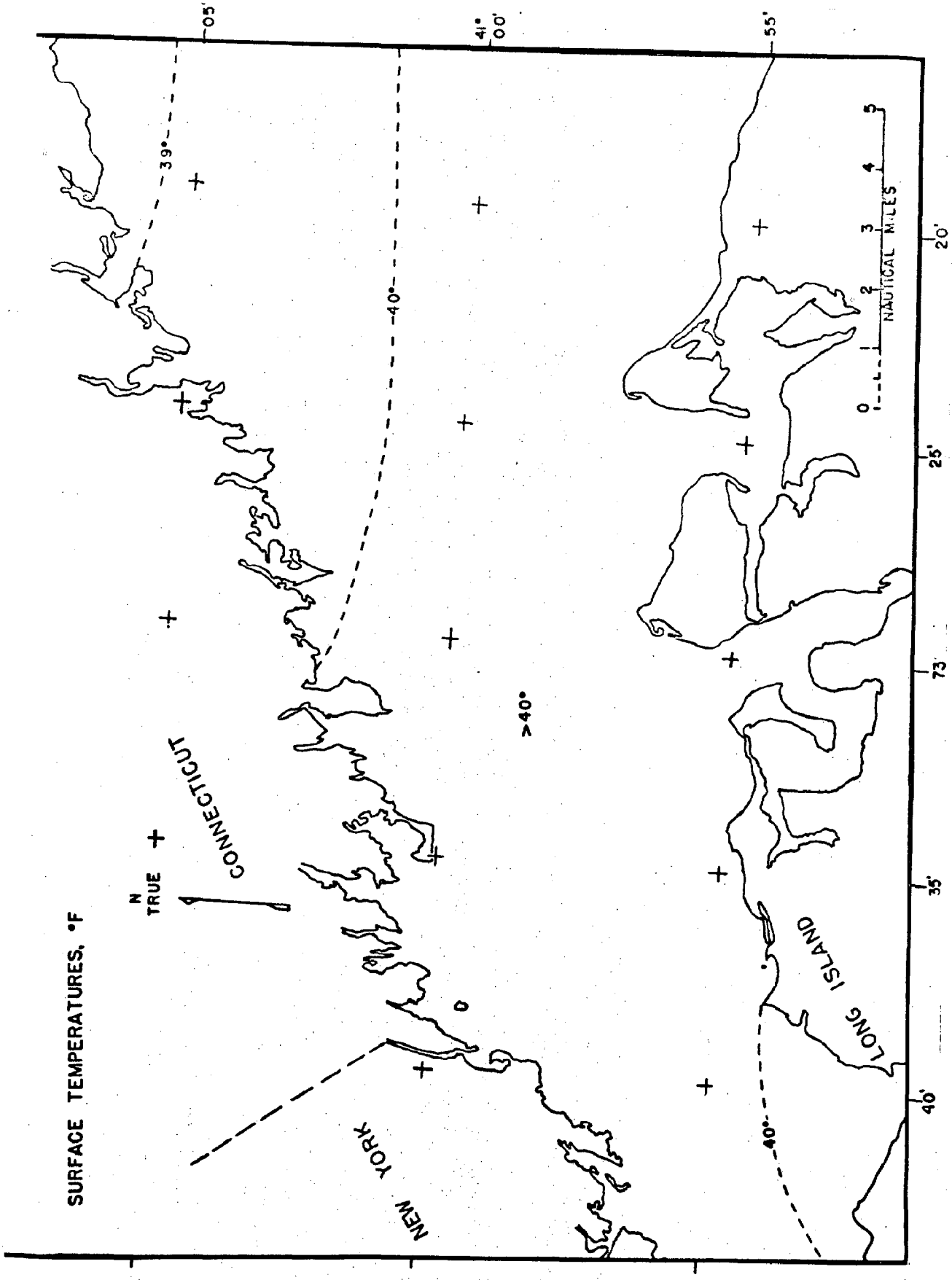
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-169	Surface Temperature Distribution in Western Long Island Sound - Summer - Slack Before Ebb (Public Health Service, 1963 & 1967)



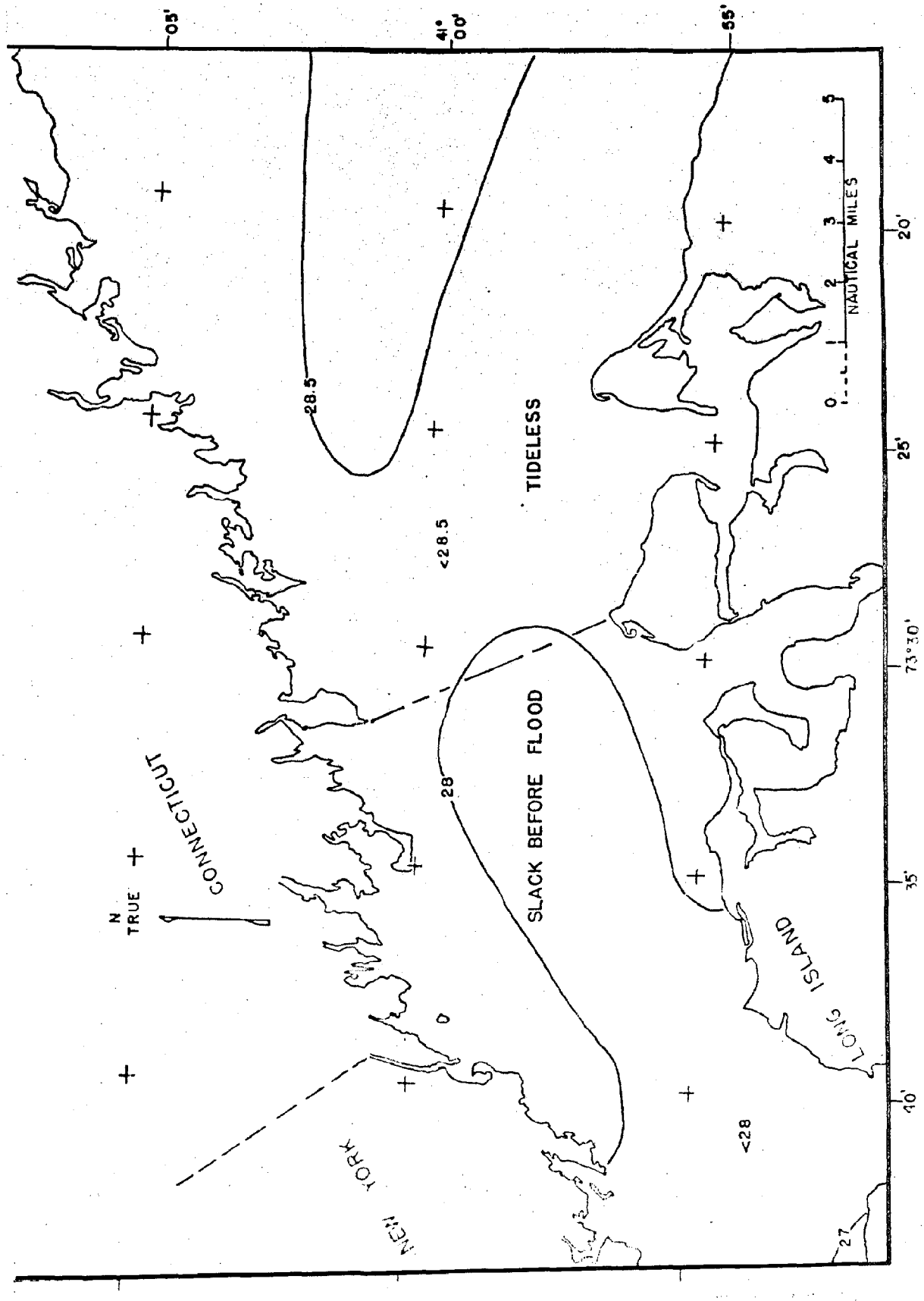
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-170	Surface Temperature Distribution in Western Long Island Sound - Winter - Slack Before Flood (Public Health Service, 1963 & 1967)



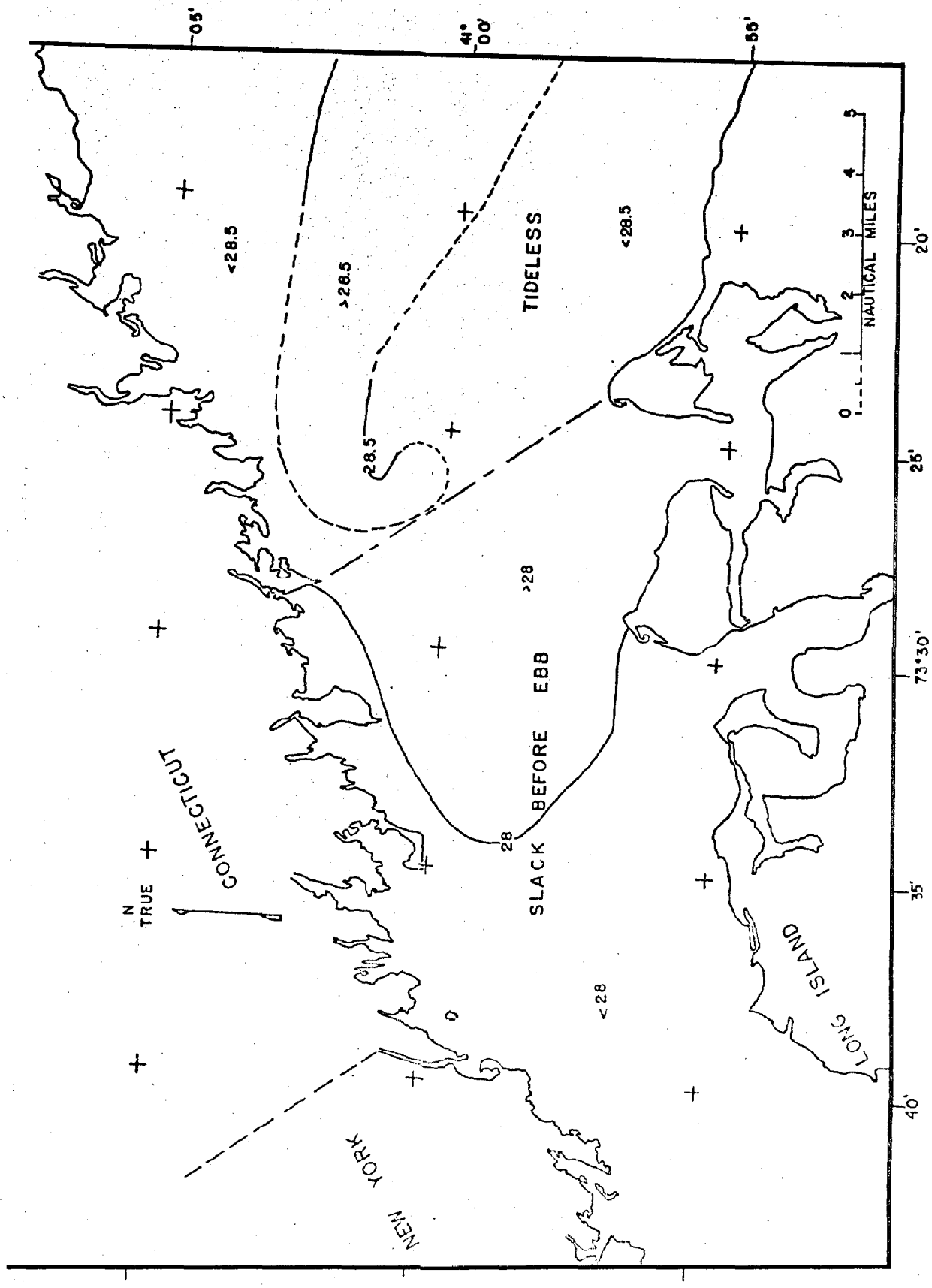
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-171	Surface Temperature Distribution in Western Long Island Sound - Winter - Slack Before Ebb (Public Health Service, 1963 & 1967)



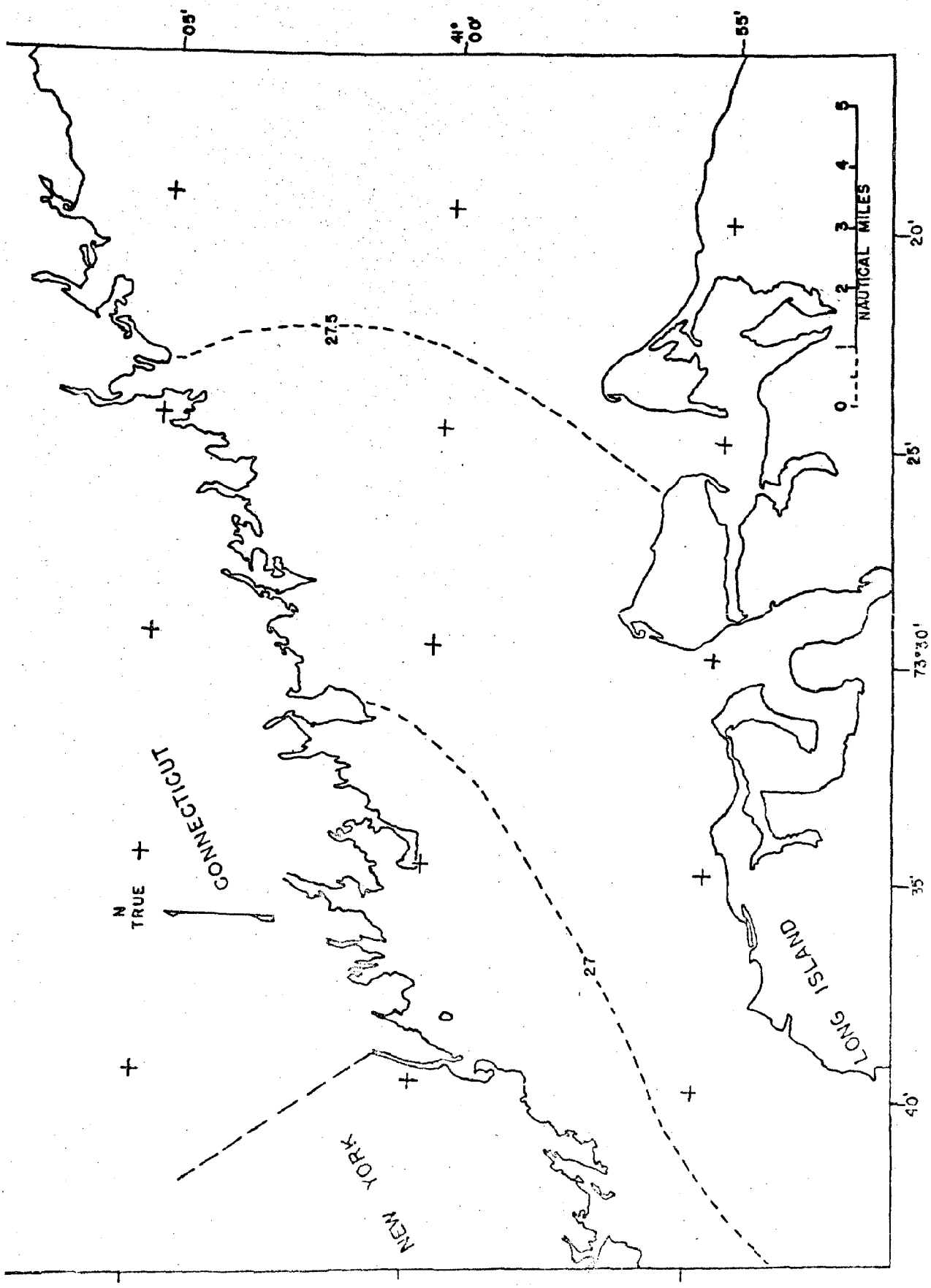
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-172	Surface Salinity in Western Long Island Sound - Summer - Slack Before Flood (Public Health Service, 1963 & 1967)



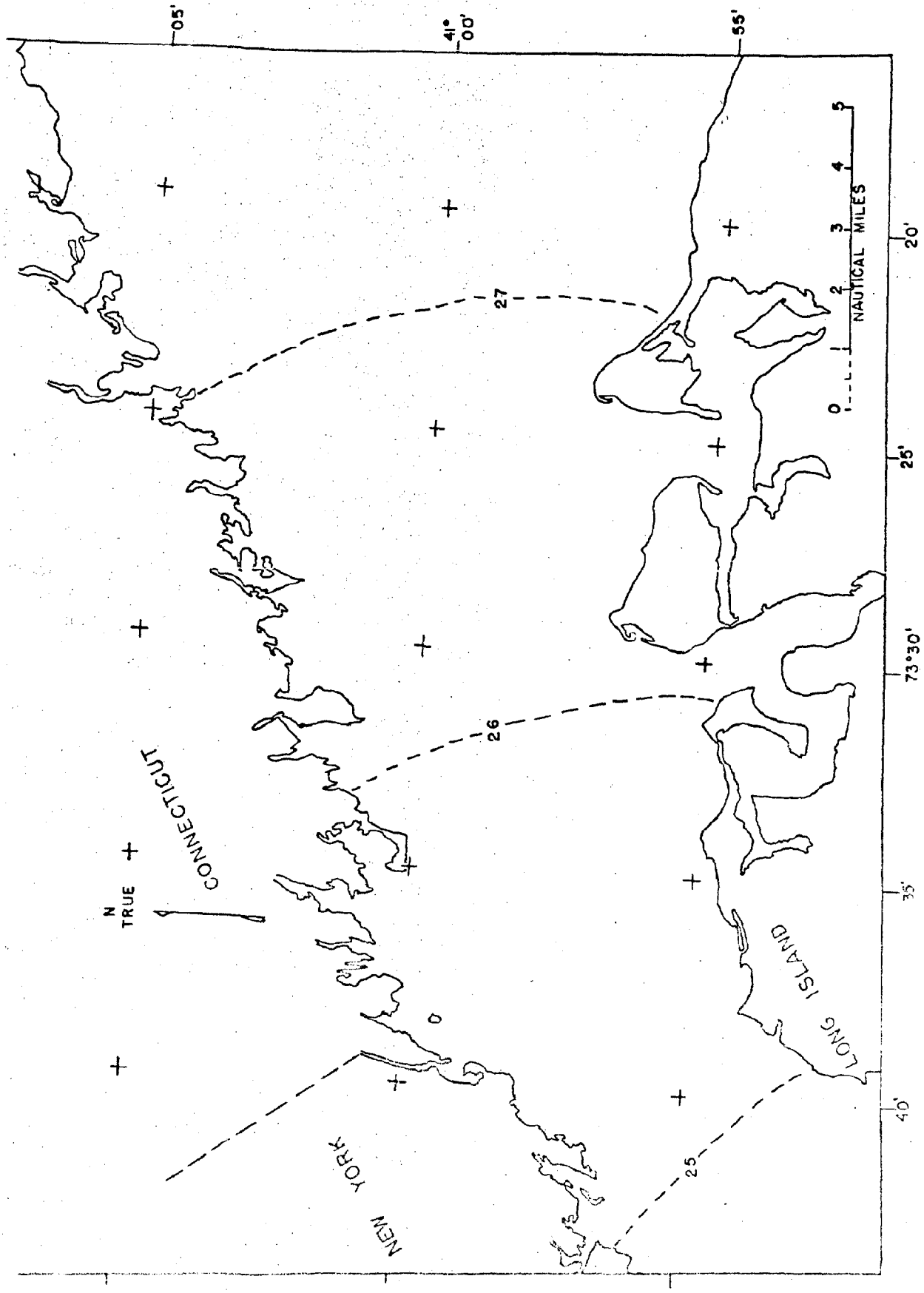
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-173	Surface Salinity in Western Long Island Sound - Summer - Slack Before Ebb (Public Health Service, 1963 & 1967)



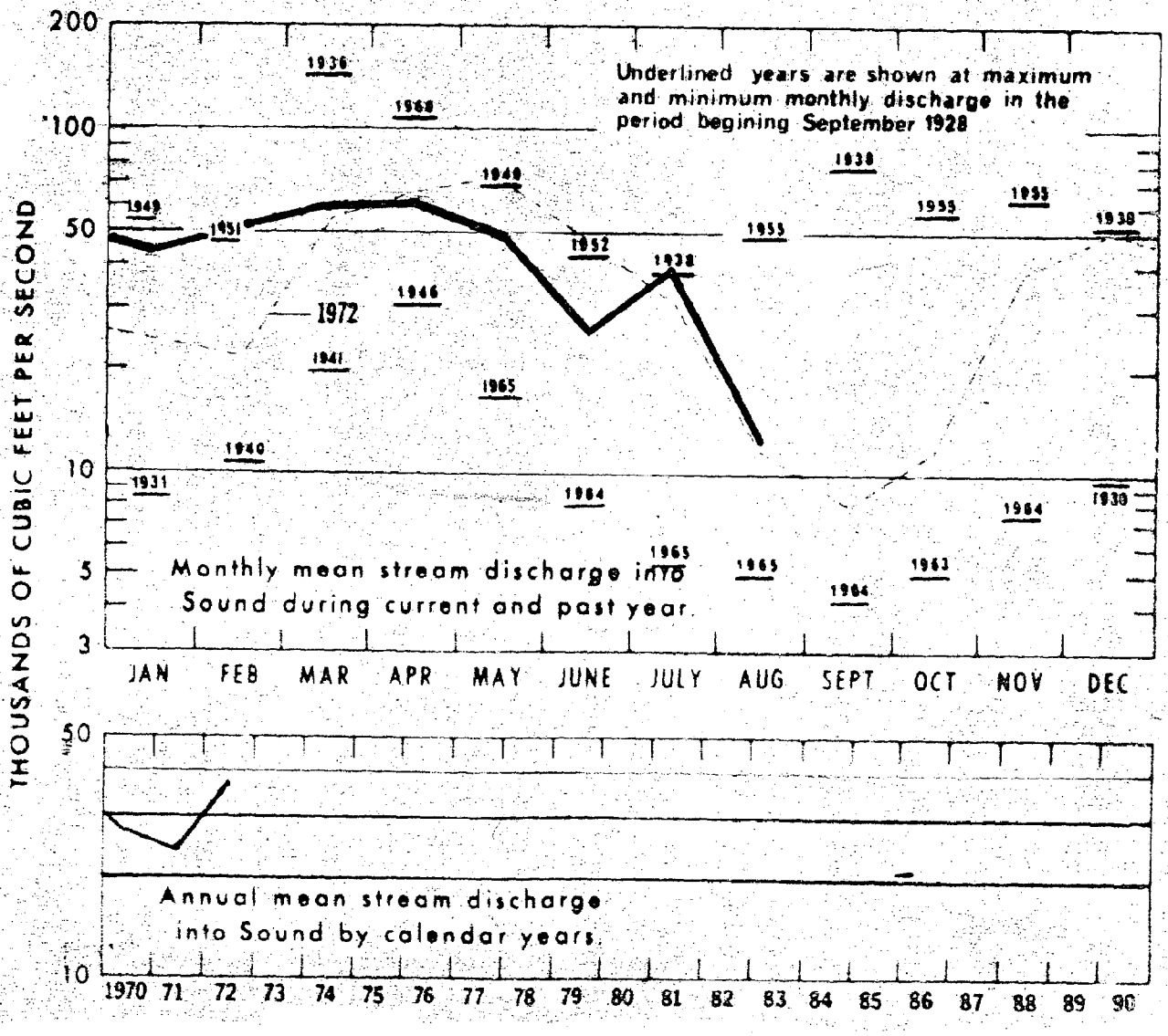
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-174	Surface Salinity in Western Long Island Sound - Winter - Slack Before Flood (Public Health Service, 1963 & 1967)	4-317



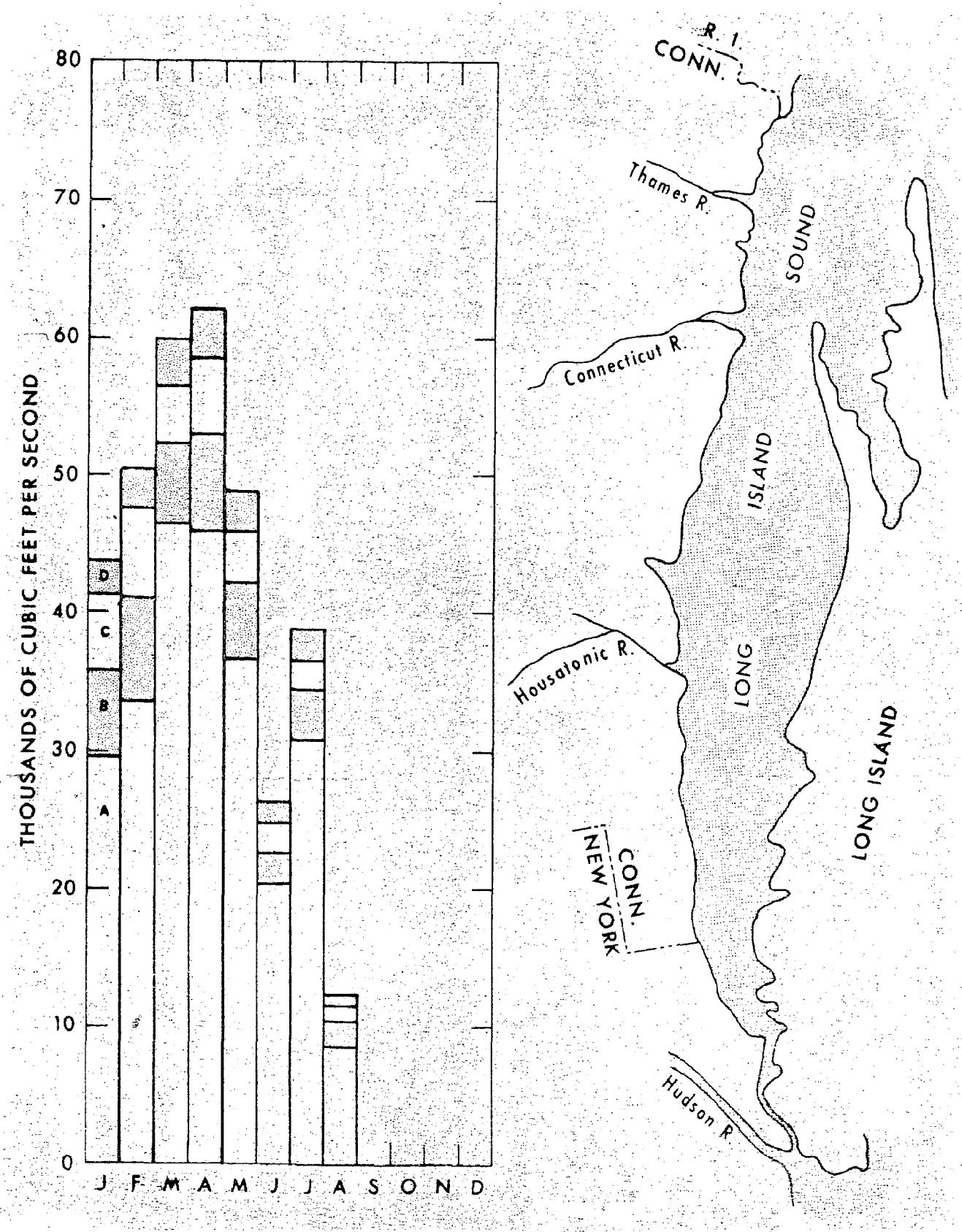
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-175	Surface Salinity in Western Long Island Sound - Winter - Slack Before Ebb (Public Health Service, 1963 & 1967)



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

TRIGOM PARC	FIGURE 4-176	Estimated Stream Discharge Entering Long Island Sound (U.S.C.G.S.)



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

TRIGOM PARC	FIGURE 4-177	Cumulative Stream Discharge Entering Long Island Sound (U.S.C.G.S.)

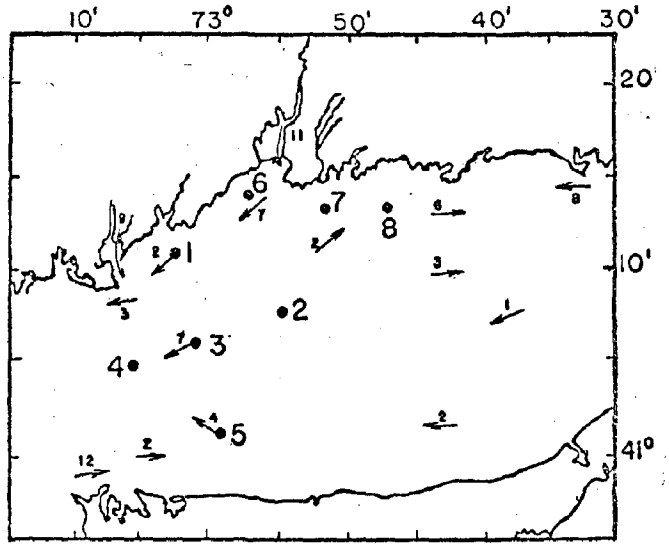


Figure 3. Chart of central Long Island Sound. Dots and large numbers indicate routine stations. Arrows and small numbers show observed direction and speed of nontidal drift in centimeters per second. Values at Sts. 1, 3, and 5 were obtained during the present survey. Others are estimates from Riley (1952), based on U. S. Coast and Geodetic Survey tidal current charts.

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-178	Sampling Stations in Central Long Island Sound (Riley, 1959)

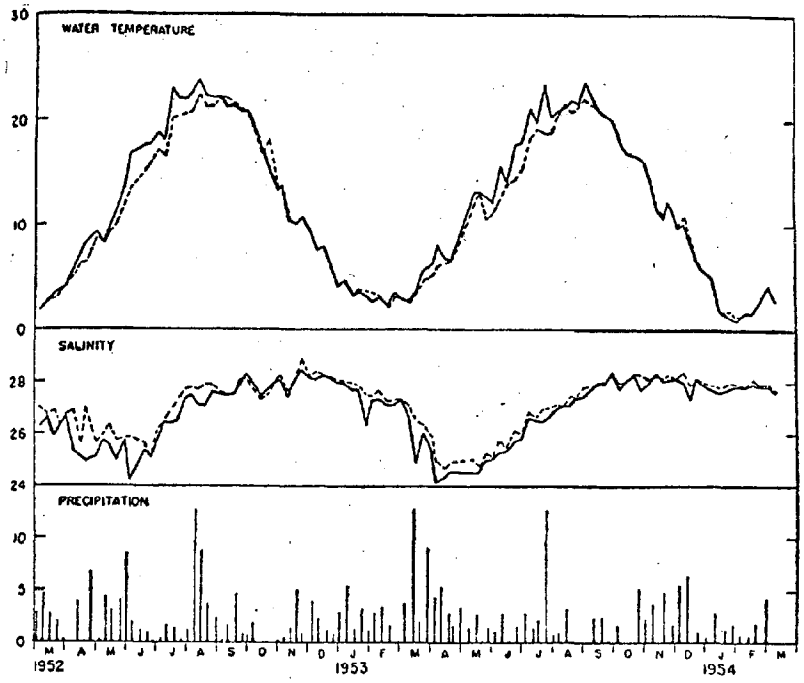


Figure 1. Average temperature (°C) and salinity (°/oo) at the surface (solid lines) and bottom (dashed lines) at inshore stations in the central part of Long Island Sound. Total precipitation (cm) between successive dates of oceanographic observation.

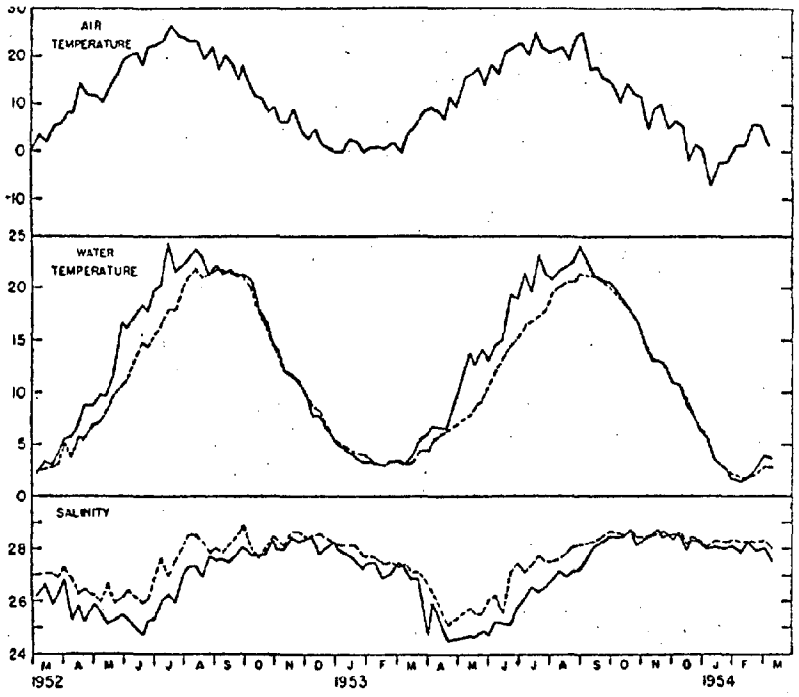


Figure 2. Weekly averages of air temperature (°C) recorded by the New Haven Weather Bureau. Average water temperature (°C) and salinity (°/oo) at surface (solid lines) and bottom (dotted lines) at offshore Sts. 2 to 5.

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TRIGOM PARC	FIGURE 4-179	Annual Temperature and Salinity Cycles in Central Long Island Sound (Riley, 1959)

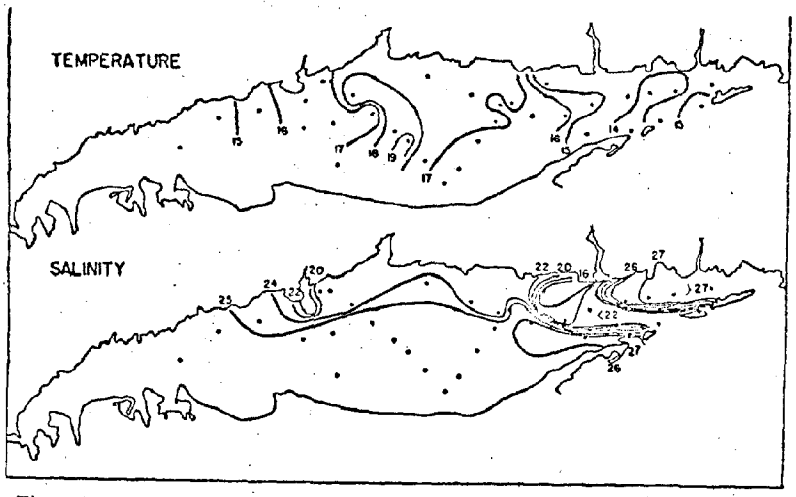

Figure 4. Surface temperature (°C) and salinity (°/₀₀). June 4 to 11, 1952. Dots indicate positions of observation.

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

TRIGOM PARC	FIGURE 4-180	Surface Temperature and Salinity in Central Long Island Sound (Riley, 1959)

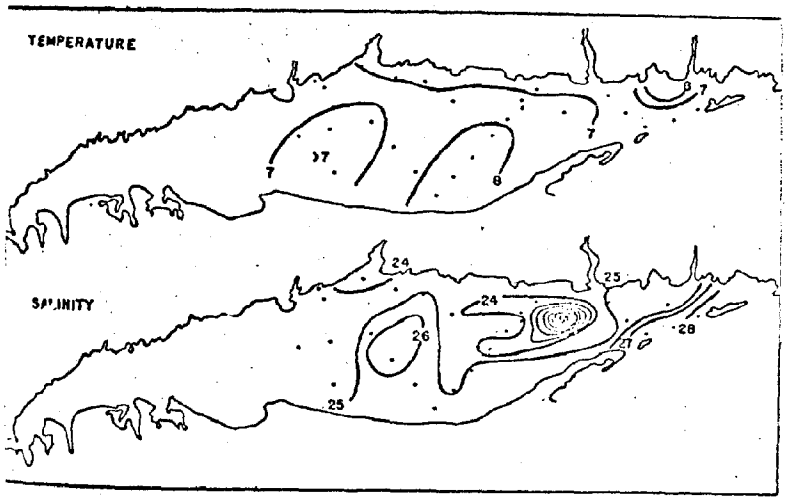

Figure 6. Surface temperature (°C) and salinity (°/oo). April 6 to 15, 1953.

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TRIGOM PARC	FIGURE 4-181	Surface Temperature and Salinity in Central Long Island Sound (Riley, 1959)

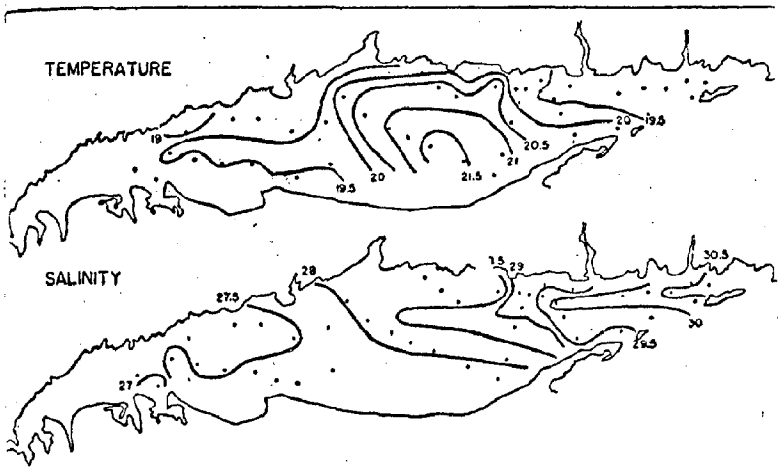

Figure 6. Surface temperature (°C) and salinity (°/oo) September 29 to October 8, 1952.

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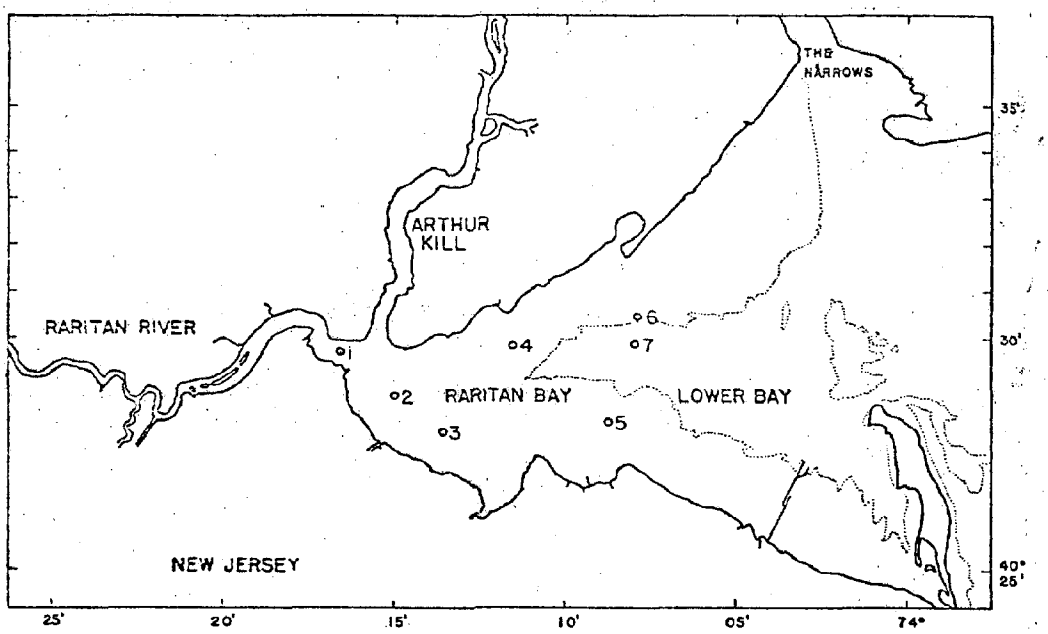
TRIGOM PARC	FIGURE 4-182	Surface Temperature and Salinity in Central Long Island Sound (Riley, 1959)



	Temperature					
	Surface stations			Bottom stations		
	1	5	6	1	5	6
Summer	24.3 ± 0.9	23.0 ± 1.0	23.2 ± 0.9	23.7 ± 0.7	22.1 ± 0.7	21.7 ± 0.8
Fall	11.7 ± 4.5	9.7 ± 4.3	11.1 ± 4.2	11.9 ± 4.0	10.0 ± 4.1	12.1 ± 5.2
Winter	3.4 ± 2.9	2.9 ± 1.6	2.4 ± 1.8	3.0 ± 2.0	3.4 ± 1.8	2.3 ± 1.5
Spring	14.1 ± 6.0	13.6 ± 5.5	12.0 ± 4.5	13.4 ± 5.3	12.4 ± 5.1	11.6 ± 4.9
Summer	24.0 ± 2.8	23.2 ± 3.0	22.8 ± 2.9	23.6 ± 1.2	22.3 ± 2.6	21.6 ± 2.5

	Salinity					
	Surface stations			Bottom stations		
	1	5	6	1	5	6
Summer	24.02 ± 1.14	26.37 ± 0.46	26.91 ± 0.60	24.26 ± 1.12	26.59 ± 0.54	27.10 ± 0.41
Fall	21.77 ± 2.24	26.12 ± 1.20	27.14 ± 0.71	22.71 ± 2.45	26.35 ± 1.22	27.28 ± 0.82
Winter	12.88 ± 6.86	19.55 ± 1.38	23.27 ± 2.17	18.93 ± 4.42	21.46 ± 3.14	22.75 ± 3.26
Spring	11.82 ± 6.91	17.98 ± 4.47	19.13 ± 6.41	16.50 ± 4.07	19.80 ± 4.36	20.69 ± 4.56
Summer	25.09 ± 2.22	26.23 ± 1.42	26.74 ± 0.82	24.95 ± 1.32	26.59 ± 1.72	27.39 ± 0.80

TABLE 2. *Mean daily discharge rate of Raritan River in ft³, sec, 1957–1958*

Month	1957	1958
January	925	2,739
February	1,754	1,854
March	1,578	3,716
April	3,022	3,246
May	648	2,359
June	280	557
July	131	709
August	95	360
September	122	346
October	148	—
November	283	—
December	2,393	—

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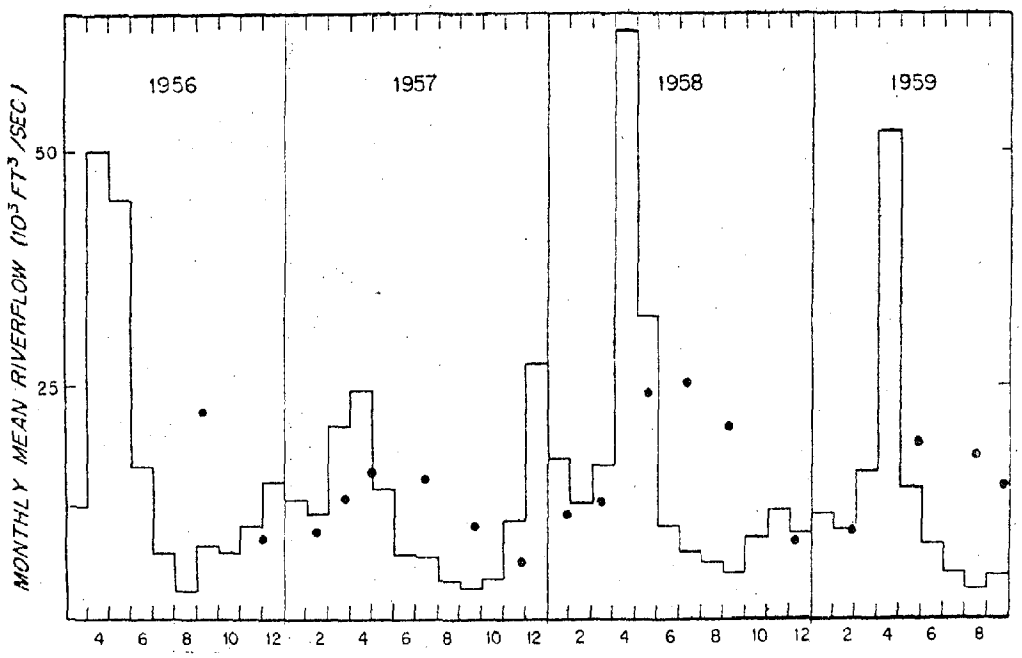
TRIGOM PARC

FIGURE 4-183

Sampling Stations Within Raritan Bay (Jeffries, 1962)



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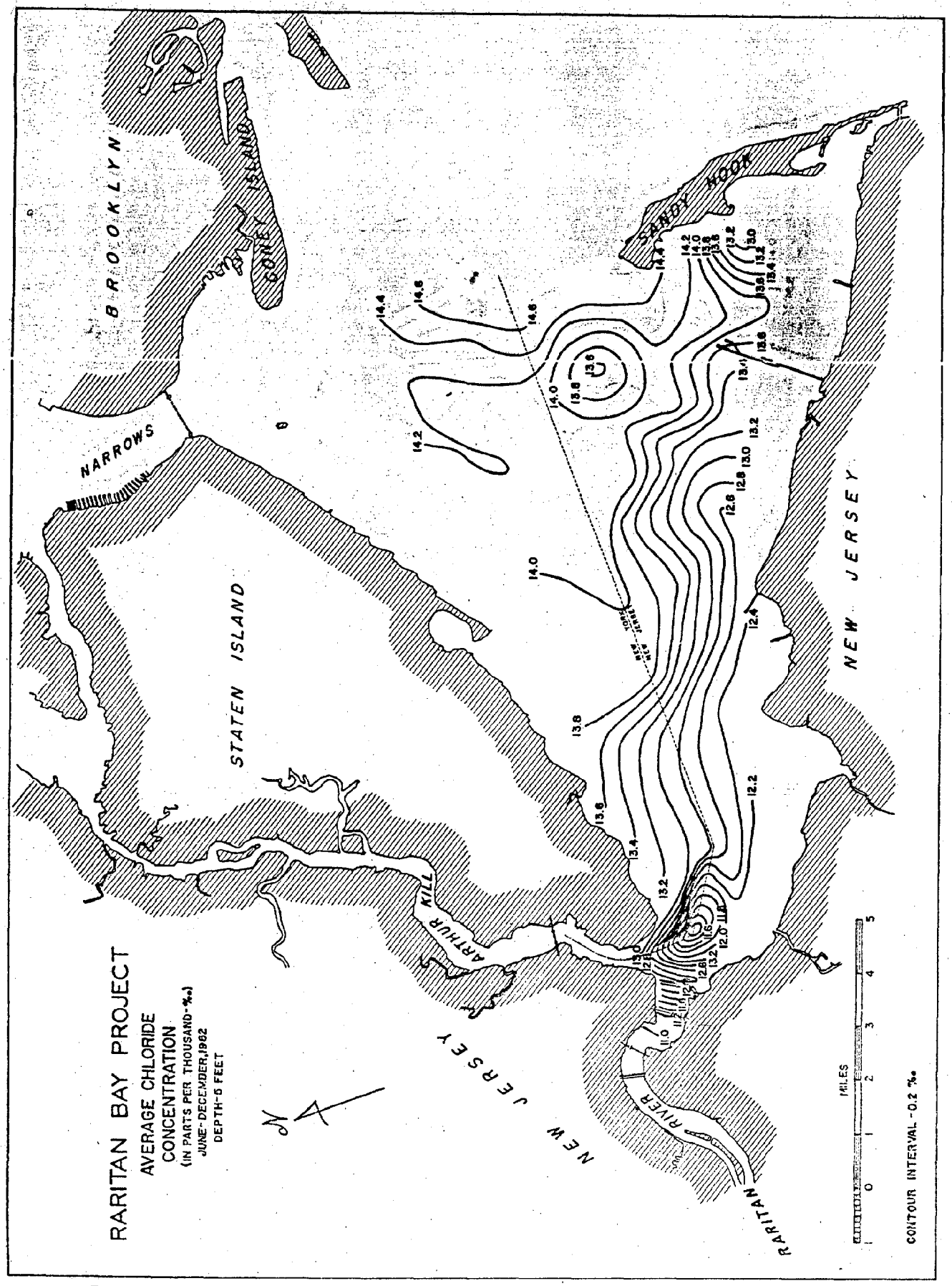
TRIGOM PARC	FIGURE 4-184	Seasonal River Discharge - Raritan Bay (Jeffries, 1962)



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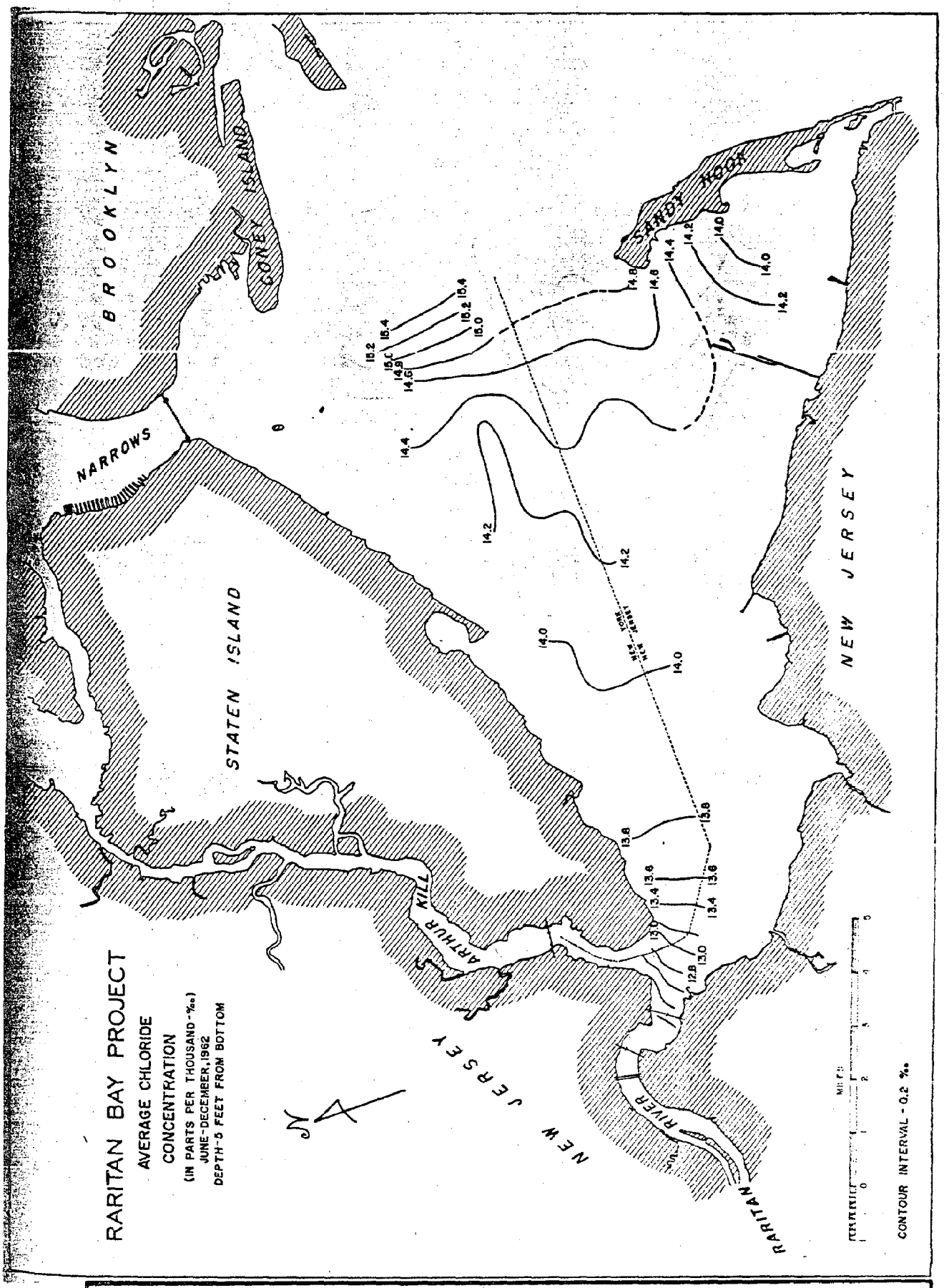
TRIGOM PADC

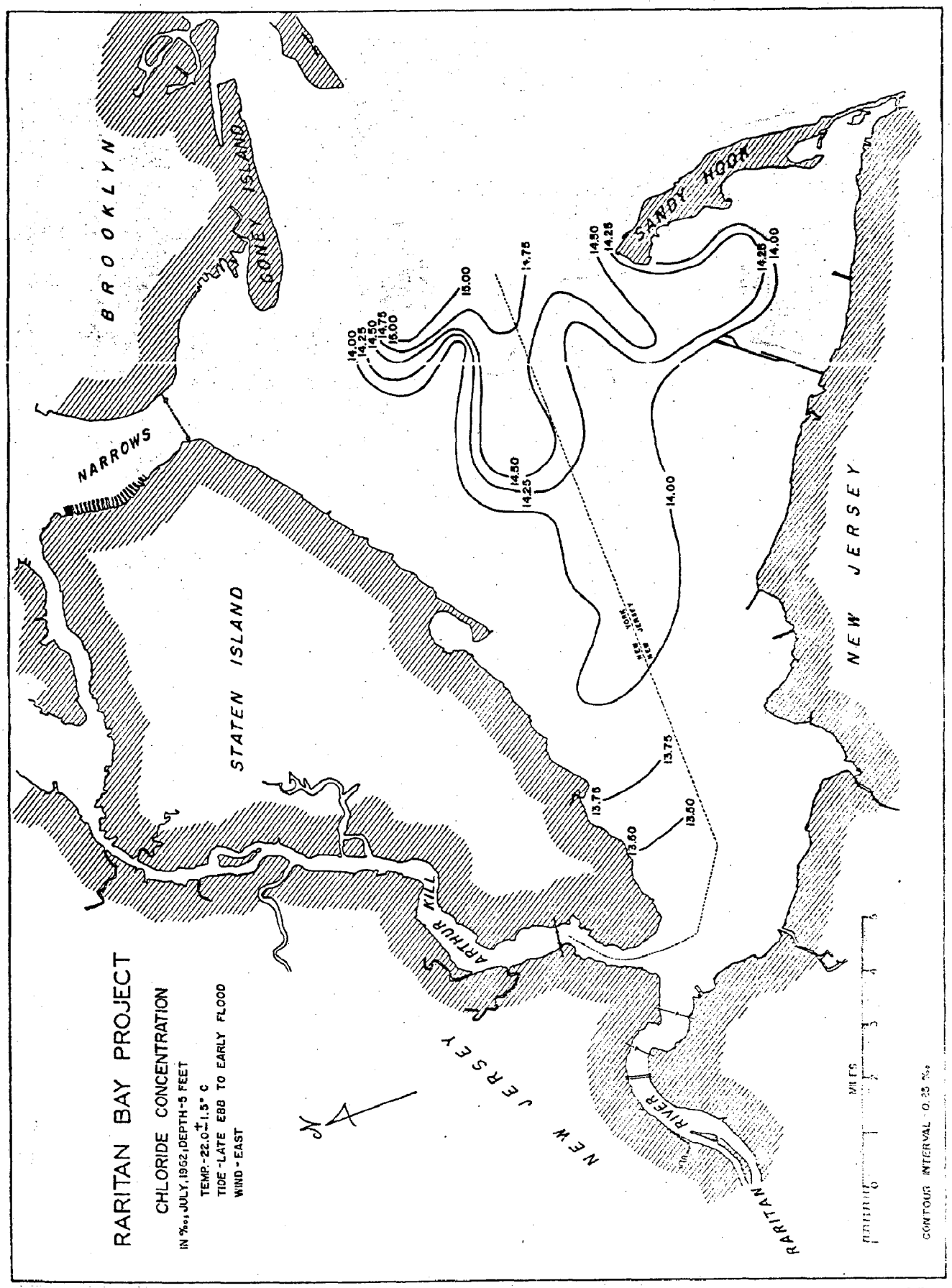
FIGURE 4-185

Mean Chloride Concentration at - 5 Feet - Raritan Bay (Public Health Service, 1953 & 1957)



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

TRIGOM PARC | FIGURE 4-186 | Mean Chloride Concentration - 5 Feet From Bottom - Raritan Bay (Public Health Service 1953 & 1957)



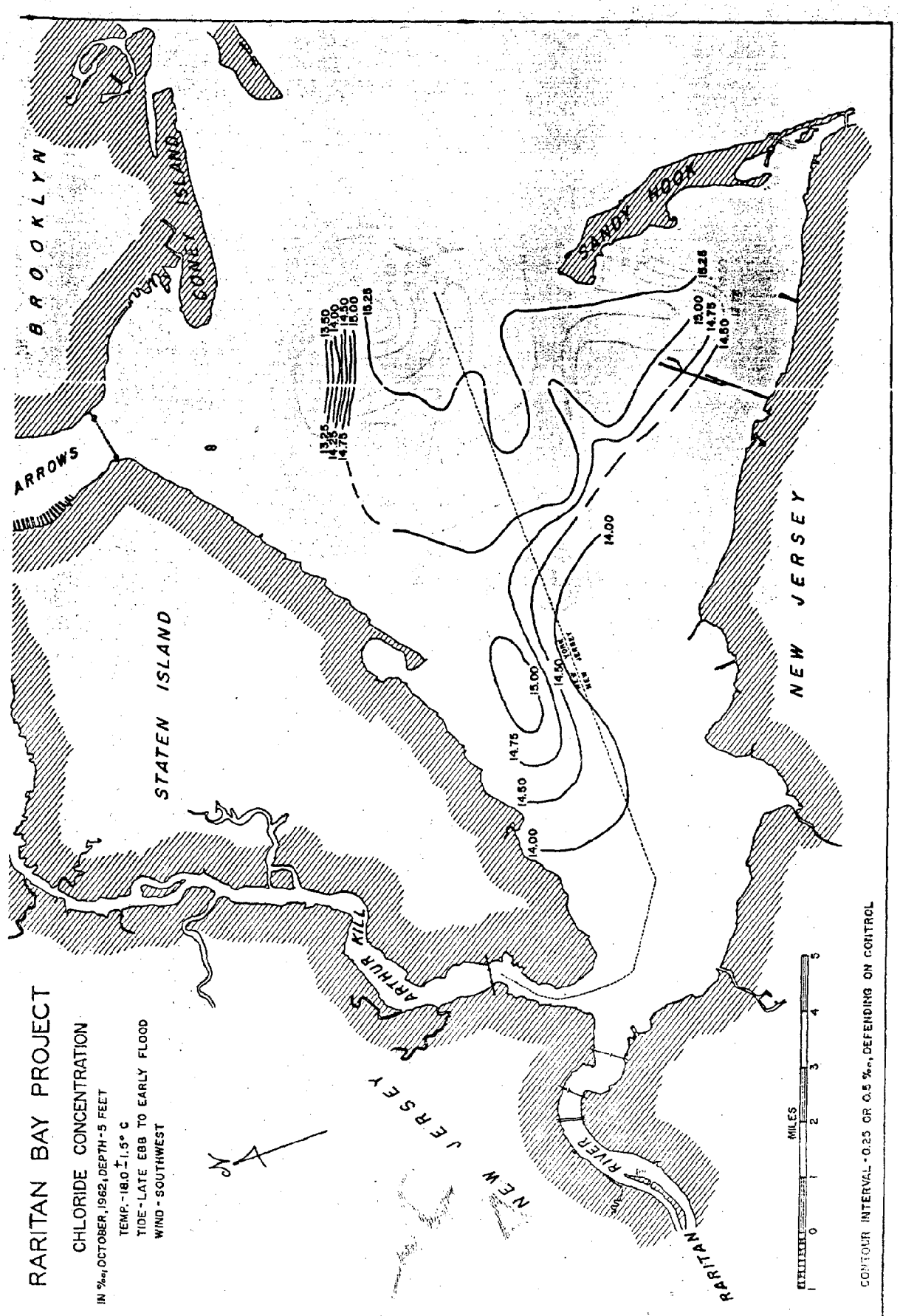
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

4-330

TRIGOM

FIGURE 4-197

Chloride Concentration in Raritan Bay at - 5 Feet in July, 1962 (Public Health Service 1953 & 1957)

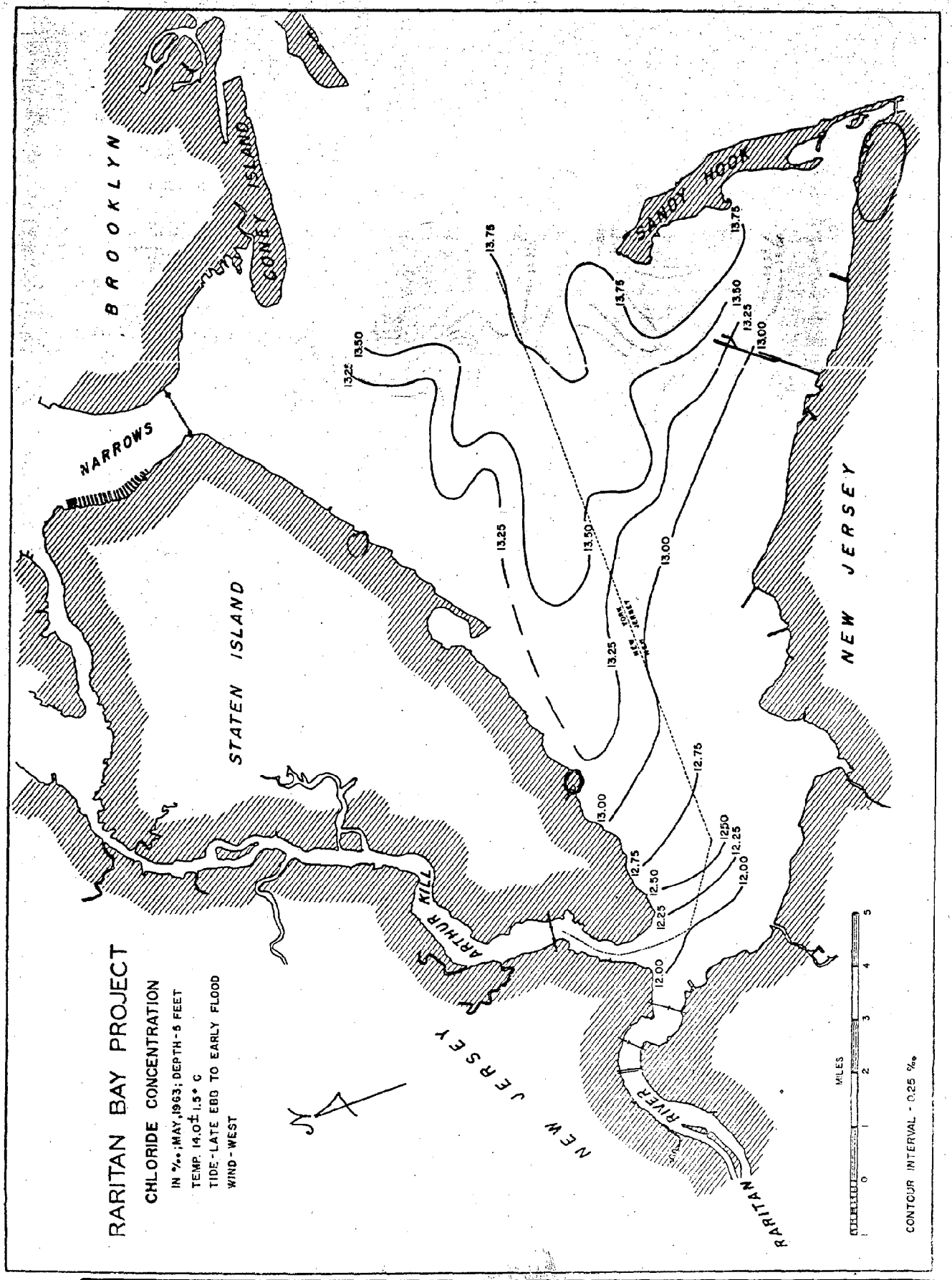


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

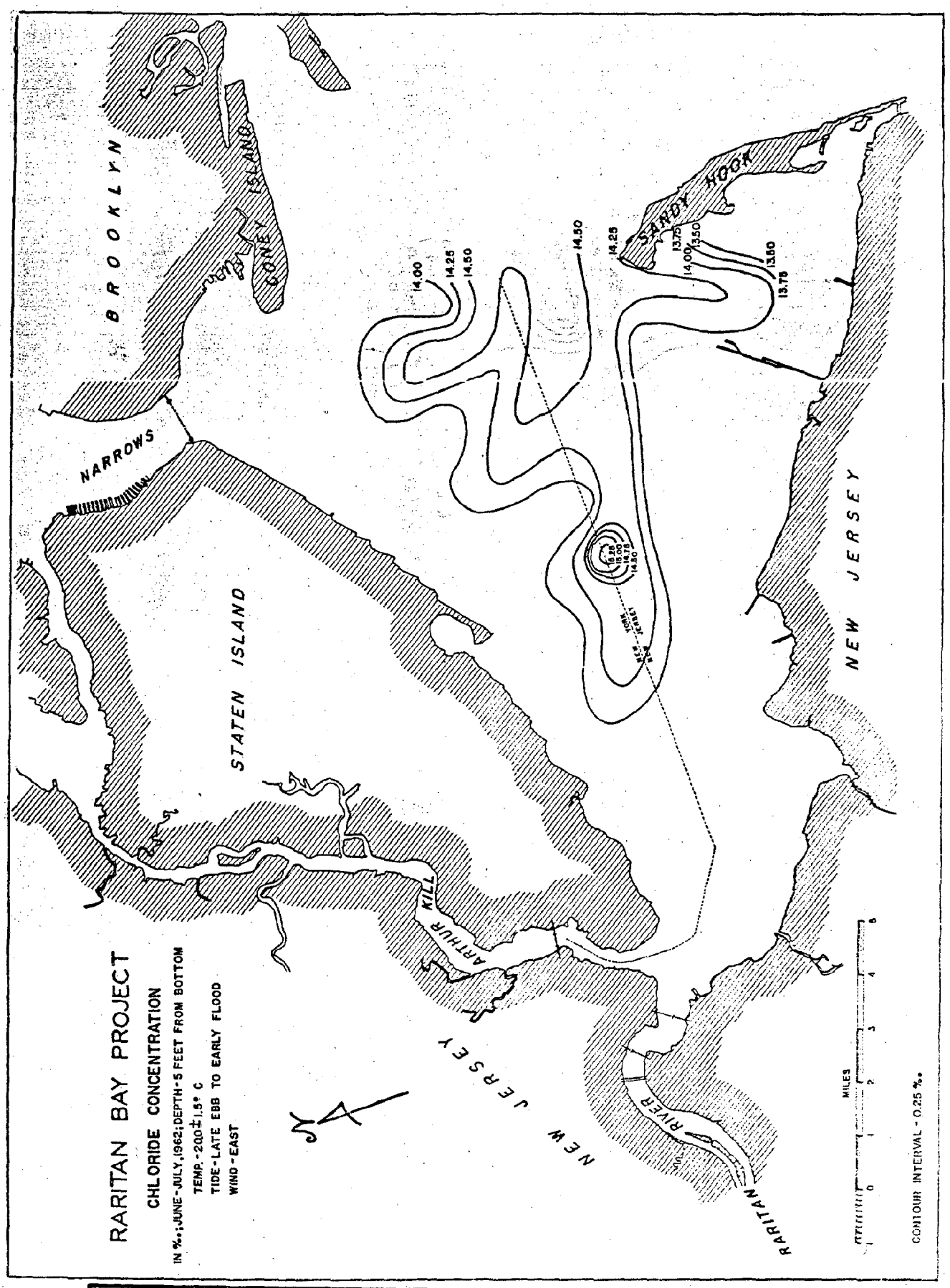
FIGURE 4-188

Chloride Concentration in Raritan Bay at - 5 Feet in October, 1962 (Public Health Service 1953 & 1957)



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

TRIGOM DADC | FIGURE 4-189 | Chloride Concentration in Raritan Bay at - 5 Feet in May 1963 (Public Health Service 1953 & 1957)

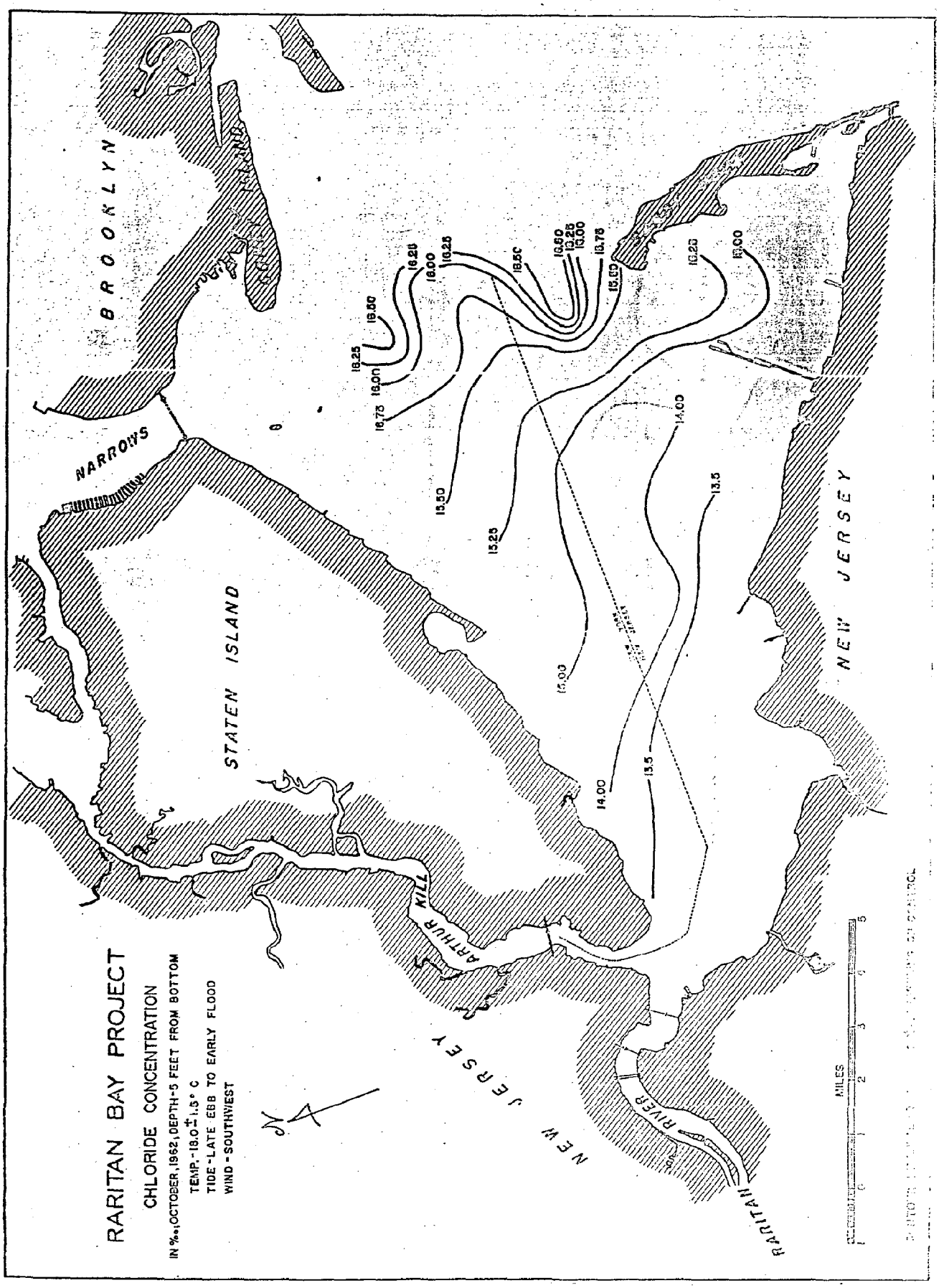


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 4-190

Chloride Concentration in Raritan Bay at - 5 Feet from Bottom in July 1972 (Public Health Service 1953 & 1957)

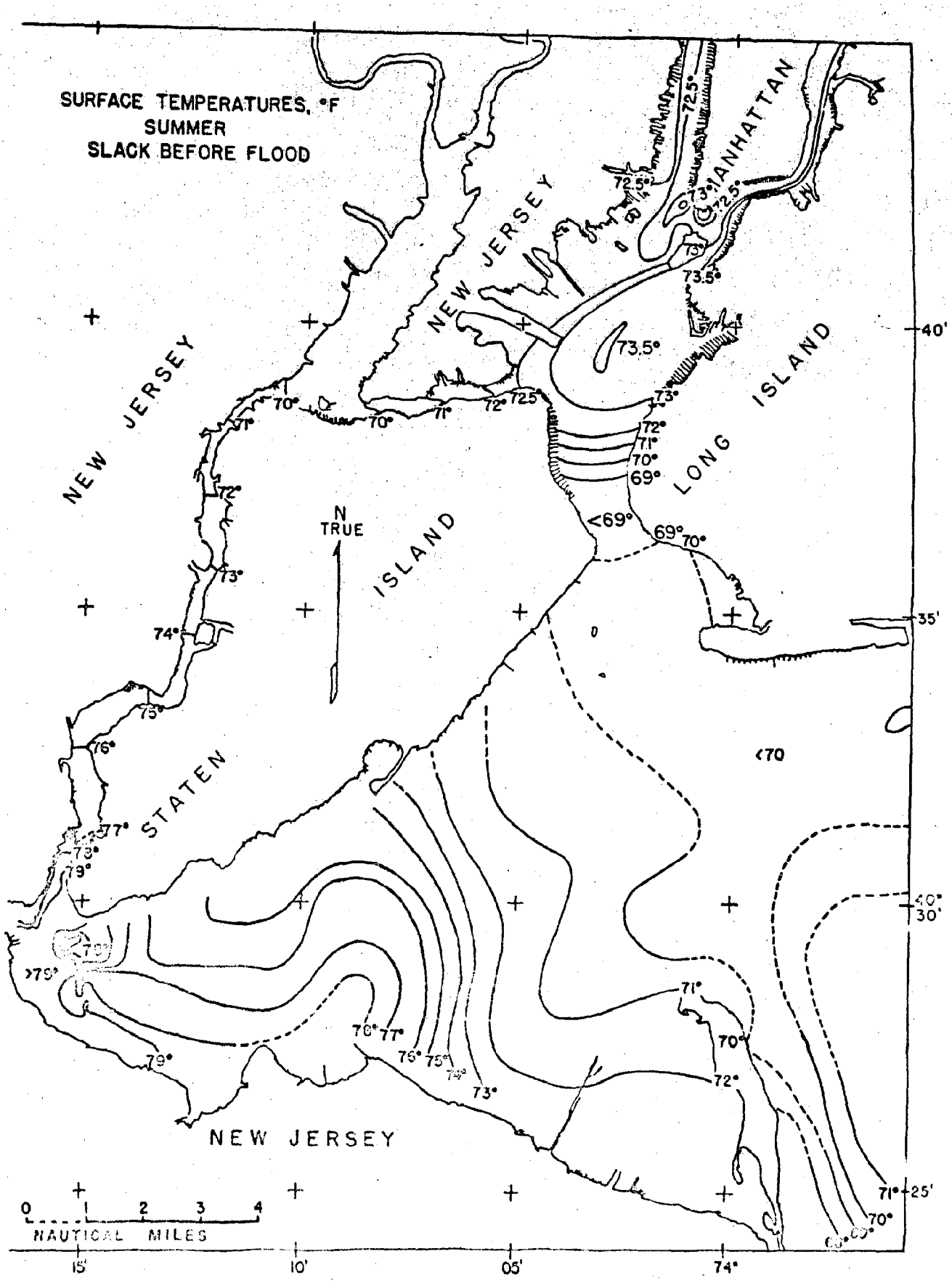


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

FIGURE 4-191

Chloride Concentration in Raritan Bay
October 1962 (Public Health Service 1953 & 1957)

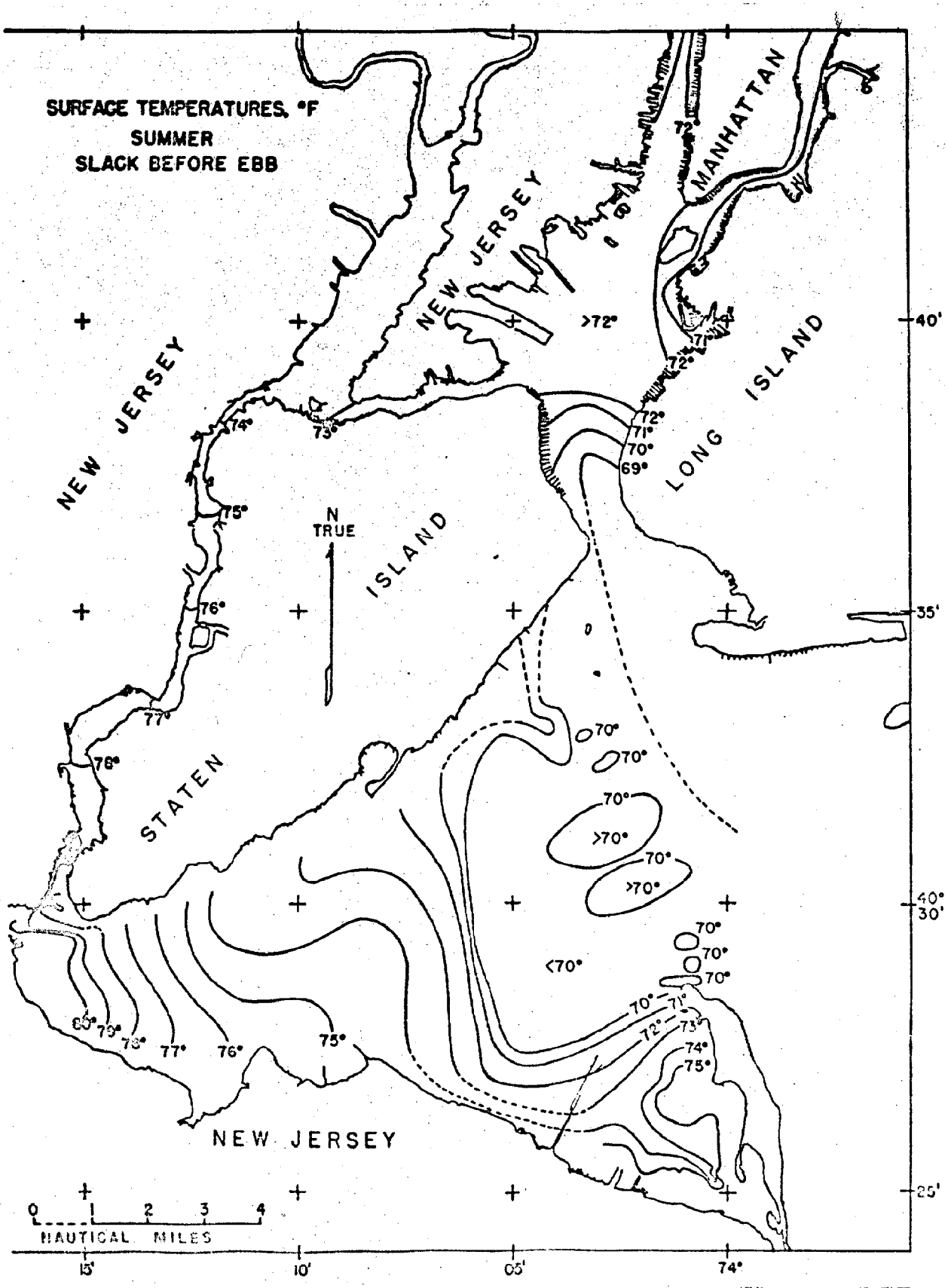


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

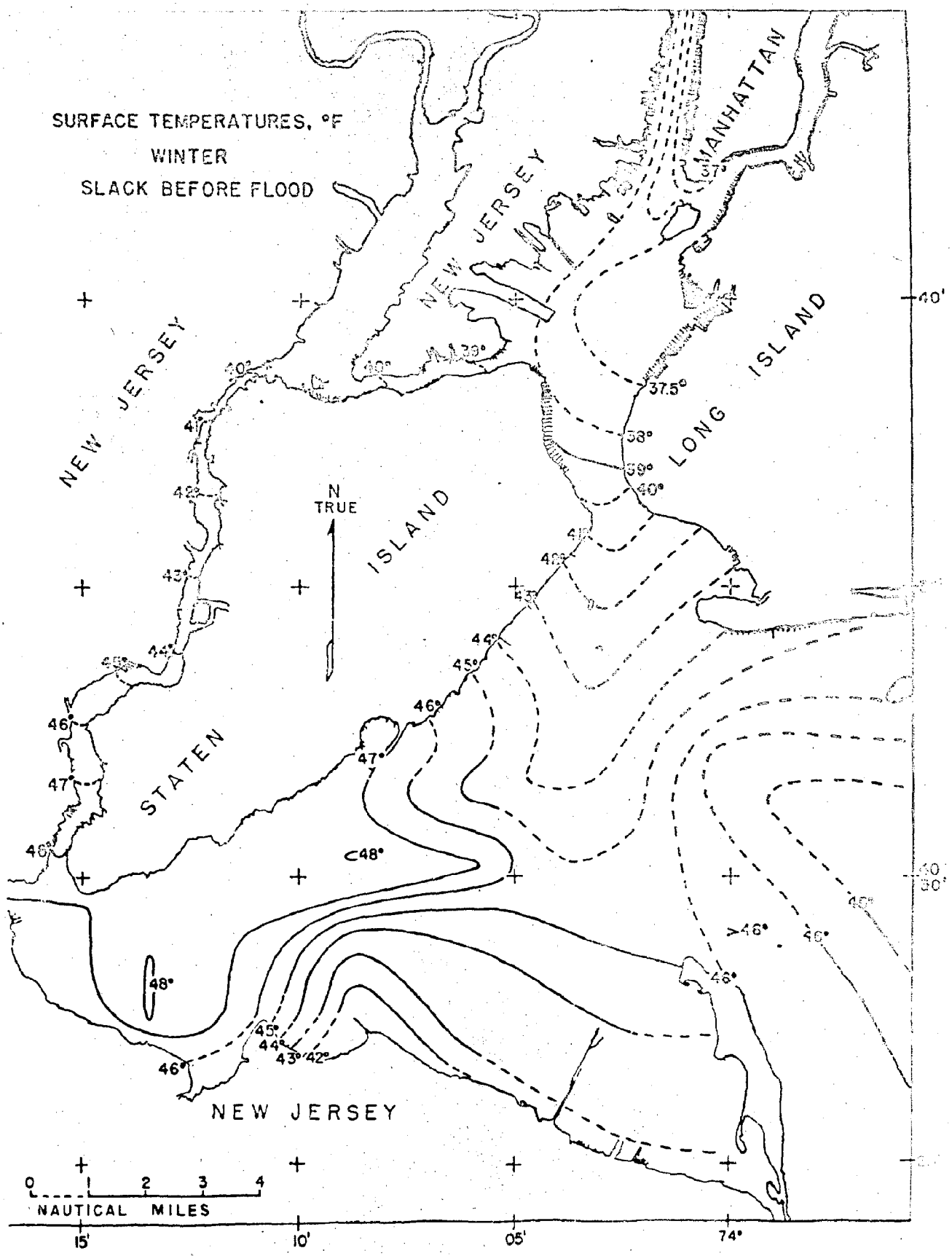
FIGURE 4-192

Surface Isotherms for New York Harbor - Summer - Slack Before Flood (Public Health Service 1953 & 1957)



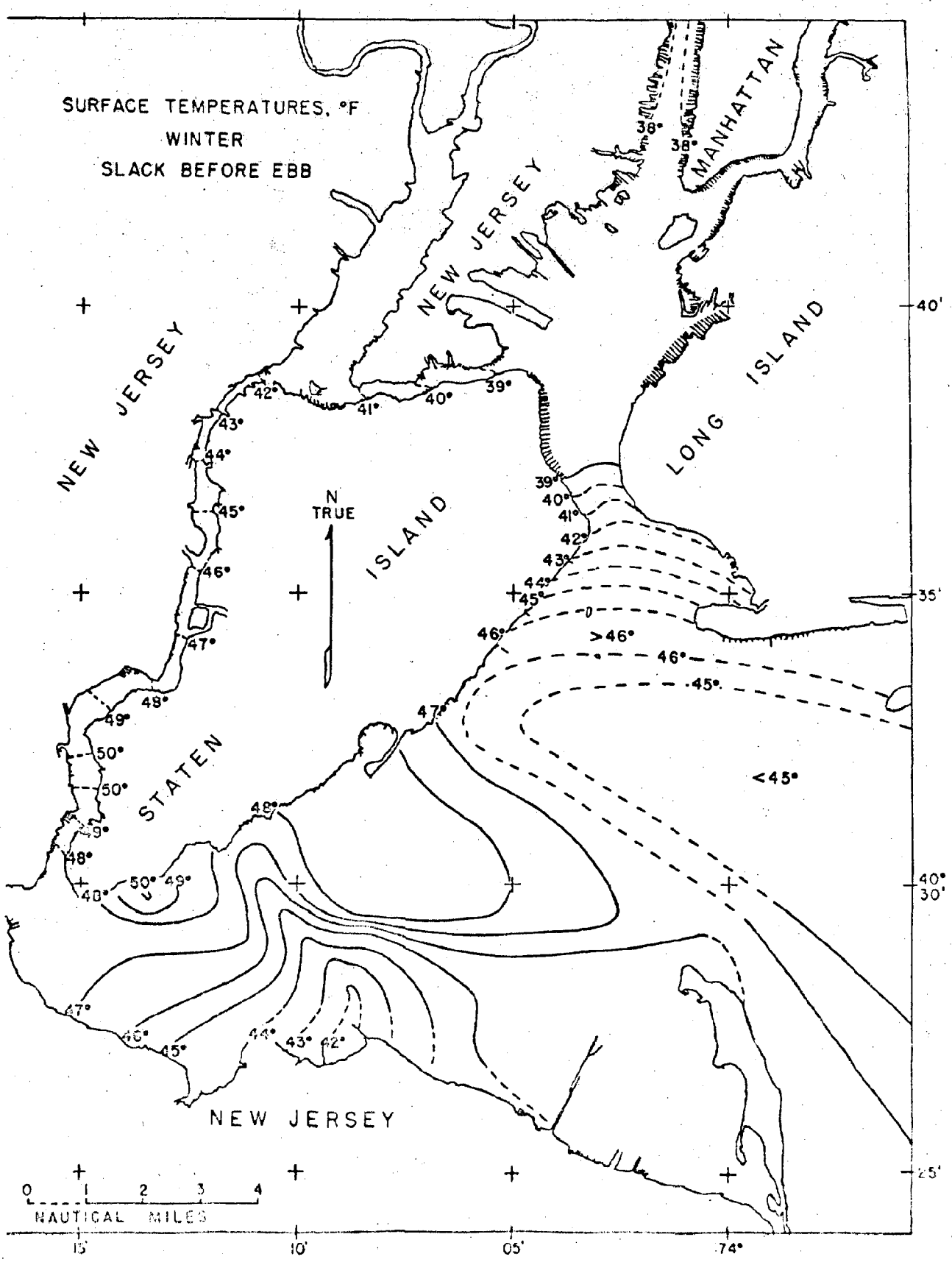
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-193	Surface Isotherms for New York Harbor - Summer - Slack Before Ebb (Public Health Service 1953 & 1957)



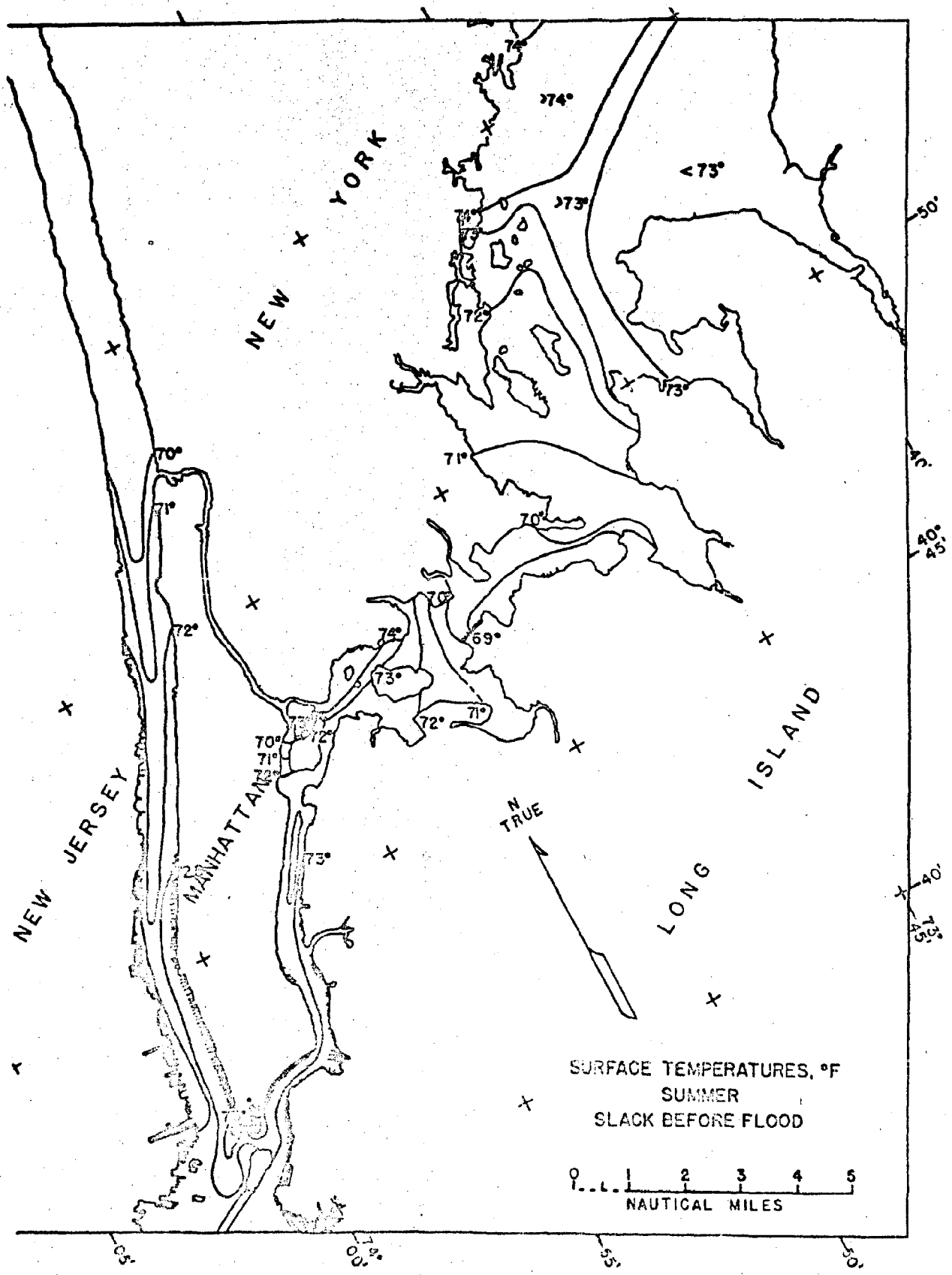
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-194	Surface Isotherms for New York Harbor - Winter - Slack Before Flood (Public Health Service 1953 & 1957)



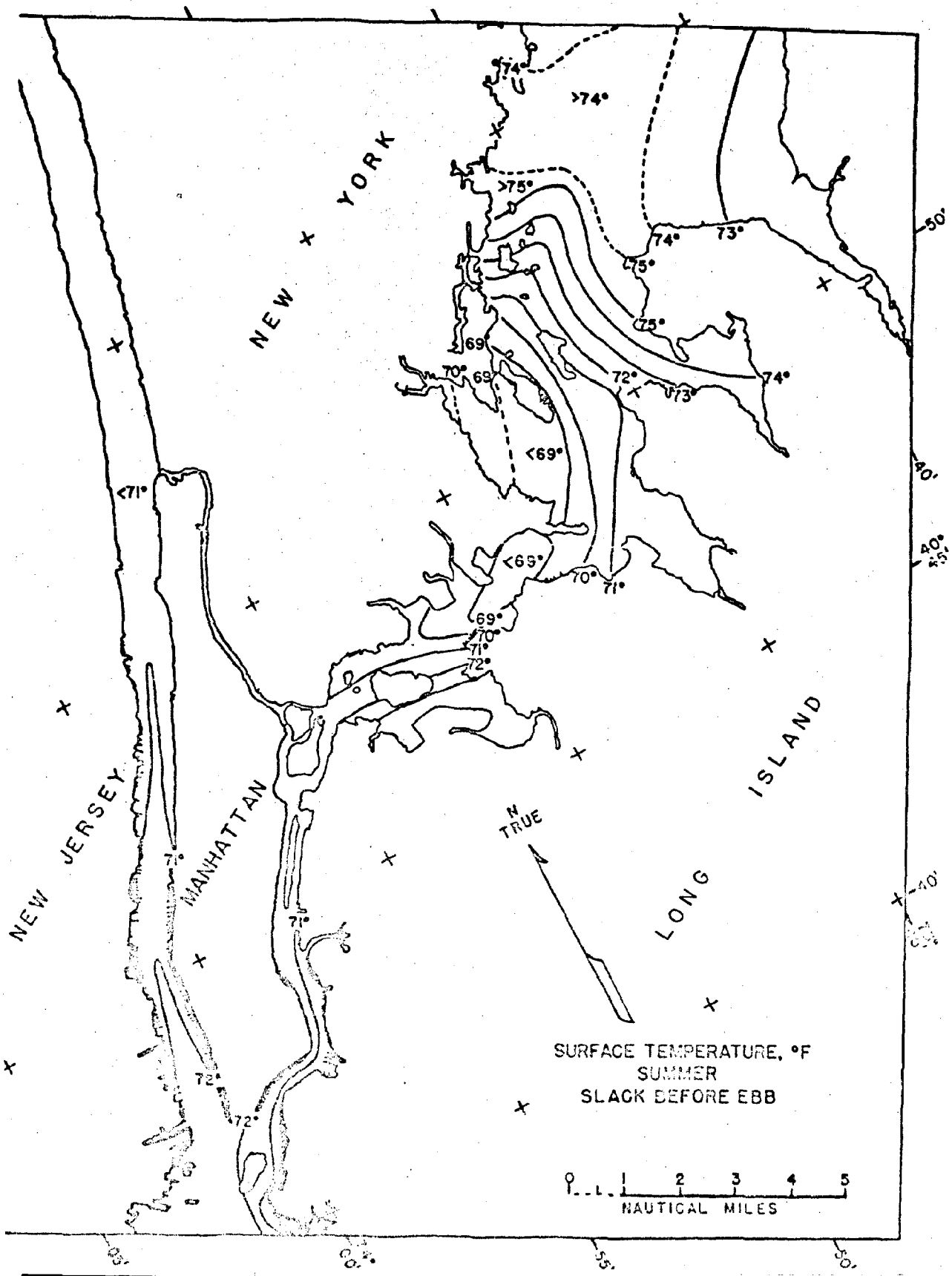
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-195	Surface Isotherms for New York Harbor - Winter - Slack Before Ebb (Public Health Service 1953 & 1957)



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

TRIGOM PARC	FIGURE 4-196	Surface Isotherms for New York Harbor - Summer - Slack Before Flood (Public Health Service 1953 & 1957)

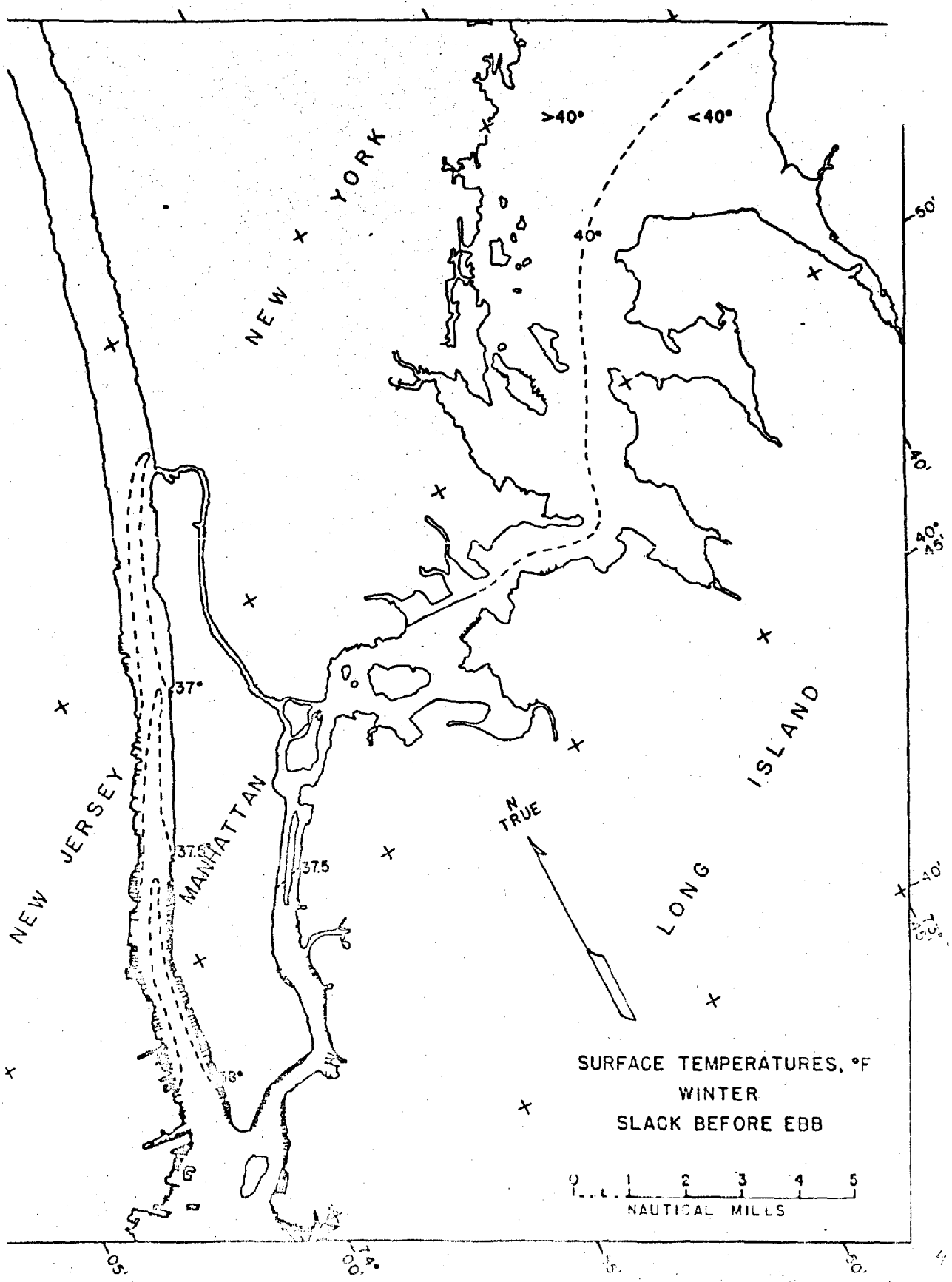


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

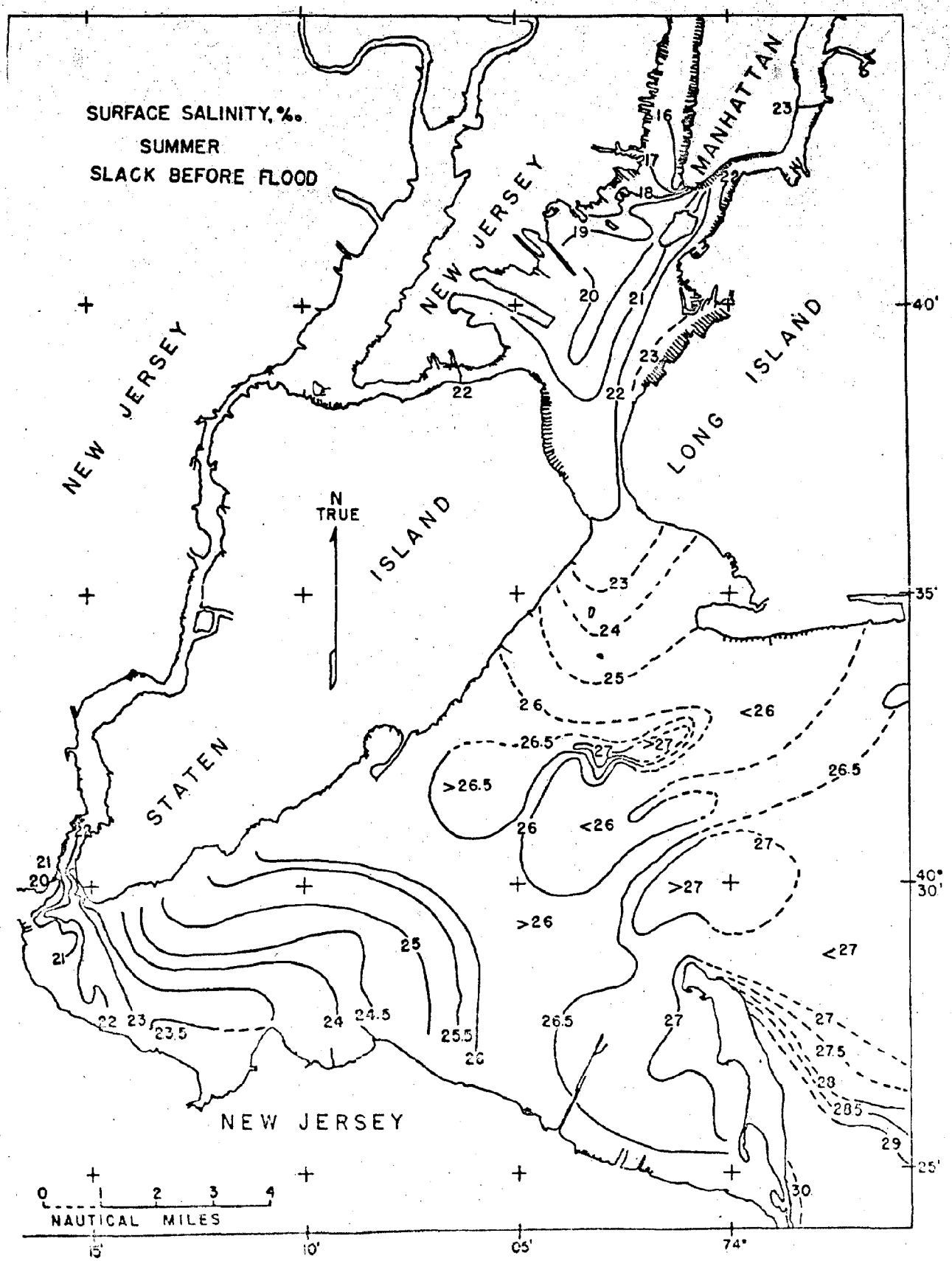
FIGURE 4-197

Surface Isotherms for New York Harbor - Summer - Slack Before Ebb (Public Health Service 1953 & 1957)



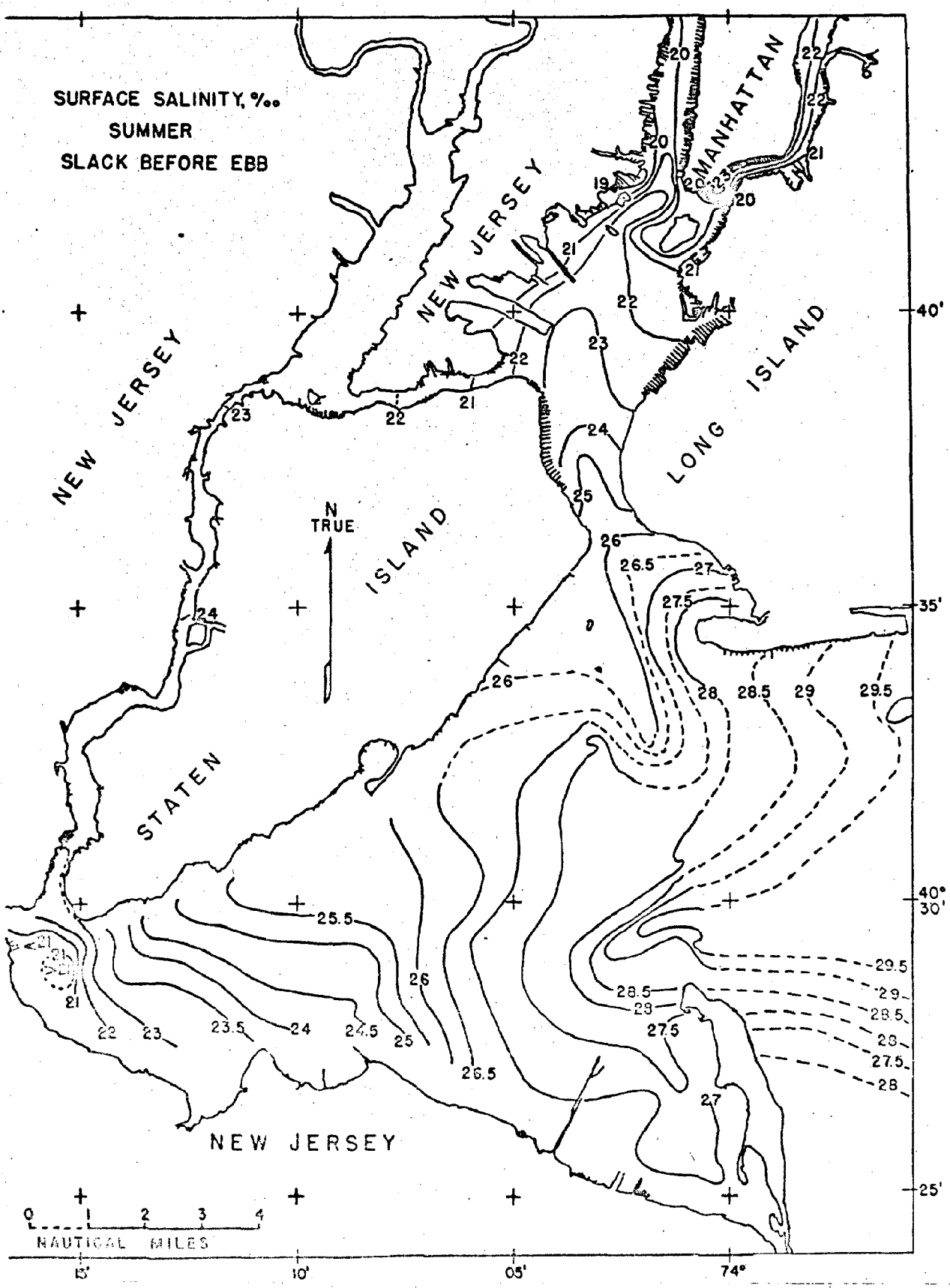
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 4-198 | Surface Isotherms for New York Harbor - Winter - Slack Before Ebb (Public Health Service 1953 & 1957)



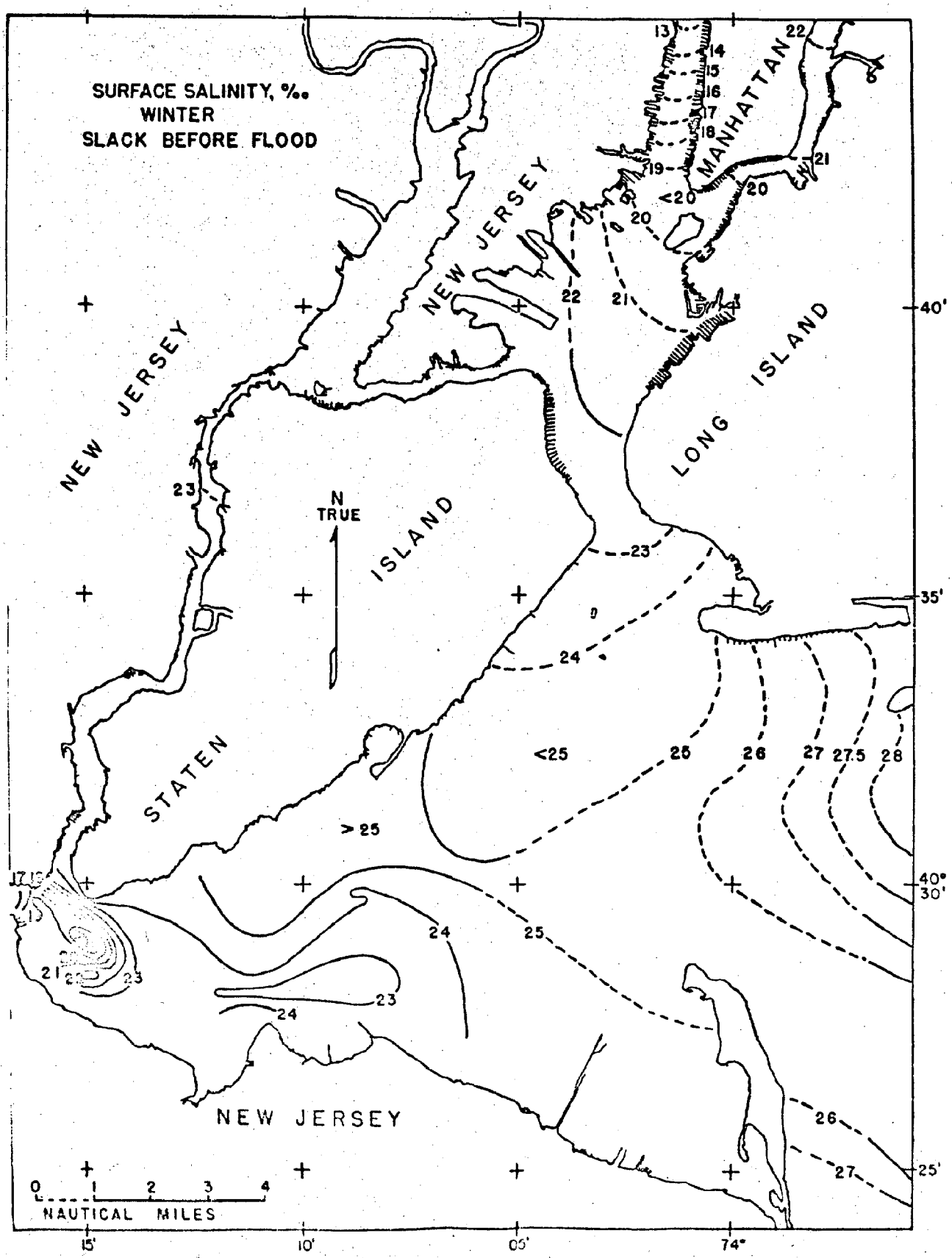
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-199	Surface Isohalines for New York Harbor - Summer - Slack Before Flood (Public Health Service 1953 & 1957)



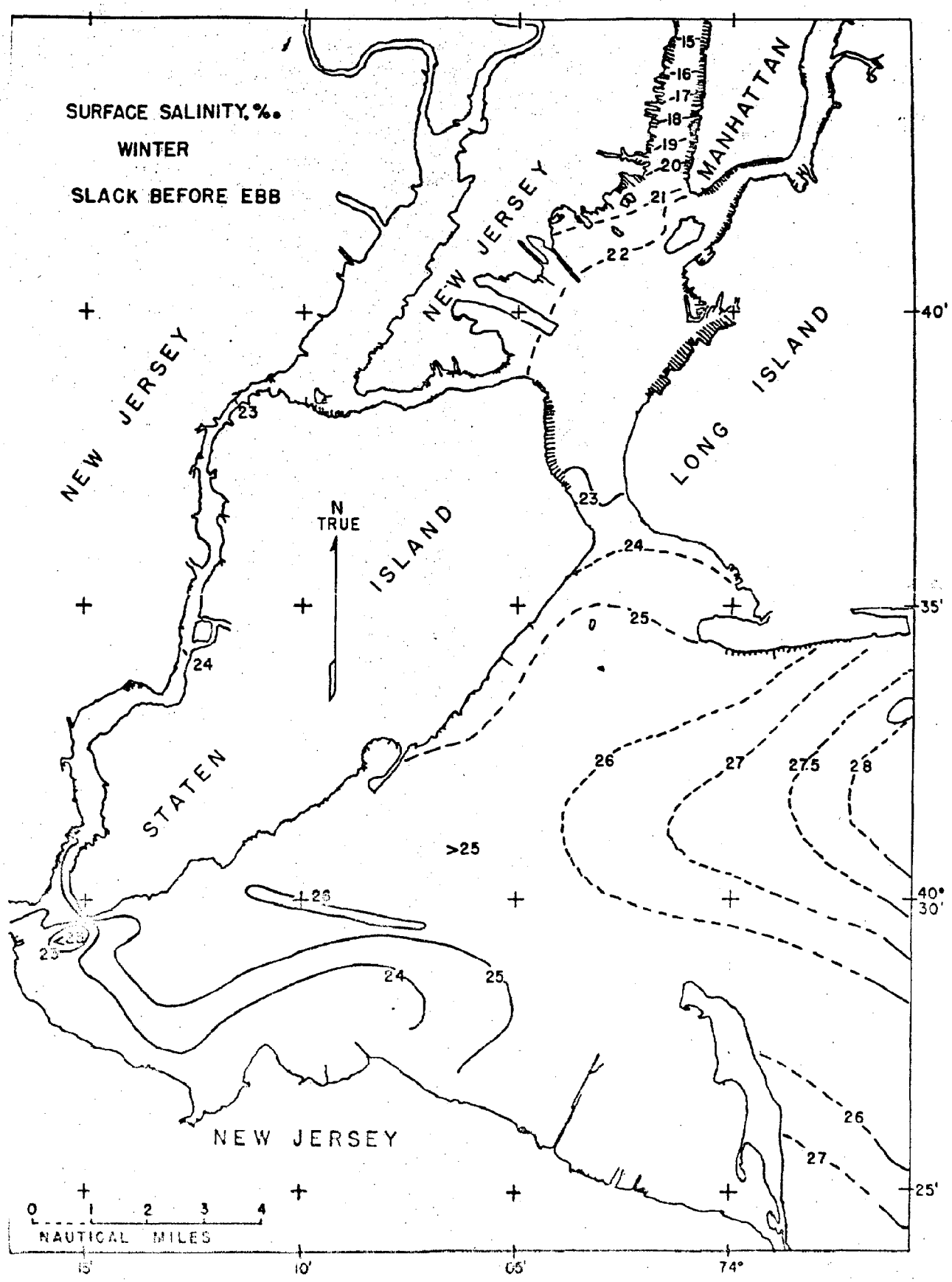
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-200	Surface Isohalines for New York Harbor - Summer - Slack Before Ebb (Public Health Service 1953 & 1957)



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

TRIGOM PARC	FIGURE 4-201	Surface Isohalines for New York Harbor - Winter - Slack Before Flood (Public Health Service 1953 & 1957)

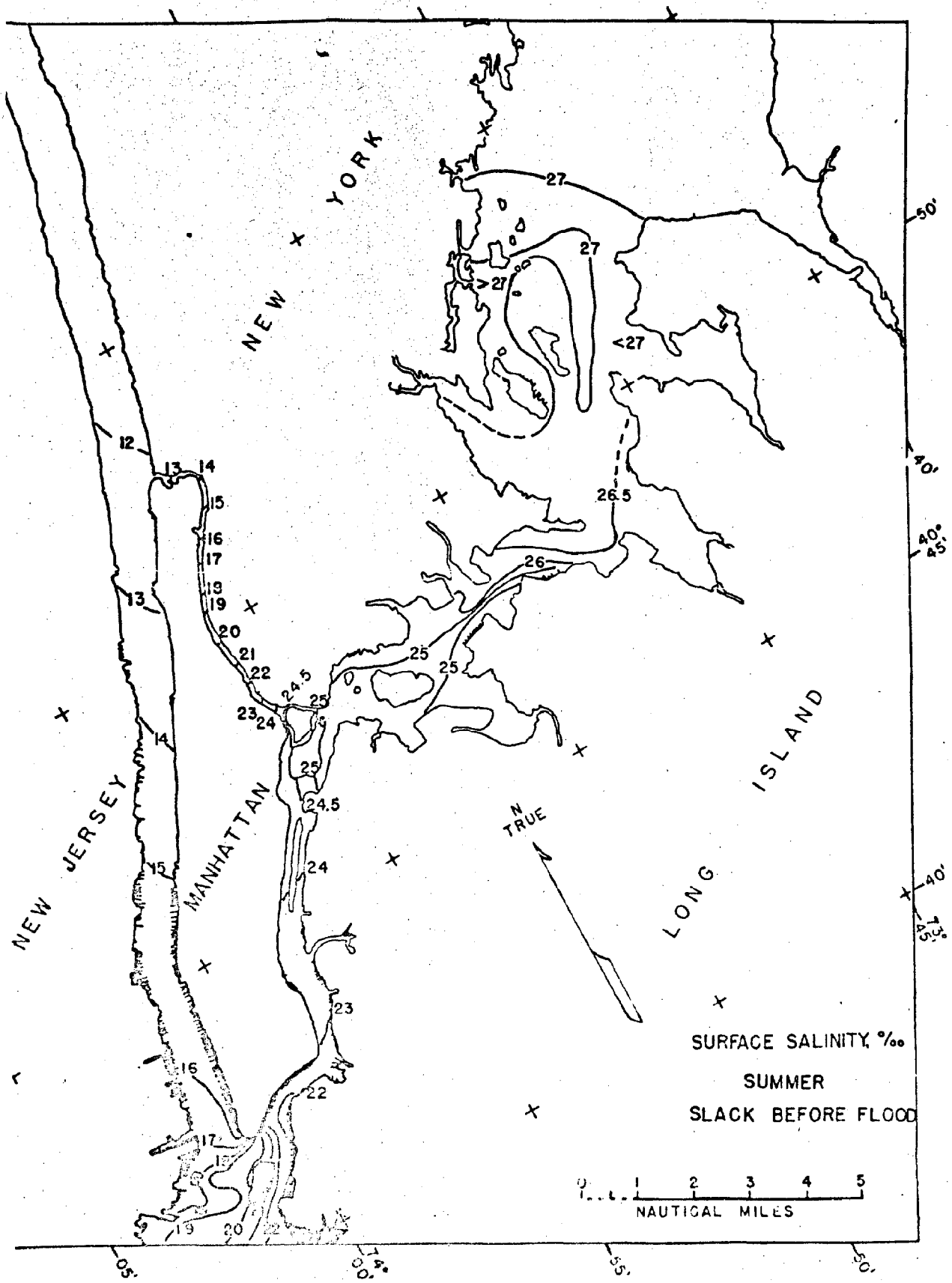


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

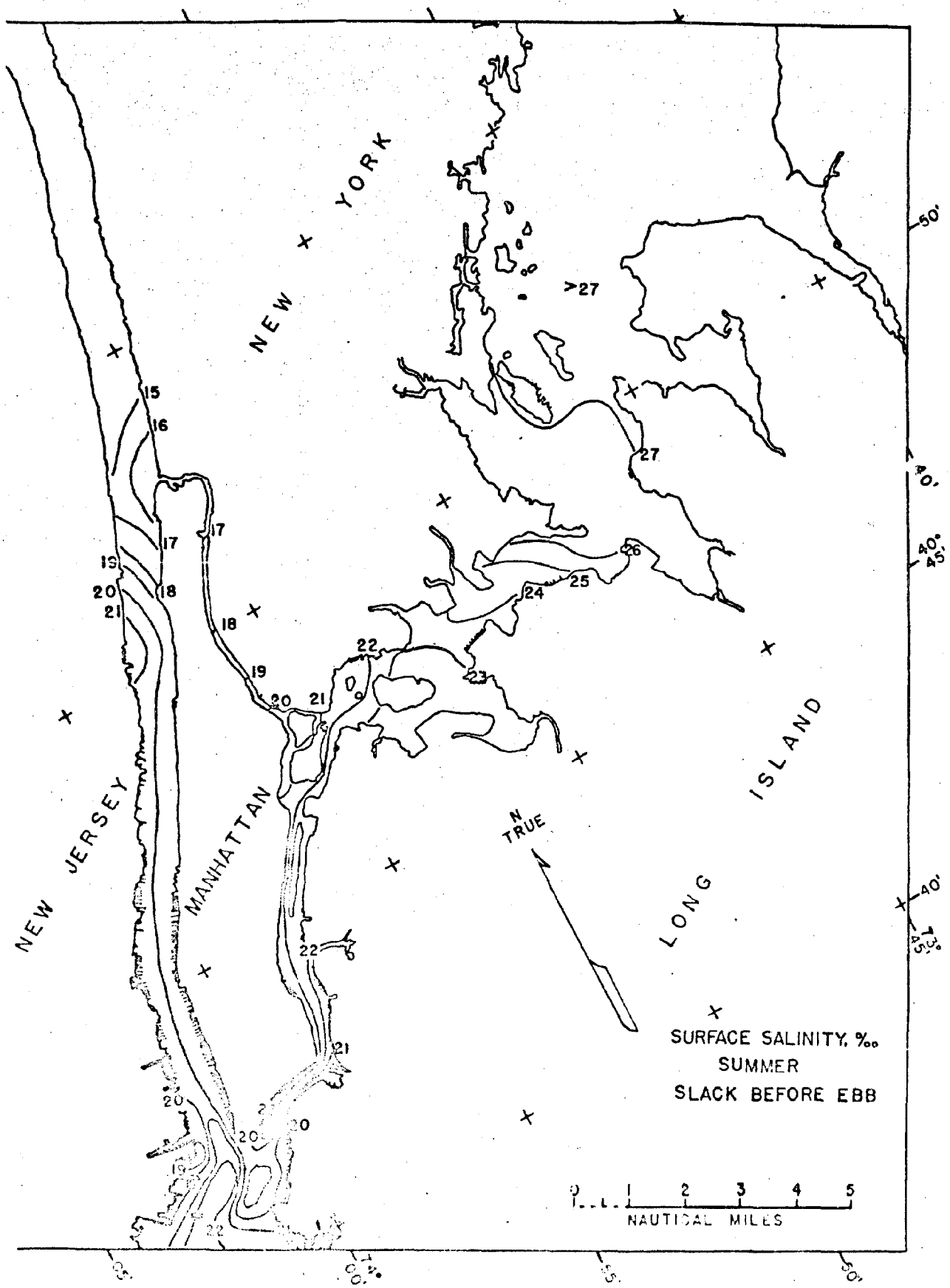
FIGURE 4-202

Surface Isohalines for New York Harbor - Winter - Slack Before Ebb (Public Health Service 1953 & 1957)



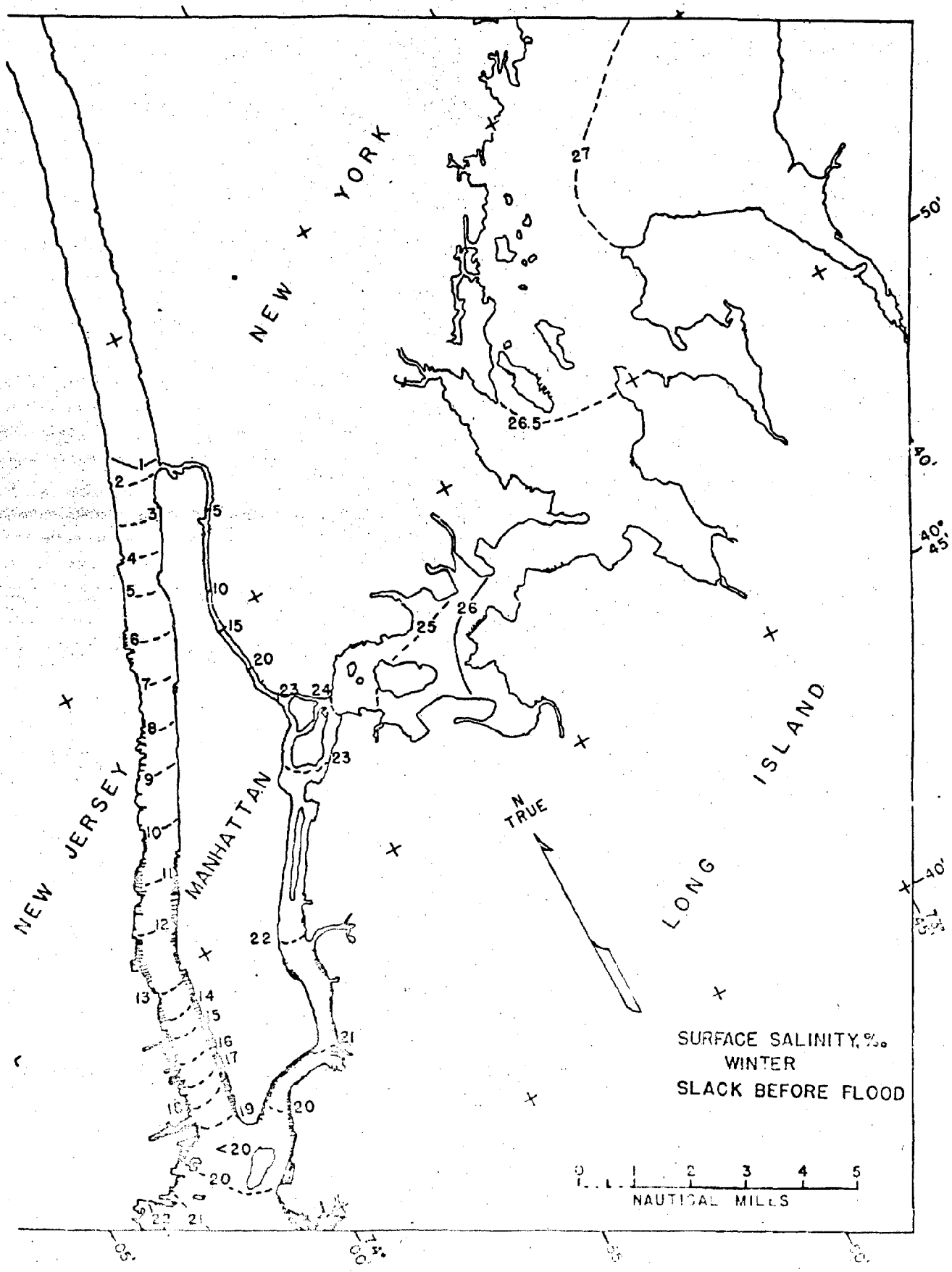
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-203	Surface Isohalines for New York Harbor - Summer - Slack Before Flood (Public Health Service 1953 & 1957)



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

TRIGOM DADC | FIGURE 4-204 | Surface Isohalines for New York Harbor - Summer - Slack Before Ebb (Public Health Service 1953 & 1957)

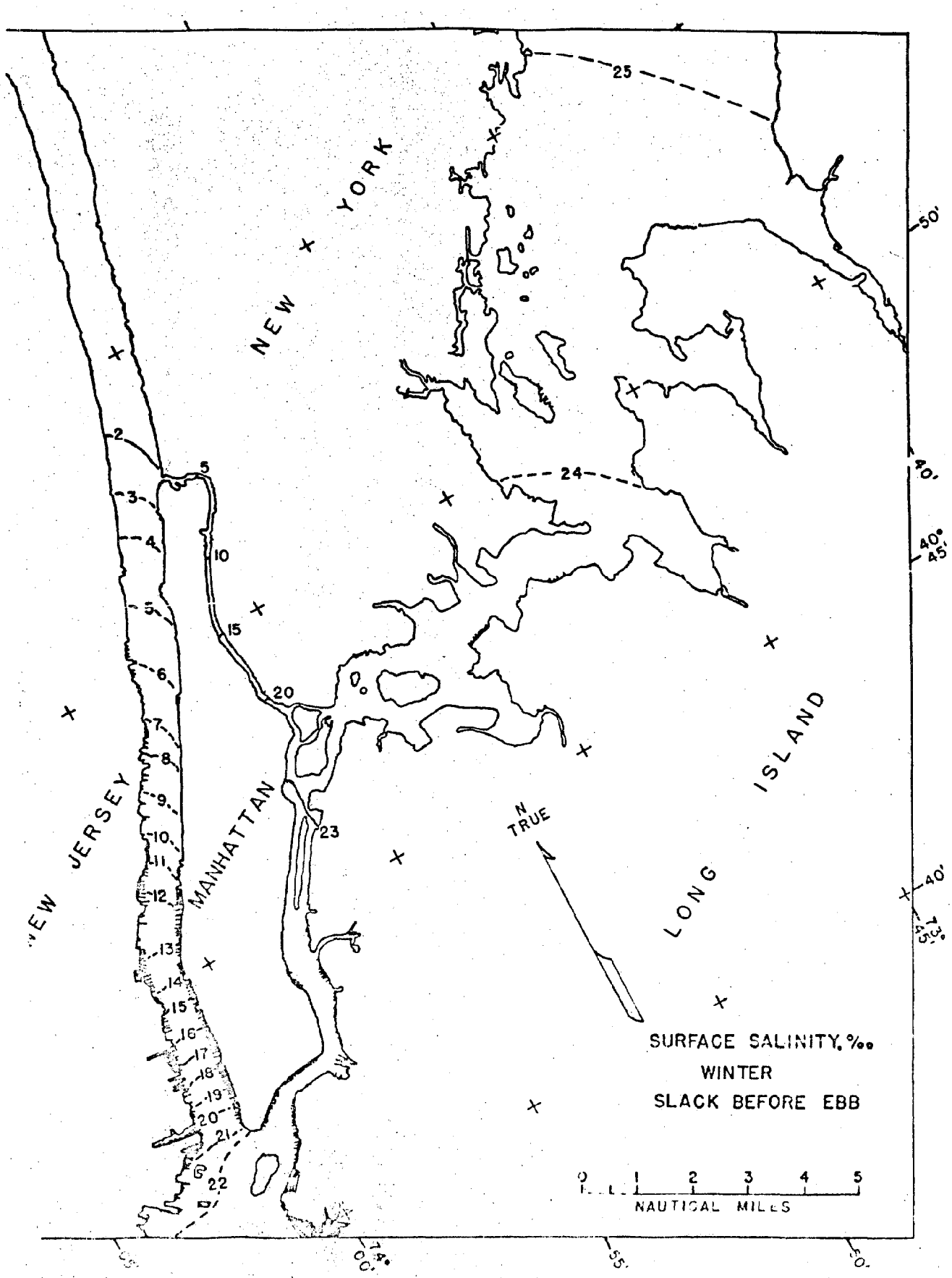


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

IRIGOM PADC

FIGURE 4-205

Surface Isohalines for New York Harbor - Winter - Slack Before Flood (Public Health Service 1953 & 1957)



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

TRIGOM PARC | FIGURE 4-206 | Surface Isohalines for New York Harbor - Winter - Slack Before Ebb (Public Health Service 1953 & 1957)

Chapter 4 Major Sounds and Embayments

		Page
Chapter 4.3	Chemical Oceanography of Coastal Waters	
4.3.1	Areas South of Cape Cod	4-352
	Continental Shelf South of Long Island	4-352
4.3.2	New York Bight	4-354
4.3.3	Raritan Bay	4-364
4.3.4	Long Island Sound	4-364
4.3.5	Narragansett Bay	4-370
4.3.6	Massachusetts Bay	4-377
4.3.7	Cape Ann to Cape Elizabeth	4-379
4.3.8	Casco Bay to Eastport	4-395
4.3.9	References	4-406

4.3 COASTAL WATERS

4.3.1 AREAS SOUTH OF CAPE COD

Continental Shelf South of Long Island

The continental shelf discussed here is that area east of New Jersey and south of Long Island to Cape Cod and to a depth of about 200 meters.

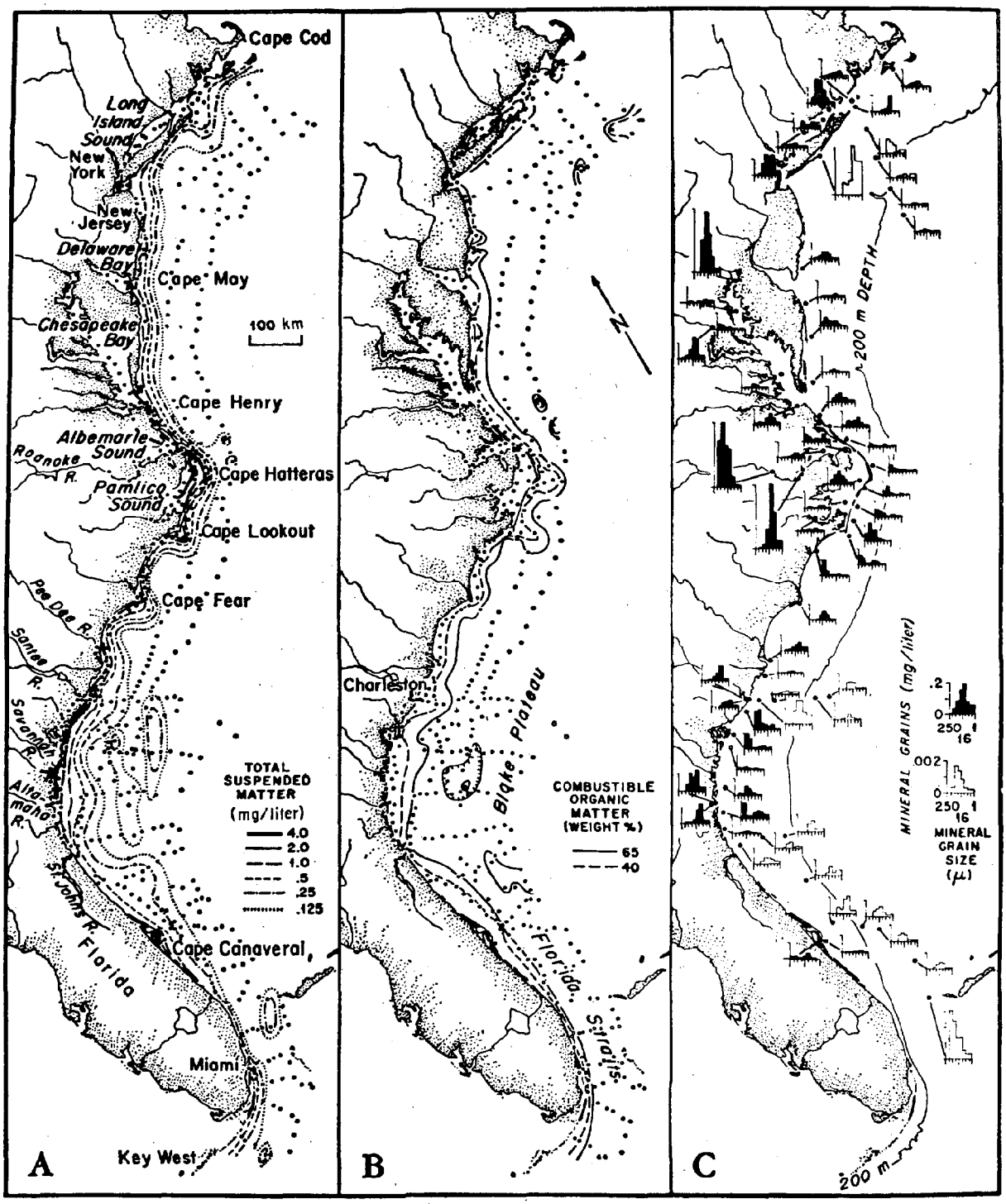
A review of the distribution of dissolved oxygen, nutrients, and other chemical parameters has been discussed by Kester and Courant (1973) and Smayda (1973). Much of their data was taken from that collected in September, 1969, by the R/V Atlantis II and summarized in a comprehensive data report by Corwin (1970). Colton, Marak, Nickerson and Stoddard (1968) reported dissolved oxygen data for some of this area collected by R/V Albatross IV (Figures 4-188 to 4-191). Nutrient data for a triangular set of 25 stations south of New York have been reported by Ketchum, Ryther, Yentsch, and Corwin (1958); and Vaccaro (1963).

Ryther and Dunstan (1971) reported some nutrient and particulate organic carbon data for surface waters on three transects from the New York Bight (Figure 4-43 of this report). A detailed study of the concentration of urea and inorganic nitrogen was reported by Remson (1971), who found an average surface layer concentration of 1.32 μg-at Urea-N/liter. Harvey, Steinhauer, and Teal (1973b) reports one PCB (polychlorinated biphenyl) concentration (29 mg/l) for surface water in the area south of Cape Cod. Although trace metal analyses must have been run on water from this area, none were found in our literature search.

The suspended matter in the surface waters on the Atlantic continental margin has been summarized by Manheim, Meade and Bond (1970). Their study was conducted during May and June, 1965, and aimed at determining the concentration by weight and composition of the suspended matter. Of the 600 total stations, 72 stations were occupied in the waters south of Cape Cod to Sandy Hook (Figure 4-207).

Only within a few kilometers off the coast were concentrations greater than 1.0 mg/l found. Concentrations of suspended matter in the offshore surface waters were 0.1 mg/l or less. In general during these months, particles that escaped the estuaries tended to travel longshoreward rather than seaward (Manheim et al. 1970).

The composition of the offshore particles was greater than 65 percent cumbustible organic matter by weight, and chiefly composed of amorphous organic particles with widespread occurrences of soot, fly-ash, processed cellulose and other pollutants. Manheim et al. (1970) did not present any quantitative data on the percentage of suspended material that was pollutants, but did remark that they were particularly evident in the New York Bight area.



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

TRIGOM PARC	FIGURE 4-207	Distribution of suspended matter, combustible organic matter and particle size, N. Y. Bight to Cape Cod (Manheim, et. al., 1970)

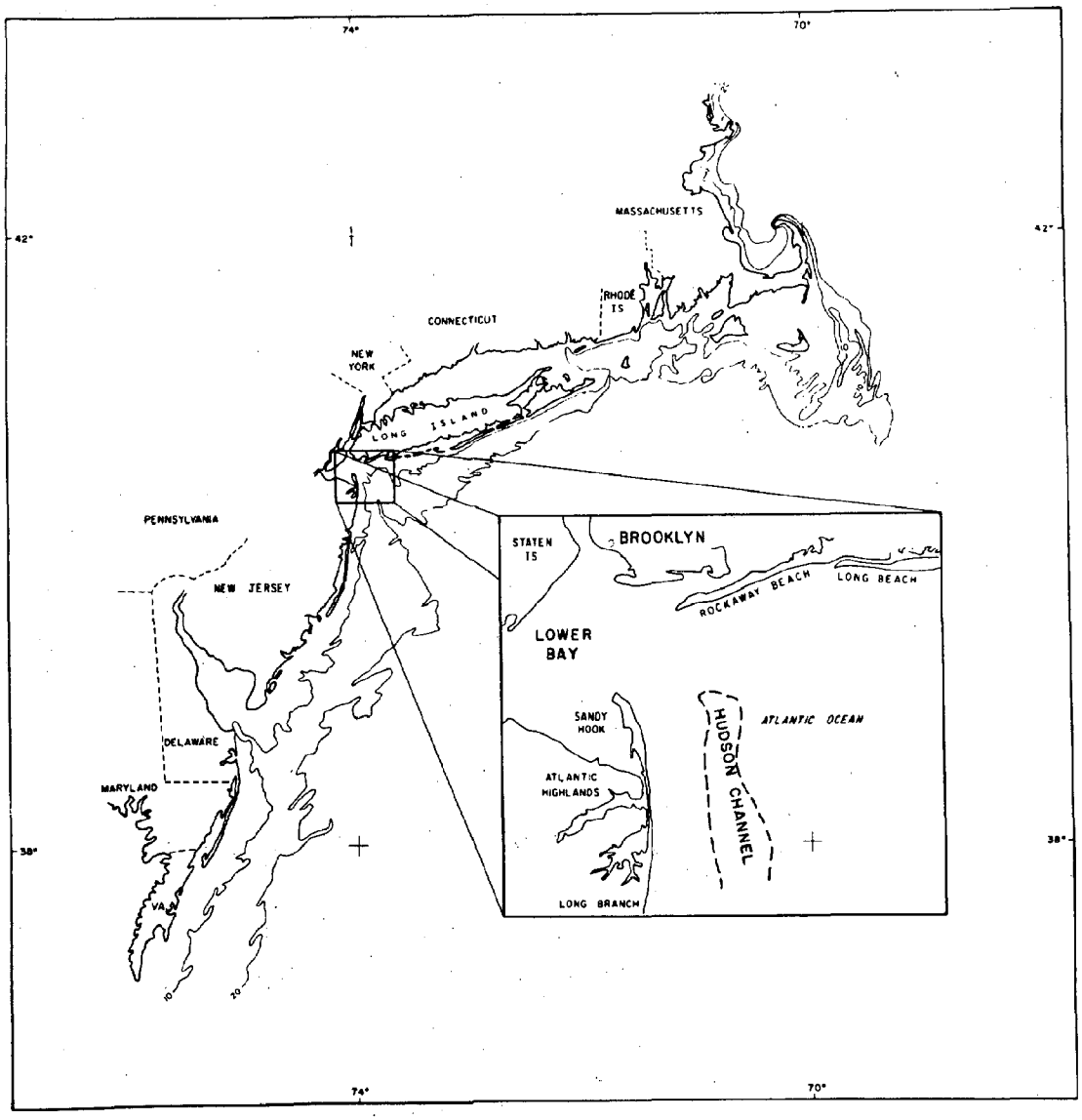
4.3.2 NEW YORK BIGHT

The New York Bight is part of the coastal ocean overlying the continental shelf between Cape May, New Jersey, and Montauk, Long Island (Figure 4-208). The Inner New York Bight covers an area of about 650 sq km (Figure 4-208) and is of major interest because of the extensive dumping in this area. The New York Harbor with its mouth between the sand spits on the New Jersey and Long Island coasts has an area of about 390 sq km (Gross, 1972).

The flow of the two major rivers (Hudson and Raritan) into the Bight varies seasonally from less than 0.6×10^9 to greater than 3.68×10^7 m^3 per day (Pararas- Carayannis, 1973). About 50 percent of the annual total river discharge occurs in the spring between late March and the end of May. A study by Ketchum, Redfield and Ayers (1951) showed that when the river flow is high there are steadystate, predictable oceanographic conditions; whereas when river flow is low, the patterns are changeable and unpredictable. Surface waters in the Bight generally move southward, more or less parallel to the shoreline (Bumpus and Lauzier, 1965); while near-bottom water movement over the inner shelf is directed toward the New York Harbor or nearby shoreline (Bumpus, 1965). Ketchum et al. (1951) found that there is an active circulation pattern in the bight that tends to remove pollutants from the area. They estimated the flushing rate to be on the order of 6 to 10 days. It appears to be dependent upon the tidal oscillations, but independent of the river flow. This is not surprising, since the water flow through this area is 50 to more than 200 times the incoming river flow. For a detailed summary of the circulation in the Bight area see Pararas-Carayannis (1973).

The New York Bight area has been a region of intensive oceanographic study because of man's dumping activities and the proximity of numerous laboratories. Over 900 publications are available relating to this area (Ali, Hardy, Baylor, and Gross, 1973). Some of the most recent studies include the Technical Reports from SUNY at Stony Brook (Bowman and Weyl, 1972), the reports from the Sandy Hook Marine Laboratory (1972), and an excellent survey-summary from the Army Corps of Engineers (Pararas-Carayannis, 1973).

Physical-chemical studies of this area, including temperature, salinity, dissolved oxygen, and iron were done by Ketchum et al. (1951). Some of this data is shown in Figure 4-209. The most recent, detailed study of the chemistry of the area has been done by Sandy Hook Laboratory (1972). They determined concentration of total iron, chlorophyll, nitrate, phosphate (ortho-, organic, meta-, and total), dissolved oxygen, pH for the water column, as well as trace metal concentration in sediment. Station locations for the Sandy Hook Laboratory study and location of the various dump areas are given in Figure 4-208. The ranges they found for individual parameters are given in Table 4-39.



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

TRIGOM PARC	FIGURE 4-208	New York Bight (Williams and Dunne, 1969)

The concentration of dissolved oxygen (DO) in the area around the Bight dumping grounds varies with proximity to dump sites and seasonally (Figures 4-209 and 4-210). The reduction of DO in the bottom waters has been correlated with the biochemical oxygen demand (BOD) of organic-rich waste materials (Pararas-Carayannis, 1973). According to the Sandy Hook Laboratory study (1972) the range of DO is from less than 2.0 to 15.2 ppm during the year with the lowest values found near the bottom during the late summer and the highest values during late winter early spring. The lower level is insufficient to support many forms of life.

As with DO, the nutrient concentrations vary in the Bight area depending on the season and proximity to dump areas. The concentration range for the nitrate and the phosphate nutrients found by Sandy Hook Laboratory are given in Table 4-39. The input of nutrients to the Bight area are included in the 4 billion kiloliters of waste material that enter the New York Bight on a daily basis. This includes some 90 metric tons of nitrogen and 36 metric tons of phosphorus (Ryther and Dunstan, 1971). Approximately half of the phosphorus entering the system is in excess of that amount required by the phytoplankton. As a consequence, phosphate can be used as a convenient index of organic pollution (Ryther and Dunstan, 1971).

Phosphorous is abundant in the sewage sludges, where much of it comes from domestic detergents, and can be used in following movements of contaminated water. Because of the prevailing currents, the concentration of phosphate remains high along the New Jersey coast (Figure 4-211). Concentrations of orthophosphate have been found up to 5.6 μg-at PO_4-P liters in some dump areas while outside the dumping grounds values of 0.2 to 0.9 μg-at PO_4-P liters were found (Sandy Hook Laboratory 1972).

The concentration of nitrate-nitrogen sometimes approaches zero in surface waters even though there is still phosphorus remaining in the water. The available nitrogen (as nitrate, nitrite and ammonia) seems to be utilized by microorganisms in the Bight as quickly as it becomes available, and the only really high values are seen in New York Harbor and Raritan Bay.

The ratio of nitrogen to phosphorus (by atoms) is commonly 12:1 to 15:1 for offshore waters and the average phytoplankton cell has a ratio of 15:1. The N:P ratios for dumping areas are lower, on the average, than elsewhere in the Bight, ranging from 0 to 14.4 for surface waters and 0 to 7.7 for bottom waters. Sewage itself, depending on the extent of primary or secondary treatment, has N:P ratios (by atom) of 5.4:1 to 5.8:1 (Ryther and Dunstan, 1971). The low ratios are due to higher phosphate concentrations rather than to lower nitrogen values (Pararas-Carayannis, 1973).

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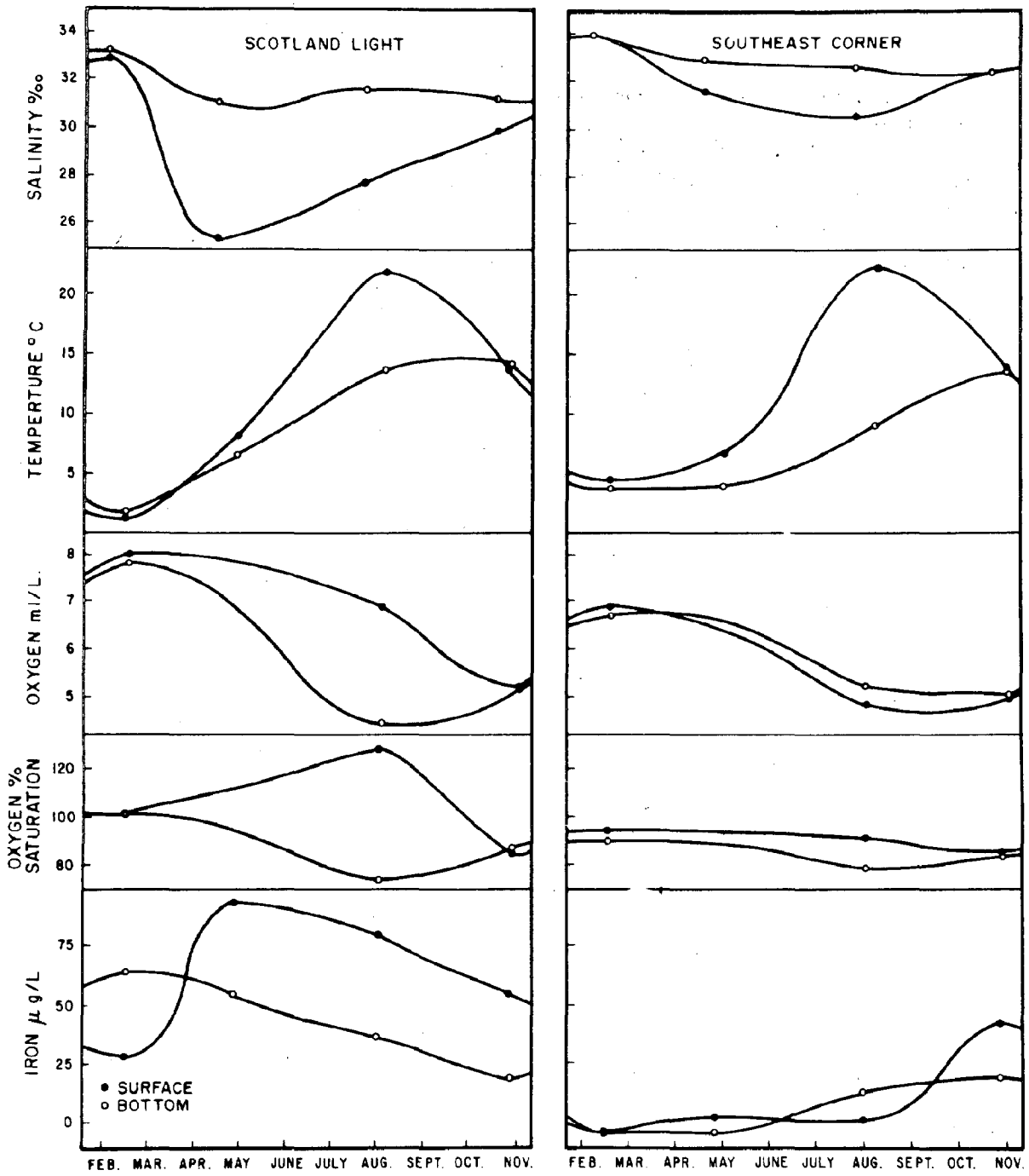
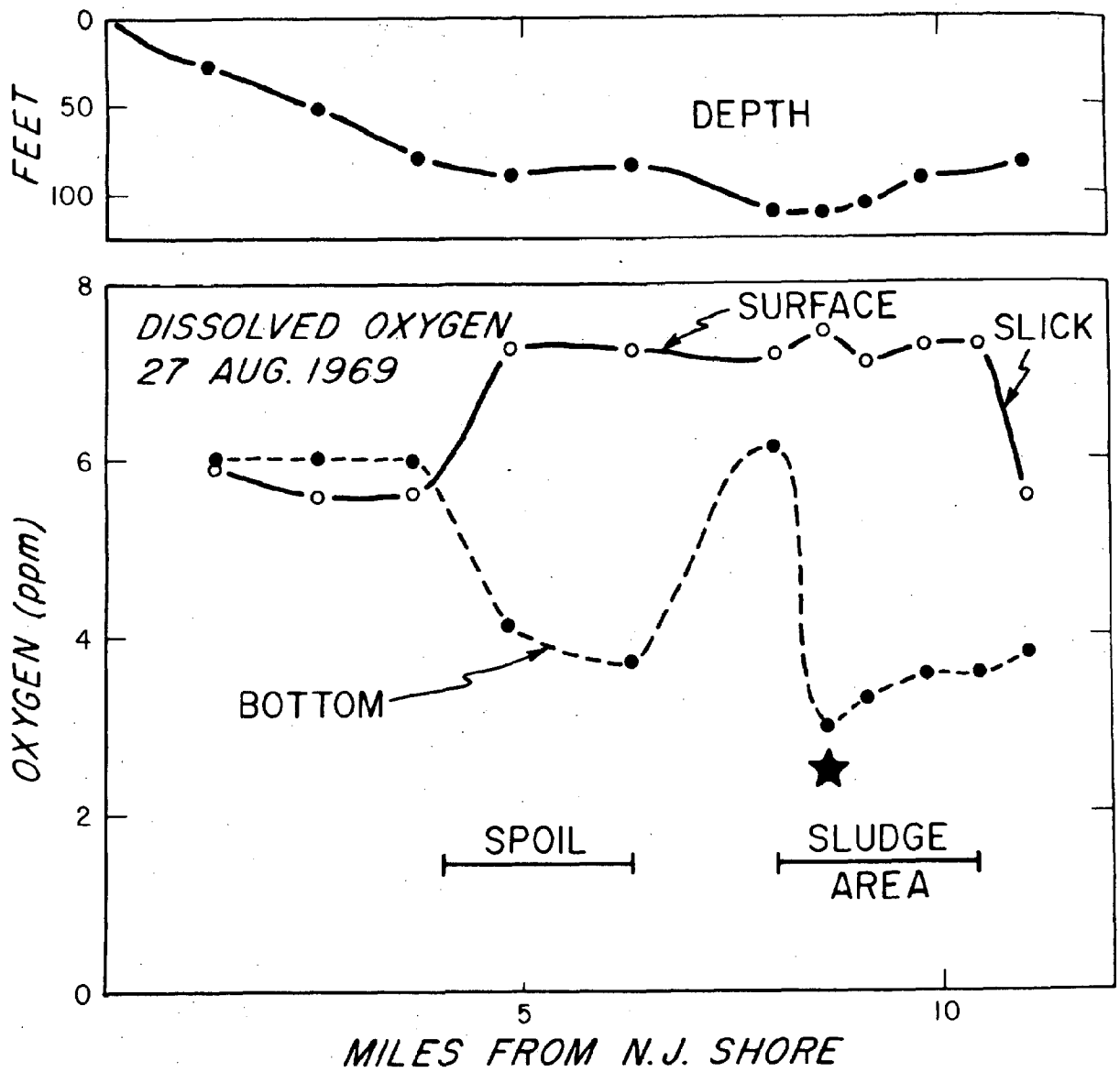
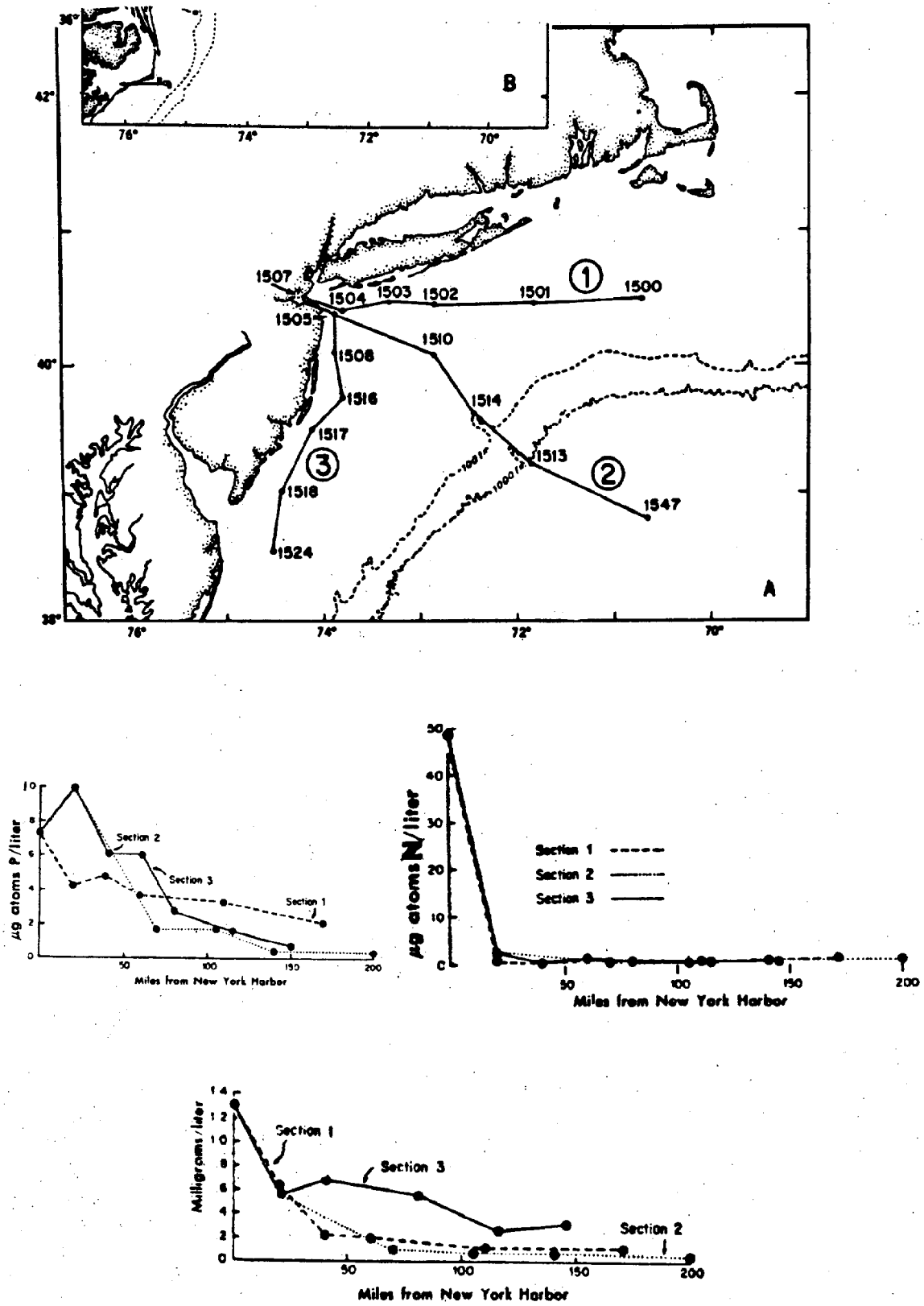


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-209	Seasonal Variations of Certain Physical Properties at Two Stations in the New York Bight (Ketchum et al., 1951)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-210	Dissolved Oxygen Content of Surface Water and Water 3 Feet Off Bottom (Ketchum et al., 1970)



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

TRIGOM PARC	FIGURE 4-211	Distribution of Phosphate Inorganic Nitrogen and Particulate Organic Carbon (Ryther, J. H. and E. Dunstan, 1971)

Table 4-39 Ranges of Chemical Data Measurements Near the New York Dumping Grounds.

Chemical Variable	Range
Total iron	0 to 37.3 μg-at/1*
Chlorophyll-a	0.38 to 33.3 μg-at/1
Nitrate	0 to 3.28 μg-at/1
Orthophosphate	0.02 to 5.64 μg-at/1
Organic phosphate	0.04 to 2.28 μg-at/1
Metaphosphate	0.01 to 2.35 μg-at/1
Total phosphate	0.84 to 7.48 μg-at/1
Dissolved oxygen	2.0 to 15.2 ppm †
pH	7.10 to 8.40
Lead in sediment	0.55 to 249 ppm
Copper in sediment	0.013 to 338 ppm
Chromium in sediment	0.25 to 197 ppm

* microgram-atom per liter

† parts per million

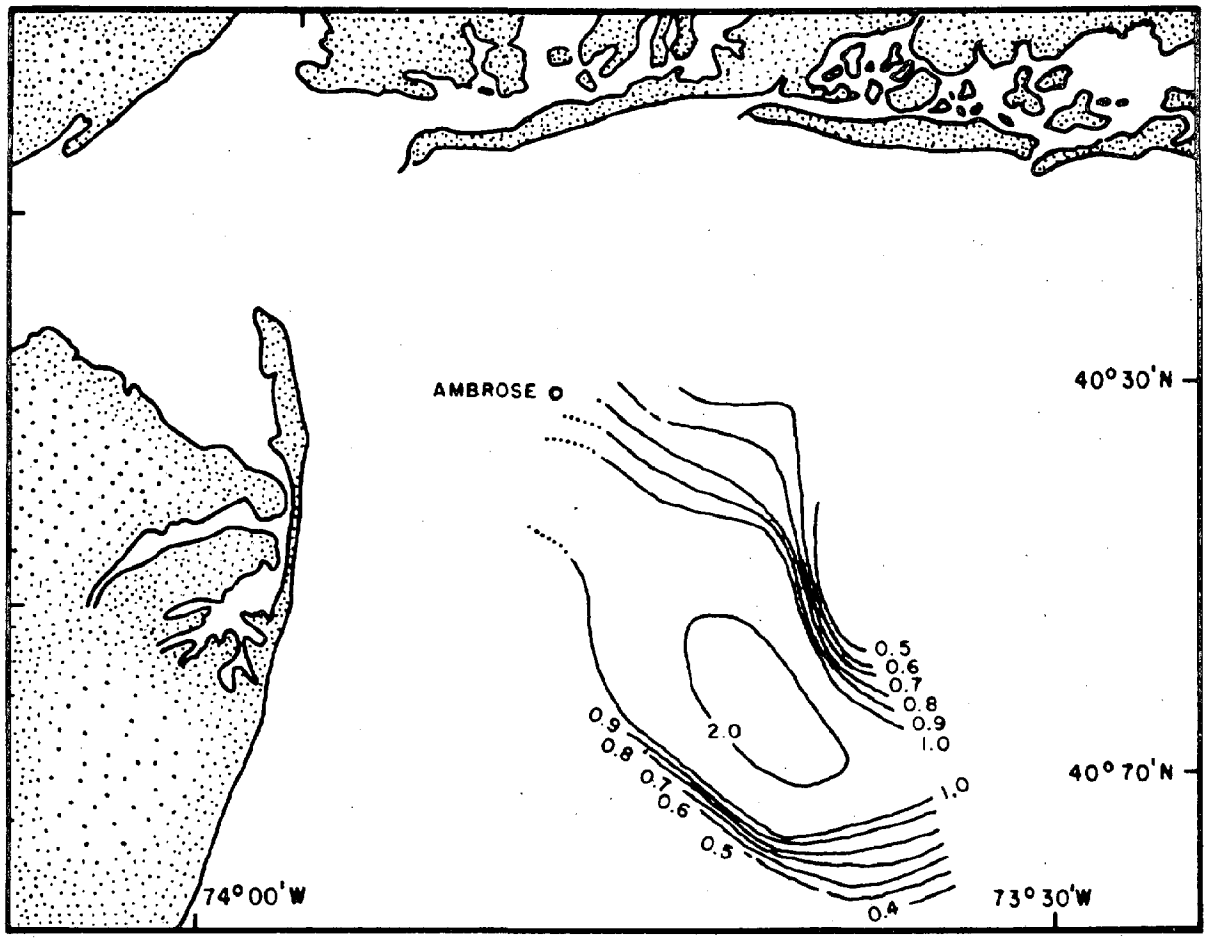
after SHL 1972

A number of other chemical species have been measured in the New York Bight area. Iron, for example, is contained in acid wastes (8.5 percent sulfuric acid and 10 percent ferrous sulfate in solution) that are dumped in the Bight. The acid is quickly neutralized by seawater and the ferrous iron is oxidized to ferric iron and precipitates as an iron hydroxide. The amount of iron dumped in the area has increased from 60 tons per day in 1948 to 229 tons per day in 1969 and 1970 with subsequent maximum dissolved iron concentrations of 1 μg-at/l in 1950 to 8.9 μg-at/l in 1969 and 1970 (Pararas-Carayannis, 1973). Sandy Hook Laboratory (1972) found the total concentration of iron for surface, mid-depth and bottom water to average 0.46 to 3.42 μg-at Fe/l with the highest values in the bottom water. The iron-rich deposits appear to be spread along the bottom by bottom currents which are associated with an increase in bottom turbidity. The average iron concentration at mid-depth is shown in Figure 4-212.

The concentrations of many trace metals in sewage sludge, spoils and other waste materials are known (Gross, 1970; Train, Cahn and MacDonald, 1970). Their concentrations have been measured in the sediments of the Bight dumping area by Gross, Black, Kalin, Schramel and Smith (1971) who felt that because of the low extraction efficiency of trace metals from sediments using hot hydrochloric acid, very little amounts of trace metals in sediments would move into the water column above. Although Sandy Hook Laboratory (1972) reports that some metals in the water column such as copper, lead, chromium, and mercury appear to originate from the dump sites, this conclusion appears to be a matter of debate (Pararas-Carayannis, 1973).

The concentrations of polychlorinated biphenyls (PCB) in near surface waters in 1971 have been reported to be in the range of 0.12 to 0.49 μg/liter (Dr. Terry Bidleman, URI, personal communication). The average concentration in the surface layers was 0.43 μg/liter (ppb) while subsurface concentrations were less, with an average of 0.20 μg/liter. Bidleman feels that the values today are probably substantially lower than those reported for 1971.

Particulate matter studies in the New York Bight area have been restricted to dissolved iron (Ketchum, et al, 1951; and Redfield and Walford, 1951). Studies conducted by the Sandy Hook Laboratory (1972) have included total iron and turbidity. Walter (1961) analyzed the organic components of suspended solid material in sewage sludge dumped in this area. These studies have been summarized in Pararas-Carayannis (1973). He concludes that turbidity in the New York Bight waters is due to both fine-grained suspended matter (clay, silt and finely-divided organic matter) and ferric hydroxide floc from the disposal of acid wastes. The effects of increased turbidity due to the ocean dumping of waste material on the water quality and the primary productivity of the New York Bight were not considered adverse or lasting (Pararas-Carayannis, 1973). The greatest source of settleable solids to



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TRIGOM PARC	FIGURE 4-212	Total Iron Mid-Water Depth Average by Station (SHL, 1972)

the New York Bight area is ocean dumping (Gross, 1970). Fine-grained dredge wastes, which constitute about 76 percent of the total wastes dumped (Gross, 1972), exceed the input of any river on the U. S. Atlantic coast (Holeman, 1968).

The distribution of particulate organic carbon for surface waters of the New York Bight and adjacent continental shelf areas indicates a rapid decrease in the weight of DOC per liter in an offshore direction, but a high level of concentration along the New Jersey shore (Figure 4-211d).

4.3.3 RARITAN BAY

Raritan Bay is a heavily polluted estuary surrounded by an intensely developed area. It is a triangular-shaped bay, occupying about 190 sq km, consisting of the Raritan River and Arthur Kill to the west, the bay itself and the Narrows to the east. This area receives about 1,500 million gallons of wastes per day containing over 1,300,000 pounds of BOD. Although most of the waste volume is from industry (about 75 percent), the major impact on the estuary is from the nutrient and bacteriological content of the municipal sewage (Anon., 1970). As a consequence of this pollution, Raritan Bay has high concentrations of nutrients, and very low dissolved oxygen values which reach zero in parts of the rivers during the summer. It is assumed that little of the suspended sediment in the outflows of the Raritan River reaches the New York Bight; however, this may not be true under heavy rainfall and storm conditions (Pararas-Carayannis, 1973).

Jefferies (1962) studied both chemical and physical aspects of the Bay on a seasonal basis. His data and others are summarized by Kester and Courant (1973) and Smayda (1973). The pollution problem of Raritan Bay has been discussed in more detail by Anon. (1967).

4.3.4 LONG ISLAND SOUND

Long Island Sound is a semi-enclosed body of water approximately 166 nautical km long and a maximum of 28 km wide. It has an area of about 2413 sq km (Riley, 1955). The mean depth is 20 m, with a maximum depth up to 35 m in the west and central basins and up to 100 m in the eastern Sound. The major rivers, the Connecticut and the Thames are along the north shore. There is a net-surface flow of water toward the eastern end of the Sound due to these rivers which discharge along the northern shore. Compensating bottom currents flow into the Sound from the eastern end.

The distribution of hydrographic parameters, dissolved oxygen, and nutrients in Long Island Sound were studied in detail by G. A. Riley and his co-workers at the Bingham Oceanographic Laboratory of Yale University during the 1950's (Riley 1952, 1955, 1959). The SUNY at

Stony Brook Technical Report Series (Hardy, 1972, and others) provide more recent data on the Sound. Kester and Courant (1973) and Smayda (1973) have reviewed the dissolved oxygen and nutrient distributions in the API Report.

The seasonal variations of several chemical parameters are shown in Figure 4-213 and summarized in Table 4-40.

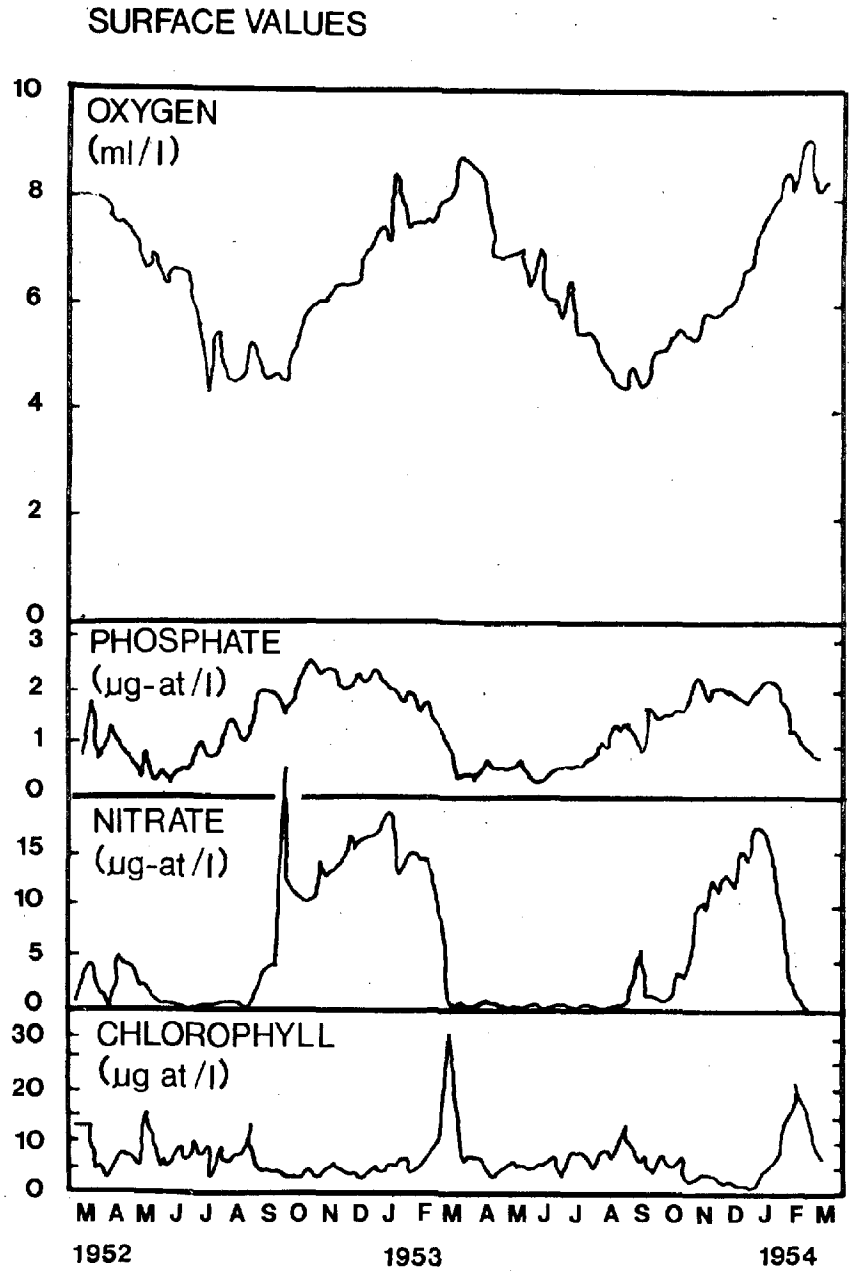
Table 4-40

Comparison of chemical data obtained in Long Island Sound in 1952 and 1969.

	Riley and Conover (1956)		Hardy (1970)	
Constituent	June 1952	October 1952	July 1969	October 1969
Phosphate (μg at/l	0.2 - 0.5	0.5 - 2.5	0.9 - 1.6	1.0 - 3.0
Nitrate (μg at/l	0.2 - 3.0	1 - 15	0.9 - 2.0	1.8 - 6.0
Chlorophyll a (μg/l)	3 - 15	2 - 4	3 -15	3 - 7

There is a major influx of nutrients and high BOD material at the western end of the Sound from sewage that is emptied into the East River. There is a similar but lesser input of sewage at the mouth of the Connecticut River. Szechtman (1972) found that the East River is the major source of phosphate to the Sound (62 percent of the total; 57.5 percent comes from New York City Sewage Treatment plants) compared with the sewage treatment plants around the Sound which input 19.2 percent, and land runoff input of 18.8 percent. During the summer of 1969 concentrations of phosphate ranged from 11.6 μg-at PO_4-P/l at the narrow western end of the Sound, about 6 μg/at PO_4-P/l south of Greenwich, Connecticut, and dropped down to about 1 μg-at PO_4-P/liter at the extreme east end of the Sound (Szechtman, 1972). Although Kester and Courant (1973) suggested that there does not appear to have been significant changes in nutrient data since the 1950's (Table 4-40), Szechtman (1972) found a 100 percent or more increase in phosphate concentration throughout the Sound since 1952. This is shown graphically in Figure 4-214 for the summer phosphate data; similar trends were seen for the fall data.

Other chemical components in the Long Island Sound waters have been studied. Wangersky (1959) studied the concentrations of dissolved



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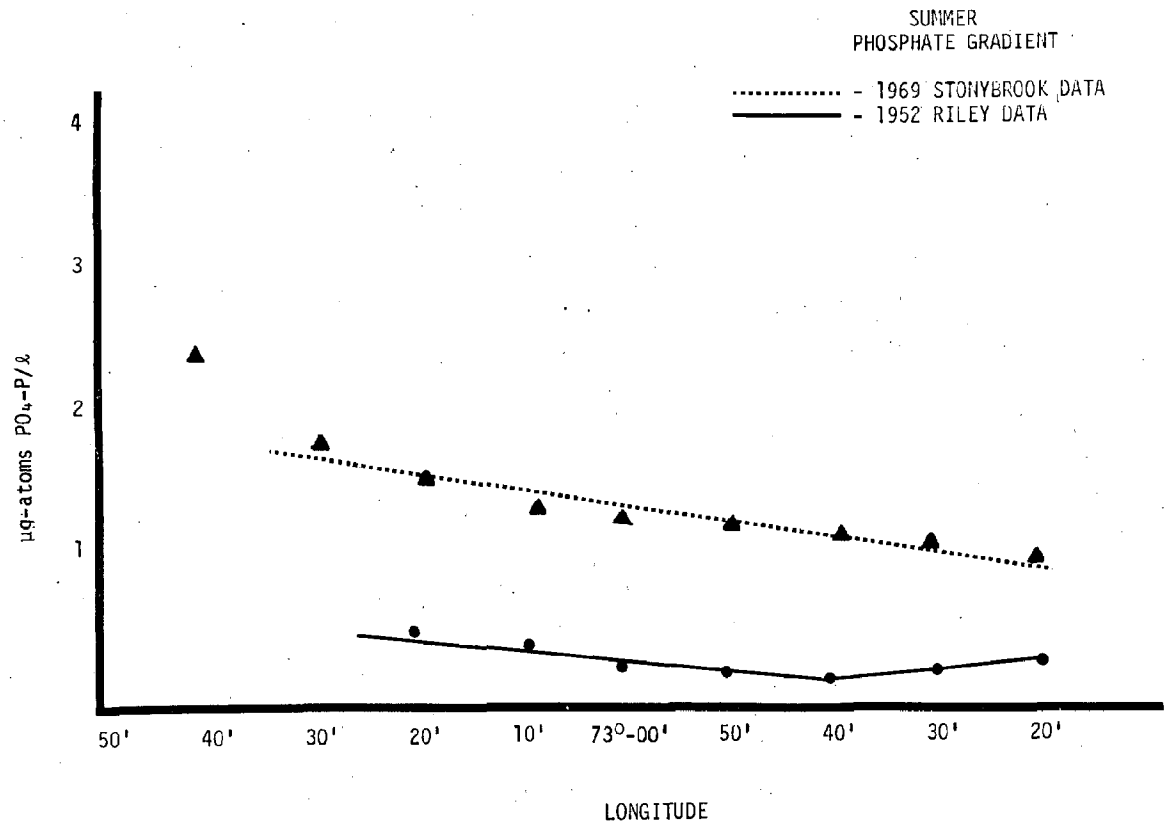
TRIGOM PARC

FIGURE 4-213

Seasonal Variations in Chemical Parameters in Long Island Sound (Riley and Conover, 1956)



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TRIGOM PARC	FIGURE 4-214	Summer Phosphate Gradient

carbohydrates and found none during the spring diatom bloom but found values of 0.5 to 1.5 mg/l in late July after dinoflagellate bloom. He concluded that carbohydrates are probably used as fast as they are released.

Turekian (1971) discussed the silicon budget of Long Island Sound and found that silicon is being "pumped" from the open ocean by currents into the sediments of the Sound, presumably by biological removal. He also studied the specific alkalinity and found a slight increase with decreasing chlorosity, showing the influence of dilution by streams. He was unable to detect alkalinity removal by clay mineral reactions by using the specific alkalinity measurements.

There are numerous inlets and coastal salt ponds along both the north and south coasts of Long Island Sound. The biology and chemistry of many of these have been covered in Smayda (1973). The water quality of a number of the harbor areas along the north shore of Long Island during the summer and fall has been reported by Gross, Davies, Lin, and Loeffler (1972). They concluded that ammonia and dissolved oxygen were the two most useful chemical parameters in measuring water quality; they also measured nitrate, nitrite, and phosphate. For ammonia, they reported average values ranging from 2.9 to 35 μg-at NH_3-N/liter. All seven harbors studied have some local ammonia sources. Pollution problems of Great South Bay on the north east end of Long Island are discussed by Foehrenbach (1969).

The distribution of trace metals in Long Island Sound have been studied in detail by Turekian (1971) and Fitzgerald, Hunt, Lyons and Szechtman (1973).

Fitzgerald et al. (1973) studied the distribution of copper, lead, cadmium, nickel, and zinc in the eastern region of Long Island Sound. The distribution of these trace metals was controlled by the water circulation dynamics. They found that the most significant input was from the Connecticut River with little input from the central Sound waters. Lead and copper appear to be released from suspended matter and are organically associated. The concentrations and the distribution of the trace metals was comparable to other well-flushed continental shelf regions of the eastern U. S. (Fitzgerald et al., 1973).

Lead and cadmium concentrations off the mouth of the Connecticut River appear to be lower than the typical world river concentrations (Riley and Chester, 1971), while the copper concentrations are average for the typical river. Concentrations in the Sound during August, 1972 and February, 1973 were about 1 μg Cu/liter, o.3 μg Pb/liter and 0.1 μg Cd/liter.

A significant fraction of the copper, about 50 percent, in the Sound and Connecticut River is associated with acid leachable material,

while 20 to 30 percent of the copper is organically associated, which agrees with Williams (1969); the remainder is in a soluble form.

Lead concentrations in the Eastern Sound are higher than in the open ocean, 0.3 μg Pb/l versus 0.07 μg Pb/l (Chow and Patterson, 1966). This increased amount appears to be related to the input of freshwater. About 80 percent is associated with leachable material and the rest as soluble forms. Cadmium concentrations in the Sound compare with other nearshore waters. Preston, Jefferies, Dutton, Harvey and Steele (1972) found little association with suspended matter.

Fitzgerald et al. (1973) have summarized the transport and removal mechanisms for trace elements in the Eastern Sound. They found that a major fraction of the copper is transported within the crystalline structure of suspended sediments; this is in agreement with Gibbs (1973). Fitzgerald et al. (1973) found that low suspended sediment concentrations were associated with low metal concentrations. The relationships between lead and copper concentrations, and salinity suggest that the most important removal process of copper is by settlement of the material carrying the metal.

Concentrations of nickel and zinc in the Eastern Long Island Sound were studied in October, 1972 (Fitzgerald et al., 1973). Average concentrations were 1.7 μg Ni/l (with a range of 1.0 to 2.0 μg Ni/l) and 3.0 μg Zn/l (with a range of 0.8 to 6.4 μg Zn/l) respectively. These concentrations compare favorably with those reported in the Gulf of Maine by Spencer and Brewer (1968).

The distribution of Ni has been studied by Turekian (1971) in Long Island Sound in which he found higher concentrations than Fitzgerald et al. (1973) for the eastern Sound (1.9 to 5.9 μg/l versus 1.0 to 2.0 μg/l). Turekian found a range of 0.13 to 10 μg/l in western Long Island Sound and 3.9 to 5.0 μg/l in the central Sound for nickel. Turekian (1971) indicates the Sound is a sink for nickel with an input from Block Island Sound. This conclusion has been disputed by Fitzgerald et al. (1973).

Total mercury concentrations in the eastern Sound ranged from 0.045 to 0.078 μg/l (Fitzgerald et al., 1973). They found that 50 to 60 percent of the mercury may exist either in association with organic matter or as organic compounds. The transport and removal mechanisms for trace metals in sea water are complex and the ultimate fate of mercury, as well as the other metals, will depend upon their physical and chemical form (Fitzgerald et al., 1973).

The effects of trace metals on marine phytoplankton have been summarized by Rice, Leighty, and McLeod (1973) in an excellent review paper which covers work conducted in this area as well as the rest of the world.

Measurements of suspended matter have been made in Long Island Sound by Riley (1959), Riley and Schurr (1959), and Bohlen (1973).

Riley (1959) found that particulate-matter concentrations for the south-central Long Island Sound in 35 m of water varied from about 2.0 mg/l to 7.5 mg/l. Particulate organic matter varied within narrow limits (1.2 to 3.1 mg/l). The fraction of living organic matter, as indicated by chlorophyll concentrations, varied from 70 percent during blooms in February and September to an average of 37 percent during April to July. From Fig. 4-215 it appears that the organic matter fraction (living and detritus) make up only about 50 percent by weight of the total suspended matter population in Long Island Sound.

A total of 888 Secchi-disc readings were analyzed by Riley (1956) and Riley and Schurr (1959). Secchi-disc readings varied in general from 1 to 5 m. Minimal readings recorded were as little as 0.2 m during heavy plankton blooms and during high runoff. Maximum values recorded were about 9 m. The clearest water was found in the eastern end of the Sound whereas Secchi-disc readings of less than 0.5 m are common in the East River at the western end of the Sound (Bowman, personal communication, 1973).

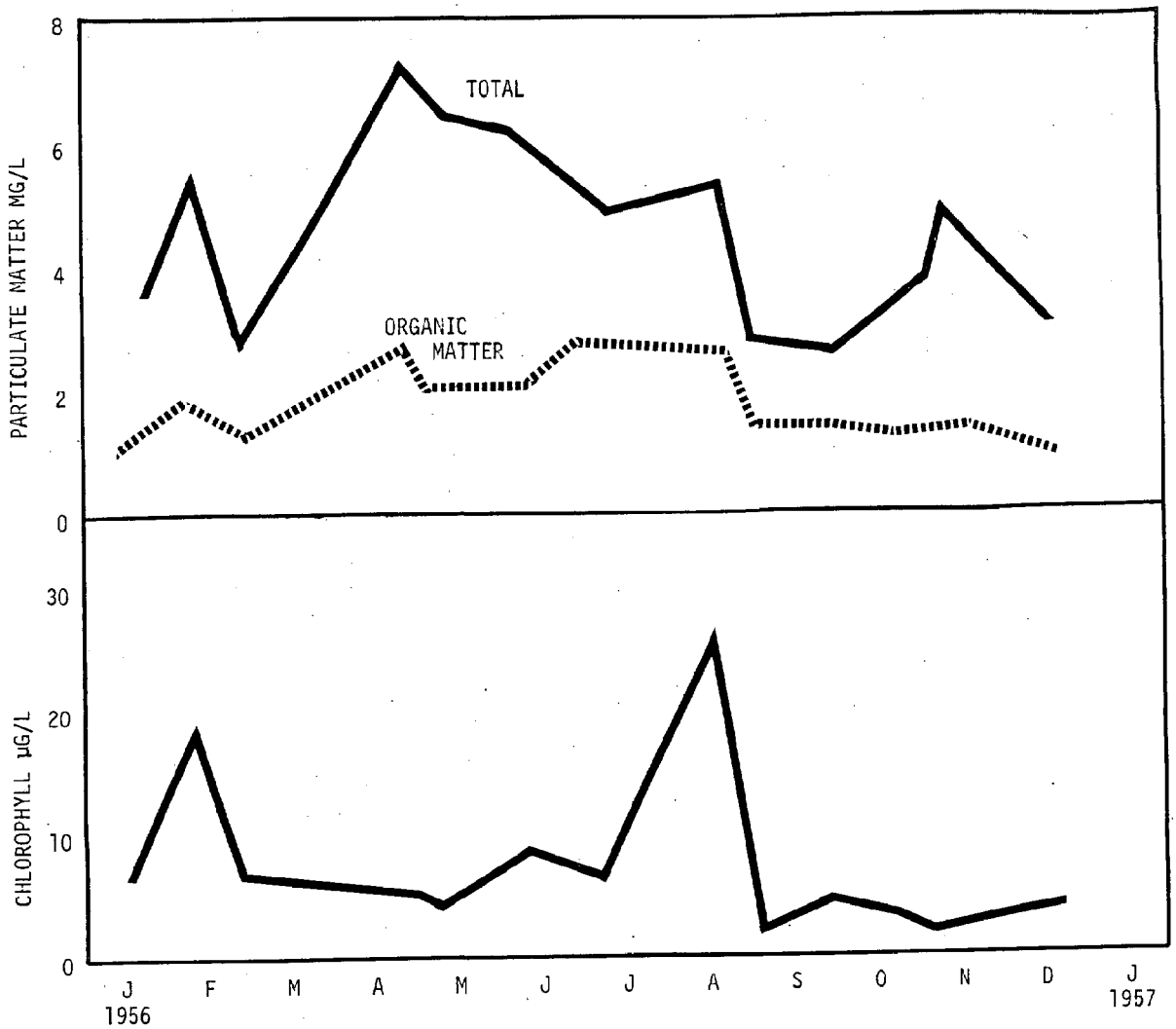
Riley (1956) found in preliminary analyses that phytoplankton accounted for 33 percent of the total light extinction. The remaining two-thirds he attributed to effects of dissolved substances, river-derived silt, bottom sediment in suspension, and the water itself.

Bohlen (1973) conducted a baseline investigation of near-surface and near-bottom, suspended-matter transport in Eastern Long Island Sound (Fig. 4-216). Average concentrations ranged from 15mg/l near the Connecticut River to less than 5 mg/l in the deeper waters of the Sound (Fig. 4-217). From Bohlen's data a simple seasonal cycle of suspended matter was not evident. periodic storm events were generally the cause for the increased concentrations of suspended matter. In general the bottom concentrations by weight were higher than corresponding surface values.

4.3.5 NARRAGANSETT BAY

Narragansett Bay has an area of about 100 sq. miles with a north-south length of about 26 miles and an east-west width of about 4 to 5 miles. The mean depths for the Bay are 10 m overall, 7 m for West Passage and 18 m for East Passage (Hicks, 1959). Kester and Courant (1973) and Smayda (1973) have summarized the available dissolved oxygen, nutrient and trace-metal information on Narragansett Bay. Consequently only a few trends are reported herein.

The east-west gradients of various parameters are small compared to



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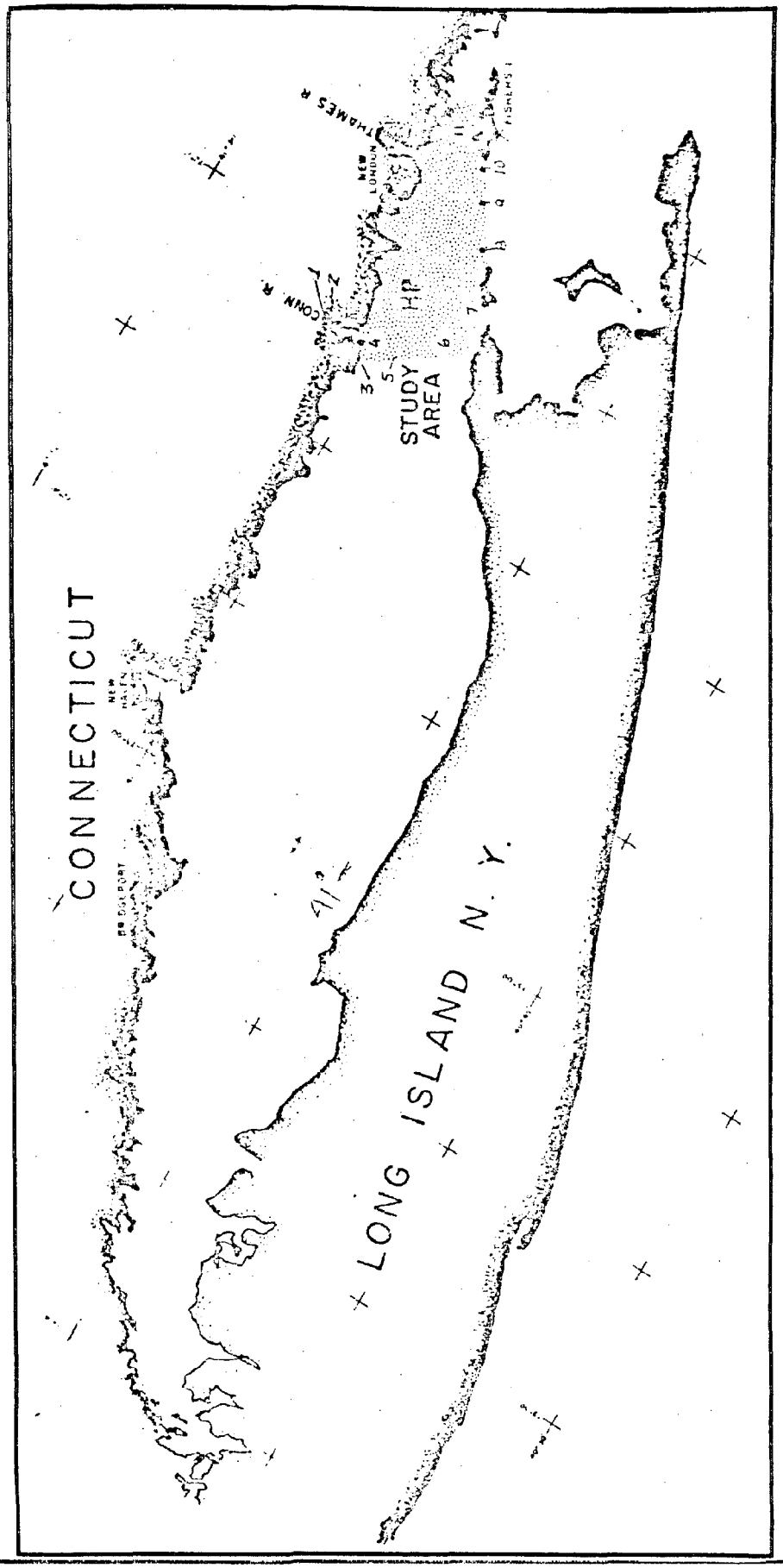
TRIGOM PARC	FIGURE 4-215	Seasonal Cycle of Total Particulate Matter and Organic Matter and Chlorophyll (Riley, G. A., 1959)



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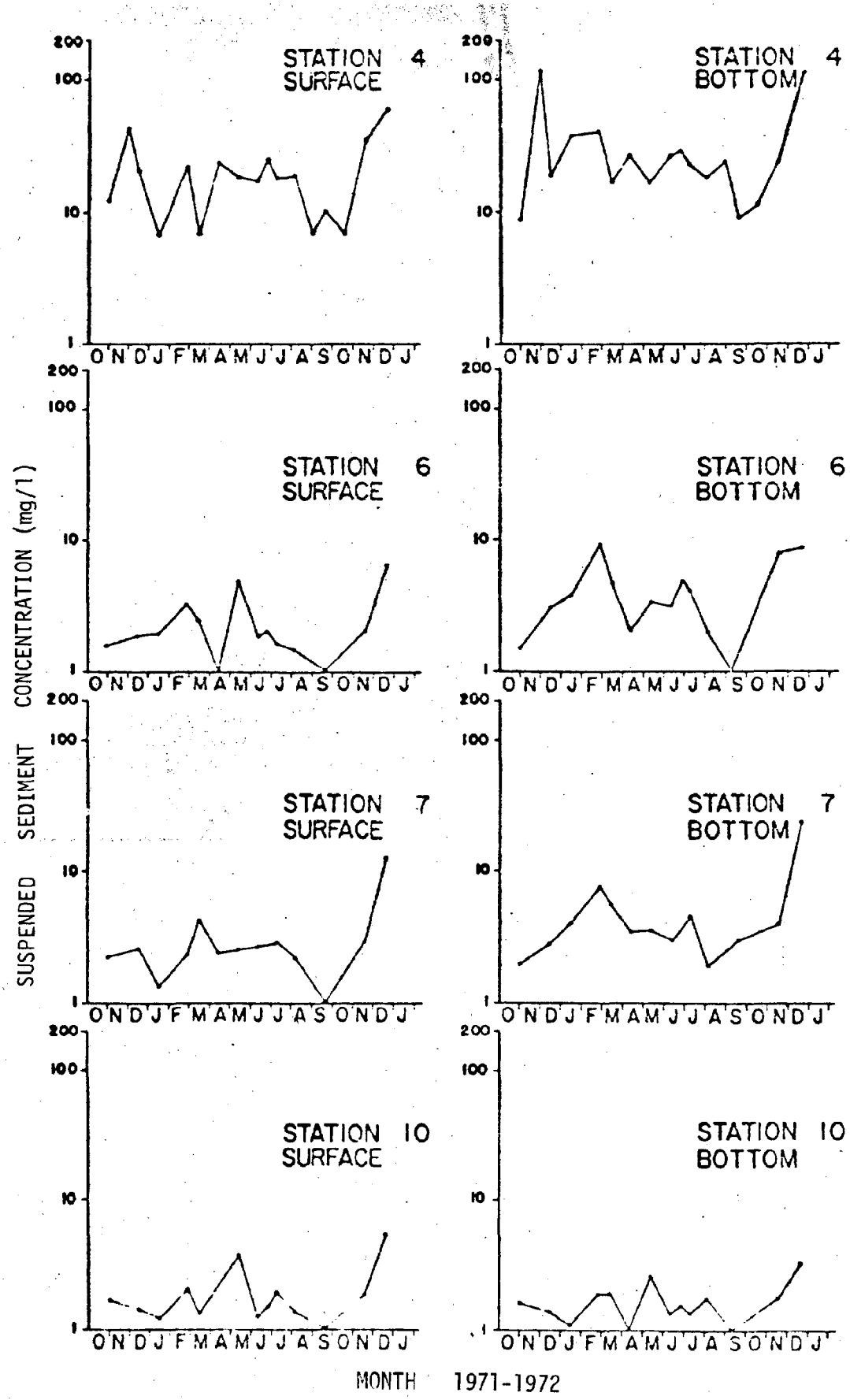
TRIGOM BADC

FIGURE 4-216

Suspended Matter Transport in the Eastern Long Island Sound (Bahler, 1972)



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

TRIGOM PARC

FIGURE 4-217

Suspended Material Concentrations (Bohlen, 1973)

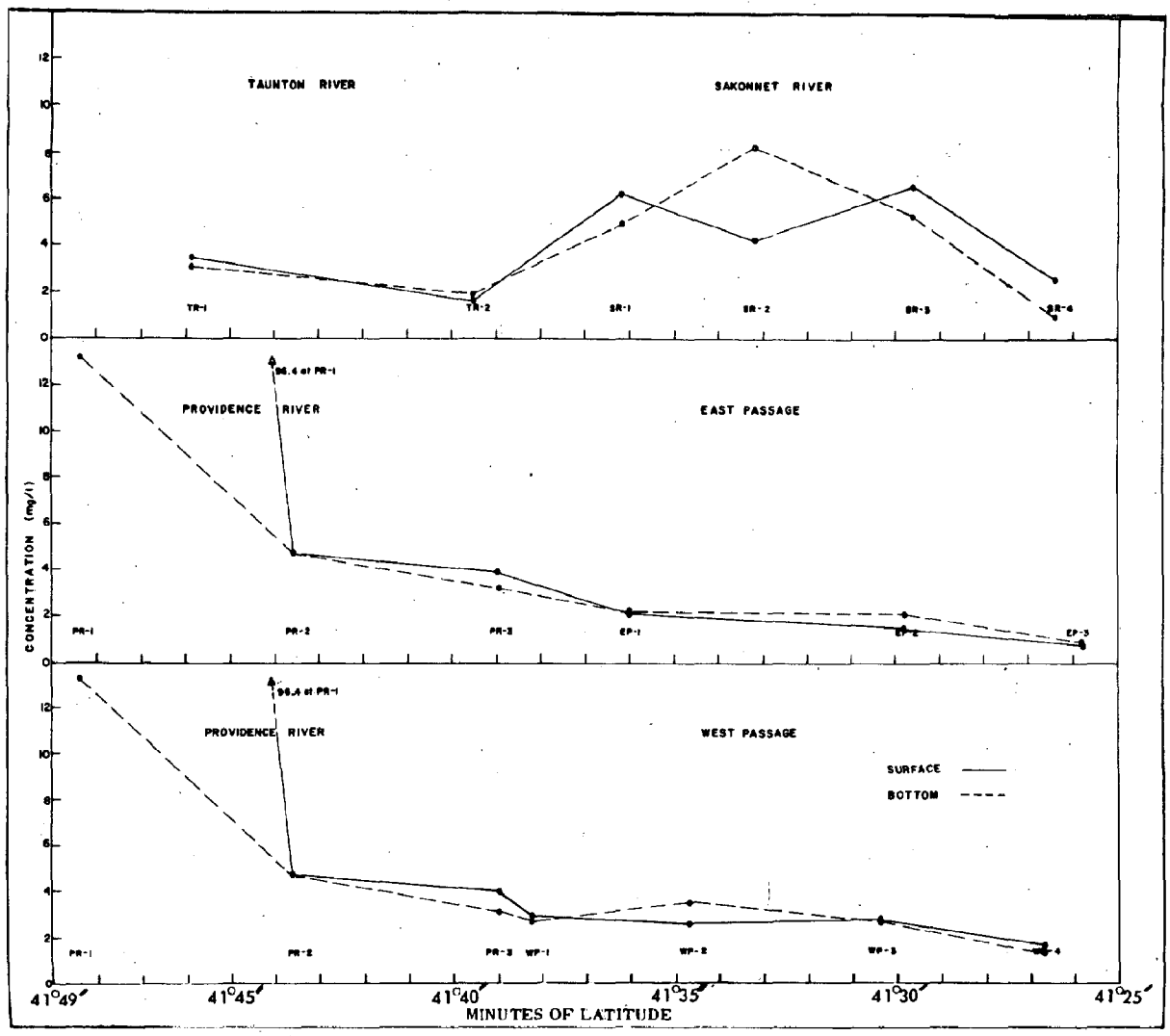
north-south variations. There is greater biological activity at the head of the Bay resulting in higher surface oxygen values than at the mouth. There is excess phosphate added to the Bay and values are high at the head and seasonably variable (often higher in summer than in winter). Nitrate may be a limiting nutrient at certain times of the year. Silicate is not detectable during winter and spring and then reaches an annual maximum during July. The annual nutrient distribution is atypical for coastal waters and is discussed in more detail by Smayda (1973) and Pratt (1965). The annual cycle of biologically active components off Narragansett are more typical of coastal waters and are discussed by Smayda (1973). Kester and Courant (1973) report that there is a significant increase in concentrations of manganese, nickel, copper, and zinc near the head of the Bay as a result of industrial and domestic input.

Morton (1967) studied the distribution of suspended-matter concentrations by weight in Narragansett Bay and Rhode Island Sound. The Narragansett Bay data were collected during October and November, 1965; whereas the Rhode Island Sound data were collected during January, 1966. A water turbidity study of Narragansett Bay was made by Schenck and Davis (1973) during the summer months (July-August) of 1971.

Morton (1967) found that the spatial distribution varied 4.5 times greater than the tidal distribution; therefore, he felt his data were representative of the autumn months and not significantly affected by short-period tidal variations. The distribution of suspended-matter concentrations by weight showed a seaward decrease in the East and West Passages with concentrations ranging from 4.7 mg/l at PR-2 to 0.86 mg/l at EP-3 and 1.5 mg/l at WP-4 (Fig. 4-218b). The Sakonnet River, on the other hand, had large fluctuations of sediment concentrations in the central portion of the Bay with low concentrations in the Tauton River and seaward extent of the Bay. In the central portion of the Bay concentrations ranged from 2.3 mg/l to 6.2 mg/l (Fig. 4-218b). The tidal data presented by Morton (1967) suggest the concentration fluctuations are because of tidal motion (Fig. 4-218a). The suface concentrations are generally highest near low tide and lowest near high tide. This is due to a horizontal concentration gradient in the surface water. The bottom concentrations appear to be controlled by bottom-current speeds rather than by tidal height.

Schenck and Davis (1973) observed similar spatial changes in water turbidity for Narragansett Bay and also noted wedges of clear water at intermediate depths. These wedges were most prevalent at the southern end of the Bay.

Suspended-sediment samples (8) collected in Rhode Island Sound indicate a relatively large amount of suspended matter is bypassing the Bay environment (Morton, 1967). The surface concentrations appear to be



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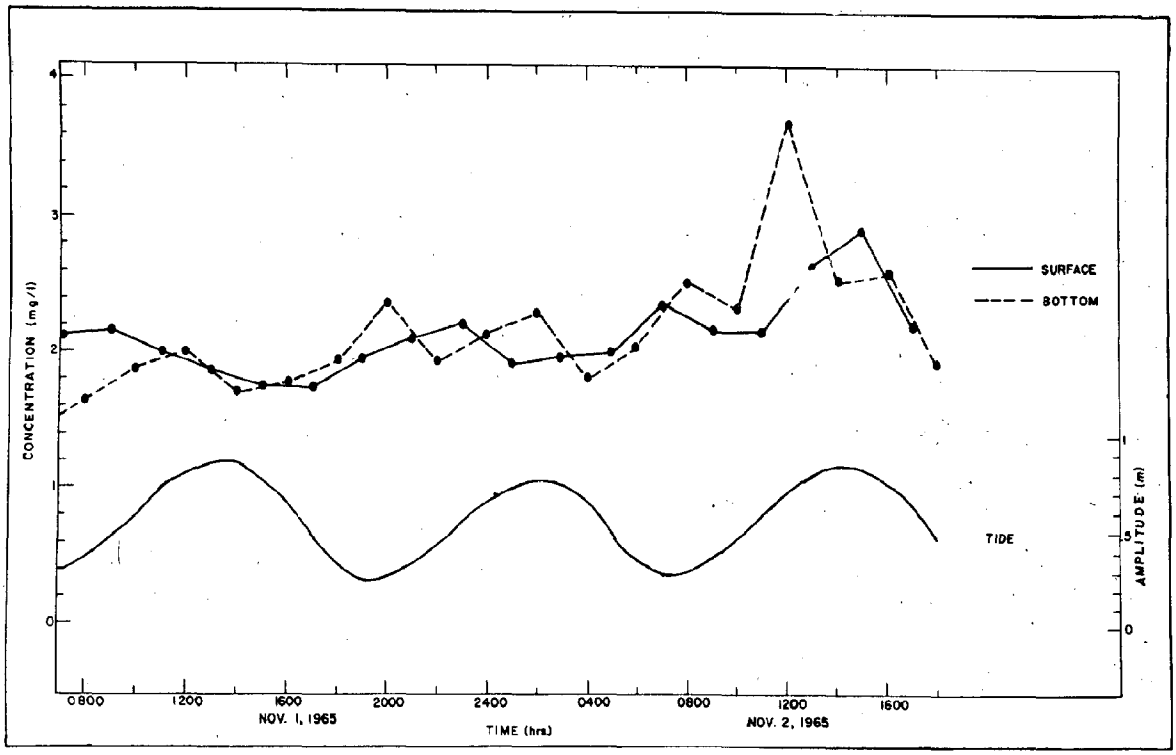
TRIGOM PARC	FIGURE 4-218b	Spatial Distribution of Suspended Sediment (Morton, R. W., 1967)



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TRIGOM PARC	FIGURE 4-218a	Time Variation of Suspended Sediment (Morton, R. W., 1967)

largely controlled by the cyclonic circulation pattern observed by McMaster (1960). Most of the more turbid water probably originated in Buzzards Bay (Fig. 4-219). Turbid water originating from Narragansett Bay is probably transported westward by this current pattern (Morton, 1967).

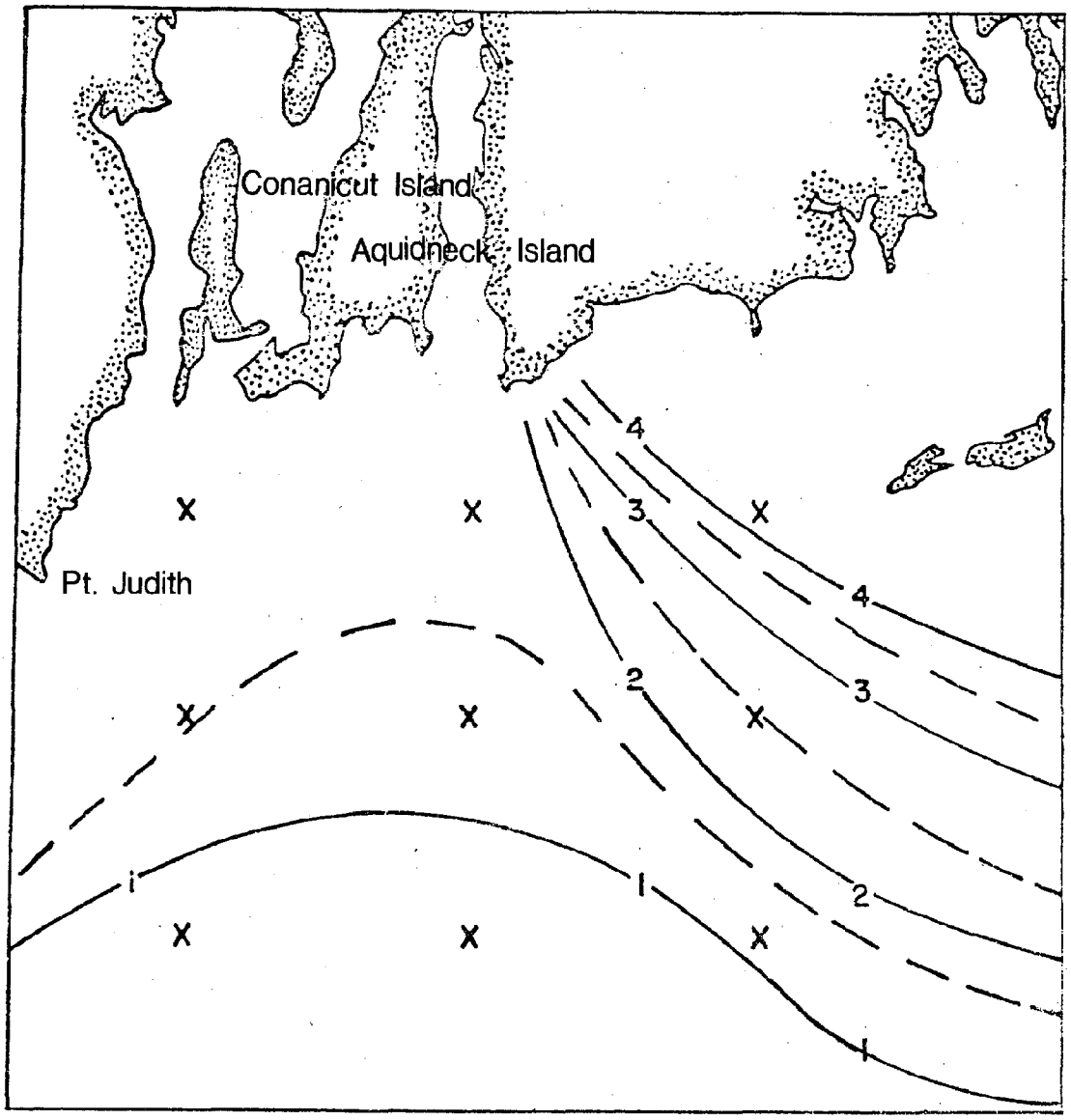
The estuaries feeding into the Gulf of Maine can be categorized into two major groups. Those north of Casco Bay are generally deep with only minor marginal tidal-flat areas. The estuaries south of Casco Bay are generally shallower with extensive tidal flats or marshlands. Because they are semi-sheltered, these coastal bays and estuaries are subject to a greater range of physical and chemical changes during the year than deeper waters offshore. There are large seasonal influxes of fresh water from local rivers that will vary the salinity and temperature. As a result, there are changes in the suspended matter, large seasonal amounts of nutrients, and pollutants added to these waters.

The turbidity in the shallow types of estuaries is complex as resuspension by wind-wave activity is significant (Anderson, 1973). In salt marsh estuaries organic matter and local productivity are important sources of the suspended matter (Odum and de la Cruz, 1967). In the estuaries north of Casco Bay the primary sources, river discharge, productivity, and saltwater intrusion, generally control the distribution of suspended sediment and its periodicity. Because the inshore waters tend to warm rapidly in the early spring, the plankton blooms start there and move offshore as the water columns become stratified. In some of these waters very strong thermal stratification may occur during summer and nutrients may become limiting. Exceptions to this are the estuaries that have strong tidal currents which tend to keep the water column well mixed (for example, the Great Bay Estuary, New Hampshire). This happens in many of the estuaries north of Cape Ann because of the increased tidal ranges toward the Bay of Fundy.

4.3.6 MASSACHUSETTS BAY

Massachusetts Bay is bordered on the south by Cape Cod and on the north by Cape Ann. Chemical oceanographic parameters have been measured by MIT from 1970 to 1973 (Frankel and Pearce, 1973). Water-quality measurements of Boston Harbor have been collected by the New England Aquarium (McLeod, 1973). Limited water-quality data for Quincy Bay (Jerome, Chesmore and Anderson, 1966), Dorchester Bay (Chesmore, Testaverde and Richards, 1971), and Lynn-Saugus Harbor (Chesmore, Brown and Anderson, 1972) has been collected by the Massachusetts Department of Natural Resources, Division of Marine Fisheries.

Both nitrogen and phosphorus concentrations are highest in the Inner Boston Harbor. This is because of the high amount of untreated sewage



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TRIGOM PARC	FIGURE 4-219	Distribution of Suspended Sediment in Rhode Island Sound (Morton, R. W., 1967)

in the Mystic, Charles and Chelsea Rivers (McLeod. 1973). There is a seasonal cycle of nitrogen and phosphorus which is associated with phytoplankton productivity (Fig. 4-220). The spring bloom (high concentrations of chlorophyll) depletes the nutrient level, with nitrates becoming the limiting nutrient. Annual ranges for nutrients, dissolved oxygen and biological parameters are reported in Table 4-41 and 4-42.

The waters in the Outer Harbor are generally well mixed with respect to dissolved oxygen. However, supersaturation conditions are sometimes found as a result of photosynthetic activity and are associated with high chlorophyll concentrations. The dissolved-oxygen content in the Inner Harbor waters is complex because of the input of freshwater and its subsequent effects.

Data from Quincy Bay and Dorchester Bay fall within similar ranges as those found by McLeod (1973) for Boston Harbor.

Extensive nutrient, total suspended solids with percent organics, and turbidity data have been presented in a data report prepared by Frankel and Pearce (1973). The data were collected for the New England Offshore Mining Environment Study (NOMES) and a baseline study of Massachusetts Bay waters (Fig. 4-221). Collections were made in February through June, and August, 1973.

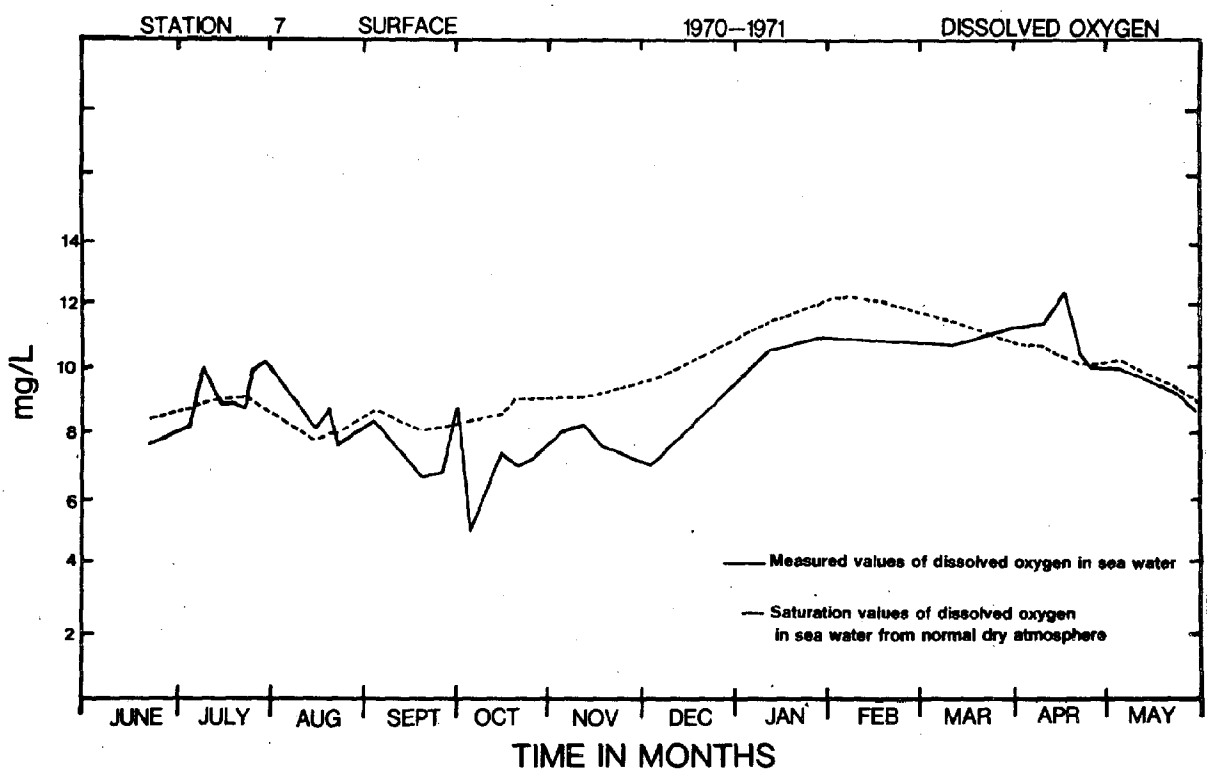
Nutrient concentrations decreased in an offshore direction from Boston Harbor (Fig. 4-222). This trend is complicated by seasonal variations associated with the cycle of phytoplankton growth (Fig. 4-223). The lowest concentrations occurred during the spring phytoplankton bloom in late April. Nitrate was found to be the limiting nutrient. These observations are consistent with those observed in other coastal environments of New England.

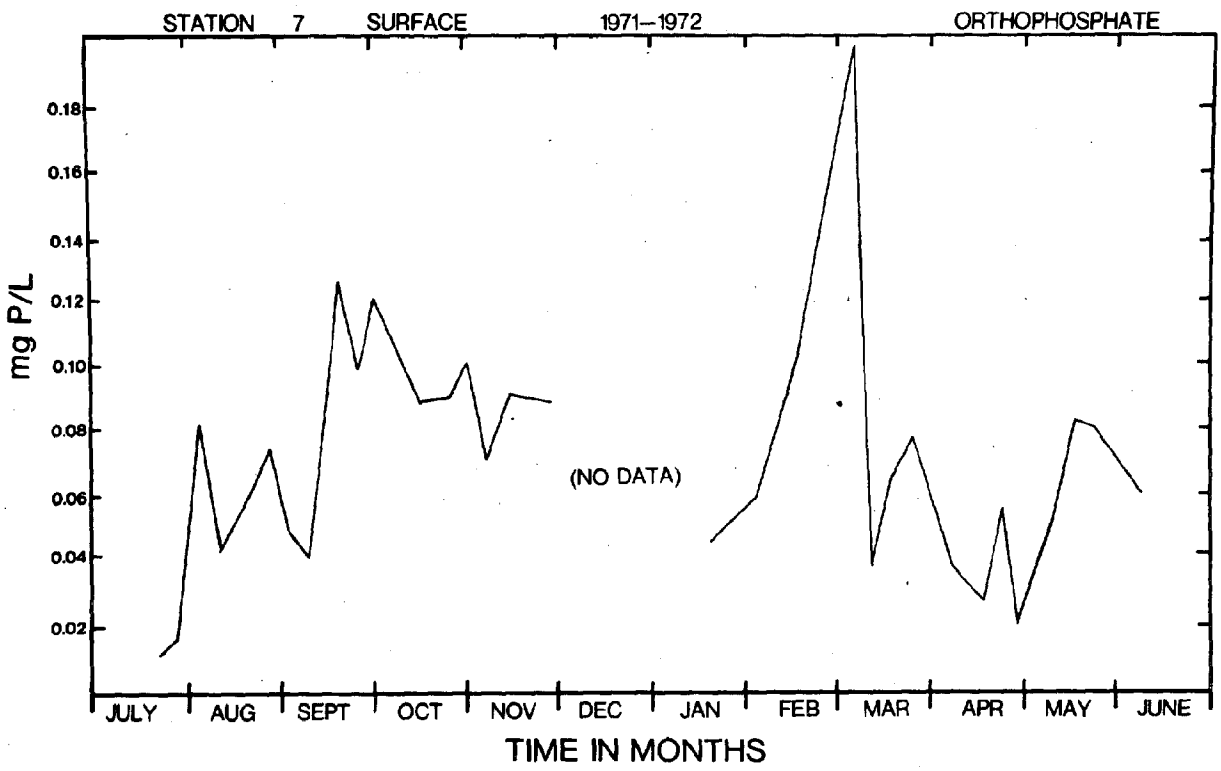
The suspended-matter concentrations ranged from about 8 mg/l to 0.5 mg/l in an offshore direction (Fig. 4-224). Outside Boston Harbor the month to month variability of concentrations at any particular station was about 3 mg/l. Near Boston Harbor tidal variations were evident with ranges similar to those observed by McLeod (1973). (Table 4-43).

4.3.7 CAPE ANN TO CAPE ELIZABETH

The coastal area north of Cape Ann to Cape Elizabeth has two major estuaries, the Merrimack and the Great Bay, which are located near Cape Ann. North of the New Hampshire coast, there are few estuaries and the coastline is generally a mixture of rocky coast and sand beaches.

Limited dissolved oxygen and nutrient data are available for the New





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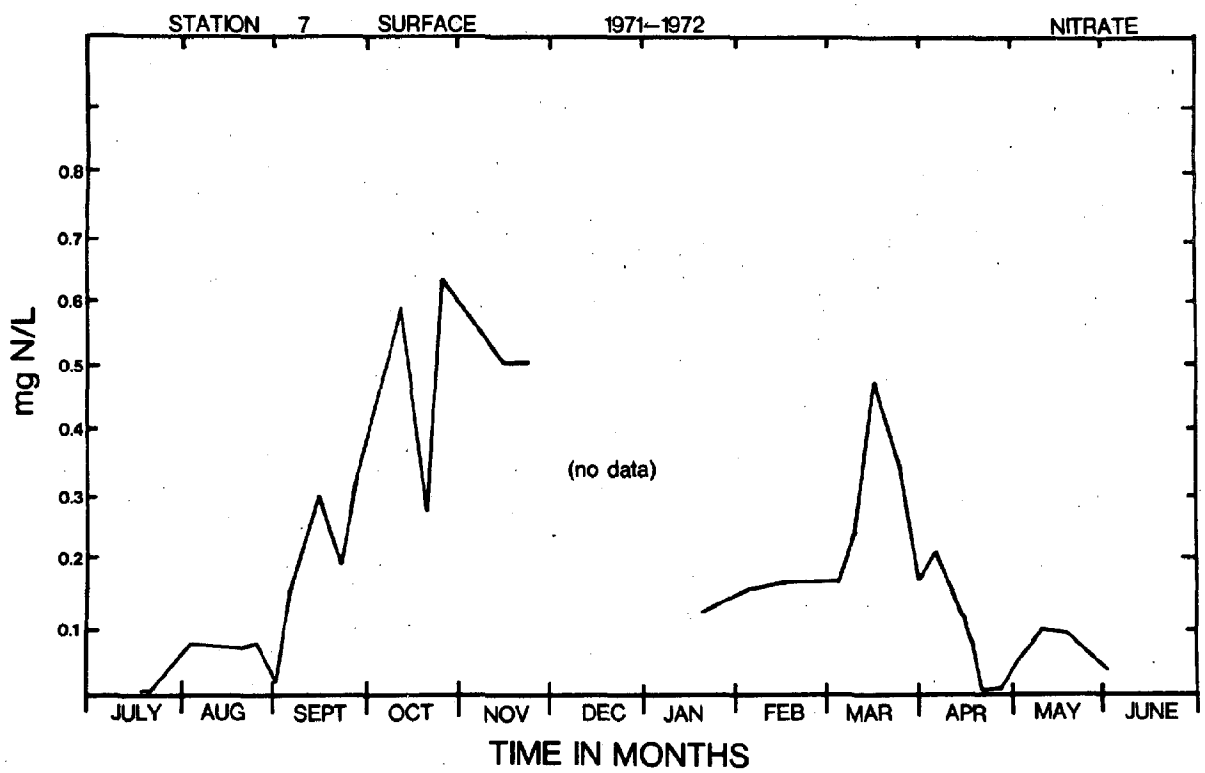
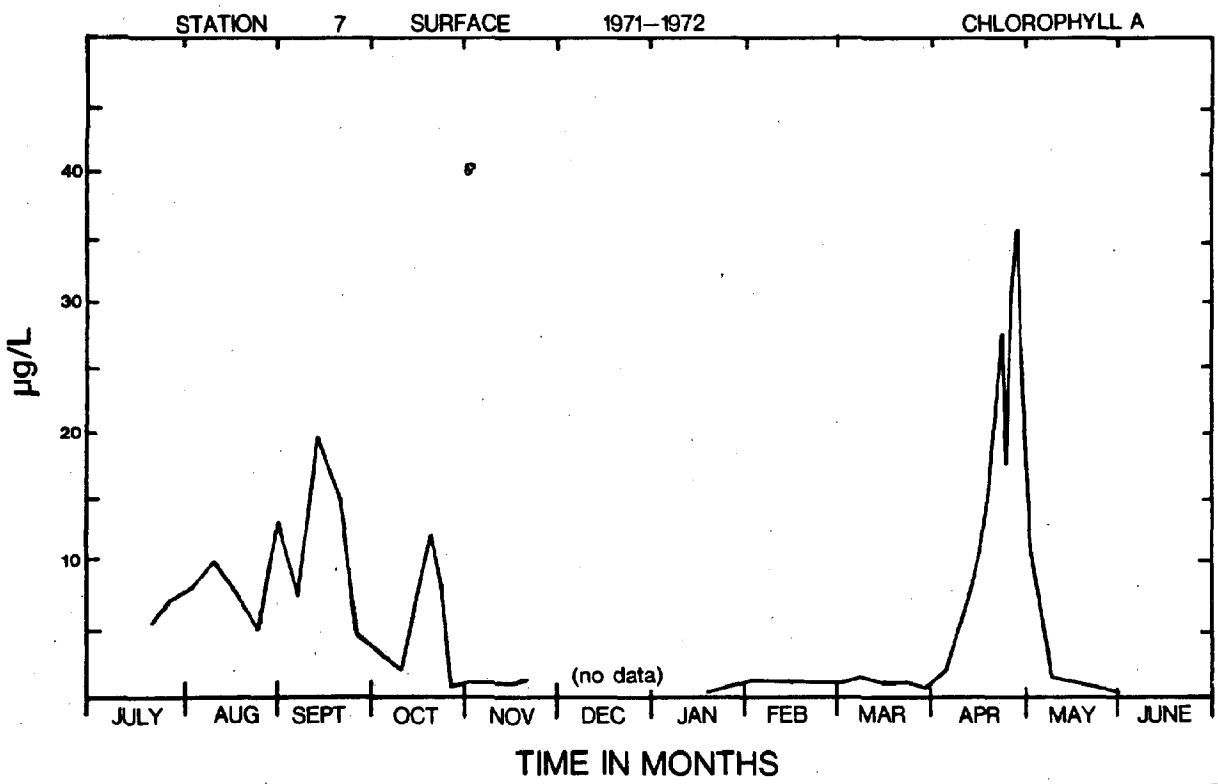
TRIGOM PARC	FIGURE 4-220 a/b	Phytoplankton Productivity in the Inner Boston Harbor (McLeod, G., 1973)





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TRIGOM PARC	FIGURE 4-220 c/d	Phytoplankton Productivity in the Inner Boston Harbor (McLeod, G., 1973)

TABLE 4-41

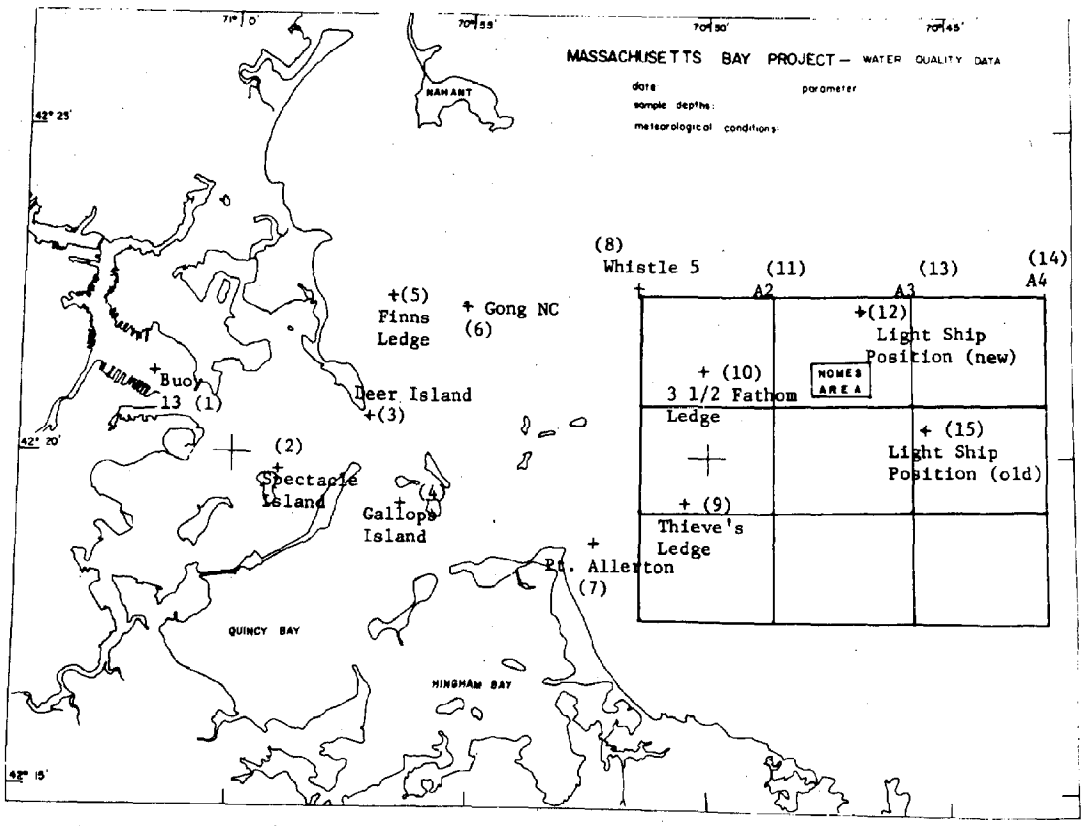
BOSTON HARBOR SURVEYS
1967-1969

	Maximum-Minimum Values		
	1967	1968	1969
Physical Parameters			
Turbidity Color Suspended Solids T° C.	Little seasonal change. Are at a maximum in vicinity of sewage outfalls		
Salinity	27-28.5%	29.7-31.3	-
Chemical			
D.O. (ppm)	5.0 - 6.5	5.0 - 6.5	5.7 - 9.1
Nitrogen mg/l.			
Ammonia - N	0.1 - 0.3	-	-
Nitrate - N	<0.1	0.03-0.08	0.03-0.11
Organic - N	<0.5	-	-
Phosphorus mg/l.			
Total - P	0.06-0.12	-	0.07-0.15
Soluble - P	0.03-0.08		
Orthophosphate		0.13-0.65	
Organic Carbon % (Bottom Deposits)	4%		
Radioactivity			
Uranium mg/l.	2.7-4.4		
Radium pico-curies/l.	0.03-0.09		
Strontium pico-curies/l.	19-85		
Lead picocuries /l.	barely detectable		
Biological			
Phytoplankton	>1000/ml	500/ml	
Benthic Population	5365/sq.ft.	179/sq.ft.	
Bacterial Cts. (Coliform)			

TABLE 4-42

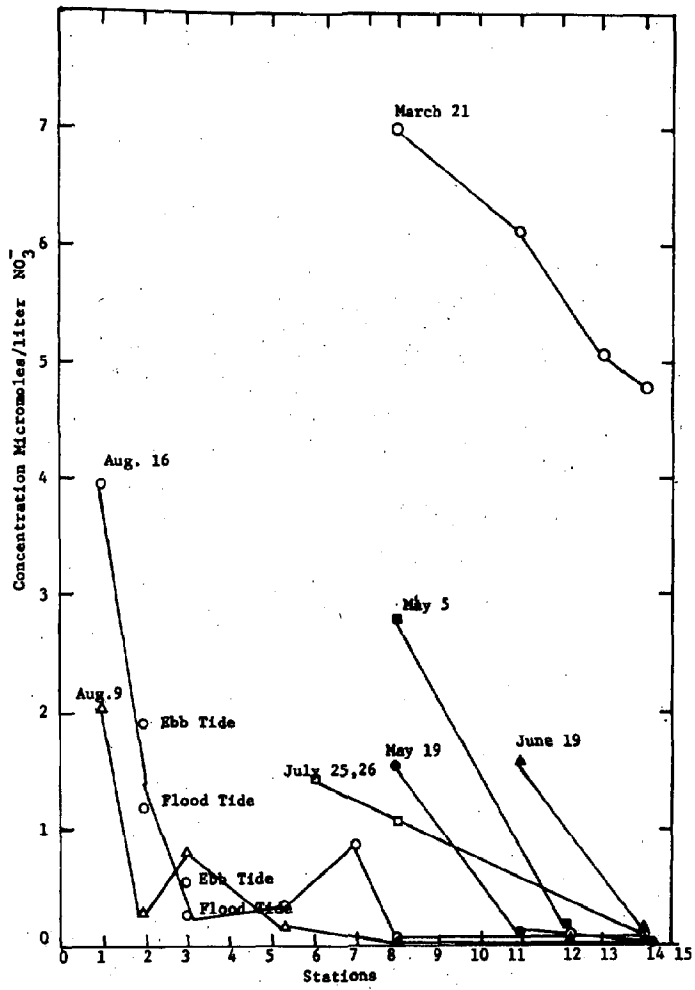
NEA DATA SET 1970-1972

	Minimum-Maximum Values		
Physical Parameters	River Complex	Outer Harbor	Outside Harbor
T° C.	0-21	0-22	0-20.5
Salinity, ppt	4-32	21-34	28-34
Chemical			
D.O., ppm	2.41-11.49	6.02-14.0	6.48-12.55
Nitrogen mg/l			
Ammonia - N	0.01-1.10	0.01-1.02	0.01-0.40
Nitrate - N	.002-1.24	.001-.570	.002-.940
Organic - N			
Phosphorus mg/l			
Total	0.05-1.02	.024-1.33	.010-.133
Ortho	.007-.924	.010-1.17	.018-.082
Biological			
Bacterial cts. (coliform)	0-96,000	0-10,000	0-4,200



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

TRIGOM PARC	FIGURE 4-221	Chart of Positions for Concentrations vs. Distance (Frankel, S. L. and B. R. Pearce, 1973)



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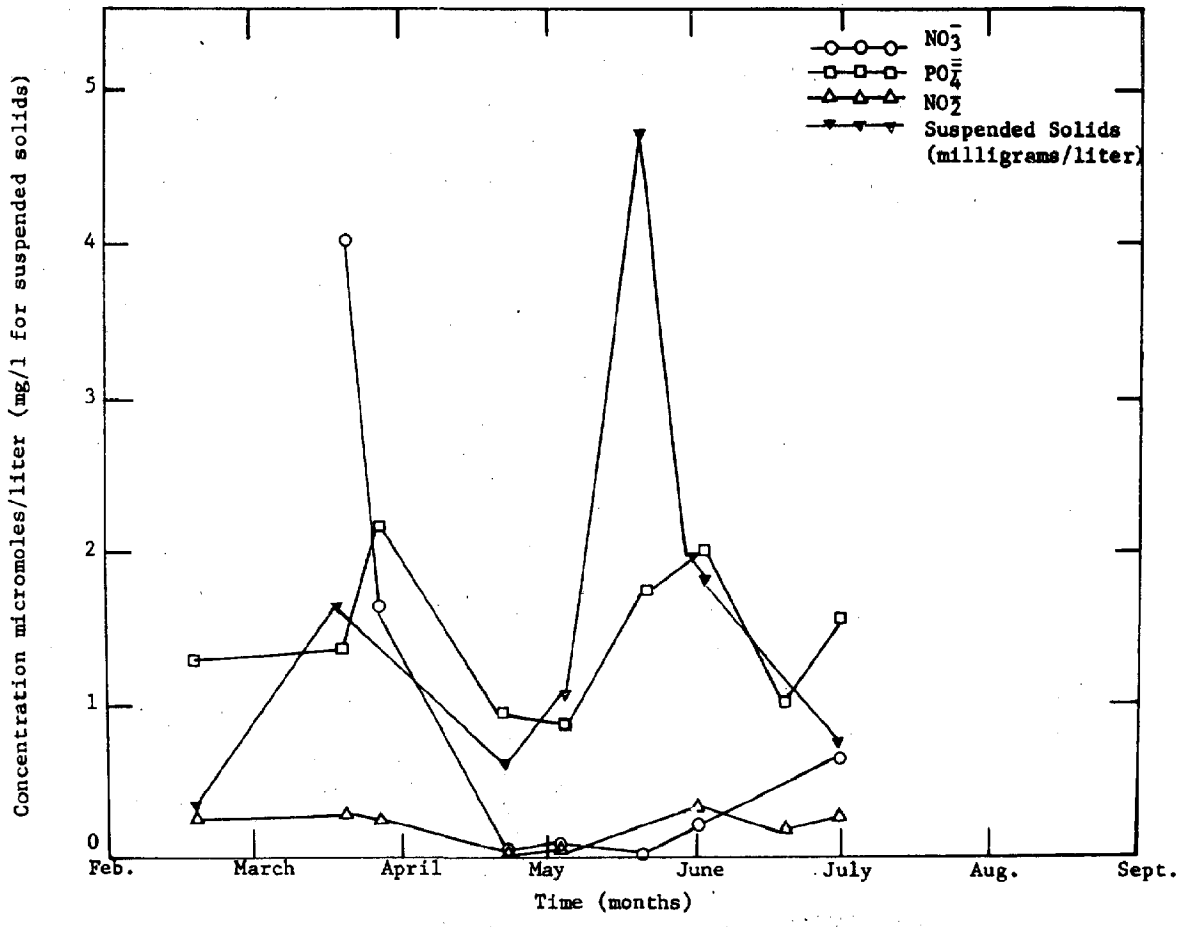
TRIGOM PARC	FIGURE 4-222	Concentration of NO_3 as a Function of Increasing Distance from Boston Harbor (Frankel, S. L. and B. R. Pearce, 1973)



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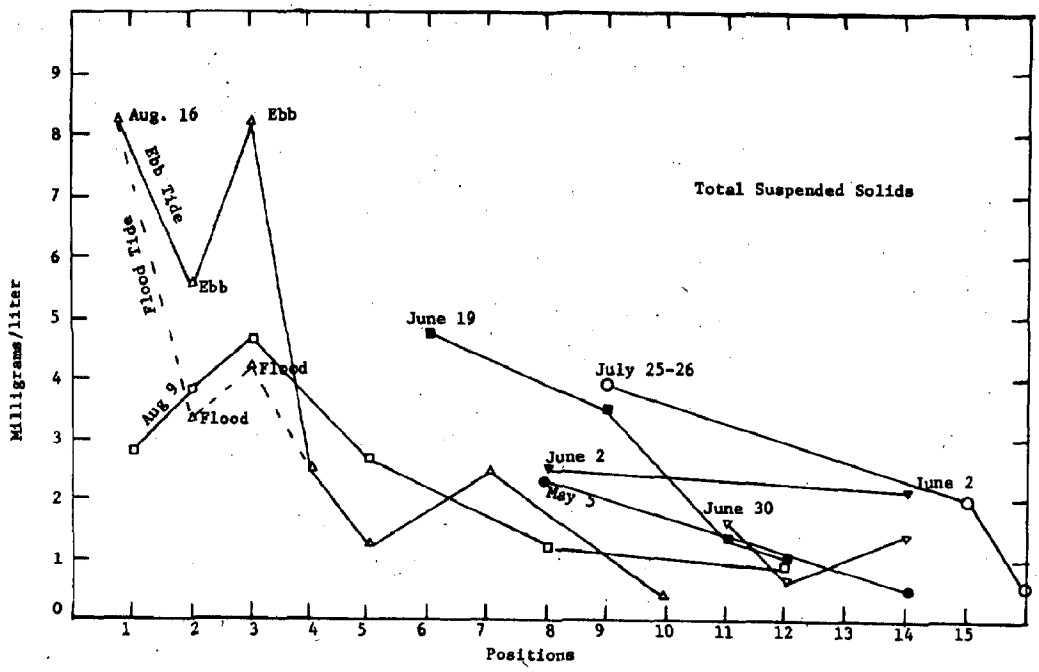
TRIGOM PARC	FIGURE 4-223	Concentrations of Various Nutrients and Total Suspended Solids vs. Time (Frankel, S. L. and B. R. Pearce, 1973)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-224	Suspended Solids vs. Relative Distance from the Harbor (Frankel, S. L. and B. R. Pearce, 1973)

Table 4-43 Diurnal Study Feb. 16-17, 1972

Parameter	Concentration Range During Tidal Cycle
Temp. ^{o}C.	1.9 - 2.8
Salinity $^{o}/oo$	31 - 34
pH	7.70 - 7.88
Turbidity mg SiO_2/l	2.7 - 10.3
D.O. mg/l	10.3 - 11.0
NO_3^- µg N/l	137 - 177
NO_2^- µg N/l	2.8 - 11.6
Ortho P mg/l	0.05 - 0.61
Chlorophyll a µg/l	0.9 - 6.6
Coliform Bacteria/100 ml	15 - 220

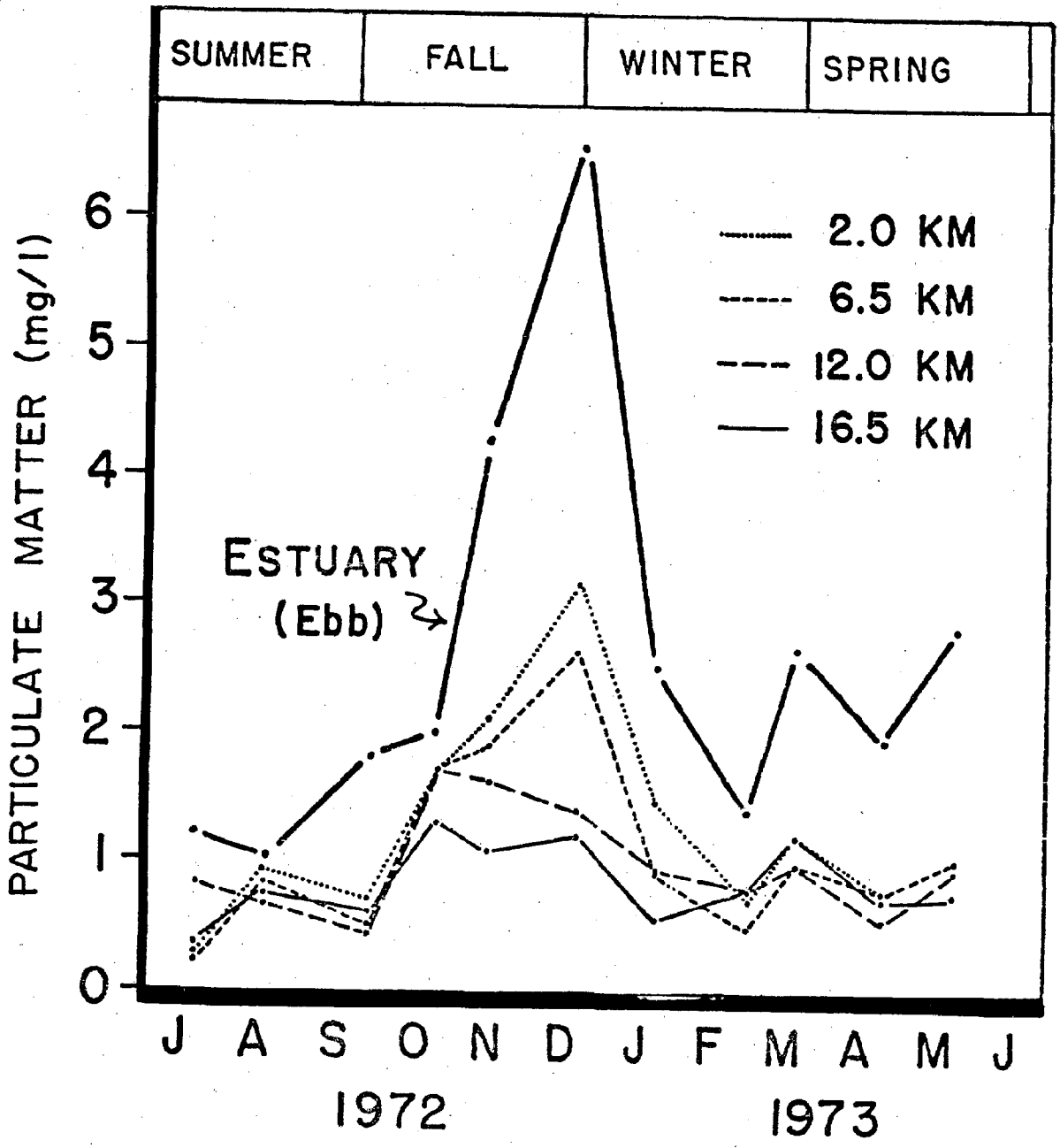
Hampshire coastal area. The dissolved oxygen content at a station 11 km off the New Hampshire coast near the Isles of Shoals was reported to range from 4.6 to 8.5 ml/l with near-saturated to slightly supersaturated conditions existing year around (Loder, Anderson, and Shevenell, 1973). Phosphate data taken at the same station ranged between near zero to between 1 and 2 μg-at PO_4-P/l during most of the year (July to March) but showed a large peak of greater than 3 μg-at PO_4-P/l just prior to the fall bloom.

Shevenell (1973) found that the surface transparency of the water off the New Hampshire coast was lowest during the late summer to early fall and the greatest during the late winter in January to March. The change in surface transparencies was primarily a function of the seasonal cycle of phytoplankton observed in the Gulf of Maine. Inorganic-sediment content in the surface water also varied seasonally with greatest input during the late fall and during the spring runoff. The effect of this input was observed offshore to a distance of about 10 km (Fig. 4-225).

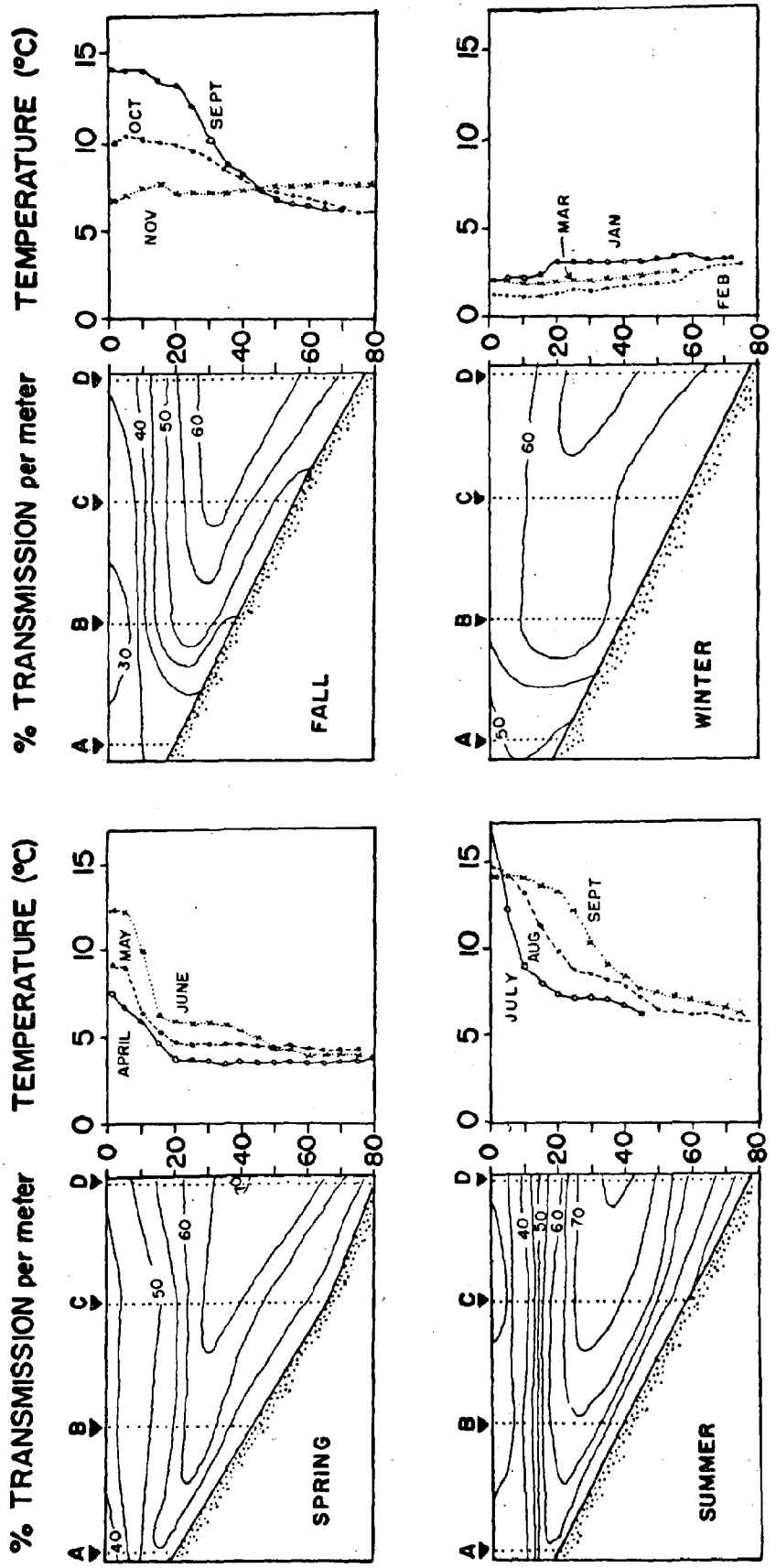
The vertical distribution of turbidity is characterized by a near-surface turbid layer which is maintained in the mixed zone. The sources of suspended matter are the estuary and biological productivity. A turbid layer is also present near the bottom, primarily the result of resuspension of bottom sediments (Shevenell, 1973). There are seasonal changes in the intensity of these turbid zones (Figure 4-226). Winter suspended matter concentrations, determined by weight, are comparable to those observed in the summer; however, the water is much less turbid (Fig. 4-226). This is because of a high concentration of low-density, organic matter in the water during the summer months. In the winter the suspended matter is primarily inorganic sediment.

Water quality in Essex Bay has been monitored by the Massachusetts Department of Natural Resources, Division of Marine Fisheries (Chesmore et al, 1973). Dissolved oxygen, pH, and carbon dioxide were measured monthly from May to December, 1969, at 5 locations around the edge of the Bay. Table 4-44 summarizes the range of data recorded. Minimum readings of pH were associated with low salinity. At that time Essex Bay was found to be relatively free from domestic and industrial pollution.

The hydrography of the Merrimack River estuary including suspended sediment, has been studied by Hartwell and Hayes (1969). Data were collected in August, 1968. Concentrations measured during the tidal cycle at a point 2.4 km from the mouth ranged from greater than 15 mg/l at low tide to less than 2 mg/l on the flooding tide near high-tide level. The maximum concentration was 19 mg/l in the fresh river water.



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-225	Average P.M. Concentrations of Ebbing Coastal and Estuarine Waters (Shevenell, T. C., 1973)



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

TRIGOM PARC	FIGURE 4-226	Seasonal Changes in Vertical Distribution of Turbidity (Shevenell, T. C., 1973)

Suspended load data for the Merrimack River for 1967 ranged from 2860 tons/day in April to 46 tons/day in September (Water Resources Data, USGS, 1967).

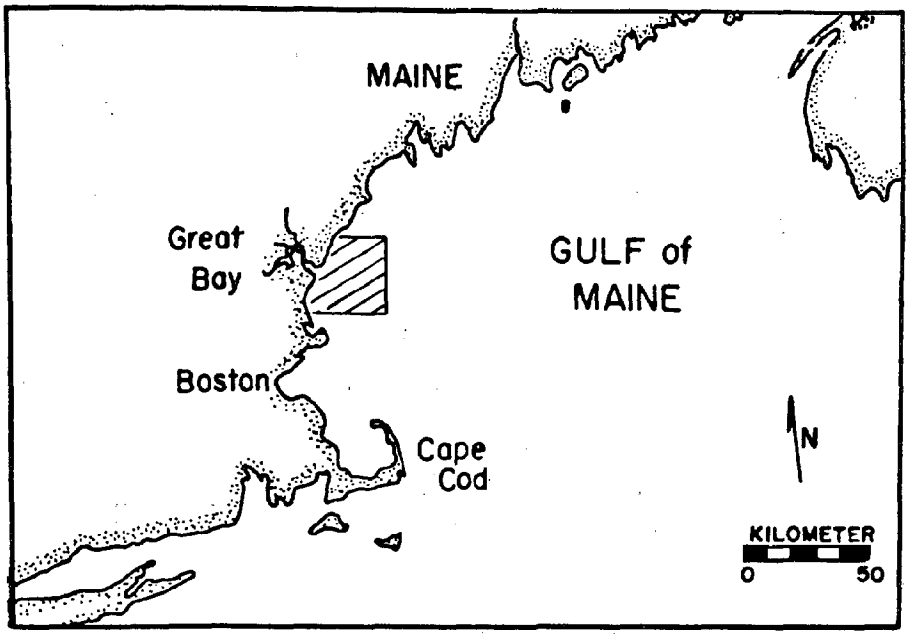
In light of the circulation patterns Hartwell and Hayes felt much of the suspended load was deposited on Joppa Flats. A significant portion of the sediments there contain pollutants from the river and possibly effluent from sewage plants (Hartwell and Hayes, 1969).

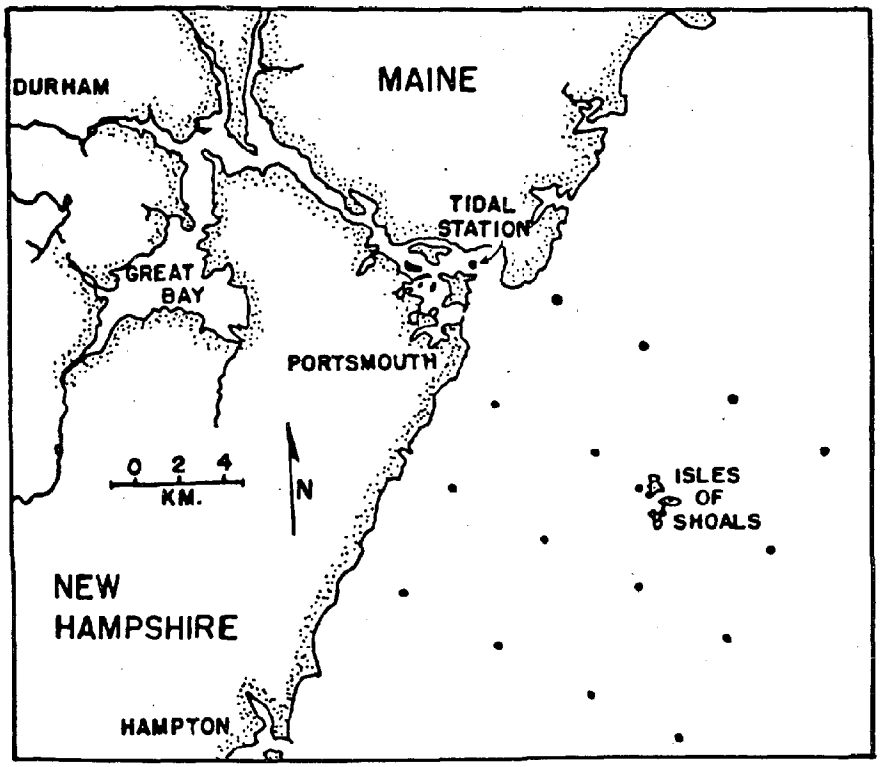
Suspended-sediment concentrations and water turbidity have been studied in the Great Bay estuarine system by Anderson (1970, 1972, 1973, and 1974), Shevenell (1973), and Normandeau Associates, Inc. (data reports to the Public Service Co. of New Hampshire, 1973). Studies by Anderson were located at the mouth of the Bellamy River estuary and at the entrance to Great Bay proper. The tidal station used by Shevenell was located in Portsmouth Harbor at the mouth of the estuarine system (Fig. 4-227). Data were collected during the tidal cycle and seasonally. Water depth ranged from 15 to 20 m at the inner stations and 75 to 80 m for the outer stations as shown in Fig. 4-227.

Periodic variation in suspended-sediment concentration during the tidal cycle, as well as during the season was observed at these locations. Most of the material in suspension is the result of erosion of tidal-flat sediments. This is because this estuary is shallow with 50 percent of the area exposed at low tide. The resuspension may be periodically controlled by tidal currents, or aperiodically as the result of wind-wave resuspension (Anderson, 1973). Anderson (1974) found that water waves from boats may also be a significant factor in increasing the suspended load.

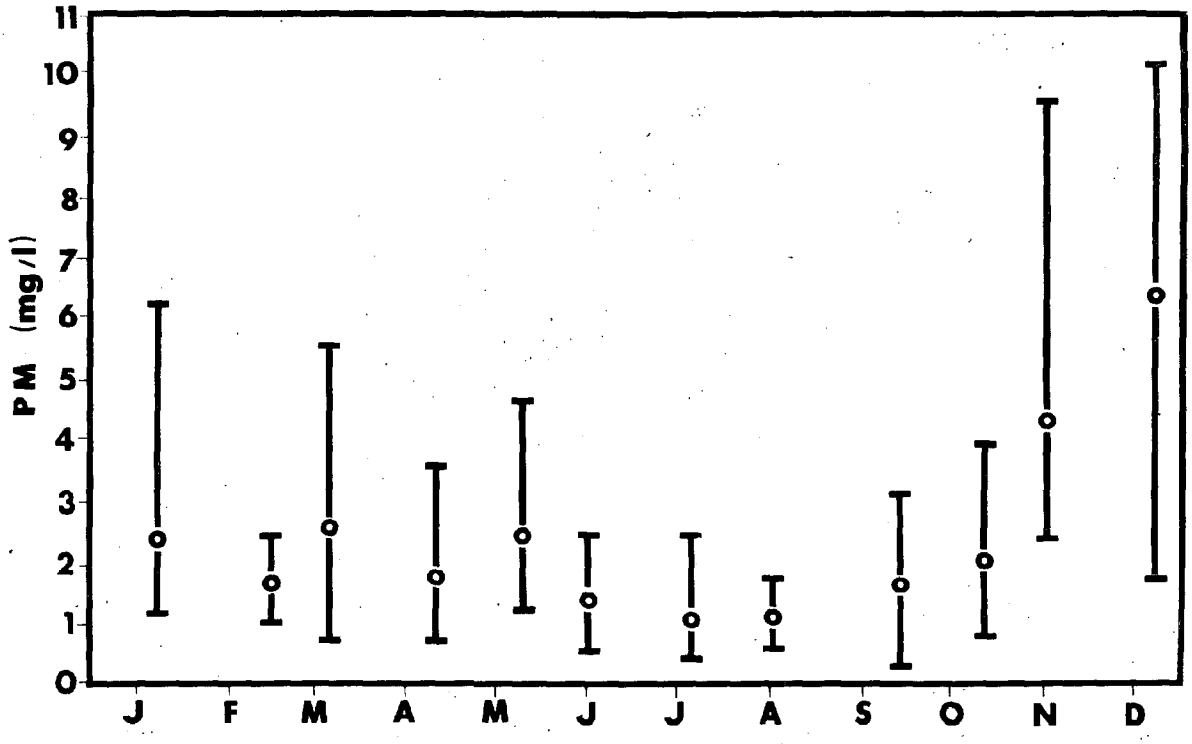
Shevenell (1973) observed that the concentration of suspended matter ebbing out of the Great Bay system changed periodically during the seasons (Fig. 4-225). Average concentrations in the ebbing water ranged from one mg/l in August to 6.5 mg/l in December. A tidal periodicity was observed in Portsmouth Harbor because of the increase in suspended sediment concentrations up the estuary. The highest surface concentrations occurred just before low tide. This tidal periodicity was observed for all months of the year. At the Bellamy River station the tidal periodicity broke down during the winter months (Anderson, 1970). However, at the Portsmouth Harbor station the periodicity was during summer months (Shevenell, unpublished manuscript, 1974) (Fig. 228).

Secchi-disc measurements have been made in the main channel of the Great Bay System and in Portsmouth Harbor using a one-meter-pathlength, beam-transmissometer (Shevenell, unpublished manuscript, 1974). Secchi-disc measurements range from 4.9 to 0.9 m (Normandeau Associates, Inc., personal communication) with the most turbid waters in the upper extremes of Great Bay where resuspension from the mud flats occurs.





A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-227	Index Map of Study Area (Shevenell, T. C., 1973)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-228	Range of Particulate Matter Over the Tidal Cycle at Portsmouth Harbor (Shevenell, unpublished manuscript, 1974)

Table 4-44 *Ranges for temperature, salinity, and water quality measurements for Essex Bay, 1969.*

Sampling Station	Temperature (F) Water Min.	Water Max.	Air Min.	Air Max.	Salinity (0 00) Min.	Max.	Ave.	pH Min.	Max.	Ave.	Dissolved Oxygen (ppm) Min.	Max.	Ave.	Carbon Dioxide (ppm) Min.	Max.	Ave.
Castle Neck River	32	65	29	72	22.0	31.5	27.5	7.0	8.5	7.9	5.0	10.0	8.0	5.0	20.0	11.2
Island Road	31	68	29	76	20.5	29.0	25.6	7.5	8.0	7.8	5.0	11.0	7.1	5.0	20.0	12.5
Clay Point	34	67	30	71	3.0	29.0	23.2	7.0	8.5	7.9	6.0	11.0	7.8	5.0	15.0	10.6
Conomo Point	27	63	30	68	25.0	32.0	28.8	8.0	8.0	8.0	5.0	10.0	8.0	5.0	15.0	10.0
Farm Creek	33	65	28	68	25.0	30.0	28.5	8.0	8.5	8.1	6.0	11.0	8.1	5.0	25.0	10.6

4.3.8 CASCO BAY TO EASTPORT

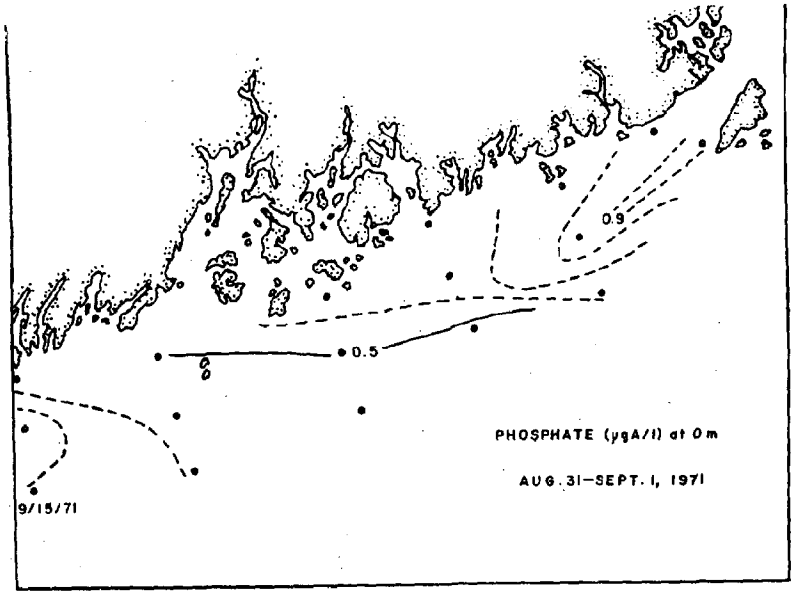
Nutrients in Maine coastal waters have been studied since late 1969 by Apollonio and Applin (1972) on a one to two-month basis. The data include nitrates, phosphates, and silicates with accompanying temperature, salinity, and chlorophyll data. The concentrations and seasonal cycles of the nutrients fall within the expected ranges for this area of the Gulf of Maine. The nutrient distribution is controlled by the coastal circulation patterns. Graham (1970b) found that upwelling was a prominent feature in these coastal waters. Apollonio and Applin observed a tongue of nutrient-rich water approximately 18 km off the coast during the summer (Fig. 4-229). Associated with the tongue is relatively colder water which may be an upwelling of deeper, nutrient-rich water. This relatively high-nutrient water mass is not maintained during the periods of winter mixing. In the vicinity of the Penobscot River, enriching effects during January are evident. The assessment of the control of nutrient distribution by dynamic, physical and biological factors has not, at present, been made (Apollonio and Applin, 1972).

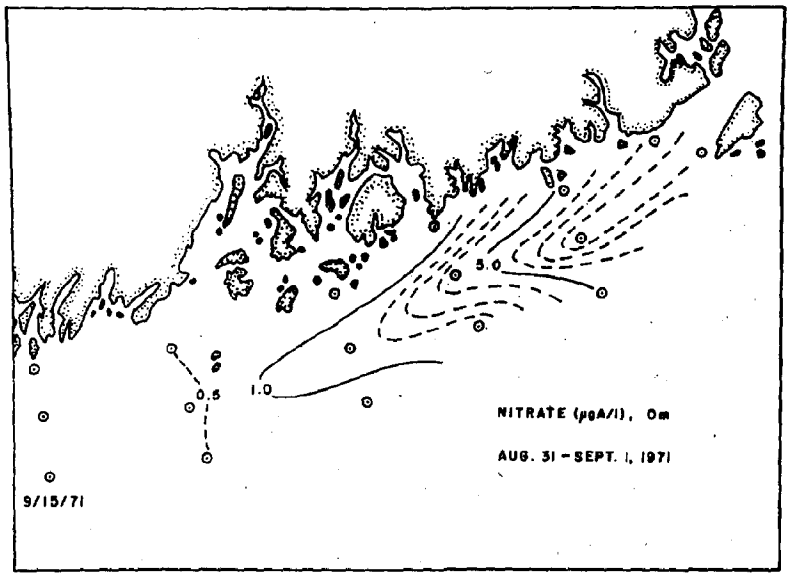
Studies on the annual cycles of nutrients in the estuarine environment are sparse (McAlice, 1971). The best known estuaries and bays which make up the inshore waters of coastal Maine are Casco Bay, the Sheepscot River and adjoining Montsweag Bay.

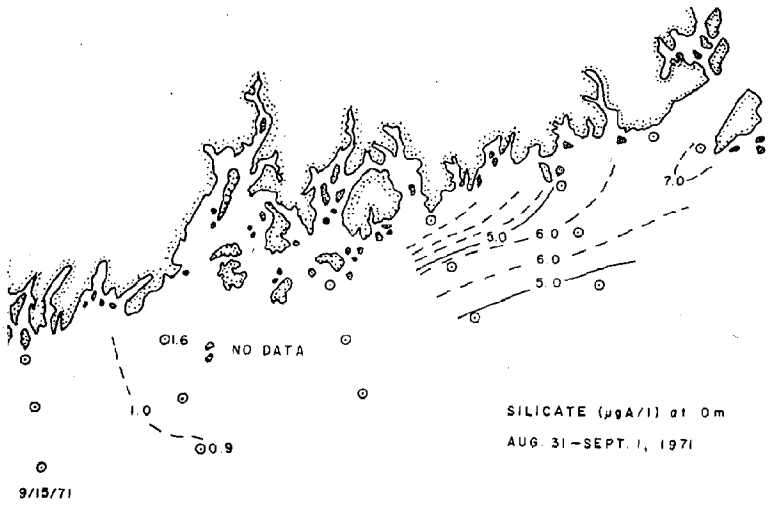
The distribution of nutrients in Casco Bay for the months of March to July and November, 1966, to 1968, has been studied by Hulburt and Corwin (1970). Concentrations of inorganic phosphate and inorganic nitrate from a series of stations into Casco Bay indicate that nutrient renewal from ocean sources is restricted to Outer Casco Bay (Fig. 4-230). After depletion of inorganic nitrate during the spring bloom, nitrate concentrations in the Inner Bay are not renewed as rapidly as would be expected if there was this influx of nutrient-rich, ocean water.

Monthly dissolved oxygen, nitrate, phosphate and silicate data, along with supporting hydrographic and turbidity data, were collected at three stations in Montsweag Bay and from a station in the Sheepscot River (Fig. 4-231) from 1969 to 1972 (McAlice, 1972).

The annual nitrate cycle has a form typical of inshore waters. High winter levels decrease during the spring phytoplankton bloom; late in the summer they build up to a secondary maximum which is depleted by a fall plankton bloom. By late fall high concentrations are observed. McAlice (1972) found stations in the Bay surprisingly low in oxidized inorganic nitrogen. The Sheepscot River generally contained higher supplies of nitrate than the Bay (Fig. 4-231). Concentrations, in general, were less than 5 μg-at NO_3-N/l in both the Sheepscot River and Montsweag Bay. The nitrate concentrations in the coastal waters







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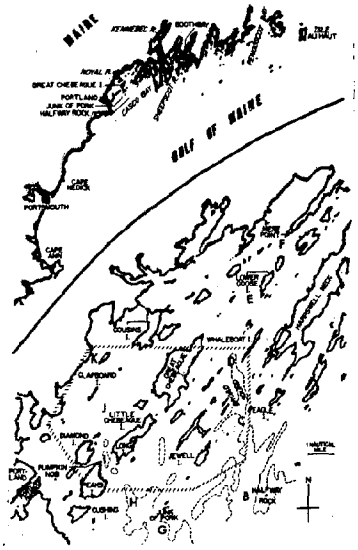
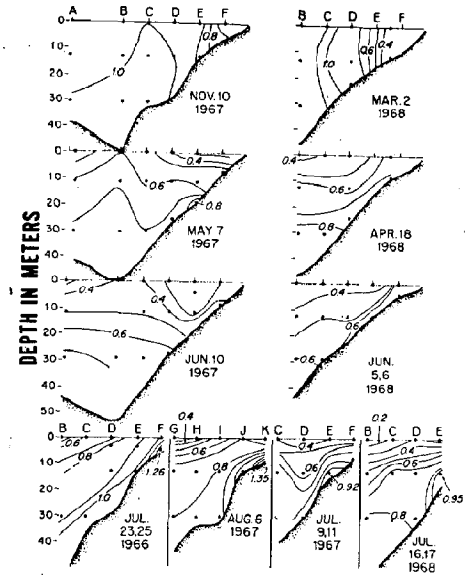
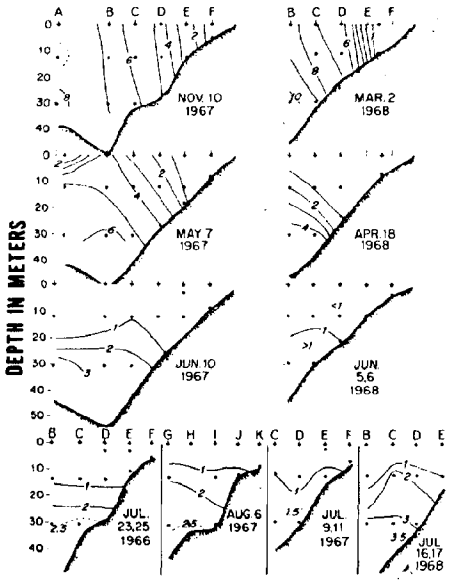
TRIGOM PARC	FIGURE 4-229	Nutrient Concentrations in the Western Gulf of Maine (Apollonio, S. and Applin, H. H. Jr., 1972)

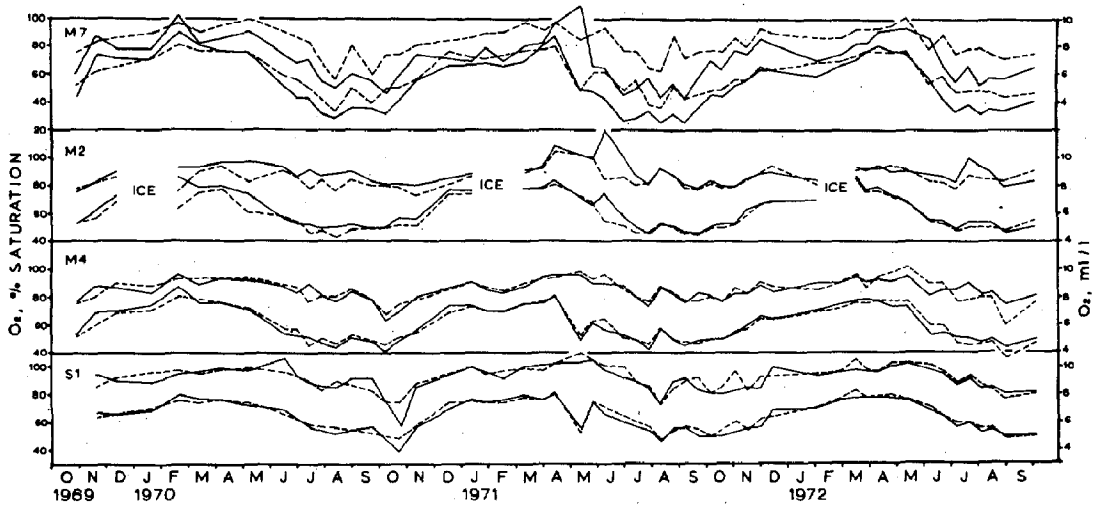


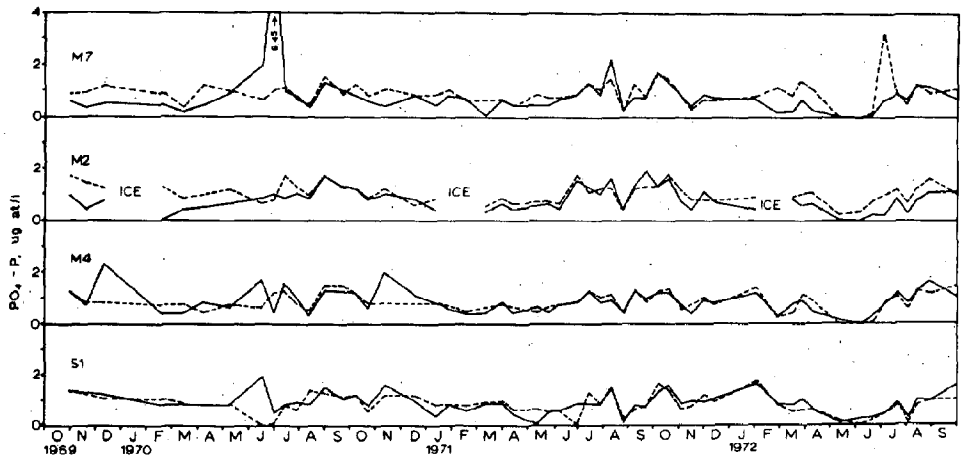




A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-230	Distribution of Inorganic Phosphate and Nitrate (Hulbert, E. M., J. Corwin, 1970)





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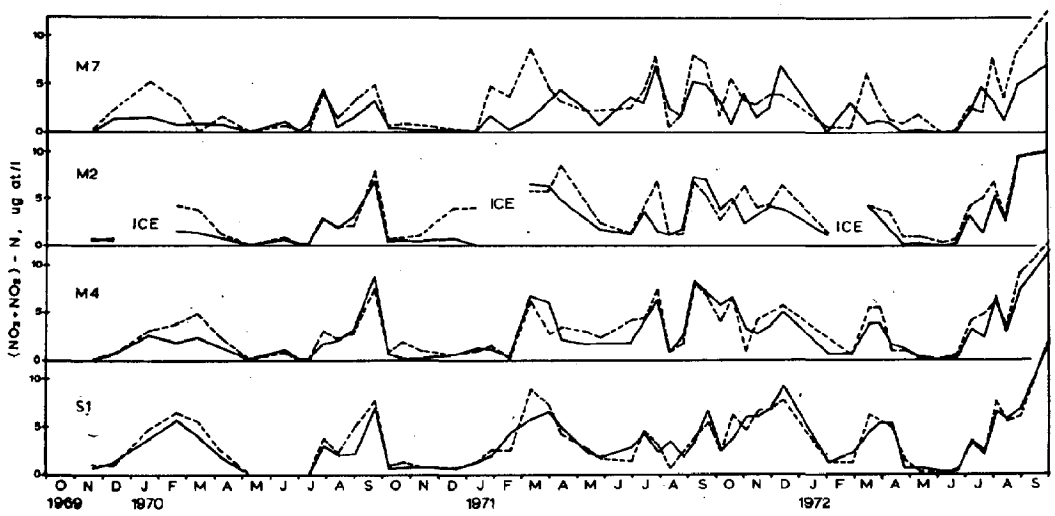
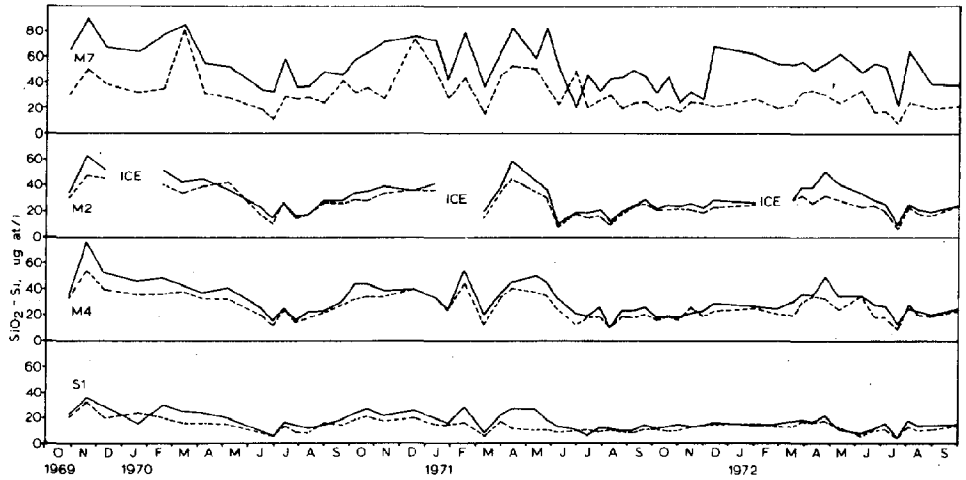
TRIGOM PARC	FIGURE 4-231 a/b	Annual Changes in Dissolved Oxygen, Phosphate, Nitrate and Silicate Concentration (McAlice, B.J., 1972)





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

TRIGOM PARC	FIGURE 4-231 c/d	Annual Changes in Dissolved Oxygen, Phosphate, Nitrate and Silicate Concentration (McAlice, B.J., 1972)

off the entrance to the Sheepscot River range from 11 to 12 μg-at NO_3-N/l in the winter to 0.5 μg-at NO_3-N/l in the summer (Bigelow, Lillick and Sears, 1940).

Phosphate concentrations show little seasonal periodicity (Fig. 4-231). In general, higher concentrations of phosphate are found in both the winter, which is typical, and in the summer, which is atypical but observed in Naragansett Bay (Smayda, 1973). Concentrations of phosphate range between 0.5-1.5 μg-at PO_4-P/l. Annual changes in the N:P ratio largely reflect the nitrate changes. The ratio is generally less than 8:1, thus being lower than the 15:1 ratio in plankton (McAlice, 1971). Like other near coastal areas nitrogen is the limiting nutrient.

The lack of an annual phosphate cycle in estuarine waters is not unusual. Short-term changes in the supply of phosphate to the area may exceed the amount utilized by biologic activity (McAlice, 1971).

The silicate concentrations indicate a seasonal distribution of diatom species. The lowest concentrations were late spring to late summer with a range of about 20 to 60 μg-at SiO_4-Si/l (Fig. 4-231). Concentrations in the Sheepscot River were generally lower than those seen in the Bay with an average around 20 μg-at SiO_4-Si/l. The lowest concentration seen in the Sheepscot station was about 4 μg-at SiO_4-Si/l and occurred after spring diatom blooms.

Percent saturation of dissolved oxygen in Montsweag Bay and Sheepscot River water varies in response to respiratory demands and reduced oxygen input because of decreases in freshwater and low wind-wave activity (McAlice, 1972). During the summer months the lowest dissolved oxygen values and percent saturation values are observed (Fig. 4-231). Throughout the remainder of the year the dissolved oxygen content exceeds 75 percent saturation. The seasonal fluctuations in the amount of dissolved oxygen saturation is greater in Montsweag Bay than in the Sheepscot River. Supersaturation rarely occurs and never approaches the supersaturated values reported by Stickney (1968) in Boothbay Harbor. The lowest values of dissolved oxygen are not as low as those reported for the Penobscot River estuary by Haefner (1967).

Stickney (1968) reported dissolved oxygen concentrations in the coastal waters off Boothbay Harbor. He found 120 to 150 percent supersaturation during the spring and summer. These coastal waters were more highly saturated than nearby offshore waters. Concentrations of nitrogen gas were also found to be occasionally supersaturated during late spring and sometimes in mid-summer, suggesting that some of the supersaturation is because of physical causes, such as warming in shallow embayments and strong tidal mixing of saturated waters.

As the coastline is approached, the waters of the Gulf of Maine become

more dynamic and as a result, the suspended-matter distribution (spatially and temporally) becomes more complex. These waters are generally less than 100 m deep, and therefore, are commonly well mixed to the bottom during the winter months. The seasonal thermocline varies in depth from 10 to 30 m, and is generally deepest in the late summer-early fall.

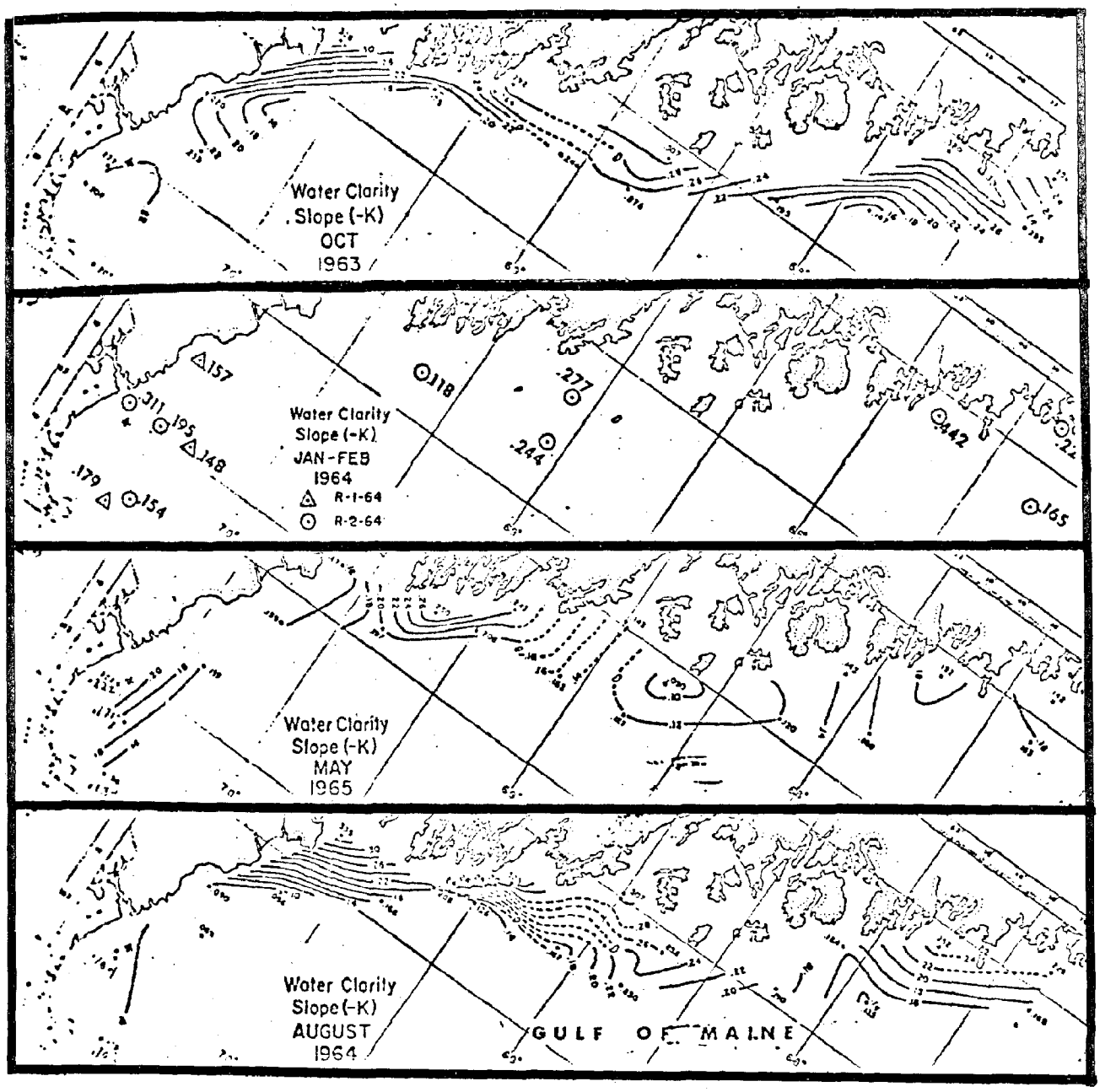
Surface Secchi-disc and photometer measurements taken in conjunction with temperature and salinity profile data for the coastal waters of the Gulf of Maine from 1962 to 1965 have been summarized by Graham (1970a). Transparencies in these areas ranged from 0.400 to 0.062 for reciprocals (1/D), and 0.442 to 0.089 for extinction coefficients (K). Off the Maine coast Graham (1970a) found the surface water was most transparent during the spring (average K=0.167 and average 1/D=0.106). The least-transparent water was found during the fall and winter (average K-0.245 and average 1/D-0.209) (Fig. 4-232).

Graham (1970a) observed that there was an offshore increase in transparency, and at times it was closely related to the surface temperature. The transparency of the surface water in this area depends on both the amount of sediment discharged from the inner bays and estuaries, and the relative abundance of phytoplankton (Brayton and Campbell, 1953).

The Narragansett Marine Laboratory (1953 to 1954) conducted a seasonal survey of physical oceanography off Casco Bay and Portland. Data reports for the summer and fall, 1953, and winter of 1954 include transparency data using black and white Secchi discs, as well as temperature, salinity, sound velocity, and weather data. The range of white disc depths during the summer (July 27-28, 1953) was 3 to 8 m with a general decrease in turbidity in an offshore direction (Fig. 4-233). A similar range in turbidity for the summer months was observed by Hulburt and Corwin (1970) for waters off Casco Bay.

Studies of water turbidity in Montsweag Bay have been conducted from 1970 to the present with the results summarized in the annual reports of Environment Studies by the Maine Yankee Atomic Power Company (1970, 1971, 1972). Secchi-disc depths ranged from less than 0.5 m to greater than 4.5 m. The turbidity in this area was affected by seasonal increases in runoff, by tidal-current action, by wind-wave activity on tidal flats, and the spring and fall overturns.

Haefner (1967) found a similar range of transparencies for the Penobscot River estuary. Sampling was during the spring through the fall months, 1963 to 1965. At the most landward station near Bangor, Secchi disc depths ranged from 0.75 to 1.25 m during the study period. The most seaward station, near Searsport, exhibited a range in trans-



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TRIGOM PARC	FIGURE 4-232	Water Transparency, Extinction Coefficients (Graham, J. J., 1970a)

parency of 2.75 to 3.00 m.

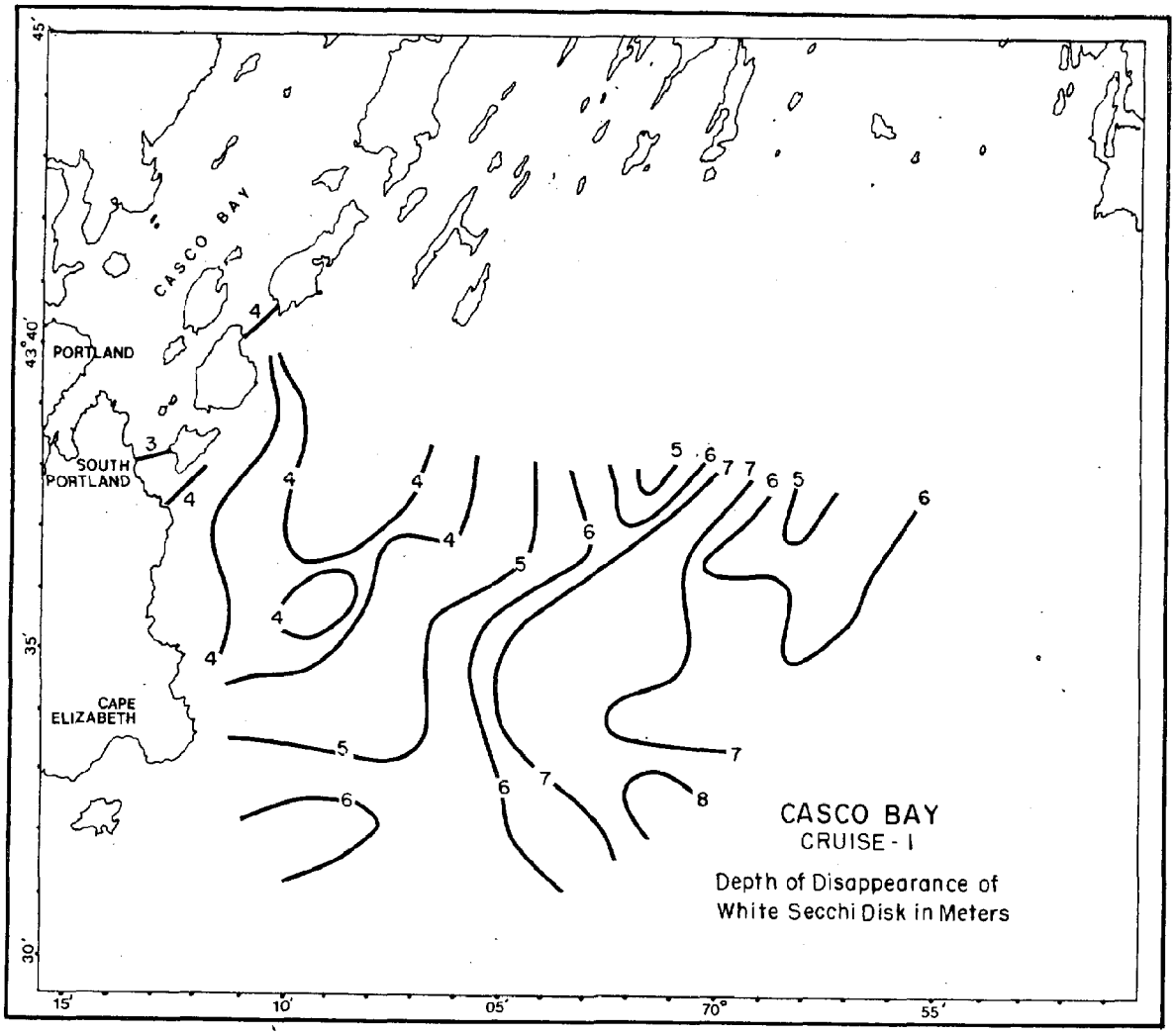
Suspended-matter concentrations have been measured in Somes Sound on Mount Desert Island by Folger, Meade, Jones and Corey (1972). Suspended matter in the near surface waters ranged from 0.6 to 1.6 mg/l; the bottom waters were slightly more turbid, having a range of 1.0 to 4.1 mg/l. In the near-bottom samples they found a correlation between the bottom-sediment texture and the concentration of suspended material.

Toxic trace-metal concentrations have been studied by the Department of Sea and Shore Fisheries of Maine near the Castine-Blue Hill Peninsula (Dow, 1969, 1970). Copper, zinc, cadmium, lead, cobalt, iron, chromium, manganese and nickel concentrations were measured at 13 stations around the peninsula (Fig. 4-234). The stations were located near known sulfide outcrops, previously worked surface mines and at sites away from those types of areas.

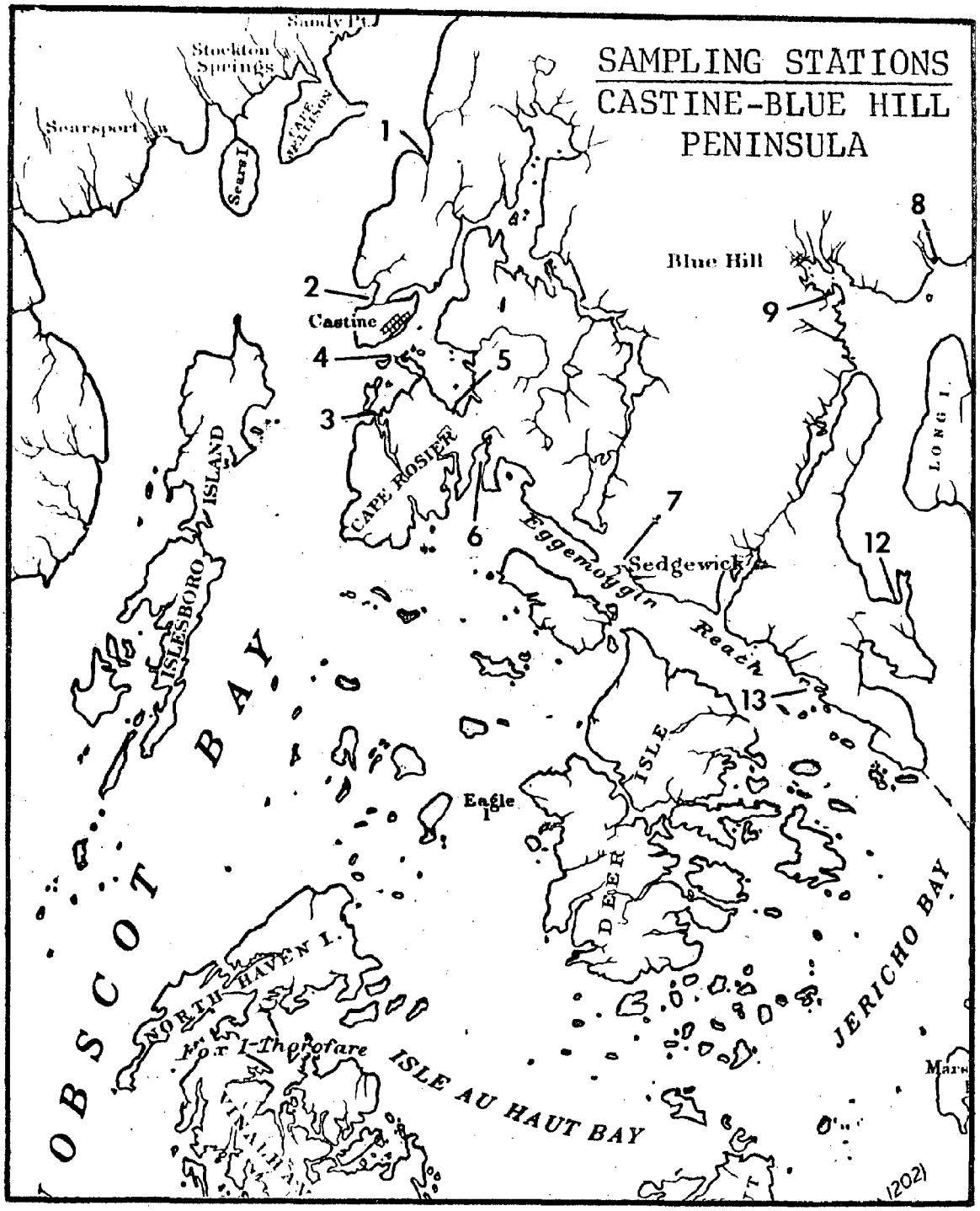
The concentrations are extremely high when compared to open ocean concentrations and maximum concentrations in Atlantic Coastal areas (Table 4-45).

Table 4-45 Comparison of Toxic Metals in the Maine Marine Environment and from other Atlantic Coastal Areas (ppm) (from Dow, 1970).

Metal	Maximum of Range Elsewhere	Maximum at Cape Rosier
Zinc	28.00	69.58
Copper	90.00	8.41
Iron	1710.00	2471.50
Manganese	29.90	341.20
Cadmium	.90	.85
Lead	10.20	19.50
Chromium	5.00	6.78
Nickel	2.30	2.67
Cobalt	.20	1.49



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-233	Turbidity in Casco Bay (Narragansett Marine Laboratory 1953-1954)



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

TRIGOM PARC	FIGURE 4-234	Sampling Stations - Castine - Blue Hill Peninsula (Dow, R. L., 1969)

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Chapter 4 Major Sounds and Embayments

		Page
Chapter 4.4	Meteorology and Climate	
4.4.1	Introduction	4-416
4.4.2	Southern Sub-Region	4-416
	Precipitation	4-418
	Temperature	4-420
	Humidity	4-420
	Data from Environmental Impact Statements	4-420
4.4.3	Northern Sub-Region	4-429
	Precipitation	4-436
	Temperature	4-436
	Data from Environmental Impact Statements	4-436
4.4.4	Storms	4-452
	Introduction	4-452
	Tropical Cyclones	4-452
4.4.5	References	4-502

4.4 METEOROLOGY AND CLIMATE

4.4.1 INTRODUCTION

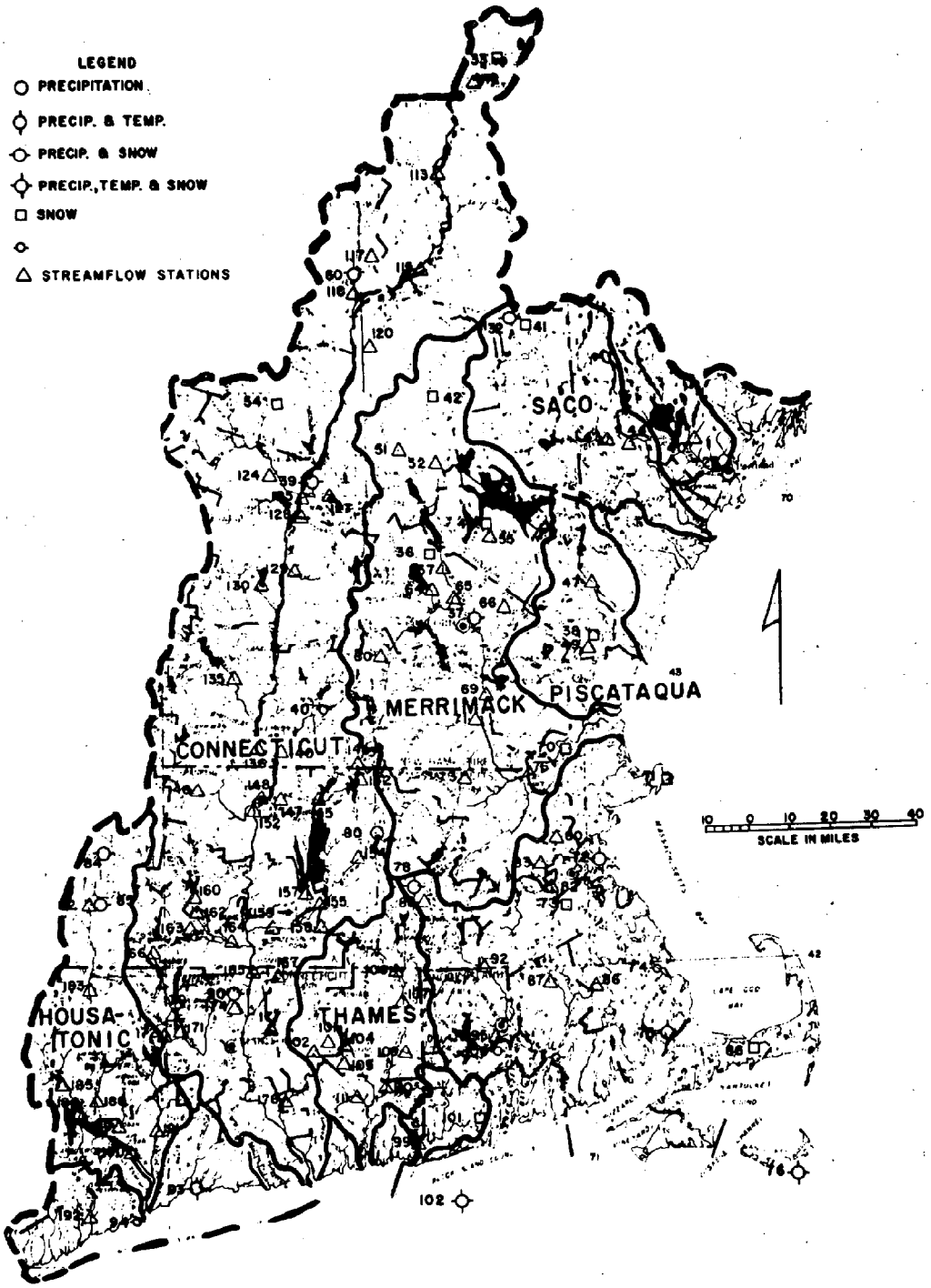
The following section presents a characterization of coastal and local weather conditions in somewhat more detail than the regional overview with occasional focus on sites studied in greater detail for the location of power plants. Little attempt was made to review the fairly extensive literature of the entire coastal region, but many data were extracted from atlases and summary reports such as U. S. Army Corps of Engineers (1972) and Havens, Shaw, and Levine (1974). A list of Environmental Impact Statements used and the attendant available data for all types can be found in Appendix A-3. A more detailed description of storms for the whole coast is presented in the following Section 4.4.4.

4.4.2 SOUTHERN SUB-REGION

The southern sub-region, beginning at Long Island and including New York Bight (Westinghouse, 1972) has relatively sparse numbers of meteorological stations. Stations used by the North Atlantic Report (U. S. Army Corps, 1972) are shown on Figure 4-236. Only a few of these record all three parameters of temperature, precipitation, and wind.

The marine climate in New York Bight and stretching to Cape Cod is characterized by the prevailing westerly belt of winds along the east coast of the continent. There is a modified continental climate. Lying in the paths of extratropical cyclones, this area experiences frequent and abrupt changes of wind, temperature, and clouds in winter. Tropical cyclones bring stormy weather in summer and fall. The cold Labrador Current flowing along the coast and the warm Gulf Stream to the eastward have strong effects on the weather. During the winter the area lies between the Icelandic Low and the North American High, and in summer it lies under the northwest quandrant of the Bermuda High. There is little seasonal variation in barometric pressure, but there may be wide day-to-day fluctuations, especially in winter.

The temperatures are affected by maritime influences. In spring and summer, sea breezes reduce temperatures and in fall and winter, raise them. Changes in wind direction in any season can cause large fluctuations in temperature. In winter south and southwest winds bring mild temperatures, and northwest winds bring cold. In summer, southwest and west winds bring warmer temperatures, and northeast winds bring cooler. Air temperature over the New York Bight averages 2.5 C to 5 C higher than those ashore in January and 1 C to 3 C lower in July.



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

TRIGOM PARC	FIGURE 4-235	Meteorologic and Stream Flow Stations - Sub-Region B (NAR, 1972)

Relative humidity in the region is high throughout the year, especially in summer. It is high in the morning and lower in the afternoon. Also, relative humidity is higher with onshore winds and lower with offshore winds.

Cyclones passing off the coast in winter usually bring snow in November through April. On rare occasions freezing rain may occur. Precipitation is reported 25 percent of the time in February and 10 percent in July. During May through September, rain is mostly in local brief showers and thunderstorms. The latter occur mostly in afternoon and evening and may obscure visibility significantly. In winter overcast occurs 40 to 60 percent of the time; in summer, 30 percent.

Visibility may be restricted by fog, haze, rain, or snow, but advection fog is most common. Fog occurs about 30 percent of the time in late spring and early summer when south and southwesterly winds move moist air over the cooler waters of the Labrador Current. However, fog may occur any time of the year and may persist several weeks. Sea smoke or steam fog forms occasionally in winter.

Tropical cyclones and hurricanes occasionally move into the area in late summer and fall, but may occur as early as May or as late as November. They usually move on a northeasterly course, usually are more severe and destructive than the extratropical cyclones, and have been reported to have winds of 80 m.p.h. or more.

PRECIPITATION

Based on meteorologic and hydrologic data summarized by U. S. Army Corps of Engineers (1972) in Table 4-46, there is a fairly uniform distribution of average annual precipitation throughout the southern region, as well as relatively even monthly and seasonal distributions. The average annual precipitation, based on the 30-year records of 40 stations, is 110 cm, varying from a maximum of about 190 cm at Mt. Washington in New Hampshire to a minimum of about 92 cm at St. Johnsbury, Vermont. During the winter season (December, January and February), there is an average of 26 cm of precipitation and the Sub-region receives nearly equal amounts of rainfall (29 cm) in the spring, summer and fall seasons.

Extreme monthly variations have ranged from 63 cm in August at Barkhamsted, Connecticut, to 0.2 cm in June at Nantucket Island, Massachusetts, and traces at Block Island, Rhode Island, Table 4-46 summarizes precipitation data for the area.

The region receives a substantial amount of snow, generally from late November to late March, with ranges of from 38 to 75 cm at the southern coast to 205 to 254 cm in the northern interior. As expected, snowfall

Table 4-46

PRECIPITATION DATA

Station	Map Code	Period of Record	Elevation ft., m.s.l.	Item	Monthly Data (a) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Annual (a)
St. Johnsburg, Vt.	60	1894-1961	699	Max	5.06	4.04	6.24	5.83	6.36	7.13	6.95	6.35	7.57	8.07	5.81	4.38	
				Min	0.92	0.52	1.10	0.49	1.16	0.66	1.21	1.09	1.14	1.03	0.59	1.01	
				Mean	2.57	2.14	2.44	2.82	3.23	3.77	3.47	3.27	3.48	3.06	3.15	2.59	35.99
Mt. Washington, N.H.	32	1933-65	6262	Max	18.23	14.67	15.57	10.03	13.41	10.95	10.70	13.14	14.07	13.49	10.95	13.35	
				Min	1.80	2.64	2.15	2.19	1.78	3.30	2.69	2.77	2.74	0.75	2.31	1.49	
				Mean	5.44	5.21	5.74	5.89	5.54	6.50	6.71	6.65	7.00	6.19	6.61	6.31	74.09
Hanover, N.H.	39	1835-1960	603	Max	6.62	4.45	5.63	6.26	6.82	5.90	9.17	8.92	8.88	5.57	5.76	4.67	
				Min	0.99	1.16	1.26	0.49	1.11	0.43	1.37	0.66	0.78	0.45	1.00	0.61	
				Mean	2.87	2.40	2.77	3.13	3.30	3.24	4.18	3.07	3.38	2.82	3.36	2.72	37.24
Portland, Me.	23	1871-1965	47	Max	12.29	7.35	9.97	9.35	7.74	6.35	5.94	8.30	9.81	6.72	8.00	8.09	
				Min	0.76	1.56	1.07	0.71	0.78	0.70	0.75	0.27	0.30	0.26	0.56	0.98	
				Mean	4.37	3.80	4.34	3.73	3.41	3.18	2.86	2.42	3.52	3.20	4.17	3.85	42.85
Concord, N.H.	37	1856-1965	342	Max	5.87	5.54	9.80	6.36	8.26	10.10	7.57	6.01	10.68	6.79	7.54	7.64	
				Min	0.73	1.13	1.20	0.42	0.60	1.25	0.96	0.95	0.41	0.48	0.51	—	
				Mean	3.23	2.48	3.26	3.31	3.17	3.60	3.41	2.96	3.75	2.66	3.72	3.25	38.60
Boston, Mass.	72	1871-1965	15	Max	9.54	5.87	11.00	7.82	13.38	9.13	9.46	17.09	10.94	7.18	7.66	8.19	
				Min	0.92	1.23	1.50	1.59	0.25	0.48	0.52	0.85	0.35	0.34	0.65	0.66	
				Mean	3.94	3.32	4.22	3.77	3.34	3.48	2.88	3.66	3.46	3.14	3.93	3.63	42.77
Hartford, Conn.	90	1905-65	169	Max	7.23	5.28	9.21	6.93	7.04	8.08	11.24	21.87	14.59	11.61	7.36	6.88	
				Min	0.91	1.65	1.84	0.65	0.73	0.87	1.35	0.93	0.63	0.65	0.87	0.78	
				Mean	3.58	2.94	3.80	3.73	3.41	3.70	3.61	4.01	3.65	3.18	3.84	3.47	42.92
Nantucket, Mass.	76	1887-1965	43	Max	8.24	8.07	8.88	8.41	8.24	6.55	7.45	12.92	9.55	8.31	8.76	7.04	
				Min	1.21	1.30	1.84	0.90	0.86	0.01	0.15	0.28	0.42	0.37	1.06	1.10	
				Mean	4.22	3.76	4.54	3.76	2.88	2.92	2.71	3.68	3.51	3.70	4.05	3.93	43.66
Block Island, R.I.	102	1831-1965	110	Max	6.74	6.32	8.52	5.86	8.37	6.53	6.71	9.73	11.36	8.74	9.73	6.37	
				Min	0.73	1.27	1.61	1.81	0.72	T	0.39	0.69	0.08	0.22	0.86	0.83	
				Mean	3.84	3.29	4.07	3.61	3.01	2.56	2.69	3.86	3.20	3.02	3.71	3.59	40.45
New Haven, Conn.	93	1872-1965	6	Max	8.35	6.46	10.78	6.71	7.77	13.96	7.45	10.95	14.52	10.06	8.14	8.34	
				Min	0.63	1.49	1.67	1.32	0.89	0.12	0.52	0.72	0.32	0.63	0.85	0.96	
				Mean	3.96	3.19	4.62	3.89	3.71	3.53	3.43	4.24	3.93	3.45	4.05	4.02	46.02

(a) Data based on 30-year period 1931-60 except where record begins after 1931.

increases with elevation in the interior to a maximum annual average of 470 cm at the summit of Mt. Washington, New Hampshire (gage elevation 1,909 m). Summaries by U. S. Army Corps of Engineers (1972) showed ranges from 66 cm in Bridgeport, Connecticut, to 180 cm in Portland on an annual average.

TEMPERATURE

The average annual temperature varies from 10 C in the southern coastal region to 5 C in the northern part of the region. The average annual temperatures are influenced not only by proximity to the ocean, and its moderating influence, but also by differences in elevation, particularly in the interior of the Sub-region.

The temperature range is greatest during the winter months, varying approximately 10 C degrees, from an average of -8 C in the north to 0 C on the coast. The extremes of temperature recorded in the Subregion range from -45 C to 41 C, with approximately 10 days per year of temperatures above 32 C. Days with less than -20 C temperatures are more common, averaging 25 to 50 per year inland. Table 4-47 summarizes mean temperature data at selected stations.

HUMIDITY

Mean relative humidity generally averages about 75 percent in January and 70 percent in July. The mean annual is about 70 percent. The mean annual humidity at Boston, Massachusetts, and Hartford, Connecticut, at 1 p.m., is 56 percent, while at 7 a.m. it is 71 percent and 76 percent, respectively, at these location. Mean dew point temperatures range from -12 C to -6.5 C in January, from 10 C to 18 C in July, and are between -1 C and 4.4 C annually. The annual average dew point is 2.2 C at Concord, New Hampshire, and 6 C at New Haven, Connecticut.

DATA FROM ENVIRONMENTAL IMPACT STATEMENTS

Millstone Environment Impact Statement

Data presented in the Millstone Nuclear Power Station Unit 3 Environment Report (1973) provide a detailed look at the area of Bridgeport and New Haven, Connecticut. Figure 4-236 shows area location. The station site is located in the northern temperate climatic zone. The major local influence on the climate is due to the proximity to Long Island and the Atlantic Ocean. Climatological records are available from a number of stations in Connecticut, the most representative being New Haven and Bridgeport, located to the west, about 35 to 50 miles along the coast.

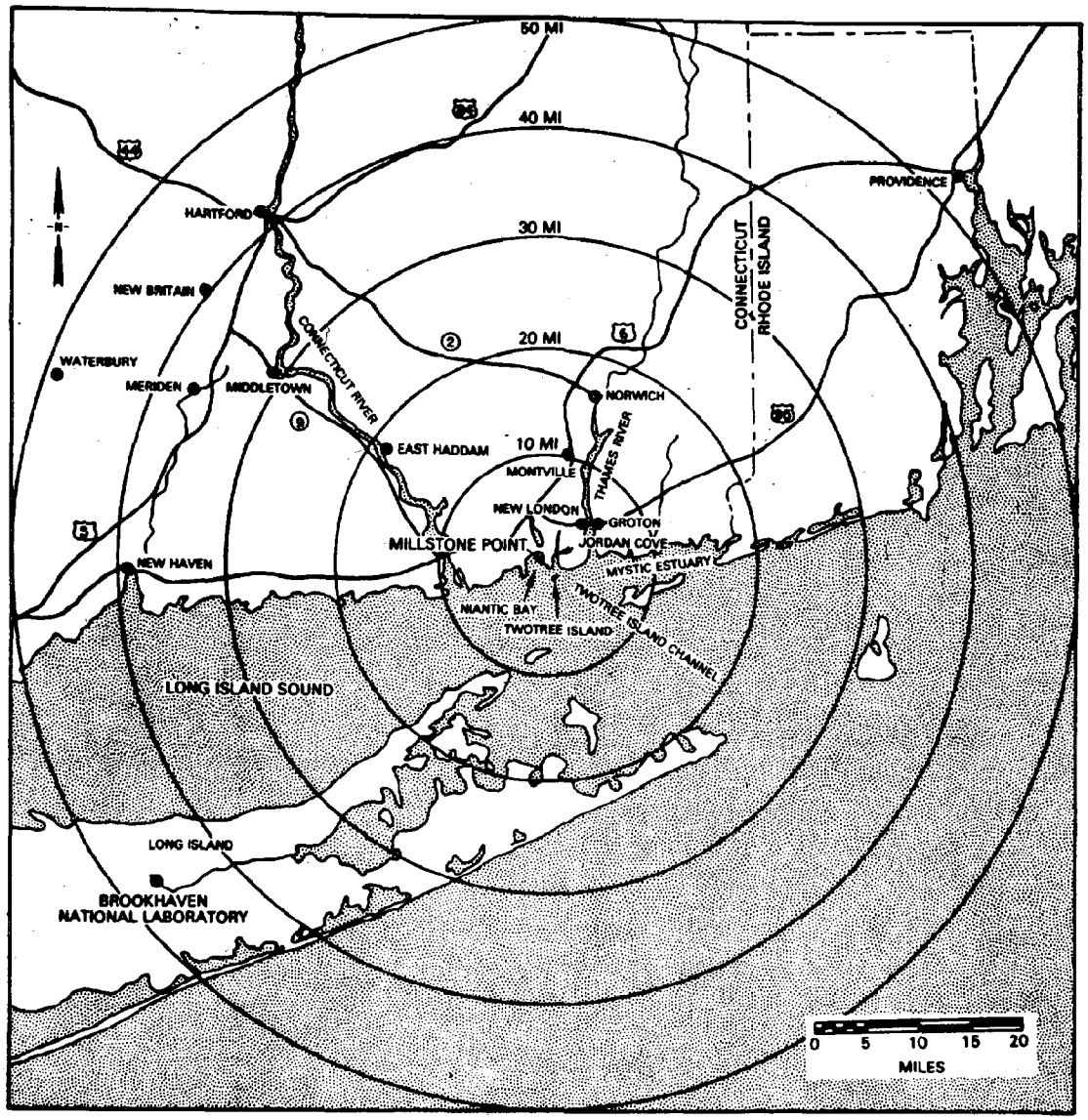
A summary of the climatology for this coastal region, based on the Bridgeport records, is presented in Table 4-48.

Table 4-47

TEMPERATURE DATA -SUBREGION B (in degrees Fahrenheit)

Station	Map Code	Period of Record	Elevation ft.,m.s.l.	Mean Annual Temperature (a)			Mean Monthly Temperature (a) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
St.Johnsbury, Vt.	60	1894-1961	699	Max.Year	46.9	Max.Month	28.4	27.0	40.1	48.4	60.9	69.4	72.6	71.7	63.8	54.0	42.9	29.9
				Min.Year	42.1	Min.Month	10.0	6.0	23.1	36.1	49.7	59.3	65.1	63.0	54.2	44.6	28.2	9.4
				Ave.Year	44.3	Ave.Month	17.8	19.6	29.4	42.9	55.6	65.0	69.3	67.2	59.2	48.3	36.1	21.7
Hanover,N.H.	39	1835-1960	603	Max.Year	47.6	Max.Month	30.0	27.5	40.8	49.4	59.8	69.3	73.0	72.0	63.4	54.3	42.0	31.1
				Min.Year	42.3	Min.Month	12.1	8.0	24.9	37.0	50.2	58.9	66.0	63.4	54.3	44.2	29.6	14.5
				Ave.Year	44.8	Ave.Month	18.9	20.9	30.6	43.4	55.3	64.5	69.2	67.2	59.4	48.3	36.5	22.9
Portland,Me.	23	1871-1965	47	Max.Year	48.6	Max.Month	32.6	30.4	39.5	47.0	56.2	65.0	71.7	72.4	63.2	55.3	44.6	33.1
				Min.Year	43.7	Min.Month	13.9	14.0	25.6	38.4	48.2	58.1	65.1	63.3	54.5	45.8	35.2	18.0
				Ave.Year	45.0	Ave.Month	21.8	22.8	31.4	42.5	53.0	62.1	68.1	66.8	58.7	48.6	38.1	25.8
Concord,N.H.	37	1856-1965	342	Max.Year	48.3	Max.Month	31.8	29.7	41.1	51.4	60.2	68.4	74.1	72.8	63.2	55.2	42.6	32.9
				Min.Year	44.2	Min.Month	13.5	12.0	25.6	38.4	50.8	60.0	66.2	63.6	54.9	46.6	33.1	17.8
				Ave.Year	45.6	Ave.Month	21.2	22.7	31.7	43.8	55.5	64.5	69.6	67.4	59.3	48.7	37.6	25.0
Keene,N.H.	40	1892-1960	490	Max.Year	49.5	Max.Month	32.0	32.4	43.6	51.2	61.7	70.1	74.2	72.3	64.7	55.4	44.1	32.9
				Min.Year	43.6	Min.Month	14.2	10.4	26.9	39.6	50.8	61.1	64.7	62.9	56.3	45.0	32.2	19.0
				Ave.Year	46.6	Ave.Month	22.8	24.2	32.9	45.1	56.4	65.1	69.8	67.8	60.4	49.8	38.5	26.1
Worcester, Mass.	78	1892-1965	986	Max.Year	49.9	Max.Month	34.1	32.4	44.9	51.3	62.5	69.6	74.3	72.7	64.7	57.0	44.7	35.4
				Min.Year	45.2	Min.Month	16.8	14.4	26.1	40.5	52.1	59.9	67.6	64.4	57.0	46.9	35.1	20.9
				Ave.Year	46.8	Ave.Month	24.0	24.9	32.8	44.6	55.2	64.6	69.8	68.3	60.8	50.5	39.2	27.2
Boston,Mass.	72	1871-1965	15	Max.Year	53.6	Max.Month	38.8	36.4	47.2	52.5	63.2	71.6	77.5	74.7	68.1	61.6	49.6	40.2
				Min.Year	48.5	Min.Month	23.0	17.5	32.7	43.4	55.0	63.6	70.8	67.3	61.1	49.6	38.3	26.4
				Ave.Year	51.4	Ave.Month	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55.0	44.9	33.3
Plymouth, Mass.	74	1886-1962	25	Max.Year	53.7	Max.Month	41.1	37.0	46.4	52.5	61.5	71.3	76.5	75.1	67.7	60.0	49.7	41.1
				Min.Year	47.4	Min.Month	22.2	19.5	32.4	40.0	54.2	63.1	69.1	66.4	60.9	49.1	38.4	26.8
				Ave.Year	51.0	Ave.Month	30.8	31.2	37.8	47.3	57.6	66.5	72.2	70.7	64.1	54.8	45.0	33.8
E.Wareham, Mass.	75	1912-62		Max.Year	51.5	Max.Month	37.2	34.2	43.0	50.8	59.4	69.1	75.6	73.7	66.4	56.8	47.4	38.3
				Min.Year	47.0	Min.Month	20.9	17.0	30.1	41.4	51.2	61.2	67.8	65.8	59.8	48.0	36.8	23.7
				Ave.Year	49.3	Ave.Month	29.0	29.1	36.1	45.7	55.9	64.7	71.0	69.8	62.8	52.9	43.2	31.9
Fall River, Mass.	77	1887-1960	190	Max.Year	53.3	Max.Month	38.4	36.8	45.7	52.3	62.2	71.2	77.1	74.0	68.0	60.0	49.0	39.6
				Min.Year	47.6	Min.Month	22.2	17.8	31.8	42.9	53.4	62.9	69.2	66.9	61.4	48.6	38.3	25.8
				Ave.Year	50.7	Ave.Month	29.7	30.2	37.2	47.3	57.8	66.6	72.7	71.7	64.3	54.5	43.8	32.9
Providence, R.I.	100	1905-65	51	Max.Year	54.4	Max.Month	38.6	36.2	48.4	54.5	64.2	72.2	78.2	75.6	68.4	61.4	49.8	38.4
				Min.Year	48.8	Min.Month	22.7	17.4	31.5	43.9	53.4	62.5	70.3	67.8	60.1	50.4	38.8	25.3
				Ave.Year	50.1	Ave.Month	29.2	29.7	37.0	47.2	57.5	66.2	72.1	70.5	63.2	53.2	43.0	32.0
Nantucket, Mass.	76	1887-1965	43	Max.Year	51.6	Max.Month	40.3	36.2	43.2	49.3	57.2	65.0	71.6	71.8	66.8	57.7	50.0	41.3
				Min.Year	48.0	Min.Month	25.8	22.6	31.8	41.8	48.7	58.0	65.7	64.9	59.9	51.0	41.4	28.6
				Ave.Year	49.5	Ave.Month	33.0	31.4	36.1	44.3	52.6	61.3	68.0	68.1	62.9	54.3	45.9	36.1
Block Island, R.I.	102	1881-1965	110	Max.Year	52.8	Max.Month	40.4	36.9	42.9	48.8	57.4	66.4	73.8	72.8	66.4	60.0	50.6	41.8
				Min.Year	48.3	Min.Month	25.2	20.3	32.4	41.4	49.8	59.8	66.8	66.4	61.8	51.0	41.6	28.8
				Ave.Year	50.1	Ave.Month	32.1	30.9	36.7	44.6	53.9	62.9	69.6	69.6	64.0	55.2	45.2	35.9
New Haven, Conn.	93	1872-1965	6	Max.Year	53.1	Max.Month	39.6	36.7	44.0	53.5	61.4	72.8	75.4	75.2	69.2	58.1	48.4	37.6
				Min.Year	49.0	Min.Month	22.8	17.4	31.7	43.4	53.6	62.3	69.4	67.5	61.2	50.8	39.4	26.7
				Ave.Year	50.1	Ave.Month	29.6	29.6	36.9	46.9	57.2	66.2	71.9	70.6	63.9	54.0	43.4	32.4
Bridgeport, Conn.	94	1893-1965	7	Max.Year	53.9	Max.Month	38.8	37.1	46.4	53.4	63.2	72.6	77.4	76.1	69.4	67.6	38.4	26.4
				Min.Year	48.4	Min.Month	21.8	15.6	32.1	43.6	54.9	64.0	71.1	68.0	61.6	49.4	48.8	38.8
				Ave.Year	51.5	Ave.Month	30.2	30.5	37.5	48.0	58.7	68.0	73.7	72.3	65.5	55.4	44.5	33.2

(a) Data based on 30-year period 1931-60 except where record begins after 1931.



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TRIGOM PARC	FIGURE 4-236	Location of Millstone Nuclear Power Plant

Table 4-48

SUMMARY OF CLIMATOLOGY, NORMALS AND MEANS[a]

Months	Normal Air Daily Temperatures Max. °F	Normal Air Daily Temperatures Min. °F	Precipitation Normal Total in.	Precipitation Max 24 hr. in.	Precipitation Snow in.	Relative Humidity, % 1:00 AM	Relative Humidity, % 1:00 PM	Mean Hourly Wind Speed	Mean Hourly Wind Direction	Heavy Fog Frequency No. Day
January	34.7	21.8	3.49	2.42	7.1	67	59	12.9	NW	3
February	38.5	22.2	3.35	2.31	8.3	70	60	13.5	NW	3
March	46.4	29.0	3.85	2.74	5.5	71	58	13.4	NW	3
April	57.7	38.0	3.79	2.54	0.5	71	54	12.8	N	3
May	68.6	47.9	3.63	3.23	Trace	78	59	11.7	E	4
June	77.9	57.7	3.10	2.02	0.0	84	62	10.3	SW	3
July	82.9	63.5	3.72	5.95	0.0	82	60	9.7	SW	2
August	81.3	62.0	4.16	3.97	0.0	83	60	9.9	SW	1
September	74.7	55.4	3.52	4.67	0.0	83	61	11.0	NE	1
October	64.6	44.7	3.29	2.39	Trace	76	60	11.7	NE	2
November	52.3	35.2	3.82	4.07	0.5	75	63	12.6	NE	2
December	40.5	25.1	3.64	3.69	5.7	71	61	12.8	NW	2
Year	60.0	41.9	43.36	----	27.6	75	60	11.9	SW	29
Actual Years or Length of Record[b]	1932-1971	1932-1971	1932-1971	23 yr	23 yr	6 yr	6 yr	15 yr	7 yr	23 yr

(a) Based on Bridgeport, Connecticut, Local Climatological Data, 1971 Annual Summary.

(b) Length of record when given in terms of the number of years is based on January data. Other months may be for more or fewer years if breaks have occurred in the record. The actual years are given where available.

From: Millstone ER (1973)

Extremes in temperatures are moderated by the proximity of Long Island Sound. Mean daily maximum and minimum air temperatures during the warmest month (July) are about 28.3 C and 17.4 C, respectively. January is the coldest month with mean daily maximum and minimum temperatures of about 1.6 C and -5.5 C. The record high temperatures for the coastal area include 39 C at Bridgeport and 37 C at New Haven while the record low temperatures include -29 C and -26 C at Bridgeport and New Haven. Table 4-49 presents the means and extremes for the general area.

On the average, precipitation is well distributed over the year. For example, New Haven records show March with the greatest average rainfall of 11.5 cm and October the least with 8.5 cm, based on the record period 1931-1960. The pattern of rainfall is quite variable from year to year; the extremes in precipitation ranging from a record minimum of .30 cm to a maximum of 44 cm per month. Summer precipitation is associated mainly with thunderstorms and smaller convective storms. Coastal storms moving up the coast can bring heavy precipitation and strong winds during other seasons. The maximum 24-hour snowfall record on this coastal region is about 48 cm. Table 4-50 presents the means and extremes of precipitation for the general area.

The site is located in an area occasionally traversed by hurricanes. According to observations from Montauk Point, which is located about 37 km southeast of Millstone Point on the eastern tip of Long Island, the maximum reported wind speed associated with the passage of a hurricane is 185 km/h with short term gusts of up to 225 km/h.

Hurricane Diane, which occurred in August of 1955, was notable for its heavy precipitation which caused extensive flood damage in northern Connecticut but had little effect on the coast. Maximum rainfall at the site resulting from this hurricane was less than 10 cm compared to 25 cm over Providence, Rhode Island, and 41 cm in the hills of northern Connecticut.

High tides due to hurricane winds were considered for the Millstone Station. Since Millstone Point is a peninsula which projects into Long Island Sound, it is subjected to tidal flooding from severe storms. The highest such flooding has resulted from the passage of hurricanes. The literature (U. S. Army Corps of Engineers (1965), Harris (1963), and Redfield and Miller (1957), indicated that twelve severe hurricanes have crossed coastal southern New England since 1635 and that four of these storms occurred in the past 35 years. These most recent storms include the hurricanes on September 21, 1938; September 14, 1944; August 31, 1954, and September 12, 1960. The center of the September, 1938 storm crossed the Connecticut coast about 24 km east of New Haven and about 32 km west of Millstone Point. The center of the 1944 hurricane passed inland between Charlestown and Point Judith, Rhode Island, about 56 km east of Millstone Point. The center of the August, 1954 storm crossed the Connecticut coast in the vicinity of Millstone Point.

Table 4-49

MEANS AND EXTREMES OF TEMPERATURE

	Bridgeport				New Haven				Providence				Block Island			
	Average Maximum	Average Minimum	Extreme Maximum	Extreme Minimum	Average Maximum	Average Minimum	Extreme Maximum	Extreme Minimum	Average Maximum	Average Minimum	Extreme Maximum	Extreme Minimum	Average Maximum	Average Minimum	Extreme Maximum	Extreme Minimum
		(Deg. F)				(Deg. F)				(Deg. F)				(Deg. F)		
January	37.4	22.9	63	-3	37.1	22.0	65	-8	37.3	21.0	65	-5	37.9	26.3	57	-2
February	38.2	22.7	55	-2	38.0	21.1	60	-5	38.3	21.1	56	-5	36.7	25.1	55	-2
March	45.2	29.7	66	4	44.9	28.9	74	1	45.3	28.6	73	1	42.2	31.2	60	8
April	56.7	39.3	76	21	55.9	37.9	83	17	56.6	37.7	84	19	50.8	38.4	73	21
May	67.9	49.5	92	31	66.8	47.5	86	32	67.7	47.2	94	32	60.1	47.6	82	34
June	77.1	58.8	94	41	75.2	57.1	96	40	76.1	56.3	94	41	69.6	56.2	90	41
July	82.6	64.8	100	55	80.5	63.2	100	47	81.4	62.7	97	49	75.9	63.2	91	51
August	81.1	63.4	93	48	79.4	61.8	100	45	80.0	60.9	93	40	75.6	63.6	88	43
September	74.6	56.4	93	41	73.3	54.5	91	33	73.1	53.3	93	35	70.2	57.8	87	43
October	64.7	46.0	84	26	63.7	44.2	84	24	63.4	42.9	85	21	61.1	49.2	77	30
November	52.7	36.3	76	21	51.9	34.9	75	14	52.2	33.8	73	16	51.7	38.6	70	20
December	40.8	25.6	65	6	40.4	24.4	63	-3	40.4	23.5	69	-2	42.7	29.6	64	-4
Periods of Record	CSN	CSN	1965-1971	1965-1971	CSN	CSN	1943-1971	1943-1971	CSN	CSN	1963-1971	1963-1971	CSN	CSN	1950-1971	1950-1971

NOTE: CSN means the climatological standard time period 1931 - 1960.

Revised 1/2/73

(FROM MILLSTONE ER 1973)

Table 4-50

MEANS AND EXTREMES OF PRECIPITATION

All Precipitation (Water Equivalent (in))

	Bridgeport			New Haven			Providence			Block Island		
	Mean Monthly	Maximum Monthly	Minimum Monthly	Mean Monthly	Maximum Monthly	Minimum Monthly	Mean Monthly	Maximum Monthly	Minimum Monthly	Mean Monthly	Maximum Monthly	Minimum Monthly
January	3.7	6.4	0.4	4.0	8.4	0.6	3.8	7.1	0.5	3.8	6.7	0.3
February	3.0	6.2	1.4	3.2	4.8	1.5	3.1	5.6	1.3	3.3	6.9	1.2
March	4.3	9.4	1.2	4.6	10.8	1.6	4.1	7.8	1.7	4.1	8.5	1.2
April	3.8	6.2	0.8	3.9	6.5	1.6	3.8	7.3	1.5	3.6	6.2	1.2
May	3.7	5.8	0.8	3.7	7.8	0.8	3.4	7.3	0.7	3.0	6.0	0.7
June	3.4	5.7	0.1	3.5	4.9	0.1	2.8	5.5	0.4	2.5	6.8	T
July	3.8	12.8	0.8	3.4	6.8	0.7	2.9	6.3	1.0	2.7	6.2	0.4
August	4.5	13.3	1.0	4.2	11.0	0.9	4.0	11.1	0.9	3.9	9.7	0.3
September	4.0	7.4	0.4	3.9	10.0	0.6	3.5	7.9	0.8	3.2	11.5	0.3
October	3.4	10.7	0.3	3.5	10.1	0.3	3.1	11.9	1.6	3.0	8.7	0.8
November	4.0	7.0	1.6	4.1	8.6	1.7	4.1	6.5	2.1	3.7	8.1	1.3
December	3.5	7.5	0.3	4.0	7.9	1.0	3.6	10.8	0.6	3.6	8.1	0.8
Periods of Record	CSN	1948-1971	1948-1971	CSN	1943-1971	1943-1971	CSN	1953-1971	1953-1971	CSN	1950-1971	1950-1971

NOTE: CSN means climatological standard normal time period 1931-1960.

Revised 1/2/73

The center of the September, 1960 storm also crossed the coast in the vicinity of Millstone Point. The maximum flood tide levels recorded in the vicinity of Millstone Point during these storms are indicated below:

HURRICANES	MAXIMUM FLOOD TIDE LEVELS (MSL)
September 21, 1938	2.9 m
September 14, 1944	1.9 m
August 31, 1954	2.7 m
September 12, 1960	1.8 m

The design storm surge level at the site was computed using the probable maximum hurricane (PMH), as reported by the U. S. National Oceanic and Atmospheric Administration (NOAA) in their unpublished report HUR 7-97 which describes the PMH as "...a hypothetical hurricane having that combination of characteristics which will make it the most severe that can probably occur in the particular region involved". The characteristics of the PMH used in computing the maximum surge levels were:

1. Central Pressure Index = .94 kg/sq cm

2. Radius of Maximum Wind = 89 km

3. Forward Speed = 28 km/hr

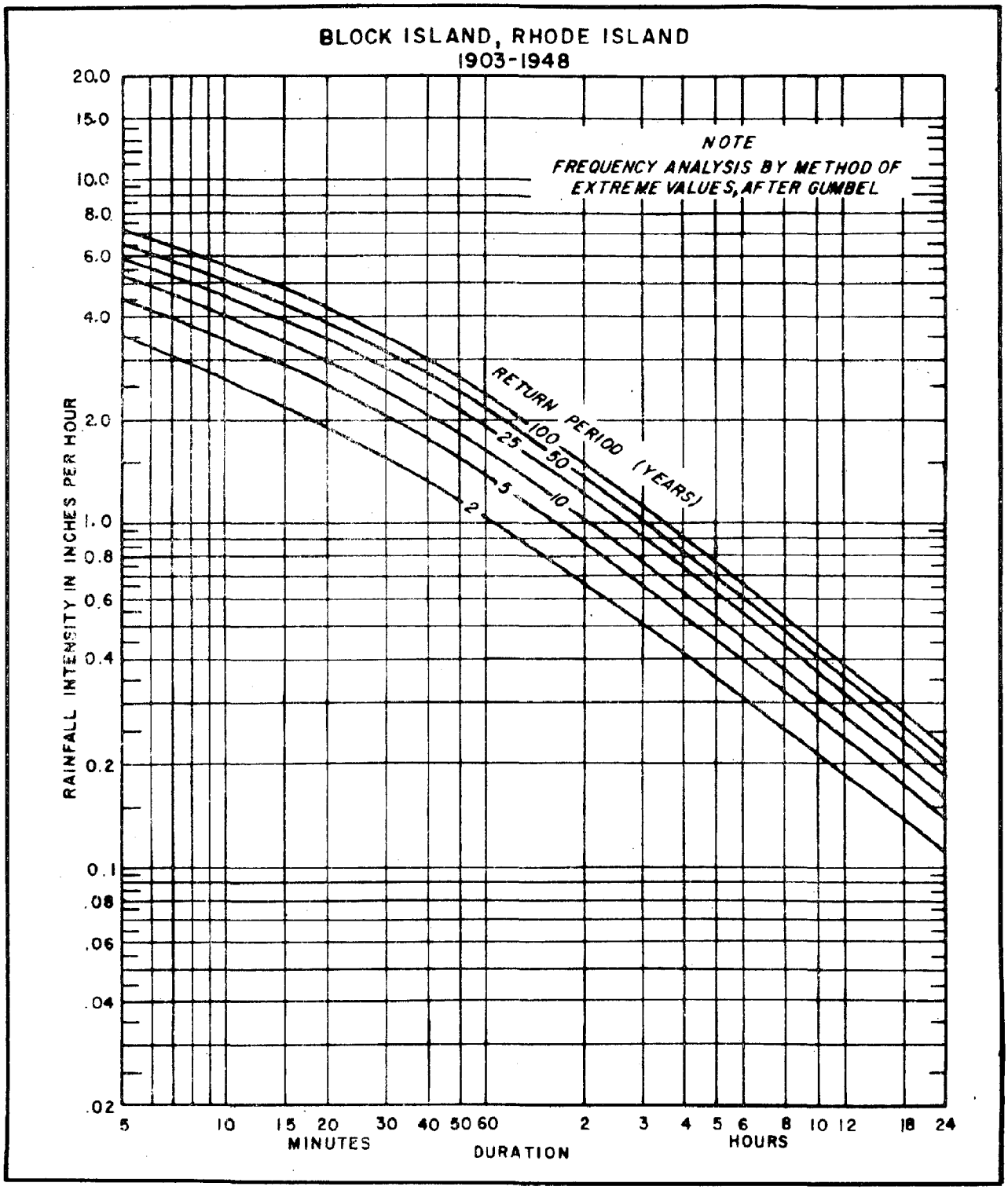
4. Maximum Gradient Wind = 205 km/hr

5. Peripheral Pressure = 1.05 kg/sq cm

The locus of maximum winds of the PMH was brought inshore along a track which passes just to the east of the east of the eastern end of Long Island. This calculated maximum surge height is El. 5.5 m MSL. The total surge includes .7 m of astronomical tide, .3 m of forerunner or initial rise, .68 m of rise due to barometric pressure drop, and 3.9 m of wind setup.

Intense rainfall will be produced by severe tropical storms, severe nontropical cyclones, and occasionally by thunderstorms. The return period of extreme short interval rainfall for Block Island, Rhode Island (located 57 km to the east-southeast of Millstone Point), which is expected to be representative of that at the site, is shown in Figure 4-237.

Tornadoes have been reported in Connecticut on 15 occasions during the period from 1953 to 1962. No wind speed measurements are available. Only one tornado has been reported in New London County during the period from 1916 to 1965. Thus, the probability of experiencing a



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TRIGOM PARC	FIGURE 4-237	Return Period of Extreme Short-Interval Rainfall - Block Island, Rhode Island

tornado at the site is quite small. Based on a method suggested by Thom (1963), it is estimated that the probability is less than one per 1,250 years. A summary of severe weather for the area is shown on Table 4-51.

Fog. Most of the fog in the Millstone area is an advection type caused by the passage of warm moist air over relatively cold water; hence, it is more pronounced during the summer months. The line of demarcation between fog and no fog is frequently very sharp depending upon whether cold water is immediately adjacent to the site. For this reason, it is closely associated with tidal stages and currents. Table 4-52 compares the number of fog days by month at the four surrounding locations. Heavy fog has been reported on an average of 29 days per year at Bridgeport with slightly greater occurrence of heavy fog during winter and spring. The average range of relative humidity in January is 69 percent at 7 a.m. EST, and 59 percent at 1 p.m. EST. In July the range is 77 percent and 60 percent for the same hours.

The diffusion climatology of Millstone Point is influenced mainly by land-sea meteorological interactions. The site is located on the north coast of Long Island Sound, which runs generally east-west. Offshore NW winds predominate in the winter, and onshore SW winds predominate in the summer months. The station is situated such that any wind from east to west or clockwise will have an upwind over-water trajectory, and a downwind overland trajectory within about 2.8 km of the site. Wind speed and direction data for 1965-1972 are summarized in Figure 4-238. A shift in the predominating wind direction from SW to NW appears to have occurred when this summary is compared to the wind rose in the environmental report based on three years of data. However, National Weather Service records for nearby coastal stations indicate that directional shifts of up to 90° in annual predominating winds can occur from year to year.

Stability results of wind measurements are analyzed for the period from December 1965 through November 1966. The onshore and offshore wind frequencies for the stable cases show the average annual wind speed at the site is 17 km/hr and the most frequent direction is WSW. The site has onshore winds 59.6 percent of the time. An additional summary of climatological data for New York, Bridgeport, New Haven, Block Island, Providence, and Nantucket is given on Table 4-53.

4.4.3 NORTHERN SUB-REGION

Consistent with the division made in most of the topical treatments of this report there is a natural partition caused by the land mass of Cape Cod which affects water movement, animal distribution, and probably to a lesser degree, the climate. Since the U. S. Army Corps of Engineers NAR study was based on river basins the division is different and the southern region continues part way into Maine to the

Table 4-51
SEVERE WEATHER

	Maximum 24-Hour Precipitation (inches)				Mean Number of Thunderstorm Days			
	Bridgeport	New Haven	Providence	Block Island	Bridgeport	New Haven	Providence	Block Island
January	2.42	2.85	3.34	4.06	*	*	*	*
February	2.31	2.76	2.72	2.01	*	*	*	*
March	2.74	3.11	4.53	3.63	1	1	1	*
April	2.54	2.81	2.82	2.50	2	2	2	2
May	3.23	3.09	3.76	2.35	3	4	3	2
June	2.02	2.69	1.99	2.25	4	5	4	2
July	5.95	4.29	2.80	2.66	5	6	5	4
August	3.97	3.90	5.47	4.86	4	4	4	4
September	4.67	5.55	4.89	8.52	2	3	2	1
October	2.39	3.81	6.63	6.63	1	1	1	1
November	4.07	4.68	3.04	3.96	*	1	1	*
December	3.69	4.25	3.85	4.39	*	*	*	*
Period of Record	1948-1971	1943-1971	1953-1971	1950-1971	1948-1971	1947-1971	1953-1971	1957-1971

Extreme Maximum 24-Hour Snowfall (inches)

Bridgeport	16.7 (1948-1971)
Providence	18.3 (1953-1971)
Block Island	16.9 (1950-1971)
New Haven	17.2 (1943-1971)

*Less than 1/2

Revised 1/2/73

TABLE 4-52

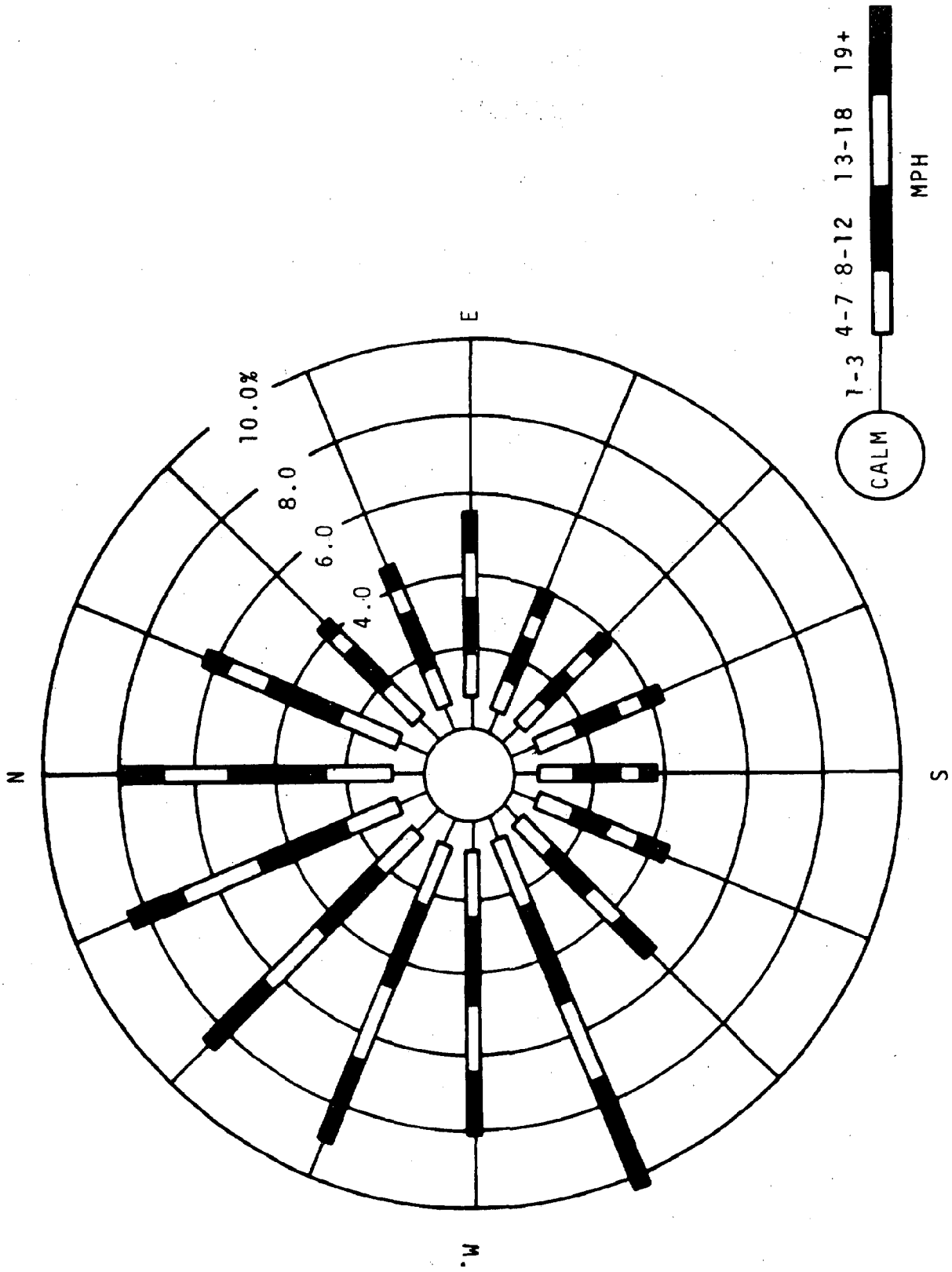
FOG FREQUENCY

(Number of Days With Heavy Fog (Visibility ≤ 1/4 Mile))

	Bridgeport	New Haven	Providence	Block Island
January	3	3	2	4
February	3	2	2	4
March	3	3	2	5
April	3	3	2	9
May	4	4	2	11
June	3	3	2	11
July	2	2	2	12
August	1	2	2	11
September	1	2	2	5
October	2	2	4	4
November	2	2	2	3
December	2	1	2	3
Period of Record	1948-1971	1947-1971	1953-1971	1957-1971

FROM: Millstone ER

Revised 1/2/73



152 FT MSL
ALL STABILITY CLASSES COMBINED

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

TRIGOM PARC	FIGURE 4-238	Annual Millstone Point Wind Rose

TABLE 4-53
Summary of Climatological Data
SOURCE: U. S. Coast Pilot, Atlantic Coast 2 (1973)

NEW YORK, NEW YORK (John F. Kennedy International Airport) 40°39'N., 73°47'W. Elevation (ground): 13 feet NWS-1970

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	10	10	(b)	23	12	9	9	12		7		12	12	12	12	12	12	12	12
Jan.	38.0	25.6	31.8	64	0	3.23	1.60	7.1	70	59	11.5		45WSW		6.0	9	8	14	10	2	*	2
Feb.	38.5	24.7	31.6	62	-2	2.93	2.87	9.3	69	58	12.1		40WSW		6.3	7	8	13	10	2	*	3
Mar.	45.9	31.4	38.7	72	7	4.15	2.27	5.2	71	57	11.8		36WNW		6.0	8	10	13	12	2	1	3
Apr.	57.5	40.4	49.0	82	26	3.48	1.79	0.1	71	56	11.1		38WSW		6.2	7	10	13	11	*	2	3
May	69.5	50.9	60.2	99	34	3.67	2.88	T	70	55	10.2		30WSW		6.0	7	13	11	11	0	3	3
June	79.3	60.9	70.1	99	45	3.35	1.81	0.0	73	59	9.5		28WNW		6.0	7	11	12	9	0	4	4
July	84.7	67.1	75.9	104	55	4.04	3.21	0.0	74	57	9.2		32NNW		6.2	6	12	13	9	0	5	3
Aug.	82.9	66.0	74.5	97	46	4.97	6.59	0.0	76	57	9.0		40WNW		5.9	7	13	11	9	0	5	2
Sept.	76.2	59.3	67.8	94	40	4.16	5.83	0.0	78	56	9.3		35WNW		5.2	11	9	10	8	0	2	1
Oct.	65.9	49.3	57.6	84	25	3.21	3.21	T	77	53	8.7		34WSW		5.1	12	9	10	7	0	1	3
Nov.	53.2	39.1	46.2	73	20	3.51	2.93	0.2	75	58	10.7		38NE		6.4	8	8	14	11	*	1	2
Dec.	41.3	28.4	34.9	68	5	3.23	2.05	6.0	73	61	11.1		40ENE		6.1	8	9	14	11	2	*	3
Year	61.1	45.3	53.2	104	-2	43.93	6.59	27.9	73	57	10.4		45WSW		6.0	97	120	148	118	8	24	32

BRIDGEPORT, CONNECTICUT (Bridgeport Municipal Airport) 41°10'N., 73°08'W. Elevation (ground): 7 feet NWS-1970

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	5	5	(b)	22	22	5	5	14	7	10		22	22	22	22	22	22	22	22
Jan.	37.4	22.9	30.2	63	-3	3.69	2.42	7.0	70	59	11.1	NW	58NNW		6.2	9	7	15	11	2	*	3
Feb.	38.2	22.7	30.5	53	-2	2.96	2.31	8.5	72	59	11.6	NW	56NNW		6.2	8	7	13	10	2	*	3
Mar.	45.2	29.7	37.5	66	4	4.25	2.74	5.6	73	59	11.6	NW	44WSW		6.3	8	9	14	11	1	1	3
Apr.	56.7	39.3	48.0	76	21	3.80	2.54	0.5	73	57	11.0	N	48NW		6.4	7	9	14	11	*	2	3
May	67.9	49.5	58.7	92	31	3.71	3.23	T	74	60	10.2	E	43E		6.4	7	11	13	11	0	3	4
June	77.1	58.8	68.0	94	41	3.40	2.02	0.0	79	64	9.0	SW	33WSW		5.9	9	9	12	9	0	4	3
July	82.6	64.8	73.7	100	55	3.77	3.57	0.0	76	60	8.4	SW	31SSW		6.0	7	12	12	9	0	5	2
Aug.	81.1	63.4	72.3	93	48	4.45	3.97	0.0	78	60	8.5	SW	36W		5.7	9	11	11	10	0	4	1
Sept.	74.6	56.4	65.5	93	41	3.95	4.67	0.0	80	60	9.6	NE	41NNE		5.4	10	9	11	9	0	2	1
Oct.	64.7	46.0	55.4	84	26	3.38	2.39	T	74	58	10.3	NE	44WSW		5.2	11	9	11	6	0	1	1
Nov.	52.7	36.3	44.5	76	21	4.02	4.07	0.5	78	64	10.9	NW	50SE		6.2	8	8	14	10	*	*	2
Dec.	40.8	25.6	33.2	62	6	3.51	3.69	5.9	72	61	11.1	NW	46WSW		6.1	9	8	14	11	2	*	2
Year	59.9	43.0	51.5	100	-3	44.89	4.67	28.0	75	60	10.3	SW	58NNW		6.0	102	109	154	118	7	22	28

TABLE 4-53 (Cont.)

NEW HAVEN, CONNECTICUT (Tweed-New Haven Airport) 41°16'N., 72°53'W. Elevation (ground): 6 feet NWS-1968

Month	Air temperature (°F.) Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extreme: Record highest	Extreme: Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	25	25	(b)	25	25	25	25	21		25	25	25	25	25	25	25	25	21	21
Jan.	37.1	22.0	29.6	65	-8	3.96	2.85	9.3	76	63	7.2		39S	55	6.3	9	7	15	12	3	*	3
Feb.	38.0	21.1	29.6	60	-5	3.19	2.76	10.3	76	61	7.4		36W	60	6.3	8	6	14	11	3	*	2
Mar.	44.9	28.9	36.9	74	1	4.62	3.11	6.9	75	61	7.6		36E	60	6.2	8	9	14	12	2	1	3
Apr.	55.9	37.9	46.9	83	17	3.89	2.81	0.7	75	61	7.3		41NW	57	6.4	7	9	14	12	*	2	3
May	66.8	47.5	57.2	86	32	3.71	3.09	T	77	63	6.4		30SW	60	6.5	6	11	14	12	0	4	4
June	75.2	57.1	66.2	96	40	3.53	2.69	0.0	80	65	5.7		28SW	65	6.0	8	10	12	10	0	5	3
July	80.5	63.2	71.9	100	47	3.43	4.29	0.0	81	66	5.5		30SW	68	5.9	7	13	11	10	0	6	2
Aug.	79.4	61.8	70.6	100	45	4.24	3.90	0.0	83	67	5.6		43W	66	5.8	8	12	11	10	0	4	2
Sept.	73.3	54.5	63.9	91	33	3.93	5.55	0.0	84	65	6.1		36N	65	5.5	10	9	11	8	0	3	2
Oct.	63.7	44.2	54.0	84	24	3.45	3.81	0.1	82	63	6.4		38E	65	5.2	12	8	11	7	*	1	2
Nov.	51.9	34.9	43.4	75	14	4.05	4.68	1.1	81	64	7.0		50E	53	6.3	8	8	14	11	*	1	2
Dec.	40.4	24.4	32.4	63	-3	4.02	4.25	8.7	77	63	7.2		39SW	55	6.2	9	7	15	12	3	*	1
Year	58.9	41.5	50.2	100	-8	46.02	5.55	37.1	79	64	6.0		50E	61	6.1	100	109	156	127	11	27	29

BLOCK ISLAND, RHODE ISLAND (State Airport) 41°10'N., 71°35'W. Elevation (ground): 110 feet NWS-1970

Month	Air temperature (°F.) Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extreme: Record highest	Extreme: Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	20	20	(b)	20	20	14	14					18	18	18	18	20	20	14	14
Jan.	37.9	26.3	32.1	57	-2	3.84	4.06	5.3	73	65					6.5	8	9	14	11	2	*	4
Feb.	36.7	25.1	30.9	55	-2	3.29	2.52	6.6	73	65					6.0	8	8	12	9	2	*	4
Mar.	42.2	31.2	36.7	60	8	4.07	3.63	6.9	75	65					5.8	9	9	13	10	2	*	5
Apr.	50.8	38.4	44.6	73	21	3.61	2.50	0.3	79	65					6.3	8	9	13	10	*	2	9
May	60.1	47.6	53.9	82	34	3.01	2.35	0.0	80	67					6.2	7	11	13	10	0	2	11
June	69.6	58.2	62.9	90	41	2.56	2.25	0.0	84	69					6.2	9	10	11	8	0	2	11
July	75.9	63.2	69.6	91	51	2.69	2.66	0.0	87	72					6.8	7	11	13	7	0	4	12
Aug.	75.6	63.6	69.6	88	51	3.86	4.86	0.0	86	71					6.6	7	11	13	9	0	4	11
Sept.	70.2	57.8	64.0	87	43	3.20	8.52	0.0	84	70					5.9	10	9	11	7	0	1	5
Oct.	61.1	49.2	55.2	77	30	3.02	6.63	T	80	66					5.4	11	8	12	8	0	1	4
Nov.	51.7	38.6	45.2	70	20	3.71	3.96	0.2	76	65					6.6	7	9	14	10	*	*	3
Dec.	42.1	29.6	35.9	64	-4	3.59	4.39	3.5	72	65					6.1	7	10	14	11	1	*	3
Year	56.2	43.9	50.1	91	-4	40.45	8.52	22.8	79	67					6.2	98	114	153	110	7	16	82

TABLE 4-53 (cont.)

NANTUCKET, MASS. (Memorial Airport) 41°15'N., 70°04'W. Elevation (ground): 43 feet NWS-1969

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	4	4	(b)	23	23	4	4	23	14	23	23	23	23	23	23	23	23	22	22
Jan.	39.2	26.8	33.0	63	2	4.22	2.82	8.7	79	67	12.8	NW	51NW	42	7.0	7	6	18	13	2	*	5
Feb.	38.1	24.6	31.4	54	5	3.76	2.32	10.6	79	67	13.2	WNW	57NW	48	6.9	6	6	16	12	2	*	5
Mar.	42.5	29.6	36.1	60	10	4.54	2.92	7.5	80	67	13.2	NW	63N	56	6.5	8	8	15	12	2	1	6
Apr.	50.6	38.0	44.3	69	23	3.76	4.48	0.9	80	65	12.7	WSW	55N	56	6.5	7	8	15	12	*	2	8
May	59.9	45.3	52.6	77	32	2.88	6.53	0.0	80	69	11.3	SW	43N	59	6.7	7	8	16	10	0	3	10
June	67.8	54.8	61.3	89	40	2.92	3.02	0.0	88	76	10.4	SW	34NE	61	6.6	7	8	15	8	0	3	12
July	74.3	61.7	68.0	90	50	2.71	2.65	0.0	87	76	9.6	SW	36S	60	6.8	6	9	16	8	0	4	15
Aug.	74.4	61.7	68.1	86	46	3.68	3.67	0.0	89	75	9.5	SW	63SE	60	6.4	8	8	15	9	0	3	13
Sept.	69.3	56.4	62.9	83	36	3.51	5.05	0.0	87	74	10.3	SW	63SE	60	6.1	9	8	13	8	0	2	7
Oct.	60.8	47.8	54.3	77	22	3.70	3.21	T	82	67	11.2	SW	60E	58	5.8	10	8	13	9	0	1	7
Nov.	52.3	39.5	45.9	68	20	4.05	4.85	0.3	80	71	11.6	NW	61NW	42	7.1	5	8	17	12	*	1	5
Dec.	42.5	29.6	36.1	58	4	3.93	4.26	6.8	76	69	12.3	WNW	50W	41	7.0	6	8	17	13	2	*	4
Year	56.0	43.0	49.5	90	2	43.66	6.53	34.8	83	70	11.5	SW	63SE	55	6.6	86	93	186	126	8	20	93

PROVIDENCE, RHODE ISLAND (T. F. Green Airport) 41°44'N., 71°26'W. Elevation (ground): 51 feet NWS-1970

Month	Air temperature (°F.) Normal: Daily maximum	Daily minimum	Monthly	Extreme: Record highest	Record lowest	Precipitation (inches): Normal total	Maximum 24 hrs.	Snow, sleet mean total	Humidity (percent): 7 a.m. EST	1 p.m. EST	Wind (knots): Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	7	7	(b)	17	17	7	7	17	10	17	17	17	17	17	17	17	17	17	17
Jan.	37.3	21.0	29.2	65	-5	3.81	3.34	10.0	68	55	10.2	NW	40S	57	6.2	11	6	14	11	3	*	2
Feb.	38.3	21.1	29.7	56	-5	3.10	2.72	10.5	70	55	10.4	NNW	40SW	56	6.5	8	7	13	10	2	*	2
Mar.	45.3	28.6	37.0	73	1	4.14	4.53	10.8	70	54	10.8	WNW	52S	57	6.6	9	8	14	11	3	1	2
Apr.	56.6	37.7	47.2	84	19	3.75	2.82	0.7	68	47	11.0	SW	44SSW	56	6.5	8	9	13	11	*	2	2
May	67.7	47.2	57.5	94	32	3.35	3.76	0.0	69	48	9.9	S	36SSW	59	6.5	8	10	13	11	0	3	2
June	76.1	56.3	66.2	94	41	2.76	1.99	0.0	74	55	9.0	SW	35SSW	59	6.2	8	10	12	11	0	4	3
July	81.4	62.7	72.1	97	49	2.91	2.80	0.0	76	56	8.4	SW	30NNW	58	6.4	7	12	12	9	0	5	2
Aug.	80.0	60.9	70.5	93	40	3.96	5.47	0.0	77	54	8.4	SSW	73ESE	58	6.1	9	11	11	10	0	4	2
Sept.	73.1	53.3	63.2	93	35	3.52	4.89	0.0	79	54	8.6	SW	50S	59	5.6	11	7	12	8	0	2	2
Oct.	63.4	42.9	53.2	85	21	3.10	6.63	0.1	79	51	8.7	NW	36SE	59	5.3	12	7	12	8	*	1	3
Nov.	52.2	33.8	43.0	71	16	4.11	3.04	0.5	77	59	9.3	SW	45S	49	6.3	9	6	15	11	*	1	2
Dec.	40.4	23.5	32.0	69	-2	3.62	3.85	8.9	75	60	9.7	WNW	42SE	54	6.0	9	8	14	12	3	*	2
Year	59.3	40.8	50.1	97	-5	42.13	6.63	41.5	74	54	9.6	SW	73ESE	57	6.2	109	101	155	123	11	23	25

These tables were compiled from National Weather Service data. Sky cover is expressed in a range of 0 for no clouds to 10 for complete sky-cover. The number of days is based on average cloudiness of 0 to 3, partly cloudy days on 4 to 7, and cloudy days on 8 to 10.

Heavy fog includes data referred to at various times in the past as "Dense" or "Thick". The upper visibility limit for heavy fog is 1/4 mile.

(a) means length of record in years.
(b) means climatological standard normals, 1931-1960.
* means less than one-half.
T means trace, an amount too small to measure.

Androscoggin River, east of Portland. Therefore there is some overlap between the NAR presentation and the north and south division used in the present report. Locations of the stations for meteorological measurements are shown on Figure 4-239.

PRECIPITATION

There appears to be little difference in the annual precipitation in the two sub-regions described by U. S. Army Corps of Engineering with an average of 112 cm in both areas. Sharp increases occur inland in mountainous areas along the Maine-New Hampshire border as well as along a narrow coastal band. Table 4-54 gives a sub-region precipitation for representative stations in Maine.

TEMPERATURE

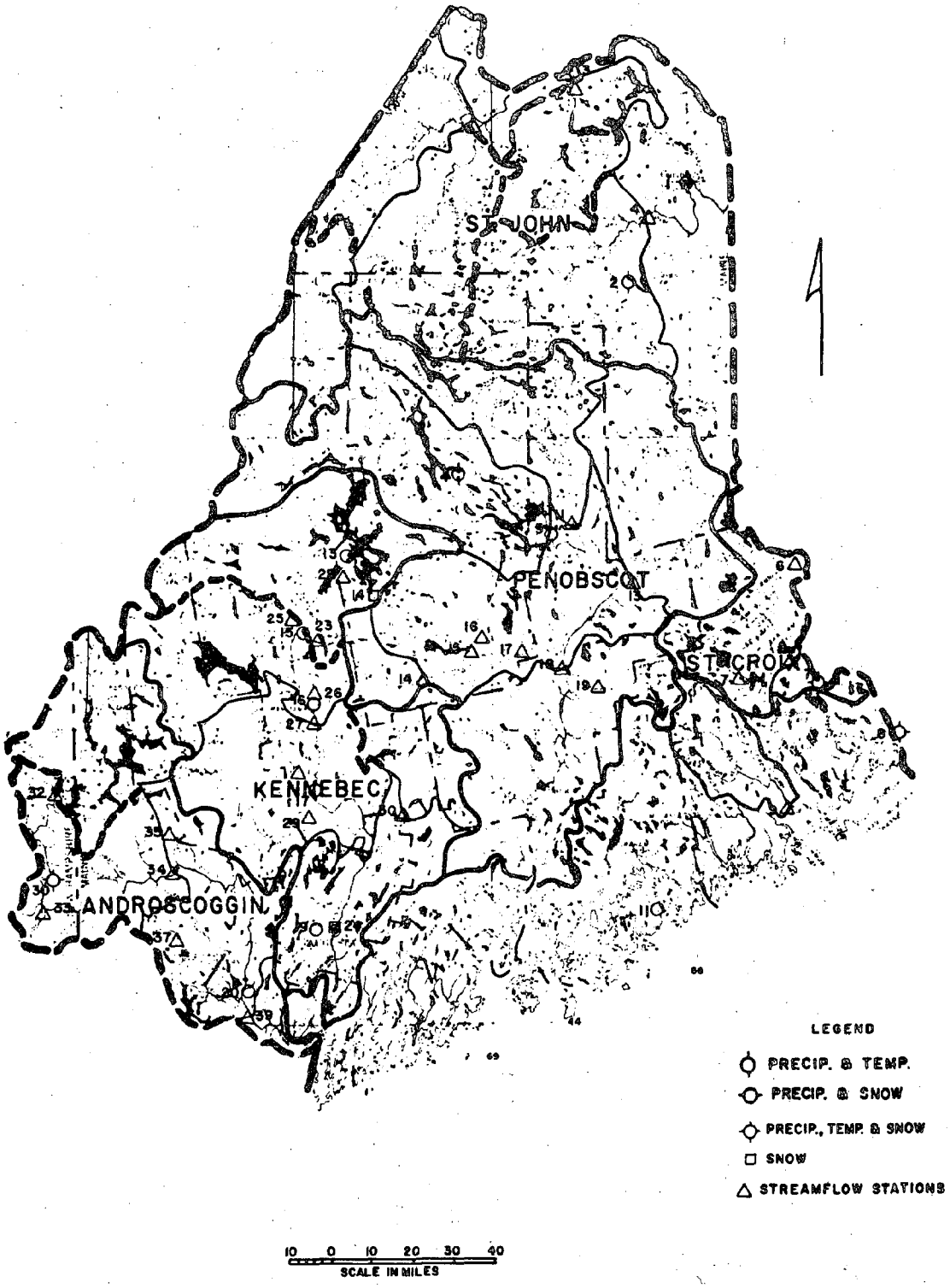
There is a decided change in the temperature for the northern sub-region where the average annual temperature varies from about 7.2 C near the coast to 3.2 C in the northern headwaters. During a normal winter, the temperature averages about -9.4 C, with temperatures below -17.5 C on approximately 30 days each year. The number of days with temperatures below -17 C increases rapidly with distance from the coast, and is more than 50 days in the St. John Basin and in the highest elevations near the northern Maine-New Hampshire border. Temperature data at selected stations are shown in Table 4-55.

DATA FROM ENVIRONMENTAL IMPACT STATEMENTS

Pilgrim Environmental Impact Statement

The first available detailed data found north of Cape Cod are from the Pilgrim Station. The final Environmental Statement Pilgrim Nuclear Station (1972) provides the following data. The Station is located on the rocky, western shoreline of Cape Cod Bay and is on the Bay side of the northeast end of Pine Hills.

The main features of the weather of eastern Massachusetts are variety and changeability since it lies in a transition zone of westerly air currents which encompass the southward movement of polar air masses and northward movement of tropical air masses. The area is frequently situated in or near the tracks of low pressure systems during the fall, winter and spring seasons. As a result, the region has no dry season, with summer precipitation coming in the form of showers or thunderstorms. The coastline location of the site results in seasonal temperatures which are less extreme than inland locations due to onshore winds in the summer (seabreezes) and the presence of relatively warm water in the winter. The storm cycle in this area consists generally of northeasters in the winter and spring, and thunderstorms in late spring and summer. Hurricanes sometimes occur in the late summer and fall.



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

TRIGOM PARC	FIGURE 4-239	Meteorologic and Stream Flow Stations - Sub-Region A

TABLE 4-54

PRECIPITATION DATA -SUBREGION A(in inches)

Station	Map Code	Period of Record	Elevation ft.,m.s.l.	Item	Monthly Data (a) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Annual (a)
Caribou,Me.	1	1937-65	624	Max	3.59	4.13	5.13	4.50	6.27	7.11	6.83	8.45	8.14	6.20	6.53	5.01	36.31
				Min	.12	1.14	1.11	.86	.64	1.70	1.97	.93	1.26	.63	.45	.79	
				Mean	2.11	2.02	2.38	2.63	3.03	4.07	4.04	3.67	3.53	3.36	3.04	2.43	
Soma Pan Dam,Me.	2	1931-60	610	Mean	2.52	2.33	2.57	2.87	2.89	4.06	3.71	3.38	3.46	3.42	3.34	2.68	37.23
Ripogenus Dam,Me.	4	1931-60	965	Mean	2.62	2.47	2.81	3.46	3.36	4.28	4.20	3.84	3.77	3.95	3.75	2.89	41.40
Millinocket,Me.	5	1931-60	388	Mean	3.24	2.84	3.22	3.44	3.12	3.89	3.47	3.73	3.67	3.72	4.11	3.50	41.95
Moosehead,Me.	13	1931-60	1,028	Mean	2.57	2.27	2.80	3.09	2.96	3.78	4.05	3.52	3.31	3.52	3.47	2.85	38.19
The Forks,Me.	15	1931-60	610	Mean	2.76	2.32	2.83	3.00	2.97	3.57	3.46	3.13	3.26	3.39	3.45	2.78	36.92
Woodland,Me.	7	1931-61	140	Max	9.03	7.19	7.78	6.49	7.25	8.14	7.10	6.92	9.08	8.17	12.61	7.87	43.94
				Min	.54	1.03	1.74	.63	.67	1.05	.74	.56	.97	.57	1.06	.96	
				Mean	3.71	3.20	3.47	3.57	3.46	3.42	3.23	2.95	3.82	4.29	4.82	4.00	
Eastport,Me.	8	1873-1961	80	Max	9.23	6.85	7.42	6.35	8.18	7.95	5.37	6.61	7.65	6.37	8.57	8.40	42.67
				Min	.56	.40	1.37	.46	.75	.52	.75	.64	.92	.19	.94	1.07	
				Mean	4.11	3.44	3.68	3.50	3.09	3.55	3.07	2.86	3.53	3.62	4.48	3.74	
Madison,Me.	17	1931-60	260	Mean	3.29	2.83	3.28	3.30	3.23	3.33	3.18	2.63	3.45	3.20	3.92	3.28	38.92
Bar Harbor,Me.	11	1931-60	30	Mean	4.46	3.79	4.39	3.91	3.83	3.34	3.10	3.12	4.22	4.38	5.25	4.38	48.17
Berlin,N.H.	30	1917-60	1,110	Max	7.15	4.01	10.46	6.05	6.58	7.50	6.08	6.96	12.26	7.40	8.11	5.79	38.44
				Min	.78	.89	.75	.47	1.12	1.63	1.18	.74	.62	.46	.73	.89	
				Mean	2.92	2.32	3.15	2.94	3.18	3.94	3.61	3.02	3.85	3.12	3.46	2.93	
East Winthrop,Me.	19	1931-61	173	Max	7.85	6.90	9.59	6.91	7.51	6.36	7.24	5.86	10.77	7.44	7.22	7.33	41.70
				Min	1.13	1.07	1.02	0.60	0.68	0.97	0.34	0.64	0.55	0.16	0.56	0.93	
				Mean	3.57	3.09	3.58	3.51	3.33	3.16	3.41	2.85	3.94	3.40	4.26	3.60	
Lewiston,Me.	20	1931-60	180	Mean	4.01	3.37	4.13	3.78	3.33	3.23	3.39	2.76	3.65	3.51	4.46	3.96	43.58

(a) Data based on 30-year period 1931-60 except for station 1 where period of record is used.

TABLE 4-55

TEMPERATURE DATA -SUBREGION A (in degrees Fahrenheit)

Station	Map Code	Period of Record	Elevation ft.,m.s.l.	Mean Annual Temperature (a)			Mean Monthly Temperature (a)											
							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Caribou,Me.	1	1937-65	624	Max.Year	41.1	Max.Month	21.4	22.9	31.8	41.9	57.1	62.8	69.6	67.2	57.5	48.8	36.5	22.4
				Min.Year	36.3	Min.Month	1.3	4.7	15.2	29.1	43.7	54.5	61.1	58.6	50.2	38.6	25.2	5.5
				Ave.Year	38.4	Ave.Month	10.5	12.5	22.8	36.4	49.9	59.0	64.5	62.6	53.8	43.0	30.2	15.5
Woodland,Me.	7	1931-61	140	Max.Year	45.6	Max.Month	25.4	26.0	37.2	44.6	58.2	64.8	72.9	71.4	60.8	51.9	41.1	31.8
				Min.Year	40.9	Min.Month	8.9	8.2	21.4	36.0	46.8	57.7	64.0	62.5	53.8	42.8	27.3	10.6
				Ave.Year	43.1	Ave.Month	17.5	18.7	28.5	40.8	52.2	61.4	68.0	66.5	57.9	47.2	36.1	22.2
Eastport,Me.	8	1873-1961	80	Max.Year	45.7	Max.Month	30.2	30.1	37.2	43.5	52.0	59.0	64.7	64.3	58.6	53.6	43.3	34.6
				Min.Year	41.0	Min.Month	15.6	13.2	26.0	36.0	45.2	53.4	59.4	59.4	53.6	44.2	31.4	17.6
				Ave.Year	43.0	Ave.Month	22.9	23.5	30.8	40.1	48.7	55.8	61.5	61.9	56.7	48.6	39.0	26.8
Berlin,N.H.	30	1917-60	1,110	Max.Year	44.2	Max.Month	26.2	23.7	37.3	46.2	58.3	65.8	70.3	69.7	60.4	52.5	41.0	29.3
				Min.Year	39.6	Min.Month	8.5	5.7	19.5	33.8	47.2	56.4	62.7	59.8	50.5	42.3	27.0	11.0
				Ave.Year	42.0	Ave.Month	16.1	17.6	26.8	40.5	52.4	61.7	66.5	64.3	56.3	47.6	34.4	20.2
Winthrop,Me.	19	1931-61	173	Max.Year	47.8	Max.Month	26.4	27.5	38.5	47.8	58.8	67.0	73.5	71.4	61.8	54.6	43.8	32.7
				Min.Year	43.7	Min.Month	11.0	16.1	23.3	38.8	49.7	59.7	65.2	64.3	55.2	45.4	35.4	15.1
				Ave.Year	45.2	Ave.Month	19.4	22.1	31.1	43.3	54.8	63.6	69.0	67.5	59.7	49.5	38.3	24.3

(a) Data based on 30-year period 1931-60 except for station 1 where period of record is used.

Tornado activity in eastern Massachusetts is uncommon.

Meteorological data for the Pilgrim site have been collected from the site meteorological tower. The most frequent wind directions observed were from the SSW through WNW which are all offshore directions.

The site experienced onshore winds 36 percent of the time, offshore winds 63.6 percent of the time, and calm conditions the remaining 0.4 percent of the time.

Seabrook Environmental Impact Study

The Seabrook Nuclear Power Plant is in Seabrook, New Hampshire, two miles from the Atlantic Ocean. The Seabrook site is located between two National Weather Service Class A airport stations. The Boston, Massachusetts, Logan International Airport is 60 km to the south-southwest, while the Portland (Maine) International Jetport is 94 km to the north-northeast. The Boston Airport is on a land fill that extends into Boston Harbor, which is part of the Atlantic Ocean. The Portland Airport is located just inland from the Atlantic Ocean.

Data from these stations were used to obtain climatological means and extremes for the Seabrook area. Climatological data from Portsmouth, New Hampshire, and Pease AFB have also been used. Both stations are about 21 km NNE of the site. Portsmouth data are from the Department of Public Works, a cooperative weather observer.

Temperature. Temperature extremes are moderated by the proximity of the site to the Atlantic Ocean. This effect is more pronounced during the summer when the sea breeze counters inland heating. Cold air outbreaks can produce low minimum temperatures, but the persistence of extreme values along the coast is less than for inland stations. Table 4-57.

Precipitation. A mean monthly precipitation between 7 and 10 cm each month is expected for Seabrook, with a mean annual total close to 111 cm. Most summer rain is from showers and thunderstorms, which are less frequent along the coast than farther inland. Heavy precipitation between December and March is usually associated with stormy conditions caused by nor'easters moving up along the coast. Table 4-56.

On the average, there are about 130 days per year with more than a trace of precipitation (Lautzenheiser, 1967) and 79 days with over 0.2 cm. At Pease Air Force Base, October, the driest month, averages 9 days with measurable precipitation, while November, the wettest month, averages 12 days.

Heavy precipitation at Seabrook usually occurs only with storm centers that form along the east coast and move northeastward toward New

Table 4-56

PRECIPITATION (INCHES)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean Monthly														
Boston	3.9	3.3	4.2	3.8	3.3	3.5	2.9	3.7	3.5	3.1	3.9	3.6	42.8	1931 - 1960
Portland	4.4	3.8	4.3	3.7	3.4	3.2	2.9	2.4	3.5	3.2	4.2	3.9	42.9	1931 - 1960
Portsmouth	4.2	4.0	3.4	3.6	2.8	2.7	3.4	2.7	3.8	4.1	4.6	3.5	42.6	1954 - 1967
Maximum Monthly														
Boston	9.5	7.1	11.0	9.1	13.4	9.1	11.7	17.1	10.9	8.8	11.3	9.7		1871 - 1972
Portland	9.4	6.8	10.0	6.5	7.7	6.3	5.9	8.3	9.8	12.3	9.8	9.7		1941 - 1972
Portsmouth	13.8	5.8	6.2	6.5	6.4	6.3	5.4	6.7	9.1	10.8	9.7	6.4		1954 - 1967
Minimum Monthly														
Boston	0.9	0.4	T	0.9	0.2	0.3	0.5	0.4	0.2	0.1	0.6	0.7		1872 - 1971
Portland	0.8	1.3	0.8	0.7	0.5	0.7	0.6	0.3	0.3	0.3	2.1	1.0		1941 - 1971
Portsmouth	0.9	1.3	1.7	1.4	1.0	0.8	1.3	1.4	1.5	1.9	2.4	1.0		1954 - 1961
Maximum 24 Hour Total														
Boston	3.2	4.4	4.1	3.2	5.7	5.4	6.0	8.4	5.6	4.9	5.4	4.2		1871 - 1972
Portland	2.0	3.2	3.5	2.4	2.3	5.6	2.2	4.2	7.5	7.7	3.4	3.8		1941 - 1972
Portsmouth	2.6	3.4	1.8	1.7	1.8	2.4	2.4	2.2	6.6	5.6	2.8	2.0		1954 - 1967

T = less than 0.01 inches

Table 4-57

MEAN TEMPERATURES AND EXTREMES (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean Daily Maximum														
Boston	37	37	45	56	68	76	82	80	73	63	52	40	59.0	1931 - 1960
Portland	32	34	41	52	64	73	80	78	70	60	48	35	55.6	1931 - 1960
Portsmouth	32	34	42	53	66	75	80	78	70	61	49	35	56.4	1954 - 1967
Mean Daily Minimum														
Boston	23	23	31	40	50	59	65	63	57	47	38	26	43.6	1931 - 1960
Portland	12	12	22	32	42	51	57	55	47	37	29	16	34.4	1931 - 1960
Portsmouth	13	13	22	32	41	51	56	54	46	37	29	17	34.4	1954 - 1967
Record Lowest														
Boston	-13	-18	-8	11	31	41	50	46	34	25	-2	-17		1872 - 1972
Portland	-26	-39	-21	8	23	33	40	33	23	18	5	-21		1941 - 1972
Portsmouth	-23	-15	-8	10	22	35	40	33	26	14	11	-12		1954 - 1967
Mean No. of Days with Minimum 0° or Below														
Boston	0	1	0	0	0	0	0	0	0	0	0	*		1954 - 1971
Portland	6	5	1	0	0	0	0	0	0	0	3	15		1941 - 1971
Portsmouth	4	5	*	0	0	0	0	0	0	0	2	11		1954 - 1967

* = less than 1 day

From: Seabrook EIS

England. These nor'easters usually have a small, intense circulation and move rapidly through the New England area. If the center passes sufficiently close to the site, considerable rain or snow can occur. A maximum monthly precipitation amount close to 25 cm could be expected at the site. Maximum 24 hour precipitation amounts will occur with thunderstorms during the summer or as a result of nearby hurricanes during the fall.

Fog. The cool Atlantic waters can produce extensive advection fog when warmer, moist air is carried over the cool water. With any persistent eastern component in the wind direction, the fog that often lies just off shore during the summer can reach the Seabrook site. This situation is supported during the summer by local heating and a resulting sea breeze.

All months of the year have a fairly consistent frequency of occurrence of fog. This is shown in the following table which lists the occurrence of fog at Pease AFB (USNWS, 1970), about 8 km inland. Although localized and contiguous fog is seen at Pease AFB about 15 percent of the time, it is dense enough to restrict visibility to two km or less about 3.5 percent of the time.

ANNUAL FREQUENCY OF FOG AT PEASE AFB

1956-1961

Month	Percent of Hours
January	13.5
February	12.3
March	13.3
April	16.6
May	13.9
June	18.1
July	15.3
August	12.2
September	16.9
October	19.0
November	17.0
December	14.2
Annual	15.2

Wind. Wind directions were from sectors around WNW during the year of 1972 of collected data. During the winter, 55.6 percent of all winds at 10 m above ground were from the W through NW sectors. This peak is reduced to 35.2 percent during the spring when 25.3 percent of the winds come from the NNE through E. Winds from the west and northwest predominate, even during the summer, with winds from NE through SE account-

ing for only 27.1 percent. On-shore winds are at a minimum during the winter months. Northeast winds, usually associated with a nor'easter moving up along the New England coast, show a peak during the spring.

During the year, the maximum wind direction persistence in a 22.5 percent sector was 20 hours with a WNW wind. There were ten occurrences of the wind direction remaining within a 45 percent sector over 48 hours. These occurred with winds from the SW westward through the NNW.

Highest hourly wind speeds during the year occurred with winds from the ENE and the NW.

Strong Winds. The Boston and Portland climatology data show that wind speeds over 40 mph can occur during any month of the year. During the winter these high winds are normally caused by nor'easters that move up along the coast and are normally accompanied by moderate to heavy precipitation.

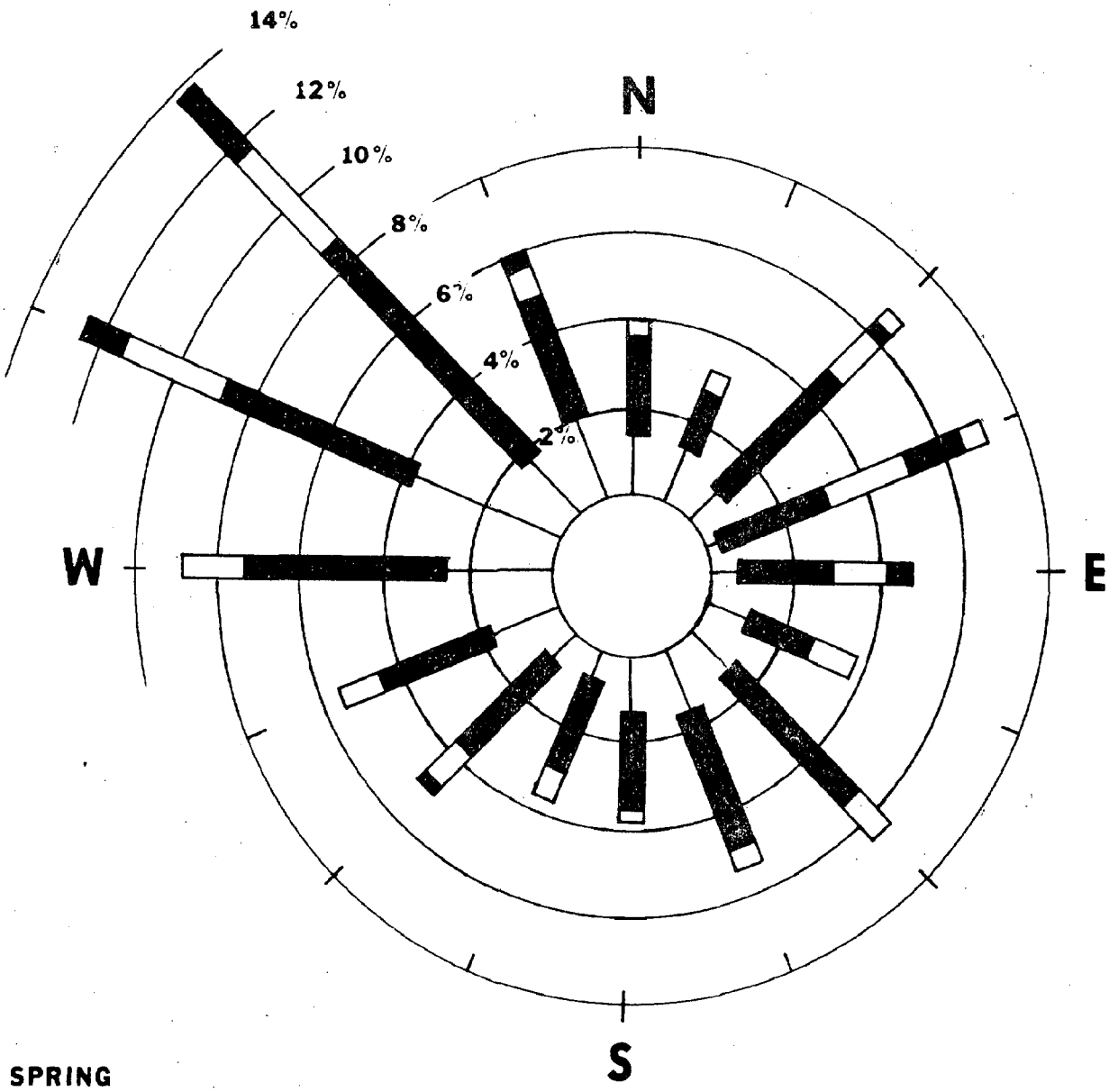
During the warmer months, high winds are normally the result of thunderstorms or squall lines that move through the area. Hurricanes could produce high wind speeds during the late summer and early fall.

Table 4-58 lists the fastest-mile wind speeds recorded at Boston and Portland (NOAA 1954, 1965, 1971). The Boston wind data are considered to be representative for the Seabrook area due to comparable exposure. Seasonal wind roses and the annual summary are given in Figures 4-240 through 4-244.

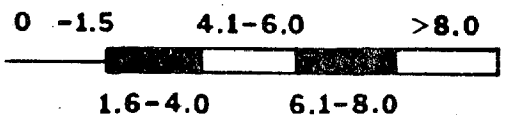
Table 4-58

FASTEST MILE WIND SPEED (MPH)

	Boston	Portland
January	52	52
February	56	58
March	57	76
April	56	57
May	58	50
June	63	44
July	64	45
August	65	69
September	61	62
October	58	45
November	58	76
December	49	62
Years	1926-1971	1941-1971

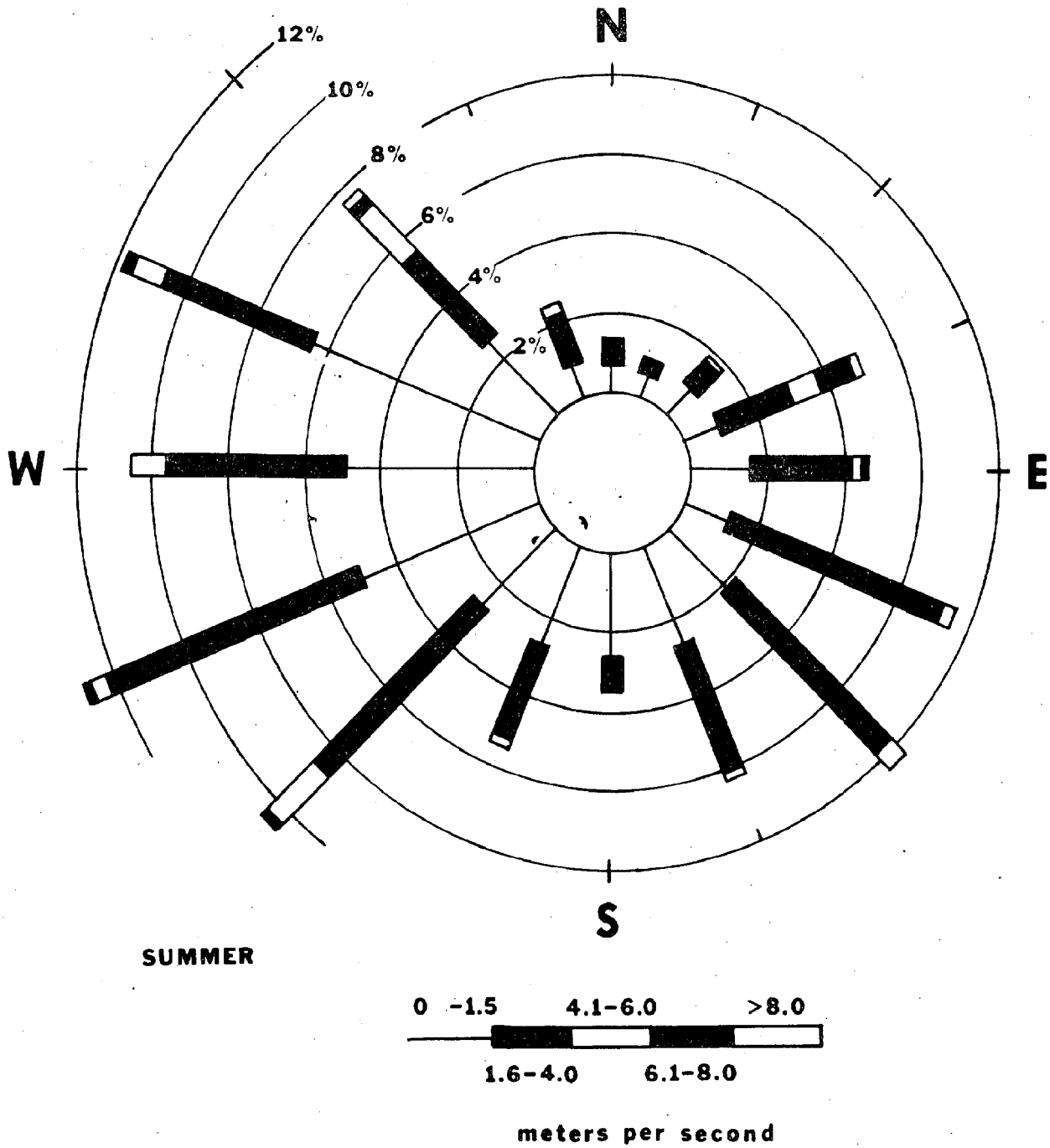


SPRING

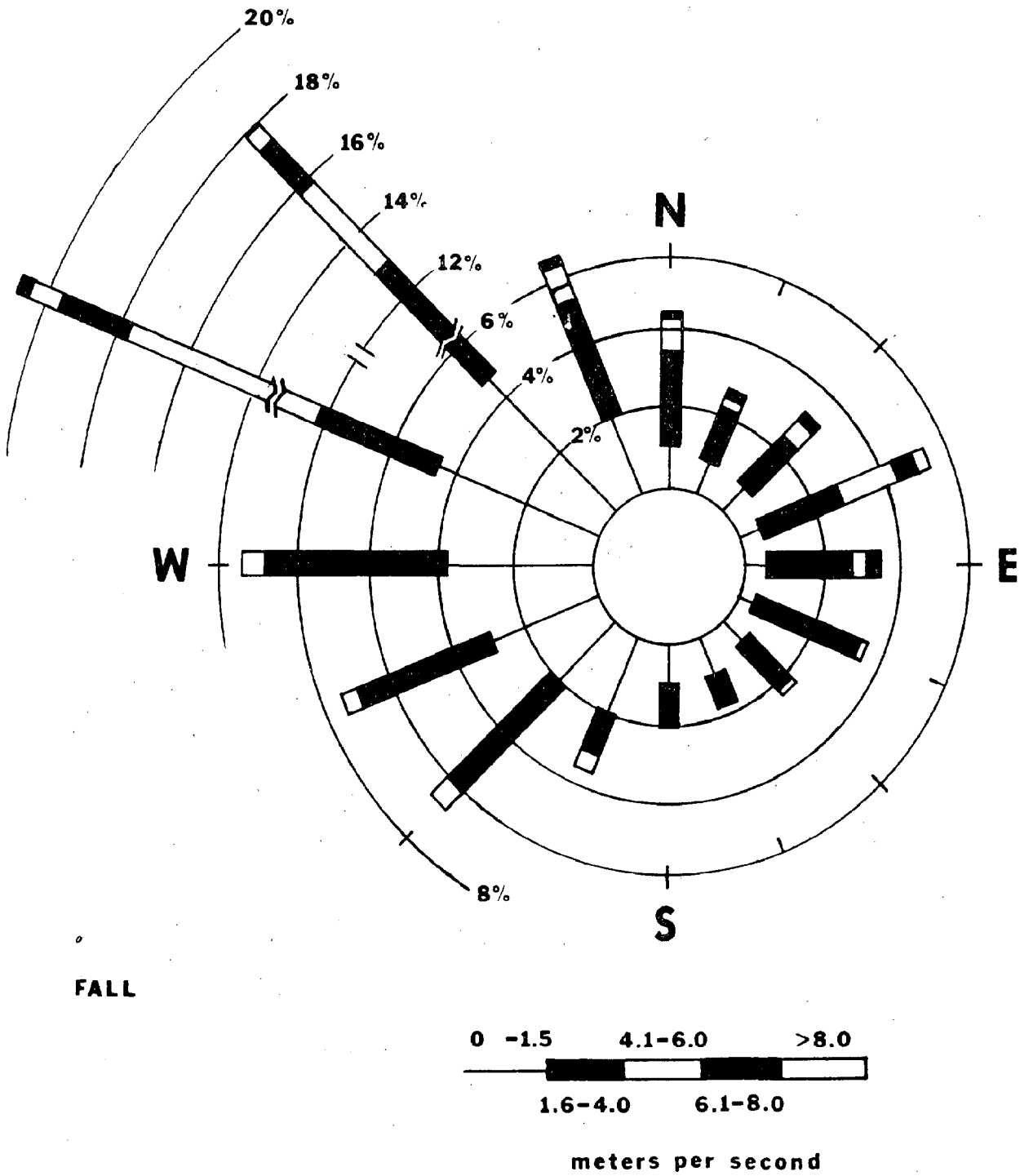


meters per second

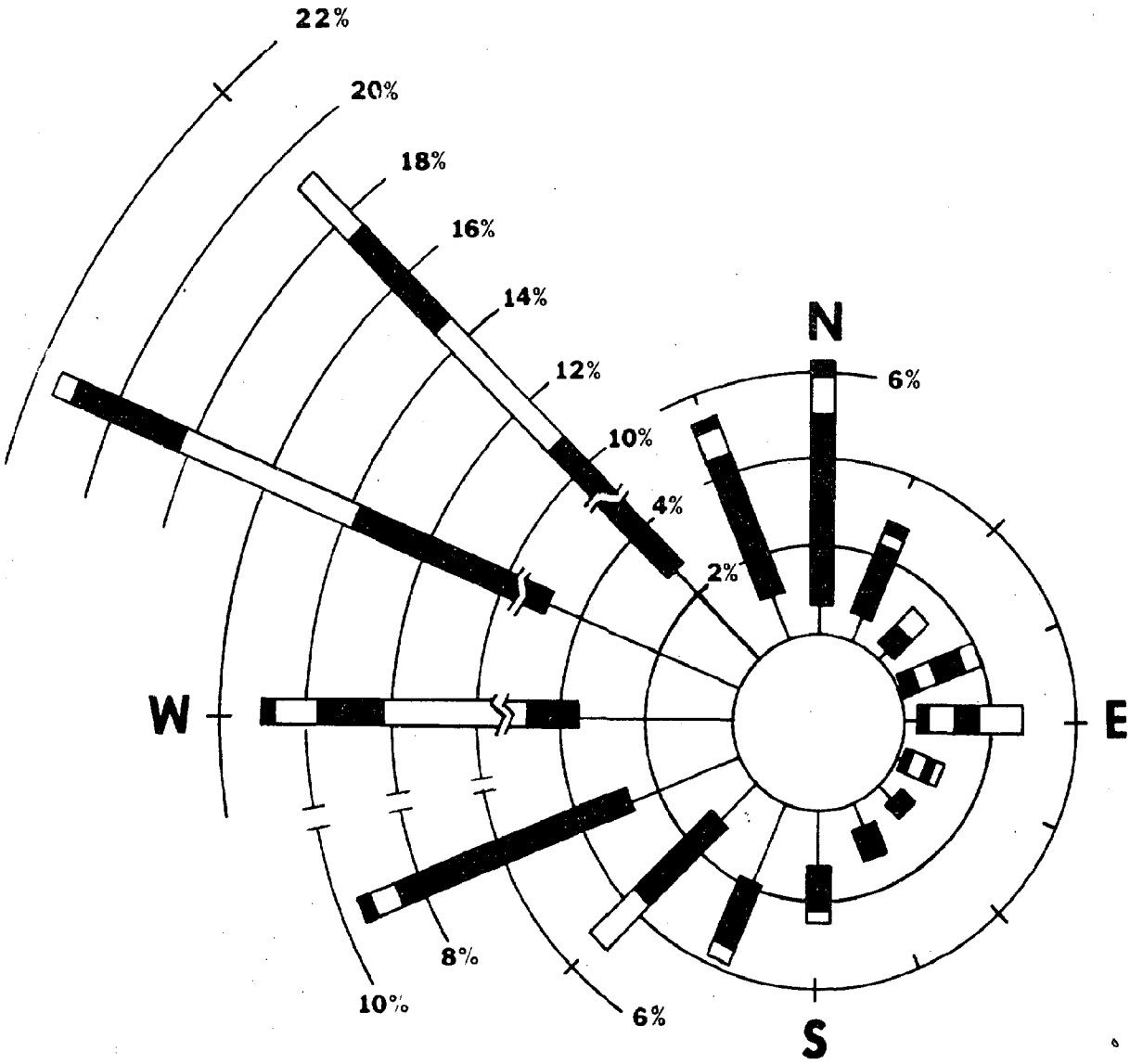
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-240	SEABROOK POWER STATION Spring Wind Rose 30 Feet Level



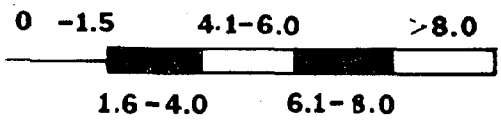
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-241	SEABROOK POWER STATION Summer Wind Rose 30 Feet Level



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-242	SEABROOK POWER STATION Fall Wind Rose 30 Feet Level

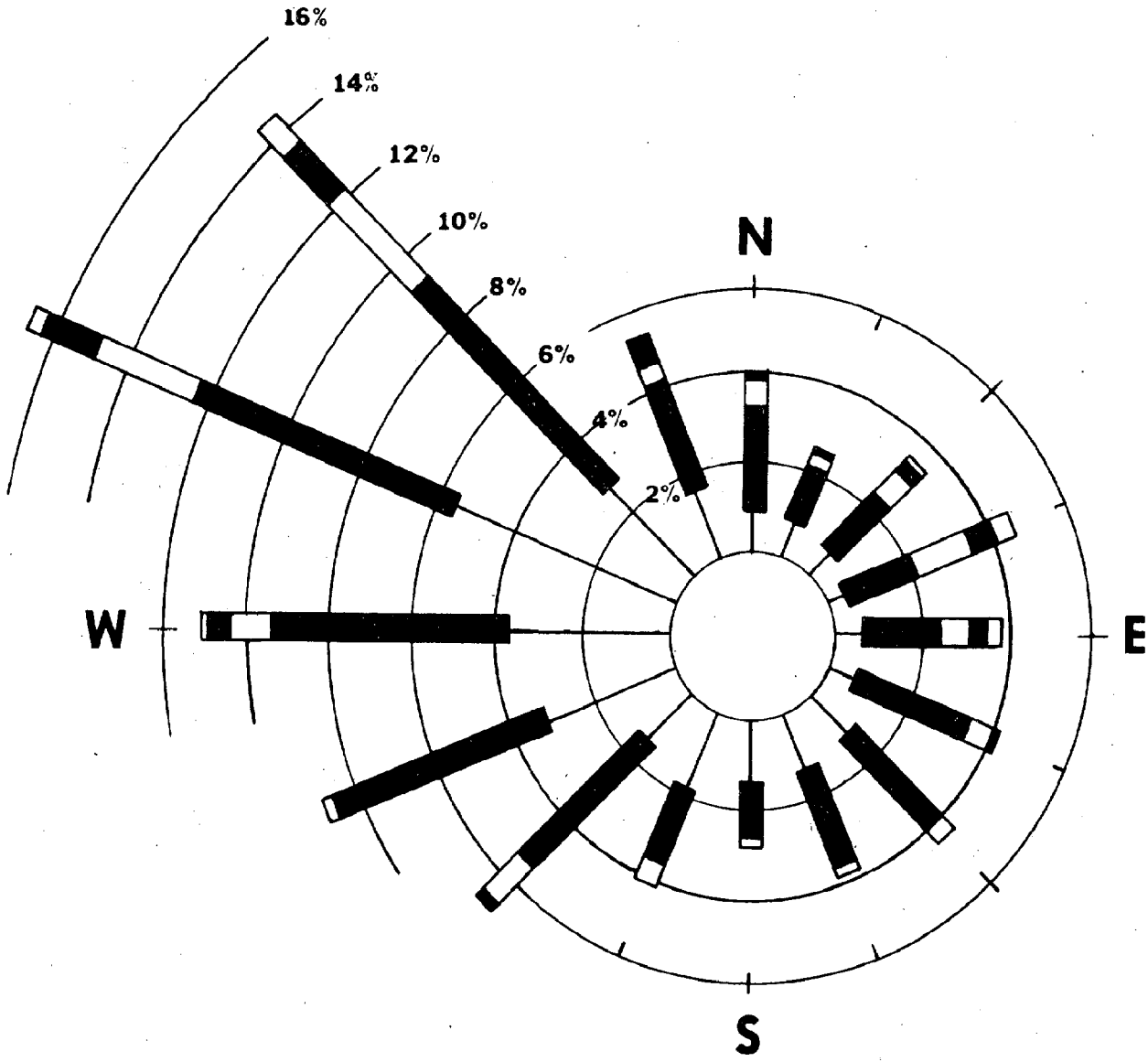


WINTER

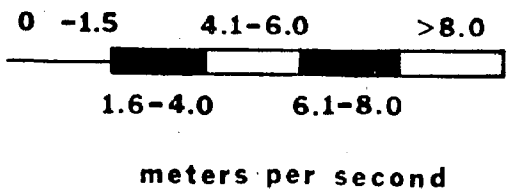


meters per second

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-243	SEABROOK POWER STATION Winter Wind Rose 30 Feet Level



ANNUAL



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 4-244	SEABROOK POWER STATION Annual Wind Rose 30 Feet Level

The annual extreme-mile at 10 m above ground for four recurrence intervals is as follows:

ANNUAL EXTREME-MILE FOR 10 M ABOVE GROUND
SEABROOK AREA

Return Interval (years)	Speed (mph)
10	70
25	80
50	90
100	95

From: Seabrook EIS

Hurricanes. A review of all tropical cyclone events for the period 1886 through 1970 (Simpson & Lawrence, 1971) shows that no tropical storms or hurricanes have come onshore within the 185 km strip of coast line from 42.08°N, 69.90°W north to 43.52°N, 70.32°W. The Seabrook site is located at 42.9°N, 70.9°W. While no tropical storms or hurricanes have come ashore in the Seabrook area, such storms that reach the New England area usually pass northward west of the site or on a northeast track south of the site. Since, to date, the only hurricanes or tropical storms to reach the Seabrook area have had to travel a substantial distance overland, the potential impact of such storms is significantly reduced.

One of the more critical aspects of tropical storms passing south of the site is the possibility of flooding caused by a substantial onshore fetch. The record high tide for the New Hampshire coast associated with a hurricane was 2.3 m MSL recorded at Newburyport (U. S. Army Corps of Engineers, 1965).

Tornadoes. Minor tornadoes have occurred in all of the New England states. The average annual number of tornadoes for the entire State of New Hampshire is 2.2 (Pautz, 1969). The 1° square from 42 - 43°N and 71 - 72°W that contains this Seabrook site shows a total number of only 4 tornadoes during the period 1955-1967 for an annual tornado probability of 0.308.

Data for the 2° square from 42 - 44°N and 70 - 72°W for 1916-1968 give a total of 51 tornadoes over the 43 years, for an annual frequency of 1.186 for the square. For the 1° square containing Seabrook, this value is divided by 4 for an annual tornado probability in a 1° square of 0.296.

Ice Storms. Freezing precipitation, or glaze ice, does occur in the

Seabrook area. Data for freezing rain at Pease AFB for 1956 through 1961 are presented on Table 4-59.

TABLE 4-59
AVERAGE FREQUENCY OF OCCURRENCE (PERCENT OF HOURS)
OF FREEZING RAIN AT PEASE AFB, NEW HAMPSHIRE

Jan	Feb	Mar	Apr	Nov	Dec	Annual
0.9	0.5	0.3	0.0	0.2	1.0	0.3

Mapped data for the period 1925 - 1953 show 7 to 13 ice storms reported for the Seabrook area. For a 9 year period, 12 ice storms occurred resulting in ice of a thickness of 0.62 cm or more, of which 8 storms had ice of 1 cm or more.

The greatest radial thickness of ice on utility wires for the Seabrook region was between 4 cm and 5.1 cm.

Thunderstorms and Hail. Thunderstorms have occurred in New England during every month of the year, with the maximum number during the summer. Table 4-60 presents the mean number of days with thunderstorms. The days with thunderstorms at Seabrook are represented by the Pease AFB data.

TABLE 4-60
MEAN NUMBER OF DAYS WITH THUNDERSTORMS

	Boston	Portland	Pease AFB
January	*	0	0
February	*	*	0
March	*	*	0
April	1	1	0.8
May	2	2	2.5
June	4	4	3.2
July	5	4	5.4
August	4	4	3.4
September	2	2	1.5
October	1	1	0.4
November	*	*	0.1
December	*	*	0
Annual	19	18	17.3
Years	36	31	10

*Less than 0.5

Wyman Environment Impact Statement. A proposed Unit 4 to be added to Wyman Power Station lying 16 km east of Portland, Maine, on Casco Bay has resulted in a compilation of wind data and uses Portland Airport meteorological data for other elements. Table 4-61 presents a complete summary of Portland data. As with all nuclear and fossil fuel plants detailed direction and stability data as measured at the site are available.

4.4.4 STORMS

INTRODUCTION

The coastal region from Sandy Hook to the Bay of Fundy is often traversed by tropical and extra-tropical storms. This area straddles a land-water boundary and is often near the front between continental and maritime air masses. Storms can penetrate this region while still remaining in contact with their water and energy source, the Atlantic. Damage due to storms in the study area has been high in the period 1921-1964.

The discussion of storms will begin with a description of tropical cyclones and their spatial and temporal distributions. Cyclogenesis along the U.S. East Coast is discussed, and primary and secondary extra-tropical storm tracts are presented for each month. Detailed storm climatologies of two coastal and two nearshore areas within the study area are included to illustrate storm occurrences on a smaller spatial scale. Finally, storm damage estimates are given for the U. S. East Coast and smaller coastal increments.

TROPICAL CYCLONES

The properties and features of tropical cyclones in the North Atlantic Ocean are discussed with reference to data from Cry and Haggard (1962) and Cry (1965). These data were taken primarily from storm locations published in the Monthly Weather Review.

Winds traveling counterclockwise in the northern hemisphere around a center of low pressure are called cyclones. Tropical cyclones originate in the tropical Atlantic just north of the Inter-Tropical Convergence Zone where the trade winds are fairly uniform. Because of the homogeneity of the surrounding water and air these systems are characterized by a circular symmetry with diameters of up to 1000 km.

Tropical cyclones experience a life cycle of development, intensification, maturity, modification, and decay. During this life cycle they may be classified by their maximum sustained wind speeds. Storms with closed isobars are classified as hurricanes for wind speed greater than

TABLE 4-61

SUMMARY OF MONTHLY AND ANNUAL METEOROLOGICAL VARIABLES AT PORTLAND

NORMALS, MEANS AND EXTREMES

Month	Temperature: Normal: Daily maximum	Temperature: Normal: Daily minimum	Temperature: Normal: Monthly	Temperature: Extremes ø: Record highest	Temperature: Extremes ø: Year	Temperature: Extremes ø: Record lowest	Temperature: Extremes ø: Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Precipitation: Maximum monthly	Precipitation: Year	Precipitation: Minimum monthly	Precipitation: Year	Precipitation: Maximum in 24 hrs.	Precipitation: Year	Snow, Ice pellets: Mean total	Snow, Ice pellets: Maximum monthly	Snow, Ice pellets: Year	Snow, Ice pellets: Maximum in 24 hrs.	Snow, Ice pellets: Year	Relative humidity (Local time): Hour 01	Relative humidity (Local time): Hour 07	Relative humidity (Local time): Hour 13	Relative humidity (Local time): Hour 19
(a)	(b)	(b)	(b)	32		32		(b)	(b)	32		32		32		32	32		32		32	32	32	32
J	31.8	11.7	21.8	64	1950	-26	1971	1339	4.37	9.41	1958	0.76	1970+	2.04	1966	18.1	38.2	1966	14.2	1944	76	78	62	71
F	33.5	12.1	22.8	64	1957	-39	1943	1182	3.80	6.76	1971	1.26	1968	3.21	1965	21.6	61.2	1969	21.5	1969	76	78	60	69
M	40.7	22.0	31.4	86	1946	-21	1950	1042	4.34	9.97	1953	0.81	1965	3.47	1951	14.3	46.6	1956	11.7	1972	76	75	59	70
A	52.5	32.4	42.5	85	1957	8	1954	675	3.73	6.48	1961	0.71	1941	2.43	1954	3.1	15.7	1967	8.7	1971	80	74	55	70
M	64.2	41.7	53.0	92	1944	23	1956	372	3.41	7.74	1948	0.49	1965	2.33	1952	0.3	7.0	1945	7.0	1945	85	75	57	71
J	73.1	51.1	62.1	97	1941	33	1944	111	3.18	6.23	1967	0.70	1941	5.58	1967	0.0	0.0		0.0		89	78	60	74
J	79.5	56.7	68.1	98	1949+	40	1965+	12	2.86	5.87	1951	0.61	1965	2.23	1947	0.0	0.0		0.0		90	80	59	75
A	78.4	55.2	66.8	100	1948	33	1965	53	2.42	8.30	1946	0.27	1947	4.18	1946	0.0	0.0		0.0		90	83	59	78
S	70.2	47.2	58.7	95	1945	23	1941	195	3.52	9.81	1954	0.30	1948	7.49	1954	T	T	1959	T	1959	90	86	61	80
O	59.8	37.4	48.6	88	1963	18	1966+	508	3.20	12.27	1962	0.26	1947	7.71	1962	0.3	3.8	1969	3.6	1969+	86	85	60	79
N	47.6	28.6	38.1	73	1950	5	1940	807	4.17	9.81	1963	2.10	1946	3.39	1951	3.5	15.6	1972	11.1	1972	83	84	64	77
D	35.3	16.3	25.8	62	1962	-21	1963	1215	3.85	9.69	1969	0.98	1955	3.82	1969	15.8	54.8	1970	22.8	1970	79	80	62	74
YR	55.6	34.4	45.0	100	AUG. 1948	-39	FEB. 1943	7511	42.85	12.27	OCT. 1962	0.26	OCT. 1947	7.71	OCT. 1962	77.0	61.2	FEB. 1969	22.8	DEC. 1970	83	80	60	74

ø For period November 1940 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites i
Highest temperature 103 in July 1911; maximum monthly precipitation 12.29 in January 1935; minimum monthly precipitation
maximum snowfall in 24 hours 23.3 in January 1935.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

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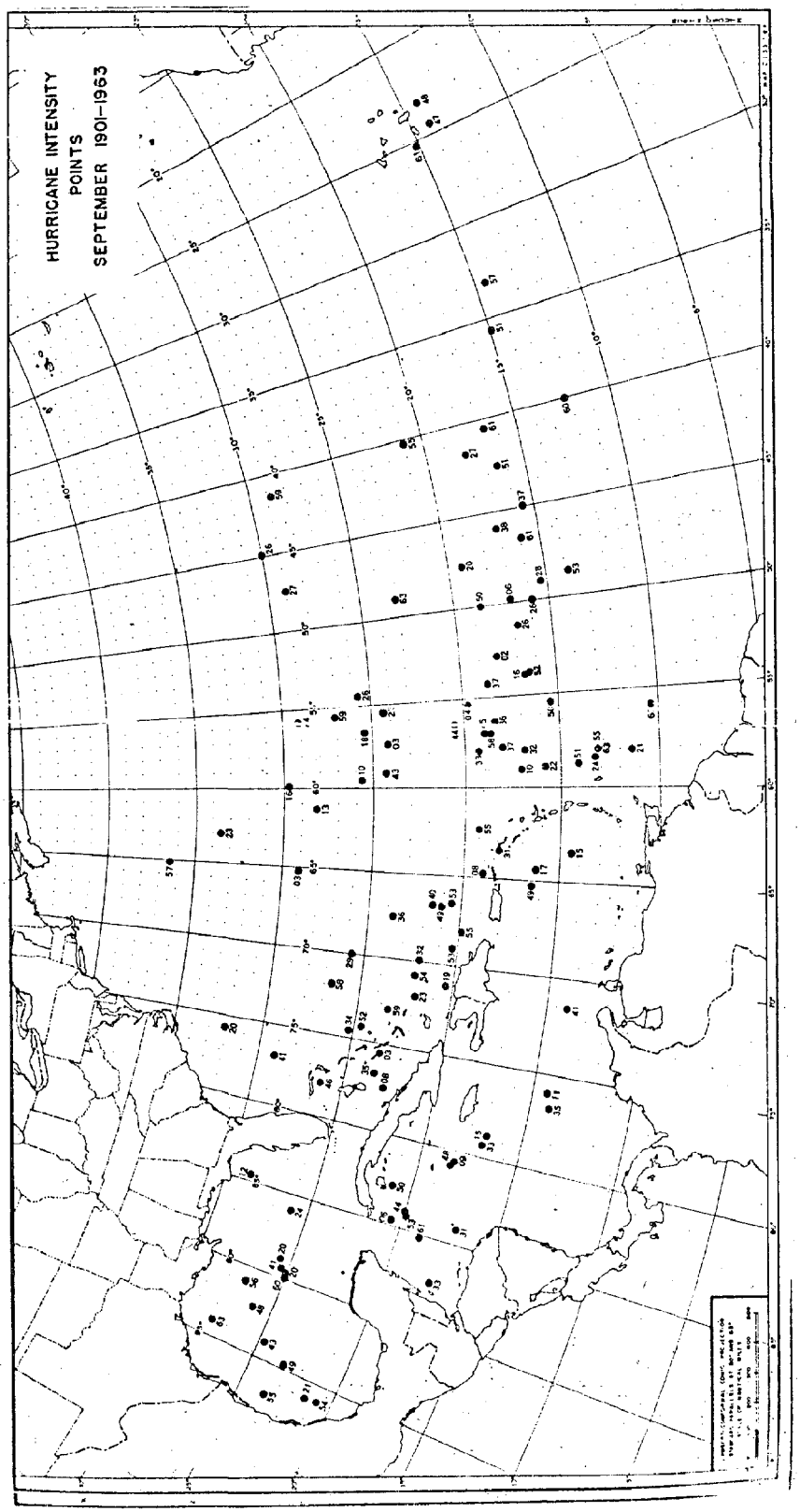
118 km/hr, tropical storms for wind speeds between 62 km/hr and 116 km/hr and tropical depressions for speed less than 62 km/hr. The development of these storms and their passage through the various categories depends on the surrounding environment. Modification may be due to admixture of colder northern air masses. This would result in an extra-tropical cyclone. Movement over land masses is another reason for modification since its energy source would be sharply reduced and surface friction greatly increased.

Storm Characteristics

The tropical cyclone season covers the interval from June through November with September having the maximum number of storms reaching hurricane intensity. For the years 1901 through 1963, 290 full-fledged hurricanes have been recorded. This number is roughly 58 percent of the total number of tropical cyclones tracked for that period. Most of these storms originated between 10°N and 20°N latitude. During June, formation occurs mainly in the western Caribbean and Gulf of Mexico. In July the preferred points of origin move eastward to the lesser Antilles and the southwest Atlantic. Storms are active over the largest area during August and September, particularly in the southwest Atlantic east of the Bahamas and West Indies. The points of origin shift back to the western portion of the Caribbean as the season wanes. The attainment of hurricane intensity occurs principally between 50°W and 80°W along 20°N. This may be seen in Figure 4-245 which is a compilation of the positions where all hurricanes reported during the month of September first reached hurricane intensity.

The track taken by tropical cyclones is affected by atmospheric conditions from the sea surface to about 15 km; hence, large scale atmospheric circulation is a major determinant of storm travel. Most tropical cyclones begin in a northwesterly direction and then veer toward the northeast upon coming under the influence of the Westerlies. The point of recurvature is defined as the position where the storm track changes direction with respect to longitude. More simply, the point of recurvature is the westernmost position that the storm occupied. Although this clockwise sense of travel is the dominant mode, occasionally storms will transcribe a closed loop due to the influence of two interacting wind regimes. Figure 4-246 gives the points of recurvature and loops for all September tropical cyclones reported from 1901-1963. As in the case of storm origins, the points of recurvature shift eastward from June to September and then westward from September to November. Most recurvature points are seen to be centered between 20°N and 35°N latitude.

Temperal and Spatial Distribution. Figure 4-247 is an historical display of all reported tropical cyclones from 1871 to 1963 and those reaching hurricane intensity from 1886 to 1963. The shading indicates the type of movement. Note that about 60 percent of all hurricanes



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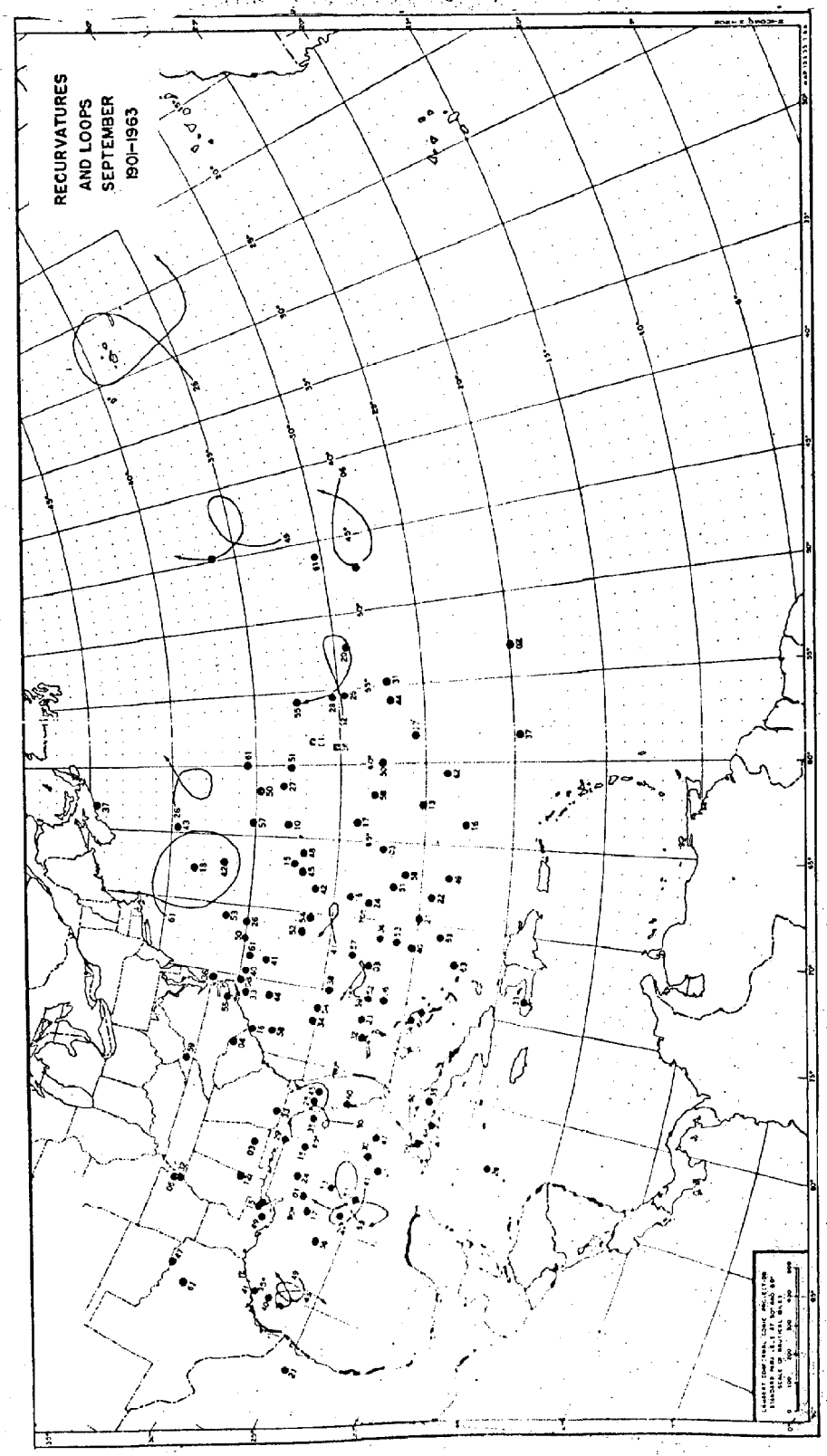
TRIGOM PARC	FIGURE 4-245	Points of Initial Hurricane Intensity (Cry, 1965)



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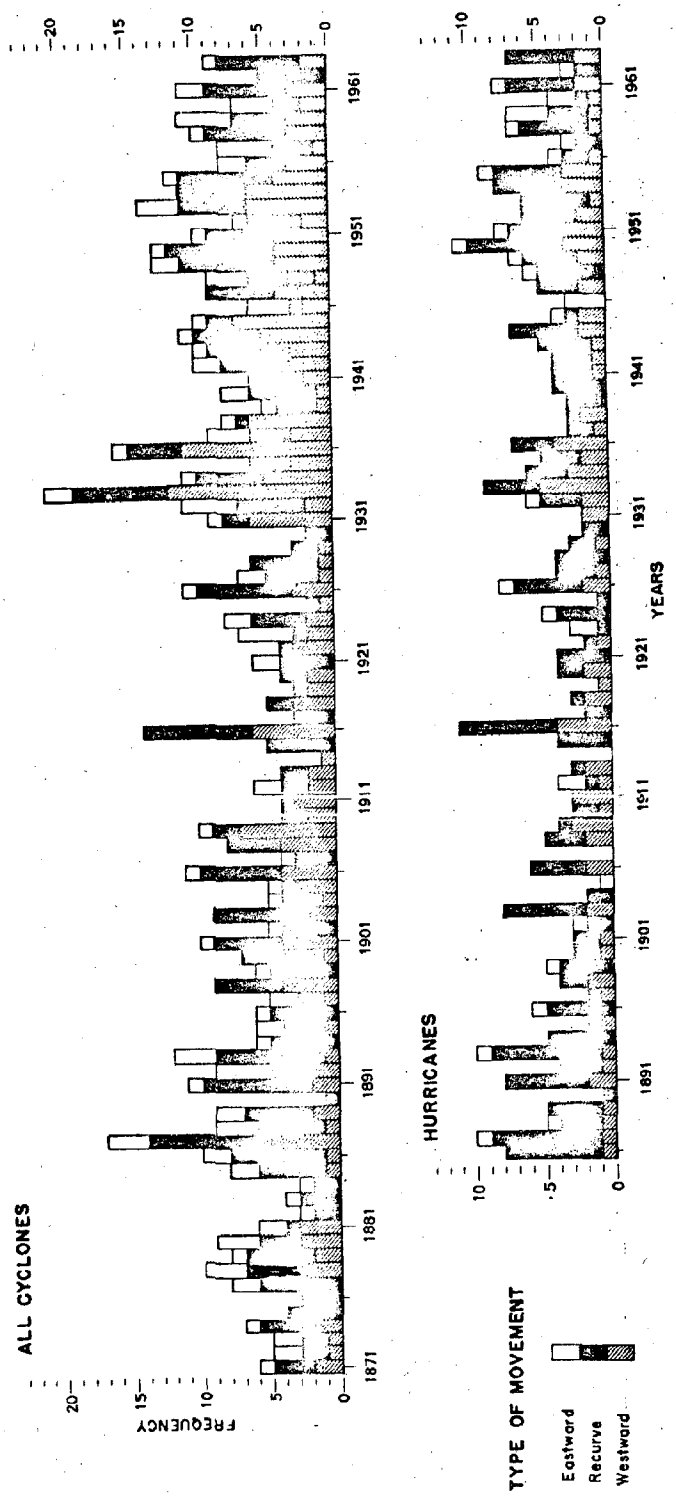
TRIGOM PARC	FIGURE 4-246	Points of Recurvature and Location of Loops in Tracks (Cry, 1965)



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TRIGOM PARC	FIGURE 4-247	Frequency of Cyclones and Hurricanes (Cry, 1965)

recurve. Although periods of maximum and minimum storm occurrence can be detected subjectively, the record length of about 90 years is too short with respect to the bandwidth of storm frequency fluctuations to arrive at any prediction of future storm trends.

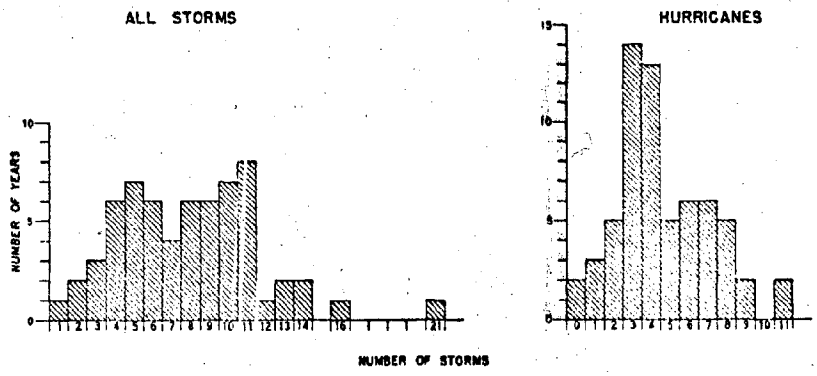
Figure 4-248 shows the annual frequency of tropical cyclones and hurricanes for the years 1901-1963. The mean number of hurricanes per year is 4.6 with the maximum number occurring in any given year being 11. Since the distribution is skewed positively, the mode, 3 hurricanes per year, is perhaps more important than the mean.

Turning now from yearly totals to daily distributions, Figure 4-249 illustrates the extent of the tropical cyclone season. The number of tropical storms and hurricanes in existence for each calendar day during the years 1901-1963 is plotted. August, September, and October are the most significant months with the maximum number of storms and hurricanes occurring around September 10. The peaks during October are attributed to storms occurring in the Western Caribbean.

Table 4-62 gives the frequency of occurrence, by months, of the 63 North Atlantic hurricanes recorded during 1901-1963. From this table an observed probability of occurrence may be obtained. This is shown in Table 4-63 for both tropical cyclones and hurricanes. There is only a 5 percent probability of hurricane occurrence outside the season of June through November. Figure 4-250

The spatial distribution of tropical cyclones affecting the states along the Gulf of Mexico and East Coast is shown in Figure 4-251. Texas, the middle Gulf coast, Florida, and the Carolinas receive the brunt effect. Although New England and the Middle Atlantic states experience fewer tropical cyclones, many have had disastrous consequences due to their paths of approach and points of landfall. As an example, Figure 4-252 shows the tracks of hurricanes reported during 1954. The two hurricanes crossing the New England states were of particular destructive significance. Individual hurricane tracks have a very broad geographical distribution. An example of their complexity may be seen in Figure 4-253 which shows the tracks of all hurricanes reported from September 1-10 during the years 1901-1963. Clearly, the definition of a mean track line is of little value due to the large variance of the individual tracks. The majority of these hurricane tracks veer off into the Atlantic and do not intersect the New England states.

A further compilation of all hurricane tracks from 1901-1963, on an approximate ten-day basis, spanning the peak of the tropical cyclone season, is given in Figures 4-254 through 4-262.



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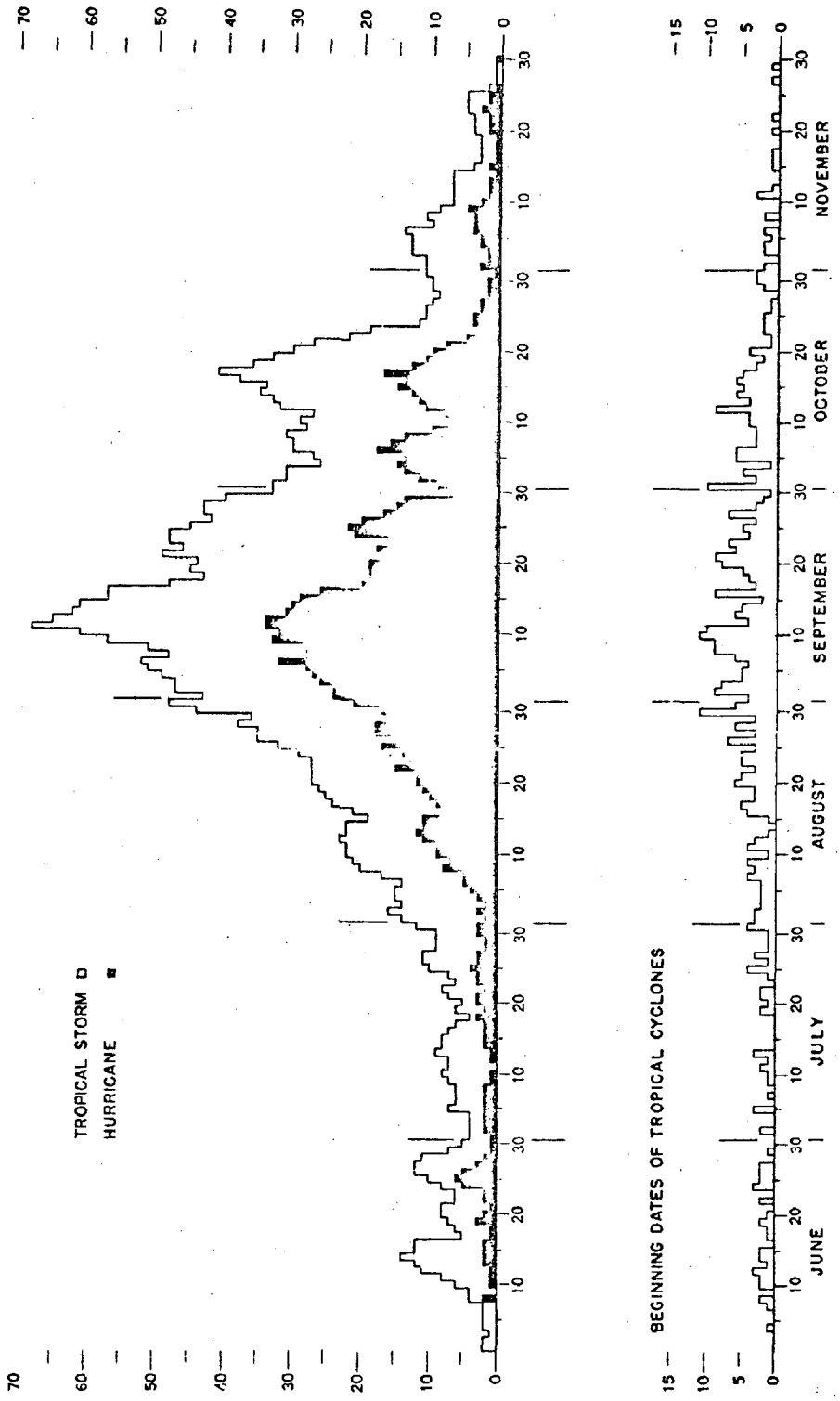
TRIGOM PARC	FIGURE 4-248	Frequency Distribution of Cyclones and Hurricanes (Cry, 1965)



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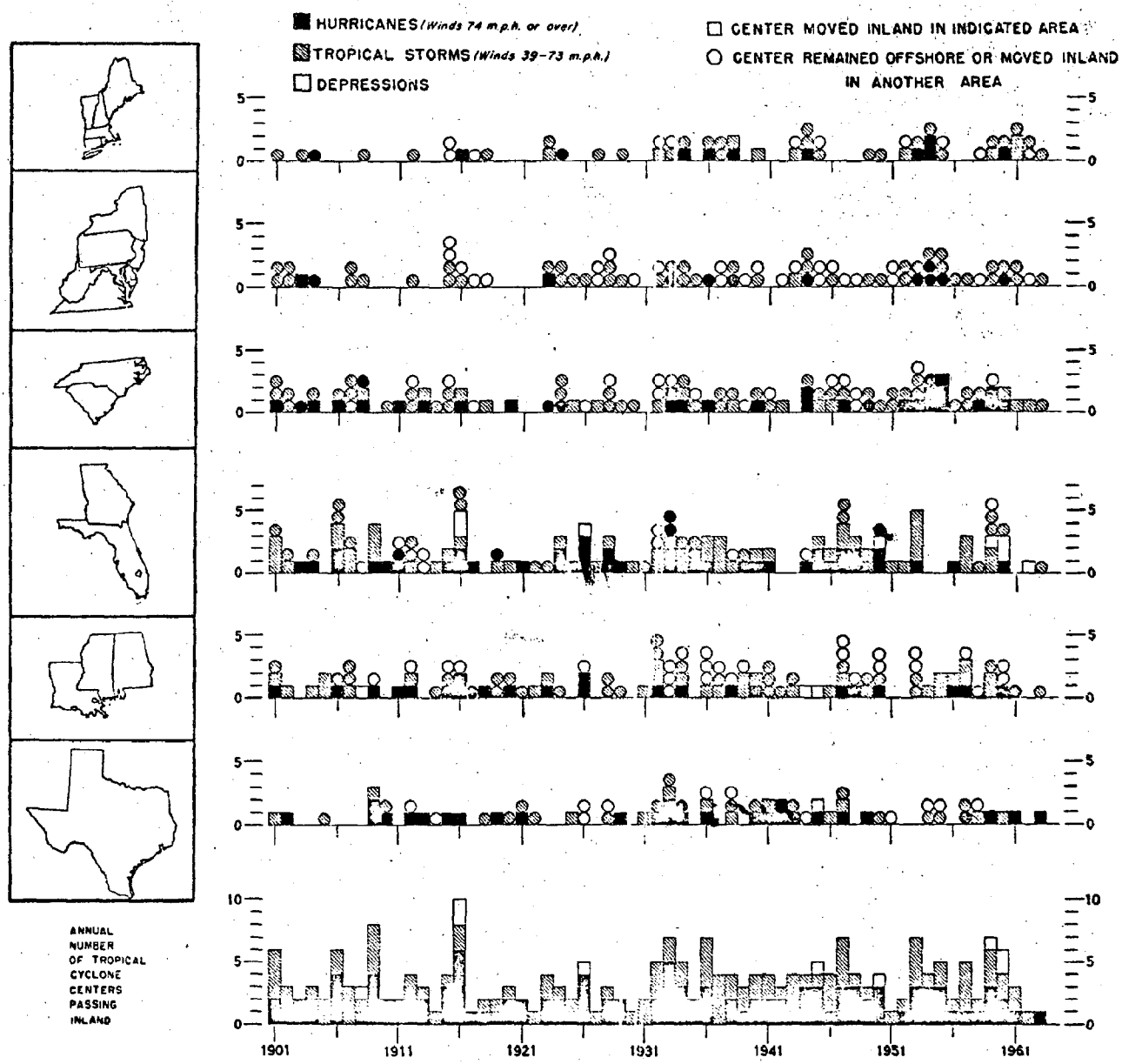
TRIGOM PARC	FIGURE 4-249	Hurricane/Tropical Storm Seasonal Data (Cry, 1965)



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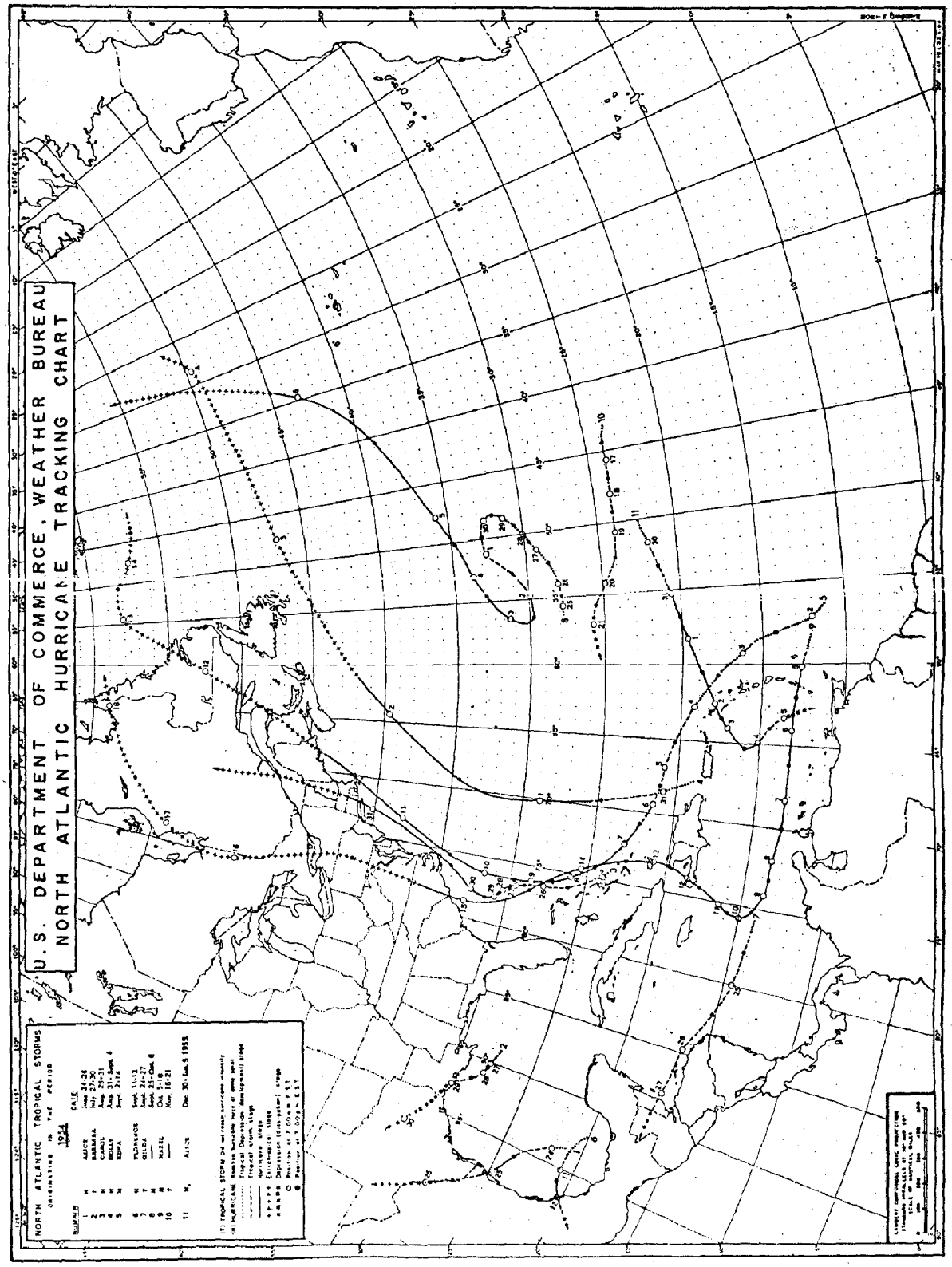
TRIGOM PARC	FIGURE 4-250	Hurricanes Significantly Affecting Coastal Areas (Cry, 1965)



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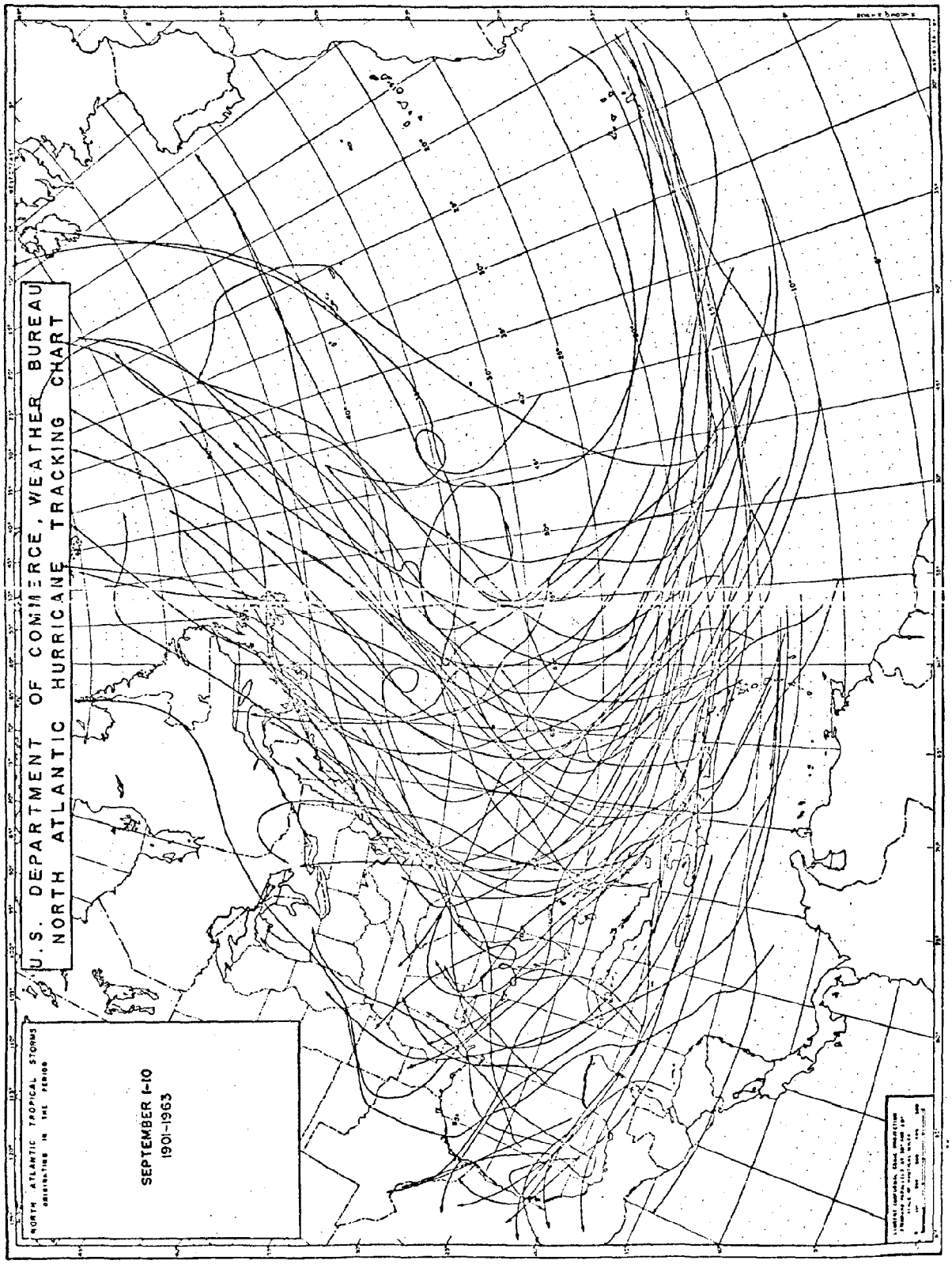
TRIGOM PARC	FIGURE 4-251	1954 Tropical Storm Tracks (Cry, 1965)



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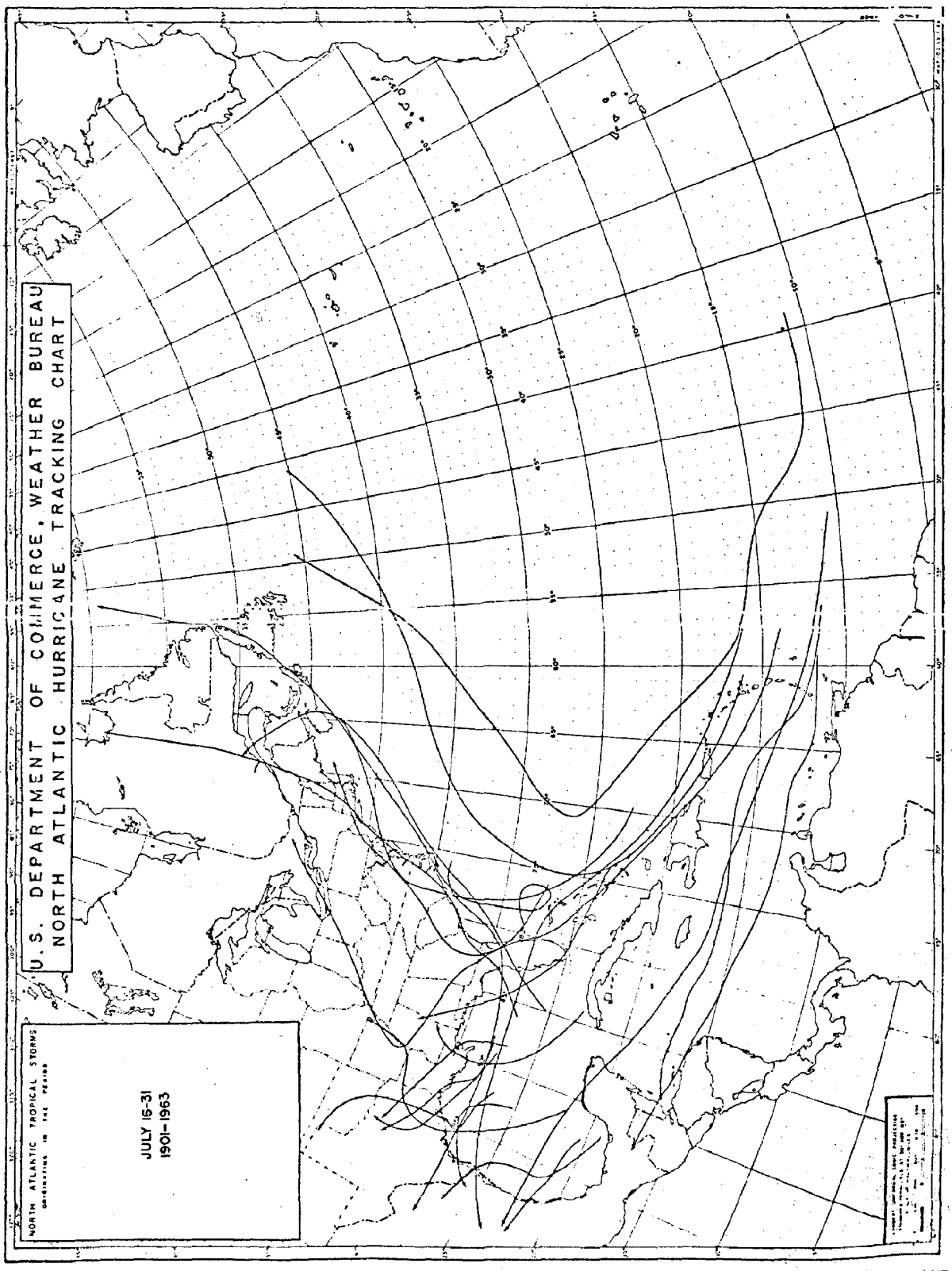
TRIGOM PARC	FIGURE 4-252	Tropical Storms - September 1-10 from 1901 to 1963 (Cry, 1965)



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TRIGOM PARC	FIGURE 4-253	Tropical Storms - July 16-31 from 1901 to 1963 (Cry, 1965)

Hurricanes, 1886-1900

Number of Storms	June	July	Aug.	Sept.	Oct.	Nov.	Dec.-May
0	12	9	0	3	6	13	13
1	2	6	8	3	5	2	2
2	1	0	6	5	3	0	0
3	0	0	0	4	1	0	0
4	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0

Hurricanes, 1901-1963

Number of Storms	June	July	Aug.	Sept.	Oct.	Nov.	Dec.-May
0	50	46	21	8	21	53	60
1	13	14	16	26	32	10	3
2	0	3	16	10	9	0	0
3	0	0	9	13	0	0	0
4	0	0	1	4	1	0	0
5	0	0	0	2	0	0	0

Table 4-62 Observed frequency of North Atlantic hurricane occurrences. (From Cry, 1965).

	All Tropical Cyclones						
	June	July	Aug.	Sept.	Oct.	Nov.	Other Months
At least 1	0.41	0.43	0.78	0.98	0.84	0.33	0.19
2 or more	0.09	0.13	0.57	0.71	0.57	0.02	0
3 or more	0.02	0.03	0.27	0.56	0.22	0	0
4 or more	0	0	0.10	0.32	0.06	0	0

	Hurricanes						
	June	July	Aug.	Sept.	Oct.	Nov.	Other Months
At least 1	0.21	0.27	0.67	0.87	0.67	0.16	0.05
2 or more	0	0.05	0.41	0.46	0.16	0	0
3 or more	0	0	0.16	0.30	0.02	0	0
4 or more	0	0	0.02	0.10	0.02	0	0

Table 4-63 Observed probability of occurrence of North Atlantic tropical cyclones 1901-1963. (From Cry, 1965).

Cyclogenesis and Extra-tropical Storms. Cyclogenesis -- the initiation of cyclonic circulation, or its strengthening around an existing low pressure center -- is discussed by Miller (1946) and Andrews (1963), among others, for the East Coast of the U. S. Numerous environmental conditions contribute to the formation or intensification of low pressure systems in this region. Andrews (1963) summarized the following contributing factors: temperature contrasts between maritime and and continental air masses; the sharpening of atmospheric temperature gradients by the Gulf Stream; deformation of fronts by the Appalachian mountain range; differential heating between land and water surfaces; and the concave nature of the coastline north and south of Cape Hatteras.

Cyclogenesis of extra-tropical storms is most intense during the period October through April, and is often associated with the presence of an upper air trough between the Mississippi Valley and the coast. For the period of maximum cyclogenesis, Andrews recognizes three principal mechanisms for storm formation and gives examples of their synoptic characteristics. The three types noted are:

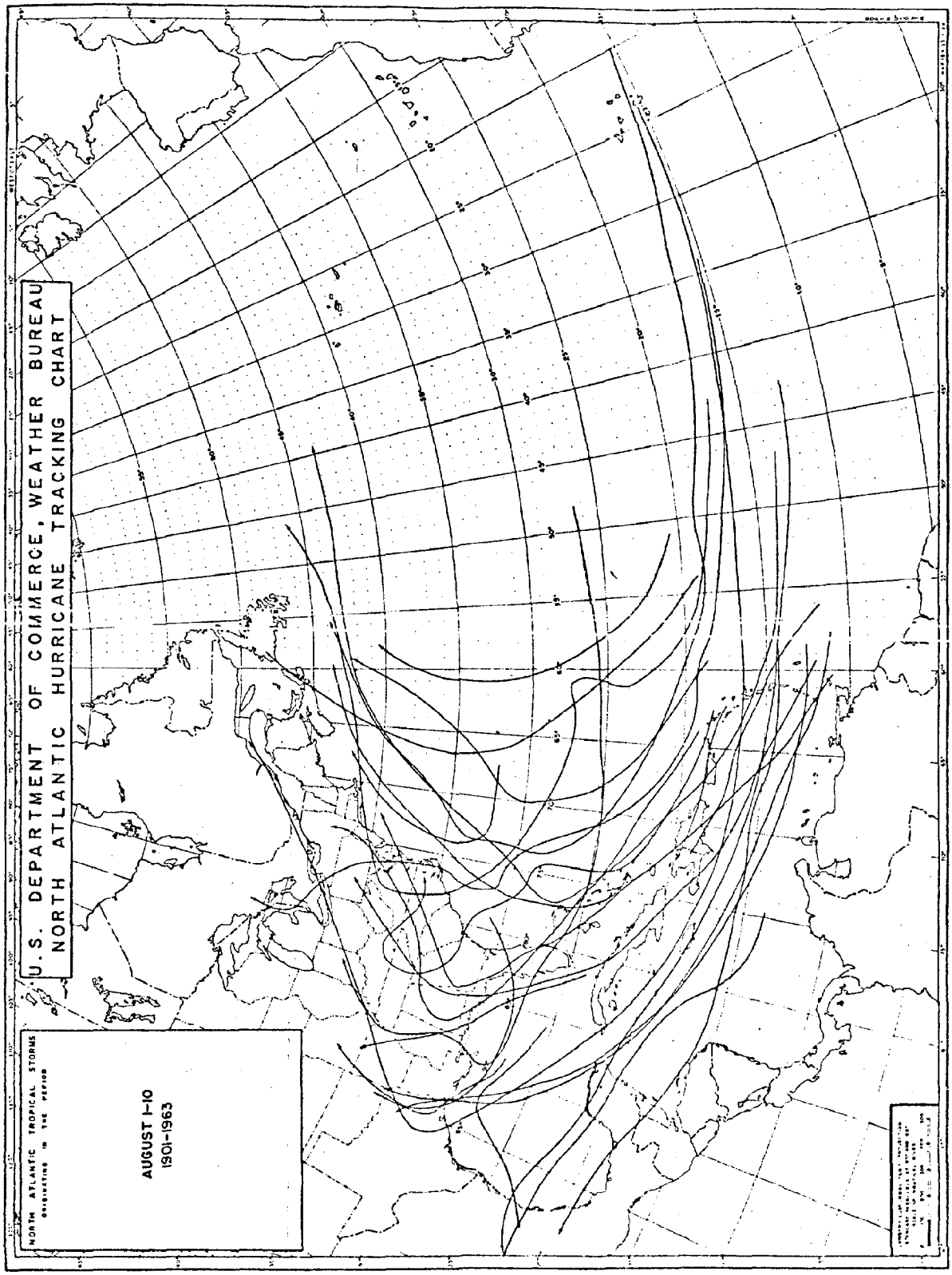
(a) A low pressure center first appears as a wave on a cold front.

(b) A secondary cyclone develops near the middle Atlantic coast along the warm front of an older cyclone.

(c) A blocked low forms off the coast which is closely related to the breakdown of the large-scale planetary circulation in the upper westerlies.

Extra-tropical cyclones are generally asymmetrical low pressure systems that form in non-tropical regions and have a frontal structure. Although associated winds can attain considerable speed, they are usually weaker than those associated with tropical disturbances. The frontal nature of extra-tropical cyclones causes marked wind shifts and temperature fluctuations. Figures 4-252 through 4-273, (U. S. Department of Commerce, 1959, reproduced here from Brower, Sisk, and Quayle, 1972) show primary and secondary extra-tropical storm tracks for each month of the year. The offshore area from Sandy Hook to the Bay of Fundy lies under the influence of primary tracks for all months except July, August, and September, During July and August a secondary storm track traverses the region. In September the study area is shown to be located between a primary and a secondary track.

Selected coastal and nearshore areas. Brower, et al. (1972) discuss tropical and extra-tropical cyclones for ports that have been proposed as supertanker terminals. Included in their report are the coastal zones near Machiasport, Maine,and New York City. Also included in their discussion is a consideration of tropical storm penetration of 1° latitude by 1.5^{o} longitude offshore areas for the Machiasport region,



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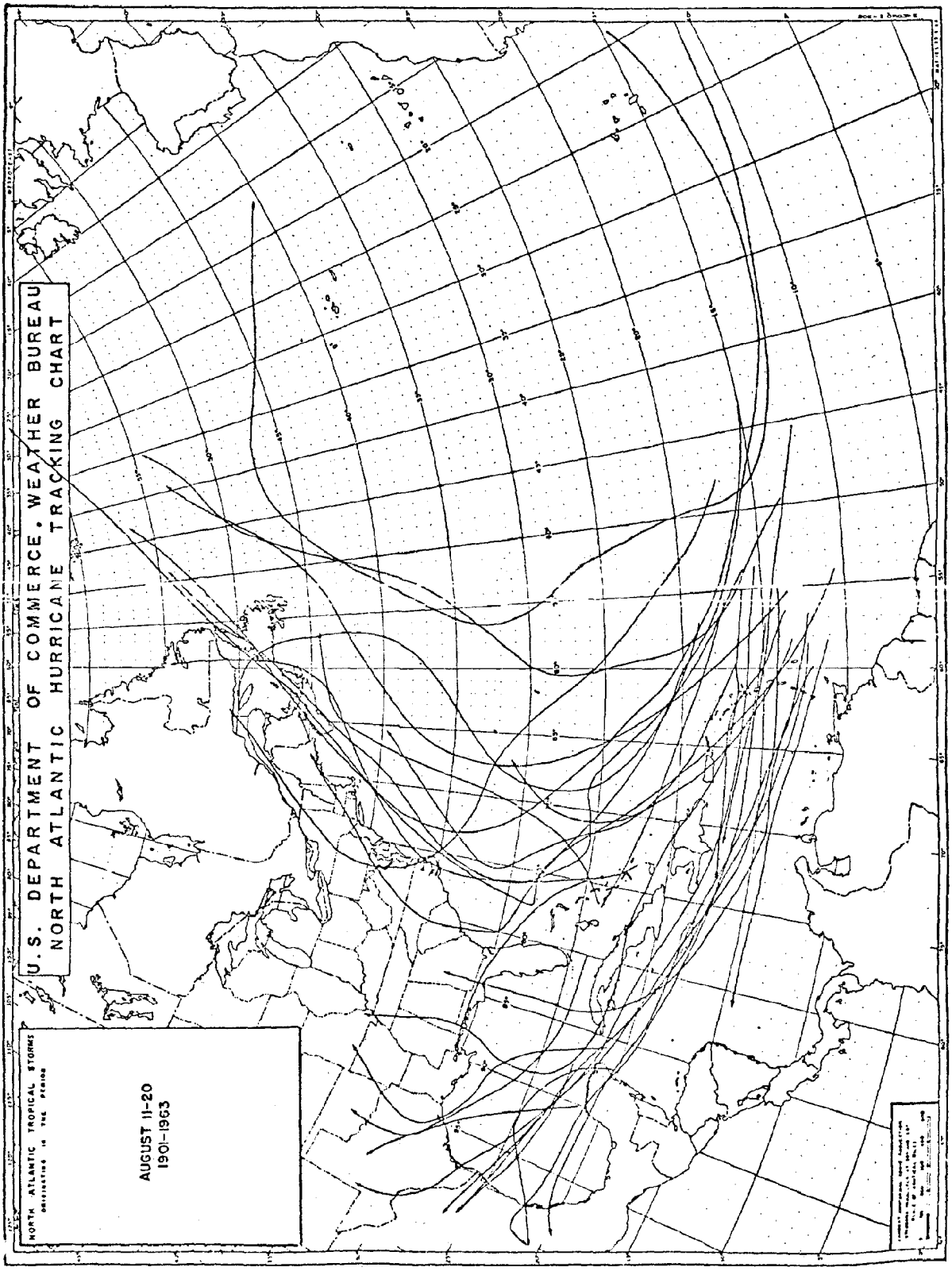
TRIGOM PARC	FIGURE 4-254	Tropical Storms - August 1-10 from 1901 to 1963 (Cry, 1965)



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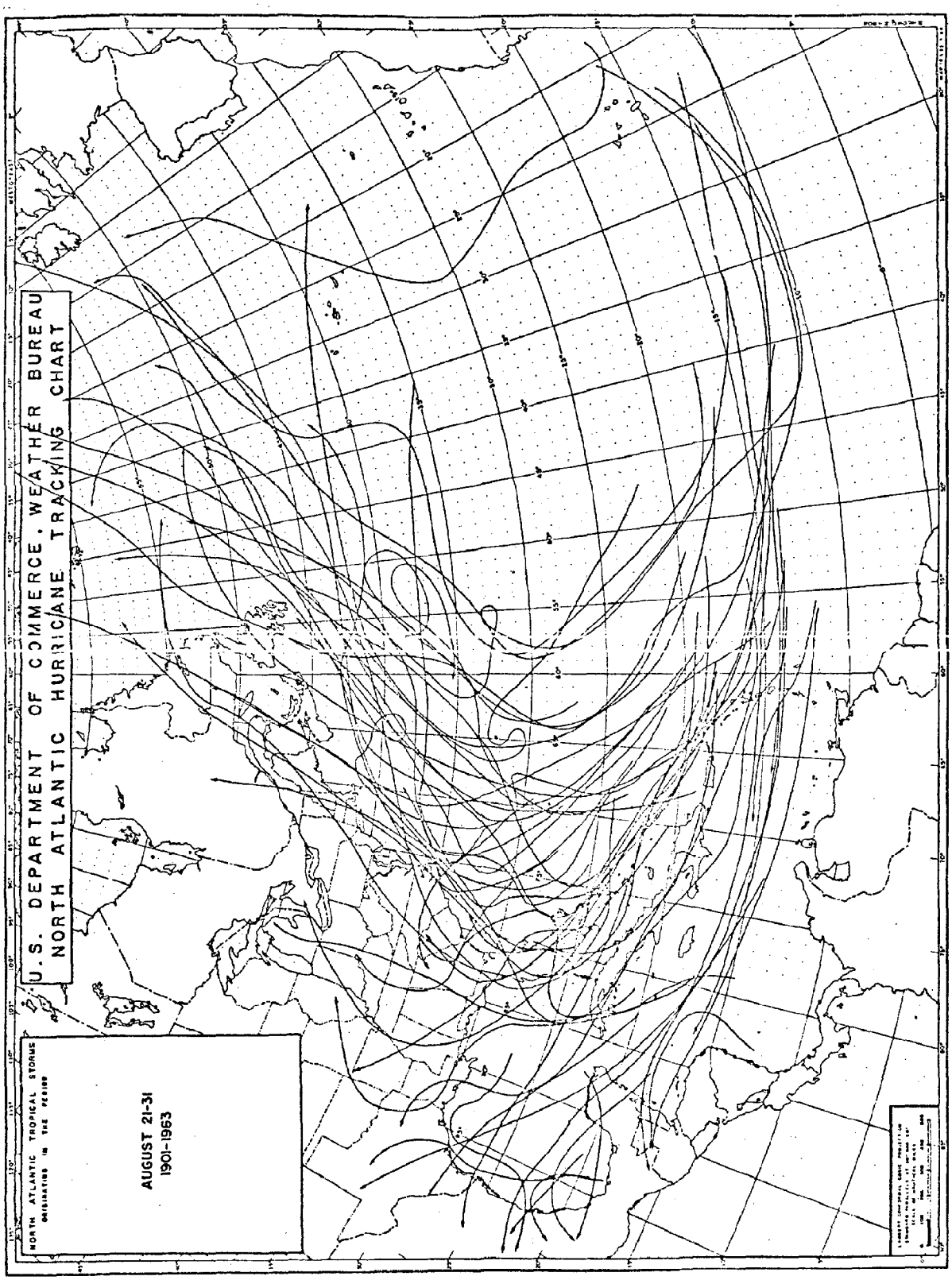
TRIGOM PARC	FIGURE 4-255	Tropical Storms - August 11-20 from 1901 to 1963 (Cry, 1965)



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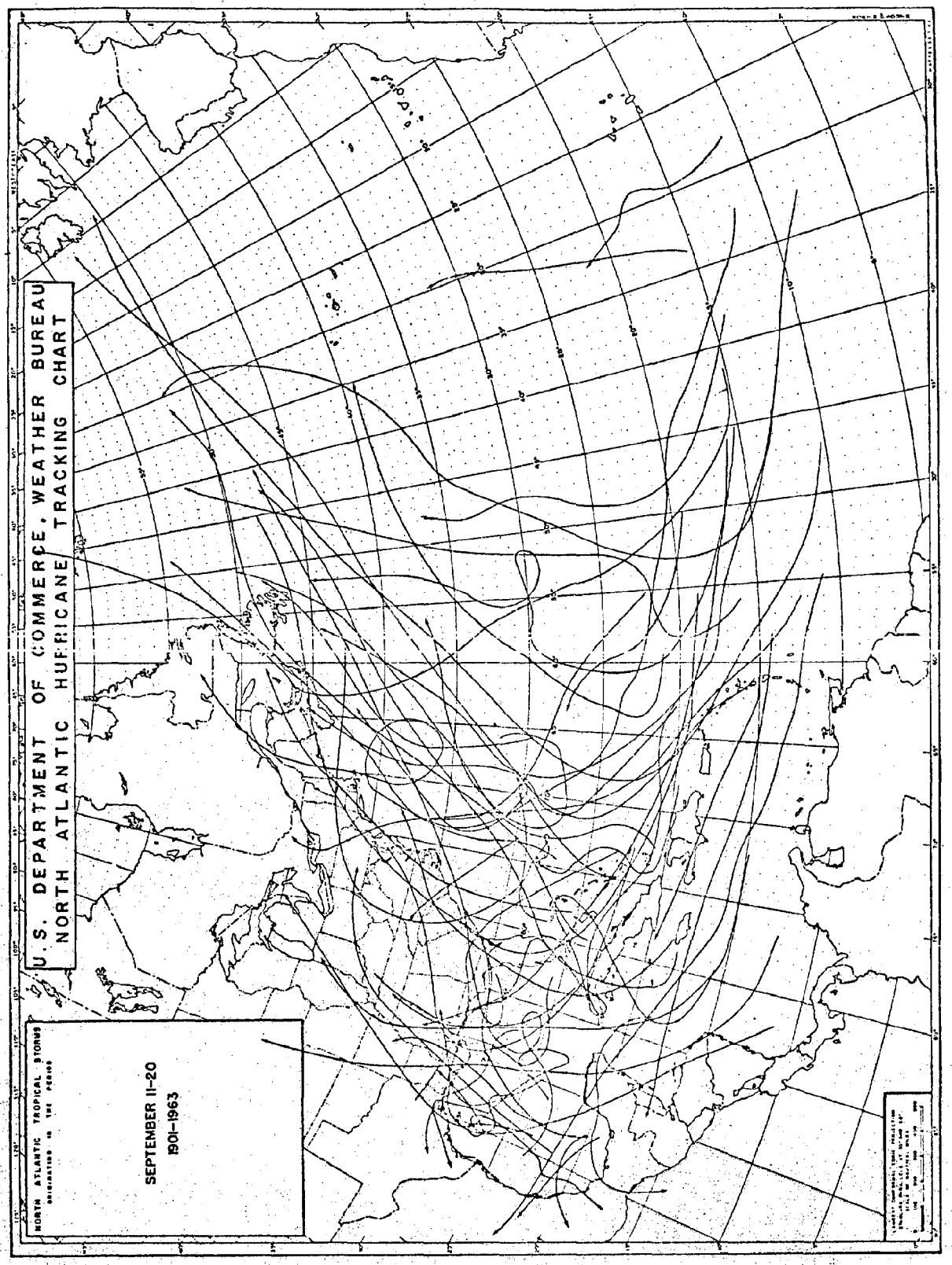
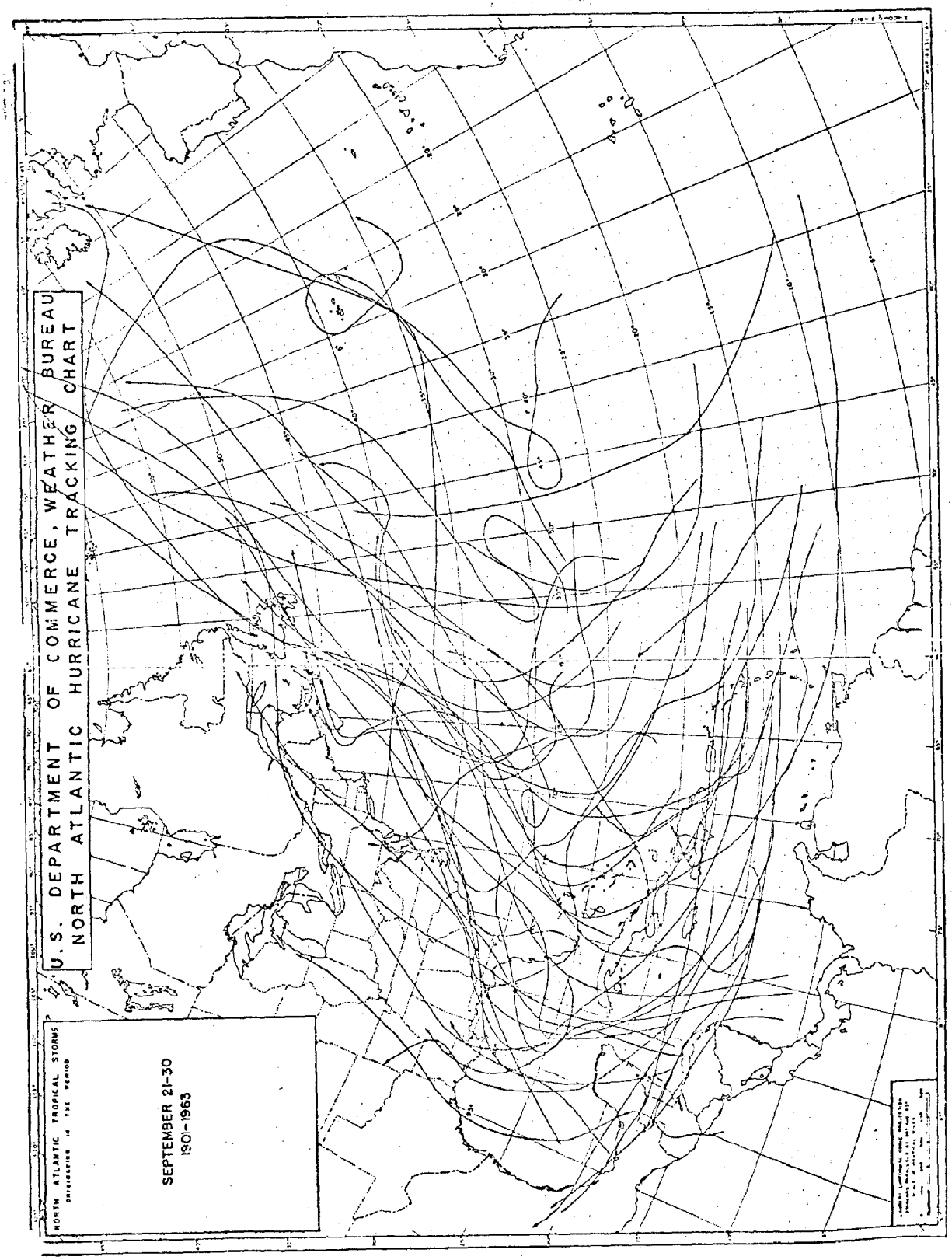
TRIGOM PARC	FIGURE 4-256	Tropical Storms - August 21-31 from 1901 to 1963 (Cry, 1965)



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

TRIGOM PARC	FIGURE 4-257	Tropical Storms - September 11-20 from 1901 to 1963 (Cry, 1965)



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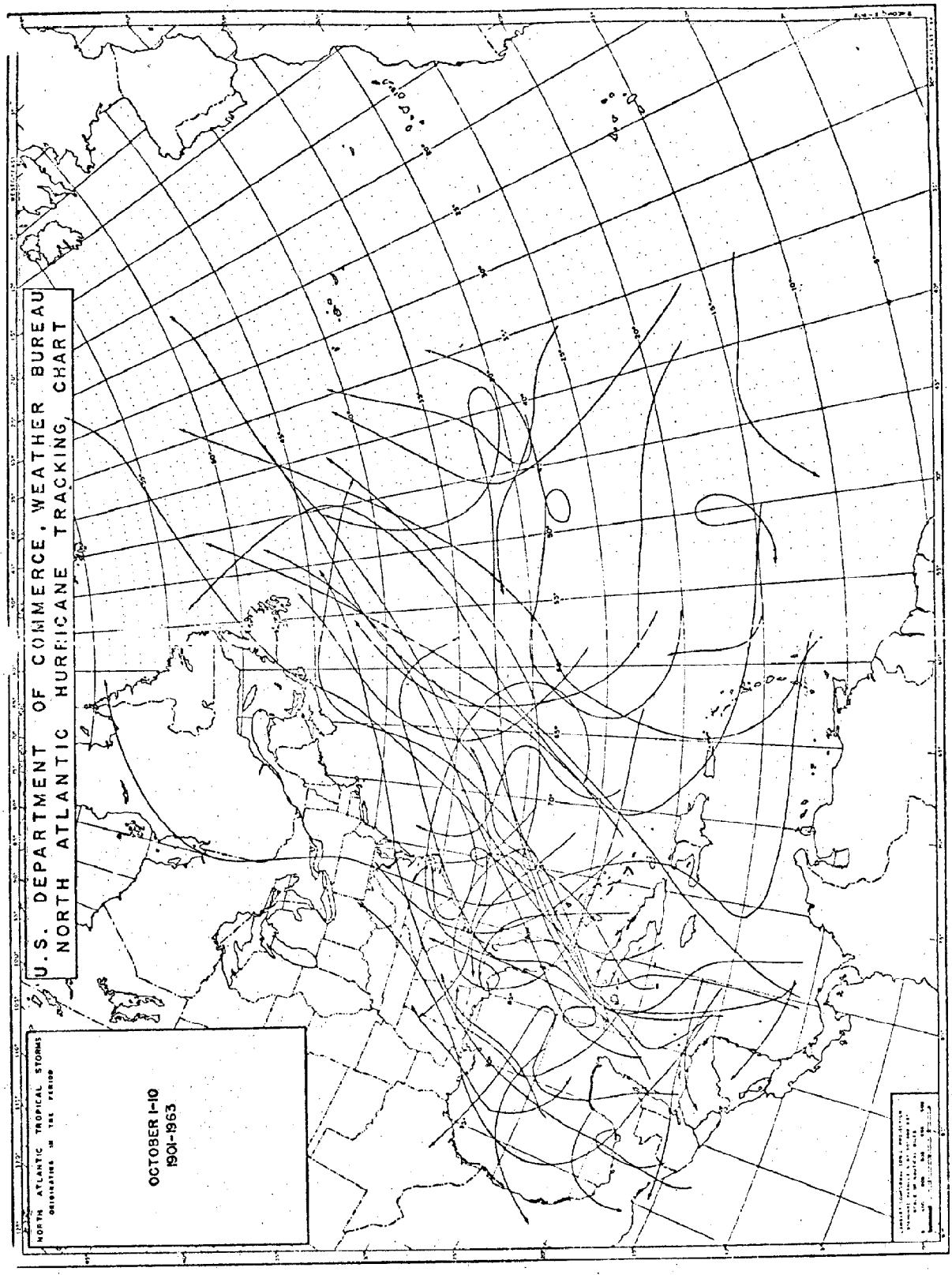
TRIGOM PARC	FIGURE 4-258	Tropical Storms - September 21-30 from 1901 to 1963 (Cry, 1965)



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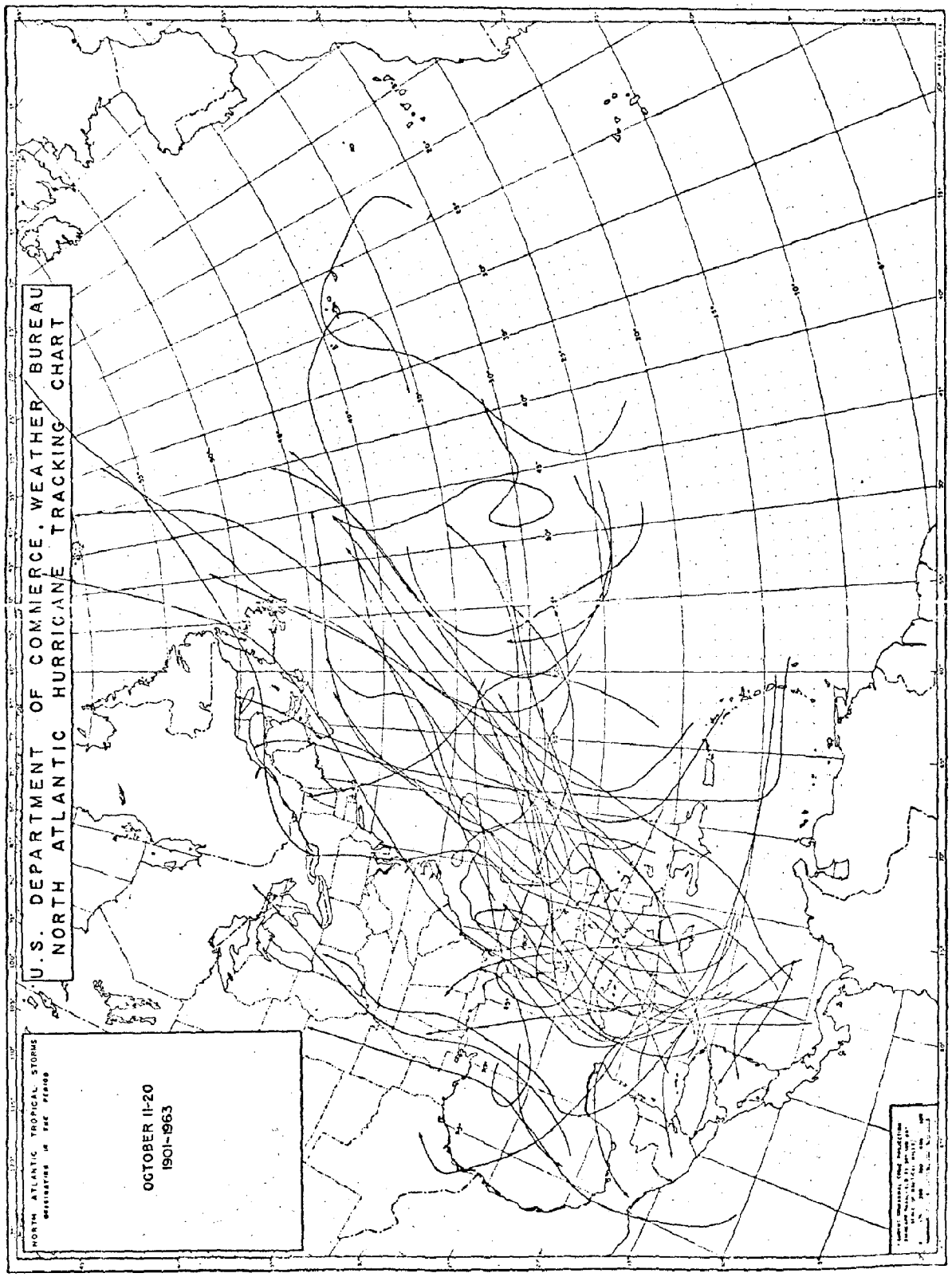
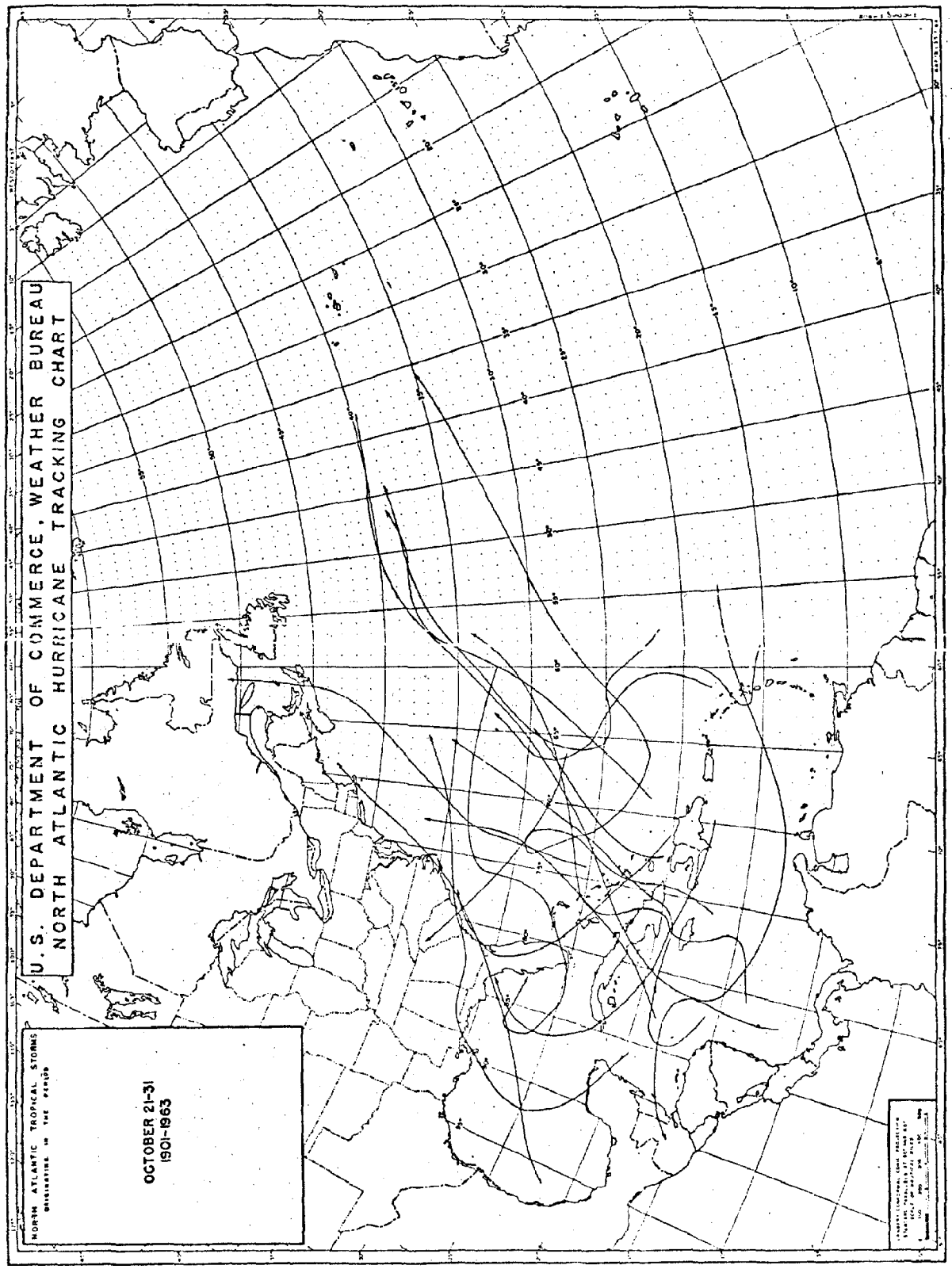
TRIGOM PARC	FIGURE 4-259	Tropical Storms - October 1-10 from 1901 to 1963 (Cry, 1965)



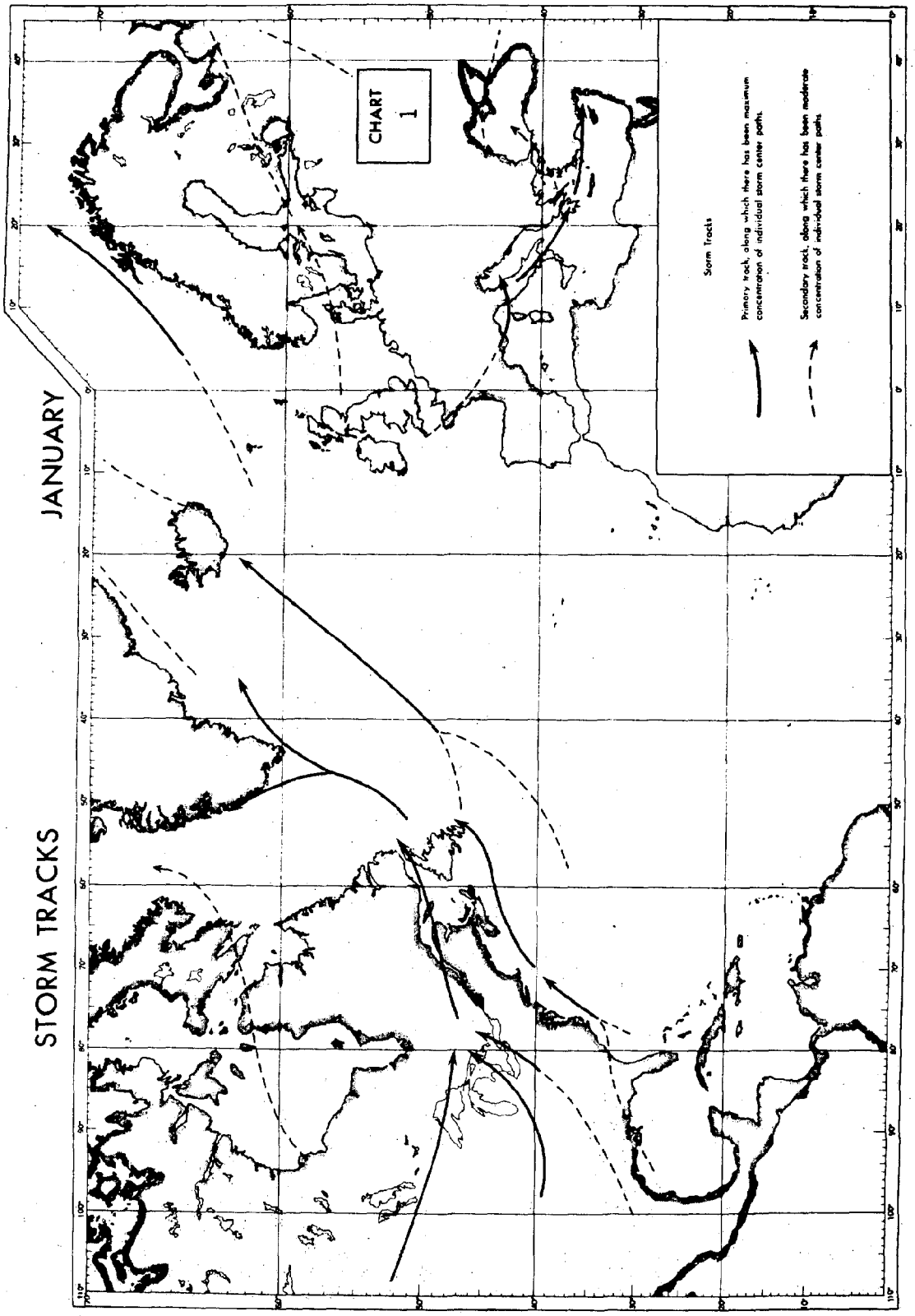
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-260	Tropical Storms - October 11-20 from 1901 to 1963 (Cry, 1965)



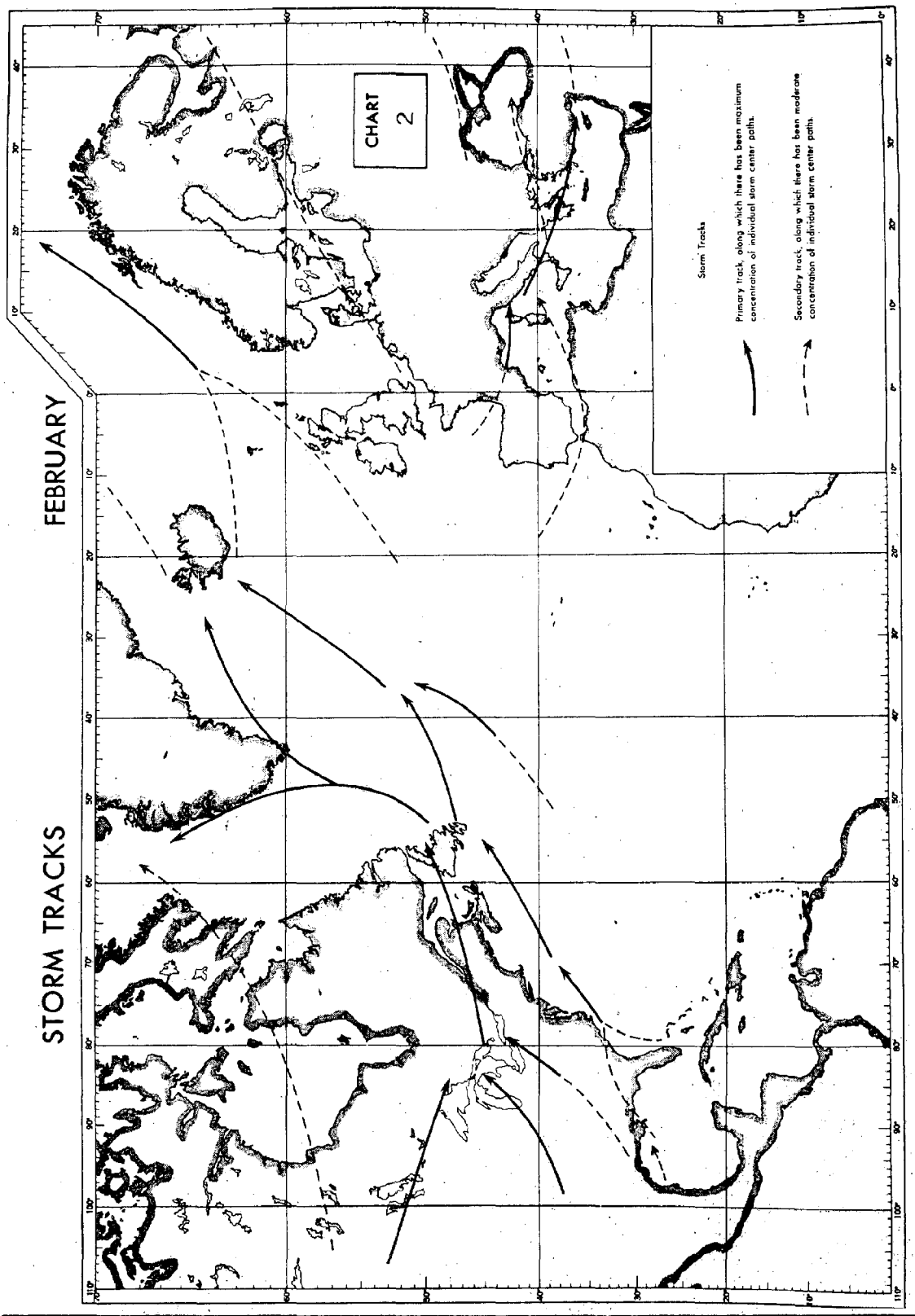
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-261	Tropical Storms - October 21-31 from 1901 to 1963 (Cry, 1965)



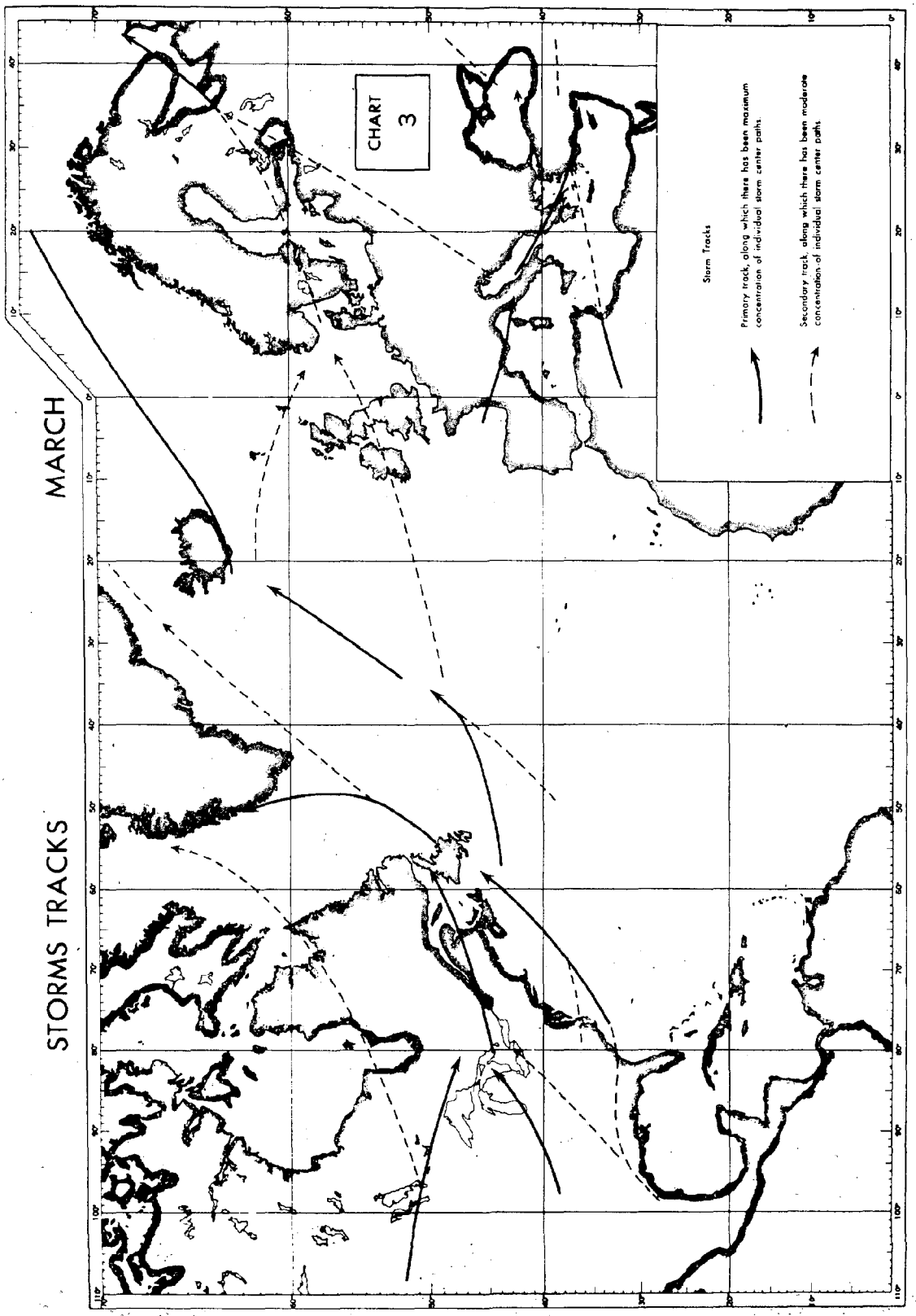
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-262	Storm Tracks - January (Brower et al., 1972)



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

TRIGOM PARC	FIGURE 4-263	Storm Tracks - February (Brower, et al., 1972)

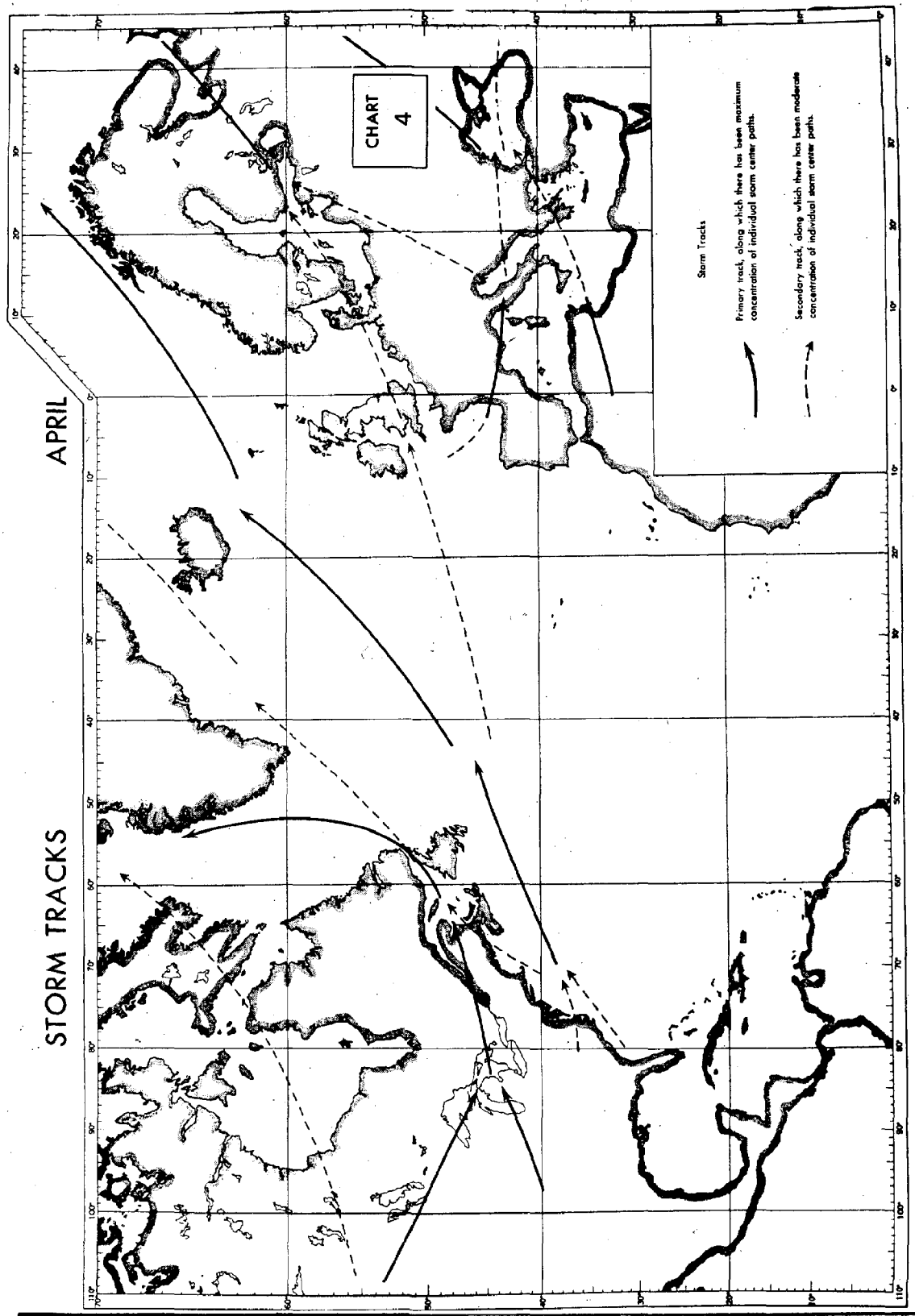


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

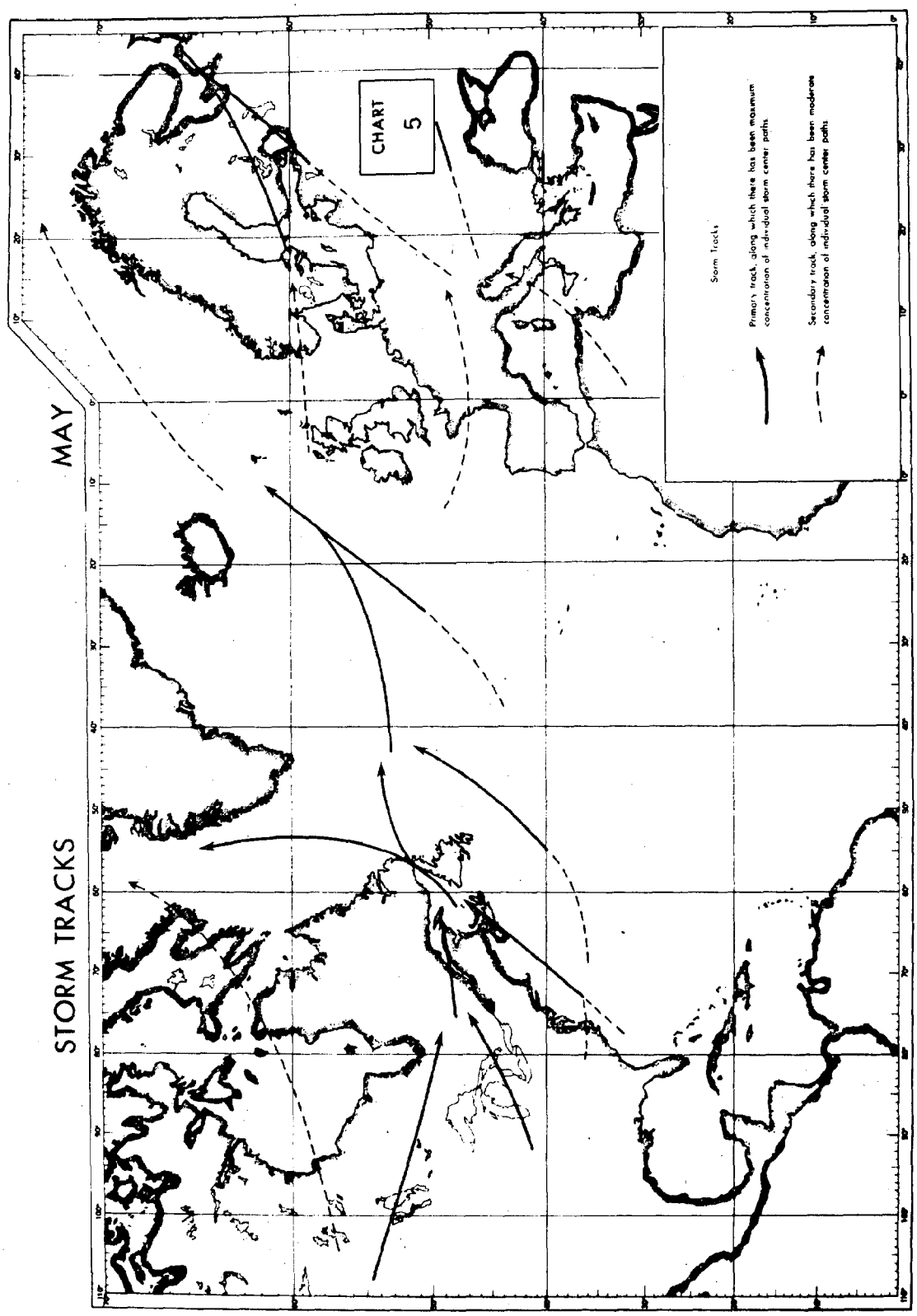
FIGURE 4-264

Storm Tracks - March
(Brower et al., 1972)



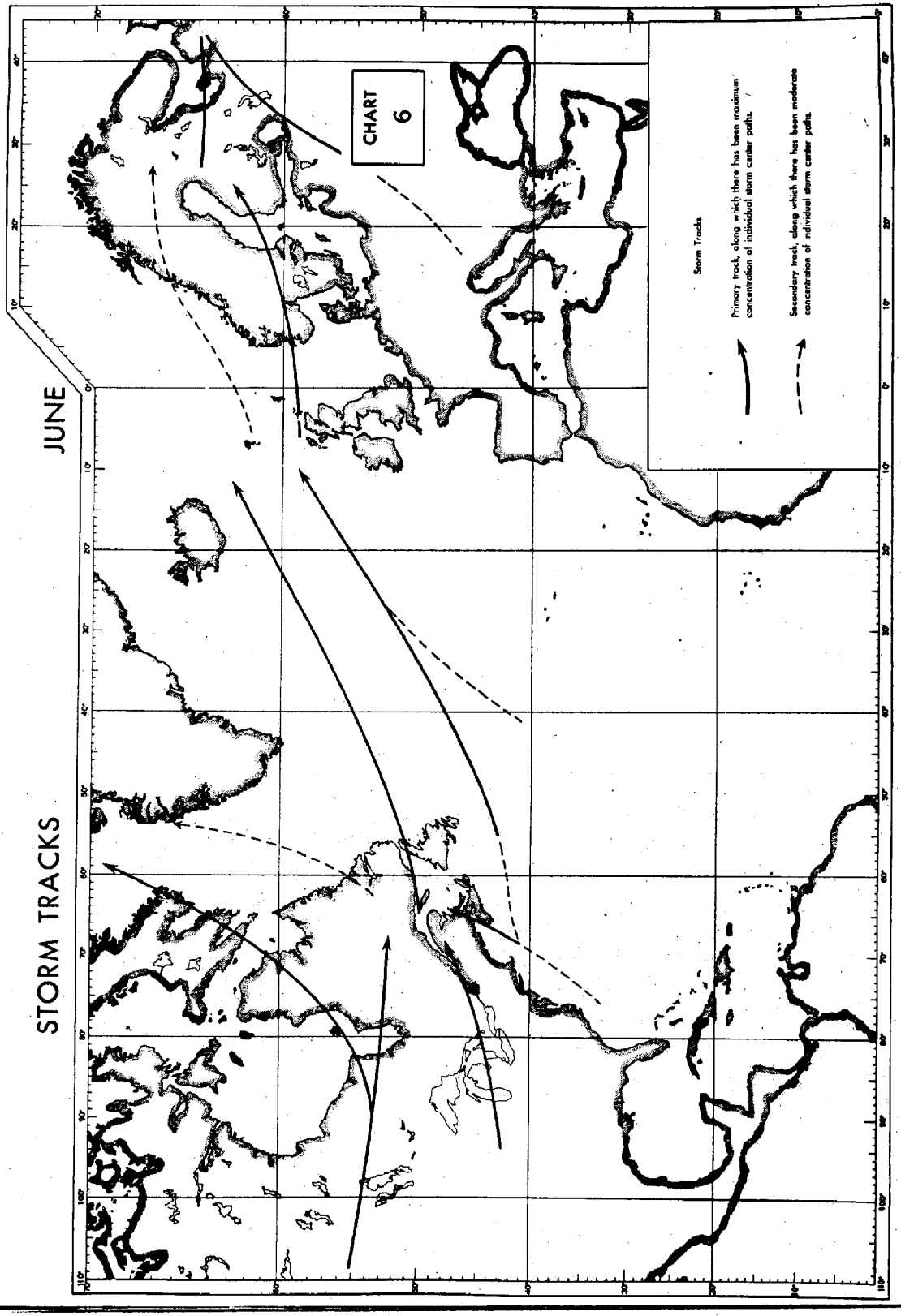
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-265	Storm Tracks - April (Brower et al., 1972)



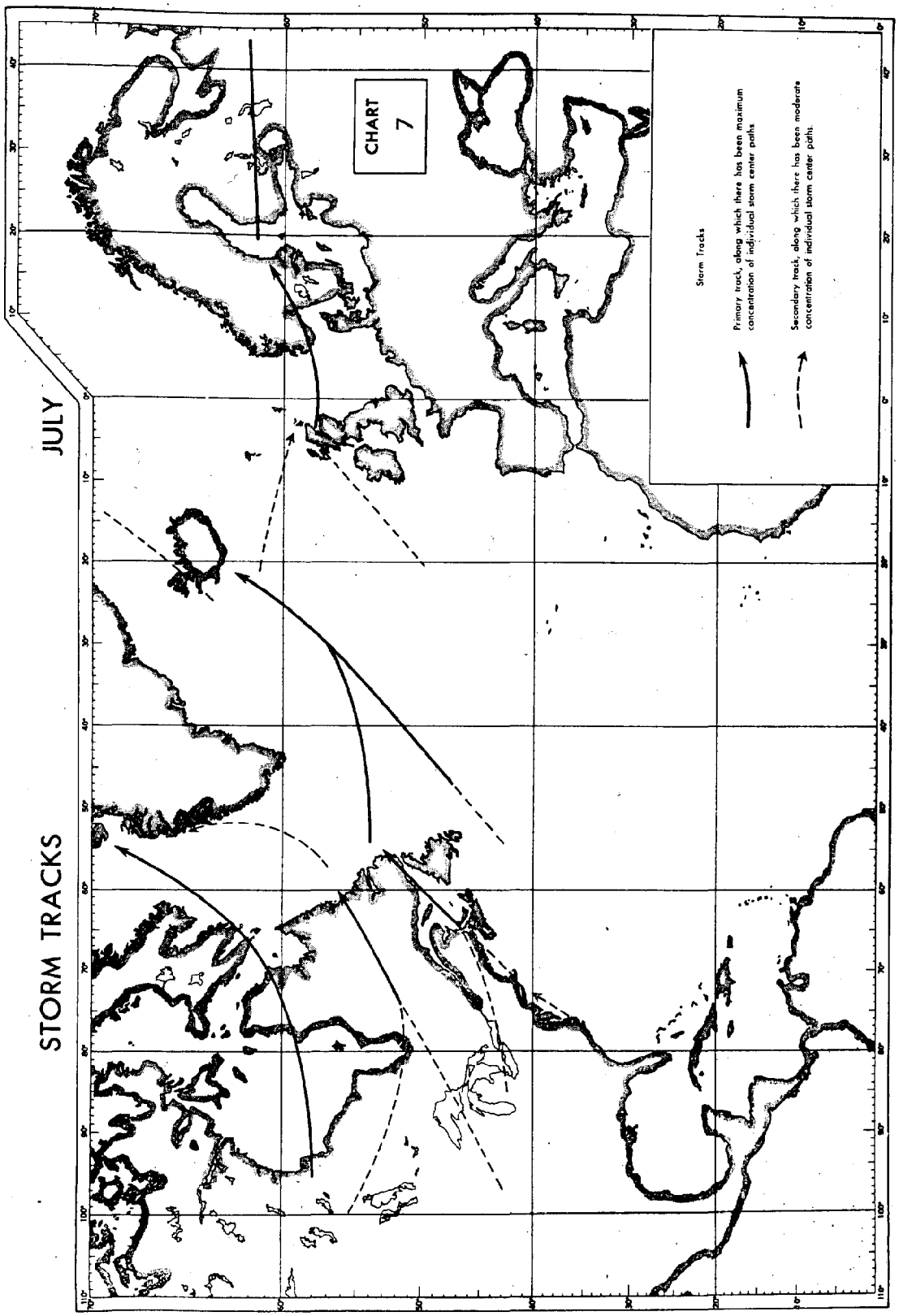
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-266	Storm Tracks - May (Brower et al., 1972)



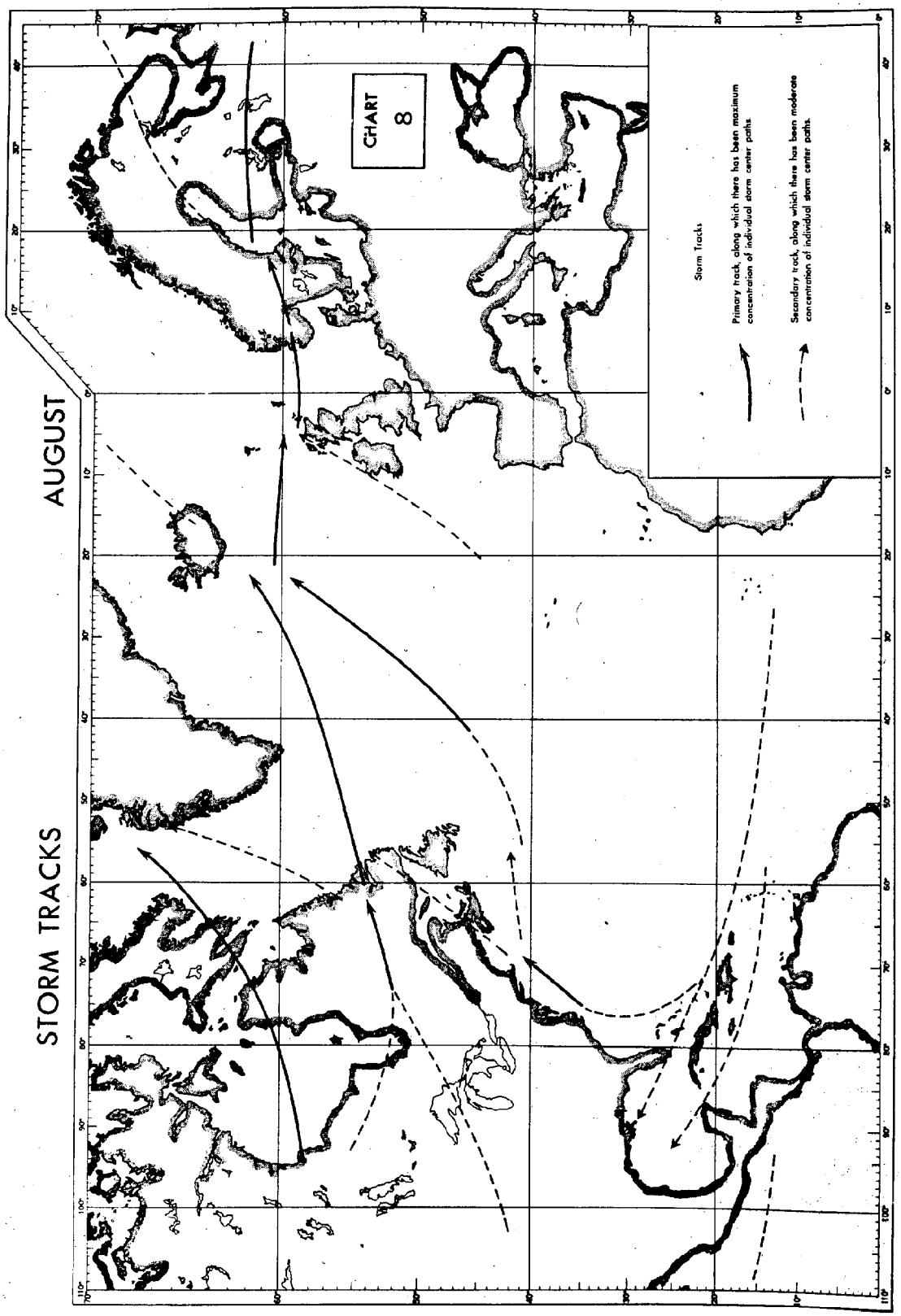
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-267	Storm Tracks - June (Brower et al., 1972)



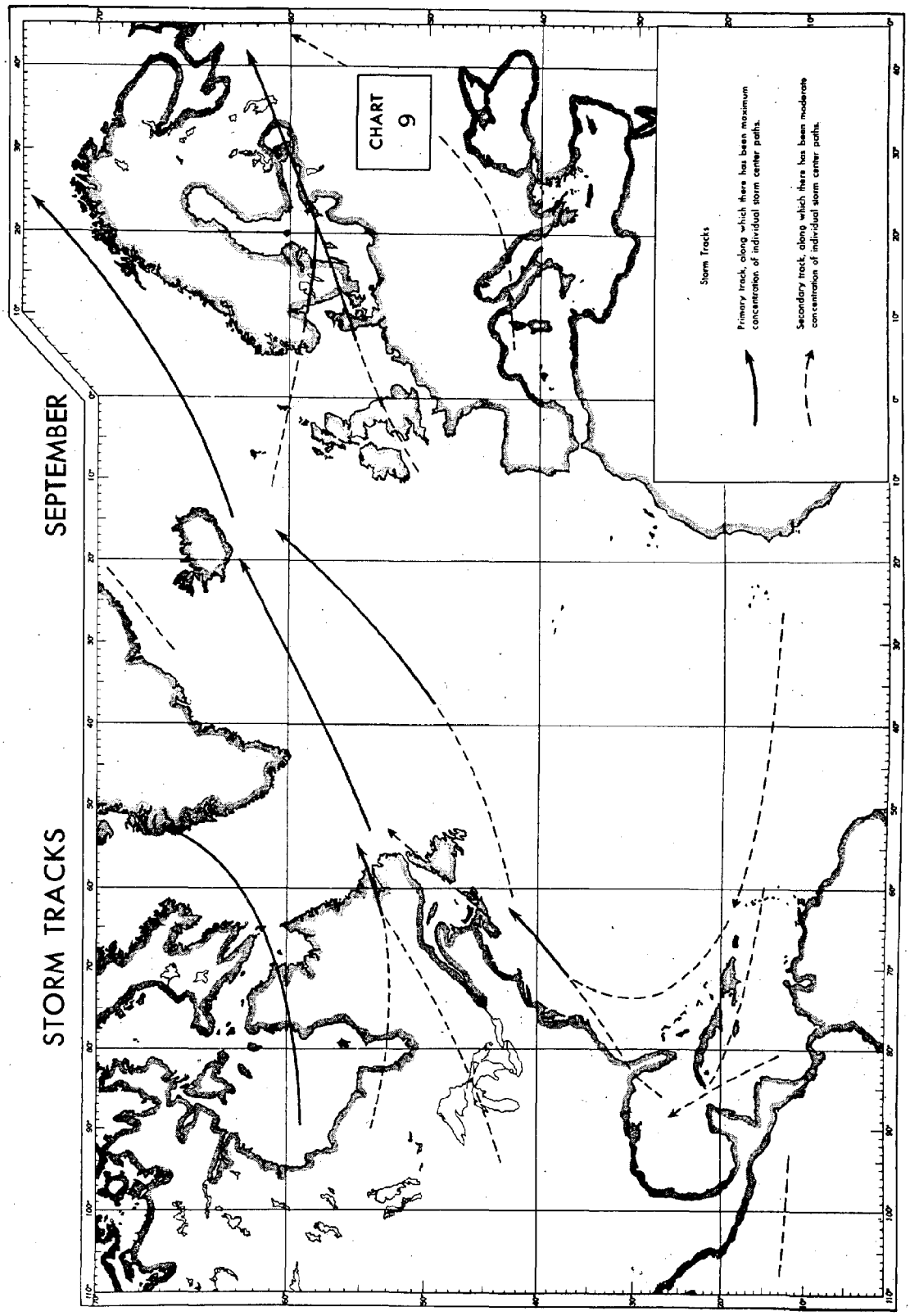
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-268	Storm Tracks - July (Brower et al., 1972)



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

TRIGOM PARC	FIGURE 4-269	Storm Tracks - August (Brower et al., 1972)	4-483

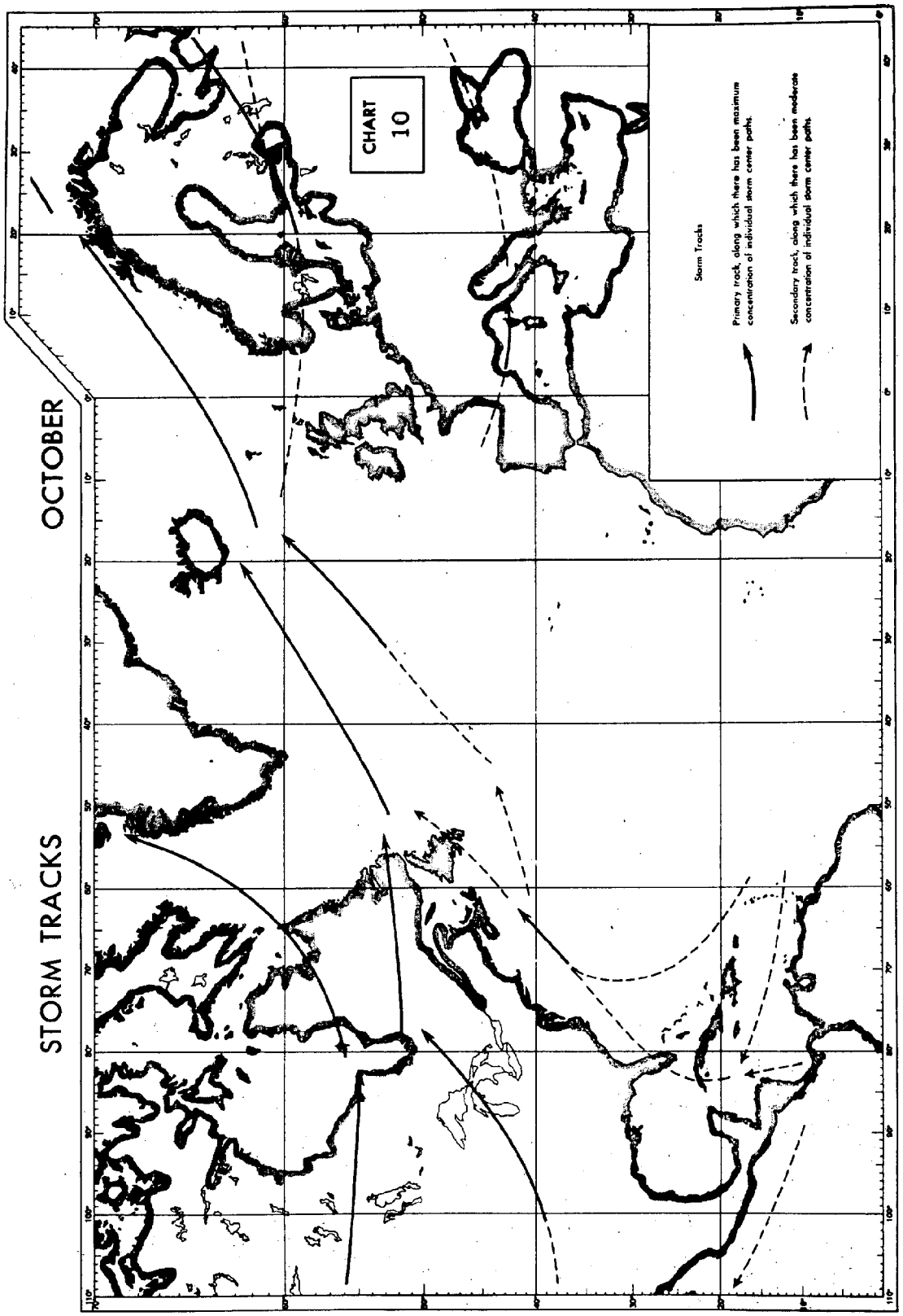


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

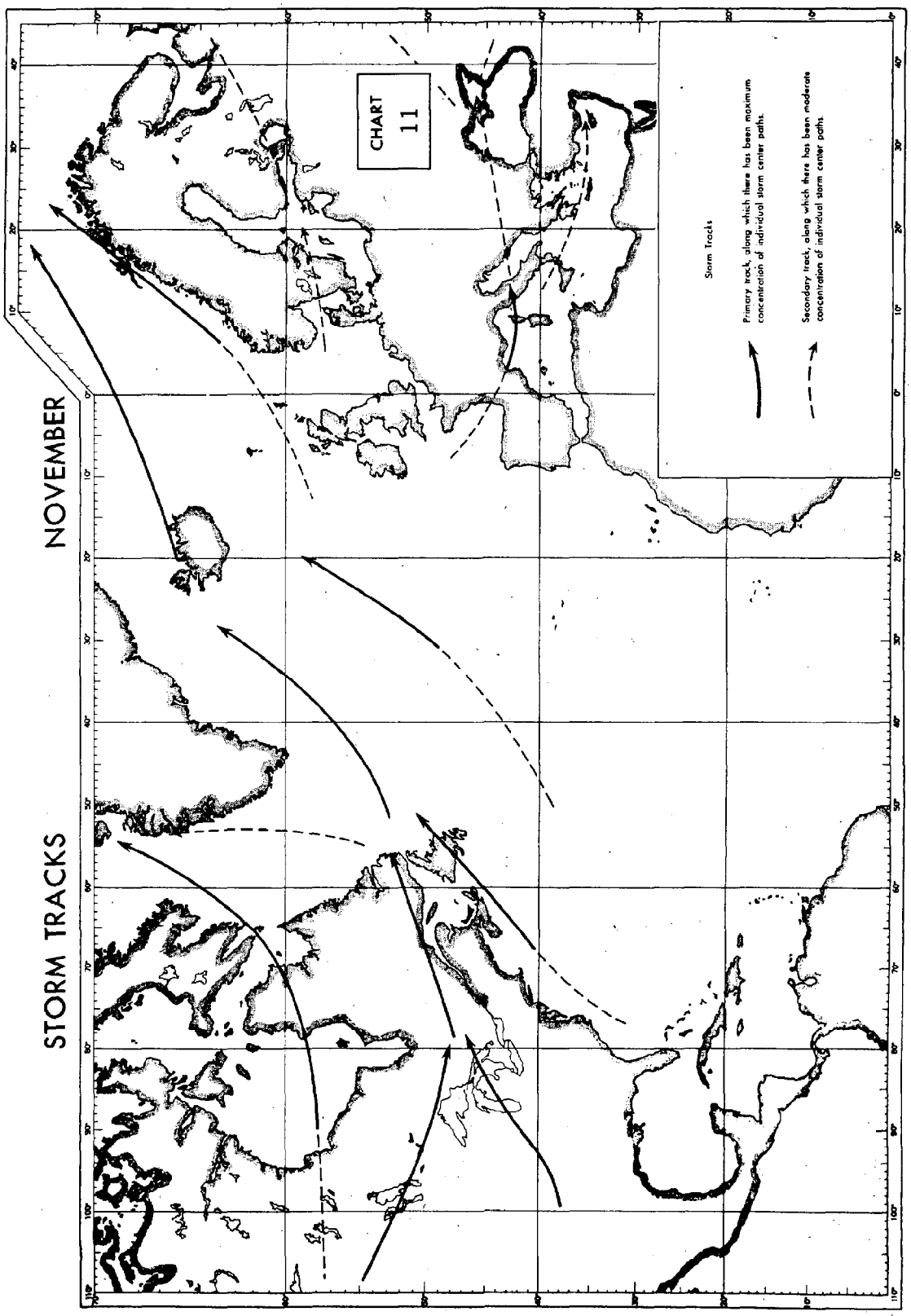
FIGURE 4-270

Storm Tracks - September
(Brower et al., 1972)



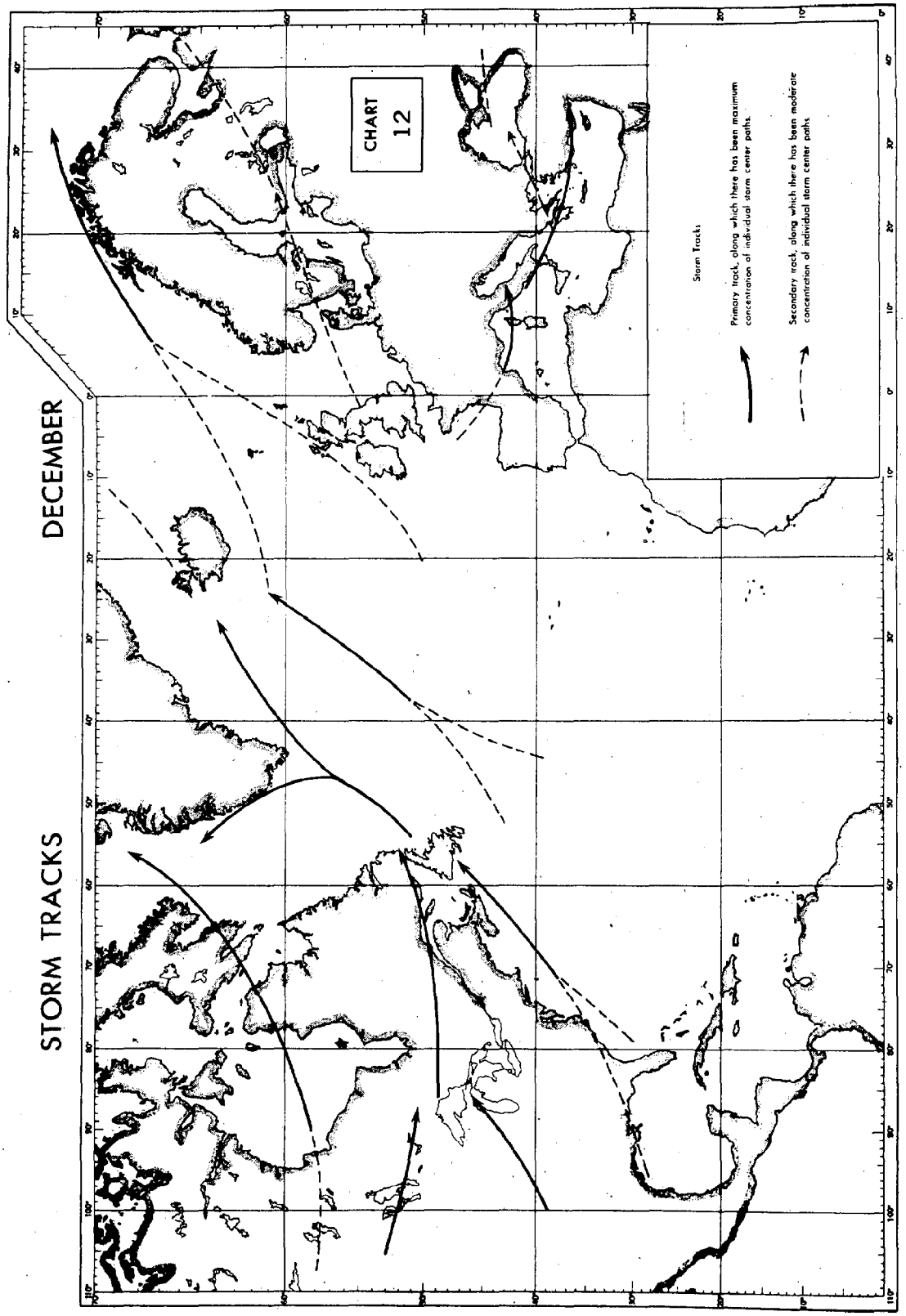
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-271	Storm Tracks - October (Brower et al., 1972)	4-485



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

TRIGOM PARC	FIGURE 4-272	Storm Tracks - November (Brower et al., 1972)



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

TRIGOM PARC	FIGURE 4-273	Storm Tracks - December (Brower et al., 1972)

and for Raritan Bay and Sandy Hook, N. J.

(A) Machiasport, Maine area. Table 4-64 , from Brower, et al. (1972), compares the two most violent storm types occurring in Northern New England -- "northeasters" and hurricanes. Machiasport (Figure 4-274 lies along the primary path of extra-tropical cyclones, which generally approach from the west or southwest. Storms approaching from the southwest (northeasters) are generally more severe, partially due to abundant moisture supply. Heavy rain or snow and strong winds often precede the storm center. Northeasters are particularly well-developed between September and April and usually occur within 100 miles of the coast between 30°-40°N. They typically move north northeastward and intensify near New England and the Maritime Provinces.

Tropical cyclone strike probabilities for the Machiasport coastal zone are shown in Figure 4-275 (Brower, et al., 1972). Note the rather low strike probabilities. Tropical cyclone centers generally move through the region in a northeasterly direction and are usually more violent than extra-tropical storms occurring during the same season. However, the storms have generally weakened during their travel from low latitudes. For the Machiasport region itself, as distinguished from the coastal zone, Table 4-65 shows tropical cyclone occurrences.

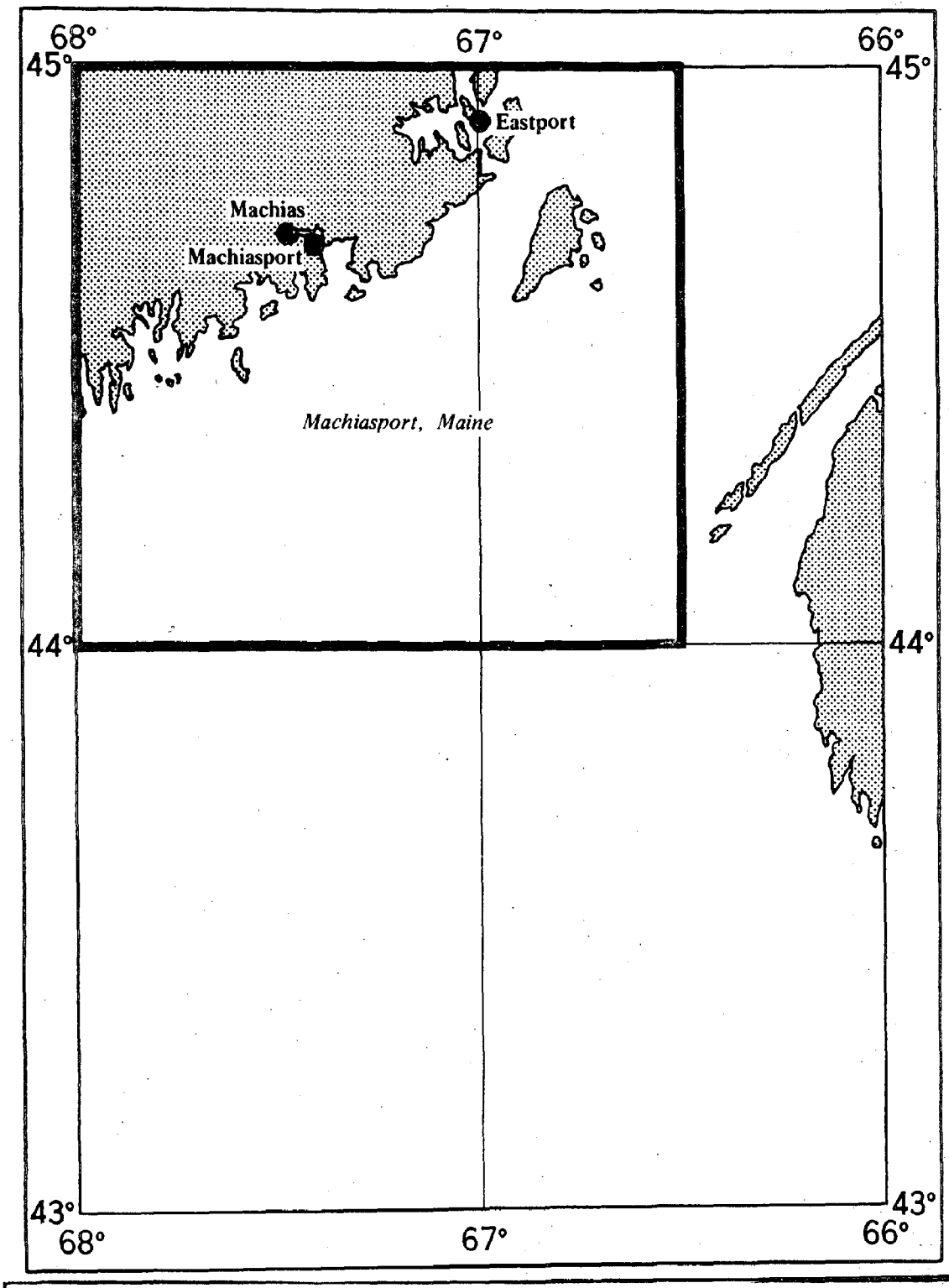
	Total number 1886-1971	Average number of years between occurrences
Tropical cyclones	9	10
Hurricanes	4	21

(B) New York City area. The mean tracks of extra-tropical winter cyclones traverse the New York area (Figure 4-276). They usually enter the area from the west or southwest with the storm track itself offshore. These storms can cause considerable damage due to coastal flooding. Rapid weather changes are associated with these winter cyclones.

Probabilities of occurrence of tropical cyclones, hurricanes, and intense hurricanes (sustained winds greater than 200 km/hr) are summarized in Figure 4-277. Zone 2 (south shore of Long Island) has a higher probability of tropical cyclones and hurricanes than zone 1 (Raritan Bay). For the New York City area itself, the following table summarizes frequencies of tropical storms:

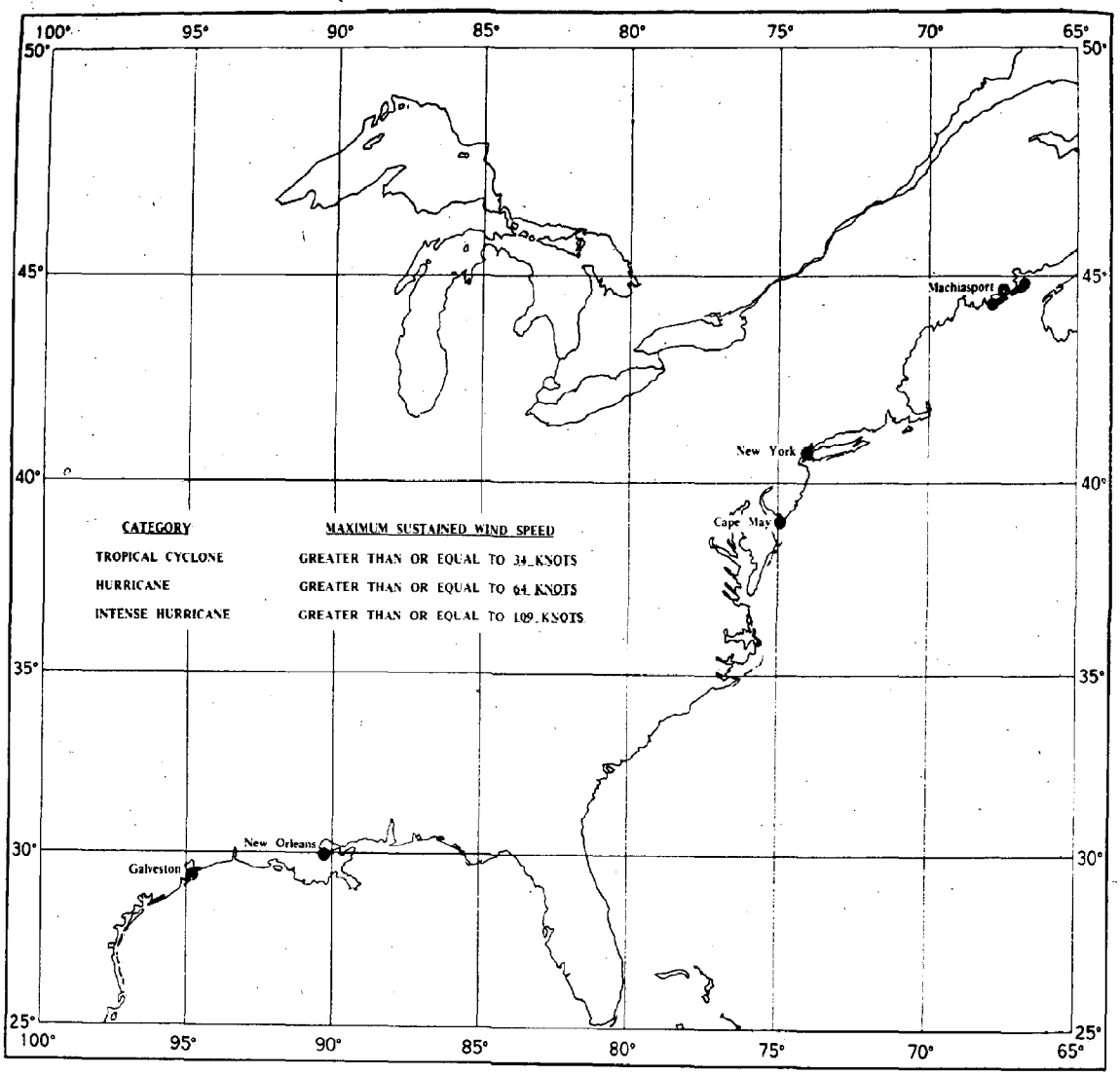
Table 4-64 Comparison of hurricanes and northeasters in northern New England.

Characteristics	Hurricanes	Northeasters
Climatology		
Origin	Tropics, always over water	Mostly Gulf of Mexico or South Atlantic regions, usually near coast
Season	August-October	October-April
Development	Reach greatest intensity south of New England and then diminish	Reach greatest intensity as they pass New England
Frequency	Average of 1 per 6 yr.	1-2 per yr. with surge $\geq$ 2.0 ft.
Track		
Direction	N to NE	N to E
Speed	Avg. 36 kt.; range 29-48	Avg. 22 kt.; range 6-43
Pressures		
Central pressure	Avg. 958 mb.; lowest 943 mb.	Avg. 983 mb.; lowest 957 mb.
Pressure pattern	Usually Symmetrical	Usually asymmetrical
Average storm diameter	Small (400-600 n. mi.)	Large (600-1500 n. mi.)
Winds		
Maximum speeds	80-100 kt. not uncommon	70 kt. is rare
Radius of maximum winds	22-66 n. mi., well-defined	90-340 n. mi., not well-defined, sometimes more than one
Fetch lengths	Short	Long, 300-1400 n. mi.
Surge		
Surge heights	3.7 ft. highest observed	Up to 5.1 ft. observed
Duration of high surge and strong wind	6-12 hr.	12 hr. to 3 days
Inverted barometer effect	May give important contribution to surge	Relatively unimportant contribution to surge
Topographical considerations	Cape Cod protects northern New England to some extent	Little protection afforded by Cape Cod



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

TRIGOM PARC	FIGURE 4-274	Machiasport, Maine, Area Map (Brower et al., 1972)



AREA Machiasport

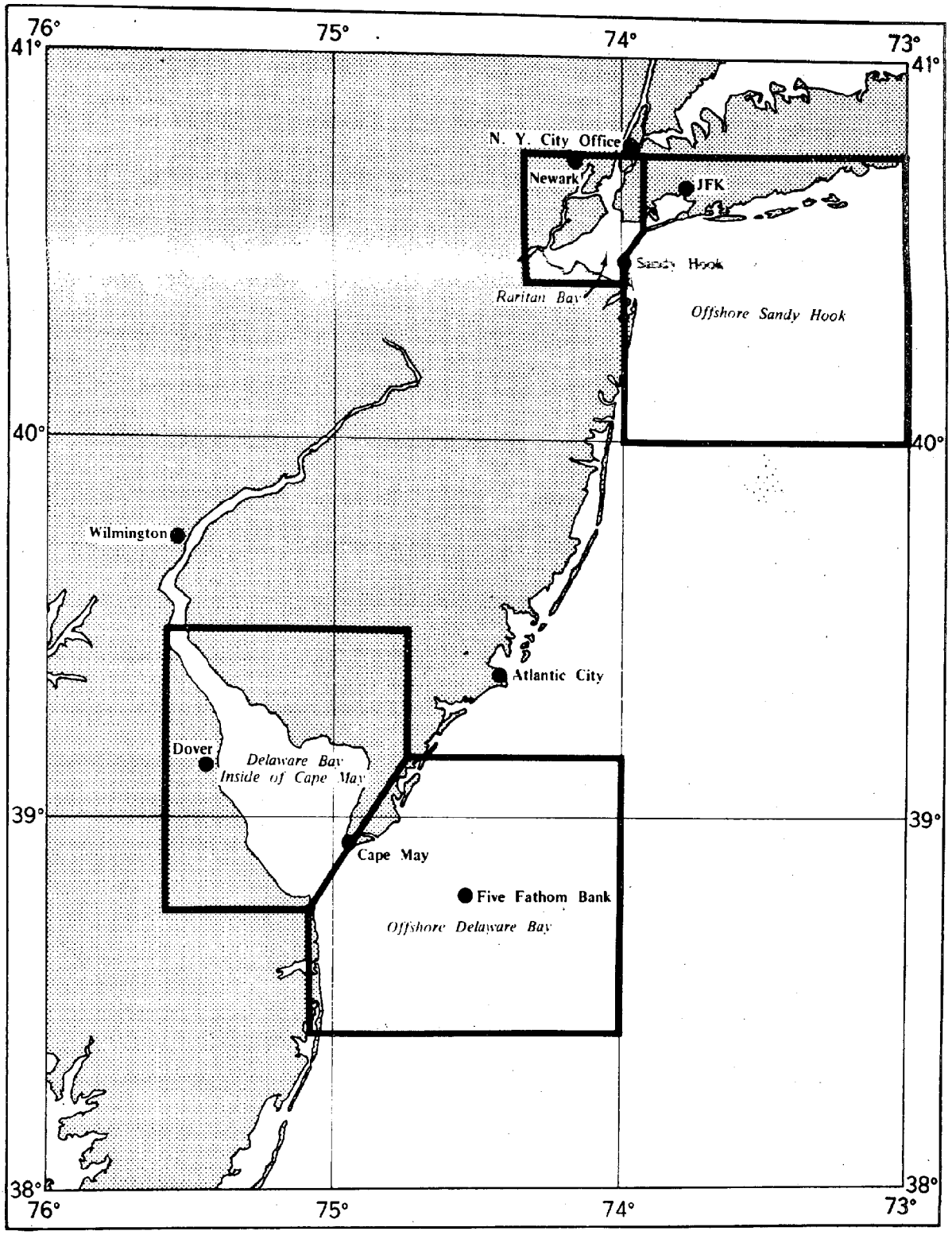
	PROBABILITY (%) OF OCCURRENCE IN ANY ONE YEAR	AVERAGE NUMBER OF YEARS BETWEEN OCCURRENCES	TOTAL NUMBER OF OCCURRENCES 1886-1970
TROPICAL CYCLONE	13%	7	11
HURRICANE	5%	21	4
INTENSE HURRICANE	<1%	–	–

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

TRIGOM PARC

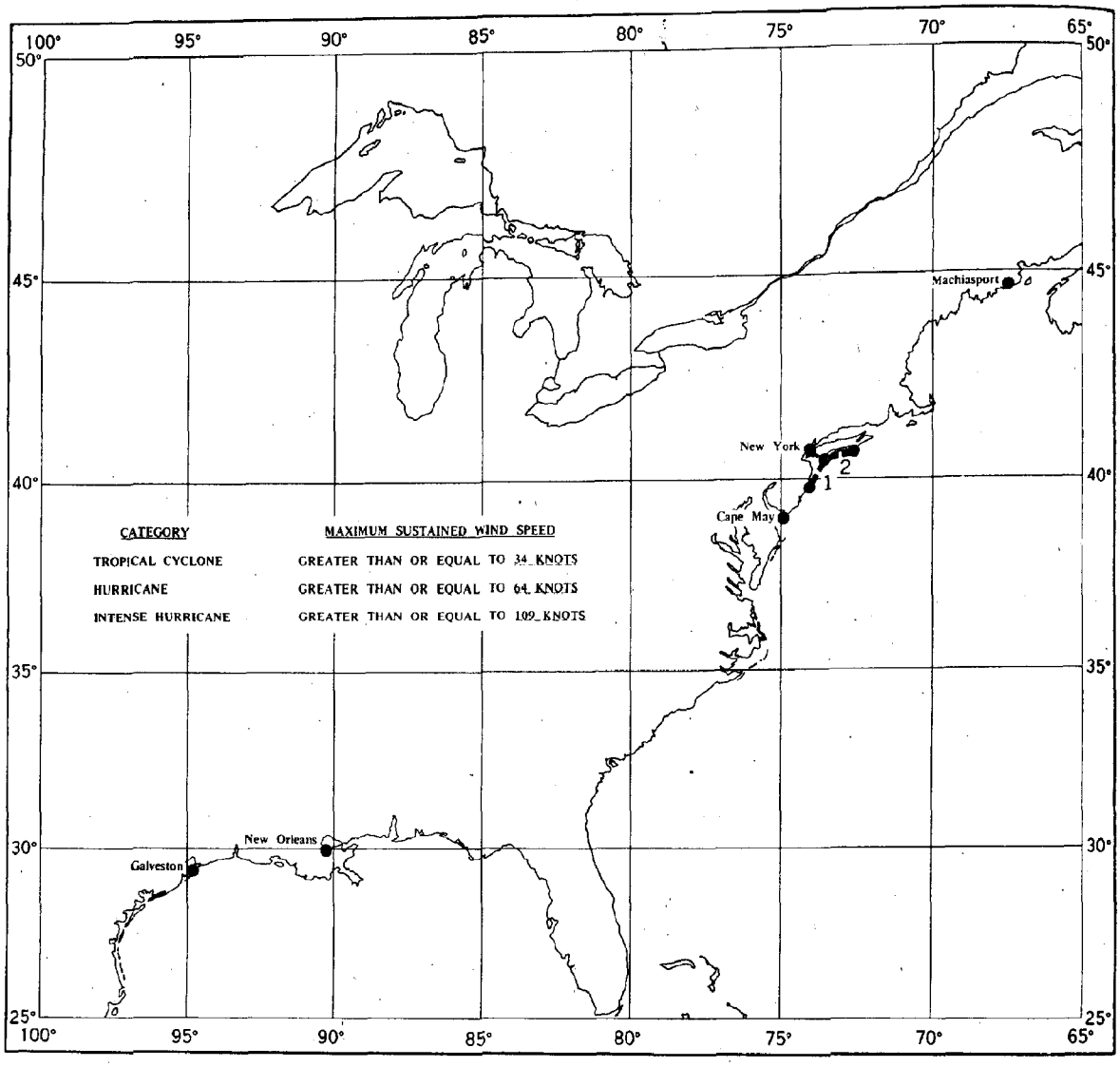
FIGURE 4-275

Tropical Cyclone Strike Zone and Probabilities for Machiasport Area (Brower et al., 1972)



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

TRIGOM PARC	FIGURE 4-276	New York and Delaware Bay Area Map (Brower et al., 1972)



AREA New York Zone 1

	PROBABILITY (%) OF OCCURRENCE IN ANY ONE YEAR	AVERAGE NUMBER OF YEARS BETWEEN OCCURRENCES	TOTAL NUMBER OF OCCURRENCES 1886-1970
TROPICAL CYCLONE	1%	85	1
HURRICANE	1%	85	1
INTENSE HURRICANE	<1%	–	–

AREA New York Zone 2

	PROBABILITY (%) OF OCCURRENCE IN ANY ONE YEAR	AVERAGE NUMBER OF YEARS BETWEEN OCCURRENCES	TOTAL NUMBER OF OCCURRENCES 1886-1970
TROPICAL CYCLONE	11%	9	9
HURRICANE	6%	17	5
INTENSE HURRICANE	<1%	–	–

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

TRIGOM PARC

FIGURE 4-277

Tropical Cyclone Strike Zone and Probabilities for New York Area (Brower et al., 1972)

	Total number 1886-1971	Average number of years between occurrences
Tropical cyclones	11	8
Hurricanes	4	21

Tropical cyclones generally occur in the New York area in late summer or autumn. They usually travel northeast towards Nova Scotia or out over the adjacent ocean.

(C) Offshore areas. Brower, et al. (1972) include a study of occurrences of tropical cyclones that penetrated offshore areas near Machiasport (Figure 4-275) and Raritan Bay and offshore Sandy Hook (Figure 4-277). If a tropical cyclone penetrated any of these areas in any respect, it was tabulated. Maximum tropical cyclone activity occurred from June through September with September registering as the peak month. The chronological listings of Brower, et al. (1972), reproduced here as Tables 4-65 and 4-66, for each area were taken from a number of references, coded in the table and listed as follows:

D = Dunn and Miller, Atlantic Hurricanes
L = Ludlum, Early American Hurricanes 1492-1870
N = USAF, USMC, USN Annual Hurricane or Reports, 1950-1970
R = Cry, Technical Paper No. 55, Tropical Cyclones of the North Atlantic 1871-1963
T = Tannehill, Hurricanes, Chapter XV
W = Mariners Weather Log, Vol. 16, No. 1, January 1972.

Storm intensity was classified according to the following:

TS = Tropical Storm (sustained winds 62 to 115 km/hr)
H = Hurricane (sustained winds 115/hr)

The Machiasport subsquare, Figure 4-275, was penetrated by storms listed in Table 4-65. Cyclones prior to 1871 were considered to have penetrated if their passage east of Cape Cod from the south or over Massachusetts Bay appeared to follow the general cyclone paths indicated by Cry (1965).

Table 4-66 presents similar data for Raritan Bay and off Sandy Hook. Brower, et al. (1972), included in this listing any cyclone prior to 1871 passing the middle to northern New Jersey coast and western Long Island.

Storm Damage

The climatology of storms damaging to the U. S. East Coast is

Table 4-65 Machiasport Tropical Cyclone Penetrations.

Year	Date	Intensity	Ref. Found
1635	Mid Aug.		D,L
1638	23-25 Sept.		D,L
1675	Late Aug.		L
1727	Sept.		L
1806	Late Aug.		L
1830	Mid Aug.		L
1839	30-31 Aug.		L
1850	9-10 Sept.		L
1858	Mid Sept.		L
1867	3 Aug.		L
1885	23 Sept.		R
Total:	11 Tropical Cyclones		
1888	22 Aug.	TS	R
1888	12 Sept.	TS	R
1888	22 Sept.	TS	R
1889	25 Sept.	H	R
1940	2 Sept.	TS	R
1953	7 Sept.	H	N,R
1954	11 Sept.	H Edna	N,R
1969	10 Sept.	H Gerda	N
1971	14 Sept.	TS Heida	W
Total:	9 Tropical Cyclones for the period 1886-1971 consisting of 5 Tropical Storms (TS) and 4 Hurricanes (H)		

Period 1635 to 1971: 20 recorded Tropical Cyclones

Period	Aug.	Sept.	Total
Before 1871	6	4	10 Tropical Cyclones
1871 - 1971	1	9	10 Tropical Cyclones
1886 - 1971	(1)(0)	(4)(4)	(5 Tropical Storms) (4 Hurricanes)

Table 4-6C Raritan Bay and Off Sandy Hook Subsquare Tropical Cyclone Penetrations.

Year	Date	Intensity	Ref. Found
1769	Early Sept.		L
1788	19-20 Aug.		D,L
1806	21-23 Aug.		L
1815	22-23 Sept.		D,L
1821	3 Sept.		D,L
1874	29 Sept.		R
1882	23 Sept.		R
Total:	7 Tropical Cyclones		
1888	11 Sept.	TS	R
1893	23-24 Aug.	H	D,R
1897	24 Sept.	TS	R
1904	14 Sept.	TS	D,R
1944	14 Sept.	H	D,R
1954	31 Aug.	H Carol	D,R
1955	18 Aug.	TS Diane	D,N,R
1960	30 July	TS Brenda	N,R
1960	12 Sept.	H Donna	N,R
1961	14 Sept.	TS	R
1971	27-28 Aug.	TS Doria	W
Total:	11 Tropical Cyclones for the period 1886-1971 consisting of 7 Tropical Storms (TS) and 4 Hurricanes (H)		

Period 1769 to 1971: 18 recorded Tropical Cyclones

Period	July	Aug.	Sept.	Total
Before 187-	0	2	3	5 Tropical Cyclones
1871 - 1971	1	4	8	13 Tropical Cyclones
1886 - 1971	(1)(0)	(2)(2)	(4)(2)	(7 Tropical Storms) (4 Hurricanes)

discussed by Burton, Kates, Mather, and Snead (1965). Using U.S. Weather Bureau publications as their primary source, the authors show a marked increase in the number of damaging storms during the period 1945-1965 (Figure 4-279). Coastal storms that occurred in the period 1921-1964 were divided into eight categories based upon origin, structure, and path of the storm as follows:

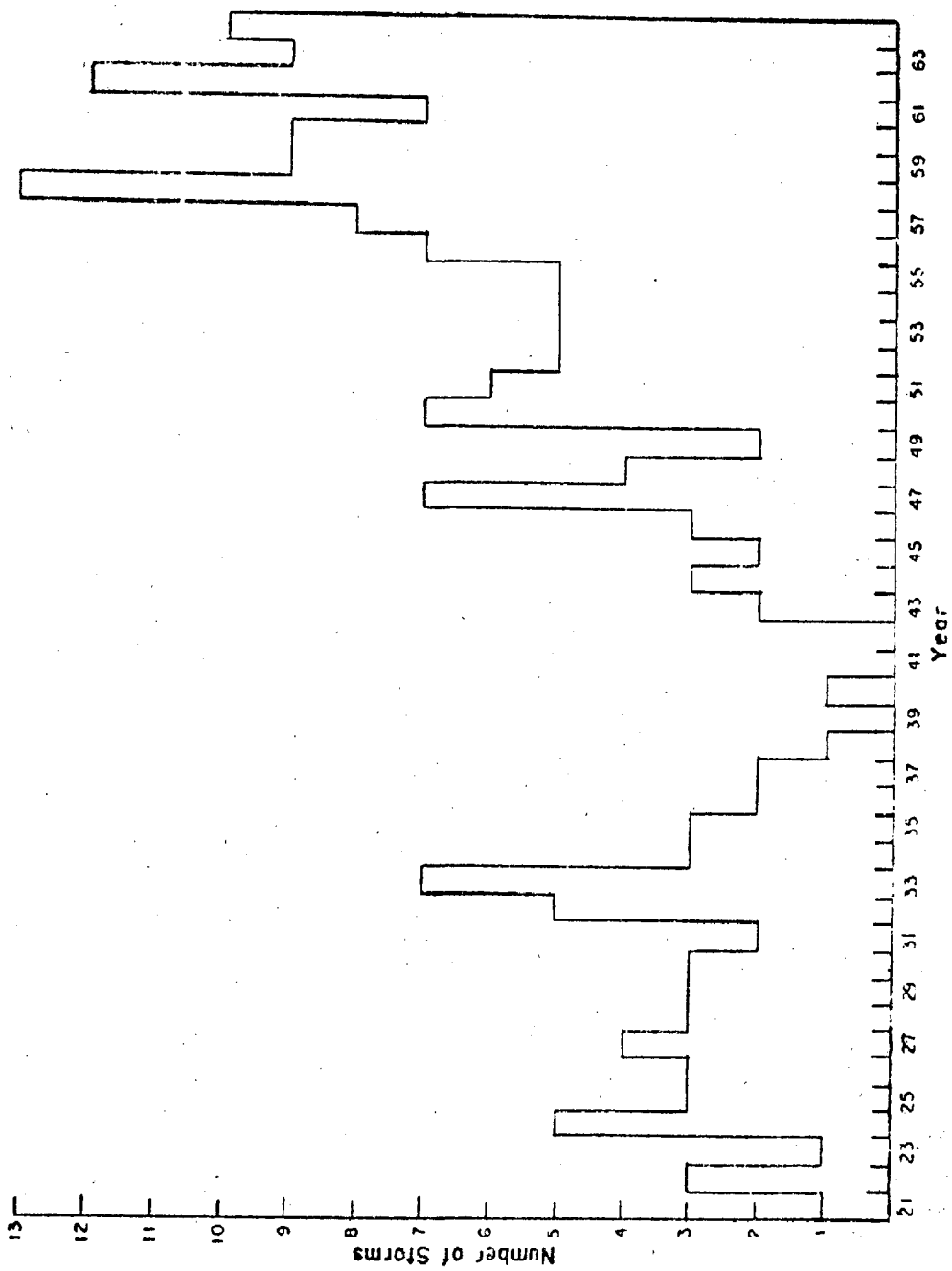
1. Hurricanes and severe tropical storms.
2. Wave developments forming in the Atlantic Ocean well east of the United States mainland or in the vicinity of Cuba.
3. Wave developments along cold or stationary fronts over the southeast coastal states or in the Atlantic Ocean just off the southeast coast.
4. Wave developments along cold or stationary fronts in the Gulf of Mexico forming west of 85 W longitude.
5. Depressions moving across the southern half of the United States that intensify upon reaching the Atlantic coast; no secondary development ahead of the storm center.
6. Depressions which develop as strong secondary cyclonic disturbances along the coast (often in the Hatteras area) ahead of a trailing wave or occluded center.
7. Intense cyclonic storms whose origin and entire path of movement are over land surfaces so that the low center remains west of the coastal margin.
8. Strong cold fronts accompanied by squall lines and severe local weather.

Weather maps are presented by the authors to illustrate each of the above categories.

Table 4-67 (Burton, et al., 1965) presents the number of damaging coastal storms occurring in each east coastal state for the period 1921-1964. It should be noted that coastlines are not normalized in this table. Within the study area, the largest number of occurrences is experienced by coastal Massachusetts.

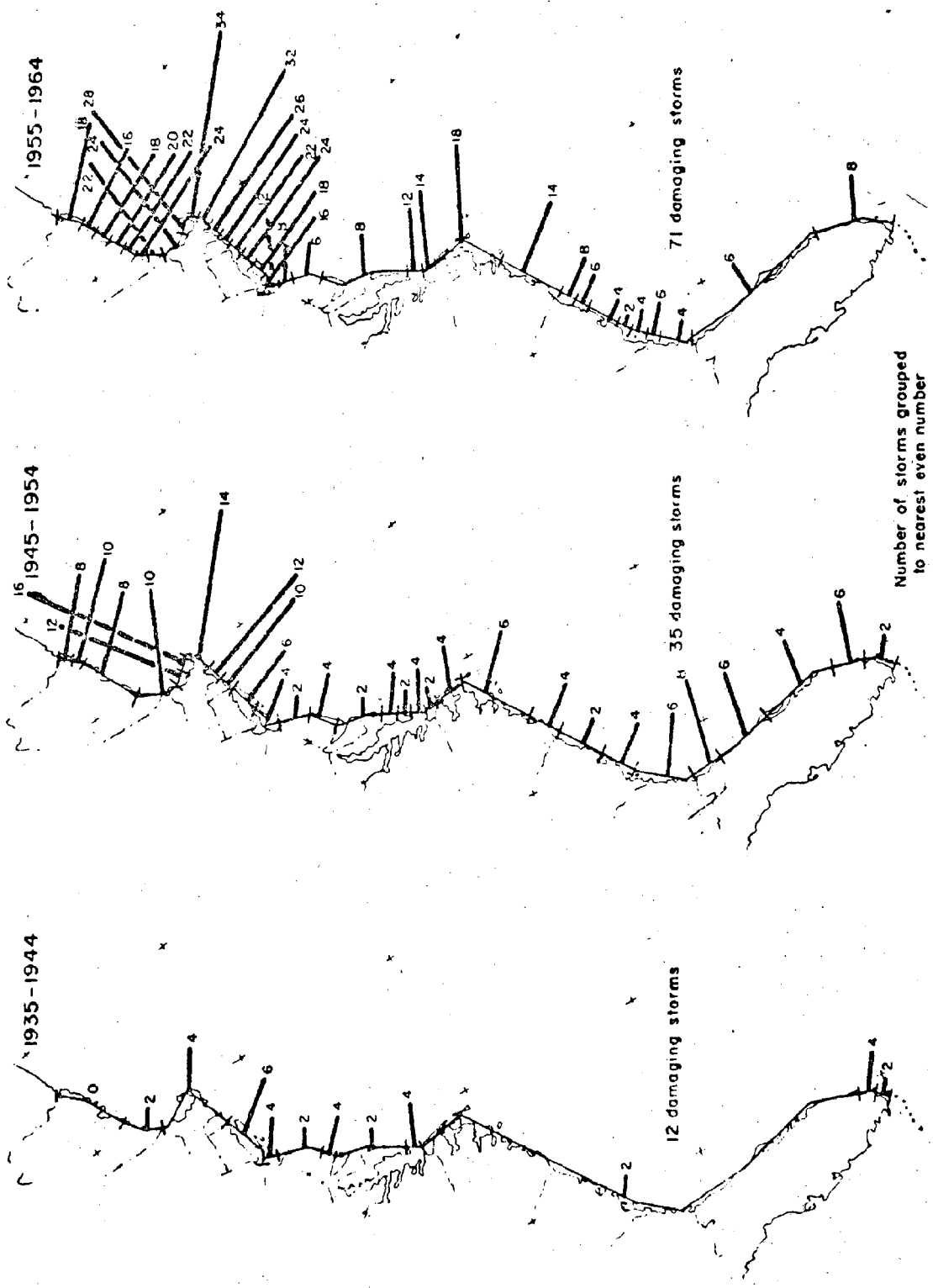
Table 4-68 lists intensity and recurrence intervals for coastal storms for the period 1921-1964. Although the number of storms is generally greater for the more northern states, intensity is generally higher to the south. For the study area the average severity is highest for New York, and lowest for New Jersey. The mean recurrence interval (computed for moderate and severe storms only) is shortest for Massachusetts, 0.8 years, where the coast is well oriented for coastal damage in two areas. The south facing shore of Cape Cod is particularly vulnerable to southeast and southwest winds; and the north shore of Cape Cod, and the shore north and south of Boston, are vulnerable to winds from the north through east.

Storm damage records for the period 1935-1964 have been analyzed by



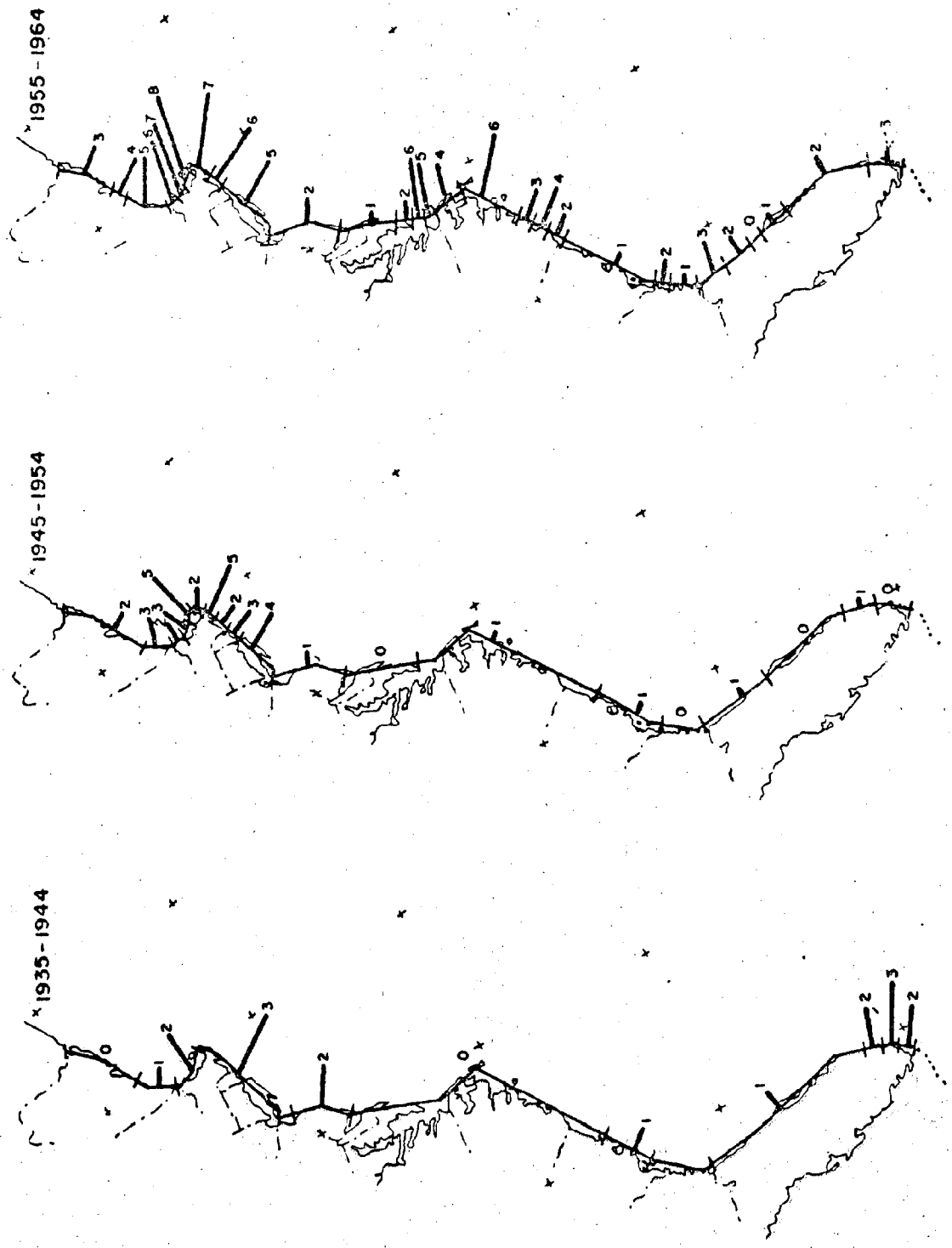
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 4-278	Frequency of Damaging Coastal Storms - Eastern United States 1921-1964 (Burton, et al., 1965)



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

TRIGOM PARC	FIGURE 4-279	Number of Storms Producing Significant Reported Coastal Damage (Burton, et al., 1965)



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

TRIGOM PARC	FIGURE 4-280	Number of Storms Producing Heavy Coastal Damage (Burton, et al., 1965)

Table 4-67

Number of Damage-Producing Storms, by Class and State, 1921-1964

State/Class	1	2	3	4	5	6	7	8	Total	Storms per Year
Maine	9	5	9	13	6	5	8		55	1.25
New Hampshire	8	2	8	11	3	5	4		41	.93
Massachusetts	22	4	14	16	7	14	7	4	88	2.00
Rhode Island	11	1	10	10	6	12	3	1	54	1.23
Connecticut	11	1	7	10	5	10	5	1	50	1.14
New York	11	1	10	8	4	9	4		47	1.07
New Jersey	18	3	10	8	4	8	4	1	56	1.27
Delaware	8	1	5	4	1	2			21	.48
Maryland	12	1	5	4	2	2		2	28	.64
Virginia	22	1	7	7		1			38	.86
North Carolina	27	3	5	8	3				46	1.05
South Carolina	19	1	3	2		1			26	.59
Georgia	16		1	2					19	.43
Florida	26	5	5	2					38	.86

Table 4-68

Intensity of Coastal Storms and Recurrence Interval for Storms Bringing Moderate and Severe Damage, by State, 1921-1964

	Numbers of Storms			Average* Severity	Mean Recurrence Interval (years)
	Light	Moderate	Severe		
Maine	25	24	6	1.76	1.5
New Hampshire	15	21	5	1.88	1.7
Massachusetts	31	46	11	1.90	.8
Rhode Island	24	24	6	1.78	1.5
Connecticut	22	23	5	1.76	1.6
New York	14	24	9	2.09	1.3
New Jersey	25	26	5	1.73	1.4
Delaware	7	13	1	1.76	3.1
Maryland	10	14	1	1.61	2.9
Virginia	11	22	5	1.97	1.6
North Carolina	14	23	9	2.09	1.4
South Carolina	7	15	4	2.04	2.3
Georgia	5	14	0	1.74	3.1
Florida	7	21	10	2.34	1.4

* Based on 1 for light damage, 2 for moderate damage, and 4 for severe damage.

Burton, et al. (1965) to determine damage frequency of the U. S. East Coast (excluding interior shorelines) as far north as Eastport, Maine.

Damage reports from coastal and interior coastlines was supplemented by tidal information to determine the extent of damage due to each of the 121 storm occurrences. The coast was divided into 40 km reaches; and maps of damage were prepared to determine the frequency of significant damage for each coastal reach.

The frequency of damaging storms for the three decades contained in the period 1935-1964 is presented in Figure 4-280 (Burton, et al., 1965). The overall frequency of damaging storms for the whole length of coast has increased from about one per year to eight per year in this 30 year period. Since 1945 the New York-New England coast has been significantly more affected by storm damage than more southerly areas. Within New England, the Rhode Island-Massachusetts coastline is especially prone to storm damage. On the average the storm damage south of New York is less than half the value for the New York-New England Coast.

The large increase in storm damage frequency over the 30-year period in all coastal reaches is partially attributed to the increased occupancy of the coastal zone. Burton, et al. (1965) believe that continued development of vulnerable coastal area can only further increase the potential for storm damage.

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Chapter 4 Major Sounds and Embayments

		Page
Chapter 4.5	Biological Oceanography	4-507
4.5.1	Mussel-Oyster Reefs	4-507
	Habitat Definition Description	4-507
	Habitat Dynamics	4-507
	Effect of Man-induced Stresses	4-509
	Biological Components	4-510
	References	4-541
4.5.2	Worm-Clam Flats	4-544
	Habitat Definition Description	4-544
	Habitat Dynamics	4-544
	Effect of Man-induced Stresses	4-548
	Biological Components	4-550
	References	4-566
4.5.3	Shallow Salt Pond	4-569
	Habitat Definition Description	4-569
	Habitat Dynamics	4-569
	Effect of Man-induced Stresses	4-571
	Biological Components	4-573
	References	4-595
4.5.4	Salt Marshes	4-596
	Habitat Definition Description	4-596
	Habitat Dynamics	4-596

		Page
	Effect of Man-induced Stresses	4-598
	Biological Components	4-600
	References	4-617
4.5.5	Plankton-Based Pelagic-Estuarine	4-618
	Habitat Definition and Description	4-618
	Habitat Dynamics	4-618
	Effect of Man-induced Stresses	4-621
	Biological Components	4-622
	References	4-624

4.5 BIOLOGICAL OCEANOGRAPHY

4.5.1 MUSSEL-OYSTER REEFS

This section treats the biology of the mussel-oyster reef communities. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed, and its areal distribution shown. The major biological components of the habitat are the benthic invertebrates, the fish, and the macrophytes. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to Chapters 10.0 Benthic Invertebrates, 11.0 Macrophytes, and 12.0 Fishes.

HABITAT DEFINITION AND DESCRIPTION

The oyster-mussel reef is a fairly specialized habitat, based on accumulations of the filter-feeding bivalves Mytilus edulis (blue or edible mussel) and Crassostrea virginica (oyster). Both of these epifaunal bivalves will form enormous aggregations wherever any small site of attachment exists, because of the gregarious behavior of the larvae which will often settle wherever another of its kind exists. The mussel reefs are cemented by the byssal threads spun by individual bivalves, while oysters cement their lower valve directly onto the shell of another. The surfaces, cracks, and crevices of both types of reefs harbor enormous numbers and a great diversity of other species.

HABITAT DYNAMICS

Environmental Conditions

Mussel-oyster reefs form both subtidally and intertidally, but are most successful intertidally probably because there they escape from many of the predators (Wells, 1961). Reefs originate almost anywhere a small site of attachment (e.g., small rock, half-buried log) exists on a flat near low-tide level. Higher on the intertidal, dessication at high tide, lack of sufficient feeding, and perhaps stronger currents render conditions unsuitable (Emery, Stevenson, and Hedgpeth, 1957).

Elongate beds may form parallel to currents along the banks of tidal flat channels or crescent-shaped dams may form across narrow inlets at right angles to the current (Emery, et al., 1957). In either case, reefs are most successful when currents are fairly strong, bringing food and carrying off wastes (Nixon, Oviatt, Rogers, and Taylor, 1971).

Mussel-oyster reefs are estuarine (salinities of 13 to 23 o/oo) in nature and subjected to wide variations in temperatures, salinities, and oxygen levels of estuarine conditions.

Oyster reefs are rare north of New Hampshire to the Gulf of St. Lawrence, and, when present, are in poor condition. Oysters are especially rare in Maine waters due to low water temperatures, generally high salinity, currents too strong for successful spatfall, and the predominance of unsuitable substrates (rocky covered with competing organisms, or too soft; (Taxiarchis, Dow, and Baird, 1954). In contrast, mussel reefs are very common north of Cape Cod and are often of high commercial quality (Scattergood and Taylor, 1949; Logie, 1956).

Microenvironments

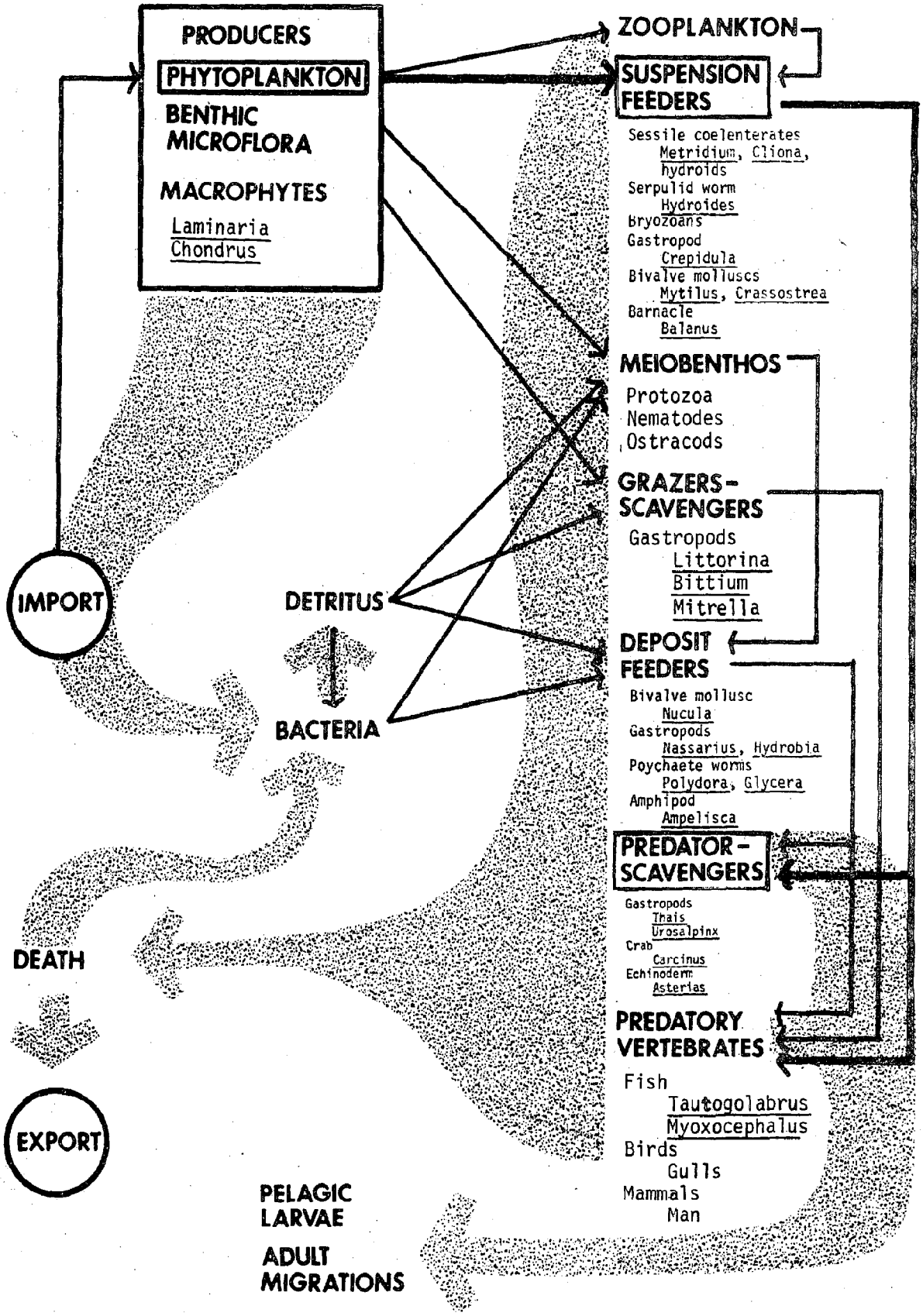
See discussion under General Distribution.

Nutrient Cycles and Food Webs

The most important members of the habitat, both in ciomass and numerically, are filter feeders (Nixon, *et al.*, 1971). Consequently, the main energy source is almost wholly imported being extracted from the overlying waters and then passed through the filter feeders to the associated species. Experimentally derived filtering rates show that an acre of oysters can strain 9-16,000 metric tons of water a day and an acre of mussels 2-20,000 metric tons (Anon., 1973). The filter feeders provide abundant food for predators (e.g., *Carcinus maenas*, *Nassarius trivittatus*, *Eupleura candata*, *Urosalpinx cinerea* of which the most disruptive is man, especially of oyster reefs.

Both oysters and mussels are capable of producing enormous quantities of feces and pseudofeces containing valuable nutrients. These feces and pseudofeces settle out in the cracks within the reef providing rich sediment for burrowing and deposit-feeding species. They also settle in great quantities on the surrounding sediment, changing its texture and often smothering the lower levels of the reef (Chestnut, 1969). The softer, siltier sediment resulting in the vicinity of the reef provides a food source for other deposit feeding species.

Laird (1961) studied the epizootics of oyster reefs and described one of the first marine decomposer food chains known in detail. Oysters react to environmental stress by closing their valves. Since the oyster can no longer flush itself, metabolites accumulate within the shell and, if stressful conditions continue long enough, eventually become abundant enough to provide a medium for bacterial growth. The higher level of bacterial growth leads to invasion of the oyster by protozoa feeding on the bacteria (bacteriophagous and saprozoic flagellates, and carnivorous and bacteriophagous ciliates). At some point, the oyster is so weakened that *Hexamita inflata*, a bacterio- and sapiophagous flagellate, invades the tissues and blood. This leads to the death of the organism and the establishment of a highly polysaprobic community of bacteria and protozoa.



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

TRIGOM PARC	FIGURE 4-281	Food Web of Mussel-Oyster Reef

Seasonal Cycles

The most important cycle for the biota in the mussel-oyster reef habitat is probably reproduction and recruitment with its associated cycle of growth. Both cycles are ultimately controlled by temperature (see "Biology of Key Species" in Chapter 10). The spring and summer are dominated by the appearance and establishment of the small, newly settled spat while the summer, fall and winter are periods of growth and gamete production.

Natural Stress

Because of their estuarine, predominantly intertidal environment, mussel and oyster reefs are subjected to many stresses of which the following documents only a few.

In the spring, freshets are common and create two adverse conditions suddenly; radically lowered salinity and high turbidity (Laird, 1961; Thomas and White, 1969). During the winter, ice scouring can remove entire beds (pers. observation) and individuals may freeze solid (Brongersma-Sanders, 1957). Finally, tidal currents and storm waves may scour or smother entire beds (Dare, 1973).

EFFECT OF MAN-INDUCED STRESS

Mussel and oyster reefs are also especially vulnerable to man-induced stresses. The following are only a few of the documented cases of the effects of man's activities on this habitat.

Entire reefs may become smothered with silt or be scoured away when currents are altered due to dredging, erection of jetties or establishment of marinas (R. Dow, per comm.).

Filter-feeding organisms are especially vulnerable to water-borne pollutants. Mussels of otherwise acceptable commercial quality become useless where hydrocarbon pollution results in "pearling" (hard inclusions within the body; Scattergood and Taylor, 1949). The combination of oil and dispersant causes outright death in *Mytilus* (Griffith, 1972). Oysters have been shown to accumulate DDT (Butler, Childress, and Wilson, 1972) which, at even very low concentrations, decreases growth rate (Butler, 1966; quoted in Chestnut, 1969). The eutrophication of estuarine waters alters the composition of the phytoplankton. In Moriches Bay, Long Island, oysters were unable to utilize the new community of phytoplankton and part of an industry vanished (O'Connor, 1972.).

Finally, thermal pollution, by raising the water temperature above normal limits, causes abnormal development in *Mytilus* larvae and could therefore interfere with successful recruitment (Davis, 1972).

BIOLOGICAL COMPONENTS

General Distribution

The diversity of the mussel and oyster reef communities is a result of the many microenvironments present. The shell surface provides a hard surface for sessile, attached algae (e.g. Chondrus crispus) and invertebrates both burrowing (Cliona sp.) and epifaunal (hydrozoans, Metridium, ectoproct; for other species in each microenvironment, consult checklist). Within the reef, gradients of exposure to currents exist from the outermost edges to the innermost cracks and crevices and from top of the reef to the substrate. Motile, epifaunal suspension feeders (Jalia) inhabit these cracks which offer protection, as well as access to currents of varying speeds. Also within the cracks, silty sediments rich in nutrients accumulate which are inhabited by motile deposit feeders (Hydrobia, Gammams sp.) and tube-dwelling and burrowing deposit feeders (Heteromastus, Amphithoe sp.). The silty bottom in the vicinity of the reef also harbors many deposit-feeding forms (Clymenella, Nucula. For each of these groups a set of carnivores exists, further adding to the diversity.

Tables. The following checklists of the fauna associated with oysters and mussels from the Bay of Fundy to Sandy Hook are compilations from available literature. Emphasis in the literature search was directed at publications that treated these habitats as units, and no concerted effort was made to sieve through literature on the taxonomy or ecology of specific taxa which might record their findings on oyster or mussel beds. In general, there has been a lack of studies on these biotopes, and quantitative studies are all but lacking.

The oyster beds are a much more complex and ecologically distinct habitat than are the mussel beds. For this reason, it was not unexpected to find many more species in association with oysters than with mussels (215 vs. 61). So much emphasis has been placed on the predators and competitors of both of these species that even biologists are often surprised at the number of cohabiting species which have no direct effect on either the oyster or the mussel.

Studies on the associated oyster fauna in New England include only one comprehensive study (Verrill and Smith, 1873). For this reason the author chose to include four recent studies just outside of the study area, two to the north (Hughes and Thomas, 1971, a,b), and two to the south (Maurer and Watling, 1973, and Larsen, 1974). Species which were identified as oyster associates from these studies, and which are also documented as occurring within the study area, are included in the checklist marked by asterisks. Once more complete surveys are accomplished in New England these

species will unquestionably be found to be oyster associates in this region also.

The fauna of mussel beds is principally based on three studies done in New England. These studies are Field (1923), Newcombe (1935) and Rowe, (1973).

Several points should be emphasized as to the scope and accuracy of these checklists. First, inclusion of a species in a checklist and reference to it as an oyster or mussel associate does not imply any functional interaction. In the vast majority of cases only co-occurrence can be assumed. Ranges of species are based on the best available published data, but still, one should not be shocked if they inadequately describe a species' distribution. This again is a function of the lack of sufficient survey work in this geographic area. Likewise many species not included in these checklists will undoubtedly be found as more intensive sampling is undertaken.

The phyla, and higher taxa within each phylum, are arranged in phylogenetic order. Within the lowest taxon above the generic level however, species are listed in alphabetical order for the convenience of non-specialists.

Table 4-69a. Annotated checklist of species occurring with the American Oyster, Crassostrea virginica

Phylum Porifera

Cliona celata Grant, 1926. The boring sponge most characteristic of areas of high, stable salinity. Occurs throughout study area. Filter feeder. Documented as oyster pest.

Cliona lobata Hancock, 1849. Boring sponge somewhat tolerant to reduced salinity. Identified in Long Island Sound and probably occurs in southern part of study area. Filter feeder. Oyster pest.

Cliona truitti Old, 1941. Most tolerant boring sponge to lowered salinity. Range identical to C. lobata. Filter feeder. Oyster pest.

Cliona vastifica Hancock, 1949. Boring sponge. Salinity tolerance between C. celata and C. lobata. Range like C. lobata. Filter feeder. Oyster pest.

Halichondria sp. Crumb-of-bread sponge. Genus represented in area by at least four species: H. bowerbanki, H. fibrosa, H. genetrix, and H. panicea. Conspicuous summer fouling organism. Filter feeder.

*Microciona prolifera Ellis and Solander, 1786. Red Finger Sponge. Occurs throughout study area, especially in Long Island Sound. Year around. Filter feeder. No effect on oyster.

*Prosuberties microsclerus de Laubenfels, 1936. A small encrusting sponge occurring throughout study area. Uncommon. Filter feeder. No effect on oyster.

Tedania suctoria O. Schmidt. An encrusting sponge occurring in northern part of study area. Uncommon. Filter feeder. No effect on oyster.

Phylum Cnidaria

Class Hydrozoa - All of the hydroids are carnivorous on zooplankton. They are epifaunal with preferred substrates including shells, rocks, pilings and Zostera blades. As a group they are universally associated with oysters but their life form precludes

them from having a significant effect on oyster production. They provide habitat space for several other taxa, especially Amphipoda.

*Campanulina sp. van Beneden, 1847. A taxonomically dynamic taxon represented by several species in the study area.

*Clytia hemisphaerica Linnaeus, 1767. Reaches abundance in oligohaline areas from the Arctic to the Caribbean.

*Cordylophora caspia Pallas, 1771. A low salinity species occurring along the entire Atlantic coast of the U.S.

*Ectopleura dumortieri van Beneden, 1844. Occurs from Massachusetts southward.

*Gonothyrea loveni Allman, 1859. A conspicuous winter species occurring throughout study area.

Halecium gracile Verrill, 1874. Believed to be a tropical species although it ranges as far north as the Gulf of St. Lawrence.

Hartlaubella gelatinosa Pallas, 1766. Grows in large colonies (31 cm). Has been included in six genera; Verrill identified it as both Obelia gelatinosa and O. pyriformis. Occurs throughout study area and is probably most abundant in winter and spring.

*Hydractina echinata Fleming, 1828. A polyhaline species occurring from Labrador to Gulf of Mexico.

*Hydrallmania fulcata Linnaeus. A fernlike hydroid occurring from Long Island Sound northward.

*Obelia bicuspidata Clark, 1876. A morphologically variable species probably known by several names. Is euryhaline and occurs southward from Maine.

*Obelia commisuralis McCrady, 1857. Up to 5 cm high. A summer form from Maritime Provinces to Florida.

Obelia geniculate Linnaeus, 1758. A morphologically variable species with a cosmopolitan distribution.

*Obelia longicyatha Allman, 1877. Up to 25 cm high. From Massachusetts to Caribbean particularly in late summer and fall.

Sertularia argentea Linnaeus, 1758. A polyhaline, winter species occurring throughout the study area.

*Tubularia crocea L. Agassiz, 1862. A high salinity summer form occurring along entire east coast of the U.S.

Class Anthozoa

*Edwardsia elegans Verrill, 1869. An infaunal species in sand and sandy-mud substrates. Can withstand mesohaline conditions. Reported up to 400/m^2. Carnivorous. Incidental in oyster assemblage.

*Haliplanella (Aiptasiomorpha) luciae Verrill, 1898. Small, common species throughout study area. Epifaunal, carnivorous and incidental to oyster assemblage.

Metridium senile Linnaeus, 1758. The large common anemone of New England. Epifaunal. Carnivorous. Incidental to oyster assemblage.

Diadumene leucolena Verrill, 1866. Small, epifaunal species which can be extremely abundant on oysters. Carnivorous. Ranges south from Cape Cod.

Phylum Platyhelminthes

*Euplana gracilis Girard, 1850. A polyclad common among sponges and hydroids along the entire New England coast. A predator that has no impact on oyster.

Procerodes littoralis (wheatlandi) Girard, 1850. A small triclad with at least an amphiAtlantic distribution. Tolerates low salinity. Predator. No effect on oyster.

*Stylochus ellipticus (Girard, 1850. The oyster leech. Common throughout study area. Its predation on young oysters or barnacles is well documented. A problem in certain areas.

Phylum Rhynchocoela - The nemerteans as a group are very active predators. Most common prey probably are peracarid crustaceans and polychaetes. Although not abundant they are constant members of the oyster assemblage.

*Amphiporus bioculatus McIntosh, 1873. Occurs southward from Cape Cod.

Amphiporus ocraceus Verrill, 1873. Up to 70 mm long. Occurs southward from Massachusetts Bay.

*Micrura rubra Verrill, 1892. Up to 25 mm long. Occurs throughout study area.

Zygonemertes virescens Verrill, 1879. Up to 40 mm long. Locally very abundant. Wide geographic range on both U.S. coasts.

Lineus socialis Leidy, 1855. A common, often gregarious species occurring throughout study area.

Polinia glutinosa Verrill, 1873. A small species, 30 mm, described by Verrill from Vineyard Sound. This name is invalid and its valid name is unknown.

*Tetrastemma elegans Girard, 1852. A locally abundant species up to 20 mm long. Occurs southward from Cape Cod.

*Zygeupolia rubens (Coe, 1895). Up to 80 mm long. Abundant in sandy substrates in bays and estuaries. Occurs southward from Cape Cod.

Phylum Entoprocta

Pedicellina cernua Pallas, 1771. Small species growing on hard substrates. Suspension feeder. Ranges all along coast, especially abundant in southern New England. Incidental to oyster assemblage.

Phylum Ectoprocta - A group of small, suspension feeding, usually colonial organisms. They occur as free-standing or encrusting forms. It has been suggested that bryozoa affect oysters by consuming planktonic larvae and by covering shell surfaces that could otherwise be used by oyster spat. Neither supposition is sufficiently documented to label this group as oyster pests.

*Aeverrillia armata Verrill, 1874. A nonencrusting species found principally in the southern half of the study area. Does not occur densely.

Alcyonidium hirsutum Fleming, 1828. Forms gelatinous colonies throughout the study area.

*Alcyonidium polyoum Hassall, 1841. Encrusts on several substrate types throughout study area.

*Alcyonidium verrilli Osburn, 1912. Forms erect branching colonies up to 12 inches high. Occurs uncommonly from Cape Cod southward.

Amathia vidovici Heller, 1867. Grows in erect branching colonies about 2 inches high. Occurs commonly on several substrates throughout the study area.

*Anguinella palmata van Beneden, 1845. A small erect species reportedly common from Maine to the Carolinas but rare in the Woods Hole region.

*Bowerbankia gracilis Leidy, 1855. A nonencrusting species occurring throughout the study area.

Bugula turrita Desor, 1848. Grows in colonies up to 12 inches in height. Distributed abundantly from Casco Bay to North Carolina. MacKenzie (1970) suggested that secretions from species of this genus may be a cause of oyster spat mortality.

*Electra crustulenta Pallas, 1766. A cosmopolitan encrusting species which locally can be very abundant. Withstands reduced salinities.

Electra hastingsae Marcus, 1938. Encrusting species which occurs on rocks and shells throughout the study area.

*Membranipora tenuis Desor, 1848. A common species south of Cape Cod encrusting stones and shells. Occurs in estuaries.

Schizoporella unicornis Johnston, 1847. An encrusting form very common in Long Island Sound where it has been indicted as a cause of oyster spat mortality.

*Victorella pavida Kent, 1870. A soft membranous form which occurs in brackish water south of Cape Cod.

Phylum Mollusca

Class Gastropoda

Subclass Prosobranchia

Bittium alternatum Say. Alternate Bittium. Very small, locally abundant. Occurs throughout study area. Feeds on diatoms, sponges and detritus.

Busycon canaliculata Linnaeus, 1758. Channeled whelk. A large predacious gastropod occurring principally south of Cape Cod. Is known to eat molluscs, annelids and dead fish. Locally can seriously deplete and oyster population. Under experimental conditions one conch consumes about three adult oysters per week.

Busycon carica Gmelin, 1970. Knobbed whelk. Distribution and feeding habits similar to B. canaliculata.

*Cerithiopsis greeni C. B. Adams, 1839. Green's miniature cerith. Very small, locally abundant. Occurs from Cape Cod southward. Feeds on diatoms, sponges and detritus.

Cingula aculeus Gould, 1841. A minute snail which can be locally abundant anywhere along the New England coast.

Crepidula convexa Say, 1822. Convex slipper shell. A common species on shells and eelgrass south of Cape Cod. Smaller than its congeners listed below it is also more tolerant to reduced salinity. A suspension feeder. Not a significant competitor to the oyster.

Crepidula fornicata Linnaeus, 1767. Common Atlantic slipper shell. This species occurs in chains. Although it has occasionally been found to be abundant on American oyster grounds, it has never been shown to be detrimental to the oysters. It was accidentally introduced into Europe where it has caused problems. During World War II it was marketed for human consumption. A suspension feeder that occurs throughout the study area.

Crepidula plana Say, 1822. Eastern white or flat slipper shell. Suspension feeder occurring throughout study area. Not detrimental to oyster.

*Epitonium rupicolum Kurtz, 1860. Brown-banded wentletrap. Observed to feed on sea anemones. Exudes purple dye when disturbed. Occurs from Massachusetts southward. Does not interact with oyster.

*Eupleura caudata Say, 1822. Thick-lipped or rough oyster drill. Abundant on oysters in polyhaline areas. Bores through mollusc shells by a mechanical-chemical process. One of the most important oyster predators. Occurs from Cape Cod southward.

*Hydrobia minuta Totten. A minute species, especially abundant in meso- and oligohaline areas throughout the study area. Omnivore. Incidental to oyster assemblage.

*Littorina littorea Linnaeus, 1758. Common European periwinkle. Occurs on intertidal oysters throughout the study area. Feeds on the diatomaceous surface film of rocks, shells and plants. Incidental to oyster assemblage.

Mitrella lunata Say, 1826. Lunar dove shell. A constant and locally abundant member of the oyster assemblage throughout study area.

Feeds on soft algae and animal detritus.

Nassarius obsoletus Say, 1822. Eastern mud nassa. Common on muddy intertidal areas all along Atlantic Coast. Omnivore. Incidental to oyster assemblage.

*Nassarius trivattatus Say, 1822. New England nassa. Common on sand. Scavenger. Occurs throughout study area. Incidental to oyster assemblage.

*Nassarius vibex Say, 1822. Common eastern nassa. Abundant or common in certain habitats with muddy-sand substrates, including oyster beds. Scavenges on animal remains. Occurs south of Cape Cod.

*Polinices duplicatus Say, 1822. Atlantic moon snail. Most common on high salinity, shallow-water sand bottoms throughout study area. Principally a predator on clams and probably has little impact on oyster assemblage.

*Polinices immaculatus Totten. Immaculate moon snail. Habits and range similar to above species, but much smaller and prefers cooler water. Only coincidentally occurring with oysters.

*Skeneopsis planorbis Fabricus. Minute, locally abundant species occurring throughout region. Omnivore.

*Triphora nigrocincta C. B. Adams, 1839. Black-lined Triphora. Specialized for feeding on sponges. Locally common in shallow water areas south of Cape Cod. Little, if any, impact on oyster assemblage.

Urosalpinx cinerea Say, 1822. Atlantic oyster drill. Most common and serious oyster predator in this region. Bores through shells of molluscs by mechanical-chemical means.

*Acteocina (Retusa) canaliculata Say, 1822. Channeled lathe shell. A minute, abundant species occurring throughout range. Selective deposit feeder. No direct relationship to oyster.

*Cratena pilata Gould, 1870. A small, eolid nudibranch. Occurs throughout study area. Feeds on hydroids. Usually rare or uncommon.

Doridella obscura Verrill, 1870. A small, dorid nudibranch occurring south of Cape Cod. Probably most abundant nudibranch on oyster assemblage. Feeds on bryozoa.

*Eubranchus pallidus Alder and Hancock, 1842. Small, eolid nudibranch

occurring throughout study region, especially winter and spring. Feeds on hydroids.

*Haminoa solitaria Say, 1822. Eastern paper bubble. Minute snail occurring south of Cape Cod. Reported to 300/m^2. Carnivorous, but also known to feed on algae.

Odostomia bisuturalis Say, 1821. Minute species occasionally found on oysters. Occurs throughout study area. An ectoparasite on one or several species.

*Odostomia impressa Say, 1822. Impressed Odostome. Minute species often extremely abundant on oysters. Historically believed to be host specific to oysters; has been abundantly found in other habitats. Ranges from Massachusetts southward. No evidence that their ectoparasitism is serious enough to classify them as an important oyster enemy.

Odostomia trifida Totten, 1834. Another minute species occurring south of Cape Cod. Not as abundant as above species.

Pyramidella fusca C. B. Adams, 1839. Brown pyram. Minute ectoparasite occurring throughout study area. Density on oysters second only to O. impressa.

*Rictaxis (Acteon) punctostriatus C. B. Adams, 1840. Minute species which can occur abundantly south of Cape Cod. Selective deposit feeder. No direct relationship to oyster.

*Tergipes despectus Johnston, 1835. An eolid nudibranch found throughout the study area. Feeds on hydroids.

*Turbonilla interrupta Totten, 1835. Interrupted Turbonille. Minute species distributed from eastern Canada to Caribbean. Reported to 150/m^2 on fine sand. Ectoparasite.

Phyllum Mollusca

Class Bivalvia

Anadara ovalis Bruguière, 1792. Blood ark. An infaunal suspension feeding species occurring southwards from Cape Cod in sandy mud. Locally very abundant, but relatively unimportant in oyster assemblage.

Anadara transversa Say, 1822. Transverse ark. Smallest species of genus. Often epifauna attached to rocks. Suspension feeder. Occurs south of Cape Cod. Probably more abundant on oyster reefs than above species.

Anomia simplex Orbigny, 1822. Smooth jungle shell. Sedentary, epifaunal suspension feeder, often attached to oyster shells. Occurs throughout study area. Does not occur in sufficient abundance to be a pest.

*Barnea truncata Say, 1822. Fallen angel wing. A boring clam. Members of this family dig into mud, stiff clay, hard shells and rocks. Barnea is common in intertidal clay from Maine southwards. Suspension feeder. No effect on oyster.

Brachiodontes recurvus Rafinesque, 1820. Hooked mussel. A small, epifaunal species occurring from Cape Cod southward. Suspension feeder. Occurs in high densities in estuarine areas.

Crassostrea virginica Gmelin, 1792. The central species of this assemblage.

*Cumingia tellinoides Conrad. Tellin-like Cumingia. Small species living in mud throughout the study area. Infaunal. Probably suspension feeder. No relationship to oyster.

*Cyrtopleura costata Linnaeus, 1758. Angel wing. Moderately common in mud and clay south of Cape Cod. Suspension feeder. Probably never very abundant on oyster grounds.

*Gemma gemma Totten, 1834. Amethyst gem clam. Minute suspension feeder living in fine sand throughout study area. Can be very abundant. Known to buffer predatory stress on young hard clams. Incidental to oyster assemblage.

*Lysonia hyalina Conrad, 1831. Glassy Lyonsia. Small, fragile, suspension feeder common in sandy mud throughout region. Reported to 1,200/m^2. Occurs in estuaries. Common, but not abundant on oyster grounds.

*Macoma balthica Linnaeus, 1758. Baltic Macoma. A dominant deposit feeder in estuarine areas with fine sediments. Reported to 2,000/m^2. Important fish food. Common throughout the study area. Doesn't reach high densities on oyster grounds.

Mercenaria mercenaria Linnaeus, 1758. Hard clam, quahog. Large, heavy shelled species. Important as commercial species. Suspension feeder. Very common throughout study area. Derelict oyster grounds often contain dense populations of this species.

*Modiolus demissus Dillwyn. Atlantic ribbed mussel. Large species common intertidally in brackish water throughout region. Epifaunal suspension feeder. May compete with oyster in intertidal areas.

*Mulinia lateralis Say, 1822. Coot clam. Occurs in estuaries and disturbed areas throughout study area. Sporadically abundant, up to 22,000/m^2. Infaunal, suspension feeder. No direct relationship to oyster.

*Mya arenaria Linnaeus, 1758. Soft-shell clam. Important commercially throughout northeast U.S. Suspension feeder. Very common intertidally and often on oyster grounds where the oyster shells protect it from predation.

*Mysella planulata Stimpson. Small species occurring in muddy sand from Nova Scotia to Cape Hatteras. Often abundant. Suspension feeder. Not important member of oyster assemblage.

Mytilus edulis Linnaeus, 1758. Common blue mussel. Common intertidally throughout region. Important commercially in Europe. Suspension feeder. Could be a competitor to intertidal oysters.

*Nucula proxima Say, 1822. Atlantic nut clam. Small, deposit feeder occurring throughout study area, in fine sediments. Up to 675/m^2. Not as abundant on oyster grounds.

Aquipecten irradians Lamarck, 1819. Atlantic bay scallop. Throughout study area. Epifaunal suspension feeder. No important on oyster grounds.

*Petricola pholadiformis Lamarck, 1818. False angel wing. Common intertidally in stiff clay or peat all along east coast. Suspension feeder. Not important in oyster assemblage.

*Solen viridis Say, 1821. Green jackknife clam. Infaunal, suspension feeder occurring in patches from Rhode Island southwards; on intertidal sand bars. Not important oyster associate.

*Tagelus divisus Spengler, 1794. Purplish Tagelus. Locally abundant in sandy mud from Massachusetts southward. Feeding type debatable. Incidental to oyster assemblage.

*Tellina agilis Stimpson, 1858. Northern dwarf tellin. Small deposit-feeding clam occurring throughout study area in sandy mud. Locally common. Incidental to oyster assemblage.

Phylum Annelida

Class Polychaeta

Arabella iricolor Montagu, 1804. A burrowing carnivore. Found in a number of shallow-water habitats including oyster and

mussel beds. Cosmopolitan in temperate regions. Reported to $12/m^2$.

*Boccardia hamata Webster, 1879. A shell-boring, selective deposit feeder occurring throughout study area. Can be numerically dominant in mesohaline oyster assemblages.

Cirratulus grandis Verrill, 1873. The fringed worm. Up to 6 inches long. Lives in a variety of sediments throughout region. Up to $575/m^2$. Not as abundant on oyster grounds. Selective deposit feeder.

*Clymenella torquata Leidy, 1855. An infaunal, tube-builder occurring throughout the study area in sheltered sandy substrates. Non-selective deposit feeder. To $400/m^2$. Incidental to oyster assemblages.

*Drilonereis filum Claparede, 1868. A burrowing carnivore. Common throughout study region in sand and mud.

Enoplobranchus sanguineus Verrill, 1873. Infaunal, selective deposit feeder occurring in mud and sand throughout study area. Up to 14 inches long. Probably not numerous on oyster grounds.

Spirorbis sp. Identified as such by Verrill (1873), probably is S. borealis Daudin. This is an epifaunal, tube building, suspension feeder. Extremely common in New England.

Eteone sp. Identified as such by Verrill (1873). At least 5 species occur in study area; two known to be oyster associates are listed below.

*Eteone heteropoda Hartman, 1951. Burrowing, carnivorous species in sand, mud, clay and shell bottoms. Occurs throughout study area and can be relatively abundant on oyster grounds.

*Eteone lactea Claparede, 1868. Burrowing carnivore in sand and mud. Occurs throughout region. Not as abundant as above species.

Eulalia sp. Identified as such by Verrill (1873). At least three species, E. viridis, E. annulata and E. bilineata occur in study area. Biology similar to Eteone. E. viridis is possibly an important oyster associate.

*Eumida sangrinea Oersted, 1843. Occurs abundantly among shells and in several other habitats throughout study area. Epifaunal. Carnivorous.

Fabricia sabella Ehrenberg, 1837. Small, slender, epifaunal tube-

builder. Suspension feeder. Potentially an important fouling organism.

Glycera americana Leidy, 1855. Blood worm. Found in sand, mud and in oyster beds. Often in brackish water. Carnivorous. Occurs principally south of Cape Cod.

Glycera dibranchiata Ehlers, 1868. Blood worm. The abundant commercially valuable bait species. Occurs in muddy bottoms throughout study area. Carnivorous. Probably not as common with oysters as above species.

*Gyptis vittata Webster and Benedict, 1887. Carnivorous, probably epifaunal. Commonly found on shell bottoms. Found throughout study area.

*Harmothöe extenuata Grube, 1840. A scale worm. Widely distributed throughout study area in a great variety of habitats including oyster grounds. Carnivore. Reported to 200/m^2.

*Harmothöe imbricata Linnaeus, 1767. A scale worm. Widely distributed and nearly ubiquitous within its range. Carnivorous.

*Heteromastus filiformis Claparede, 1864. Locally abundant. Reported to 2,000/m^2. Eurytopic. Non-selective deposit feeder. Important associate of oyster.

Hydroides dianthus Verrill, 1873. A tube-building, epifaunal species. Suspension feeder. Common throughout study region. Important member of fouling community.

*Hypaniola grayi Pettibone, 1953. A selective deposit feeder occurring throughout study area. Common in low salinity areas.

Lepidonotus squamatus Linnaeus, 1758. A scale worm. Can occur in great numbers in a variety of habitats in New England region. In brackish water. Carnivorous.

Lepidonotus sublevis Verrill, 1873. Relatively rare. Often commensal with hermit crab Pagurus pollicaris. On oyster shells. Carnivorous. Massachusetts southward. Incidental to oyster assemblage.

*Lumbrinereis fragilis O. F. Muller, 1776. A fragile, burrowing carnivore. Found on a variety of bottom types. Occurs throughout study area.

*Maldanopsis elongata Verrill. Up to 12 inches long. Common in New England coast in muddy sand. Non-selective deposit feeder.

Incidental to oyster assemblage.

Marphysa sanguinea Montagu, 1815. Large predacious worm occurring southward from Cape Cod. Principally a burrower, but is known to leave burrow in search of prey. Occurs in several bottom types.

Nereis succinea Frey and Leuckart, 1847. An abundant ubiquitous species, especially in estuaries. Burrowing form. Omnivore. Important member of oyster community.

Nereis virens Sars, 1835. The sand or clam worm. Important bait species. Burrows in sand and mud in sheltered and estuarine areas throughout study area. Much larger than above species. Omnivore. Not important member of oyster assemblage.

Nicolea simplex Verrill, 1873. A selective deposit feeder occurring southwards from Vineyard Sound.

*Owenia fusiformis Della Chiaje. A tube-building, infaunal species. Ocurring in sand throughout study area. Deposit feeder. Incidental to oyster assemblage.

*Parahesione luteola Webster, 1880. Small, epifaunal, carnivore occurring from Cape Cod southward. Characteristic, but not abundant, of oyster grounds.

Pectinaria gouldii Verrill, 1873. Abundant in muddy-sand throughout region. Builds cone-shaped tube of sand grains. Selective deposit feeder.

Phyllodoce sp. Identified as such by Verrill (1873). Six species occur in New England. Active, predacious, often epifaunal worms.

Pista palmata Verrill, 1873. Occurs uncommonly from Cape Cod southward. Selective deposit feeder.

Podarke obscura Verrill, 1873. Small, active, predator found in several habitats from Cape Cod southward.

Polycirrus eximus Leidy, 1855. Selective deposit feeder occurring throughout study area. Reported to 2,900/m^2. Probably not important to oyster assemblage.

Polydora ligni Webster, 1879. Small worm which builds mud tubes. Extremely abundant on oysters throughout study area. Brackish water. Selective deposit feeder. Heavy sets of P. ligni have caused oyster mortality.

*Polydora websteri Hartman, 1943. Shell-boring species. Abundant on oysters throughout study area. Occurs in estuarine areas. Selective deposit feeder. Detrimental to oyster through its boring activity.

Potamilla reniformis Linnaeus, 1758. Epifaunal tube-builder throughout study area. Suspension feeder. Probably never very abundant in oysters.

Sabella microphthalma Verrill, 1873. Epifaunal tube-builder throughout study area. Reported to 5,800/m^2. Suspension feeder. Important fouling species on oysters and other hard substrates.

Sabelaria vulgaris Verrill, 1873. Another epifaunal tube-builder. Occurs principally south of Cape Cod. Reported to 7,500/m^2. Suspension feeder. Important fouling species on oysters and other hard substrates.

*Scolecolepides viridis Verrill, 1873. A common estuarine species throughout study area. Occurs in fine sediments and on oyster grounds. Selective deposit feeder.

*Scoloplos fragilis Verrill, 1873. A burrowing, non-selective deposit feeder found in sand and sandy mud throughout study area. Occurs in estuaries.

*Streblespio benedicti Webster, 1879. An extremely abundant selective deposit feeder in estuarine fine sediments throughout study area. A numerically dominant member of oyster assemblage.

Phylum Annelida

Class Oligochaeta - There is no record of any oligochaete species occurring on New England oyster grounds. However, this important taxon is often overlooked by accident or design because of their small size and difficult taxonomy. These deposit feeders can be especially important in estuarine areas and several species will undoubtedly be identified from oyster beds once this environment is more carefully examined.

Phyllum Arthropoda

Subphylum Pycnogonida

Class Pantopoda

*Callipallene breviorostris Johnson, 1837. A rather small common species occurring throughout the study area. Feeds on hydroids. May occur in estuaries. Not important to oyster assemblage.

Subphylum Chelicerata

Class Merostomata

*Limulus polyphemus Linnaeus, 1758. Horseshoe crab. Common all along east coast in sand and mud. Plows through sediment in seach of small animals. Probably incidental to oyster assemblage.

Subphylum Mandibulata

Class Insecta

Chironomus oceanicus. Midge larvae. Selective detritus feeder. Several species may occur, especially in estuarine areas. Although they seldom if ever, become abundant on oyster grounds.

Class Crustacea

Subclass Copepoda

*Acartia sp. Epifaunal, suspension feeding genus. Can be very abundant and euryhaline. Occurs throughout study area.

*Centropages hamatus Lilljeborg, 1853. Biology like above species. Winter-spring form throughout study area.

Subclass Cirripedea

Balanus balanoides Linnaeus, 1758. Rock barnacle. Very abundant throughout study area. Suspension feeder. Can be important fouler of oyster shells.

*Balanus eburneus Gould, 1841. Ivory barnacle. Most abundant in intertidal southwards from Boston. Suspension feeder. Important fouler of oyster shells.

Balanus improvisus Darwin, 1854. Most common barnacle on subtidal oysters in estuarine areas. Suspension feeder.

Subclass Malacostraca

Order Cumacea

*Cyclaspis varians Calman, 1912. A brackish water selective deposit

feeder occurring southward from Cape Cod. Not abundant on oyster grounds.

*Leucon americanus Zimmer, 1943. A brackish water selective deposit feeder occurring southward from Cape Cod. Not abundant on oyster grounds.

*Oxyurastylis smithi Calman, 1912. A euryhaline selective deposit feeder. Occurs throughout study area. Not abundant on oyster grounds.

Order Isopoda

*Cyathura polita Stimpson, 1855. An infaunal tube-builder in areas of low salinity throughout study area. Omnivore. Common, but not abundant on oyster ground.

Edotea triloba Say, 1818. A selective deposit feeder throughout study area. Often in estuaries. Not uncommon on oyster grounds.

Order Amphipoda

Ampelisca sp. Identified as such by Verrill (1873). Undoubtedly one of three species listed below.

*Ampelisca abdita Mills, 1964. In fine sediments in marine and brackish water. Sheepscot Estuary southward. Selective deposit feeder. Locally abundant.

*Ampelisca vadorum Mills, 1963. In coarser sediments and more sheltered areas than above. Selective deposit feeder. Throughout study area. Locally abundant.

*Ampelisca verrilli Mills, 1967. Abundant in coarse sand south of Cape Cod. Selective deposit feeder.

*Ampithoe longimana Smith, 1873. Tube-builder occurring throughout study area. Selective deposit feeder. Locally very abundant.

*Ampithoe valida Smith, 1873. Biology as above. Occurs principally in estuaries southward from New Hampshire.

*Cerapus tubularis Say, 1818. In muddy sand south of Cape Cod. Probably selective deposit feeder.

*Corophium acherusicum Costa, 1857. Common in shallow, protected areas often with slightly reduced salinity. From central Maine southward. Suspension feeder. Builds epifaunal tubes.

Corophium insidiosum Crawford, 1937. Tube-builder throughout study area. In estuaries. Locally common. Suspension feeder.

*Corophium lacustre Vanhoften, 1911. Locally very abundant tube-builder throughout study area. In upper reaches of estuaries. Suspension feeder.

*Corophium tuberculatum Shoemaker, 1934. Throughout study area on sandy mud bottoms in shallow bays and estuaries. Suspension feeding tube builder.

*Cymadusa compta Smith, 1873. Epifaunal tube-builder from central Maine southward. Common in shallow water and estuaries. Selective deposit feeder.

*Elasmopus levis Smith, 1873. Motile epifaunal species occurring in shallow water south of Cape Cod. Selective detritus feeder.

*Gammarus mucronatus Say, 1818. Common species in estuaries throughout study area. Selective deposit feeder. Motile epifauna.

*Gammarus tigrinus Sexton, 1939. A very common species in the upper reaches of estuaries throughout the study area. Motile epifauna. Selective deposit feeder.

*Leptocheirus plumulosus Shoemaker, 1932. Infaunal tube-builder southward from Cape Cod. Principally estuarine. Suspension feeder.

Melita nitida Smith, 1873. A mesohaline species occurring throughout study area. Motile epifauna, often among hydroids. Omnivore. Abundant on oyster grounds.

*Microdeutopus gryllotalpa Costa, 1853. Occurs from Cape Cod southward on a variety of substrates including oyster beds. Selective deposit feeder.

*Microprotopus raneyi Wigley, 1966. Infaunal tube-builder from Cape Cod southward. In sandy substrates. Feeding type unknown.

*Monoculodes edwardsi Holmes, 1905. Free-infauna in fine sand throughout study area. Euryhaline. Selective deposit feeder.

*Orchestia grillus Bosc, 1802. Intertidal along east coast. Amongst marsh grasses. Herbivore. Incidental to oyster assemblage.

*Paracaprella tenuis Mayer, 1903. A caprellid. Occurs all along east coast. Motile epifauna amongst sponges and hydroids. Often estuarine. Carnivore. Common on oyster grounds.

*Parametopella cypris Holmes, 1905. Uncommon southward from Cape Cod. Polyhaline. Motile epifauna on hydroids, ectoprods and sponges.

*Pleusymtes glaber Boeck, 1861. Uncommon motile epifaunal species throughout study area. Omnivore.

*Stenothoe minuta Holmes, 1905. Often abundant species from Cape Cod southward. Motile epifauna in shallow bays and estuaries among hydroids and ectoprots. Selective deposit feeder.

Unciola irrorata Say, 1818. Infaunal, tube-builder throughout study area. Common in estuarine and marine waters. Selective deposit feeder. Coarse to medium sand. Often shares tube of other organisms.

*Unciola serrata Shoemaker, 1942. Tube-builder in sandy mud southwards from Cape Cod.

Order Mysidacea

Neomysis americana Smith, 1873. Very common throughout study area. Often in estuaries. Suspension feeder. Incidental to oyster assemblage.

Order Decapoda

*Callinectes sapidus Rathbun, 1896. Blue crab. Large active crab of commercial importance. Euryhaline. Occurs throughout study area. Omnivore. Will prey on oysters. Locally abundant.

*Cancer borealis Stimpson, 1859. Jonah crab. Large crab with commercial importance. Occurs throughout study area. Euhaline. Can prey on oysters. North of Cape Cod.

Cancer irroratus Say, 1817. Rock crab. Biology as above.

Carcinus meanas Linnaeus, 1758. Green crab. Common inshore crab throughout study area. Sporadically abundant. Potentially serious predator of oyster.

Crangon septemspinosa Say, 1818. Sand shrimp. Euryhaline, omnivore occurring all along east coast. Sand burrow. Uncommon on oyster grounds.

Eurypanopeus depressus Smith, 1869. Flat mud crab. Small carnivorous crab occurring from Massachusetts Bay southward. Declining in abundance, possibly due to a disease. A minor predator on oyster spat.

Libinia emarginate Milne Edwards, 1834. Spider crab. Sluggish scavenger occurring throughout study area. Poly-euhaline. Often numerous.

Neopanope sayi Smith, 1869. Abundant, small, carnivore on mud and oyster bottoms. Occurs throughout study area.

Pagurus longicarpus Say, 1817. Hermit crab. Small, common species, most abundant south of Cape Cod in sheltered areas. Omnivore. Not common on oyster grounds.

Pagurus pollicaris Say, 1817. Hermit crab. The large species which occurs all along the east coast. Omnivore. Not common on oyster grounds.

*Palaemonetes pugio Holthuis, 1949. Motile, epifaunal omnivore of brackish water. Occurs throughout study area. Not abundant on oyster grounds.

*Palaemonetes vulgaris Say, 1818. Common prawn. Motile, epifaunal species occurring from Cape Cod southward in salinities higher than above species. Omnivore. Not abundant on oyster reefs.

Panopeus herbstii Milne Edwards, 1834. Common mud crab. Large xanthid occurring southwards from Boston. Predator on adult oysters and spat.

Pinnotheres ostreum Say, 1817. Oyster or pea crab. Small omnivore living within mantle cavity of oyster. Complex life cycle. May be detrimental to oyster.

*Rhithropanopeus harrisi Gould, 1841. Small, carnivore numerous in low salinity areas throughout the study area. Probably not a serious predator on oyster spat.

*Upogebia affinis Say, 1818. Burrows in estuarine mud flats and shallow estuaries from Cape Cod southward. Suspension feeder. Not abundant on oyster grounds.

Phylum Echinodermata

Asterias forbesi Desor, 1848. Common starfish. Principal distribution south of Cape Cod. A predator on molluscs. Serious predator on oyster reefs.

Asterias vulgaris Verrill, 1866. Northern starfish. Occurs in shallow water only north of Cape Cod. Biology as above.

Phylum Hemichordata

Saccoglossus kowalewskyi A. Agassiz, 1873. The common hemichordate throughout the region. Burrows in sand and sandy mud. Not important member of oyster assemblage.

Phylum Chordata

Subphylum Urochordata

Molgula manhattensis DeKay, 1843. Sea grapes. Very abundant sea squirt on oyster reefs from Cape Cod southward. Suspension feeder. Seasonal in occurrence. No evidence that its fouling is harmful to oysters.

Styela partita Stimpson, 1852. Sea peach. Suspension feeder occurring southwards from Cape Cod. Not influential in oyster assemblages.

Table 4-69b Annotated checklist of species occurring with the blue mussel, Mytilus edulis

Phylum Porifera

Microciona prolifera Ellis and Solander, 1786. Red finger sponge. Occurs throughout study area, especially in Long Island Sound. Year round. Suspension feeder. Probably never very dense in mussel beds.

Phylum Cnidaria

Class Hydrozoa - Although only two taxa of these predators of zooplankton have been recorded from mussel beds of the New England region, several more probably exist.

Sertularia sp. Reported as such by Newcombe (1935). Probably S. argentea Linnaeus, 1758; a polyhaline, winter species occurring throughout the region.

Tubularia crocea L. Agassiz, 1862. A species known to occur on mussel shells as well as other substrates. Incidental to mussel assemblage.

Class Anthozoa

Metridium senile Linnaeus, 1758. The large common anemone of New England. Epifaunal. Carnivorous. Not important in mussel assemblage.

Phylum Rhynchocoela

Lineus socialis Leidy, 1855. A common, often gregarious, species occurring throughout study area. Active predator, probably on polychaetes and paracarid crustaceans.

Phylum Ectoprocta

Alcyonidium sp. Identified as such by Newcombe (1935). At least six species of this encrusting genus occur in the study region. Several species of this genus and other genera most likely occur in the mussel bed habitat.

Phylum Mollusca

Class Polyplacophora

Tonicella marmorea Fabricius. Chiton. Common grazer from Massachusetts northward. Fairly common on mussel beds.

Class Gastropoda

Subclass Prosobranchia

Acmaea testudinalis Linnaeus, 1758. Tortoise-shell limpet. A small grazer on hard substrates from Connecticut northward. Conspicuous on mussel beds in all seasons.

Buccinum undatum Linnaeus, 1758. Channeled whelk. A large predacious gastropod occurring principally south of Cape Cod where it is a significant predator on mussel beds.

Busycon carica Gmelin, 1790. Knobbed whelk. Distribution and feeding habits similar to B. canaliculata.

Littorina littorea Linnaeus, 1758. Common European periwinkle. Biology as above except smaller and found higher in intertidal zone.

Littorina saxatilis Olivi. Northern rough periwinkle. Like above except found even higher in intertidal zone. Up to 500/m^2 on mussel beds.

Lunatia heros Say. Common northern moon snail. Common in shallow water throughout study area. An uncommon predator on mussel beds.

Nassarius obsoletus Say, 1822. Eastern mud nassa. Common on muddy intertidal areas all along Atlantic coast. Omnivore. Does not interact with mussels.

Neptunea decemcostata Say. New England neptune. A common carnivore northward from Massachusetts. Uncommonly on mussel beds.

Thais (Nucella) lapillus Linnaeus, 1758. Atlantic dogwinkle. Common intertidal predator especially north of Cape Cod. A drill. Principal predator of mussel beds where it feeds on mussels and barnacles. 20-40/m^2.

Urosalpinx cinerea Say, 1822. Atlantic oyster drill. Common predator throughout region. Impact on mussel beds limited to removal of juveniles.

Subclass Opisthobranchia

Odostomia sp. Identified as such by Hughes and Thomas (1971). A number of these ectoparasites probably occur on New England mussel beds.

Class Bivalvia

Anomia sp. Identified as such by Newcombe (1935). Could be A. aculeata Gmelin or A. simplex Orbigny. Latter is more common. Incidental to mussel assemblage.

Modiolaria discors. Reported as such by Field (1923). Valid name, therefore range, unknown. An epifaunal, suspension feeding, mussel-like species.

Mulinia lateralis Say, 1822. Coot clam. Occurs in estuaries and disturbed areas throughout study area. Sporadically abundant, up to 22,000/m^2. Infaunal suspension feeder. Probably seldom important in mussel beds.

Mya arenaria Linnaeus, 1758. Soft-shell clam. Important commercially throughout northeast U.S. Infaunal suspension feeder. Overgrowth by mussels is detrimental to this species.

Mytilus edulis Linnaeus, 1758. Common blue mussel. The central species of this assemblage.

Petricola pholadiformis Lamarck, 1818. False angel wing. Common intertidally in stiff clay or peat all along east coast. Suspension feeder. Incidental to mussel assemblage.

Saxicava rugosa. A rock borer. Reported as being uncommon in mussel beds by Newcombe (1935). Exact valid name unknown; probably Hiatella arctica or H. striata both of which occur throughout region. Suspension feeder.

Phylum Annelida

Class Polychaeta

Arabella iricolor Montagu, 1804. A burrowing carnivore. Found in a number of shallow water habitats including mussel beds. Cosmopolitan in temperate regions. $12/m^2$.

Eteone lactea Claparede, 1868. Burrowing carnivore in sand and mud. Occurs throughout study area.

Eulalia viridis Linnaeus, 1767. Common throughout region in mussel beds among other habitats. Motile, epifaunal predator.

Glycera americana Leidy, 1855. Blood worm. Found in burrows in sand and mud. Often in brackish water. Carnivorous. Occurs principally south of Cape Cod.

Glycera dibranchiata Ehlers, 1868. Blood worm. The abundant commercially valuable bait species. In muddy bottoms throughout study area. Carnivorous. Mussel beds incompatible with harvest of this species.

Harmothöe extenuata Brube, 1840. A scale worm. Widely distributed in study area. Abundant in mussel beds. Reported to $200/m^2$. Epifaunal carnivore.

Harmothöe imbricata Linnaeus, 1767. A scale worm. Widely distributed and nearly ubiquitous within region. Epifaunal carnivore.

Heteromastus filiformis Claparede, 1864. Locally abundant. Reported to $2,000/m^2$. Eurytopic. Non-selective deposit feeder. Does not interact with mussels.

Lepidonotus squamatus Linnaeus, 1758. A scale worm. Occurs in

great numbers in a variety of habitats in New England region. In brackish water. Carnivorous.

Nereis virens Sars, 1835. The sand or clam worm. Important bait species. Burrows in sand and mud in sheltered estuarine areas throughout study area. Infaunal omnivore.

Notomastus latereus Sars, 1851. Uncommon cosmopolitan species. A burrowing, non-selective deposit feeder. Not important member of mussel assemblage.

Phyllodoce mucosa Oersted, 1843. Found on a variety of bottom types throughout study area. Carnivorous. Probably epifaunal.

Polydora sp. Field (1923) identified as P. ciliata. As this species does not occur in North America it is not clear what species he found.

Polydora ligni Webster, 1879. Tube-building selective deposit feeder occurring throughout study area. Brackish water.

Polydora socialis Schmarda, 1861. Tube-building selective deposit feeder. May occur in dense beds. Distributed throughout study area. Not known to bore into mussel shells.

Scoloplos fragilis Verrill, 1873. A burrowing non-selective deposit feeder found in sand and sandy mud throughout study area. Occurs in estuaries.

Spio setosa Verrill, 1873. Common in sandy tubes on beaches. Selective deposit feeder.

Class Oligochaeta

Oligochaeta - Non-selective deposit feeder found in mussel bed. Not identified to species.

Phylum Arthropoda

Class Crustacea

Subclass Cirripedea

Balanus balanoides Linnaeus, 1758. Rock barnacle. Dominant species in mussel beds. Occurs in densities of 3,000-5,000/m^2. Suspension feeder.

Subclass Malacostraca

Order Isopoda

Jaera marina Fabricius, 1780. Very common among weeds and mussels. Occurs throughout study area. Omnivore.

Order Amphipoda

Ampithoe rubricata Montagu. Constructs nests among weeds and mussels from Long Island Sound northward. Selective deposit feeder.

Gammarus annulatus Smith, 1873. Principally pelagic species in coastal water and surf zone. Occurs throughout study area. Presumably a suspension feeder.

Gammarus marinus. Reported as such by Newcombe (1935). Present synonymy unknown.

Gammarus oceanicus Segerstrade, 1947. Dominant intertidal and shallow water species in region. Also in estuaries. Selective deposit feeder.

Microdeutopus gryllotalpa Costa, 1853. Occurs from Cape Cod southward on a variety of substrates including mussel beds. Selective deposit feeder.

Order Decapoda

Crangon septemspinosa Say, 1818. Sand shrimp. Euryhaline. Omnivore occurring all along east coast. Burrows in sand. May be numerous among mussels.

Neoparope sayi Smith, 1869. Abundant, small carnivore on mud bottoms. Often among mussels. Occurs throughout study area.

Pagurus sp. Identified as such by Newcombe (1935) who noted it was only occasionally found with mussels. Omnivore.

Phylum Echinodermata

Class Asteroidea

Asterias forbesi Desor, 1848. Common starfish. Principal distribution south of Cape Cod. A predator on molluscs. Probably limits mussel distribution to intertidal areas.

Asterias vulgaris Verrill, 1866. Northern starfish. Occurs in

shallow water only north of Cape Cod. Biology as above.

Crossaster papposus Linnaeus, 1758. The common or spiny sun-star. Large, colorful predator occurring throughout study area. 10-12 arms. Probably not a serious threat to mussel beds.

Henricia sanguinolenta O. F. Muller. Blood sea-star. Small predator especially abundant in our region. Not serious threat to mussel beds.

Class Echinoidea

Strongylocentrotus droebachiensis O. F. Muller, 1776. Green sea urchin. Only common urchin north of Cape Cod. Uncommon southward. May be responsible for 20 percent of mussel mortality.

Class Holothuroidea

Cucumaria frondosa Gunnerus, 1770. Large northern sea-cucumber. From Nantucket northward. Especially abundant on rocky coast of Maine and northern Massachusetts. Non-selective deposit feeder. Incidental to mussel assemblage.

Psolus fabricii Duben and Koren. The scarlet psolus. Uncommon. Occurs in Maine. Non-selective deposit feeder. Incidental to mussel assemblage.

Phylum Chordata

Subphylum Urochordata

Boltenia sp. Linnaeus. Identified as such by Newcombe (1935). Two species, B. ovifera and B. echinata are known to occur from Cape Cod northward. Suspension feeder. Frequent on mussel beds.

*Indicates species identified as oyster associates from studies conducted outside the study area which are also documented as occurring within the study area.

Fishes. The following is a list of fishes normally found in the mussel/oyster reefs habitat within the continental shelf area between Sandy Hook, New Jersey, and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, (i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community). The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance

A. The geographical distribution includes three categories

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west of that line.

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south, or throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh-water
Brackish water
Nearshore - coastline to 18 m
Coastal - out to 91 m
Offshore - 91 m to the continental slope
Basin - deep basin of the Gulf of Maine
Banks - shallow, offshore bank areas, i.e., Georges Bank.
Oceanic - Pelagic fish of open ocean habit.

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species, or a rare or endangered species. The life history of these species will be treated in Chaper 12.0, Fishes.

TABLE 4-70 CHECKLIST OF FISHES: OYSTER, MUSSEL REEFS

SPECIES	GEOGRAPHICAL DISTRIBUTION ABUNDANCE	DEPTH DISTRIBUTION	HABIT
CODFISHES			
Pollock*** *Pollachius virens*	abundant north	coastal,banks to 180m	food-small fish, crustaceans
Tomcod *Microgadus tomcod*	common throughout	brackish to nearshore	food-small crustaceans
STICKLEBACKS			
Fourspine stickleback *Apeltes quadracus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans,fish eggs and fry
Threespine stickleback *Gasterosteus aculeatus*	abundant throughout	fresh to nearshore	food-copepods, other small crustaceans,fish eggs and fry
Blackspotted stickleback *Gasterosteus wheatlandi*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Ninespine stickleback *Pungitus pungitus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans,fish eggs and fry
PIPEFISHES			
Northern pipefish *Syngnathus fuscus*	common north	brackish to nearshore to 31m	food-copepods, amphipods,fish eggs and fry
Lined seahorse *Hippocampus erectus*	occasional south	brackish to nearshore	food-copepods, amphipods, fish eggs and fry
TEMPERATE BASSES			
Striped bass*** *Morone saxatilis*	abundant throughout	nearshore to coastal	food-small fish invertebrates
SCULPINS			
Grubby *Myoxocephalus aeneus*	common throughout	nearshore to coastal	food-scavenger, fish,invertebrates

Shorthorn sculpin Myoxocephalus scorpius	common north	nearshore to coastal	food-scavenger, fish,invertebrates
Longhorn sculpin*** Myoxocephalus octodem-spinosus	abundant throughout	brackish to coastal,banks to 180m	food-scavenger, fish,invertebrates
Sea raven Hemitripterus americanus	commonthroughout	nearshore to 90m	food-scavenger, fish,invertebrates
LUMPFISHES			
Lumpfish Cyclopterus lumpus	common north	nearshore to coastal	food-crustaceans; hard bottom
Seasnail Liparis atlanticus	common north	coastal,banks to 90m	food-crustaceans, molluscs;hard bottom
Liparis inquilinus	common throughout	coastal,banks 10-180m	food-crustaceans, molluscs;hard bottom
CUNNERS			
Cunner*** Tautogolabrus adspersus	abundant throughout	nearshore to coastal,banks to 130m	food-omnivorous scavenger
Tautog*** Tautoga onitis	abundant south	brackish to coastal to 36m	food-mulluscs, other invertebrates
GUNNELS			
Rock gunnel Pholis gunnellus	common north	nearshore to coastal,banks to 180m	food-molluscs, crustaceans,hard bottom
PRICKLEBACKS			
Radiated shanny Ulvaria subbifurcata	common north	nearshore to basin to 145m	hard bottom
WOLFFISHES			
Atlantic wolffish Anarhichus lupus	common north	coast,banks to 162m	food-molluscs, echinoderms crustaceans, hard bottom
EEL POUTS			
Ocean pout*** Macrozoarces americanus	abundant throughout	nearshore to coastal,banks basin 4-190m	food-molluscs, crustaceans, echinoderms

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4.5.2 WORM-CLAM FLATS

This section treats the biology of the worm and clam flat community. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed, and its areal distribution shown. The major biological components of the habitat are the benthic invertebrates and the fishes. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to Chapters 10.0, Benthic Invertebrates and 12.0, Fishes.

HABITAT DEFINITION/DESCRIPTION

This habitat includes all coastal and estuarine areas of soft unconsolidated sediment from the intertidal to 20 m depth, with the exception of high-energy sandy beaches (see Sandy Shores). In general, worm and clam bottoms are characterized by deposition of both silt and organic detritus and are therefore found in areas protected, either by depth or by sheltering headlands or barrier beaches, from strong wave action.

HABITAT DYNAMICS

Environmental Conditions and Microenvironments

Worm and clam bottoms are generally found in sheltered bays and estuaries, but they often also extend along exposed shores beyond the low-water surf zone and all the major substrate type in very large, but shallow bodies of water (e.g., Long Island Sound, Narragansett, and Buzzards Bay). The environment is chiefly marked by several gradients. Worm and clam bottoms are found from the intertidal to 20 m depth and the range of temperature changes varies accordingly. Sediments can be anything from fine silt-clay to a clean mixture of fine and coarse sands, but generally there is a constant flow of organic matter to the sediment from overlying water. Salinity ranges from nearly full of 30 ^{o}/oo near the coast to 0.5 ^{o}/oo proceeding up the estuaries. The fauna of these bottoms is affected by these factors so that each combination of salinity, depth, temperature, and substrate type will have a different biological association from other comvinations. Within each association will be found epifaunal and infaunal species, as well as a newly described biome found beneath the aerobic layer - the sulfide biome of uniquely adapted meiofauna (Fenchel and Reidl, 1970. Thus, the worm and clam habitat is one of the more complex and varied marine habitats.

Because of its accessibility and ease of sampling, this habitat is one of the most well studied. There has been no attempt to review the literature thoroughly; the references cited will lead the reader to many studies not described here.

Nutrient Cycles

The primary producers within the worm and clam habitat are the benthic diatoms and dinoflagellates, which are often migratory intertidally moving to the surface at low tide and sinking below the surface at high tide (Taylor and Palmer, 1963). Phytoplankton and detritus also contribute importantly to the source of energy flow. The phytoplankton and detritus pass through filter-feeding species, while the benthic flora and detritus are utilized by deposit feeders and meiobenthos. Nutrients are then recycled within the habitat through the meiobenthos and deposit feeders above the anaerobic layer and by the sulfide biome within that layer (Fenchel and Reidl 1970; see food webs) nutrients pass out of the habitat as pelagic larvae and bird and fish food.

Seasonal Cycles

Seasonal cycles are also marked in the worm and clam habitat. Sea water temperature varies seasonally but the range of variation increases in amplitude from 20 m depth (4-10 C) to the intertidal where seasonal changes are complicated by the daily exposure of the flats to the air. Salinity also varies seasonally, especially in estuaries where spring runoff and summer drought most commonly decrease or increase the average salinity at a particular site. Due to differences in depth configuration of the bottom and shores, turbulent tidal mixing, and amount of freshwater inflow among other factors, the characteristic circulation and patterns of salinity changes differ from one estuary to another (e.g., Bowden, 1967). Thus, the particular seasonal changes in salinity at any site must be determined individually.

Another seasonal cycle is the change in food availability. This is especially marked for suspension-feeders (Levinton, 1972) depending on the phytoplankton blooms (see Offshore and Estuarine Pelagic habitats). As a consequence of the seasonal changes in temperature and food availability, within the fauna there are related cycles of reproduction and recruitment. These two events are generally physiologically timed to coincide with periods of optimal food supply and most favorable conditions for successful establishment of the young in the adult habitat.

Food Webs

Two studies in Scotland show the importance of soluble (1) carbon compounds and detritus as energy sources for sand and mud fauna. At Loch Ewe, McIntyre, Munro and Steele (1970) found that the energy requirement of the ecosystem was 10 times that produced (expressed in) grams carbon per square meter per year (g C $m^{-2}yr^{-1}$). Much of the requirement was due to the activity of the bacteria and meiofauna.

Laboratory studies showed that most of the carbon requirement could be met by the soluble and suspended compounds (detritus) that is filtered out onto sand grains as water circulates through the sediment. Leach (1970) found that the epibenthic algal production on a mud flat in the Ythan estuary was only one half the energy requirement of the fauna. He postulated therefore that detritus must be a very important food source. The source of the detritus is the algal production of the rocky shores, the Spartina salt marshes, and Zostera where abundant (see discussions under relevant habitats). The food web is diagrammed in Figure 4-282.

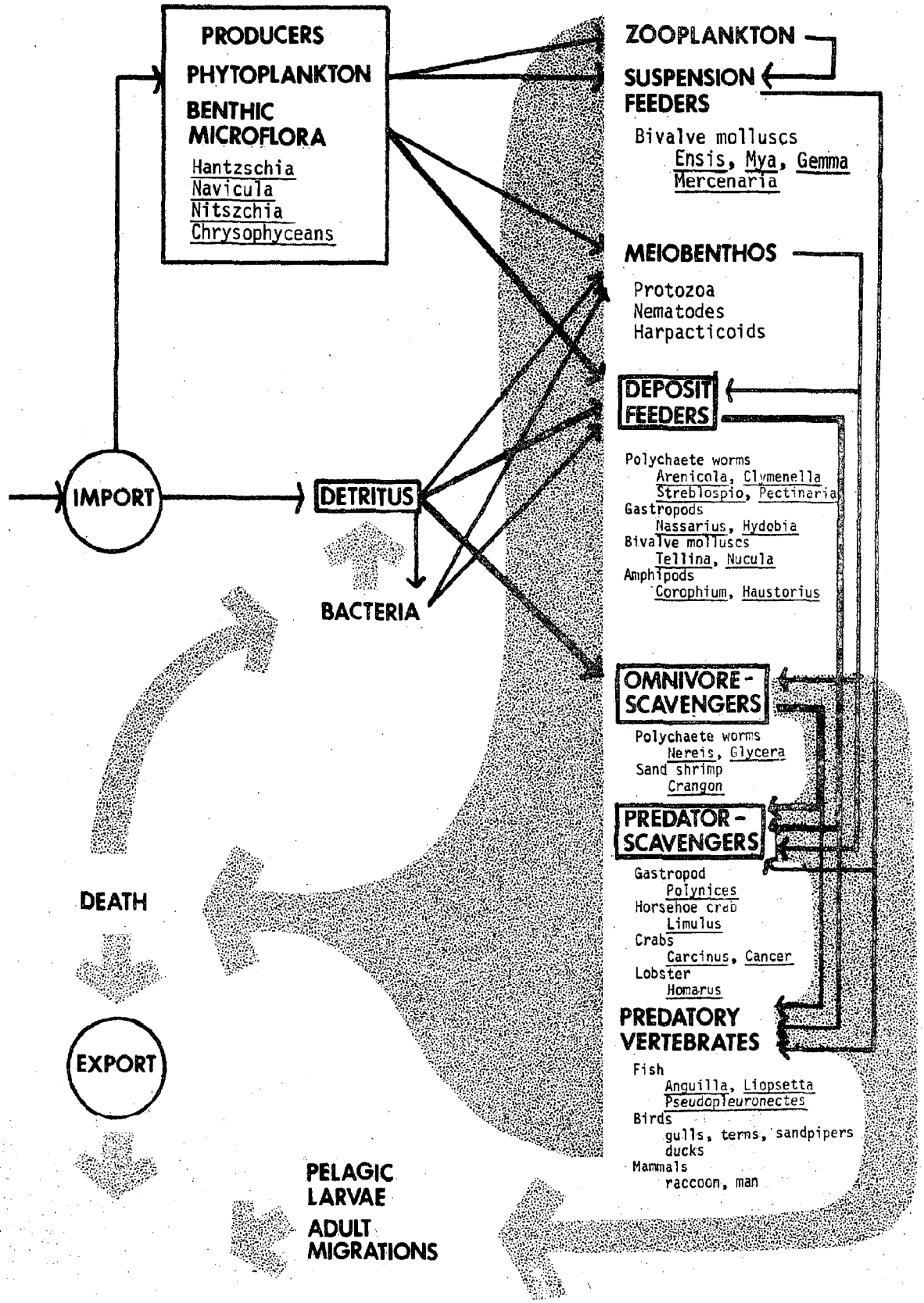
Within the sediments, bacteria utilize the detritus and in turn are fed upon by meiofaunal and macrofaunal deposit feeders. Marshall (1970) suggests that these two groups may compete for the available energy. He bases his hypotheses on the facts that worm and clam bottoms, specifically in south coastal New England, are highly productive in shellfish and fin fish and there is no organic accumulation. This implies that nutrients are very efficiently used and, in areas where the macrofauna are eliminated, the meiofauna may be able to replace them.

The deposit feeders and suspension feeders in turn are food for a wide variety of predators, many of which are finally used by man (e.g., ducks and flounder). The meiofaunal food web has been partially described in European sediments by Fenchel (1969), and it is assumed that a similar web exists in this study area.

Relative Productivity

The accompanying table shows that, in general, sandy substrates are more productive of animal biomass than muddy ones. Conversely, it appears that mudflats have higher primary productivity than sandflats. However, in both environments, animal respiration is greater than primary production and the difference is made up by imported detritus. The infauna of sand sediments is marked by a predominance of filter-feeders (see General Distribution) and thus may be more efficient at extracting the extra detritus.

The two orders of magnitude difference in animal numbers between the more northerly rivers and the southern Pocassett River and Barnstable Harbor, Massachusetts, may be in part due to differences in size of animals examined (1.5 mm and 0.5 for the northern rivers; 0.21 mm and 0.75 mm in Pocassett and Barnstable respectively). No doubt the north-south difference in primary production shown in Table 4-71 also affects the animal biomass. However, this does not explain the differences in productivity between Cape Cod and Buzzards Bay. Apparently this difference is not understood (Rhoads and Young, 1971).



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

TRIGOM PARC	FIGURE 4-282	Food Web of Worm/Clam Flat

Table 4-71 Relative productivity.

Measures of productivity in several locations.

Locality	Sed. type	Primary Production ($g\ C\ m^{-2}\ y^{-1}$)	Annual biomass (no/m^2)	Source
Ythan R.[1] Scotland	mud	29		Leach, 1970
	muddy sand	15		
	sand	5		
Loch Ewe[1]	sand	4-9		
So. New England Coast	average of all types	300		Marshall, 1970
Pocasset R. Mass.	mud-up-estuary		107,000	Sanders, et al. 1965
	down estuary		36,000	
Barnstable Harbor[1] Mass.	mud		174,000	Sanders, et al. 1962
	sand		250,000-350,000	
Cape Cod Bay	sand		16,000	Young and Rhoads, 1971
	silty-sand		11,000	
Sheepscot River	mud		1,500	Hanks, 1964
Penobscot River	fine sand)	contaminated	3-4,000	Shorey, 1973
	sandy gravel)	by ≈14%	1-2,000	
	)	sawdust		
Buzzards Bay	sandy		≈4,500	Sanders, 1958
	muddy		≈4,000	

[1]=intertidal

Dow (1966) has estimated the dollar value of certain flats in terms of their soft-shell clam bait or worm productivity. In 1965, eight acres of Scarboro marsh produced 19,500 kg of soft-shells making the flat worth $2,869 per acre. Over 20 years (1946-66), 20 acres of Cod Cove, Edgecomb produced an average of $3,750 worth of worms per acre.

Natural Stress

Worm and clam bottoms are subject to several natural stresses. One of the most common is a rapid change in salinity. Most species in this habitat have evolved one or more methods of adapting to such changes within their fairly wide salinity tolerance (Sanders, Manglesdorf, Hampson, 1965; Kinne, 1967) but if the dilution of salinity is too rapid, mass mortalities may result (Thomas and White, 1969).

A second stress is that of temperature change. Again animals have evolved tolerances to temperatures within the normal range to be expected in their locality (Kennedy and Milrursky, 1971, 1972) but when temperatures exceed these ranges, mortality again results. Bacterial populations in sediments adapt to seasonal temperature changes by changing their physiological composition to strains that, for example, thrive in high temperatures in the summer (Nedwell and Floodgate, 1971).

Another stress is that of shifting sediments, especially during storms. Several species (e.g. Nucula, Yoldia) can sense the position of a new surface and adjust their position accordingly (Rhoads and Young, 1970). Many species, however, are not so mobile and whole populations can be smothered by rapid deposition of sediments during a storm (pers. obs.).

EFFECT OF MAN-INDUCED STRESS

The effects of a large spill of Bunker C oil on the biota of Chedabucto Bay, Nova Scotia have been closely studied (Scarratt and Zitko, 1972; Thomas, 1973). A similar spill has also been studied in the southern part of the area at West Falmouth, Massachusetts (Sanders, Grassle, and Hampson). Work by Maine Department of Marine Resources has been described by Dow, Hurst, Mayo, Cogger, Donovan, Gambardella, Jiang, Quan, and Yevich, 1974. Shortly after the spill at Chedabucto Bay, layers of oil several centimeters in thickness commonly covered large areas of the mud bottoms, especially intertidally where coverage was total and often a firm pavement resulted from mixture with the sediment. Slightly over two years after the spill there was no evidence of oil degradation in the muddy areas. The upper intertidal was still completely covered and the rest of the intertidal showed only a partial and erratic decline in coverage. Subtidally,

the oil was incorporated into the sediment. Weathering of the oil was confined to only the surface layer; during warmer temperatures, oil seeps from under this layer and is redistributed elsewhere. Consequently, the Bay is at present still subject to continuous reoiling.

Extensive mortality of Mya arenaria was observed in heavily oiled areas and these populations have not yet recovered. Both Mya and Placopecten magellanecus ingested and assimulated the oil. Grazing herbivores (Littorina littorea, Strongylocentrotus droebachiensis and other filter feeders (Modiolus modiolus) showed high oil content at first, but later was greatly diminished. Oil is not, however, apparently being concentrated in the food chain; Cancer irroratus and Homarus americanus showed very low concentrations.

Specific results of hydrocarbon pollution have been found in quahogs from the Providence River (Anon., 1972) Included in these effects are a smaller average size, shortened life span, darkened meat, kidneys plugged with a black organic residue, and a raised ridge along the pallial sinus.

In contrast, a study of the effects of the effluent of a new pulp mill using the Swedish Stora process on the bottom infauna showed no changes in the benthos not attributable to normal fluctuation in spatfall success. The only change observed was an increase in the organic carbon content of sandy sediments (Pearson, 1971).

Dredging, however, is a serious disruption of worm and clam bottoms. Sykes and Hall (1970) found that both numbers of animals and of species were reduced drastically in dredged channels of Boca Ciega Bay, Florida. An average sample in dredged bottoms produced 1.1 individuals and 0.6 species as compared with 60.5 individuals and 3.8 species in undredged areas. Such effects would probably be even more severe in northern areas where diversity is lower.

Dow (1972) found that while soft-shell clams (Mya) can rid themselves of DDT residues if application ceases, lobsters continue to accumulate them. Consequently, lobster mortality is considerably increased in areas of pesticide application.

Dean and Haskin (1964) studied the Raritan River estuary as an example of how an estuary recovers after pollution abatement. After four years, the estuary had recovered the usual estuarine distribution of species. The freshwater species showed the most marked recovery; from no organisms present at the time of abatement in a very heavily polluted area, members increased to 17 species. Marine species showed a range of response. Pioneering species either remained as permanent residents, or after a brief success, vanished within 2 years. Other species showed secondary, brief successes. Finally, several slowly extended their distribution up the estuary to become permanent residents.

BIOLOGICAL COMPONENTS

General Distribution

Salinity and sediment type are two physical factors of great importance in determining the distribution of biota in this habitat. In general, the number of species shows a v-shaped curve (Dean and Haskin, 1964) as one proceeds from marine to freshwater up an estuary. Relatively few species are adapted to the highly variable salinity in mid-estuary so diversity is reduced. Stickney (1959) presents a thorough breakdown by salinity of the distribution of the more common representatives of the worm and clam biota in the Sheepscot River estuary. Sanders, et al. (1965), studied the same type of distribution in greater, quantitative detail for the Pocasset River. Their study showed that, in general, there are three types of species; those occurring only in the stations experiencing the lowest salinity (Gammarus tigrinus, Leptocheirus plumulosus): those that first appear in mid-estuary and occur to the mouth (Gemma gemma, Hydrobia sp.); and those present only at mid-estuary (Edotea tulobata, Streblospio benedicti). The study also showed that epifauna are subject to far greater salinity variation than the infauna due to the buffering action of the sediment water.

Sediment composition has several effects. Bader (1954) found that pelecypod densities are greatest at an intermediate percent organic content (1.5-3.5 percent). Above that sediments are too anaerobic and below too low in available food to support high densities. Where sediments are anaerobic whether at the surface or some distance below it the sulfide biome is present and may prove to be of great significance in energy flow (Fenchel and Riedl, 1970). In general, suspension feeders dominate sandy sediments while deposit feeders dominate in muddier ones (Shorey, 1973; Sanders, 1958; Driscoll, 1967; Rhoads and Young, 1971; Young and Rhoads, 1971). In part this is due to the differences in available food type. Currents are swifter and more constant over sandier bottoms, assuring an adequate food supply. Food for deposit feeders is corrrespondingly more abundant in muddier sediments (Sanders, 1958). Another influence is the development of a flocculent layer above the sediment surface where the bottom is intensively worked by deposit feeders. The flocculence clogs the filtering apparatus of suspension feeder and may smother their larvae, thus excluding this class from such sediments (Rhoads and Young, 1970). This hypothesis has recently been modified due to the finding that suspension feeders may be present in muddy bottoms stabilized by the tubes of certain deposit feeders (Rhoads and Young, 1971).

Driscoll (1967) discovered another biotic interaction influencing the distribution of epifaunal suspension feeders in Buzzards Bay.

This class of species (e.g., Anomia simplex, Creidula sp., Chaetopleura apiculata) is found in shell-rich areas of level bottoms, the shells providing an attachment site. When Cliona celata, a burrowing sponge, however, invades shells, it eventually destroys the shell and, concomitantly, the attachment-site for other epi-suspension feeders. Thus, the larger form of this sponge which can persist without an attachment site is often the only epifaunal suspension feeder in a shell-poor bottom.

Species Checklist. The following are checklists of benthic invertebrates and fishes considered to be regular inhabitants of worm and clam flat habitat:

Table 4-72 Benthic invertebrates check list

Checklist - Worm-Clam Bottoms

Key:

Range:	N =	north of Cape Cod
	S =	south of Cape Cod
	N+=	range mainly north, some found south of Cape Cod
	S+=	range mainly South, some found north of Cape Cod
	B =	found throughout study area
Depth:	I =	intertidal
	S =	subtidal
Sediment type:	S =	sand
	SS =	silty sand
	M =	mud, silt-clay
	G =	gravel, shell, etc.
	Epi =	epifauna, often on rocky areas
Living style:	S =	sessile
	T =	tubicolous
	B =	active burrower or burrower that doesn't form a tube
	M =	motile, on surface often
	C =	commensal
Feeding type:	SF =	suspension feeder
	DF =	deposit feeder
	C =	carnivore

Omni = omnivore, i.e. often switches feeding habit with season or food availability - carnivorous at times

G = grazer

Scav = scavenger - rarely carnivorous

Polychaetes

Species	Range	Depth	Sediment type	Style	Feeding type
Aglaopelamus sp.	N+	S	S	B,M	C
Ammotrypane aulogaster	N	S,I	M	B	DF
Ampharete acutifrons	B	S	S	T	DF
Ampharete arctica	N	S	M	T	DF
Amphitrite ornata	S	I	M	T	Omni
Arabella iricolor	S	S,I	M	B	C?
Arenicola marina		I	M	T	DF
Aricidea jeffreysii	N+	S	G,M	B?	DF
Aricidea quadrilobata	N	S	M	B?	DF
Asabellides oculata	S	S	S,SS	T	DF
Capitella capitata	B	S,I	S,SS,M	B	DF
Clymenella torquata	B	I	S	T	DF
Diopatra cupea	S	I	S	T	Omni
Diplocirrus hirsutus	B	S	M	T?	DF
Drilonereis longa	S	S,I	M,S	B	C
Eteone heteropoda	B	S,I	M	M	DF
Euchone incolor	N+	S	M	T	SF
Flabelligera affinis	N+	S,I	M	T	?
Glycera dibranchiata	S	S,I	S	B	Omni
Hartmania moorei	N	S,I	M	M	?
Heteromastus filiformis	B	I	S,M	T	DF

Species	Range	Depth	Sediment type	Style	Feeding type
Hypaniola grayi	S?	I	M	T	DF
Lumbrinereis tenuis	B	S,I	S,M	B	DF
Lumbrinereis fragilis	B	S,I	M	T	DF
Maldane sarsi	N	S	S,M	T	DF
Maldanopsis elongata	S	S,I	M	T	DF
Melinna cristata	B	S,I	M	T	DF
Nephtys caeca	N+	I,S	M	B,M	C
Nephtys incisa	N+	S,I	S	B,M	C
Nereis caudata	?	I	S	?	DF
Nereis diversicolor	N	S,I	M,S	B	Omni
Nereis virens	N+	S,I	M	B	Omni
Ninoe nigripes	B	S	S,SS,M	T	DF
Paraonis gracilis	N	S	S,SS,M	B	DF
Pectinaria gouldii	S	S,I	S	T	DF
Pectinaria hyperborea	N	I	S,M	T	DF
Pherusa plumosa	N	S	M	B	DF
Pholoe minuta	N+	S,I	S	B	?C
Phyllodoce groenlandica	B	S,I	M	M	DF?
Polydora sp.	N	S	S,G	T	DF
Praxillela sp.	N	S	S,M	T	DF
Prionospio malmgreni	N	S	G	T	DF
Pygospio elegans	N+	I	S,M	T	DF

Species	Range	Depth	Sediment type	Style	Feeding type
Rhodine loveni	N	S	M	T	DF
Scalibregma inflatum	B	S	S,M	B	DF
Scolecolepides viridis	S	S,I	S,G	T	DF
Scoloplos armiger	N+	S,I	SS,M	B	?DF
Scolopus fragilis	B	I	S,M	B	DF
Spio limnicola	B	S	S,SS,M	T	DF
Spio filicornis	B	S,I	M	T	DF
Spio setosa	S	I	S,G	T	DF
Stereonereis caeca	N+	S,I	M	M,B	C?
Streblospio benedicti	B	I	S,M	T	DF
Sternapsis sp.	N	S	M	?	?
Terebellides stroemi	N	S	M	T	DF
Tharyx sp.	N	S	S,SS,M	B	DF
Trichobranchus sp.	N+	S,I	M	T	DF

Mollusca

Species	Range	Depth	Sediment type	Style	Feeding type
Pelecypoda:					
Aequipecten irradiens	B	S	S	M	SF
Anomia simplex	B	S,I	Epi	S	SF
Astarte borealis	N	S	S	B	SF
A. undata	N+	S	S	B	SF
Arctica islandica	B	S	S	S	SF
Callocardia morrhuana	B	S	M	B	SF
Cerastoderma pinnulatum	B	S	M	M	SF
Clinocardium ciliatum	S	S	S	?	SF
Crassostrea virginica	B	S,I	Epi	S	SF
Crenella decussata	B	S	M	?	?
Crenella glandula	B	S	S	Epi	SF
Cyrtopleura costata	S	I	M	B	SF
Ensis directus	B	I	S	B	SF
Gemma gemma	B	S,I	S,M	S	SF
Macoma balthica	B	S,I	M	B	DF
Macoma tenta	B	S,I	M	B	DF
Modiolus demissus	B	I	Epi	S	SF
Mulinia lateralis	B	S	S	B	SF
Mya arenaria	B	I	G,M	B	SF
Nucula delphiodonta	N+	S	S,SS	B	DF
N. proxima	S	S	S	B	DF

Species	Range	Depth	Sediemnt type	Style	Feeding type
Placopecten magellanicus	S	S	S	M	SF
Solemya velum	B	I	S	B	SF
Tagelus plebius	S	S,I	S,M	B	SF
Tellina agilis	B	S,I	S	B	DF
Thracia myopsis	N	S	S	B	SF
Thyasira gouldi	N+	S	M	?	SF
Venus mercenaria	B	S,I	S	S	SF
Yoldia limatula	B	S,I	M	B	DF
Yoldia sapotilla	B	S	M	B	DF
Gastropoda:					
Acteon punctostriatus	S	S,I	M	M	?
Cingula aculeus	N+	S,I	M,G	M	DF?
Colus sp.	B	S	S,M	M	?
Cyclichna orzya	N+	S	M	M	?
Hydrobia sp.	B	I	S,M	M	DF
Ilyanassa obsoleta	B	I	S,M	M	DF
Lacuna vincta	N+	S,I	M	M	G
Lora scalaris	N	S	M	M	?
Lunatia triseriata	B	S,I	S	M	C
Nassarius trivittatus	B	S	S	M,S	DF
Odostomia trifida	B	S,I	S,M	C?	C?

Species	Range	Depth	Sediment type	Style	Feeding type
Polinices duplicata	S+	S,I	S,M	M	C
Retusa caniculata	B	S	M	M	C?
Retusa obtusa	B	S	M	M	C?
Turbonilla sp.	B	S	M	M	?DF
Urosalpinx cinerea	B	S,I	Epi	M	C

ARTHROPODA

Species	Range	Depth	Sediment type	Style	Feeding type
Crustacea					
Amphipod					
Acanthohaustorius millsi	S+	S	S	B,A	DF
Aeginina longicornis	B	S	S,M	M	S,F
Ampelisca macrocephela	N	S	S,M	?	DF
Ampelisca spinipes	S	S	M	?	SF
Ampelisca vadorum	B	S,I	S	?	DF
Anonyx lilljeborgi	N	S,I	S	B	DF
Byblis serrata	B+	S,I	M	?	?
Carinogammarus mucronatus	B	I	S	M?	DF
Casco bigelowi	N	S,I	M	B	?
Corophium crassicorne	N	S,I	S	T	DF
Corophium volutator	N	I	G,S	T	DF
Dulichia sp.	N	S	M	T	DF?
Gammarus lawrencianus	N	S,I	G	?	DF?
Gammarus tigrinus	B	S,I	M	B,A	DF?
Haustorius canadensis	S+	I	S	B,A	DF
Leptocheirus pinguis	N+	S,I	M	?	?
Leptocheirus plumulosis	S	S,I	M	?	?
Neohaustorius biarticulatus	S	I	S	B,A	DF

Species	Range	Depth	Sediment type	Style	Feeding type
Orchomonella pinguis	N+	S,I	M	?	?
Phoxocephalus holbolli	N+	S,I	S,G	M	DF
Unicola irrorata	S	S,I	S,M	C,T	DF
Isopod					
Cyathura carinata	N+	S,I	S,M	M	Omni
Cyathura polita	B	S,I	S,M	M	Scav
Edotea montosa	B	S,I	S,G	T	Omni?
Edotea trilobata	N+	S,I	M	M	Scav
Decapod crab (Brachyura)					
Callinectes sapidus	S	S,I	S,M	M	C
Cancer borealis	B	S,I	S,M	M	C
Cancer irroratus	B	S,I	Rock	M	C
Carcinus maenas	B	S,I	M	M	C
Hyas araneus	N+	S	S,M	M	Scav?
Neopanope texana	B	S,I	M	M	C
Caridean shrimp (Caridea)					
Crangon septemspinosa	B	S,I	S,M	M	Omni
Pandalus borealis	N	S	S,M	?	?
Mud shrimp (Anomura)					
Upogebia affinis	S	S,I	M	B	DF
Hermit crabs (Anomura)					
Pagurus acadianus	N+	S	S,M	M	Scav
Pagurus longicarpus	S	S,I	S	M	Scav

Species	Range	Depth	Sediment type	Style	Feeding type
Cephalocarida					
Hutchinsoniella macracantha	S	S	M	M	DF
Tanaid					
Leptocelia sp.	S	I	M	T	DF
mysid shrimp (Mysidacea)					
Neomysis americana	B	S	S,M	M	SF
Horseshoe crabs (Merostomata)					
Limulus polyphemus	S+	S,I	S,M	M	DF
Ostacoda spp.	B	S,I	S,M	B,M	Omni
Cumacea					
Almyracuma proximoculi	B	I	M	B	SF
Diastylis quadrispinosa	B	S	S,M	B	SF
Eudorella sp.	B	S	S,M	B	SF

Other Phyla

Species	Range	Depth	Sediment type	Style	Feeding type
Echinodermata					
Asterias forbesi	S	S,I	S,M	M	C
Caudina arenata	N	S,I	S,M	T	DF
Echinarachinus parma	B	S,I	S	M	DF
Leposynapta inhaerens	B	S,I	S	B	Omni
Ophiura robusta	N	S	S,M	M	Omni
Nemertinea					
Amphiporus sp.	B	S,I	S,M	B,M	DF
Micrura leidyi	S+	I	M	B,M	C
Tubulanus pellucidus	S	S	M	B,M	C?
Enteropneusta					
Dolichoglossus kowaleyskii (Sacoglossus)	S+	S,I	M	T	S-DF
Stereobalanus canadensis	N	S	M	T	S-DF
Tunicata					
Bostrichobranchus pilularis	B	S	M	Epi	SF
Aschelminthes					
Priapulus candatus	N+	S	M	B	C
Coelenterates					
Ceriantheopsis americanus	S	S,I	M	T	SF
Acaulis primarius	N	S	Epi	S	SF
Edwardsia elegans	N	S,I	G,S?	B,T?	SF

Fishes. The following is a list of fishes normally found in the worm-clam flats habitat within the continental shelf area between Sandy Hook, New Jersey, and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance

A. The geographical distribution includes three categories

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west to that line

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south, or throughout.

II Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh-water

Brackish water

Nearshore - coastline to 18 m

Coastal - out to 91 m

Offshore - 91 m to the continental slope

Basin - deep basin of the Gulf of Maine

Banks - shallow, offshore bank areas, i.e., Georges Bank.

Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent to the habitat, a commercially important species or a rare or endangered species. The life history of these species will be treated in Chaper 12.0, Fishes.

TABLE 4-73 CHECKLIST OF FISHES: WORM AND CLAM FLATS

SPECIES	GEOGRAPHICAL DISTRIBUTION ABUNDANCE	DEPTH DISTRIBUTION	HABIT
SMELTS			
Rainbow smelt*** *Osmerus mordax*	abundant throughout	brackish to nearshore	food-small fish, crustaceans, spawns brackish
EELS			
American Eel*** *Anguilla rostrata*	common throughout	fresh to oceanic	food-scavenger, living and dead animals, catadromous
KILLIFISHES			
Mummichog*** *Fundulus heteroclitus*	abundant throughout	fresh to nearshore	food-omnivorous plant and small animals, scavengers
Striped killifish *Fundulus majalis*	abundant south	nearshore	food-small animals
Sheepshead minnow *Cyprinodon variegatus*	common south	brackish to nearshore	food-small animals.
CODFISHES			
Tomcod *Microgadus tomcod*	common throughout	brackish to nearshore	food-small crustaceans
FLOUNDERS			
Winter flounder*** *Pseudopleuronectes americanus*	abundant throughout	brackish to coastal banks, to 130 m	food-small bottom invertebrates
Smooth flounder *Liopsetta putnami*	abundant north	brackish to coastal to 30m	food-small bottom invertebrates soft bottom
PRICKLEBACKS			
Snakeblenny *Lumpenus lumpretaeformis*	common north	nearshore to coastal to 90m	food-small crustaceans
WRYMOUTHS			
Wrymouth *Cryptacanthodes maculatus*	common north	nearshore to basin to 180m	food-fish, bottom invertebrates
TOADFISHES			
Oyster toadfish *Opsanus tau*	common south	nearshore to coastal	food-fish invertebrates, sand, mud bottom

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4.5.3 SALT PONDS

This section treats the biology of the salt pond community. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed and its areal distribution shown. The major biological components of the habitat are the benthic invertebrates, macrophytes, fishes and birds. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to the Plant and Animal Profiles presented in Chapers 10.0, Benthic Invertebrates, 11.0, Macrophytes, 12.0 Fishes, and 13.0 Birds.

HABITAT DEFINITION/DESCRIPTION

Salt Ponds are shallow coastal embayments separated from the open coastal waters by a barrier beach through which tidal exchange with those waters is usually maintained by an inlet. Salt ponds are common along the southern New England coast where alongshore currents have sealed off the mouths of many small rivers and indentations, but rare north of Cape Cod. One exception will be discussed in Biological Components. General Distribution. Because of their very high productivity, especially of species of commercial value, these ponds have been quite thoroughly studied. Smayda (1973) has summarized much of the existing literature.

HABITAT DYNAMICS

Environmental Conditions

Salt Ponds are generally shallow so that light penetrates to the bottom, allowing abundant growth of spermatophytes and macroalgae. The influence of freshwater, arising from river outflow, groundwater seepage, or runoff, results in variable salinity and temperature and contributes considerable amounts of nutrients to the pond.

The tidal regime is considerably dampened in comparison to that in coastal waters because of the effect of the small tidal inlet. This results in a small intertidal area, and a reduced flushing rate. The barrier beach also buffers the pond from the full effect of storms, reducing wave and current action. Both the reduced tidal regime and wave action results in very weak circulation or mixing of waters. In Salt Pond (Kim and Emery, 1971) and Oyster Pond (Emery, 1969), Falmouth, Mass., highly reducing (anoxic) conditions persist in the deeper basins throughout the year. In several ponds in spite of a relatively low freshwater inflow, the waters are distinctly two-layered with the fresh-water flow seaward on the surface and the more saline water flowing landward on the bottom. Examples of

this occurrence can be seen in the Maritic River, Coner Pond, and Great Pond, Falmouth, Massachusetts.

Microenvironments

Salt ponds are not a truly distinct habitat: they are unique chiefly for their very high productivity (as will be discussed later under Relative Productivity). Rather they are a mosaic of several habitats considered in this report: worm and clam bottoms, salt marsh, estuarine pelagic, and rocky shores. Consequently all the microenvironments found in these habitats are also present in a salt pond with a concomitantly high overall diversity.

One habitat not discussed elsewhere, and very well-developed in salt ponds, is the eel grass (Zostera marina) bed. Within the bed, species can live on the blades, among them, on the sediment surface, and under that surface. A more complete discussion of the fauna of eel-grass beds is presented under Biological Components, General Distribution.

Nutrient Cycles and Seasonal Cycles

Nutrients are transported into the pond both by the sea and fresh water. The circulation of the pond acts as a nutrient trap; nutrients being carried out of the pond by the fresh-water are mixed with those of the sea-water which has a net landward flow, the ebb tide being generally much weaker and prolonged than flood tide. This type of circulation is found in many estuaries (Ketchum, 1967). Due to the annual cycle of planktonic blooms and marine plant growth, nutrients, such as nitrates and phosphates, show a seasonal cycle. In Great Pond, Falmouth, Massachusetts, for example, these nutrients are utilized rapidly during the summer blooms and so are found in far less concentrations in the surface pond waters than in the water flowing into the pond. The phytoplankton sinks upon death and a high concentration of these nutrients occurs on the bottom and bottom waters. Thus, through the rapid uptake of nutrients brought into the pond from two sources by the primary producers, the benthic invertebrates are assured of an abundant food source both as detritus and plankton.

The seasonal cycle of growth and decay in Spartina has already been described in Salt Marshes. Zostera shows a similar cycle: the grass grows to 1.2 to 2 m height during spring and summer. During the fall, the blades break off at the base, leaving the underground rhizome to produce the next year's crop. The blades then undergo breakup and decay, providing food for deposit feeders, beach scavengers (when in windrows), and finally, with complete remineralization, for phytoplankton.

Bird populations show marked seasonal cycles: Salt ponds are traditional landing stops for migrating birds and nesting sites for many ducks and shorebirds. The benthic fauna also undergo seasonal cycles of reproduction and recruitment.

Food Webs

The accompanying food web diagram is a very generalized one. More specific, detailed webs, along with comments, may be found under separate habitats.

Relative Productivity

The following tables, 4-74 and 4-75, illustrate the contributions of the separate primary producers to the very high benthic productivity of salt ponds and compare the productivity of several ponds and contrast it with nearby coastal waters.

From these values, it is clear that macrophytic productivity is a very important determinant of primary productivity and along with benthic microflora, a major determinant of available food to the benthic populations.

Natural Stress

The most persistent natural stress in salt ponds is variable salinity. However, due to the dampened tidal regime, the range in salinity may be fairly slight (Emery, 1969). During storms, salinity change may be very sudden and dramatic due to runoff or widening of the inlet. Winter ice scour may also cause severe damage. Due to the shallow depth of most ponds, sediments may be extensively shifted during heavy storms. If the inlet should become closed during a storm, salinity will slowly decrease to almost fresh-water in the more shallow parts, leading to a drastic change in resident populations (e.g., Oyster Pond, Emery, 1969).

EFFECT OF MAN-INDUCED STRESS

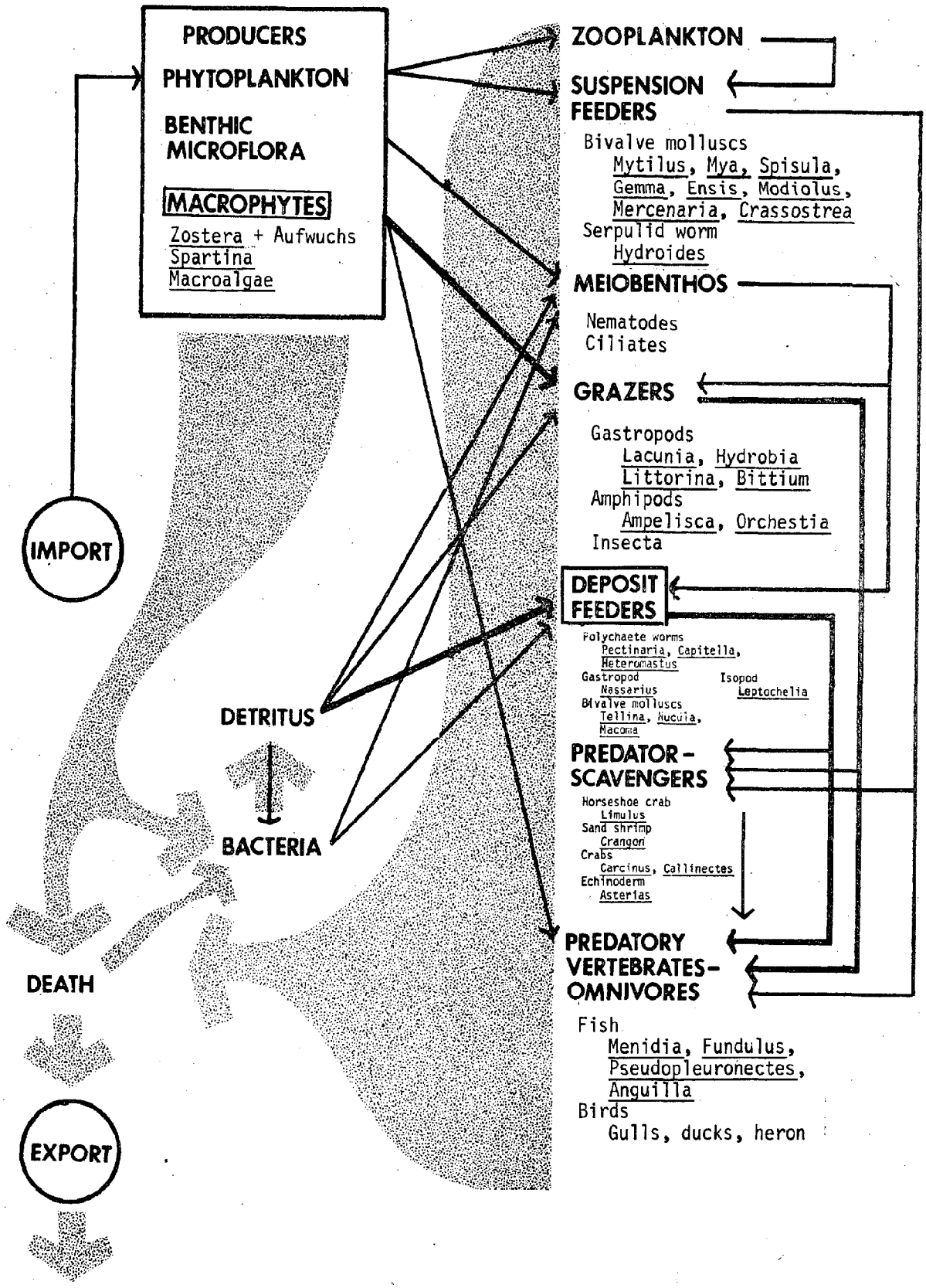
Because of their proximity to heavily populated areas, salt ponds are subject to many kinds of water-borne pollution. Because of their capacity to trap nutrients, pollutants, such as domestic sewage and agricultural waste, become highly concentrated and cause dramatic changes in contaminated ponds. One such pond that has been well-studied is Moriches Bay, on the south shore of Long Island. Along the shores of Forge River a tributary river of this bay, are several duck farms which contribute great quantities of duck wastes. This has led to a change in the dominant phytoplankton farms from diatoms to small chlorophytes, Nannochloris and Stichococcus, generally

Table 4-74 Contribution of sources of organic carbon to the substrate (Marshall, 1970)

Source	Organic carbon $g\ C\ m^{-2}\ y^{-1}$
Macroflora (*Zostera* and macroalgae	125
Benthic microflora	90
Deposition of phytoplankton	50
Allochthonous matter detritus from river, etc)	0 -10
Total	265-275

Table 4-75 Productivity of some salt ponds (taken from Smayda, 1973, who lists the primary sources) and nearby coastal waters.

Locality	Production ($g\ C/m^2/yr$) Gross	net
Oyster Pond:		
phytoplankton	350-400	-
macrophytes	50	-
Charleston, R.I.		
Green Hill Pond:		
phytoplankton	138	51
Zostera	128	43
Niantic River, Conn.		
phytoplankton	-	41
benthic microflora	-	80
Moriches Bay: Total		178
phytoplankton		56
macrophytes		122
Long Island Sound	470	205
Continental Shelf		
inshore (50 m depth)	160	-



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

TRIGOM PARC	FIGURE 4-283	Food Web of the Salt Pond

unsuitable as oyster food. Great quantities of the waste along with decaying plants cover areas of the bay producing substrate conditions unsuitable for many benthic invertebrates (organic content 10 percent by weight). Finally, highly anaerobic conditions in the Forge River, and presumably parts of Moriches Bay, have often resulted during the summer from the very high BOD (Biological Oxygen Demand) due to decomposition of the duck wastes and abnormally excessive phytoplankton blooms stimulated by the wastes. All of these stresses have directly affected the benthic invertebrates so that, in spite of very high net primary productivity (178 g C m^{-2} yr^{-1}), the standing crop of benthic invertebrates is lower (5 g m^{-2} ash-free dry weight) than in other areas with lower productivity (all foregoing from O'Connor, 1972). Oyster production has also been eliminated.

Another man-induced stress affecting most of the salt ponds is dredging to maintain boat channels and marinas. O'Connor (1972) demonstrated that diversity in these channels is very low.

BIOLOGICAL COMPONENTS

General Distribution

The distribution of species within each habitat is similar to that already described under the specific habitat. O'Connor (1972) found a clear-cut association of suspension feeders with sandy sediments and deposit-feeders in muddy substrates as would be expected from work on worm and clam bottoms. The following table, 4-76, presents the dominant species O'Connor found in various substrata.

The presence or absence of *Zostera marina* has a marked influence on the benthic fauna of a particular site. When a large bed near Woods Hole, Massachusetts, disappeared in 1931, due to a mycetozoan parasite, Stauffer (1937) found that those species living on or among the blades of grass vanished, while those living in or on the sediments were unaffected. These remaining species often showed changes in abundance, e.g., *Lumbrinereis tenuis* and *Spio setosa* markedly increased in abundance while *Glycera* sp, *Mya arenaria*, and *Leptosynapta* decreased markedly. Dexter (1950) found the following species to be abundant in a newly restored bed of eel grass in Goose Cove, Cape Anne, Massachusetts: the three *Littorina* sp., *Lacuna vincta*, *Gemma gemma*,, *Mytilus edulis*, *Idothea baltica*, *Cragnon*, *Spirorbis*, lobsters, eels, *Fundulus*, and the 3 spined stickleback (*Gasterosteus aculeatus*).

Marshall and Lukas (1970) demonstrated that the sediment under a bed of eel grass has a higher silt and organic carbon content in the top 1 cm than nearby sediments. The eel grass slows currents, creating greater silt deposition and, perhaps, lower oxygen content slowing utilization of carbon at the sediment surface.

Table 4-76 Association of certain taxa with particular substrates (O'Connor, 1972) in Moriches Bay.

Sand	Transitional	Clay-silt	Vegetation
Mercenaria	Mercenaria	Clymenella	Mytilus
Gemma	Mytilus	Bostuchobranchus	Nassarius obsoletus
Tellina	Clymenella	Molgula	Neopanope
Neopanope	Tellina	Nereis succinea	Laevicardium
Laevicardium	Pitar	Glycera	Nereis virens
	Laevicardium	Pitar	Botryllus
		Heteromastus	Urosalpinx
		Laevicardium	Platynereis
		Mulinea	Crangon

Salt Ponds north of Cape Cod are very uncommon. One does occur, however, in a landlocked estuary near Blue Hill, Maine. Read (1972) described the fauna of Salt Pond, Maine. There are two habitats: the shallows are very warm, especially in the summer, supporting a warm-water fauna while a deep water basin remains cool and supports a boreal fauna. Within the basin is a peat bank supporting a unique association of burrowers. Table 4-77 lists some components of these two fauna.

Table 4-77 Fauna of Salt Pond, Maine (Read, 1972)

Shallow	Basin	Peat Bank
Aurelia aurita	Cerianthid Anemones	Myxicola
aeolid nudibranchs	Placopecten	terebellied worms
Mysids	Myxicola infindibulum	Zirfaed crispata
Gonionemus	Henricia sanguinolenta	lobster
Mercenaria mercenaria	Holocynthia pyriformis	lumpfish
Modiolus modiolus		squirrel hake
Cylichna occulta		sea ravens
Pitar morrhuna		
Lunatia duplicata		
Asterias vulgaris		

Species checklist

The following are checklists of the benthic invertebrates, macrophytes, fishes and birds considered to be regular inhabitants of the salt pond habitat.

Table 4-78 Salt pond benthic invertebrates

Species	Common Name	Habit	Relative Dominance	Distribution	Habitat Preference
Halcampa duoducimcirrata	Anemone	Particulate feeder, attached, sessile	Common 1,286/m^2	Maine to s. New England	Mud, crevices of sea bottom, rocks
Haliplanella luciae	Anemone	Particulate feeder, attached, sessile	Very common	New England	Pilings, mussels, brackish water, marsh
Metridium senile	Anemone	Particulate feeder, attached sessile	Very common	Maine to New Jersey	Low water mark, among stones, pilings, pools
Hydractinia echinata	Hydroid	Plankton feeder, attached, sessile	Very common	Labrador to N. Carolina	Patches on rocks and shells of living hermit crabs
Ampharete arctica	Polychaete	Builds tubes of mud, shell & algae, detritus feeder	Common	New England	Mud, estuaries, marsh
Arabella iricolor	Opal worm	Burrows, deposit feeder	Common 67/m^2	Southern New England	Sandy mud at low water to 28 m
Arcteobia anticostiensis	Polychaete	Burrows, deposit feeder	Fairly common	Southern New England	Usually in mud, marsh
Axiothella catenata	Polychaete	Burrows, deposit feeder	Fairly common	Southern New England	Mud, marsh, estuary
Brania clavata	Polychaete	Burrows, deposit feeder	Common 448/m^2	Southern New England	Mud, sand, mussel beds
Cirratulus grandis	Fringed worm	Builds soft tubes, selective deposit feeder	Common 350/m^2	Coastal New England	Mud or gravel from low water to 12 m
Capitella capitata	Polychaete	Burrows, deposit feeder	Abundant 1,253/m^2	Cosmopolitan	In gravel, mud or sand, near low tide
Clymenella torquata	Polychaete	Builds sand-mucous tubes	Very common	Bay of Fundy to New Jersey	Sand or fine mud, sheltered spots in coves or marsh

Diopatra cuprea	Plumed worm	Builds parchment tube, covers with shell, algae	Common	S. New England to S. Carolina	Shallow water below low tide mark
Eteone alba	Polychaete	Burrows, deposit feeder	Common 170/m^2	Southern New England	Sandy mud
Fabricia sabella	Polychaete	Tube dweller, filter feeder	Common 330/m^2	New England	Sandy bottom at low tide mark
Harmathoe extenuata	Polychaete, scale worm	Burrows, predatory	Common	Maine to Delaware	Under stones, algae
H. imbricata	Polychaete	Burrows, predatory	Very common	Maine to N.J.	Often among mussels
Heteromastus filiformis	Polychaete	Burrows, deposit feeder	Common 3,131/m^2		Low O_2 areas, mud
Hydroides dianthus	Polychaete	Tube dweller, filter feeder	Very common 113/m^2	Cape Cod to Florida	Sand, long twisted calcareous tubes on shells esp. Mercenaria
Nereis caudata	Polychaete	Burrows, deposit feeder	Common 409/m^2	Southern New England	Pilings and algae, may swim at night
N. succinea	Clam worm	Burrows, deposit feeder	Common 166/m^2	Maine to Florida	Peaty banks, marsh clay or mud
N. virens	Common clam worm	Burrows, deposit feeder	Abundant 487/m^2	Labrador to S. New England	Euryhaline-marine sheltered bays, intertidal and low water mark, sand or mud
Pectenaria gouldii	Polychaete	Conical sand tubes	Common		Intertidal
Phyllodoce groenlandica	Polychaete	Burrows, deposit feeder	Common	New England	Mud
Podarke obscura	Polychaete	Burrows, deposit feeder	Abundant 851/m^2	Southern New England	Muddy sand, eelgrass shallow quiet water
Polydora ciliata	Polychaete	Builds upright tube in sand or mud	Abundant 1,068/m^2	Coastal Mass.	Estuaries

P. ligni	Polychaete	Verticle burrow in clay or mud	Common 587/m^2	New England	Estuaries, often in mud or clay
P. tetrabranchia	Polychaete	Burrows, deposit feeder	Abundant 42/m^2	Rhode Island, Massachusetts	Usually in mud
Prionospio malmgreni	Polychaete	Burrows, deposit feeder	Abundant 7/116/m^2	New England	Sandy areas at low water mark
Spio setosa	Polychaete	Builds fragile chimney-like tubes	Common 176/m^2	Woods Hole to Long Island	Sandy bottom at low tide mark
S. filicornis	Polychaete	Burrows, deposit feeder	Common 170/m^2		Usually in mud
Cerebratulus lacteus	Nemertean worm, ribbon worm	Very large, often to 7 m in length & 2.5 cm wide; burrows in sand or mud, swims at night	Very common	Maine to New Jersey	Sand or mud in quiet waters, well into marsh below high tide line
Aequipecten irradians	Common bay scallop	Burrows, moves by shell movement, filter feeder	Abundant locally	Cape Cod to North Carolina	Sandy bottoms, both inshore and offshore often with eelgrass in lagoons exposed or subtidal
Anomia simplex	Smooth jingle shell	Attacheds to hard substrate, filter feeder	Common	Nova Scotia to West Indies	Near low water on rocks, shells, etc.
Corbula contracta	Contracted basket shell	Burrows, filter feeder	Abundant 258/m^2	Cape Cod to Jamaica	Sandy or muddy shallows
Crassostrea virginica	American oyster	Attached to shell debris, rocks, filter feeder	Abundant locally; subject to overfishing	Mass. to Gulf of Mexico	Estuarine, in regions of low water mark to 12.2 m below
Ensis directus	Common razor clam	Rapid vertical burrower in sand, filter feeder	Common	Labrador to Florida	Lives on sandy bottom at low water mark
Gemma gemma	Gem clam	Burrows slightly in sand, 7-17 cm; filter feeder	Abundant 13,083/m^2	Labrador to Cape Hatteras	Shallow waters, sand or fine mud coves along shores or in tidal flats to 2 m below low tide

Laevicardium mortoni	Morton's cockle	Free unattached, burrows slightly, filter feeder	Abundant 357/m^2	Martha's Vineyard to Long Island	Muddy sand, occasionally with eelgrass, in sheltered shallow water
Lyonsia hyalina	Glassy lyonsia	Burrows, filter feeder	Common to uncommon 150/m^2	Gulf St. Lawrence to Tex.	Shallow sandy bottom
Macoma balthica	The little macoma	Deposit feeder in organic muds to 6 cm	Common 181/m^2	Arctic to Ga.	Sand or mud, sheltered bays, lagoons just below low water mark.
Mercenaria mercenaria	Quahog or little neck or hard shell clam	Burrows in sand or mud, filter feeder	Very abundant 93/m^2	Gulf of St. Law. to Mex.	Intertidal flats and lagoons with sand-mud bottom exposed at low tide
Modiolus demissus	Ribbed mussel	Attached by byssal threads upright to substrate, filter feeder	Abundant 10/m^2	Prince Edward Island to S.C.	Mud flats and sand spit often exposed at low tide characteristic of marsh
Mulinia lateralis	Coot clam, little surf clam	Burrows, suspension feeder; prey of fish	Common 77/m^2	New Bruns. to Texas	Shallows in mud or clay; occasionally in sand beach in surf
Mya arenaria	Soft shell clam, long neck clam	Burrows in sand 30 cm or more with siphon to surface; filter feeder	Abundant 164/m^2	Arctic to N. Carolina	Intertidal sand flats and shores exposed during low tide
Mytilus edulis	Blue mussel edible mussel	Attached to substrate by byssal threads; filter fdr.	Abundant 227/m^2	Arctic to N. Carolina	Found in marine waters on rocks, pilings, gravel, any hard substrate, mid-tide to low tide level
Nucula delphinodonta	Nut clam	Burrows; filter fdr.	Common 83/m^2	Arctic to New Jersey	Subtidal in mud
Petricola pholadiformis	Rock borer false angel wing	Bores into clay or soft rock or peat; modified deposit fdr.	Common 170/m^2	PEI to Texas	Bores in clay and soft rock around low tide mark
Solemya velum	Clam	Usually buried; may swim about	Fairly common	Nova Scotia to Florida	Intertidal mud flats and mud subtidally

Spisula solidissima	Surf clam or hen clam	Suspension feeder, partially buried	Abundant 105/m^2	Gulf of St. Law. to Cape Hatteras	Lives in surf just under sand of beach below low water mark on exposed beaches
Tellina agilis (tenera)	Delicate tellin	Deposit feeder in fine sand or muddy sand	Common 283/m^2	PEI to Gulf of Mex.	Sandy bottoms below water on intertidal fauna
Bittium alternatum	Gastropod	Grazer on hard surfaces and eelgrass	Common-ext. abund. 2,115/m^2	PEI to N.C.	Tidal flats and in shallow water offshore
Busycon canaliculatum	Channeled whelk	Grazer and predator by boring other molluscs	Abundant	S. New Eng. to N. Florida	Sandy bottoms in shallow waters
Busycon carica	Knobbed whelk	Predacious carnivore of oysters and clams	Fairly common	N.E. to Cape Hatteras	Shallow sandy bottoms
Crepidula convexa	Gray slipper shell	Suspension feeder	Fairly common 292/m^2	Nova Scotia to Fla.	Attached to shells of other molluscs, seaweed, rocks or other hard substrate, littoral
Crepidula fornicata	Boat shell, slipper shell	Suspension feeder, largest of local species; forms stacks	Abundant	PEI to Texas	Littoral and offshore; attached to other shells
Eupleura caudata	Thick-lipped drill	Predacious carnivore, boring organ	Common	Mass. to Fla.	Hard substrate, lower littoral and subtidal
Haminoea solitaria	Gastropod		Common 371/m^2	New England	Mainly in muddier inlet with eelgrass
Hydrobia sp.	Spire shell	Minute microphagus feeder	Fairly common	Lab. to N.J.	Marine to brackish water often in salt marshes
Lacuna vincta	Little chink shell	Microphagus herbivore, mostly algae	Often abundant	Lab. to N.J.	Lower littoral and shallow water, found entangled with Laminaria

Littorina littorea	Common periwinkle	Microphagus herbivore, mostly algae	Very abundant 50/m^2	Canada to N.J.	At all tide levels, marshes, rocks, mud and sand flats
Littorina saxatilis	Rough periwinkle	Microphagus feeder, herbivore	Fairly common	Lab. to N.J.	Withstands dessication, extends to upper limits of tidal zone in marshes
Lunatia (=Polinices) heros	Common moon shell	Predacious carnivore, bores other molluscs, burrows in sand	Common	Gulf of St. Law. to N.C.	Marine, sensitive to low salinity, sand and mud flats in shallow waters
Mitrella lunata	Lunar columbella	Predacious carnivore	Very abundant 214/m^2	PEI to Gulf of Mexico	Low water mark and shallows, mud and sand
Nassarius obsoletus	Mud snail	Predacious carnivore, bores other molluscs	Very abundant 35/m^2	Nova Scotia to Florida	Common on intertidal mud flats and shallows subtidally, estuarine
Odostomia bisuturalis	Pyramid shell	Ectoparasite on other shells; grazer	Fairly common 400/m^2	Gulf of St. Law. to Del. Bay	Lives on shells of Crepidula
Polinices duplicatus	Shark eye	Predacious carnivore, bores other molluscs	Abundant	Mass. Bay to Gulf of Mex.	Burrows in sandy bottoms of shallows, intertidal, survives low salinity and high temperature
Retusa canaliculata	Lathe shell	Crawls, scavenger	Very common	New Eng. to Fla.	Sand and mud flats intertidally in shallow water
Urosalpinx cinerea	Oyster drill	Boring gastropod, feeds on molluscs and barnacles	Very common	PEI to Fla.	Oyster beds, intolerant of low salinities, seek hard substrates
Mysis stenolepis	Mysid	Swims and creeps	Common	N. Eng. south	Usually found in eelgrass
Sarsiella americana	Ostracod	Filter feeder	Common 1793/m^2	Woods Hole	Eelgrass and hydroids
Cytheridea americana	Ostracod	Filter feeder	Fairly common 89/m^2	S. New Engl.	Shallow marine waters
Diastylis polita	Cumacean	Swimming	Fairly common 133/m^2	Nova Scotia to Bahamas	Soft mud or sand
Cylindroleberis mariae	Ostracod	Filter feeder	Fairly common 6,327/m^2	Southern N.E.	Among eelgrass and hydroids

Oxyurostylis smithi	Cumacean	Swimming	Fairly common 317/m^2	Casco Bay to La.	Soft mud or sand
Ampelisca macrocephala	Amphipod	Creeps in vegetation	Common	Arctic to L.I.	Eelgrass on muddy bottom
Amphithoe sp.	Amphipod sand hopper	Swims, creeps scavenger	Common 546/m^2	NE coast	Sheltered areas at surface especially algae or mud
Corophium cylindricum	Amphipod	Lives in soft tubes, scavenger	Common 4457/m^2	South NE to New Jersey	Builds soft tubes at base of eelgrass in shallow water
Haustorius arenarius	Amphipod	Rapid burrower, filter feeder	Common 402/m^2	Cape Cod to Georgia	Sandy shores near low water
Microdeutopus gryllatolpa	Amphipod	Swimmer, scavenger	Common 1264/m^2	Southern N.E.	Among seaweeds and hydroids
Cyathura polita	Isopod	Swimmer, scavenger	Common 545/m^2	Lab. to Southern New Eng.	Areas of low salinity tidal drainages of ponds
Edotea montosa	Isopod	Swimmer, scavenger	Common 99/m^2	Nova Scotia to Long Isl.	Dirt or fine sand below low water mark
Erichsonella attenuata	Isopod	Swimmer, scavenger	Uncommon 162/m^2	S. NE coast	Among eelgrass and algae
Irichsonella filiformis	Isopod	Swimmer, scavenger	Common	S. NE coast	Among eelgrass and algae
Idothea balthica	Marine sow-bug	Swimmer, scavenger	Common 158/m^2	Gulf St. Law. to N. Car.	On floating seaweed and rocks
Idothea phosphorea	Isopod	Swimmer, scavenger	Common 93/m^2	Gulf St. Law. to New Haven, Connecticut	Among weeds and on gravel bottoms
Jaera marina	Isopod	Swimmer, scavenger	Common	Lab. to S. NE	Tidal zone among vegetat.
Leptochelia savignyi	Isopod	Deposit feeder, scavenger, swims	Abundant	Cape Cod to New Jersey	Eelgrass and algae near surface
Philoscia vittata	Isopod	Scavenger	Abundant 58/m^2	S. NE coast	Under stones, wood, rubbish below low tide

Limulus polyphemus	Horseshoe crab	Burrows, feeds on worms in soft bottoms	Common	Nova Scotia to Florida	Lives in shallows of mud and sand on intertidal flats and lagoons
Callinectes sapidus	Blue crab	Swimming crab, carnivorous	Abundant - commercially sought	Cape Cod to Florida	Common in grassy bays and salt water ponds, euryhaline
Carcinus maenus	Green crab	Swimming crab, carnivorous	Very common	NE to NJ	Shallow marine and brackish water, under rocks, algae, grasses
Libinia dubia	Spider crab	Crawls, uses camouflage	Abundant	Cape Cod south	Common on oyster beds and other muddy bottoms
Libinia emarginata	Common spider crab	Crawls, uses camouflage, scavenger	Common	Maine to Fla.	Common on oyster beds and other muddy bottoms
Ovalipes ocellatus	Lady crab, calico crab	Scavenger, swims, may partially bury	Common	Cape Cod to S. Carolina	Sandy bottoms at low water and subtidally
Pagurus longicarpus	Hermit crab	Motile, crawls, inhabits shells abandoned	Abundant	Cape Cod to S. Carolina	Found in rock pools, intertidal flats, both sand and mud, marshes
Panopeus herbstii	Mud crabs	Stout built carnivores	Common	Boston to Brazil	Common on oyster beds and other muddy bottoms with shells or rocks
Golfingia gouldii	Sipunculid	Detritus feeders, ciliary mucous system	Fairly common	Southern NE	Sandy intertidal and shallow waters
Chiridota laevis	Holothurian	Feeds on plankton, burrows in sand	Abundant 311/m^2	Cape Cod to Arctic	Shallow waters with sand bottom
Leptosynapta tenuis	Holothurian	Burrows in sand or clear mud, deposit feeder	Common	Maine to S. Carolina	Sand, mud or gravel between tides into sublittoral
Botryllus schlosseri	Ascidian	Filter feeder, colonial mass on hard surfaces	Very common	Massachusetts southward	On eelgrass, pilings, hydroid stems, rocks

Molgula manhattensis	Sea grapes, ascidian	Filter feeder, jelly-like, attached to hard substrates	Very common	Massachusetts southerward	Attaches to rocks, shell, eelgrass, wood structures
Asterias forbesi	Starfish	Predacious, feeds on small bivalve molluscs, barnacles, echinoids and some crabs	Abundant locally	Maine to Gulf of Mexico	On sand or rocky substrates from low water to 60 m
Crangon septemspinosus	Sand shrimp	Burrows in sand, scavenger, feeds on worms, larvae, eggs	Ext. abundant	Baffin Bay to Florida	Sand flats, salt marsh adjacent tidal stream flats below low marsh

Table 4-79 Shallow Salt Pond (Pelagic & Shore species)

SPECIES	COMMON NAME	HABIT	RELATIVE DOMINANCE	DISTRIBUTION	HABITAT PREFERENCE
Zostera marina	eelgrass	submerged	abundant-summer	Maine to N.C.	shallow sand-mud bottom beyond low tide mark in bays and estuaries
Ruppia maritima	ditch grass	tops emergent	abundant-summer	cosmopolitan	mud marsh embayments
Ulva lactuca	sea lettuce	floating or attached up to .7m high	common-yearround SpSF abundant	Maine to Fla.	euryhaline,shallow embayments between tidal limits.
Enteromorpha sp.	green algae	attached up to 3m high	SpF abundant-occurs yearround	Maine to GA.	sand bottoms or rocks.
Agardhiella tenera	red algae	attached,20cm high,bushy	abundant-summer	Cape Cod to Fla.	sand bottoms or rocks.
Cladophora sp.	green algae	attached,filamentous 3m lengths	dominant summer abundant SpF	Maine to Va.	sand or mud bottoms.
Codium fragile	green algae	attached	common yearround	Cape Cod to N. C.	rocks or shell debris. Survives low salinity in winter.
Ascophyllum nodosum	brown algae-wrack	attached	common yearround	Maine to Ches. Bay	rocks or shell debris
Ceramium rubrum	red algae	13cm attached or free	abundant summer yearround	Maine to Fla.	marine, euryhaline in winter, low tide mark & below
Fucus vesiculosis	brown algae rockweed	attached 3-1m long	yearround,winter dominant	Maine to N.J.	euryhaline,rocks and shell debris in upper tidal region

Laminaria agarhii	kelp,brown algae	attached 2m long	yearround	Maine to Del.	rocks below low tide.
Punctaria plantaginea	brown algae	attached,large blades	common, winter		euryhaline
Rhodymenia palmata	dulce,red algae	attached	yearround	Maine to Del.	deeper waters, marine
Scytosiphon lomentaria	brown algae	attached,num. narrow blades	common winter	cosmopolitan	
Polysiphonia sp.	red algae	attached on Ascophyllum	abundant summer	Maine to Del.	euryhaline
Lyngbya sp.	mermaid's hair	filamentous 1m long	common abundant summer	Maine to S.C.	tidal creeks on mud soil stabilizer upper intertidal.
Spyridia filamentosa			common abundant summer		euryhaline,winter
Gracilaria verrucosa	red algae	attached	common abundant summer		marine euryhaline winter
Chondrus crispus	Irish moss, red algae	attached 5-15cm	common grows actively yearround	Maine to Del.	marine, rocks or shell debris in tidal pools or standing water.
Skeletonema costatum	diatom	plankton	abundant $13X10^6/L$	Cosmopolitan	marine,shallow photic zone.
Leptocylindrus minimus	diatom	plankton	abundant	cosmopolitan	marine,photic zone.
Chaetoceros sp.	" "	" "	abundant $8X10^6/L$	" "	" "
Asterionella japonica	" "	" "	common $6X10^6/L$	" "	" "
Nitzchia sp.	" "	" "	common $.03X10^6/L$	" "	" "
Thalassiosira sp	" "	" "	common $.84X10^6/L$	" "	" "

Amphidinium sp.	dinoflagellat	feeble swimming	abundant $2.8X10^3/L$	cosmopolitan	marine photic zone
Ceratium sp.	" "	" "	abundant $6.4X10^3/L$	" "	" "
Peridinium sp.	" "	" "	abundant $4.0X10^3/L$	" "	" "
Dinophysis	" "	" "	abundant $1.2X10^3/L$	" "	" "
Asteromonas propulsion	microflagellate	plankton	abundant WSp	" "	" "
Gyrodinium estuariale	" "	" "	common	" "	" "
Nephrochloris salina	" "	" "	" "	" "	" "
Bipedinomonas pyriformis	" "	" "	" "	" "	" "
Massartia rotundata	" "	" "	" "	" "	" "
Rhodomonas minuta	" "	" "	" "	" "	" "
Acartia clausi	copepod	zooplankton	abundant WSp	" "	marine
A. tonsa	" "	" "	abundant S	" "	euryhaline
Centropages hamatus	" "	" "	common WSp	" "	
Oithona brevicornis	" "	" "	common SpS	" "	
Eurytemora hirundoides	" "	" "	common WSp	" "	
Harpacticoids		" "	yearround	" "	bottom dwellers

Larvae					
Nepthys	polychaete	plankton	abundant-yearround	cosmopolitan	marine-brackish water free-swimming for 2-4 weeks, photopositive, feed on other planktonic forms
Polydora	" "	" "	" "		
Nereis	" "	" "	" "		
Balanus	barnacle	" "	" "	" "	
Lacuna	gastropod	" "	" "	" "	
Littorina	" "	" "	abundant SpSF		
Mya, Mytilus	bivalves	" "	" "	" "	
Mercenaria					
Crassostrea					
Synchaeta littoralis	rotifer	free swimming	Common SpSFW		
Mnemiopsis leidyi	comb jelly	free swimming	abundant F 15/m^3	Cape Cod to Fla	shallow water, marine
Aurelia aurita	moon jelly-fish	free swimming and polyp	abundant Sp	Maine to Fla.	pelagic marine waters, sand, littoral region
Dactylometra sp	jelly fish	free swimming and polyp	abundant Sp		pelagic and benthic stage sand bottom littoral
Agelaius phoenicus	red wing blackbird	breeds, migrates winters feeds on weed seeds, insects	common	Nova Scotia-Fla.	marshes, salt & fresh nests in marsh shrubs
Anas platyrhychos	mallard	breeds, migrates, winters feeds on 90% vegetable plus insects, nests on ground	common	Maine, Mass, R.I. & Southward	salt marsh, salt ponds, and bays

Anas rubripes	black duck	breeds, migrates winters, 75% vegetation 25% animals includes eelgrass , clams	abundant	Nfoundland-Va	salt ponds, marshes, swamps, gathers in estuaries,mud flats
Ardea herodias	great blue heron	resident, migrates winters feeds on fish insects, vegetation	common	Mass.southward	shallow water, shores of marshes bays, tidal flats sandbars,marine or brackish
Aythya marila	greater scaup	migrates,winters feeds on seeds, clams grass	abundant 2500/ flock recorded	Quebec-Fla.	bays, salt water ponds estuaries, marshes
Branta canadensis	Canada goose	breeds,migrates, winters, feeds mainly on vegetation marsh grasses eelgrass, etc.	abundant	S.N.Eng.north ward	sand and mud flats,marshes, graze in upland coastal bay
Bucephala clangula	common golden eye	migrates,winters, feeds on clams, crustaceans, worms.	abundant	Cape Cod to N.C.	broad estuaries and bay regular on ponds during migration
Butorides virescens	green heron	breeds,migrates winters feeds on fish	common locally abundant	Maine to Fla.	fresh and salt water ponds
Chlidonias niger	black tern	breeds,migrates feeds on fish	common	Maine to Fla.	marshes and coastal waters
Clangula hyemalis	oldsquaw	migrates,winters feeds on mussels fish aquatic plants	abundant	Nfoundland-N.C.	shallow offshore waters sandy bottoms,mussel beds,estuaries
Cygnus olor	mute swan	breeds winters	common locally	R.I., Conn., N.J.	marshes,ponds of southern New England

Larus argentatus	herring gull	breeds,winters migrates,feeds on carrion,fish crustaceans urchins	abundant	breeds L.I. Northward, migrates entire Atlantic coast	lakes,bays,estuaries beaches, tidal flats
Larus atricilla	laughing gull	breeds,winters migrates,feeds on garbage,fish clams crustaceans	common	Nova Scotia to N.C.	salt marsh, ocean beaches bays
Larus delawarensis	ring-billed gull	breeds,summers winters,mig. fish and scavengers	common	Nfoundland to Fla.	often along coastal ponds, and inland
Larus marinus	great black backed gull	breeds,summers winters,feeds on fish,clams crustaceans	common	Greenland to Va.	beaches,harbors, ponds,tidal rivers
Mareca americana	American widgeon	yearround,winters feeds on vegetation grains	common	New Eng. -Fla.	along shores, ponds,marshes
Melanitta deglandi	White wing scoter	winters,summers migrates,feeds on mussels,eelgrass,clams	abundant	Gulf, St. Law.-S.C.	shallow salt water estuaries to ocean,flats
Mergus merganser	common merganser	winters,migrates feeds on fish	common	New Brunswick to N.C.	mostly fresh water,upper parts of salt ponds
Pandion haliaetus	osprey	breeds,winters, migrates,feeds on surface or shallow water fish	rare to uncommon	Nfoundland to Fla	lakes,bays,estuaries

Sterna albifrons	least tern	summer resident, winters, feeds on small fish, insects	common	N. Eng. to Fla.	sandy beaches and ponds
Sterna hirundo	common tern	breeds, migrates, winters, feeds on small fish, alewives, herring, crustaceans	abundant	Nfoundland to N.C.	off shore to protected beaches and marshes

Fishes

The following is a list of fishes normally found in the Salt Pond habitat within the continental shelf area between Sandy Hook, New Jersey, and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance

A. The geographical distribution includes three categories

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west of that line.

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south, or throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh-water

Brackish water

Nearshore - coastline to 10 fms

Coastal - out to 50 fms

Offshore - 50 fms to the continental slope

Basin - deep basin of the Gulf of Maine

Banks - shallow offshore bank areas, i.e., Georges Bank

Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent to the habitat, a commercially important species or a rare or endangered species. The life history of these species will be treated in Chapter 12.0.

TABLE 4-80 CHECKLIST OF FISHES: SALT PONDS

SPECIES	GEOGRAPHICAL DISTRIBUTION ABUNDANCE	DEPTH DISTRIBUTION	HABIT
HERRING AND TARPONS			
Alewife *Alosa pseudoharengus*	abundant throughout	fresh water to coastal	food-zooplankton; anadromous
SMELTS			
Rainbow smelt*** *Osmerus mordax*	abundant throughout	brackish to nearshore	food-small fish crustaceans,spawns brackish
EELS			
American eel*** *Anguilla rostrata*	common throughout	fresh to oceanic	food-scavenger, living and dead animals;catadromous
KILLIFISHES			
Mummichog*** *Fundulus heteroclitus*	abundant throughout	fresh to nearshore	food-omnivorous, plant and small animals,scavengers
Striped killifish *Fundulus majalis*	abundant south	nearshore	food-small animals
Banded killifish *Fundulus diaphanus*	common south	brackish to nearshore	food-small animals
Rainwater killifish *Lucania parva*	common south	brackish to nearshore	food-small animals
Sheepshead minnow *Cyprinodon variegatus*	common south	brackish to nearshore	food-small animals
CODFISHES			
Tomcod *Microgadus tomcod*	common throughout	brackish to nearshore	food-small crustaceans
FLOUNDERS			
Winter flounder*** *Pseudopleuronectes americanus*	abundant throughout	brackish to coastal,banks to 128 m	food-small bottom invertebrates
Hogchoker *Trinectes maculatus*	occasional south	fresh to brackish	food-annelid worms, small crustaceans

SILVERSIDES			
Silversides*** *Menidia menidia*	abundant south	brackish to nearshore	food-small crustaceans,fish eggs,invertebrate larvae,vegetable matter
Tidewater silversides *Menidia beryllina*	common south	fresh to nearshore	food-small crust-aceans,fish eggs, invertebrate larvae
STICKLEBACKS			
Ninespined stickleback *Pungitus pungitus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans,fish eggs and fry
Threespined stickleback *Gasterosteus aculeatus*	abundant through out	fresh to nearshore	food-copepods,other small crustaceans, fish eggs and fry
Fourspined stickleback *Apeltes quadracus*	common throughout	fresh to nearshore	food-copepods,other small crustaceans fish eggs and fry
Blackspotted stickleback *Gasterosteus wheatlandi*	common throughout	fresh to nearshore	food-copepods,other small crustaceans, fish eggs and fry
PIPEFISHES			
Northern pipefish *Syngnathus fuscus*	common north	brackish to nearshore to 31m	food-copepods, amphipods,fish eggs and fry
Lined seahorse *Hippocampus erectus*	occasional south	brackish to nearshore	foo-copepods, amphipods,fish eggs and fry
TEMPERATE BASSES			
White perch *Morone americana*	common throughout	fresh to nearshore	food-small crustaceans,fish fry
CUNNERS			
Tautog *Tautoga onitis*	Abundant south	brackish to coastal to 37m	food-molluscs,other invertebrates
Cunner Tautogolabrus *adspersus*	abundant throughout	nearshore to coastal,banks to 128m	food-omnivorous scavenger

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4.5.4 SALT MARSH

This section treats the biology of the salt marsh community. The habitat is defined, its function explained, man's influence discussed, the organisms that inhabit it listed and its areal distribution shown. The major biological components of the habitat are the benthic invertebrates, macrophytes, fishes and birds. For a detailed description of the life history and ecology of these taxonomic groups the reader is referred to the Plant and Animal Profiles, Chapters 10.0, Benthic Invertebrates; 11.0, Macrophytes; 12.0, Fishes; 12.0, Birds.

HABITAT DEFINITION/DESCRIPTION

Salt marshes are those areas protected from wave action between high and mid-tide levels, where the salt-resistant grasses *Spartina alterniflora* and *S. patens* have colonized the mud surface. As the grasses grow from year to year, the mud-flat area becomes reduced to meandering tidal channels or creeks flowing through beds of *Spartina*. In a well-developed salt marsh, the *Spartina* inhabits large islands of peat separated by tidal channels (see e.g., Hay and Farb, 1966 or Leonard, 1972 for popularized description of this habitat).

HABITAT DYNAMICS

Environmental Conditions

In the salt marsh itself the most important environmental characteristic is the daily tidal fluctuation. Because the marsh lies above MTL, exposure alternates with immersion twice each day. The level of tidal rise and fall determines the boundaries of the marsh and the distribution of species within it, due to differing physiological tolerances for immersion or dessication.

A second characteristic is the steady accumulation of silt on the marsh surface due to the reduction of current speed as it passes through the grass stems. This results in a steady increase in peat thickness. Accompanying this accumulation is a steady export of plant detritus on ebb tides.

Microenvironments

In the salt marsh itself, several microenvironments can be found. Along the blades of *Spartina* grows a garden of diatoms and other microepifauna. Grazers utilize this growth. On and under the mud surface live many types of deposit feeders. On the peat bank at the edge of the tidal creek can live epifauna. Adjacent to the marsh, two microenvironments are found in and under the bottom of the channel. Proceeding inland from the salt marsh edge, there is increasing irregularity of the amount of tidal cover because of the unequal heights of the two high tides per day compounded by the bimonthly rise and fall of tidal range. Consequently

there is a gradient of increasing exposure to dessication moving inland or, conversely, of immersion moving seaward. This gradient is reflected in the distribution of species within the microenvironments.

Recently a study of a New England salt marsh, Bissel Cove, off Narragansett Bay, R.I., has appeared (Nixon and Oviatt, 1973). The authors found several fundamental differences in the way this marsh functions in comparison with the Georgia marshes which were previously most thoroughly studied on the East Coast, and so had been used as models for the whole coast. Because of that finding, as well as the study's completeness, uniqueness, and relevancy to the present study area, the following discussion will be based on Nixon and Oviatt's (1973) study, except where noted.

Nutrient Cycles and Seasonal Cycles

A salt marsh is markedly affected by seasonal changes. *Spartina* itself undergoes seasonal changes in growth and decay. From spring through summer, the grass grows. In late summer, reproduction occurs and by late fall the grass becomes dormant. Winter ice and storms shear off the dead blades, making way for the new spring shoots.

Salt marshes export much of their production - 90 percent in Georgia (de la Cruz, 1973) and 10 to 30 percent in Bissel Cove - as either dead grass stems or as smaller, more decomposed detritus. In Bissel Cove, the stems are exported in two bursts; one in the spring following ice melt and one during a February thaw. The fine particles of detritus were exported at a steady rate throughout the year, but at values much below that for southern marshes.

There is a markedly seasonal shift in animal populations in the marsh and adjoining flats. Some species were present all year (e.g., black duck, *Anas rubripes*, but in general, shrimp (e.g., *Palaemonetes pugio*) and fish (e.g., *Fundulus*) were most abundant in the fall and birds in the winter and spring. Herring gulls and terns showed a pattern of seasonal replacement; gulls were abundant during the fall and winter until the common terns arrived in the early spring. The common terns were replaced by the least tern during the summer which remained until the gulls returned.

Finally respiration and production also show a seasonal change. These two measures of metabolism rise in March to a "summer" level by mid-April and then fall again in November to the winter minimum.

Food Webs

The food web diagram (Fig. 4-284) is modified from Nixon and Oviatt,

(1973). The authors noted one specific interaction that deserves mention. The diet of the shrimp, P. pugio, was found to be omnivorous, consisting of fish and small crustaceans and pieces of plant detritus. Their manipulation of the detritus helps break down the cellulose walls of the plant tissue allowing invasion by diatoms and decomposers. The shrimp waste also seemed to fertilize the detritus, increasing the heterotrophic activity.

Relative Productivity

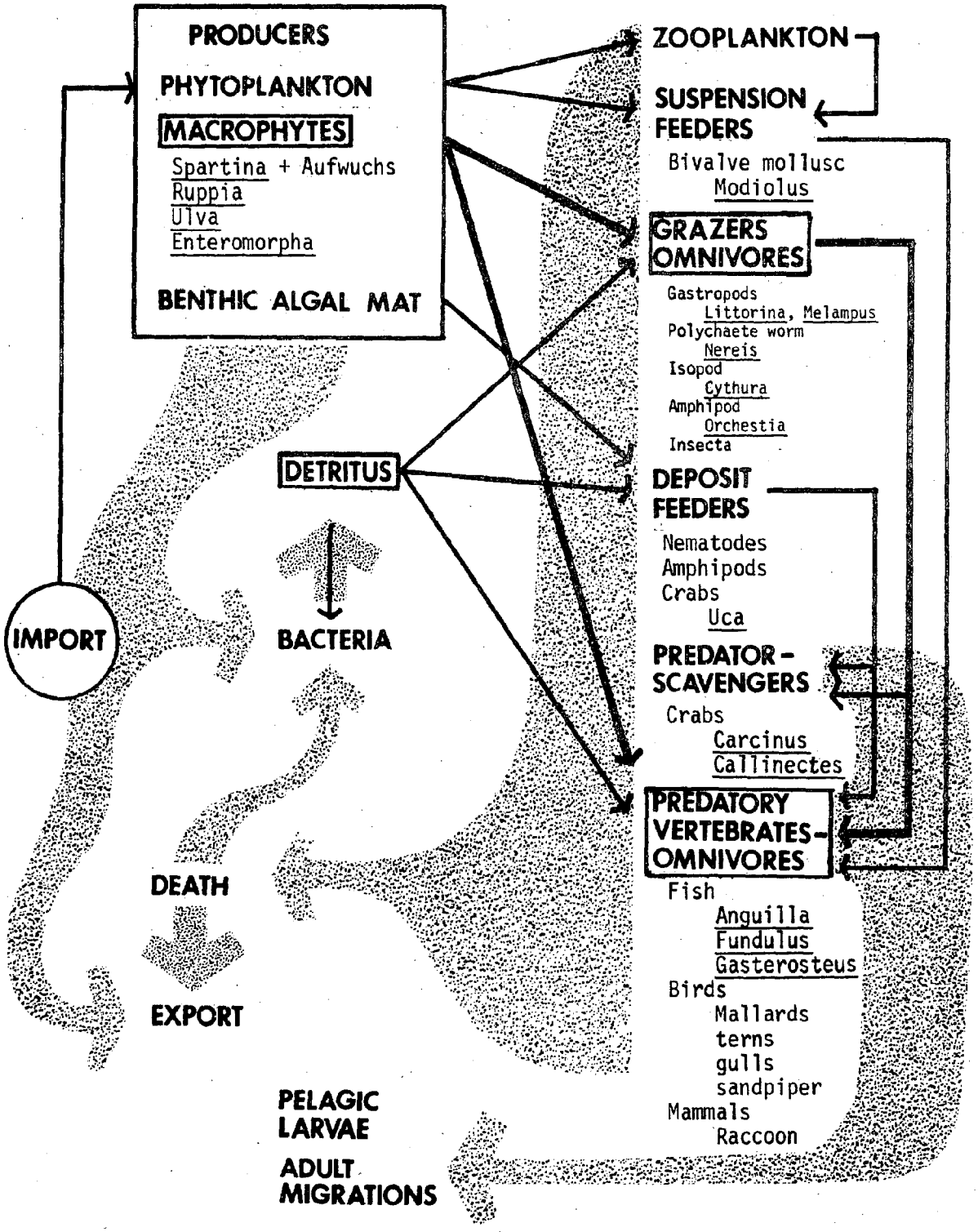
Northern salt marshes are considerably less productive than southern ones, but are nevertheless very productive with relation to other ecosystems. The overall efficiency of net production for all marsh grasses is 0.24 percent in Bissel Cove, while the same measure is 1.1 percent in Georgia marshes, and 0.1 percent in the tundra and subtropical ocean waters. The following tables, 4-81 to 4-83, (taken from Nixon and Oviatt, 1973) present some measures of several components of productivity.

Natural Stress

The major stresses in the salt marsh are due to the wide variations, diurnal and seasonal, in salinity, temperature, and dissolved oxygen. Salinity varies from 1 to 28 percent over the year and can show a 6 percent change during a day. Temperature ranges up to 10 C daily and from -0.5 C to 30.5 C over a year. Although the water never becomes anaerobic, dissolved oxygen can vary from 4 mg h^{-1} to 12 mg h^{-1} over 24 hours. Added to these stresses are the threat of dessication from the summer sun during daytime low tides and ice scour during the winter. Nixon and Oviatt (1973) observed mass mortalities of shrimp during heavy ice cover.

EFFECT OF MAN-INDUCED STRESS

Oil spills have a major effect on contaminated marshes. Thomas (1973), studying a large Bunker C oil spill in Chedabucto Bay, Nova Scotia, reported that Spartina alterniflora was eliminated in very heavily oiled areas. He noted that destruction of the blades above ground by oil had been observed before, but the shoots generally regenerated the following year from the underground rhizomes. At Chedabucto Bay, however, large quantities of the oil remained on the adjacent flats for at least two years due to the cool climate, and seeped from there onto the salt-marsh peat repeatedly. The repeated oilings killed the rhizomes, presumably by preventing oxygen from diffusing to them, and eliminated the salt marsh. Such results of an oil spill can be expected throughout most of the present study area because of a similarly cool climate. Any other pollutant that prevented diffusion to the rhizomes would also result in death of the grass.



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

TRIGOM PARC	FIGURE 4-284	Food Web of the Salt Marsh

Table 4-81 Biomass of *Spartina alterniflora* at end of growing season

Marsh Locality	Biomass (g dry weight m^{-2}
Georgia	1290
Virginia	1332
New Jersey	1600
Long Island	827
Rhode Island	840
Petpsewich, Nova Scotia	580

Table 4-82 Net phytoplankton production in some salt-marsh influenced areas

System	Net Production g $O_2 m^{-2} yr^{-1}$
Georgia estuary	648
Long Island salt marsh creeks	251 (gross)
Rhode Island	180

Table 4-83 Biomass of shrimp and fish in some aquatic ecosystems

System		Biomass (g dry wt. m^{-2})	
		Palaemonetes pugio	fish
Turtle grass community, Texas		1.75	0.08-0.5
Experimental estuarine pond, N.C. with sewage	summer	2.9	3-11
	fall	4.1	4-15
Bissel Cove, R.I.	summer	0.1	0.3-8
	fall	15.3	7-14
	winter	2.7	5

Persistent pesticides are a major problem in salt marshes because of the constant accumulation of detritus and the number of species that consume this detritus. Odum, Woodwell, and Wurster (1969) found that detrital particles (0-4000 μ) from a heavily sprayed marsh contained up to 50 ppm DDT residues. Fiddler crabs, Uca pubnax, that ate this detritus developed in five days an awkward and sluggish behavior that was detrimental to survival. Possibly this behavior could occur in other deposit-feeding organisms.

Dredging and filling of salt marshes is probably the major man-induced stress. Such activities destroy the marsh permanently. As an example of the magnitude of this problem, in one ten-mile stretch of Great South Bay, New York (Nassau-Suffolk County line to Captree Bridge), over 1100 acres of marsh were destroyed or degraded by dredging and filling from 1960-1966. (USFWS, 1970, vol. 3) "Significantly the six uses (of estuaries)found to cause the greatest problems are not particularly dependent on estuaries; these are: industry, mining, pest control, urbanization, waste disposal, and water supply" (USFWS, 1970, vol. 2). In other words, such uses could easily be located elsewhere.

BIOLOGICAL COMPONENTS

General Distribution

Zonation of plants in the salt marsh and adjacent flats is marked. Spartina alterniflora occupies the lower marsh to the tidal creeks. Spartina patens replaces alterniflora on high marsh and drier ground. Plants bordering the marsh are determined by the surrounding environment. If the marsh extends toward a sandy area, Iva frustescens (marsh elder) occurs next to the marsh and Panicum virgatium (tall parie grass) occurs next to the sand. If the marsh extends toward areas of copious fresh-water seepage, S. pectinata (tall cordgrass), Scirpeas americanus (three-square bulrush) and Phragmites communis (tall reed) are found in the seepages (Palmatier, 1973). Within the marsh, Distichlis specata is found around tide pools and Salicornia europea in salt pans. On the adjacent flat, Ruppia maritima is found where salinities are lower and Ulva lactuca and Enteromorpha in higher, more constant salinity (Nixon and Oviatt, 1973).

Animals are also highly zoned. Fiddler crabs and Melampus bidentatus are found in the high marsh on the sediment surface. Littorina littorea is found in the upper marsh both on the ground and grazing on Spartina blades. Burrowing in the peat are myriads of insect larvae. Along the edges of the peat banks bordering creeks, Modiolus demessus occurs often in large clumps.

The fauna of the tidal creek bottoms is very depauperate in New England marshes, presumably because of the very soft, anaerobic

sediments. Nematodes are the most important infauna, both in numbers and biomass. Epifaunal amphipods occur in the detrital mat and often crabs, such as Carcinus maenas (green crab) and Callinectes sapidus (blue crab), are abundant. Fish (e.g., Fundulus sp.) and shrimp are the most conspicuous and abundant in waters adjacent to salt marshes.

Species Checklist

The following are checklists of the benthic invertebrates, macrophytes, fishes and birds considered to be regular inhabitants of the salt marsh habitat.

Table 4-84 Salt marsh - benthic invertebrates

Species	Common Name	Habit	Relative Dominance	Distribution	Habitat Preference
Haliplanella luciae	sea anemone	attached to hard substrates	common	southern N. England	marshes, mussel beds brackish water
Hydractinia echinata	hydroid	plankton feeder, attached	v. common	Lab. to N.C.	patches on rocks and shells of living hermit crabs
Cerebratulus lacteus	nemertean worm, ribbon worm	very large, often to 7m in length & 2.5cm wide, burrows in sand or mud, swims at night	v. common	Maine to N.J.	sand or mud in quiet waters, well into marsh below high tide line
Ampharete arctica	polychaete	builds tubes of mud shell and algae, detritus feeder	common	New England	mud, estuaries, marsh
Axiothella catenata	polychaete	burrows, deposit feeder	fairly common	southern N. England	mud, marsh, estuary
Arcteobia anticostiensis	polychaete	burrows, deposit feeder	fairly common		usually in mud, marsh
Capitella capitata	polychaete	burrows, deposit feeder	abundant	cosmopolitan	in gravel, mud or sand near low tide mark, well into marsh
Clymenella torquata	polychaete	builds sand, mucous tubes	v. common	Bay of Fundy to N.J.	sand or fine mud, sheltered spots in coves or marsh
Harmathoe extenuata	polychaete	voracious predators, active creepers, swimmers, rock crevice livers	common	Maine to Del.	under stones, algae
H. imbricata	polychaete	voracious predators, active creepers, swimmers, rock crevice livers	v. common	Maine to N.J.	often among mussels

Heteromastus filiformis	polychaete	burrows, deposit feeder	common		mud, in low O_2 areas
Nereis succinea	polychaete	burrows in peaty banks, smaller than N. virens	common	Maine to Fla.	brackish water, marsh
Phyllodoce groenlandica	polychaete	burrows, deposit feeder	common	New England	mud
Callinectes sapidus	blue crab	swimming crab, but may burrow slightly in sand, predatory euryhaline	v. abundant	Cape Cod to Fla.	mid-littoral to well below low tide, grass bottoms, bays, adjacent to marshes
Carcinus maenus	green crab	swimming, crawling carnivorous	v. abundant	Maine to Del.	in vegetation and banks in brackish waters near low tide in marshes
Neopanope texana sayi	mud crab	crawls, slow, hides in vegetation, shells omnivorous	v. common	Canada to Fla.	muddy bottoms in lower salt marshes
Pagurus longicarpus	hermit crab	crawls, lives in abandoned mollusks shells (gastropod) diet of diatoms, detritus and algae	v. abundant	Nova Scotia to Fla.	mud flats, intertidal sand or marsh
Panopeus herbstii	mud crab	stoutly built, crawls, feeds on oysters, barnacles	common	Mass. to Brazil	muddy bottoms, shells in higher marshes often with Sesarma & Uca, estuarine
Sesarma reticulatum	marsh crab	burrows in salt marshes, diet is mainly Spartina, occasionally fiddler crab	v. common	Mass. to Texas	found in marshes to the landward, mud substrate
Uca pugilator	china-back fiddler crab	burrows in mud and sand of salt marsh omnivorous, bacteria detritus	v. abundant	Boston to Texas	prefers drier region of marsh, Salicornia in often adjacent areas where fresh-water flooding may occur

U. pugnax	mud or marsh fiddler crab	burrows about .8m below high tide mark in mud or clay among roots of Spartina plugs burrows during high tide. Feeds underwater on bacteria & organic detritus	v. abundant	Cape Cod to Fla.	wetter regions of marsh, mud and sand often in marsh vegetation
Polydora tetrabranchia	polychaete	burrows, deposit feeder	abundant	Mass, R.I.	mud
Spio filicornis	polychaete	burrows, deposit feeder	common		mud
Ensis directus	common razor clam	rapid vertical burrower in sand, filter feeder	common	Lab. to Fla.	sand, mud flats adjacent to lower marsh
Modiolus demissus	ribbed mussel	attached to substrate by byssal threads	abundant, dominant bivalve in marsh	PEI to S.C.	salt marsh, sand-mud flats around roots of vegetation
Mya arenaria	soft shell clam	burrows in muddy shallow bottoms, filter feeder	abundant	Arctic to Cape Hatteras	intertidal mud flats and shores exposed at low tide, usually adjacent to lower marsh
Tellina agilis	delicate tellin	deposit feeder in sand or fine mud	common	PEI to Gulf of Mexico	intertidal mud flats adjacent to lower marsh
Hydrobia sp.	spire shell	minute microphagous feeder	fairly common	Lab. to N.J.	marine to brackish water, often in marsh
Lacuna vincta	chink shell	microphagous feeder	often abundant	Lab. to N.J.	lower littoral in vegetation
Littorina littorea	common periwinkle	herbivore, microphagous feeder	v. abundant a dominant gastropod in marshes	Canada to N.J.	at all tide levels, mud, marsh and sand

L. saxatilis	rough periwinkle	herbivore, microphagous feeder	fairly common	Lab. to N.J.	upper limits of tidal zone, marshes, flats
Melampus bidentatus	salt marsh snail	pulmonate snail, feeds on algal detritus and grass stems	abundant	Nova Scotia to Texas	crawls on stems & leaves of S. alterniflora, salt hay and in the higer marshes
Amphithoe rubricata	amphipod	creeping, hopping may build tubes at bases of vegetation	common	Lab. to L.I.	under rocks, algae (a source of food) mud of marsh
Gammarus oceanicus	amphipod	creeps, hops, feeds on detritus and algae	common	Maine to southern N. Eng.	marine & brackish water in vegetation
G. tigrinus	amphipod	creeps, hops, feeds on detritus and algae	common	Maine to southern N. Eng.	marine & brackish water in vegetation
Cyathura polita	isopod	scavenger, lives in vegetation which provides food	abundant	Greenland to Virginia	low salinity, drainage areas or tidal flats usually in algae or grasses
Limnoria lignorum	isopod, gribble	scavenger, bores into pilings or wood debris	common	Maine to s. Cape Cod	at low tide in marshes often under debris
Orchestia platensis	amphipod, beach hopper	creeping, hopping, scavenger	common	N.H. to Fla.	among grasses, weeds mid-littoral to below low tide mark
O. uhleri	amphipod, beach hopper	creeping, hopping, scavenger	common	New England	among grasses, weeds mid-littoral to below low tide mark
Philoscia vittata	isopod	scavenger	abundant	s. New. Eng.	under stones, weeds rubbish near the high water mark

Neomysis americana	mysid, opossum shrimp	shrimp-like	common	Gulf. St.Law. to Virginia	inhabits rock pools, tidal streams in marshes
Grangon septemspinosus	sand shrimp	burrows in sand, scavenger, feeds on worms, larvae, eggs	ext. abundant	Baffin Bay to Fla.	salt marshes and adjacent tidal streams, flats below lower marsh
Limulus polyphemus	horseshoe crab	burrows, feeds on worms in soft bottoms	abundant	Maine to Fla.	mid-littoral to below low tide mark, adjacent to marshes
Balanus eburneus	barnacle	attached to hard substrate, filter feeder	common	Maine to s. Cape Cod	on mussels, shells, in marsh
B. improvisus	barnacle	attached to hard substrate, filter feeder	common	Maine to N.C.	on mussels, shells, in marsh
Palaemonetes pugio	grass shrimp	creeps on vegetation in pools	abundant	N.H. to Fla.	brackish to fresh water, marshes
P. vulgaris	com. grass shrimp	creeps on vegetation in pools	abundant	N.H. to Fla.	prefers higher salinity than *P. pugio*
Aedes sp. larvae	mosquito	feeds on organisms detritus	abundant	ubiquitous	brackish pools near extreme high tide level
Chironomid larvae		probably feeds on detritus	abundant	ubiquitous	mud in drainage ditches or mud flats where water is brackish

Table 4-85 Macrophytes

Species	Common Name	Habit	Relative Dominance	Distribution	Habitat Preference
Spartina alterniflora	smooth cord-grass	10cm to 2m high, high protein production	cosmopolitan dominant grass in lower marsh	Maine to S.C.	intertidal zone, borders all salt marshes, covers the low marsh, grows best in wet, high salinity soil regularly flooded
Spartina patens	salt meadow grass, salt hay marsh grass	15cm to 75 cm	dominant grass on fringe of high marsh	Maine to S.C.	high marsh, grows best in drier parts of the marsh, typically forms a mat as it dies seasonally
Distichlis spicata	spike grass	10cm to 1.2m perennial	abundant locally	Maine to Fla.	grows in clumps around edges of tide pools along tidal creeks and where there is considerable salt
Juncus gerardi	black grass rush	15cm to 80cm June-Sept main growth	abundant	Maine to Fla.	found in high marsh in drier soil, grows luxuriantly toward the upland
Typha latifolia	cattail	1-2.5m May-July main growth, perennial	abundant	Maine to Fla.	indicates fresh water in upland portions of the marsh
Phragmites communis	tall reed	1-4m tall perennial	abundant	Maine to Fla.	commonly grows along ditches
Salicornia europea	glasswort, chicken claws	1cm to 10cm tall, Aug.-Nov. annual, turns red in fall	common	Maine to Ga.	grows well in salt pannes or depressions in marsh

Limonium carolinianum	sea lavender marsh rosemary	15cm to 60 cm July-Oct.	common	Cape Cod to Fla.	high marsh plant
Baccharis halimifolia	sea myrtle	1m to 3m high Aug.-Sept. perennial	common	Cape Cod to Fla.	upland fringe, outer edge of marsh into upland
Solidago sempervirens	seaside golden rod	20cm to 2m high, July-Nov.	common	Maine to Cape Hatt.	upland fringe
Scirpus maritimus	bulrushes	30cm to 1m high, July-Oct perennial	abundant	Maine to Cape Hatt.	above high tide mark
Iva frustescens	marsh elder	up to 3m, shrub, perennial	common	Maine to Cape Hatt.	outer edge of marsh and high up on beach
Callothrix sp.	blue green algae	filamentous 25mm	common	Maine to Fla.	above high tide mark forms black-brown mat on rocks
Chaetomorpha sp.	green algae	up to .3m long	common	N.J. to Maine	lower intertidal area of marsh
Cladophora gracilis	green algae	30 cm or more in length	abundant	Maine to Va.	lower intertidal
Codium fragile	green algae	up to 1m long, attached	abundant	Cape Cod to N.C.	mid to lower intertidal on rocks or shell debris
Enteromorpha intestinalis	green algae	fronds up to 30cm 15cm wide	abundant	Maine to Ga.	shallow water and tidal pools
E. linza	green algae	up to 37cm, looks like Ulva	abundant	Maine to S.C.	shallow water
Lyngbya majuscula	mermaid's hair	threads up to 1m forms root-hold on mud for other plants often floating	common	Maine to S.C.	soft mud or marshes upper intertidal, stabilizes soils

Monostroma oxyspermum	green algae	2-10cm, in protected pools up to 60cm	common	Maine to Ches. Bay	shallow brackish water of marsh creeks some freshwater out-flow necessary
Rhizoclonium sp.	green algae	filamentous 7-10cm	common	Maine to N.C.	mud or sand flats intertidal brackish water
Rivularia atra	blue green algae	filamentous 5-7cm colonial	common	Maine to Ga.	tidal creek banks and under dried salt marsh grass in upper intertidal
Ulva lactuca	sea lettuce	up to 60cm long, attached or free floating	abundant	Maine to Fla.	grows between tide limits and in shallow embayments on sand or mud
Vaucheria sp.	yellow-green algae	microscopid, soil former in salt marshes, forms a mat on marsh flats	common	Maine to Fla.	salt flats, forms holds for other plants
Pennate diatoms Green flagellates Dinoflagellates	mud algae	found on surfaces of mud on marsh, microscopic	abundant	cosmopolitan	marine or brackish water forms, live on mud-soil surfaces which are regularly inundated or sub-tidal

Fishes

The following is a list of fishes normally found in the salt marsh habitat within the continental shelf area between Sandy Hook, New Jersey and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criterion has been the extent of the species' impact on a particular habitat, i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I Geographical distribution and relative abundance.

A. The geographical distribution includes three categories

North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through Georges Bank.

South - Primarily distributed south and west to that line

Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south, or throughout.

II Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh-water
Brackish water
Nearshore - coastline to 18 m
Coastal - out to 91 m
Offshore - 91 m to the continental slope
Basin - deep basin of the Gulf of Maine
Banks - shallow, offshore bank areas, i.e., Georges Bank.
Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species or a rare or endangered species. The life history of these species will be treated in Chapter 12.0.

Table 4-86 Checklist of Fishes
Salt Marsh

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Skates			
Winter skate *Raja ocellata*	common throughout	nearshore to 91 m	food-fish, small invertebrates
Little skate *** *Raja erinacea*	abundant throughout	nearshore to 137 m	food-small fish, invertebrates; sandy-pebbly bottom
Smelts			
Rainbow smelt *** *Osmerus mordax*	abundant throughout	brackish to nearshore	food-small fish, crustaceans; spawns brackish
Eels			
American eel *** *Anguilla rostrata*	common throughout	fresh to oceanic	food-scavenger, living and dead animals; catadromous
Killifishes			
Mummichog *** *Fundulus heteroclitus*	abundant throughout	fresh to nearshore	food-omnivorous, plant and small animals, scavengers
Striped killifish *Fundulus majalis*	abundant south	nearshore	food-small animals
Banded killifish *Fundulus diaphanus*	common south	brackish to nearshore	food-small animals
Rainwater killifish *Lucania parva*	common south	brackish to nearshore	food-small animals
Sheepshead minnow *Cyprinodon variegatus*	common south	brackish to nearshore	food-small animals
Codfishes			
Tomcod *Microgadus tomcod*	common throughout	brackish to nearshore	food-small crustaceans

Table 4-86 (continued)

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Flounders			
Winter flounder *** *Pseudopleuronectes americanus*	abundant throughout	brackish to coastal, banks to 128 m	food-small bottom invertebrates
Smooth founder *Liopsetta putnami*	abundant north	brackish to coastal, to 27 m	food-small bottom invertebrates; soft bottom
Silversides			
Silversides *** *Menidia menidia*	abundant south	brackish to nearshore	food-small crustaceans, fish eggs, invertebrate larvae, vegetable matter
Tidewater silverside *Menidia beryllina*	common south	fresh to nearshore	food-small crustaceans fish eggs, invertebrate larvae
Sticklebacks			
Ninespined stickleback *Pungitus pungitus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Threespined stickleback *Gasterosteus aculeatus*	abundant throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Fourspined stickleback *Apeltes quadracus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry

Table 4-86 (continued)

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Blackspotted stickleback *Gasterosteus wheatlandi*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Pipefishes			
Northern pipefish *Syngnathus fuscus*	common north	brackish to nearshore to 31 m	food-copepods amphipods, fish eggs and fry
Lined seahorse *Hippocampus erectus*	occasional south	brackish to nearshore	food-copepods, amphipods, fish eggs and fry
Mullets			
White mullet *Mugil curema*	common south	brackish to coastal	food-plankton, marine plants
Temperate basses			
White perch *Morone americana*	common throughout	fresh to nearshore	food-small crustaceans, fish fry
Drums			
Weakfish *Cynoscion regalis*	common south	brackish to coastal	food-small schooling fish, invertebrates; sandy bottom
Toadfishes			
Toadfish *Opsanus tau*	common south	nearshore to coastal	food-fish, invertebrates; sand, mud bottom
Gobies			
Naked goby *Gobiosoma bosci*	occasional south	nearshore	

Table 4-86 (continued)

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Blennies			
Striped blenny *Chasmodes bosquianus*	occasional south	nearshore	

Table 4-87 Birds and mammals

Species	Common Name	Habit	Relative Dominance	Distribution	Habitat Preference
Agelaius phoenicus	red-wing blackbird	breeds, migrates, winters, feeds on weed seeds, insects	common	Nova Scotia to Fla.	marshes, salt & fresh, nests in marsh shrubs
Anas platyrhychos	mallard	breeds, migrates, winters, feeds on 90% vegetable, nests on ground	common	Maine, Mass., R.I. southward	salt marsh, ponds and bays
Anas rubripes	black duck	breeds, migrates, winters, 75% veg. includes eelgrass, mullusks	abundant	Nfoundland-Va.	salt ponds, marshes swamps, gathers in estuaries, mud flats
Larus argentatus	herring gull	breeds, migrates, winters, feeds on carrion, fish, crustaceans, urchins	abundant	entire Atl. coast, breeds LI northward	lakes, bays, estuaries, tidal flats, marsh visitor
Rallus longirostris	clapper rail	feeds on marsh & fiddler crabs, snails on banks at ebbing tides	abundant	Cape Cod to Texas	salt marsh inhabitant active both day and night
Sterna hirundo	common tern	breeds, migrates, feeds on small fish alewives, herring, feeds on low tide areas	abundant	Nfoundland to N.C.	offshore to protected bays and marshes
Chrysemys picta	painted turtle	forages for plants insects, mollusks	common	Maine to N.C.	quiet brackish waters
Malaclemys terrapin	diamond back terrapin	carnivorous, dead fish, worms, crabs	common	Cape Cod to Fla.	hibernates in muds off marsh bank, eggs laid in high sand areas above

Microtus pennsylvanicus	meadow vole	feeds on vegetation in meadow hay	abundant	Maine to N.C.	grassy meadows and high marshes
Ondatra zibethica	muskrat	feeds on marsh vegetation, bulrush and cattail	common	Maine to Ga.	large colonies in coastal marshes
Procyon lotor	raccoon	feeds on mussels, crabs	common	North America	marsh visitors

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4.5.5 PLANKTON-BASED PELAGIC - ESTUARINE

The pelagic environments of the sounds and embayments with significant fresh water dilution are considered unique enough from a biological standpoint to be treated separately. In this section the habitat is defined, its dynamics discussed and its important biological components listed. The major taxonomic groups that inhabit this environment are the same as those in the offshore pelagic habitat; phytoplankton, zooplankton, fishes, birds, and mammals. For a discussion of the life history and ecology of these groups the reader is referred to Chapters 8.0 Phytoplankton, 9.0 Zooplankton, 12.0 Fishes, 13.0 Birds, and 14.0 Marine Mammals.

HABITAT DEFINITION/DESCRIPTION

The estuarine pelagic habitat is the water column of any semi-enclosed coastal body of water having a free connection with the sea and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard, 1967).

This habitat is considered separately from the offshore pelagic habitat because the variations in temperature and salinity characterizing estuarine waters result in considerably different planktonic and nektonic populations and seasonal and nutrient cycles than are found offshore.

HABITAT DYNAMICS

Environmental Conditions and Microenvironments

For this report, estuarine waters include those found from the 0.5 percent halocline to the headlands at the mouth of the river as well as waters in large embayments, such as Narragansett Bay and Long Island Sound, that are diluted by fresh water. Consequently these bodies are marked by a salinity gradient that fluctuates in position and steepness with season and fresh water runoff. Also due to the influence of fresh water runoff, as well as the overall shallowness of estuarine waters, temperature fluctuations are wide and often a down-estuary gradient of decreasing temperature occurs in the spring and summer. Temperature and salinity gradients, from surface to bottom waters are also found under certain conditions. The resulting mosaic of temperature and salinity conditions provides widely differing microenvironments which shift from place to place seasonally, and often may disappear altogether. For example, conditions of relatively high salinity and low temperatures may exist in the upper estuary only during the winter, being replaced by lowered salinity and higher temperatures during the spring and early summer. Thus pelagic populations preferring the former conditions become pushed farther toward the mouth of the estuary where such conditions still persist.

The semi-enclosed nature of most estuarine waters combined with a constant renewal of nutrients from both fresh and sea water causes estuarine waters to be generally highly fertile (Riley, 1967). Nutrients from both sources tend to become "trapped" in estuaries due to reduced flushing rates and, often, a two-layered transport system where fresh water nutrients flowing seaward in surface waters are returned in the deeper, more saline layer flowing landward. Characteristically, however, nutrients are utilized as rapidly as they become available so that the rate of cycling rather than the abundance of a nutrient controls population abundance (Riley, 1967).

Nutrient Cycles and Seasonal Cycles

The seasonal cycles in planktonic abundance and nutrient concentration appear to be linked in estuarine waters (Martin, 1965). During the winter (January-April), zooplankton are very scarce presumably because temperatures are too low for successful reproduction. Phytoplankton, meanwhile, reach their peak of abundance and apparently deplete the available nutrients especially of phosphate, silicate, and nitrate. The cause of the flowering is either the vernal increase in light intensity (Riley, 1967) or the relaxation of zooplankton grazing as discussed later (Martin, 1965) or both (Smayda, 1973). As spring temperatures rise, the copepod populations increase, reaching high abundances during June through November (Martin, 1965). The late spring phytoplankton populations decline steeply. Evidence exists, however, that primary productivity may continue at high levels throughout the summer in contrast to offshore waters where the level is quite low (Riley, 1967). The standing crop in inshore waters is kept very low by intensive grazing pressure of the zooplankton. During the months of zooplankton abundance nutrient levels show a higher level than in winter months presumably due to the excretory products of the zooplankton. As water temperatures cool during the fall, the zooplankton populations slowly decline while the phytoplankton, released from grazing pressure and responding to the high levels of nutrients, increases.

These cycles differ in intensity from one estuary to another and between the upper and lower levels of one estuary. For example, the winter phytoplankton bloom persists unusually long in Narragansett Bay while in Long Island Sound, where *Acartia clausi* occurs more abundantly during the winter, the bloom is very short-lived (Martin, 1965). Martin found that zooplankton populations are much higher during the fall at the upper part of Narragansett Bay than at the lower, more seaward part. Concomitantly the phytoplankton was more abundant at the lower than the upper part.

Another cycle characteristic of estuarine waters is the seasonal alternation in abundance of congeneric species associates. The

most clear-cut example is the replacement of Acartia clausi, the dominant copepod during the winter and spring, by A. tonsa during the summer and fall. Acartia clausi requires lower temperatures for reproduction and is more sensitive to lowered salinities than A. tonsa. Thus during the winter months when salinities tend to be higher and temperatures are cool, A. clausi dominates. During the spring, as salinity lowers at the head of the estuary A. tonsa first outcompetes A. clausi. As water temperatures increase, A. tonsa slowly spreads in a seaward direction while the A. clausi population shrinks to the mouth of the estuary where temperatures remain cool enough for successful reproduction (Jeffries, 1967; Jeffries and Johnson, 1973; Martin, 1965). Similar cycles occur for other congeneric pairs of species (Jeffries, 1967; Martin, 1965) and for many species of phytoplankton (Smayda, 1973; Riley, 1967). Such cycles insure that despite widely fluctuating environmental conditions, the habitat is utilized throughout the year (Jeffries, 1967).

Besides these seasonal cycles of species that can be considered characteristically estuarine, there is a seasonal augmentation by populations originating elsewhere than in the estuarine pelagic habitat. Many copepod species, such as Calanus finmarchicus, cannot reproduce in lowered salinity but are present in estuarine waters in very large numbers and constitute an important fish food. Such populations are the result of offshore reproduction. The meroplankton, generally larvae of benthic populations, are abundant at irregular intervals. For example, barnacle larvae are abundant during the winter in Narragansett Bay, while decapod and gastropod larvae are found only during the summer (Martin, 1965). Their importance also varies from one estuarine body to another (Jeffries, 1967).

Food Webs

The outstanding characteristic in estuarine food webs is the importance of the diatom Skeletonema costatum as the basic primary producer. This species occurs abundantly in almost all estuarine waters and is efficiently grazed by the dominant copepods, thus forming the fundamental support of the food web. The estuarine food web is essentially the same as the offshore pelagic except that species found under the several headings would be different (see Biota).

Relative Productivity

Refer to Table 4-75 of the Salt Pond habitat.

Natural Stress

The estuarine pelagic habitat is normally a very stressful habitat; fluctuations of salinity and temperature have been discussed above. Estuarine populations have evolved methods of dealing with such regularly occuring stresses. Irregular stresses include sudden increased turbidity and lowered salinity as a result of heavy rainfall or raised salinity due to onshore storm winds. Because estuarine organisms are mobile, however, most populations can usually escape such stresses.

EFFECT OF MAN-INDUCED STRESS

Because of the ability of many estuarine waters to concentrate nutrients, and the proximity of these areas to high-density populations, estuaries are especially vulnerable to man-made disruptions. Of current concern is the effect of oil spills on estuarine waters. Gordon and Michalik (1971) report that within a few weeks after a large Bunker C fuel oil spill in Chedabucto Bay, Nova Scotia, oil particles (5μ - 2mm) were dispersed throughout the water column in concentrations of 10-20 ppb. Fourteen months later, the concentration of oil (1.5 ppb.) averaged that typically found in shelf waters, indicating no oil from the spill remained in the water column. At the same time, oil-covered sediments persisted throughout the spill area. One agent of oil removal from the water column appears to be the zooplankton. Conover (1971) reports that perhaps 20 percent of the oil was sedimented as zooplankton feces without any apparent effect on the organisms.

DDT has been extensively studied as a model of how a long-lived pollutant can affect an organism. Since DDT has a very low solubility in water, only traces are usually found in the water column. Nevertheless, organisms store it in their fat deposits, in which it is very soluble, and thus can concentrate it to very high levels. As the DDT is removed from the water by organisms, more pesticide becomes dissolved from the large reservoirs in the sediment (Woodwell, 1967). A similar cycle takes place with heavy metals (Wolfe and Rice, 1972). The biogenic activity of Spartina roots and burrowing animals constantly expose new supplies of these pollutants to the water column and ultimately the food chain. Although most heavy metals are only of low water solubility, the holding capacity of estuarine waters is further increased by the formation of soluble organic-metal complexes (Wolfe & Rice, 1972), also making the metals more available as food.

The estuarine pelagic habitat acts therefore as a route through which many pollutants pass to become concentrated elsewhere; e.g., in benthic animals or in predatory animals. In fact, Mileikovsky (1970) reports that pelagic larvae show very little

adverse effect under polluted field conditions that would quickly kill them in the laboratory. Presumably, such larvae can escape the pollution in the field while they cannot in closed laboratory containers. These larvae, however, may die very quickly when attempting to settle because of polluted sediments.

Eutrophication, either from duck wastes as in Moriches Bay (O'Connor, 1972) or sewage (Mileikovsky, 1970), will affect the composition and abundance of the phytoplankton. In Moriches Bay, the normal diatom-dinoflagellate population was replaced by abnormally large blooms of tiny chlorophytes. The importance of Skeletonema has already been pointed out. Such a replacement in the major primary producer has important effects throughout the food chain, and, in Moriches Bay, results in lowered secondary production. Mileikovsky (1970) reports a study which showed that in a polluted area an abnormal early bloom of small flagellates triggered barnacle spawning usually occurring in response to the normal spring diatom bloom, the food of barnacle larvae. Thus the larvae were produced at a time when their food was in insufficient quantity and they probably starved. Such events disrupt the normal succession of planktonic forms and thus cause both inadequate recruitment of benthic population and distortion of food chains.

BIOLOGICAL COMPONENTS

General Distribution

In general there are few truly estuarine forms, but these occur very abundantly. Table 4-87 lists the dominant forms of phyto- and zooplankton of estuarine waters. Table 4-88 illustrates the effect of salinity on the phytoplankton composition of different bodies of water. Oyster Pond has very low salinity (3-12 percent) while a neighboring body, Great Pond, Falmouth, Massachusetts, has a wider but overall higher range of salinity (7-32 percent in summer, 18-32 percent in winter) (Smayda, 1973). One effect of salinity on zooplankton composition has already been discussed (see seasonal cycles). For detailed case-by-case description of the phytoplankton and zooplankton of waters south of Cape Cod, see Smayda (1973) and Jeffries and Johnson (1973) and for zooplankton north of the Cape, see Sherman (1966 & 1968).

Table 4-87 List of dominant estuarine phytoplanktonic and zooplanktonic species

Phytoplankton (Riley, 1967)	Zooplankton South (Jeffries & Johnson, 1973)	Zooplankton North (Sherman, 1966, 1968)
Skeletonema costatum	Acartia clausi	C. finmarchicus
Thalassionema nitzschivides	A. tonsa	T. longicornis
Paralia Sulcata	Calanus finmarchicus	C. typicus
Shroderella deliculata	Centropages hamatus	P. minutus
Thalassiosira decipiens	C. typicus	O. similis
T. gravida	Pseudocalanus minutus	O. longiremis
T. nordenskioeldii	Temora longicornis	T. discaudatus
Rhizosolenia setigera	Labidocera aestiva	Metridia lucens
Peridinium tochoideum	Tortanus discaudatus	
Prorocentrum scutellum	Sagitta elegans	
P. tiestinum	Oithoma brevicornis	
Exuviella apora	O. similis	

Table 4-88 Important phytoplanktonic species in two southern estuarine ponds of different salinity (Smayda, 1973)

Oyster Pond (1-12 percent)	Great Pond (7-32 percent, 18-32 percent)
Bluegreen Algae:	Diatoms:
Anabaina	Leptocylindrus minimus
Merismopedia	Skeletonema costatum
Microcystis	
Oscillatoria	Microflagellates:
	Nephrochloris salina
Diatom:	Bipedinomonas pyriformis
Chaetoceros	Peridinium tiouetum
	Massartia rotundata
Photosynthetic Bacteria:	Chlamydomonas
Chlorobium	

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Chapter 5 Exposed Shorelines

		Page
Chapter 5.0	Exposed Shorelines	
5.1	Geology of Sand Beaches - Maine to Cape Cod	5-4
5.1.1	Physiography	5-4
	Bedrock Land Structure Control	5-4
	Submergence and Formation of Second-Order Physiographic Shoreline Features	5-5
	Late-Pleistocene Glaciation/Post Pleistocene Sea Level Changes, Gulf of Maine	5-5
	Sources of Sediment	5-12
5.1.2	New England Beaches	5-19
	Barrier Beaches	5-19
	Pocket Beaches	5-24
	Standplain Beaches	5-25
	Tombolos and Spits	5-25
	Beach Erosion-Accretion	5-25
5.1.3	Maine Beaches	5-32
	Popham Beaches - Phippsburg	5-32
	Old Orchard Beach - Biddeford	5-33
	Saco Bay Sediments - Saco	5-41
	Wells-Kennebunk Area - Ogunquit	5-49
	Long Sands/Short Sands Beaches - York	5-55

		Page
5.1.4	New Hampshire Beaches	5-58
	Rye Gravel Beach - Rye	5-58
	Hampton/Seabrook Beaches - Hampton, Seabrook	5-61
5.1.5	Massachusetts Beaches	5-64
	Salisbury Beach - Salisbury	5-64
	Plum Island - Newburyport	5-64
	Crane Beach - Ipswich	5-77
	Coffin Beach - Essex	5-84
	Cape Ann Beaches - Gloucester, Rockport	5-86
	Boston Basin Beaches	5-88
	White Cliffs to Nobscusset Point - Plymouth	5-101
	North Dennis Beaches - Dennis	5-107
	Brewster, Eastham, Wellfleet Beaches - Dennis, Brewster, Eastham, Wellfleet	5-107
	Outer Cape Cod Beaches - Provincetown to Monomoy Island	5-113
5.1.6	References	5-140
5.2	Wind and Wave Climate	5-148
5.2.1	Winds	5-148
5.3	Biological Oceanography	5-155
5.3.1	Sandy Shores Habitat	5-155
	Habitat Definition/Description	5-155
	Habitat Dynamics	5-155
	Effect of Man-Induced Stresses	5-158

		Page
	Biological Components	5-158
	References	5-163
5.3.2	Rocky Shores Habitat	5-164
	Habitat Definition/Description	5-164
	Habitat Dynamics	5-164
	Effects of Man-Induced Stresses	5-168
	Biological Components	5-169
	References	5-179

The following is a presentation of the Exposed Shorelines. This region is dealt with in two principal divisions; the unconsolidated shores or sandy beaches in which the focus is on the geology of sand beaches and biology of sandy beaches; and the consolidated with major treatment of the biology of rocky shores. There is no specific treatment of the geology of rocky shores. Readers interested in the areal extent of these two high energy exposed shores are directed to Appendix E in which we have made a detailed inventory and map.

5.1 GEOLOGY OF SAND BEACHES - MAINE TO CAPE COD

5.1.1 PHYSIOGRAPHY

BEDROCK LAND STRUCTURE CONTROL

The seaboard section of New England is a physiographic sub-unit of the New England-Canadian Maritime Province where the relief does not exceed 150 m. The low-relief has been interpreted to be the result of fluvial peneplanation (Sharp, 1929; Johnson, 1938) - or as the result of marine erosion in post-Miocene time (Olmstead and Little, 1956).

Bedrock type and structure are the first-order features that control the shoreline configuration bordering the Gulf of Maine. From Boston Harbor north to the International Boundary, estuarine and neutral tidal embayments occupy various fault basins, fault zones, and folded bedrock zones where differential erosion of resistant and non-resistant lithologies has produced linear and curvi-linear topographic lows. Fluvial and glacial erosion and marine submergence have enhanced the shoreline complexity.

The most conspicuous shoreline features controlled by bedrock type and structure are the Boston Basin, a fault basin occupied by soft, sedimentary Carboniferous rocks; Cape Ann, a resistant headland underlain by the Quincy granite batholith (Clapp, 1921); Casco Bay, a complex of structure-controlled islands and embayments underlain by Siluro-Devonian metasediments; the Bays of Maine complex in the Mt. Desert area of Maine, a series of islands and bays controlled by Devonian igneous bodies forcefully intruded into lower Paleozoic metamorphic rocks; and the faulted Paleozoic volcanic area of "Downeast" Maine, Washington County (Doyle, 1967).

The Cape Cod peninsula shoreline is primarily controlled by the distribution and thickness of Pleistocene recessional and interlobate moraine and outwash sediments (Woodworth & Wiggleworth, 1934). Crystalline bedrock lies 106.6 m below sea-level or deeper (Oldale and Tuttle, 1964; Koteff and Cotton, 1962). The northern shore of the Inner Cape is positioned along the edge of the Sandwich Moraine, the backbone element of Cape Cod, while the forearm of the Cape is

positioned along an interlobate moraine (See Figure 5-1). Subsequent submergence during post-Pleistocene times and recent marine reworking has altered the configuration of the unconsolidated glacial deposits considerably.

SUBMERGENCE AND FORMATION OF SECOND-ORDER PHYSIOGRAPHIC SHORELINE FEATURES

Submergence of the New England coast for at least the last 6000 years (Kaye and Barghoon, 1964) has allowed reworking of bedrock and surficial sediments by ocean waves and currents. The resultant of marine reworking of unconsolidated sediments has been the formation of second-order physiographic features such as spits, barrier islands, lagoons, tombolos, and large salt-marsh tracts.

Barrier beaches and accompanying landward salt marsh tracks have been built by spit accretion enclosing low tidal embayments such as the barrier complex of Barnstable Harbor (Redfield, 1965, 1967) (See Figure 5-2) or by vertical accretion of the barrier island from a strand beach such as the Plum Island - Merrimack River and Parker River estuary embayments (McIntire and Morgan, 1963) (See Figure 5-3).

Spit accretion along Outer Cape Cod has resulted in formation of the Provincetown Provincelands (See Figure 5-4). Sand and gravel eroded from the Highlands on the east and transported north by littoral currents has formed four successive recurved spits. Sand transported south along the outer Cape has formed the Nauset and Chatham barrier island beaches and Monomoy Island which has been accreting southward toward Georges Banks by successive recurved spit growth (Goldsmith, 1972).

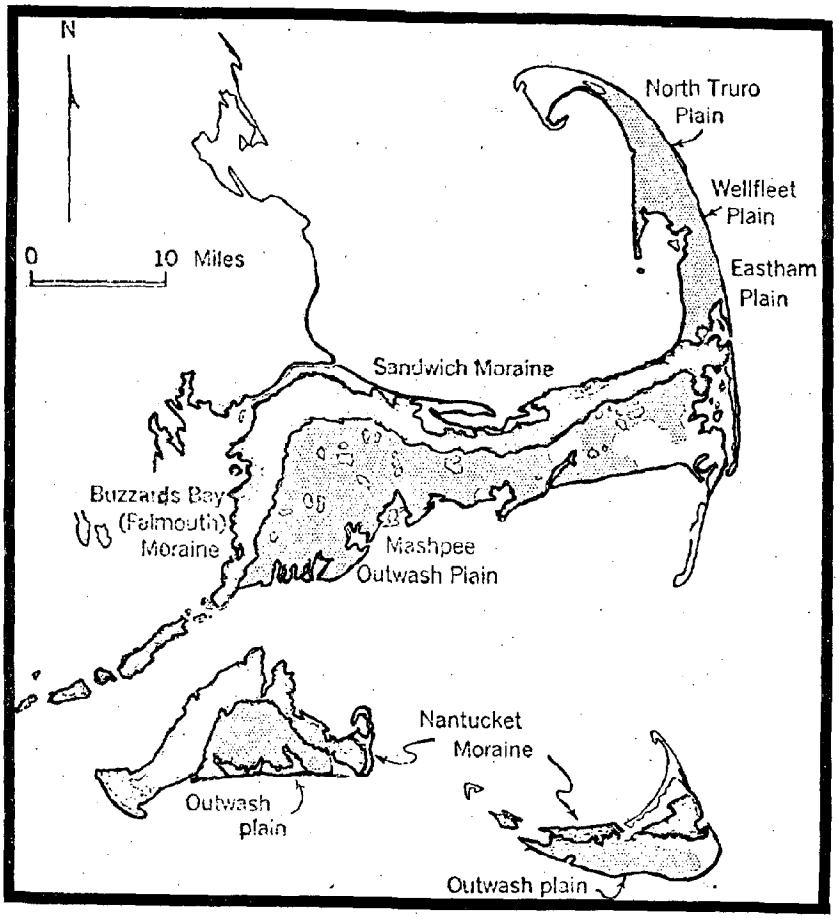
Marine reworking of drumlin islands in Boston Harbor has produced a complex of spits and tombolos restricting tidal circulation within the embayment (Johnson, 1925).

A detailed account of the processes which now effect the second-order physiographic features is the subject of the sections on beaches and estuaries.

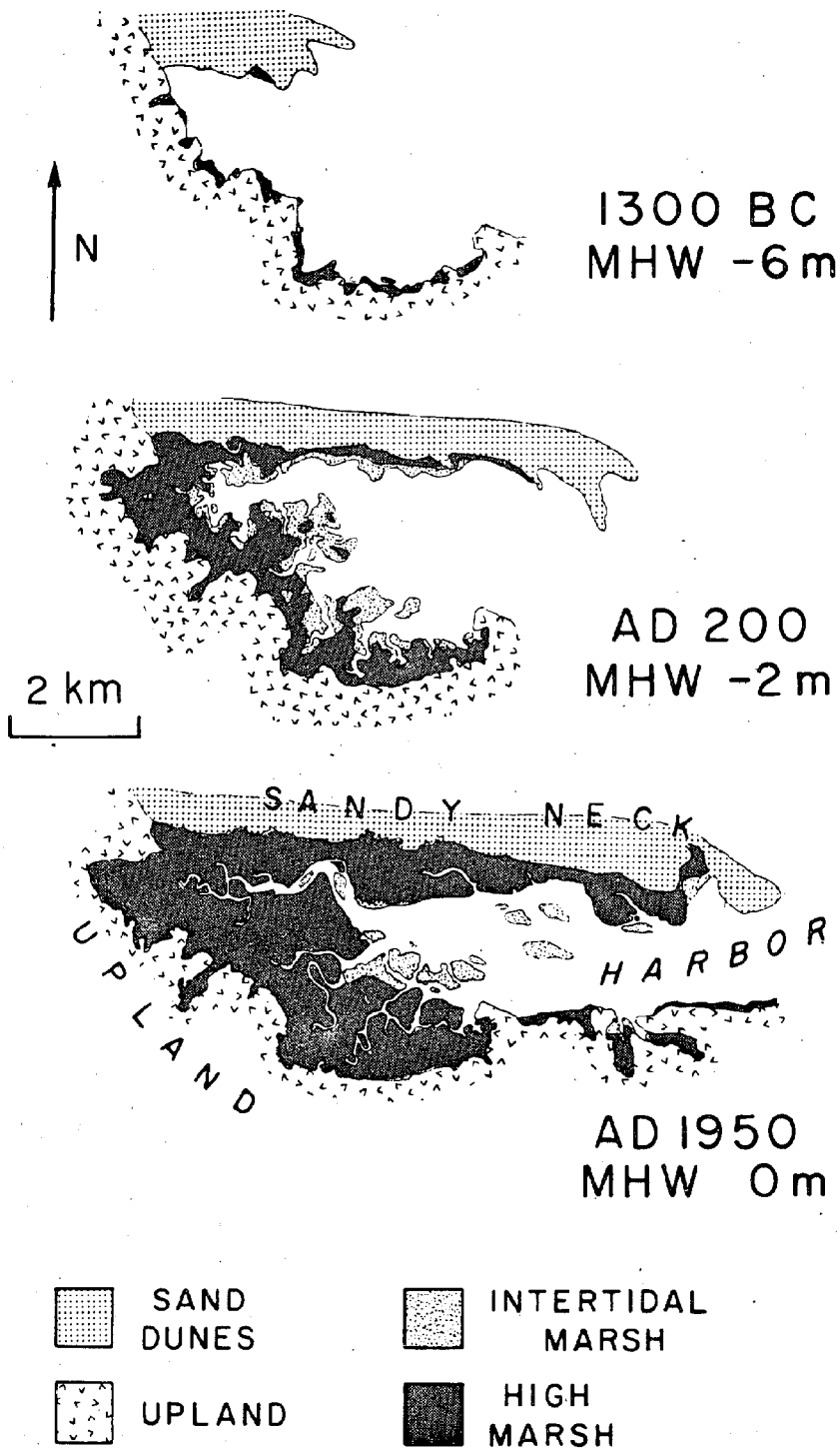
LATE-PLEISTOCENE GLACIATION AND POST-PLEISTOCENE SEA-LEVEL CHANGES IN THE GULF OF MAINE

The present configuration of the New England coastline bordering the Gulf of Maine is due to geologic events during and subsequent to the late Wisconsin glacial advance, with the exception that bedrock-controlled coastal topography may well have been shaped by fluvial erosion prior to the last glaciation.

Maximum advance of glacier lobes probably occurred sometime between 15,000 and 20,000 years ago, based on radiometic dating of marine shells

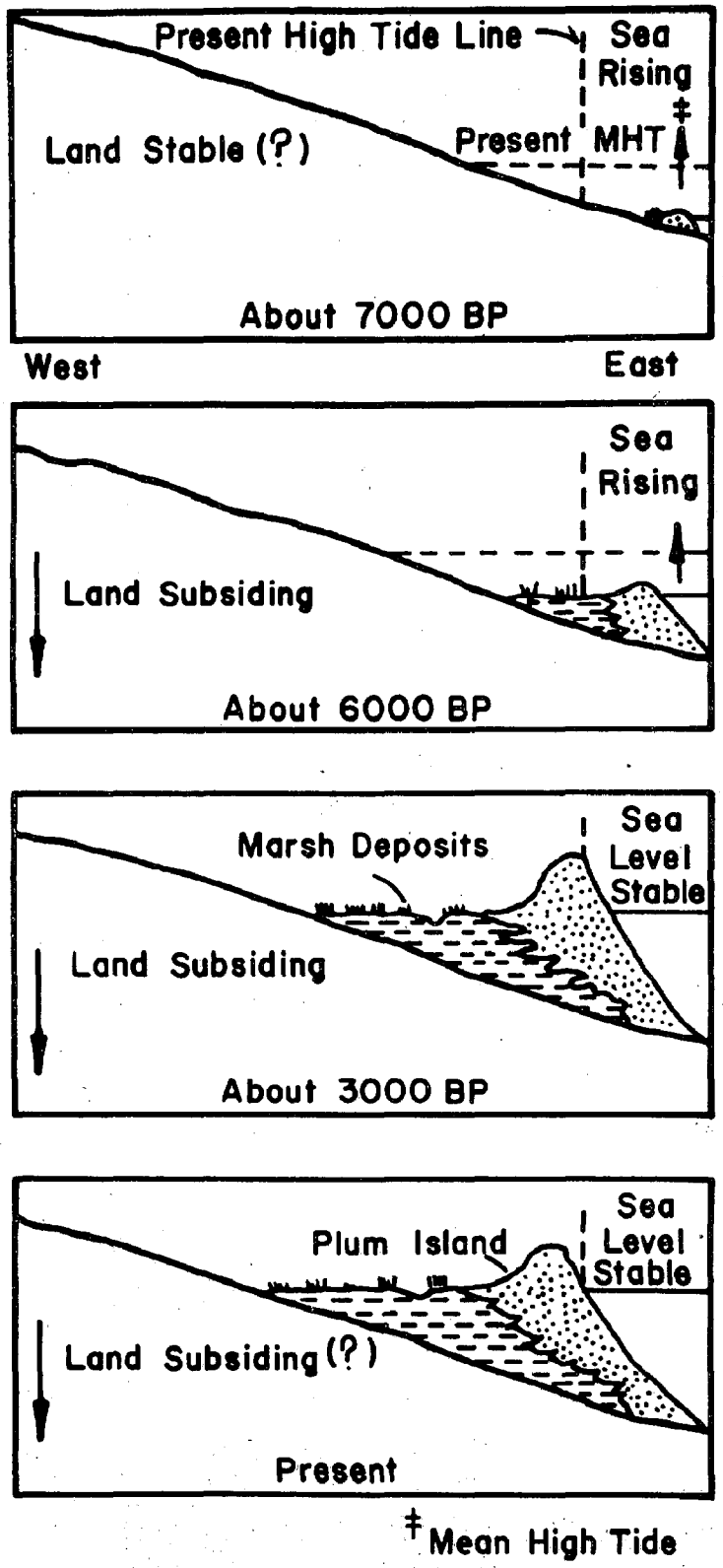


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-1	Generalized Glacial Sediment of Cape Cod (Strahler, 1966)



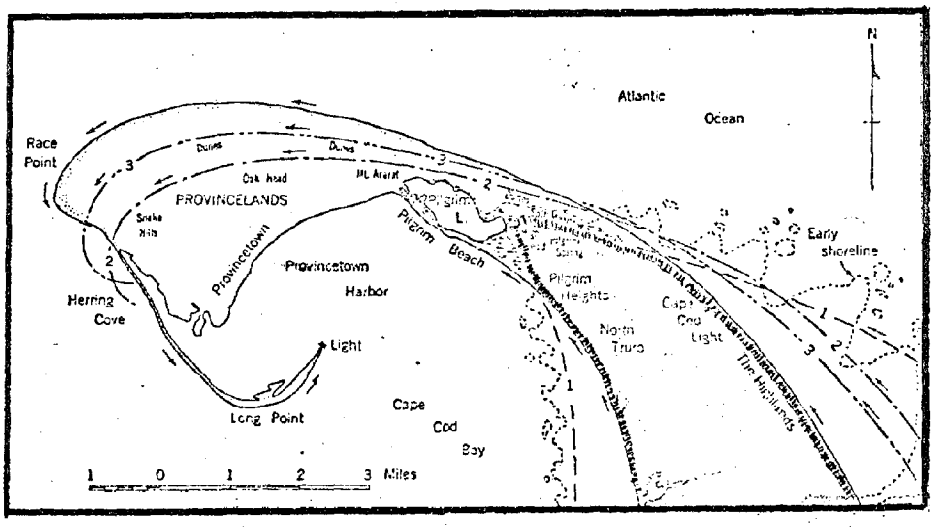
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-2	Origin of Sandy Neck and Barnstable Marsh (Meade, 1971)



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

TRIGOM PARC	FIGURE 5-3	Vertical Aceretion and Transgression of the Plum Island Barrier (McIntire & Morgan, 1963)



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

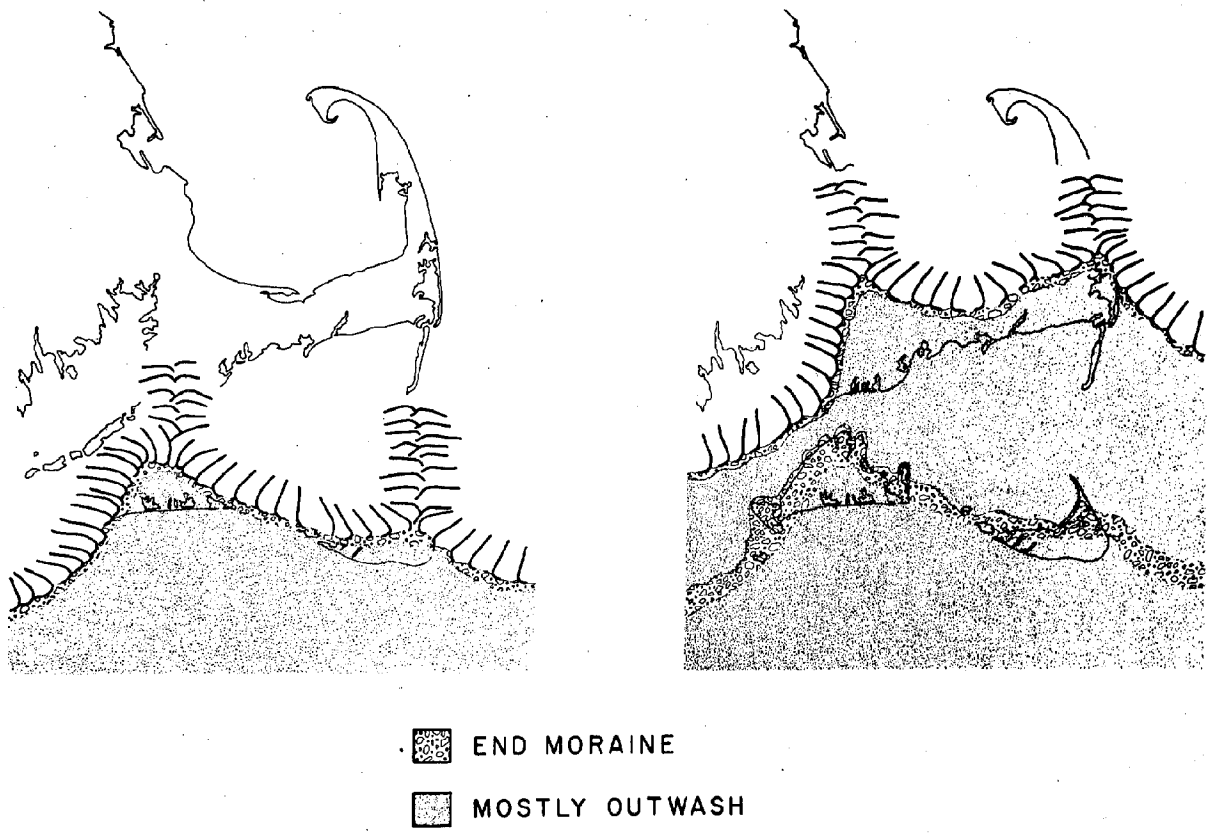
TRIGOM PARC	FIGURE 5-4	Growth of the Provincelands (Strahler, 1966)

caught up in the ice advance over Cape Cod (Hartshorn, Oldale, and Koteff, 1967) and a radiocarbon date from Martha's Vineyard (Kaye, 1964). If the maximum lowering of sea level changes to a level 125 m below the present level was coincident with maximum glacial advance, then glaciation reached its limit just prior to 15,000 years ago (Milliman and Emery, 1968).

All of Cape Cod and the New England coast to the north was covered by ice (Schlee, 1970) before the glacier receded. As the glacier front retreated, it was followed by a rapid marine transgression over most of the Gulf of Maine (Emery and Garrison, 1967). The edge of the marine transgression probably kept pace with ice-front ablation for much of its retreat across the Gulf of Maine as the edge of the continental crust, depressed from the weight of the continental glaciers, did not rebound at rates comparable to the marine advance. There is no evidence, however, to suggest that the transgression kept pace with ice retreat over George's Bank and Cape Cod. A pause in glacier retreat along the north shore of the inner Cape occurred long enough to build a large moraine and outwash plain with an ice-contact head (Hartshorn, et al., 1967) (See Figure 5-5). These glacial deposits show no evidence of marine reworking except by present day processes along the coastline.

The Laurentide glacier mass retreated to about the present coastline of Maine about 13,500 years ago (Borns, 1963). Ablation and submergence continued until at least 13,000 B.P. where the ice front stood well north of the present coastline of southwestern Maine (Bloom, 1960). Coarse outwash sediments poured out from the ice front to form moraines, deltas,and kame deposits. Rock flour was carried beyond upland areas to marginal marine and offshore areas where it formed thick (18 m to 30.4 m) deposits of blue-grey glacio-marine clays. Sea level stood approximately 70 m above present levels in southwestern Maine (Bloom, 1960). Borns and Hager (1965) have found evidence that the ice margin dissipated faster along the south-eastern coast of Maine than along the southwestern coast. A radio-metic date from estuarine shells from Bingham, Maine, suggests that the maximum transgression of the early post-glacial sea occurred approximately 12,930 B.P. at Bingham, Maine.

Crustal rebound in Maine later than 12,000 B.P. apparently accelerated to rates exceeding eustatic rise of sea level. A marine regression ensued as the glacier front farther receded in New England. Emergence continued in southwestern Maine with brief halts of the regression until sometime between 4,000 - 7,000 B.P. where sea levels stood below present levels by at least 18 m (Farrell, 1972). Similar records by shoreline emergence are evident along the coast of southeastern Maine (Harold Borns, personal communication) and probably along the coasts of New Hampshire and Massachusetts to the south of Boston, although particular events of the emergence and limits of regression have not been detailed.



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-5	Formation of Cape Cod (Meade, 1971)

The present general configuration of the New England coastline is due to submergence which commenced prior to 5,000 B.P. Submergence has been caused both by a constant eustatic sea-level rise and differential rates of crustal subsidence along the entire North Atlantic coast (See Figure 5-6).

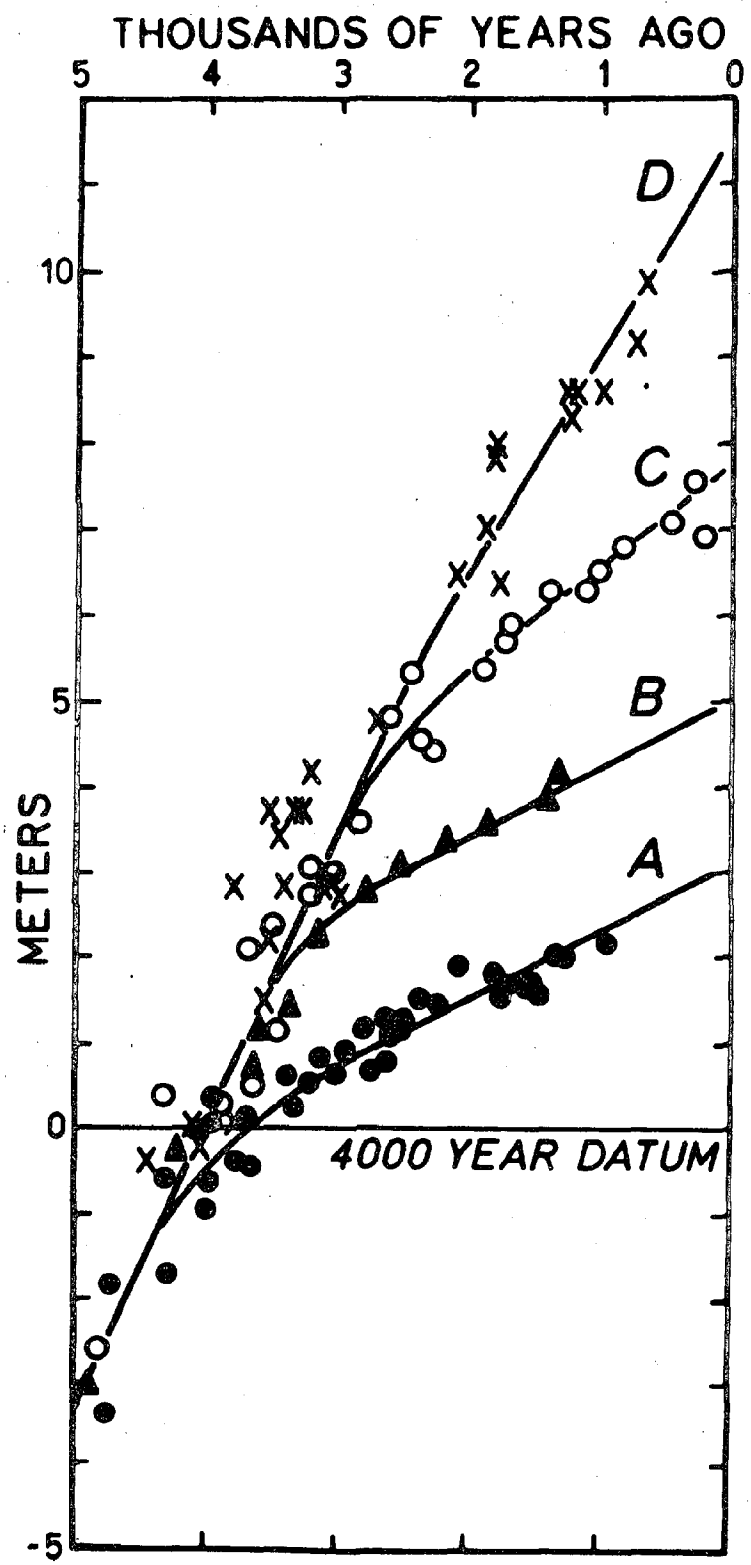
A detailed chronology of the submergence has been documented through radiometic dating of a continuous salt marsh peat record and extremely precise elevation surveys over the past fifty years. Redfield (1967) has shown that prior to 4,000 B.P. the entire Atlantic coast of North America was subsiding at a rate of about 3.4 mm per year. About 4,000 years ago, eustatic rise of sea level decreased to about 0.8 mm per year from a previously higher rate of rise. In the eastern Massachusetts area, local subsidence continued until about 2,500 years ago, after which it slowed to about 0.3 mm per year. Sea level rise and subsidence totals a relative submergence of 1.1 mm per year. The Bay of Fundy area is being submerged at a rate of 1.4 mm per year. Recent measurements by NOAA surveyors indicate that submergence has accelerated along the New England coast in the past eight years to a rate of about 9 mm per year. Assuming the eustatic rise of sea level remains at 0.8 mm per year as determined by Redfield, an increased rate of coastline subsidence must be called upon to produce the present high rate of submergence. Increased subsidence may be due mostly to coastal warping by water loading over the adjacent shelf areas (Bloom, 1967; Newman and March, 1968).

The change from emergence to submergence and the deceleration of eustatic sea-level rise and subsidence have all been recorded as initiation periods for major barrier beach and salt marsh peat growth along the margin of the Gulf of Maine (McIntire and Morgan, 1962; Redfield, 1967; Hussey, 1959; Bloom, 1960; and Farrell, 1972). Where sediment supply either from or adjacent to rivers was deficient, the submergence drowned the lower portions of the river valleys to form the relatively deep, linear estuaries typical of the south-central and southeastern coasts of Maine.

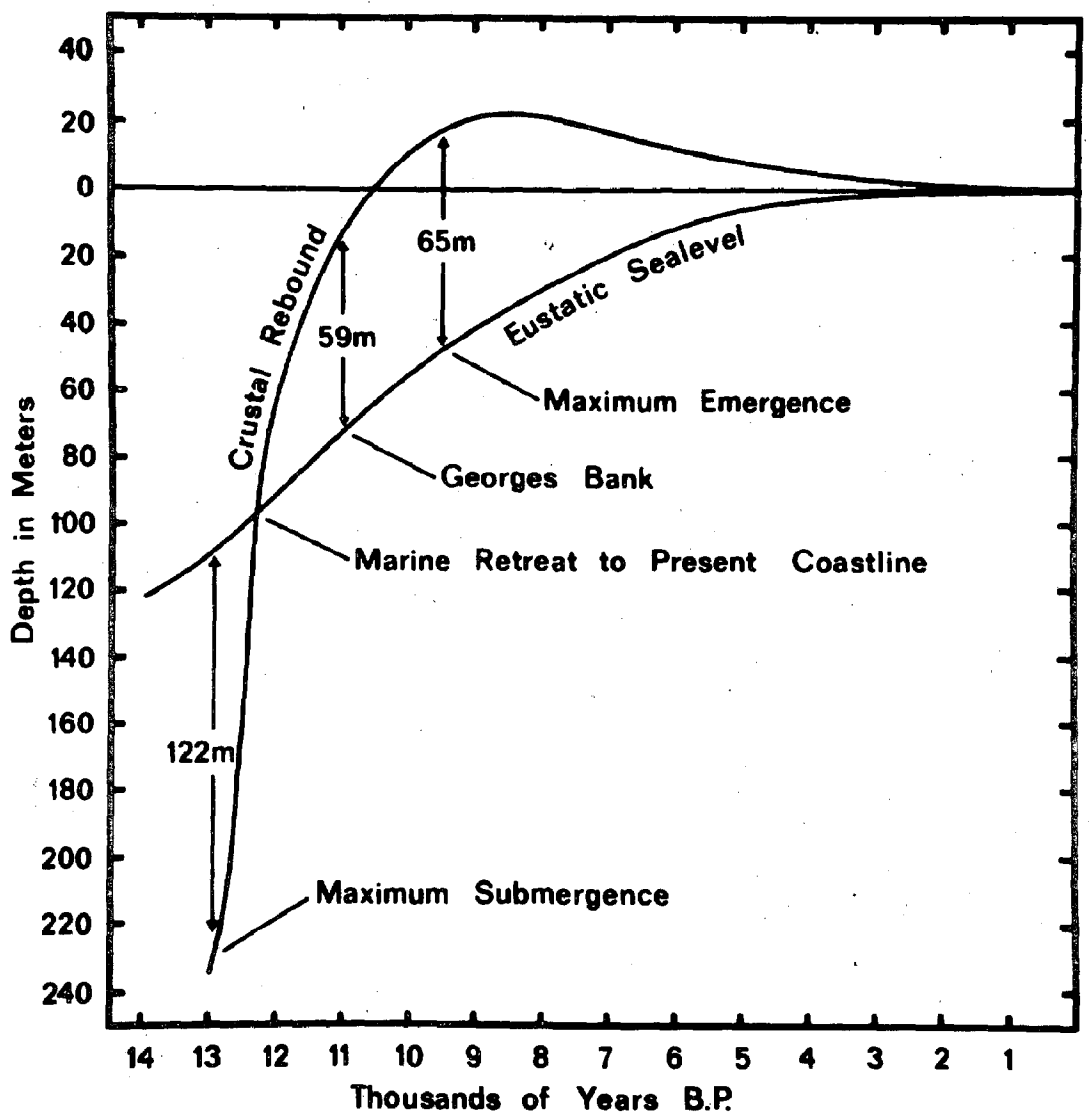
SOURCES OF SEDIMENT

Sediments available to supply beaches and estuaries are fluvial sediments transported to the coastal zone from mechanically - and chemically - eroded upland surficial sediments and exposed bedrock, offshore sediments transported onshore by waves and tidal currents, and surficial and bedrock sources attacked by waves immediately adjacent to the shoreline (Meade, 1971).

Sediments supplied to the coastal zone from rivers is minor compared to other portions of the continental United States. Rivers draining the upland areas of Maine, New Hampshire and Massachusetts and flowing into the Gulf of Maine contribute 1,650,000 metric tons of suspended sediment annually (Curtis, Culbertson and Chase, 1973). Most of this



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-6	Age and Depth of Peat in Coastal Marshes (Emery & Uchupi, 1972)



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

TRIGOM PARC	FIGURE 5-7	Crustal Rebound Curve of the Gulf of Maine (Schnitker, 1974)

suspended load is deposited within the estuaries along the coast, but the major rivers deliver sediment to the innershelf of the Gulf of Maine probably during spring freshets (Hartwell, 1970; Ross, 1970; Timson, unpublished data).

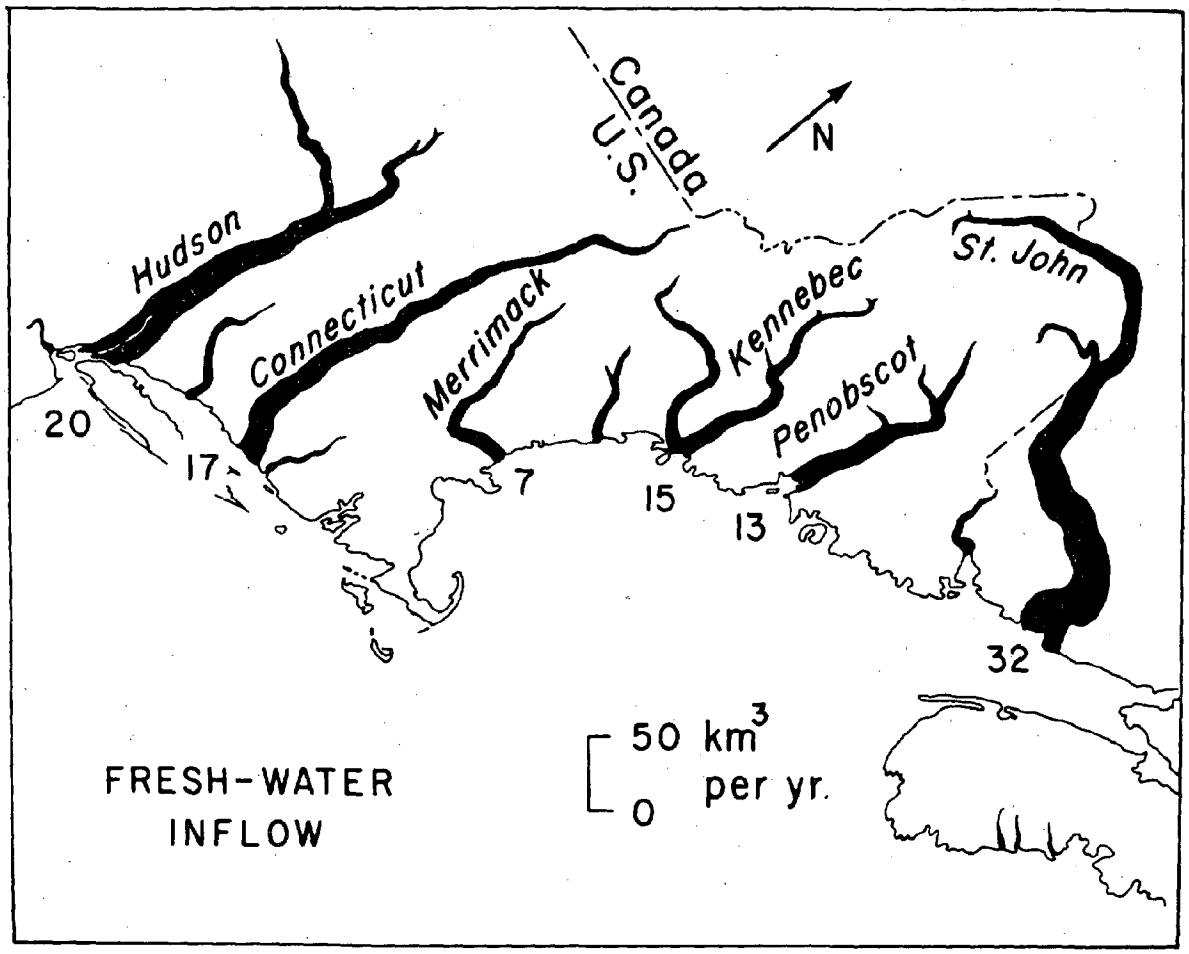
The Penobscot, Kennebec, Androscoggin, Saco, and Merrimack Rivers deliver about 70 percent of the runoff entering the Gulf of Maine (Bue, 1970; Curtis et al, 1973) (See Figure 5-8). They probably deliver about 70 percent of the suspended load to their estuaries and inner margins of the Gulf of Maine.

Much of the bedload (sand-sized material) does not reach the ocean because it is retained behind man-made dams. Some bedload does reach the ocean and contributes to adjacent beaches at the mouths of estuaries. Farrell (1970) has indicated that most of the Saco embayment beaches are composed of sand delivered by the Saco River. The Merrimack River contributes to the Plum Island barrier system (Hartwell, 1970; Anan, 1971; Hayes, Owens, Hubbard, and Abele, 1973). The Kennebec River discharge maintains the Popham Beach barrier system.

River sediment contributes little to the beaches of New England, with exception of those mentioned above. In general, however, river sediments contribute substantially to the filling of estuaries. River sediments may bypass through one estuary and be transported up another (Timson, unpublished data).

Sediments derived from relict glacial sediments on the floor of the Gulf of Maine may also contribute to beaches and estuaries. No evidence exists that terrigenous (inorganic) sediments of beaches and estuaries originate from offshore shelf-bottom sediments. Raymond and Stetson (1932) described a carbonate beach on Little Cranberry Island south of Mt. Desert Island composed largely of shells of deep water benthic fauna. Shell fragments are being transported from the offshore to the beach by storm waves. Valves of the hard clam *Mercenaria mercenaria* have been found in shell berms atop intertidal flats adjacent to lower estuarine channels in Casco Bay. Storm waves and currents have transported the shell fragments from deeper areas of the Bay into channels and up onto marginal flats. If whole, large valves of shellfish are transported onshore by storm activity, then sand-sized terrigenous sediments are probably being transported onshore in some areas. Offshore sediments, however, probably contribute very little to beach and estuarine environments; their transport has to be infrequent and intermittent.

Wave-eroded coastlines are the major local supply of gravel and sand-sized sediments to New England beaches (Timson, 1969; Zeigler, Hayes and Tuttle, 1959; Schalk, 1938; Johnson, 1925; Hartshorn, et al, 1967; Hobbs, 1972; Kaye, 1967; Bloom, 1960; Cunningham and Fox, unpublished manuscript).



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-8	Ave. Annual Freshwater Inflow to Coastal Waters in New England (Meade, 1971)

Mineralogical studies by Farrell (1970) and Greer (1969) indicate that local beach sediments may be transported into the lower portions of estuaries. Bedform directional studies by many of the Coastal Research Group also show that estuaries receive sediment from adjacent beaches by longshore currents and strong flood tidal currents.

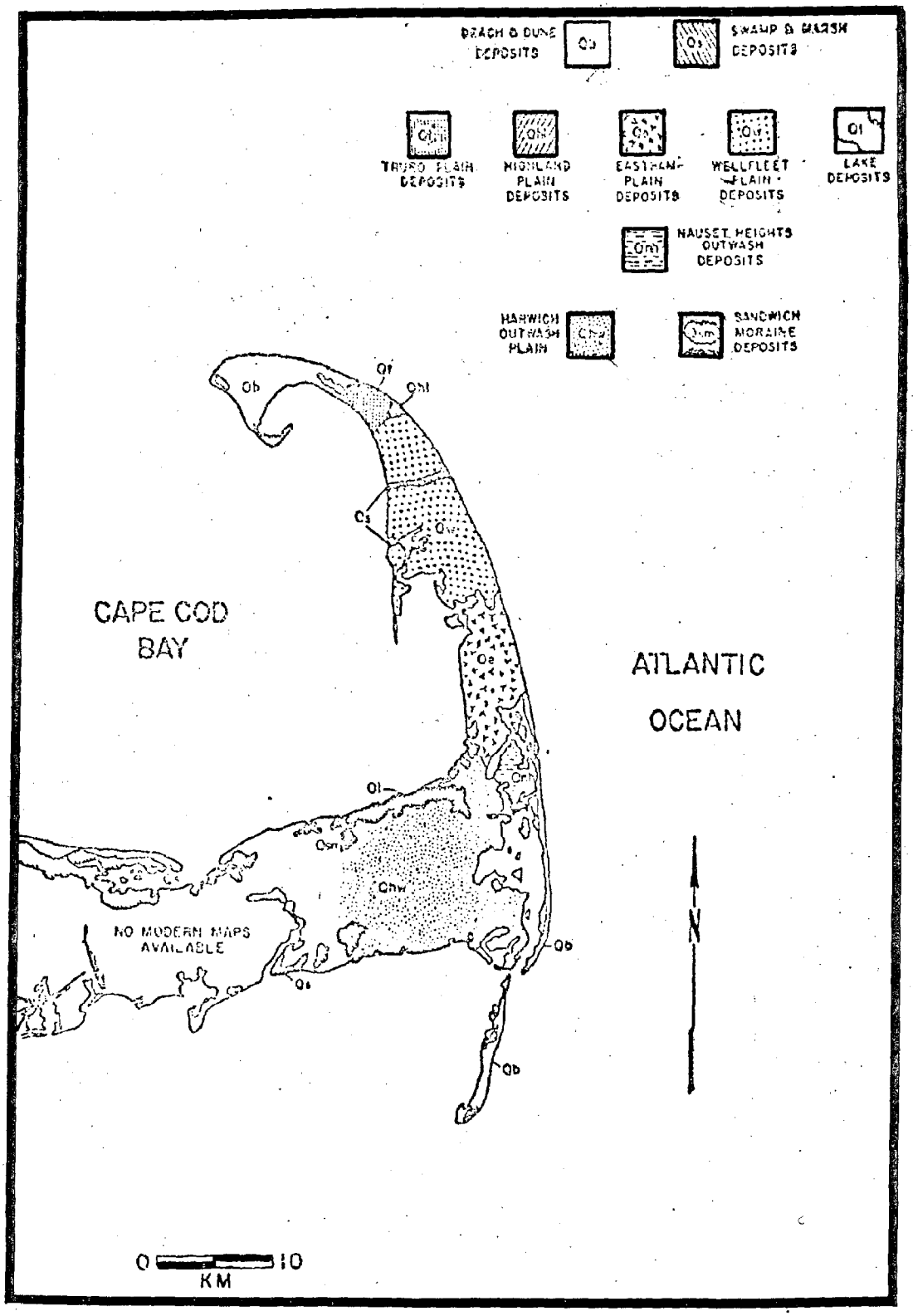
Glacial and post-glacial sediments are the major source of coastline sediments for beaches. Sediment type, distribution, and proximity to wave attack determine the location and sediment-size range of beaches.

The entire coastline of Cape Cod from the Plymouth area to Chatham is made up of glacial moraine sands, gravels, and boulders and glacial outwash sands and gravels (See Figure 5-9). The beaches of Cape Cod are sandy and extensive except where contiguous upland moraine exposures contribute gravel and boulders to the strand.

From the Plymouth, Massachusetts area north to the Massachusetts-New Hampshire border the major coastal surficial sediments are drumlin tills and ground moraine lodgment tills (Chute, 1965a, 1965b; Johnson, 1925; Crosby, 1934; Kaye, 1967; Farquhar, 1967). Strand beaches along this portion of the shoreline are extensive but gravelly and bouldery. Sandy beaches with dune ridges occur on spits, tombolos, and barrier islands where beach deposits do not abut upland glacial deposits.

Much of the coasts of New Hampshire and Maine are rock ledge, but beaches occur where surficial sediments exist below mean high water. Much of the southwestern coast of Maine is veneered by glacio-marine blue clays covered by sandy stratified drift. The major sandy beaches of Maine occur where outwash sediments are reworked by ocean waves. Elsewhere in Maine and New Hampshire pocket beaches occasionally break up the rocky shoreline where drift, ice-contact drift, and lodgment till lie adjacent to the shoreline, filling bedrock lows.

Bedrock exposures contribute little sediment to beaches and estuaries either as single grains, composite grains, or large rock fragments. Exposed ledge surfaces open to wave attack still retain glacial striations on smoothed surfaces (Hussey, 1970) and coarse-grained granites exhibit pitted surface where mafic and feldpathic minerals have been chemically-eroded, yielding clay-sized sediments. Locally bedrock fragments are contributed to littoral beaches by mechanical break-up along bedding or joint surfaces. Chapman (1962) has described massive granite slab beach ridges along the southern shoreline of Baker Island southeast of Mount Desert Island. The slabs have separated from exfoliation surfaces exposed to open ocean storm waves.



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

TRIGOM PARC	FIGURE 5-9	Surficial Geologic Map of Eastern Cape Cod

5.1.2 NEW ENGLAND BEACHES

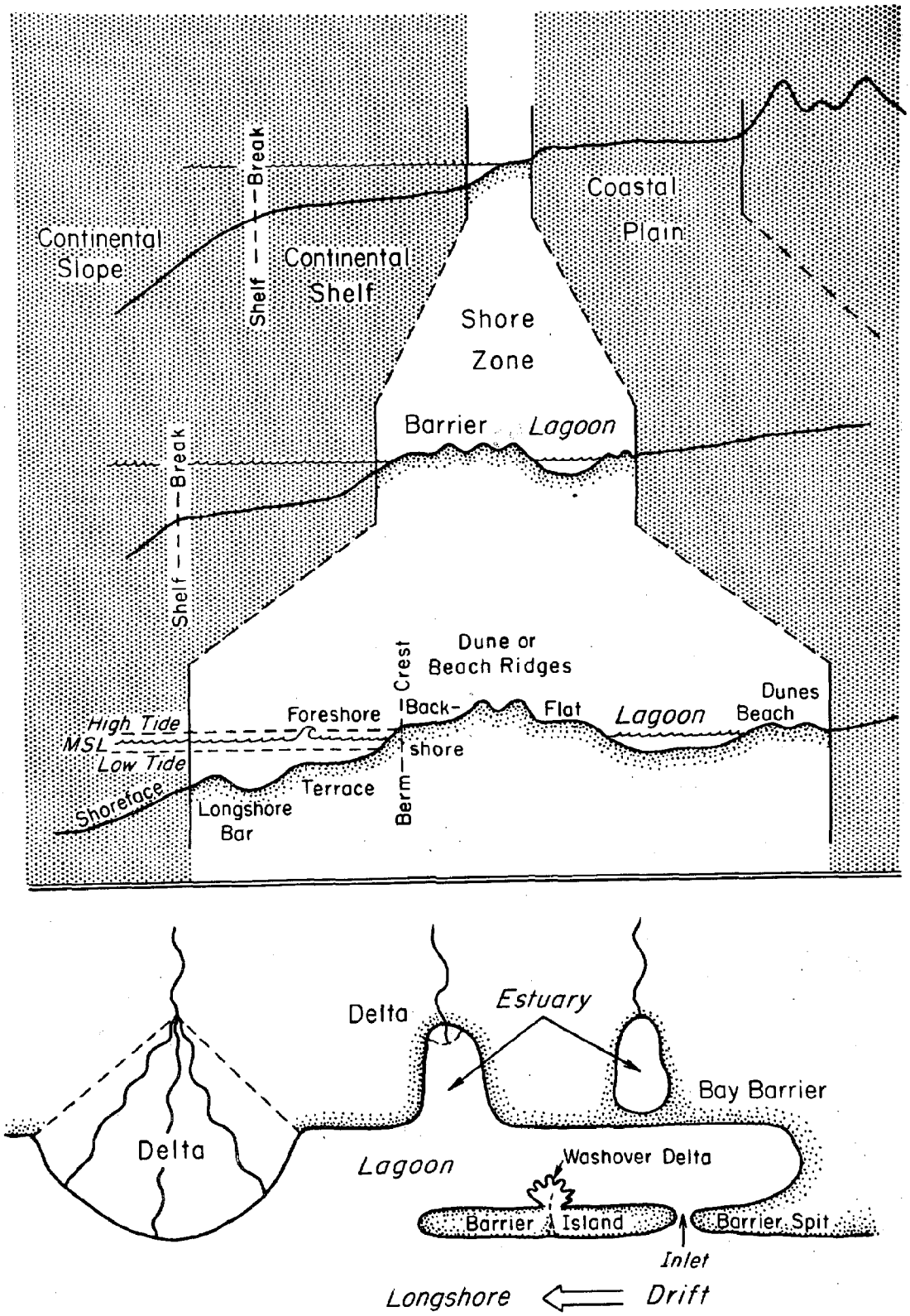
Barrier beaches, pocket beaches, strandplain beaches, and tombolos and spits comprise most of the beaches along the coast of the Gulf of Maine. These beach "types" vary morphologically as to their constituent sub-environments from one another, as well as exhibiting differences within type. Variations within type occur primarily with changes of sediment supply and sediment size.

BARRIER BEACHES

Barrier beaches are usually elongate island complexes comprised of beach, dune, interdune, washover, and occasionally, wind-tidal flat environments.

The beach consists of three elements: the shoreface, the foreshore, and the backshore. (See Figure 5-10). The shoreface is the seaward-sloping submarine portion of the beach first affected by wave translation motion. The shoreface is seaward of longshore or offshore bars where coarse to medium sand is constantly supplied to the beach zone, immediately seaward of the low-tide terrace where offshore bars are absent, and absent from many gravel beaches. One or more longshore bars exist landward of the shoreface and tens of meters seaward of the backshore where sediment supply is large. The tops of longshore bars may be exposed at low water, their existence and orientation revealed by wave surf. Multiple bars apparently occur where waves break and reform to break again when wave steepness exceeds a slope of .14, depositing its sediment load and, thus, creating another bar. Multiple parallel bars up to thirty in number occur off Eastham, Cape Cod (Nilsson, 1973), whereas one or two constantly occur offshore from Plum Island just south of the Merrimack River inlet. Goldsmith (1972) has described offshore bars oriented at oblique angles to the shore along Monomoy Island. Sediment size decreases from interbar lows to bar crests where constant wave activity sorts and isolates finer particles. Bar lows contain poorly-sorted, coarse particles that are incapable of being transported to the crests by normal wave activity (Hayes, 1973; Goldsmith, 1972). Seaweeds and other loose organic materials are frequently trapped in bar troughs (Nilsson, 1972). Longshore or offshore bars are absent off gravel, fine-grained, and sediment-deficient beaches. Longshore bars are the seaward element of the foreshore.

Shoreward of the offshore bars is a broad flat area exposed at low water - the low-tide terrace. The terrace surface consists of small-scale oscillatory (symmetrical), asymmetrical ripples formed by waves, and ground-water rills. The low-tide terrace may exhibit low mounds or tabular ridges of sand which migrate shoreward across the terrace. The sand ridges isolate troughs between their landward margins and the beach face forming a ridge-and-runnel system. Ridges migrate shoreward with landward-facing slipfaces until they weld to the beach faces to form berms. Ridges are essentially intertidal swash bars that



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

TRIGOM PARC	FIGURE 5-10	The Shore Zone and its Component Parts (A.G.I., 1969)

migrate by sand transport from the seaward margin of the bar over the bar crest by wave surge. Laminar flow conditions exist at the ridge crest where sediment is rapidly transported until it avalanches over the slip-face where water depths increase over the runnel. Runnels serve as lateral transport channels directing water drainage lateral to the beach during a falling tide. Channels cut between contiguous ridges direct runnel water seaward and may be analagous to rip-tide channels prevalent along the Pacific Coast.

The landward element of the foreshore zone is the beach face, the seaward dipping face of the berm where waves swash during the rise and fall of the tide. Coarse-grained beaches exhibit steep faces while fine-grained beaches have gently-sloping beach faces. Some beaches, usually fine-grained ones, exhibit a gentle beach face which extends from the berm to the low-water level; others feature a gently-sloping terrace from the beach face to some point of the low-tide terrace. This feature, the beach face terrace, (Coastal Research Group, 1969) is an ephemeral feature formed when ridges weld onto the beach face at its base during neap tides.

The backshore zone incorporates the beach environments from the crest of the beach berm to the base of the foredune ridge and is the transition zone between wave processes and wind processes. The backshore boundary is mean high water seaward and spring tide high water landward.

Berms are linear sand bodies parallel to the shore. They are roughly triangular in cross-section with a gently dipping landward upper surface and a seaward sloping face, the beach face. Multiple berms may occur where wave accretion continues through different tide ranges. Generally two berms persist, a neap berm and a spring berm; but three or four distinct berms may be present. Coarser beaches exhibit numerous berms at various positions down the beach surface. A berm may form during neap tides on the seaward slope of a ridge system, a phenomenon particular to beach areas adjacent to tidal inlets where sediment supply is abundant (Hine, 1972).

Berm accretion may be initiated by migration of a ridge across the low-tide terrace to fuse with the beach face or from wave surge transport of sand from the lower levels of the beach back to the upper beach face.

After extended periods of berm accretion, or widening of the beach, berm runnels are formed landward of the berm to provide runoff channels for water washed over the berm crest. Generally the berm surface abuts directly against a previously-eroded storm beach face or a steep scarp eroded into the foredunes.

The upper surface of the beach, from the berm crest to the dune line, is also subjected to winds. Wind-transport of sand may occur onshore, offshore, or alongshore. Small-scale wind ripples are ubiquitous along

the backshore during periods of strong winds. Continuous wind deposition of sand along the back of the backshore may initiate the growth of beach grass in an attempt to build a new ridge of dunes along the beach.

Dune fields are the remaining major element of barrier islands. Dune areas are the result of eolian processes and storm washovers from the seaward side of the barrier. The component environments of the dunes of New England barriers are, from beach to lagoon, fore-dune ridge, blowouts, dune lobes, interdune lows, dune ridge, and eolian flats.

The foredune ridge is a regular or irregular line of dunes immediately adjacent to the backshore. Most foredune ridges and other dune field ridges represent former beach or berm ridges which have grown vertically and landward by accretion of wind-blown sand. Accretion is initiated when a beach ridge has increased its height by deposition of windblown sand to prevent erosion by storm waves through several Marram grass (Ammophila arenaria) germination seasons. Small areas or clumps of grass induce entrapment of windblown sand heightening the grassy mounds and further enhancing more vegetation growth. Continued growth builds phytogenic dunes recognized by Goldsmith (1972) as the major dune type on Monomoy Island. Phytogenic dunes may also form by accretion of pyramidal dunes (McBride & Hayes, 1962), dunes created by accretion of sand in the lee of a vegetation clump.

Most foredune ridges are irregular ridges interrupted by blowout lows or active dune lobes building out onto the backshore or frontal scarp erosion by storm waves. Blowouts, unvegetated lows breaking up the continuity of the ridge, are basically wind eroded channels through the foredune. The seaward end of the blowout may terminate in a large dune lobe accreting onto the upper berm surface where prevailing winds flow offshore. Onshore winds blow sand into the dune field. Blowouts whose seaward ends are not terminated by large dune lobes present opportunities for storm washovers to concentrate in the low areas. Storm washovers occur at low areas and terminate within the dune field or, when the dune field is narrow, they traverse the entire barrier to deposit former beach and dune sand on lagoon marsh, tidal flat, or wind flat areas. Washover channels terminate landward in broad arcuate fans - washover fans which are subsequently reworked by tidal or eolian processes.

Interdune areas are unvegetated or vegetated low areas between dune ridges. Although interdune areas have been recognized on Plum Island (Larsen, 1969) and the Provincelands (Messenger, 1958; Hartshorn et al, 1967), most barrier islands within the study area have a single, irregular dune ridge or a dune field with scattered, isolated dunes. Interdune lows may be vegetated or unvegetated. Unvegetated areas act as sources of sand for the foredune ridge or backdune areas. These interdune deflation areas are coarser-grained than the dunes. Winds

winnow out the finer grades of sand leaving the coarse faction, including pebbles, deposited during storm washovers, behind.

Dune flats and washover fan deposits define the landward boundary of barrier islands. These environments are now unrecognizable because of development along the backs of barriers in many locations. Dune flats are vegetated or unvegetated, low, landward-sloping surfaces built by windblown sand from the dune areas. The flats are usually thick and overlie marsh deposits. In many areas, flats are veneered by algal mats in the intertidal or supratidal zone. The blue-green algae (such as Lyngbya majuscula) cover portions of the dune flats stabilizing the sandy surfaces from wind, storm wave, or tidal current erosion. Washover fan deposits in New England have not been well described in the literature because back island development of summer homes has covered most fans. Larsen (1969) and Goldsmith (1972) have indicated that they do exist on Plum Island and Monomoy Island, respectively. The author has been told that washovers occurred at Ogunquit Beach, Maine, in February of 1972 during a damaging northeast storm, but most of the washover sediment was reworked into tidal channel and bar deposits immediately after the storm.

Mention of recurved spits should be given here as they are, in part, a consequence of beach processes. Recurved spits are hooked ridges of sand occurring at the free, unconnected ends of a barrier island and they grow in response to refracted waves around the end of the barrier, tidal currents generated in tidal inlets into which the spits intrude in most cases, and the delivery of sediment from the open face of the barrier beach by longshore drift. Growth of successive recurved spits is the means by which the barrier grows in length. Farrell (1969) has detailed the growth, sediments and processes of the recurved spit at the southern end of Plum Island. The spits are anchored to beach ridges at the end of a barrier and curve around into an inlet or, in the case of Monomoy Island, the open sea. The curvature of the spit is induced by wave refraction from the open sea around the end of the barrier, but, where spits grow into inlets, tidal currents aid to retain the curvature of the spits. Recurved spits grow in length and width by beach processes, wave swash and wave washover, and vertically by wave and wind processes (Farrell, 1969). The front face of the spit resembles the foreshore and backshore of the barrier beach prograding landward and alongshore by berm construction. Since recurved spits close off back-barrier tidal flats, wave washover on the spit occurs frequently, transporting sediment across the spit to induce lateral accretion over lagoonal deposits toward the back of the barrier island. Coarse spit sediments inter-finger with fine-grained muddy lagoon flat deposits behind the spit. Eolian processes rework and deposit fine sand on the top of spits, and eventually, after vegetation occurs, form a curved dune ridge to stabilize the spit. Spit migration along the beaches rimming the Gulf of Maine have been documented by Johnson (1925), Goldsmith (1972), Nichols (1949), Farrell (1969) (1972), and Timson (1970).

POCKET BEACHES

Pocket beaches are small, narrow beaches formed in a pocket, commonly crescentic in plan and concave toward the sea (AGI, 1969). They are also called bayhead barriers. This type of beach is common along the rocky shoreline of Maine where bedrock lows are filled with glacial deposits. Pocket beaches are commonly gravel beaches with minor amounts of sand and protect small plots of salt marsh behind high beach ridges or, where sediment supply is deficient and the beach has not extended across the entire reentrant, small, marsh-rimmed lagoons with inlets.

Because of a relative deficiency of sediment and the coarseness of the available sediment supply, most pocket beaches are gravel - pebbles, cobbles and boulders. Some beaches are sandy (Short Sands Beach, York, Maine) but where sand is present with gravel, the sand is confined to the lower foreshore and shoreface. Pocket beaches generally lack offshore bars, low-tide terraces, and ridge and runnel systems apparently because of the lack of sediment supply, the average intense wave activity which keeps particles well up on the back ridge, and the coarseness of the constituent particles which allows a steep, stable beach face.

Sandy beaches exhibit beach face terraces as the seaward-most environment. Low swells or mounds of sediment may be evident on the lower terrace marking new deposition on the beach from offshore and mimicking the role of ridge and runnel systems described in the section on barrier beaches. Landward of the beach face terrace is the beach face exhibiting a number of poorly-developed berms - incipient berms (CRG, 1969). Sandy beaches exhibit the same environments landward as are common on barrier islands, but dune ridges are low and narrow and berm runnels are rare because of the poor berm development.

Gravel beaches exhibit steep beach faces which extend to the low-tide mark. Numerous gravel berms occur on the upper beach exhibiting sharp berm crests and faces. Gravel berms sit on a steep face leading up to a high gravel storm ridge, constructed during storms when the largest particles are lifted high on the beach. Storm ridges may grow to be over six meters in height above mean low sea-level. Gravel beach face slopes may be as high, or higher than 0.20, but the slopes which characterize the backs of storm ridges commonly exceed 0.25. The steep backside of the storm ridge leads directly down to marsh, lagoon, or upland surfaces. In some instances, the weight of the beach ridge induces compaction of marsh peat behind the ridge leaving shallow basins filled with salt water. Gravel washover fans occur on the backside of storm ridges as low arcuate fans sometimes vegetated with weeds and shrubs. Washover channels incised into the storm ridge have never been viewed by this investigator. Either shallow channels are eroded into the upper beach ridge, or gravel is simply thrown over the existing ridge along selected points where wave heights exceed those of the ridge.

STRANDPLAIN BEACHES

Strandplain beaches lie immediately adjacent to the upland and are built seaward by waves and littoral currents, i.e., it is a prograding shoreline. Strandplain beaches may exhibit all of the environments of barrier beaches with the exception of dune flats, washover fans, and washover channels. Commonly dunes do not exist and the backshore environment lies immediately shoreward of upland cliffs or seawalls. Sediment supply is either from longshore drift or directly from the uplands eroded during storms. Strandplain beaches occur all along the New England coastline, but are extensive along the coast south of Plymouth, Massachusetts, and Cape Cod. Strandplain beaches which are not associated with barrier islands elsewhere along the New England coastline are undernourished, gently-sloping, fine-sand beaches which resemble sandy pocket beaches. These beaches would receive sediment from adjacent upland surficial deposits except that the upland is commonly developed - seawalls and rip-rap prevent the new sediment from supplying the beaches.

TOMBOLOS AND SPITS

Tombolos and spits are, in most cases, intertidal sand or gravel bars extending from islands or points of land to the mainland or into open water, respectively. Some bars may accrete enough to be stabilized above mean high water. Both spits and tombolos are generated by refracting waves around headlands or islands; most barrier islands originated as spits. Grain sizes decrease away from the landmass anchoring the bar because wave energy decreases along the length of the bar. Both sides of a spit or tombolo generally exhibit the foreshore and backshore features of pocket beaches depending upon the size of the beach material. The most noteworthy spits and tombolos along the coast occur in Boston Harbor and have been studied by Johnson (1925), Nichols (1949), Chute and Segerstrom (1949), Jones and Locke (1951), Farguhar (1967), and Kaye (1967).

THE BEACH EROSION-ACCRETION CYCLE OF NEW ENGLAND SHORELINES

Observations by a number of investigators in different locales along the New England coast indicate that beach changes follow a cyclical, evolutionary sequence of development after storm erosion. Hayes and Boothroyd (1969) have summarized these changes and proposed a classification of beach development morphology for sand beaches. Timson (1969) has published observations of storm and post-storm morphologic changes on a gravel beach in New Hampshire.

Over five years of bi-weekly beach profiles by the Coastal Research Center of the University of Massachusetts on Plum Island have indicated the following cycle of beach development during and after the passage of northeast storms through the Gulf of Maine:

"(1) Early post-storm (up to three or four days after storm) - Profile is flat to concave and beach surface is generally smooth and uniformly medium-grained. Severest storms leave erosional dune scarps.

(2) Early accretion (usually two days to six weeks after storm) - Small berms, beach cusps, and ridge-and-runnel systems are quick to form.

(3) Late accretion, or maturity (six weeks or more after storm) - Landward-migrating ridges weld onto the backbeach to form broad, convex berms. On some beaches, welding does not occur and gigantic ridges (up to four feet in height) lie between the backbeach and the low-tide terrace." (Hayes and Boothroyd, 1969, p. 245)

Abele (1973) after two months of daily observations in the summer and winter has amended and added detail to the classification of Hayes and Boothroyd:

"(1) Early pre-weld or post-storm profile (duration dependent upon severity of storm) - A flat concave upward beach profile with heavy-mineral concentration (garnet, hornblende, and magnetite) near the distal end of the storm swash, which is commonly at the base of the dune scarp. According to Hayes and Boothroyd (1969), the grain size is uniformly medium sand. Small ridges (ampl. 20 cm) appear anytime from one day to one week after the storm passes and move quickly across the low-tide terrace. A beach step is rarely present. The gradient of the high-tide beach face varies between four and six degrees.

(2) Late pre-weld accretional (up to six weeks after storm) - Late pre-weld beach profiles characteristically have small neap berms with beach cusps. A wide low-tide terrace is present across which ridge-and-runnel systems will migrate. The sand is generally uniformly fine on the low-tide terrace (1.5-1.9Ø) with a coarse zone (often bimodal - 0.4Ø to + 0.8Ø) at the beach step. Mean grain size measurements for the high-tide beach face vary between 0.5Ø and 1.0Ø, with a zone of coarser sediment at the berm crest and finer sediment on the neap berm (1.1Ø - 1.6Ø). Coarse aeolian ripples formed by strong offshore winds may exist on the berm and the beach face. Zones of coarse sediment also may occur in other areas of higher swash energy such as at the base of cusp bays. Large runoff channels between the ridge-and-runnel systems are also prevalent. As the landward-migrating ridges weld onto the back beach and form wide berms, the early post-weld stage is reached.

(3) Early post-weld (two to three days to several weeks after welding) - After the large berm has formed by ridge migration and welding of the ridges to the backbeach, a period exists during which the active high-tide beach face is landward of the berm. Small ridges may still migrate across the berm surface and weld onto the back beach. The gradient during the early post-weld period is steeper on the high-tide beach face than on the seaward side of the berm ridge.

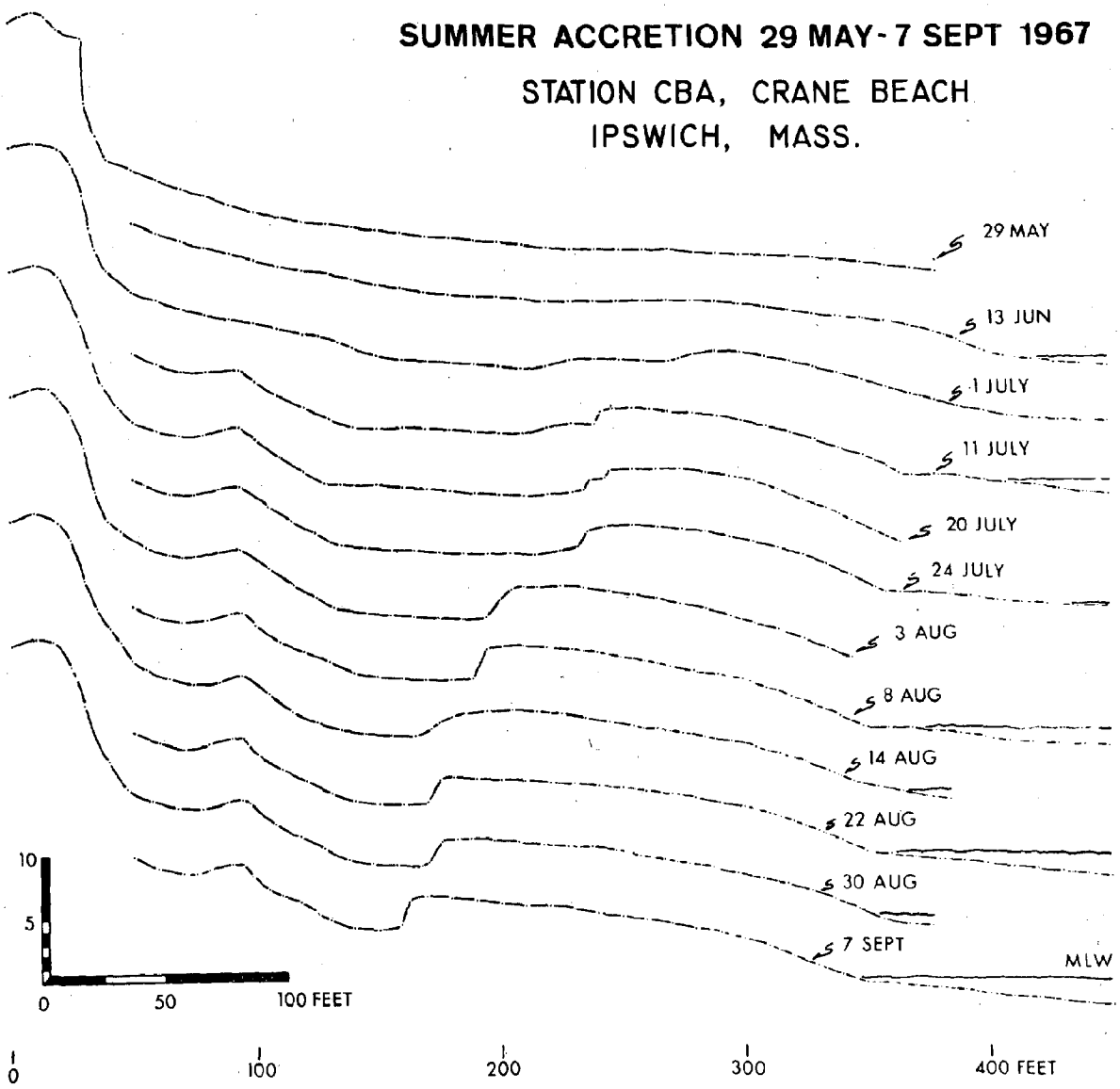
(4) Late post-weld - Late post-weld takes place after the active high-tide beach face is no longer landward of the berm, but exists on what was formerly the ridge beach face. High-tide swash does not overtop the berm crest during later maturity." (Abele, 1973, pp. 135 + 138).

The morphology cycle is entirely dependent upon the passage of storms, not seasons, and the cycle may be interrupted by recurring storms. Since storms are more frequent during the winter months, from September to March, erosion is more prevalent during these months and the beach profile commonly remains in the early post-storm stage. (See Figure 5-11)

The intensity of erosion and efficiency of reversion of a constructional beach to a post-storm profile are controlled by the following storm variables: (1) size and intensity of storm; (2) speed of storm movement; (3) tidal phase (spring or neap tide); (4) path of the storm with respect to the beach; and (5) time interval between storms (Hayes, 1969).

The accretional cycle proposed by Hayes and Boothroyd appears to hold true for sand beaches with a large sediment supply. Observations by Timson indicate that sediment-deficient beaches follow the same general erosion-construction cycle with the exception that low mounds migrate up the beach face terrace to construct incipient berms; a well-defined ridge-and-runnel system on a low-tide terrace does not exist.

Timson (1969) observed post-storm changes on Rye Beach, New Hampshire, a gravel beach. Because the beach face of gravel beaches is relatively steep, post-storm construction is limited to berm growth at high tide. Ridges or mounds of sediment do not migrate across the gently-sloping lower beach; the lower beach does not exist on the gravel beach. Where mixed sand and gravel beaches exist, migrating mounds or ridges of sand form on the lower beach while gravel berms reform quickly on the upper portion of the profile. Continued cross-beach migration of sand and accretion will cover the lower gravel berms with sand which will form a convex-upward berm itself. Gravel beaches recuperate to a constructional condition more rapidly than a sand beach, sometimes reaching a mature stage in less than a week after a storm.



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-11a	Typical Post-Storm Beach Profile Plum Island Mass. (Hayes & Boothroyd, 1969)

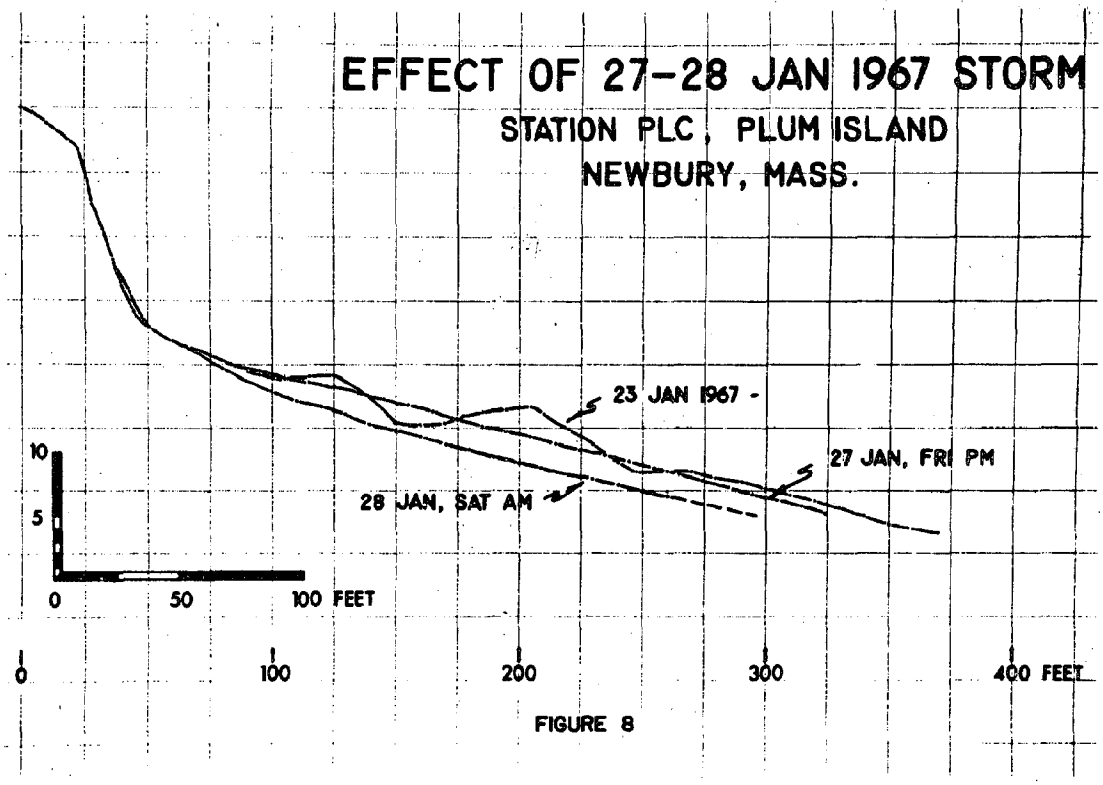
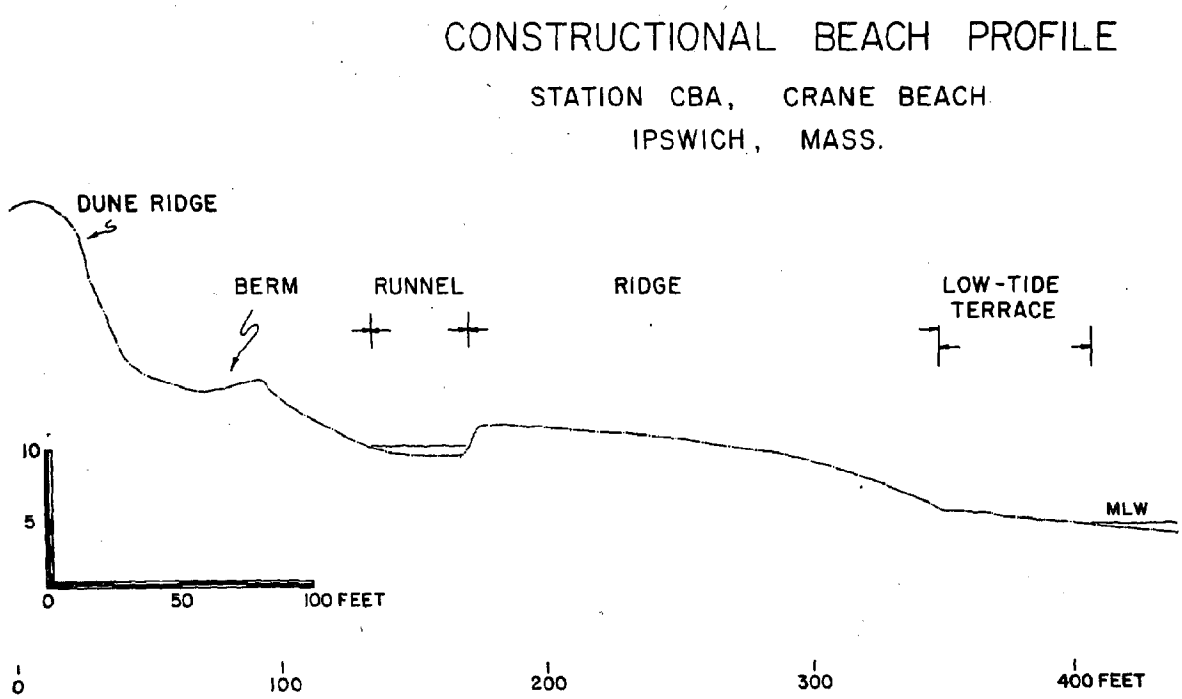


FIGURE 8

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-11b	The Constructional Beach Profile, Plum Island, Mass. (Hayes & Boothroyd, 1969)



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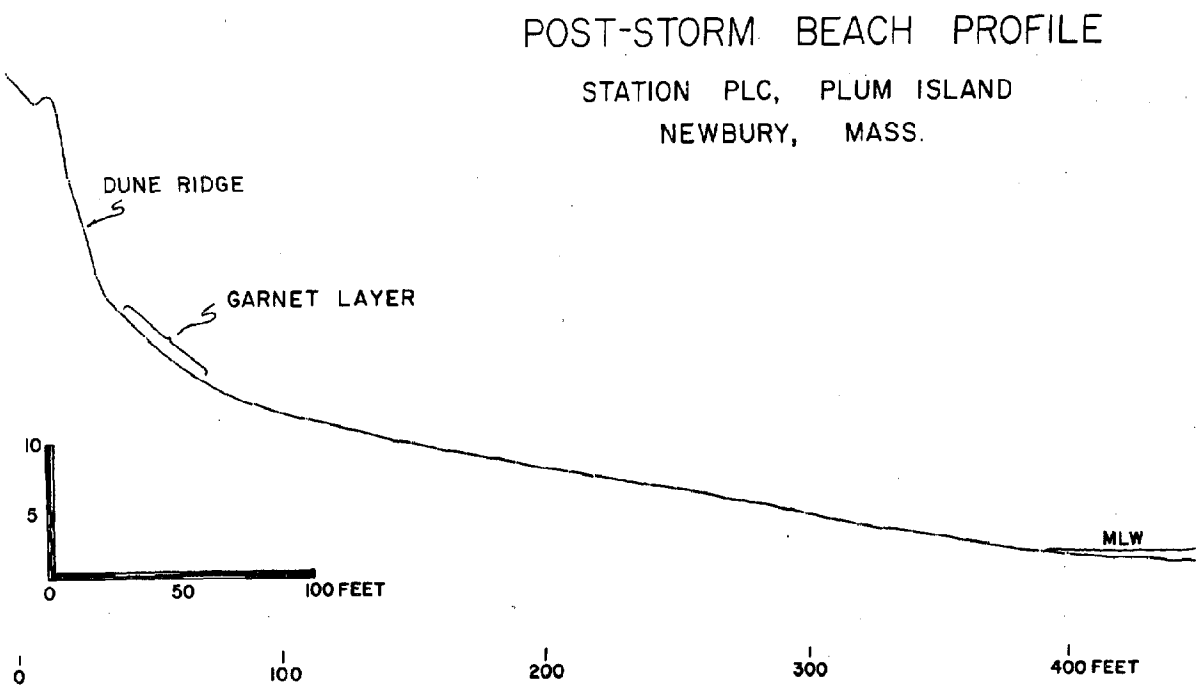
TRIGOM PARC	FIGURE 5-11c	Erosional, Post-Storm Beach Profile Development, Plum Island, Mass. (Hayes & Boothroyd, 1969)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-11d	Post-Storm Recovery of Cranes Beach Profile (Boothroyd, 1969)

5.1.3 MAINE BEACHES

POPHAM BEACH, PHIPPSBURG - SAGADAHOC COUNTY

The Popham Beach area lies at the southern tip of the Phippsburg Peninsula and consists of four beaches from east to west: Popham Beach, Hunnewell Beach, Morse Beach, and Small Point Beach. This littoral system lies on the western shore of the mouth of the Kennebec River and receives most of its sediment from the river system.

Popham Beach extends south from Fort Baldwin headland 1.2 km where it continues as a tombolo to Wood Island. The beach is coarse-grained with a steep beach face that plunges directly to the Kennebec River channel. Low, vegetated dunes extend 50 m back from the beach to the upland. Erosion is severe along this beach during storms coincident with high tides and high river runoff (Timson, 1969).

Hunnewell Beach, Morse Beach, and Small Point Beach extend southwesterly, in respective order, from the south end of Popham Beach. Hunnewell Beach is arcuate in plan, facing the southeast, and extends .4 to .6 km seaward from the beach face at low tide. Several large ridges commonly occupy the wide low-tide terrace, receiving sediment constantly from the Kennebec bedload.

Hunnewell Beach is a barrier beach which has combined with Popham Beach in a cuspate foreland to completely isolate Silver Lake, a former lagoon. Erosion of a low, wide dune ridge field is common during northeast storms over its 2 km length. The southern end of the beach adjoins Morse Beach, a barrier beach with an extensive dune field. Morse Beach extends across and has cut off Atkins Bay, a portion of the tidal Kennebec, from the ocean. Morse Beach extends one km from the Popham State Beach area at the end of Hunnewell Beach to the inlet of the Morse River, a neutral tidal river. Both Hunnewell and Morse Beaches exhibit the typical erosion-accretion cycle discussed by Hayes and Boothroyd (1969), but the southern end of Morse Beach is influenced by the channel of the Morse River which shifts north and south across the lower beach environments. Offshore bars occur 1.2 km seaward of Hunnewell Beach, but are absent in front of Morse Beach.

Small Point Beach extends 2.2 km from the Morse River inlet to the Sprague River inlet just northeast of the Cape Small inlet. The beach is a barrier spit composed of two relict, dune-vegetated beach ridges and an active ridge and beach, protecting an extensive saltmarsh embayment. The beach is composed of medium - to fine-grained quartzose sand and exhibits diminutive berms in the greatest of accretional stages with an absence of a low-tide terrace and ridges.

The net transport direction, determined by direction of spit growth and observations of grain-size distribution is from northeast to southwest. Popham Beach is composed of coarse-grained feldspathic sand while Small Point Beach - fine-grained quartzose sand. Drift directions are from southwest to northeast during the summer months when southwest winds prevail. This drift direction is evident by the shift of the Morse River channel to the north across the face of Morse Beach.

Severe erosion during northeast storms is limited to Popham and Hunnewell Beaches with minor erosion occurring on the southern beaches. Many residents have remarked that wind erosion of the extensive dune fields backing Morse Beach has been increasingly severe over the past ten or fifteen years, probably due to increased pedestrian traffic and use across the dunes.

The sediment source for the Popham Beaches is the Kennebec River drainage system with minor sediment volume contributed by local surficial deposits.

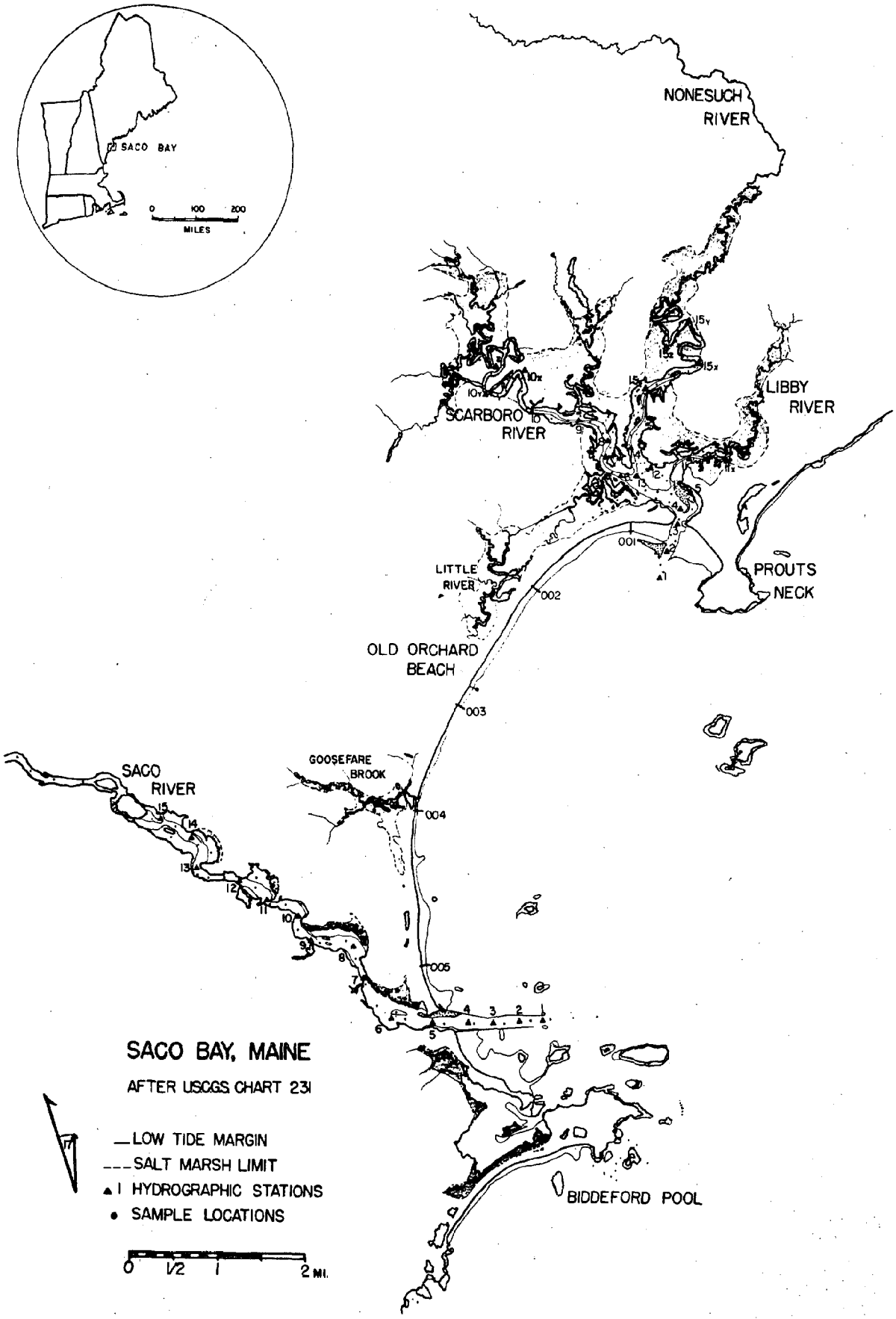
OLD ORCHARD BEACH, BIDDEFORD, SACO, SCARBOROUGH - YORK COUNTY

Old Orchard Beach is an 11 km beach arc opening directly to the east into Saco Bay. The Saco River enters the Bay at the beach's southern end while the Scarborough River and its tributaries empty into the reentrant at the northern end. The bay system is isolated from the coast to the north and south by rock headlands (See Figure 5-12) . Farrell (1970, 1972) has studied the coastal environments of Saco Bay extensively; much of what is reported here is a condensation of his work.

The beach system can be divided into three segments. The southern beach segment begins as a harbor spit in the Saco estuary (now transformed to an open beach ridge as the Saco River entrance is stabilized by jetties) and runs north to culminate in four barrier spits (three relict, one active) extending across the Goosefare Brook embayment. The Goosefare maintains a small tidal inlet across the beach system approximately 1/3 the distance from the Saco River to the Scarboro River.

The middle ridge segment extends as a barrier beach from the Goosefare Brook inlet, past two rocky points and in front of the Little River marsh basin. The northern portion of this segment is backed by a sizable dune field with three to five foot high dunes now covered by trees.

A single beach ridge extends farther north from the second portion (former site of the Little River inlet, now closed off) to end in a series of spit-accretion ridges bending into the Scarboro harbor. The Scarboro inlet is also stabilized by jetties.



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

TRIGOM	FIGURE 5-12	Physiography of Saco Bay Area Shoreline (Farrell, 1972)

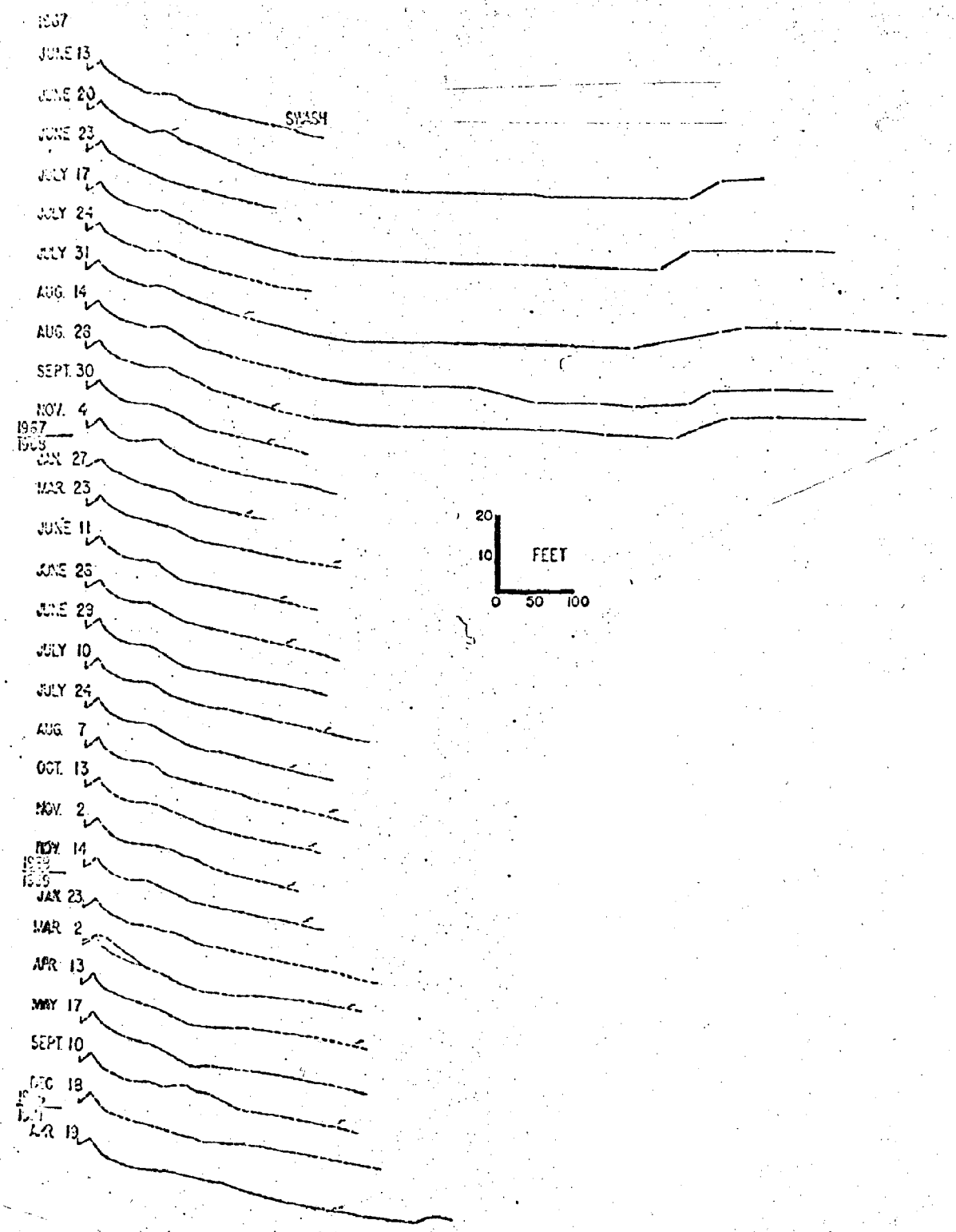
The barrier system has been modified extensively by man. The entire beach has been developed with amusements, concessions, homes, and motels. Two rock promontories have been removed near the center of the barrier arc and, as mentioned before, the two large inlets have been stabilized. No seawalls or groins have been built at present, but serious damage in the recent past at the southern end of the beach (Camp Ellis) may herald protective structures in the near future.

Farrell (1972) studied beach changes at five localities along Old Orchard Beach. Two localities on the northern segment of the beach are characterized by white, medium-size quartz grains and long, low beach profiles. Berm and ridge features change seasonally, but these features are diminutive in size. The northern-most segment of the beach is protected by a swash bar complex offshore at the mouth of the Scarboro River. This swash bar complex migrated shoreward from 1967 to 1971 but has not welded to the beach face (Figs. 5-13-16)

The rest of the beach, from the Old Orchard Beach Amusement Park south, is composed of coarse, yellow, feldspathic sand in contrast to the finer quartz sand on the northern segment. Beach features are sharper and steeper along the beach and respond quickly to seasonal and storm conditions. Berms are common along this portion of the beach but ridge and runnel systems are absent. The beach segment adjacent to the Goosefare Brook inlet is actively affected by the inlet dynamics. The inlet channel may migrate back and forth across the beach over a 200 m lateral distance. A barrier spit grows northward during the summer months forcing the channel northward. A cuspate ebb-tidal delta occupies the low-tide terrace of the beach seaward of this inlet with attendant swash bars that migrate shoreward periodically.

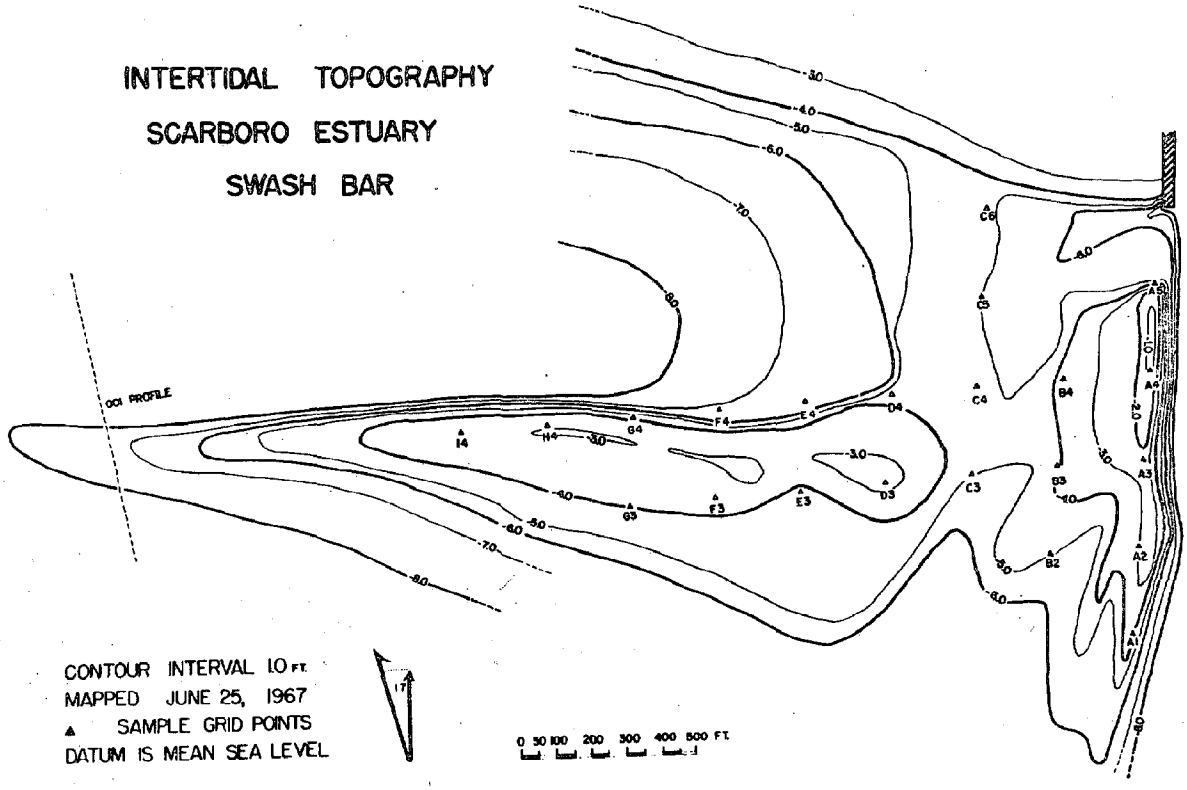
Farrell has noted no net loss to the beach system over four years time; the beach responds to climate changes through berm growth cycles whereby the beach advances up to 20 m and retreats during storms.

Grain-size decreases northward from a median diameter of 0.75 mm at Camp Ellis to about 0.20 mm at Pine Point, Scarboro. The diameter of the beach sand decreases abruptly about 2/3 of the distance from the Saco to the Scarboro River. Farrell (1969) explains the sediment distribution patterns along the beach as being the result of southeast and northeast wave interaction on the littoral zone (See Figure 5-17). Net longshore drift is northward, induced by short-period, low waves from the southeast and long-period, refracted northeast waves which transport littoral sand northward along the northern-most third of the beach. Long-period swells generated by northeast storms impinge on Old Orchard essentially parallel to the beach along the southern two-thirds portion of the reentrant. The southeast waves and refracted northeast waves are of low-energy transport capability, but capable of transporting the medium-grained quartz sand in a northerly direction



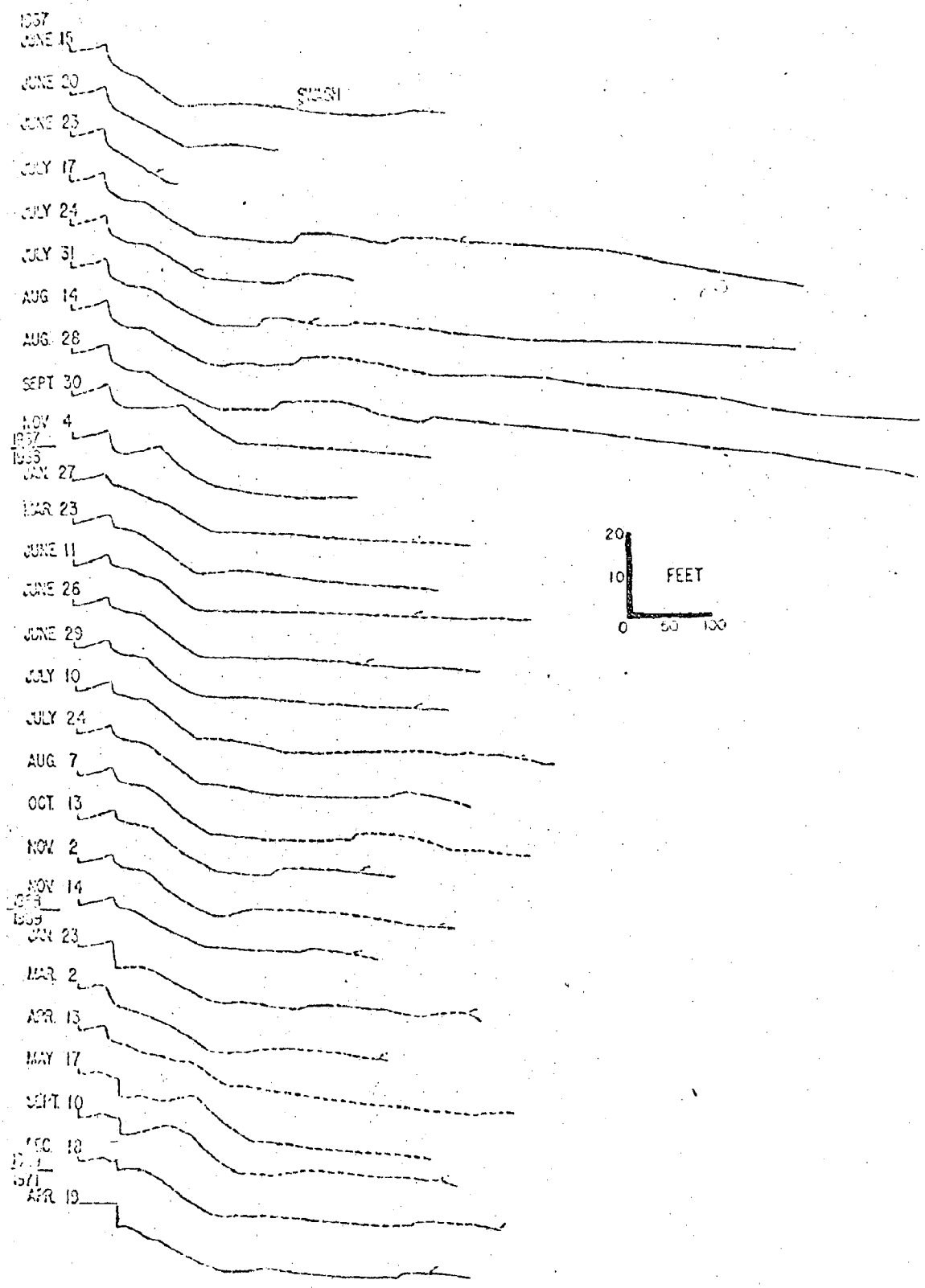
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-13	Old Orchard Beach Profiles (Farrell, 1972)



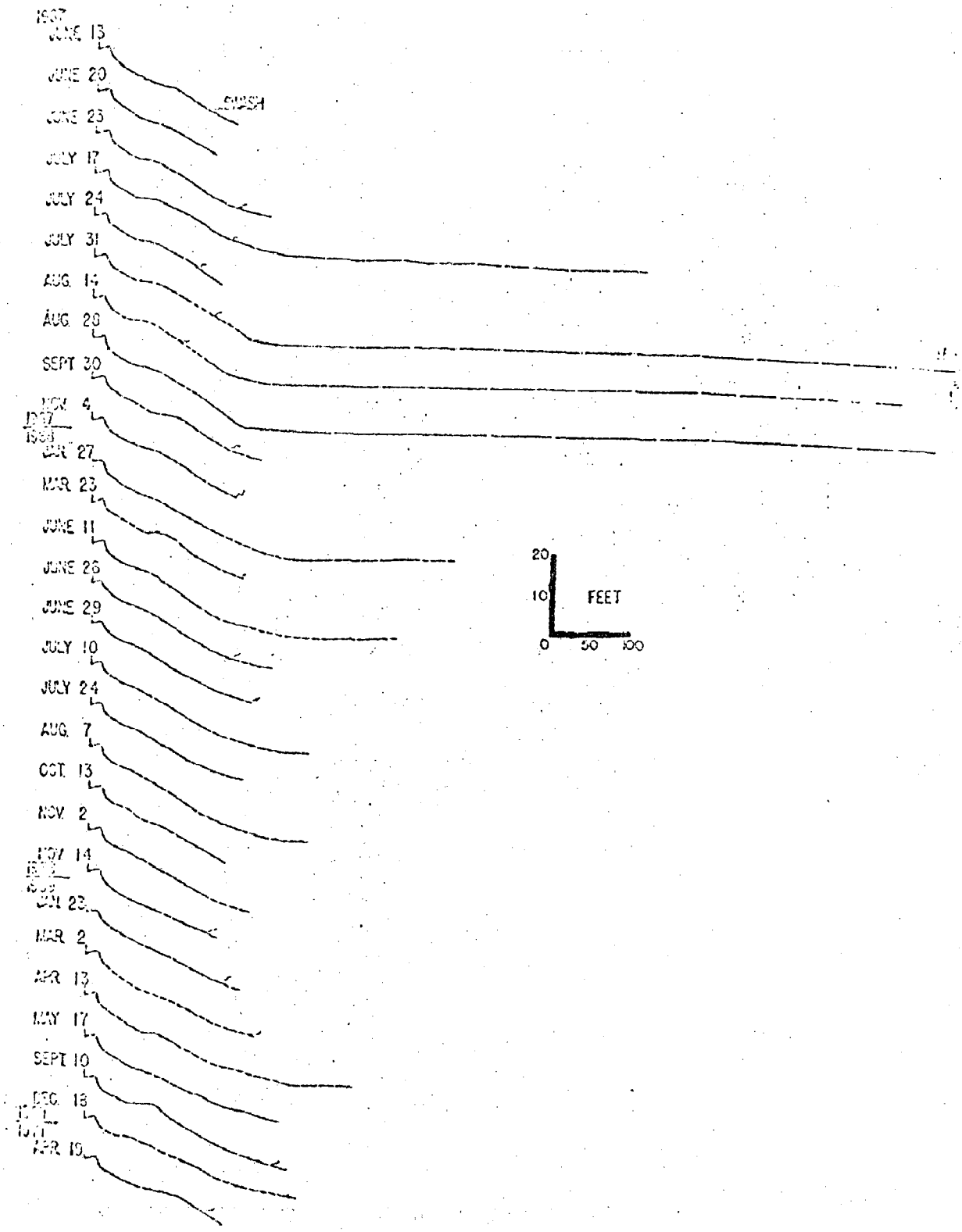
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-14	Swash Bar Topography. Scarboro Ebb Tidal Delta (Farrell, 1972a)



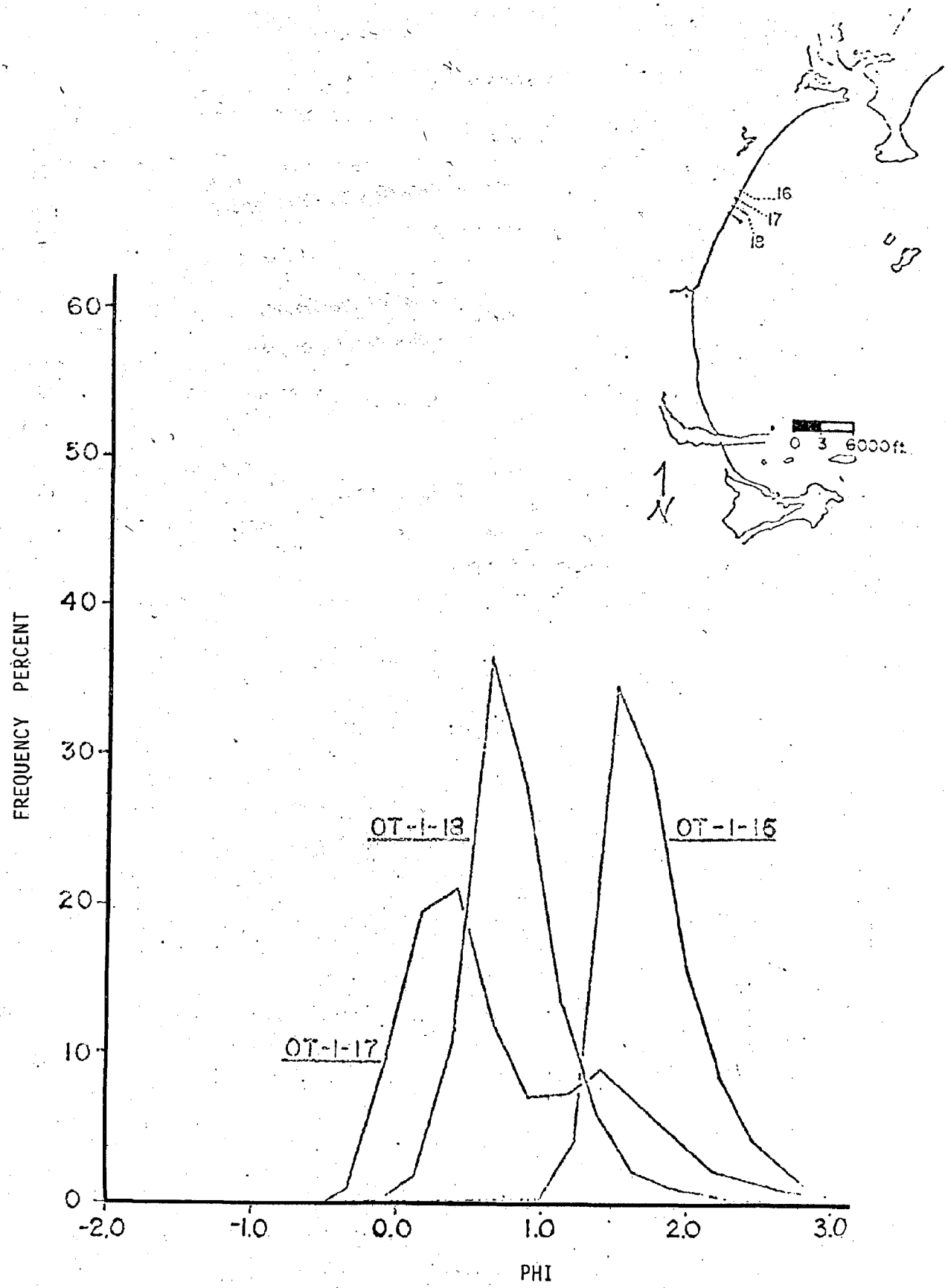
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-15	Old Orchard Beach Profiles (Farrell, 1972b)



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

TRIGOM PARC	FIGURE 5-16	Old Orchard Beach Profiles (Farrell, 1972b)



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

TRIGOM PARC	FIGURE 5-17	Frequency Distribution at the Grain-Size Separation Zone-Old Orchard Beach (Farrell, 1972b)

along the entire beach. The equally-distributed high-energy kinetics of northeast waves on the southern and central portions of the beach restrict the coarser particle sizes to these portions of the system. The increase of grain-size to the south within the coarse zone is maintained by short-period northeast waves generated by local winds and fetch across Saco Bay itself. Maximum storm-wave energy is centered at Camp Ellis where only the coarsest sand grains are capable of remaining on the beach. Camp Ellis, historically, has suffered storm damage as a result of the short-period wave generation across the Bay coupling with long-period northeast swells generated in the ocean and propagating into the Bay (See Figure 5-18).

Sediment supply to the Old Orchard Beach system is now limited to the wave-reworked, relict ebb-tidal delta of the Saco River inlet. Dam construction along the Saco River and jetty stabilization of the Inlet has prevented sand from being delivered to the delta system over the past 30 to 40 years. Slow, but continuous, loss to the system occurs with sand transport into the Saco and Scarboro estuaries.

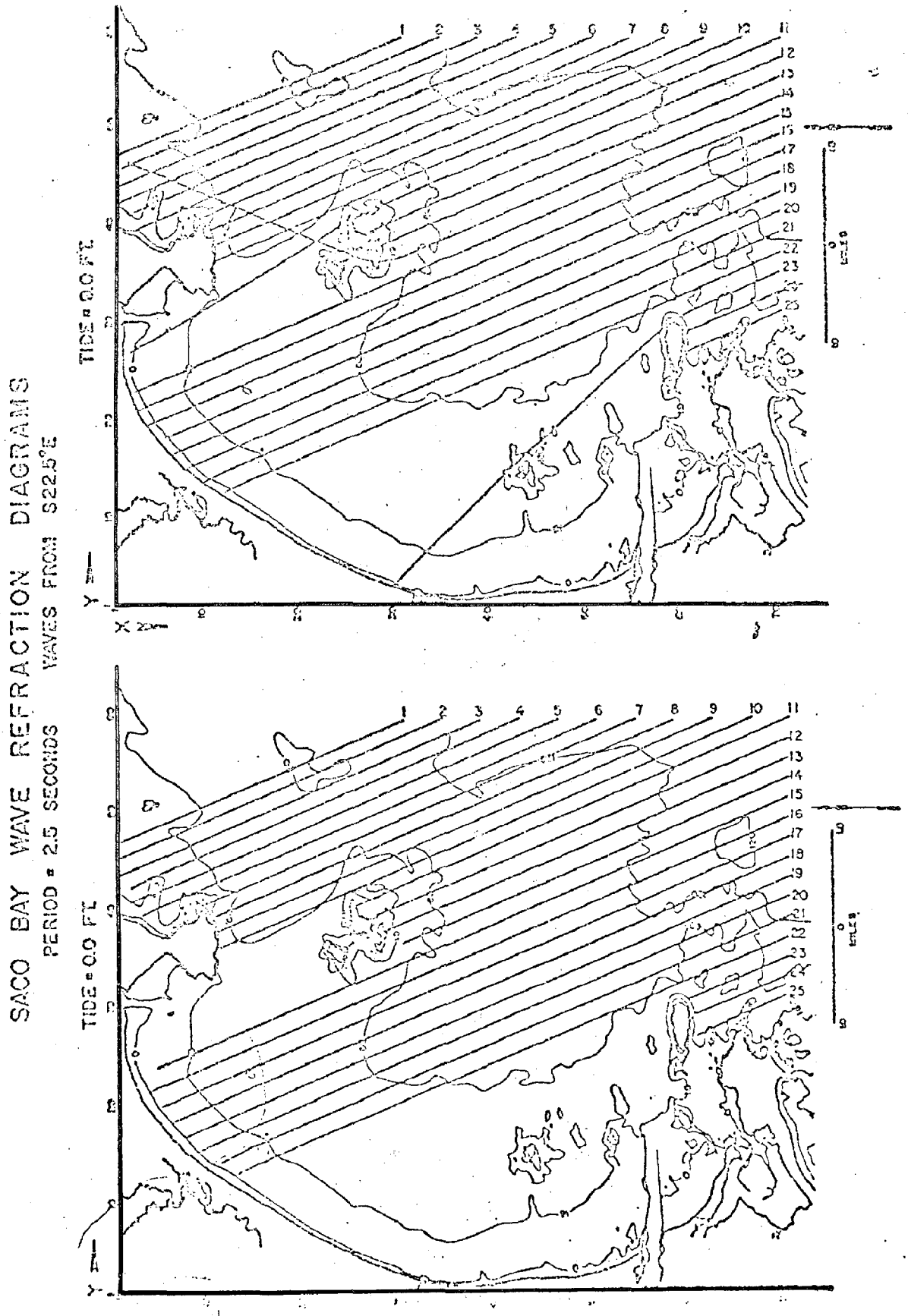
SACO BAY SEDIMENTS - SACO

Farrell (1972) has also studied the sediments of Saco Bay. The Bay is 8.5 km long and 4 km deep from the tips of the headlands to Old Orchard Beach. Two islands, Bluff Island and Stratton Island, lie at the entrance and in the middle of the bay, while several small islands lie offshore from the Saco River mouth. Depths within the Bay do not exceed 36 m.

The entire bay floor is covered by sand except where bedrock ledge extends 6 to 8 m above the sandy floor. The bay bottom drops steeply away from the barrier beaches for the first kilometer, and this slope represents the beach shoreface. The floor slopes less steeply for the next 2.5 km and steepens again to continue seaward well beyond the bay mouth; the middle, gentler slope is a zone of wave planation.

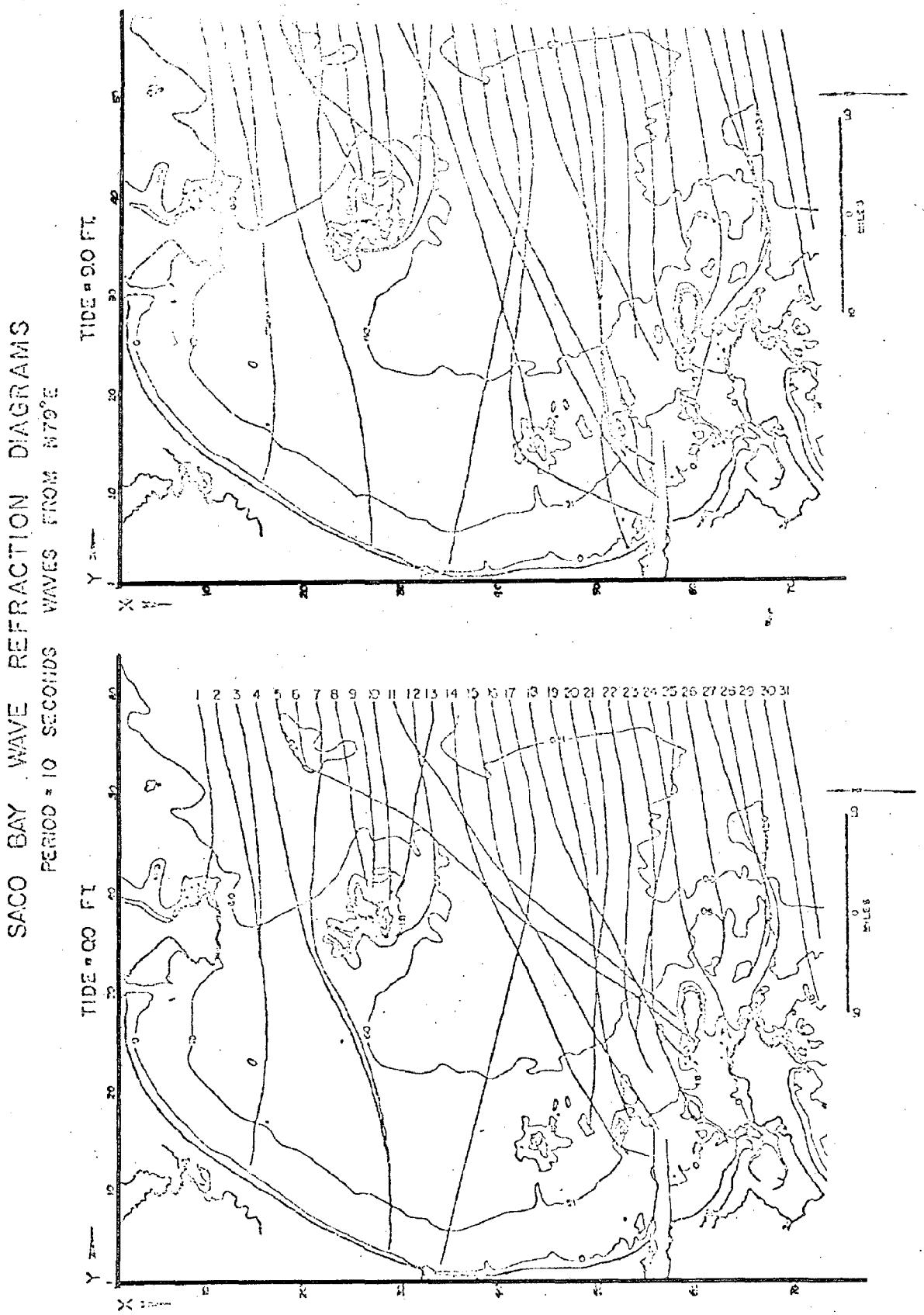
The bay sediments may be sub-divided into three groups. One group consists of fine, very light-yellow, moderately sorted quartz sand found in depths of less than 22 m. The second group is fine, light yellow, slightly muddy, poorly sorted quartz sand found below depths of 22 m. A third group, coarse, well-to-poorly sorted, rock-fragment-rich sediment, is associated with the subaqueous margins of islands, ledges, and the Scarboro ebb-tidal delta (See Figures 5-19 & 5-20).

The fine sand veneering most of the bay's floor is derived from the winnowing of finer sand-sizes from the beach by waves. The fine sand remains in suspension after storms pass to be transported offshore where it is continually reworked by wave currents on the bottom to produce a sorted sediment cover. Below 22 m storm waves are



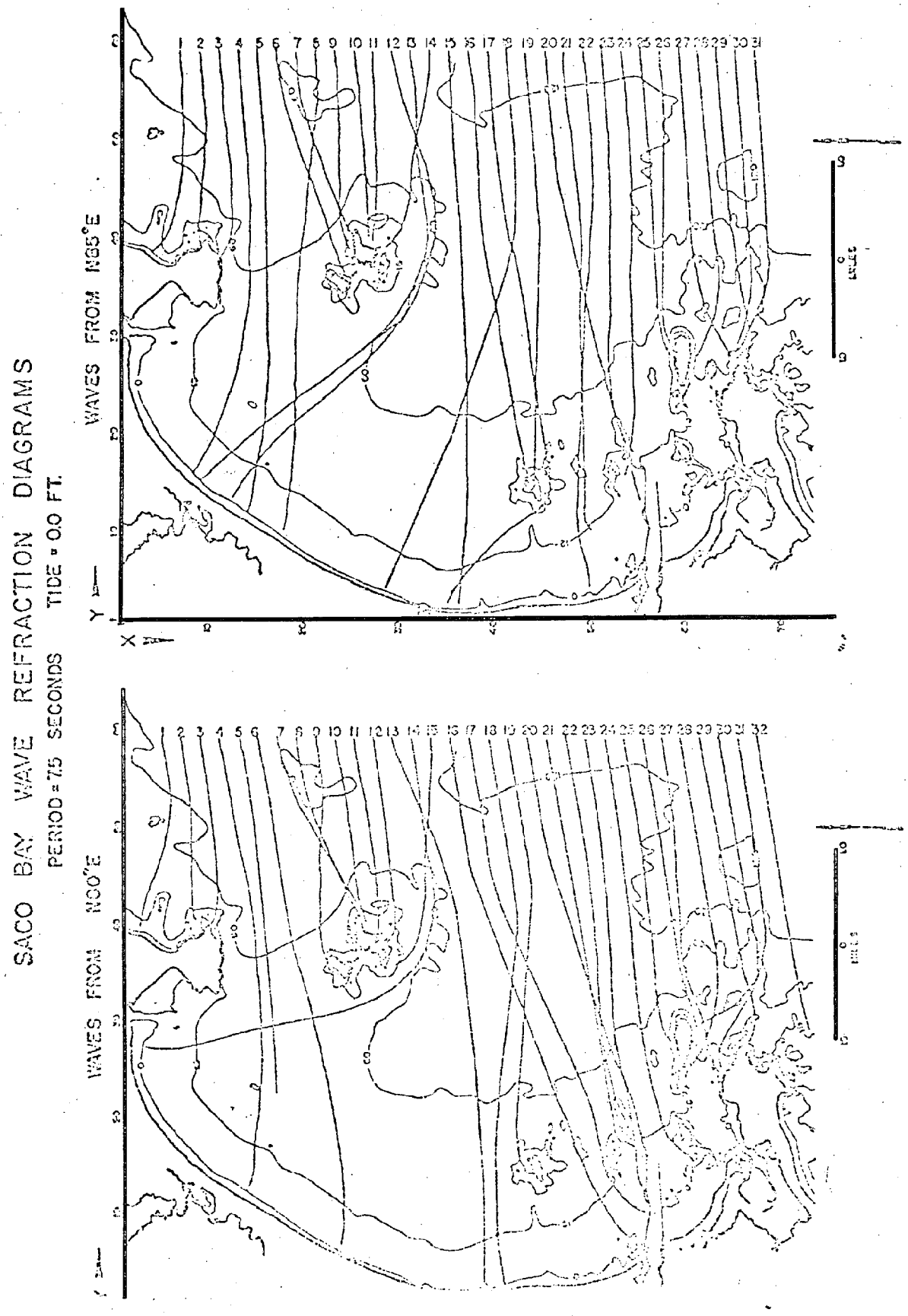
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-18 a	Wave Refraction Diagrams. 2.5 Second Period Waves (Farrell 1972b)



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

TRIGOM PARC	FIGURE 5-18 b	Wave Refraction Diagrams. 10 Second Period Waves (Farrell 1972b)



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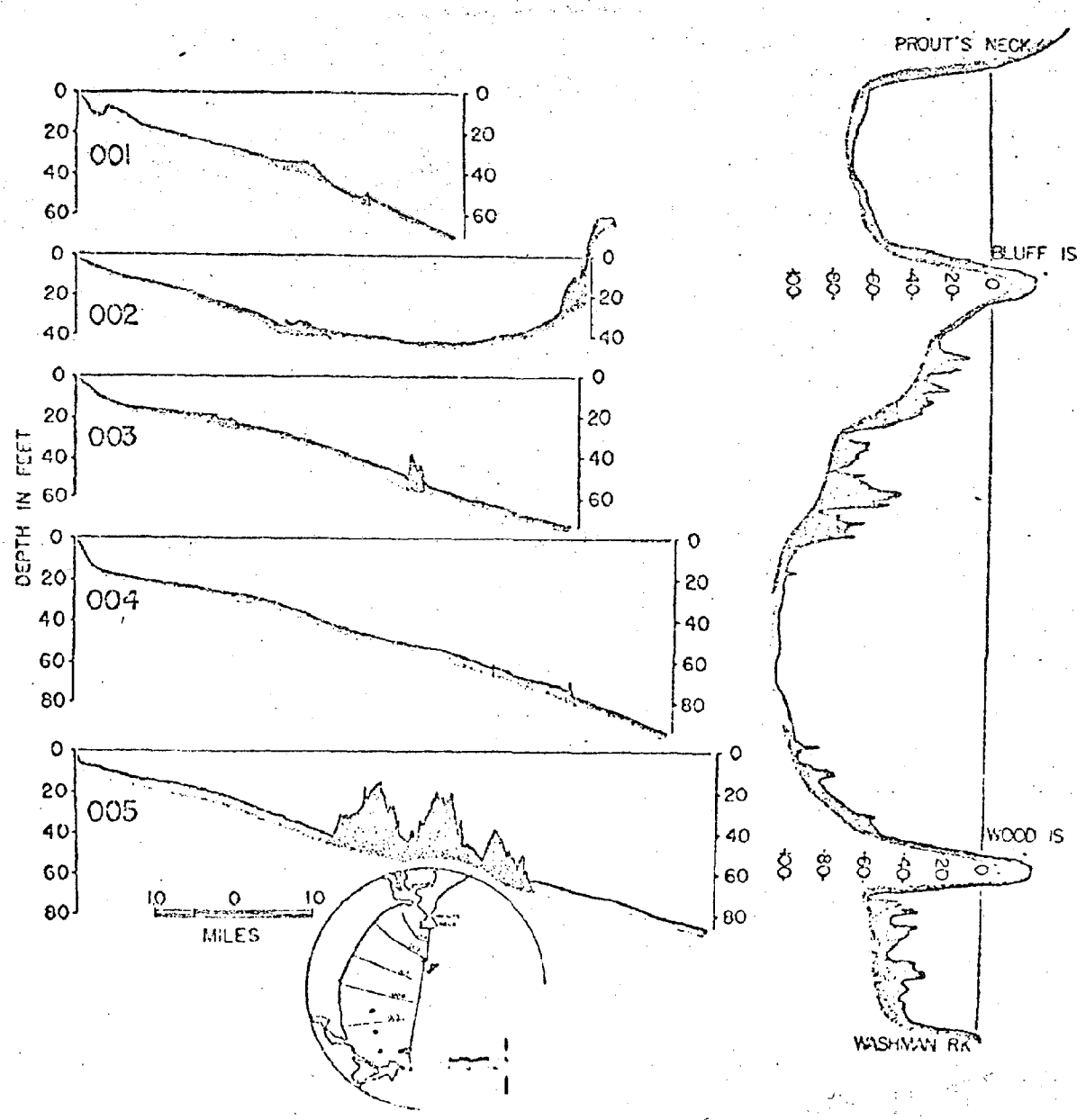
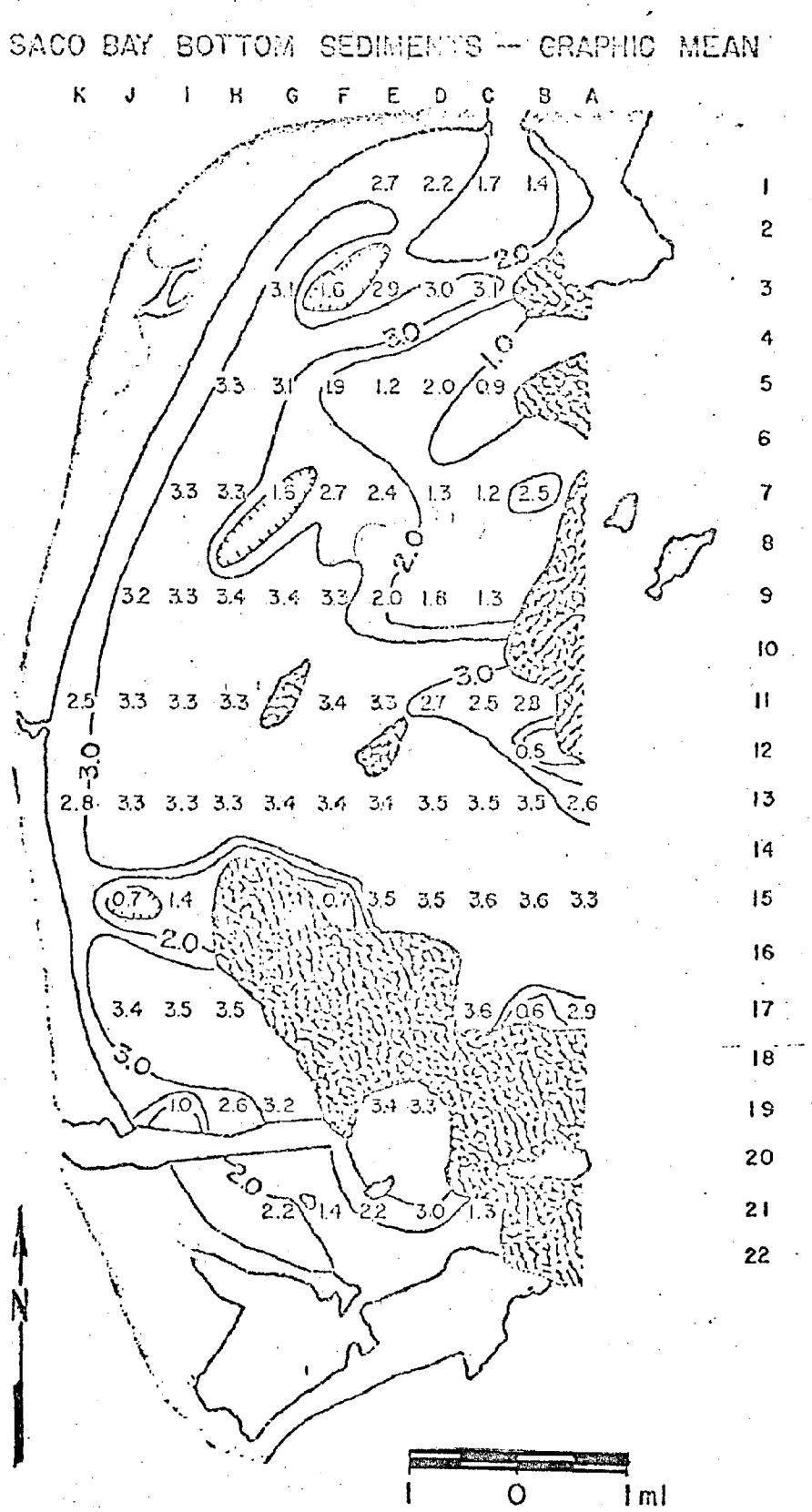
TRIGOM PARC	FIGURE 5-18c	Wave Refraction Diagrams. 7.5 Second Period Waves (Farrell 1972b)



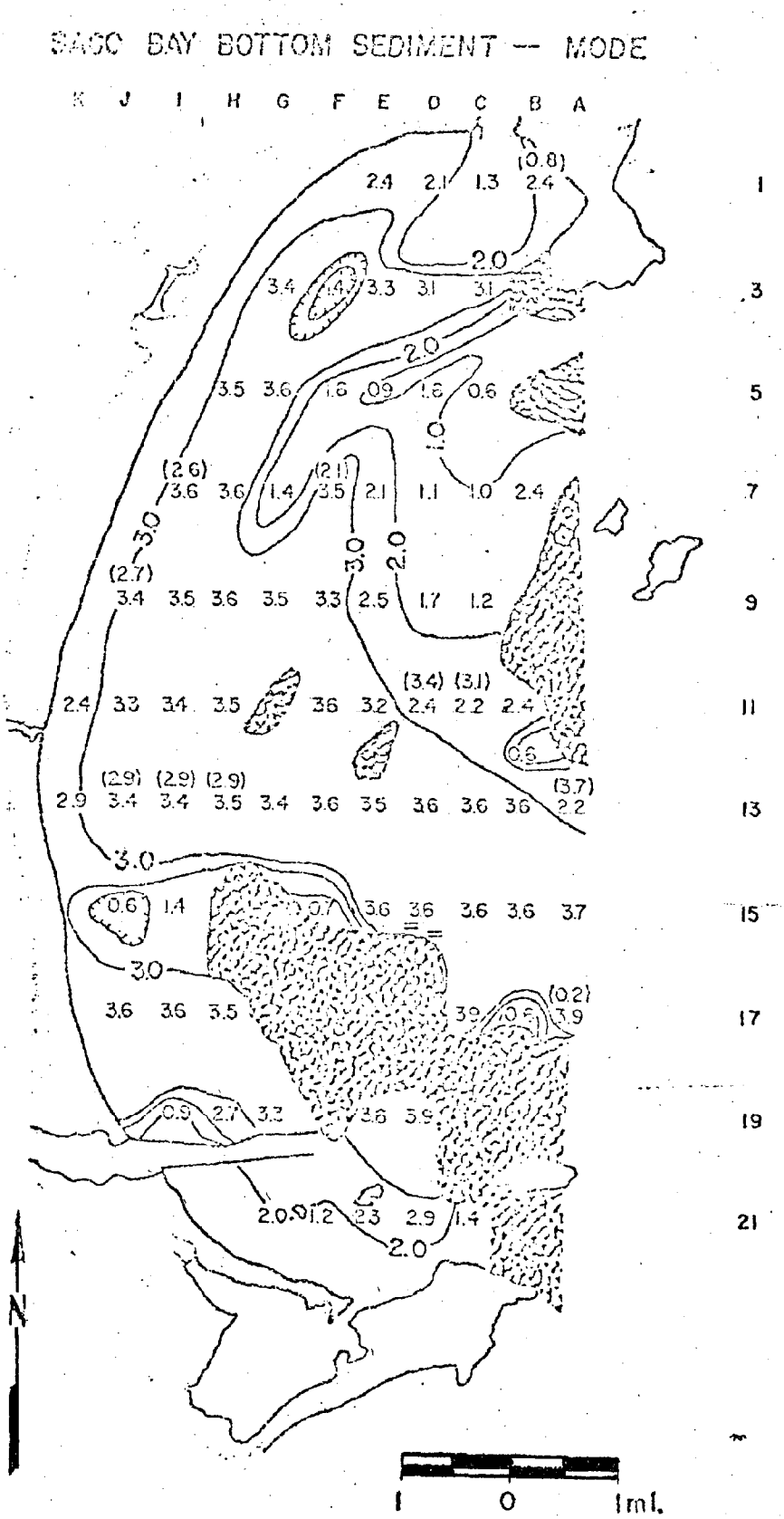
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-19	Saco Bay Substrate Surface Profiles (Farrell 1972b)



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

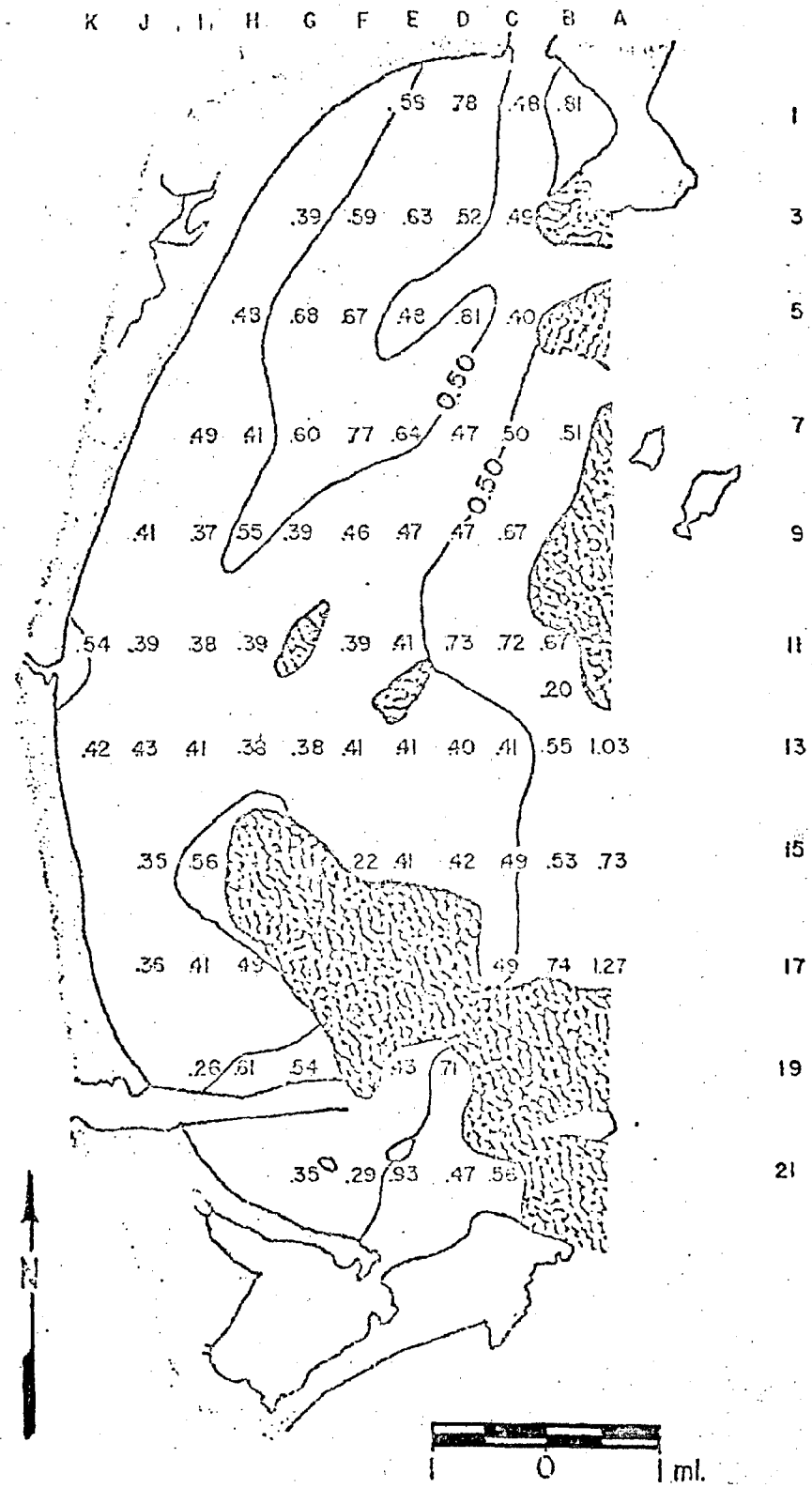
TRIGOM PARC	FIGURE 5-20a	Textural Characteristics of Saco Bay Surface Sediments-Graphic Mean (Farrell, 1972b)



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

TRIGOM PARC	FIGURE 5-20b	Textural Characteristics of Saco Bay Surface Sediments-Mode Distribution (Farrell, 1972b)

SACO BAY BOTTOM SEDIMENTS — INC. GRAPHIC STD. DEVIATION



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-20c	Textural Characteristics of Saco Bay Surface Sediments-Sorting (Farrell, 1972b)

incapable of generating bottom currents high enough to leave a single modal value of 3.0-3.5 phi characteristic of the inner bay floor. Below 22 m a substantial amount of silt exists with the fine sand. Farrell (1972) calculated that bottom, wave-induced currents must be incapable of reaching values of 25-27 cm /sec frequently below the 22 m depth. Effective wave base within the bay is 22 m, a depth at which, according to Farrell, is compatible with northeast wave swells of .75 to 1.0 m heights and 6.5 to 8.5 second wave periods observed as being capable of transmitting maximum wave energy into Saco Bay.

WELLS-KENNEBUNK AREA, OGUNQUIT, WELLS, KENNEBUNK - YORK COUNTY

The coastline of the Wells area contains over 14 km of beaches rimming a shallow reentrant between two resistant headlands. Six major beaches make up this southeast-facing reentrant shoreline. From north to south, they are: Kennebunk Beach, Parson's Beach, Laudholm's Beach, Drakes Island Beach, Wells Beach, and Ogunquit Beach.

Kennebunk Beach is an intensely-developed, narrow, 1.5 km long barrier island protecting portions of the Kennebunk River estuary from the Atlantic Ocean. The beach faces directly south and can be divided into two segments, a westerly segment characterized by short beach arcs and intervening rocky points, and an eastern segment, an unbroken sandy barrier spit terminating at the mouth of the Kennebunk River.

Kennebunk Beach is composed of medium, well-sorted quartz sand on the foreshore and pebble-to-cobble-sized gravel on the backshore. The backshore is narrow and gravel berms abut directly against storm walls protecting a road. The north portion of the beach is less gravelly than the southern portion which suffers severe erosion and seawall damage during northeast storms. Wave-refraction around the south portion of the headland concentrates storm wave energy on this south-facing shoreline. The beach makes up one-half of the reentrant northern shoreline between the Mousam River inlet and the Kennebunk River inlet. This segment is typical of an irregular shoreline of rocky points, gravelly beaches, and shallow offshore ledges and boulder fields. Since both of the bordering rivers are dammed, sediment supply is limited to wave erosion of thin glacial deposits veneering onshore and offshore ledges and the front face of a drumlin, Great Hill, lying at the mouth of the Mousam River.

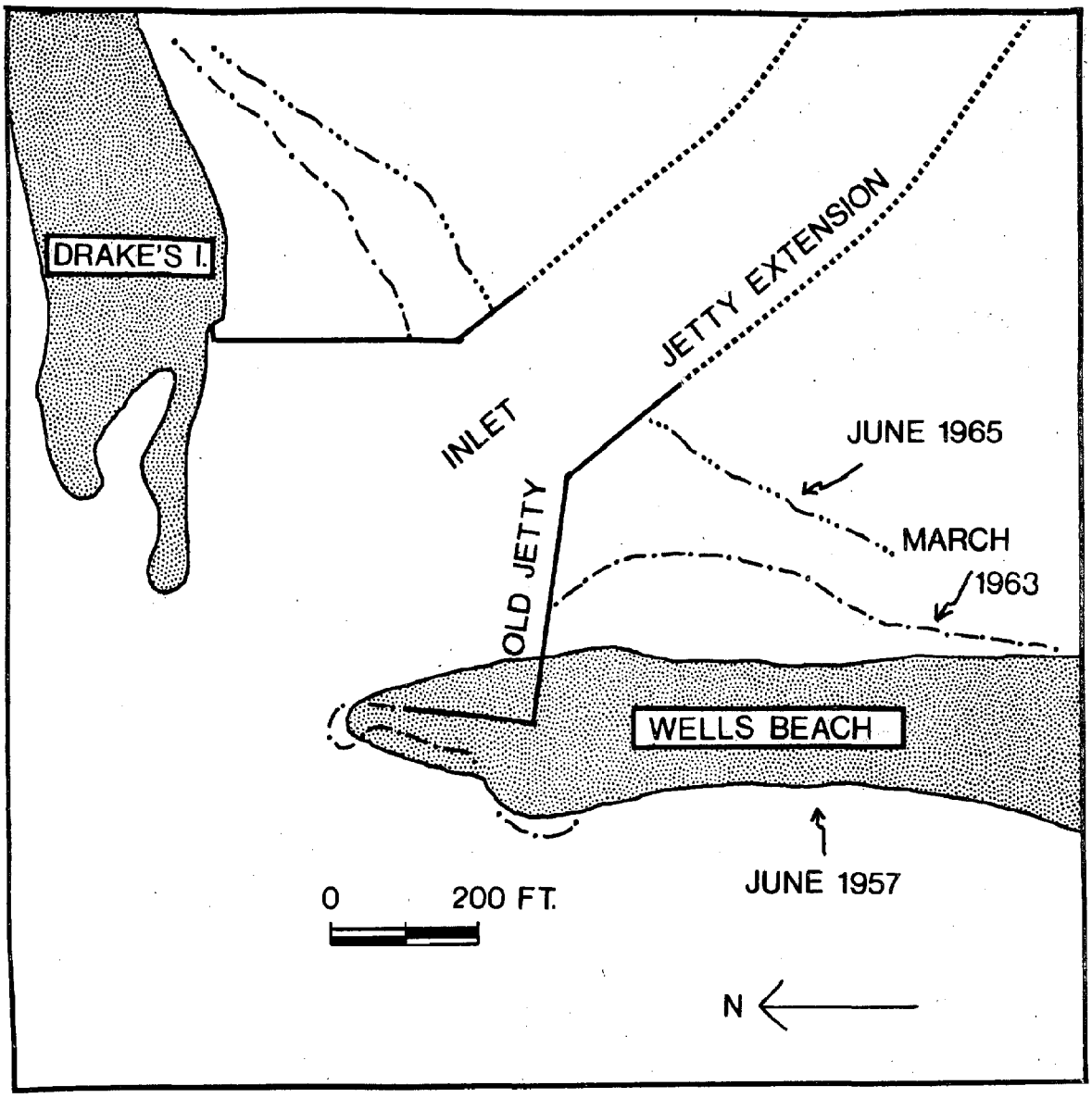
Parson's Beach extends 2.25 km south from the Mousam River to a small but dynamic inlet of the Little River. The beach is halved by a prominent ledge that extends 0.3 km offshore below mean low water. Both beaches are barrier spits extending in front of the estuarine salt marshes at their free ends. The northern beach is backed by low, well-vegetated dune ridges about 30 to 40 m wide and originates at its southern end at the prominent ledges at the midpoint of the entire beach.

The southern end of this beach portion is backed by a wide dune field now covered by low pines. The relict, recurved beach ridges at the southern end of this dune field reveal the former inlet of the Mousam River. The inlet now exists between the northern spit of Parson's Beach and Great Hill, a consequence of human desire and engineering knowhow.

The northern beach portion is coarse to medium-grained quartz and feldspar sand and decreases in size southward to the rock promontory. Littoral drift is from north to south along the beach, and although an abundant supply of sand and gravel is available to nourish the beach from the Great Hill drumlin, most of the sediment eroded from this source is transported into the Mousam River and stored in a flood tidal delta. In consequence the beach is poorly nourished with poorly-developed berms and ridges during accretional stages and suffers heavy erosion along the foredune during storms.

The southerly portion of Parson's Beach, locally known as Cresent Surf, is characterized by coarse feldspar sand, an arcuate shape, a wide, vegetated, linear dune ridge, and a much older relict beach ridge 30 m behind the foredune. The northern portion of the beach is tied to the rock prominence, while the southern tip is slightly curved into the Little River inlet. An active spit grows south in response to wave refraction around the Little River ebb tidal delta, forcing the estuary channel to loop southward. Storm erosion usually returns the main channel to a straight course through the beach, cutting back the spit. The southern end of the beach exhibits a mature beach profile continuously because of the influence of the inlet. High, wide, steep berms and well-developed ridge-and-runnel systems occur adjacent to the inlet where local sediment is supplied to the ebb-tidal delta. Drift direction is from north to south through all seasons as the ebb-tidal delta and a shallow, offshore ledge system induce refraction of southeast waves to reverse their direction at the beach. The inlet is a striking example of a classical offset inlet described by Hayes, Goldsmith, and Hobbs (1970) because of the strong local reversal of drift direction on the updrift side of the inlet. The northern portion of Cresent Surf exhibits a steep beach face and well-developed berm throughout most of the year, but a ridge-and-runnel system has never been observed by this investigator.

Drake's Island Beach extends south from the Little River inlet 2.0 km to the north jetty bounding the Webhannet River inlet. The southern portion of the beach fronts the upland, Drake's Island, where summer home development has prompted the construction of seawalls along the entire beach. The southern tip is backed by a low dune field, the results of lateral and vertical accretion of the beach by entrapment of sand against the jetty (See Figure 5-21). The northern portion of the beach is undeveloped and supports a low foredune ridge and an irregular but vegetated dunefield about 80 m wide. The back dune margin supports large pine trees. The beach terminates at the Little



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-21	Seaward Migration of Mean High Water Contour

River inlet as a recurved spit topped by the highest dunes of the island - 2.5 m.

The entire beach is composed of medium to fine-grained quartz-rich sand on the foreshore and cobbles on the backshore abutting the storm walls and foredune scarp to the north. The volume of gravel on the upper beach has increased dramatically over the past five year span and presents an aggravation to beach homes as they are pelted by wave-borne projectiles during northeast storms (Timson, 1971). Gravel berms occupy the thin backshore area while the forebeach, being relatively fine-grained is a monotonous concave-upward profile extending seaward about 40 m at low tide. A mature accretion profile has never been observed. The northern portion of the beach is coarser-grained than the southern portion, receiving sand from the Little River inlet. A wide berm and occasionally a ridge-and-runnel system develops here because of the proximity of the inlet ebb-tidal-delta.

The southern beach portion has been modified over the past 17 years because of jetty construction on the Webhannet River inlet. The beach has prograded over 80 m after jetty construction. Irregular, low dunes now cover the backbeach area. A steep beach face and wide low-tide terrace are typical beach features through all seasons. Scattered boulders and a boulder swash bar occupy the low-tide terrace; they are remnants, apparently, of an eroded drumlin once a part of Drake's Island.

Drift directions are from north to south along the southern 200 m of the beach. This direction prevails both during the summer when southeast-approaching waves are refracted around the jetty tips and during the winter when northeast-approaching waves are dominant. The remainder of the beach appears to receive equal wave energy for most of the year, but a low magnitude of northerly drift has been observed (Timson, unpublished data).

Wells Beach occupies the center of the reentrant running a distance of about 5 km from Webhannet Inlet to Moody Point, a till-mantled bedrock headland. The entire beach is a barrier island, but development has covered or destroyed the backbeach environments.

Wells Beach is divided into three beach portions by rock promontories. The southernmost beach is an arcuate beach approximately .4 km long. The beach is a mixture of boulders, cobbles, and pebbles backed by a seawall fortified by granite block riprap. The second beach arc is also approximately .4 km in length, is backed by a seawall, and consists of pebbles, coarse-, and medium-sand. Coarse-grained, high, multiple berms are fronted by a coarse sand low-tide-terrace or beach face terrace. Sand may cover the seaward gravel berms in July or August, but gravel is persistently present year round. The third beach portion, the longest beach, runs 2.5 km from a rocky point north to the Webhannet River inlet jetties. The median diameter of constituent beach material

decreases northward from coarse sand to medium-fine quartz sand adjacent to the jetty. The beach exhibits a variety of morphological stages throughout the year; the southern portion builds up very rapidly during the spring and summer months through berm and ridge-and-runnel sand bodies. This mature stage changes in a northerly direction reflecting a change in grain-size and sediment supply. The northern beach portions are wide and low and exhibit low berms. Few changes along this beach portion have been observed over the past five years other than a continual but gradual progradation.

Net sediment drift is to the north along Wells Beach. This has been determined by pebble diameter measurements (Timson and Belknap, unpublished data) and continual seaward growth of the beach on the updrift side of the inlet jetties (Timson, 1970). As of June, 1965, a minimum average yearly transport of 5,625 cubic yards of sand has been delivered to the northern end of Wells Beach. This is a minimum drift rate as sand is also transported into the harbor and around the jetties to Drake's Island. A drift rate three times the above figure would be an approximate estimate. Drift in a southern direction probably occurs during northeast storms.

Ogunquit Beach extends south from Moody Point 4.25 km to the Ogunquit River inlet and the Cape Neddick headland. The beach, a barrier island, can be broken into two equal portions. The northern portion, Moody Beach, extends for 2.0 km south and is extensively developed and backed by a high seawall. Moody Beach is composed of coarse-grained feldspathic sand and exhibits the classical profile development of post-storm accretion described by Hayes and Boothroyd (1969). The author has also observed beach protuberances along Moody Beach during the summer months. Protuberances are shoreline lobate features flanked updrift by erosional zones and downdrift by accretional zones related to non-uniform zones of wave energy caused by wave refraction over irregular offshore or onshore bathymetry (Goldsmith and Colonell, 1970). Protuberances have been recognized on Plum Island and, most notably, along Monomoy Island (Goldsmith, 1972). The author observed protuberance migration from south to north during the summer of 1971. Although protuberances have been noted along the North Carolina shore as controlling zones of extensive barrier erosion (Dolan, 1970, 1971), the phenomenon along Moody Beach are non-existent during the storm season, of small magnitude, and unrelated to severe beach erosion.

Net drift along Moody Beach is from north to south during northeast storms, but summer southeast waves induce northerly drift to periodically renew the sediment transported south to Ogunquit Beach. Sediment supply to the beach is from Moody Point, a glacial till-mantled drumlin; but supply rates are probably low, and the beach relies on opposing drift directions to maintain net supply.

Ogunquit Beach extends 2.25 km from Moody Beach to Ogunquit spit. The barrier island, here, has remained undeveloped for most of its length except for motels and a parking lot at the spit-end of the island.

The sand over most of the beach is medium-to-fine-grained quartz and feldspar. Sediment becomes finer on the backshore to the south. The beach exhibits a typical post-storm morphological development, but is strongly influenced by the Ogunquit River inlet at its southern extremity. Here, a broad, low-tide terrace is constantly occupied by multiple ridges which eventually migrate up-beach or into the inlet.

Littoral drift occurs in a northerly direction during the summer over the northern half of the beach, but this direction reverses itself and becomes a strong southerly drift toward the inlet. Refraction of southeast waves around the Cape Neddick headland induces southerly drift, a drift strong enough to stabilize the inlet position between the beach spit and the north margin of the headland. A southerly drift occurs during northeast storms.

Ogunquit Beach receives minor amounts of sediment from Moody Point to the north, the Cape Neddick headland immediately to the south, and a shallow, subaqueous sand sheet abutting the Cape Neddick headland. Northeast storms transport sediment from Ogunquit Beach around the northern half of the headland. Swells approaching from the southeast during the spring and summer months return a portion of the sand to the beach.

A dune field of variable width and height backs Ogunquit Beach. Less than 40 percent of the dune surface is vegetated with Marram grass due mainly to heavy pedestrian traffic in the dune area during summer. Ogunquit Beach is a magnetic tourist attraction. Numerous blowouts and washover channels are present within the dune field, undoubtedly induced by the lack of stabilizing vegetation. Dunes are variable in height, reaching heights of about seven m. The highest dunes are located at the narrowest portion of the barrier where the Ogunquit River channel has eroded into the backdune area. These dunes are longitudinal, seif dunes whose crest axes are oriented parallel to northwest winds, the prevailing winter winds. Dune sand is eroded from the landward facing ends of the dunes and deposited along the crest of the dune flanks, and where wide blowouts occur, on large dune lobes prograding onto the backshore. Washovers are concentrated here at the narrowest dune section, about 1.25 km north of Ogunquit River inlet, and at an area by the Ogunquit spit where a tidal channel has migrated seaward and eroded the dunes. A dune reclamation project scheduled for 1974 promises to change the character of the dune field permanently.

LONG SANDS AND SHORT SANDS BEACHES, YORK - YORK COUNTY

Short Sands and Long Sands Beaches lie immediately north and south, respectively, of the Cape Neddick promontory on the southwest coast of Maine. Short Sands Beach occupies a 400 m wide reentrant which opens directly to the northeast. The beach itself is composed of gravel and fine quartz sand (0.35 mm median diameter, sorting ranging from 1.1 to .47). The gravel is concentrated along the forebeach over the southern one-third of the beach. The beach is wider at the northern margin (25 m) and narrows to about 7 m at the southern end. The backbeach area is low and grassy and is utilized as a town park. A study by the Army Corps of Engineers (1970) indicates that beach drift is to the north during periods of southeast wave activity while drift is toward the center of the beach from both ends during east-northeasterly waves (Figure 5-22). Historical profile analysis indicates that the beach has retreated 16 m while an offshore sand sheet has prograded seaward 350 m.

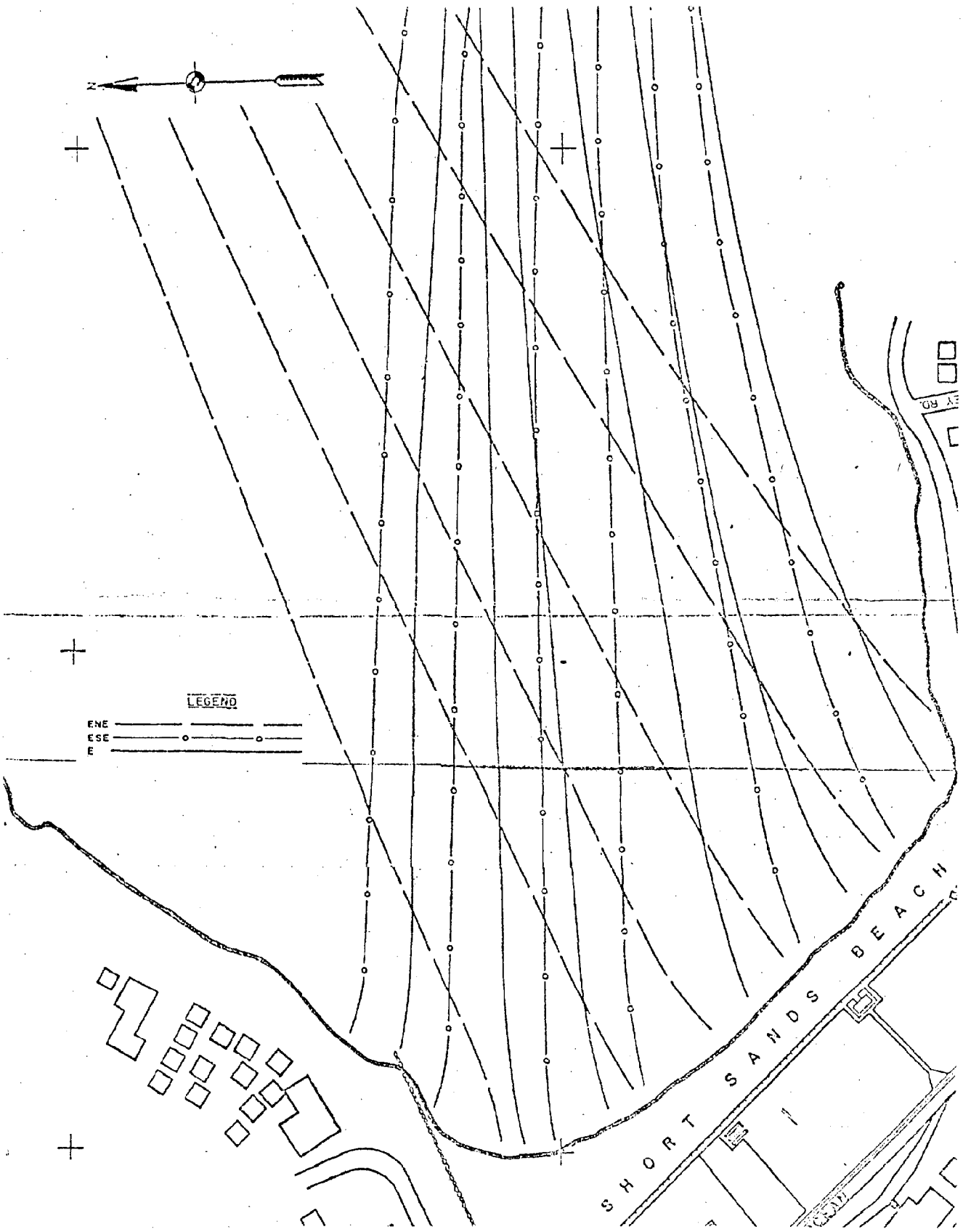
The beach is consistently low with very gentle slopes which extend seaward for over 500 m. Berms and ridge systems are lacking pointing to a lack of sediment supply. Sediment supply apparently has been limited to glacial deposits along the margins of the reentrant. These deposits have slowly been removed as a source by the construction of wave protection structures in front of dwellings. Apparently only gravel is now added to the beach along its southern portion where a zone of beach gravel is slowly extending itself to the north.

Long Sands Beach extends for about 2,150 m south from Cape Neddick to another rocky headland, Prebble's Point. The beach is divided approximately in two halves by a small protruding rocky point. The beach is a strandplain beach backed by U.S. Highway 1A which is protected along the northern beach portion by riprap and along the southern beach by a low, naturally-formed gravel ridge. The beach faces east-southeast.

The northern half of the beach varies in width from about 200 m on the north to 350 m at the dividing rocky point at mean low water. The beach material is consistently very fine sand (≈ 0.20 mm over most of the profile. The beach profile is consistently gentle and featureless throughout the year.

The southern portion of Long Sands is covered by cobbles and pebbles and is about 300 m wide over the entire length of the beach. Extended periods of accretion may cover the gravel with a thin veneer of fine sand.

Wave refraction diagrams (Figure 5-23) constructed by the U.S. Army Corps of Engineers (1971a) indicate that beach drift occurs from north



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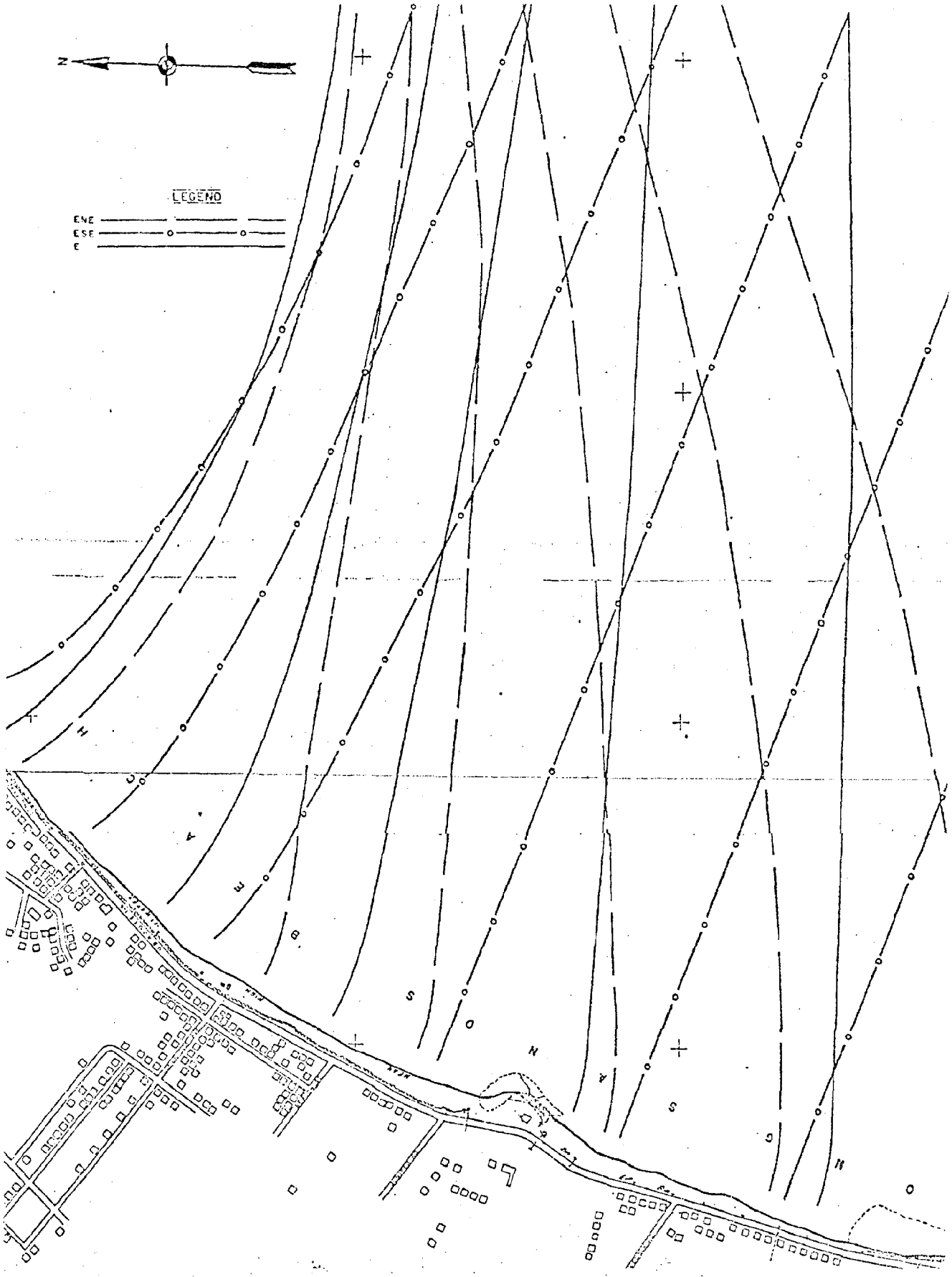
TRIGOM PARC	FIGURE 5-22	Wave Refraction Diagrams-Short Sands Beach, York, Me. (Army Corps of Engineers, 1970)



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

TRIGOM

FIGURE 5-23

Wave Refraction Diagrams-Long Sands Beach, York, Me. (Army Corps of Engineers, 1970)

to south during wave approach from all possible directions, but the beach is generally parallel to wave crests generated from the east-northeast. Historical studies of contour changes along with the refraction analysis indicate that the beach is eroding slowly; with most of the beach sand moving offshore and to the south during northeast storms.

Sediment supply has come from the glacial deposits veneering the margins of Cape Neddick to the north, but development of this shoreline now prevents sand from being removed to the beaches. Cobbles are supplied to the northern margin of the beach from area during storms.

5.1.4 NEW HAMPSHIRE BEACHES

The coastline of New Hampshire is only 23 km long, of which about 70 percent is beach. Few investigations have been published on the beaches of New Hampshire and discussion, therefore, will be limited. Generally, seven beaches occur along the New Hampshire coast; most of the beaches are gravel beaches exhibiting very high storm ridges and steep berms (Timson, 1969; Johnson, 1925). Three sand beaches do occur, however, Wallis Sands Beach lies just south of the Piscataqua River mouth and is composed of fine quartz sand. Hampton Beach and Seabrook Beach occur on either side of the Hampton estuary on the southern coast. Studies have been done on Rye Gravel Beach, a gravel beach; and Hampton and Seabrook Beaches. These areas will be discussed in detail.

RYE GRAVEL BEACH, RYE - ROCKINGHAM COUNTY

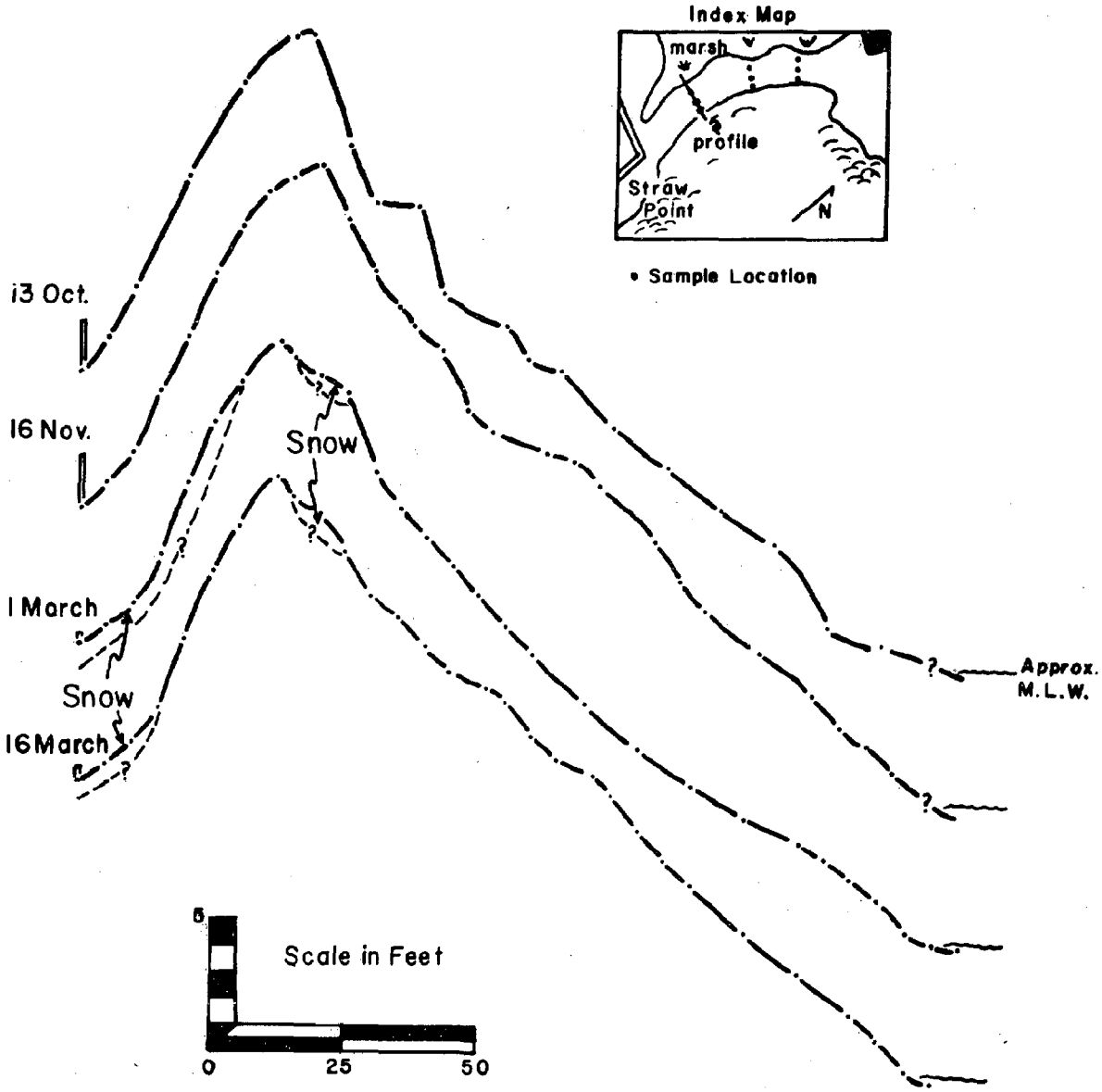
Rye Gravel Beach lies just south of Rye Harbor. The beach is a gravel ridge extending 200 m between two ledge headlands. The ridge is approximately 45 m wide, protects a portion of Rye Harbor saltmarsh, and faces directly to the east. The gravel ridge rises over 7 m above mean low water and 4 m above the salt-marsh surface. Two coalescing washover fans occur behind the northern end of the storm ridge. The fan surfaces rise to an apex only a few tenths of meters below the crest of the gravel ridge. Fan slopes average about .15, storm ridge backface -.40. and ridge face, the beach face -.20.

Gravel size decreases to the north along the beachface and down the ridge face. Average particle size is 16 mm, but boulder particles reside on the southern ridge crest and coarse sand occurs on the beachface at the northern end during storms. Resident particle sizes decrease during storms, but returning particles are continuously larger in mean diameter (Timson, 1969) (See Figure 5-25).

Particle-size distribution and washover fan location indicate that drift during storms is from north to south, while during calmer conditions, during southeast wave transport, the drift is from south to north. Berms, therefore, are well-developed along the southern beach and diminish in

Rye Gravel Profile

Fall 1968-Spring 1969



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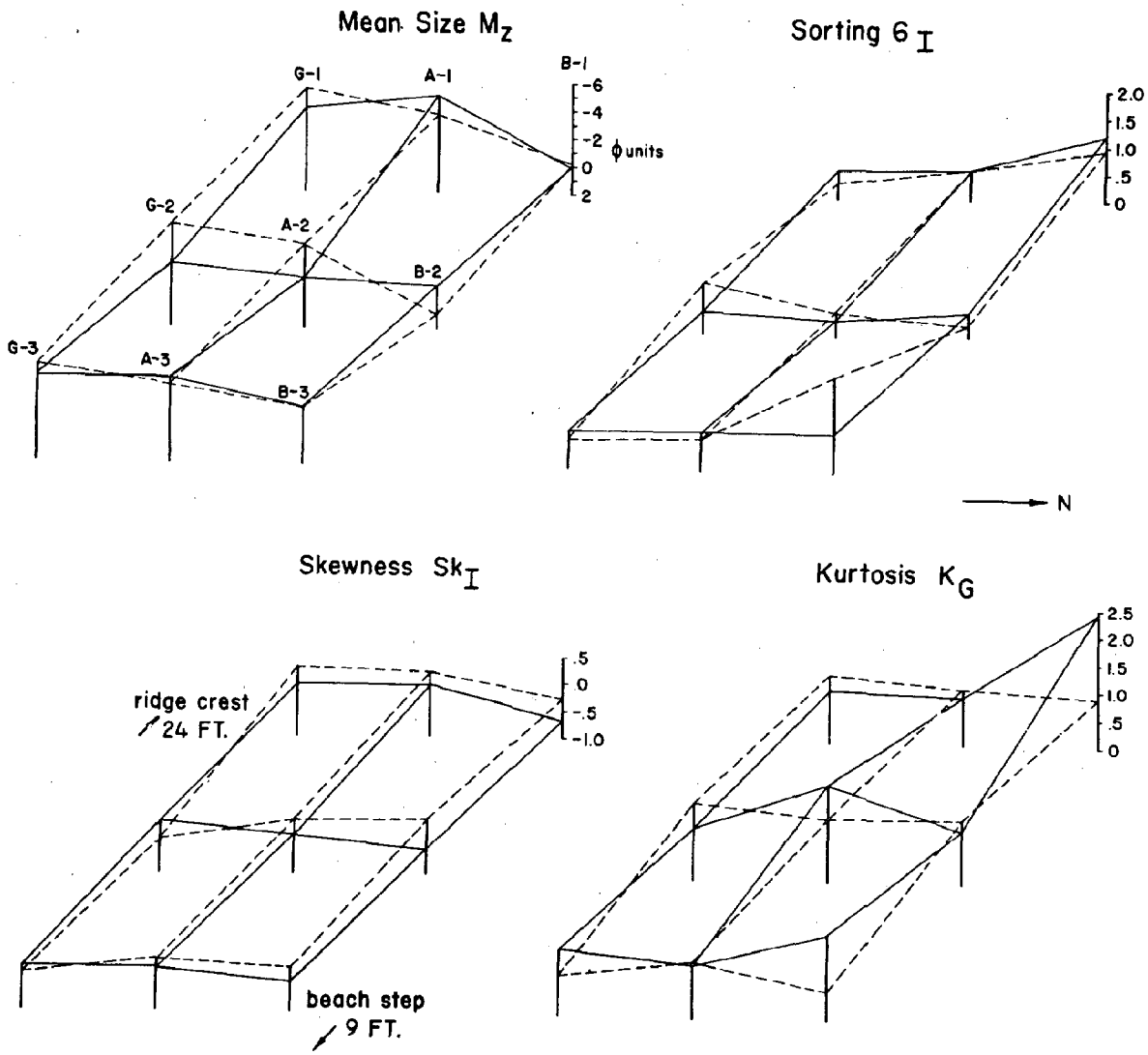
TRIGOM PARC	FIGURE 5-24	Rye Gravel Profile (Timson, 1969)



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

TRIGOM PARC	FIGURE 5-25	Graphic Grain-Size Statistics-Rye Gravel Beach (Timson, 1969)

height and width to the north. Extended periods of gentle waves from the southeast may extend berms across the entire ridge face. Gravel sediment is supplied to the beach from the till-mantled headlands to the north and south, and probably from the floor of the reentrant. New sediment, however, is probably minimal; the beach particles are continuously eroded and returned to the beach as any longshore transport is limited to the embayment.

HAMPTON AND SEABROOK BEACHES, HAMPTON AND SEABROOK - ROCKINGHAM COUNTY

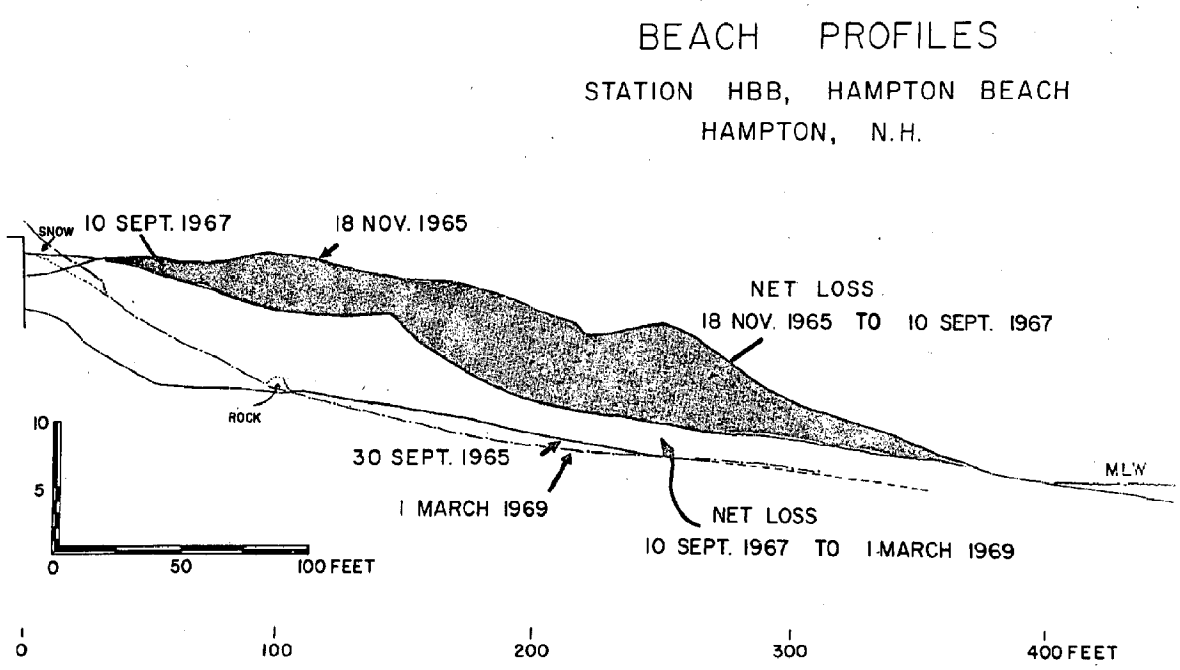
Hampton Beach is a sandy beach extending 2.25 km south from Great Boars Head, a resistant headland, to the inlet of the Hampton River, a stabilized channel. The beach is the northernmost segment of the Merrimack Embayment barrier system extending 24 km from Hampton, New Hampshire, to Cape Ann, Massachusetts (See Figure 5-27).

Hampton Beach barrier island is about .5 km at its widest point, but, because of the beach's popularity as a bathing area, heavy development has restricted natural environments to the forebeach area, a New Hampshire State Park. Four-fifths of the beach is backed by a road which is protected from wave energy by a storm wall. The southern fifth of the beach is backed by a wide parking lot facility of the State Park.

Hampton Beach has undergone severe erosion over the past three-four decades and has been the recipient of artificial nourishment in 1955 and 1965 under the direction of the Army Corps of Engineers (1955). Continued erosion occurs at the northern end of the beach at an annual rate of approximately 19,878 cu m (Byrne, 1966); most of the loss is during northeast storms when sand is transported offshore and in a southerly direction by longshore drift. (Hayes, 1969) (See Figure 5-26).

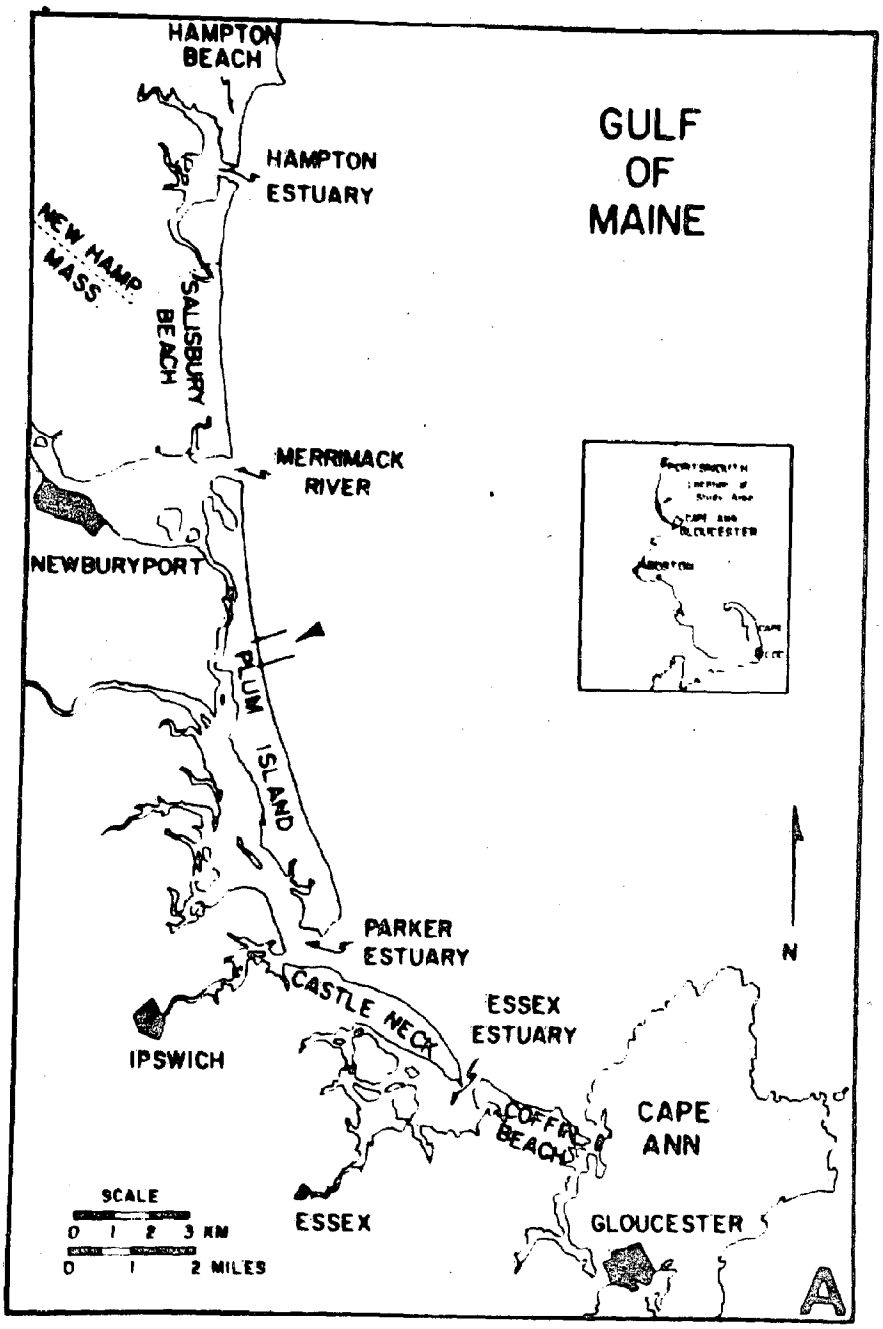
Grain size of beach sand decreases slightly from north to south along Hampton Beach. Median diameter of the beach sand is about .25 to .30 mm (Norton, in preparation). Mineralogical studies by Greer (1969) suggest that beach sand from Hampton Beach is transported into Hampton Harbor on flood tides.

Seabrook Beach extends 2.5 km from Hampton Harbor Inlet south to the New Hampshire-Massachusetts state border where the name of the beach changes to Salisbury Beach. Seabrook Beach is a barrier spit which has extended north to enclose the southern half of Hampton Harbor. The barrier is backed by the marshes, tidal flats, and tidal channels of the lower, tidal Blackwater River. The barrier spit is .5 km wide at its northern end and narrows to about .25 km at its juncture with Salisbury Beach. Median diameters of beach sands are fairly uniform along the beach at .30 mm.



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

TRIGOM PARC | FIGURE 5-26 | Net Loss of Beach Sand-Hampton Beach, N.H. (Hayes, 1969a)



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

TRIGOM PARC	FIGURE 5-27	Strand Features of Merrimack Embayment (Hayes, et al., 1973)

5.1.5 MASSACHUSETTS BEACHES

SALISBURY BEACH, SALISBURY - ESSEX COUNTY

Salisbury Beach is a 6 km long barrier beach between Seabrook Beach and the Merrimack River inlet. It is separated from the upland by the upper reaches of the Blackwater River, a tidal creek draining north into Hampton Harbor, and Black Rock Creek which empties into the Merrimack River estuary to the south. The beach is narrow (.15 to .20 km) at its northern end but widens to about 1.25 km at its south end because of the addition of recurved spit deposits accreting into the Merrimack estuary. The backbeach is entirely developed with summer cottages and an amusement center. Grain size increases in a southerly direction.

PLUM ISLAND, NEWBURYPORT - ESSEX COUNTY

Plum Island is a true barrier island 12.9 km long and up to 2.4 km wide in some places. The barrier has created the Merrimack estuary and the Parker River estuary. The intertidal environments of the Parker River estuary back the southern 4/5 of the island. The Plum Island barrier makes up the largest and mid-portion of the beaches of the Merrimack Embayment and faces about N 85° E into the open Gulf of Maine. The island is the site of the Plum Island Wildlife Refuge.

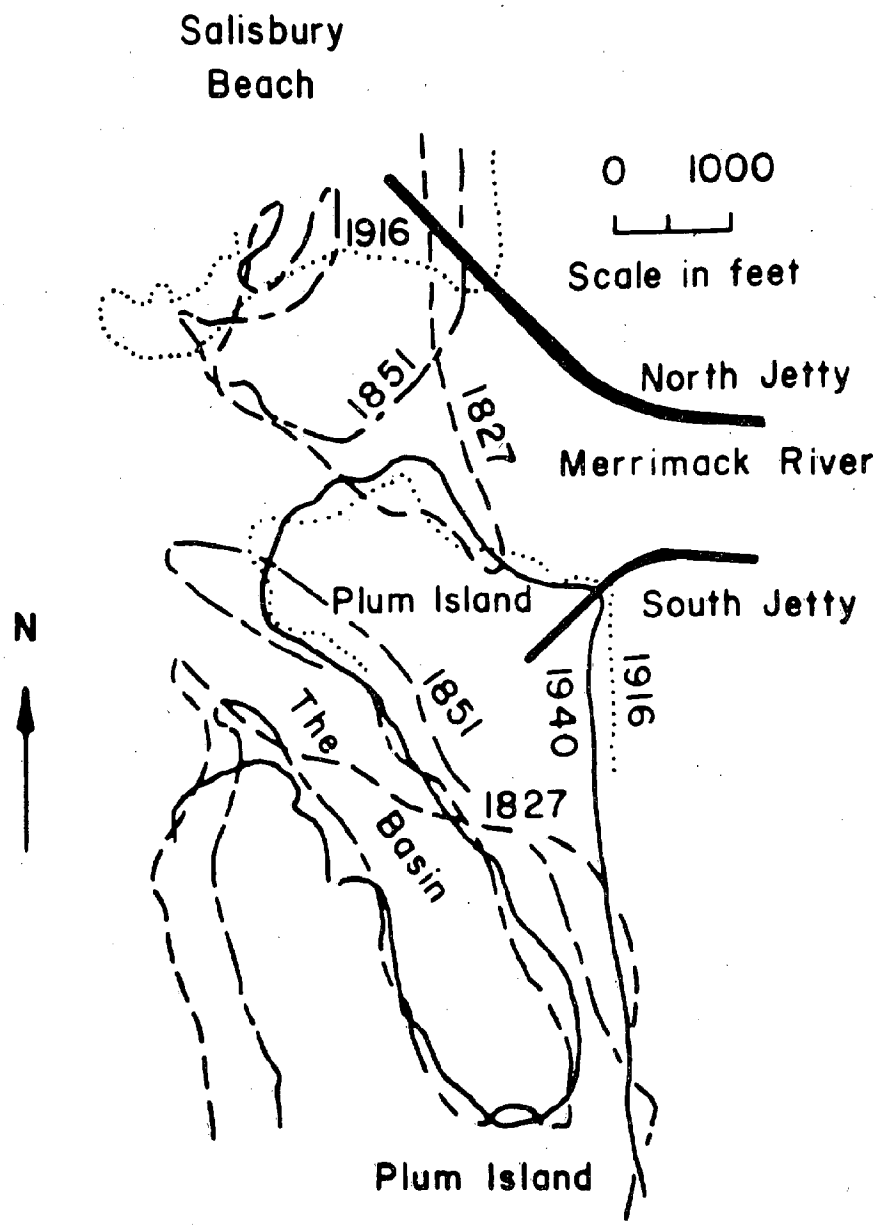
The northern fifth of Plum Island is settled by a small year-round community that swells during the summer tourist seasons. Only several acres of foredune remain undeveloped near the Coast Guard property on the northern, seaward tip of the island.

The northern portion of the barrier is divided into two barrier spits separated by a tidal lagoon. The two-pronged development by northward progradation has been detailed by Nichols (1964, p.32):

> "In 1827 the northern end of Plum Island was not forked. Between 1827 and 1851 the eastern side retrograded about half a mile southward. The western side was modified later to form the western prong. Following this period of retrograding southward, a spit, attached to the eastern side, prograded northward, so that by 1851 it was more than a mile long. Since 1851 this spit, the eastern prong, has greatly increased in size. In 1942 it had an area of approximately .3 square mile."

The inlet has been stabilized by jetties constructed in the late 1930's (See Figures 5-28).

The northward progradation of this portion of the island appears contrary to drift directions generated by northeast waves along this section of coastline. The northward growth is the direct result of



Shore Lines at Mean High Tide

------- 1827, U.S. Army Engineers

—·—·— 1851, U.S. Army Engineers

······ 1916, U.S. Army Engineers

~~~ 1940, R.L. Nichols (Plum Island only)

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-28	Development of Northern Tip of Plum Island (Nichols, 1964)
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refraction of northeast waves around the large lunate bar (ebb-tidal delta) off the mouth of the Merrimack River. Refraction induces wave crests to approach the north end of Plum Island from the southeast (Hayes, 1969b) (See Figures 5-29 and 5-30).

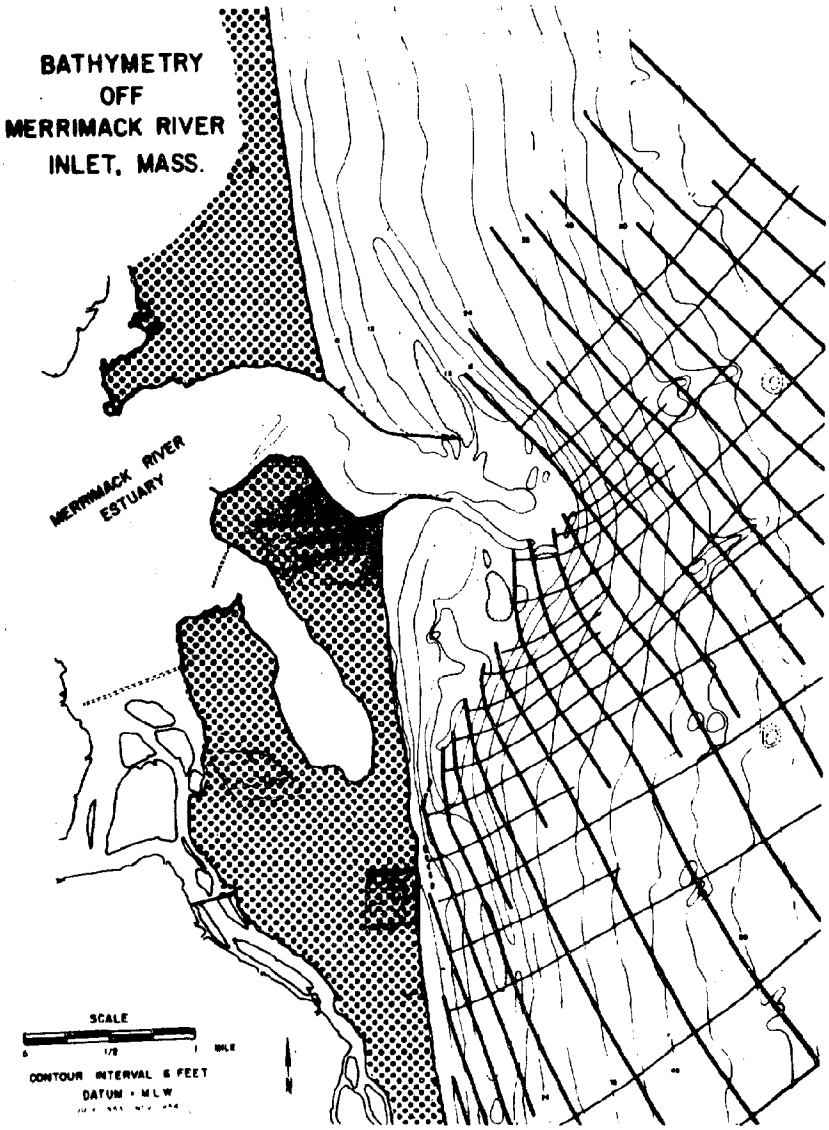
The northernmost tip of the island faces directly into the northeast, and, although it is protected from the open ocean by a jetty, the bulbous section of the tip is severely eroded during storms because of wave-wash over the jetties. A Coast Guard Station located on this island salient has had to be abandoned because of the severe erosion. Acute erosion also occurs along the beach front of the northern portion of Plum Island, the developed portion, where cottages have been built on the front edge of the foredune (U.S. Army Corps of Engineers, 1967).

This section of Plum Island is characterized by coarse to medium sand (≃ .42 mm) and sometimes may contain granule-sized material. The coarseness of the sand induces a sharp, steep beach face extending to the mean low water level. High, wide, cuspate berms mark the accretional, mature profile; ridge-and-runnel systems are uncommon because of the beach slope, but Goldsmith (1969) has documented a 120 m onshore migration of an inshore bar (ebb-tidal delta swashbar) which eventually welded onto the beach.

An offshore bar also exists seaward of the northern beach. The bar, as documented by Goldsmith (1969) is an integral part of the ebb-tidal delta system and has grown independently of onshore profile changes. The offshore bar is about 220 m offshore, 1.5 m high and extends south from the ebb-tidal delta for a distance of about 5 km. Goldsmith has linked migration of erosional zones on the beach to migration of offshore bar gaps and height of the offshore bars.

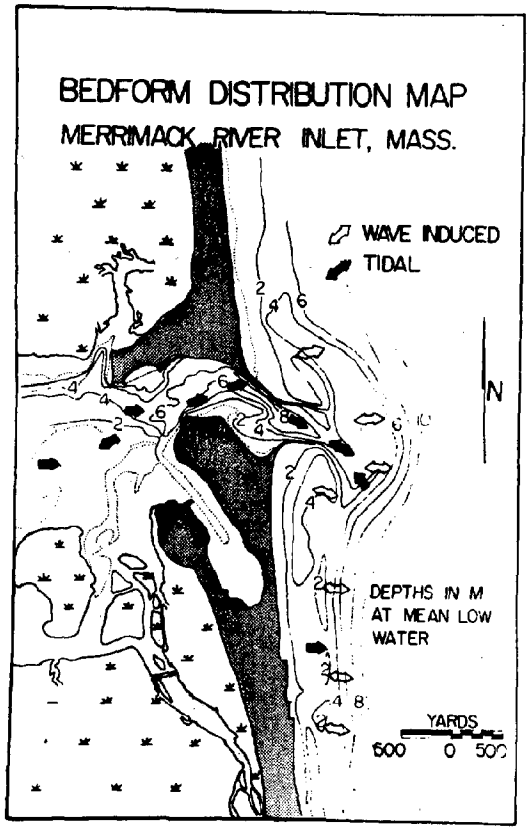
The main portion of the Plum Island barrier is an 8.5 km beach backed by a dune system. The barrier is narrowest near the junction with the developed northern portion of the island being about 330 m wide, and widest at the mid-portion, being almost 700 m in width.

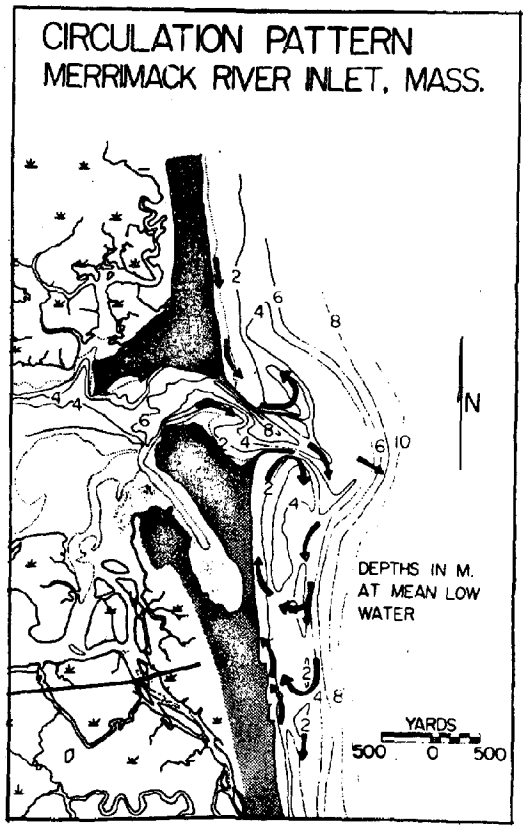
The offshore bar system occurring seaward of the northern section of Plum Island extends south to front the northern quarter of the Plum Island mid-portion. Goldsmith (1969) has observed changes of this bar extension. The bar appears to decrease in height and migrate shoreward under the influence of storm waves, but returns to a height approaching mean sea level and to its apparent equilibrium position of about 180 m from shore during accretion conditions on the subaerial beach (See Figures 5-31 and 5-32). Both Goldsmith (1969) and Abele (1973) have observed the formation of an inshore bar along the entire length of Plum Island after storms. The bar consists of sand eroded from the beach and soon migrates onshore to be transformed into ridge sand bodies on the low-tide terrace of the subaerial beach.



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

TRIGOM PARC	FIGURE 5-29	Wave-Refraction Diagram-Merrimack Inlet (Hayes, et al., 1973)



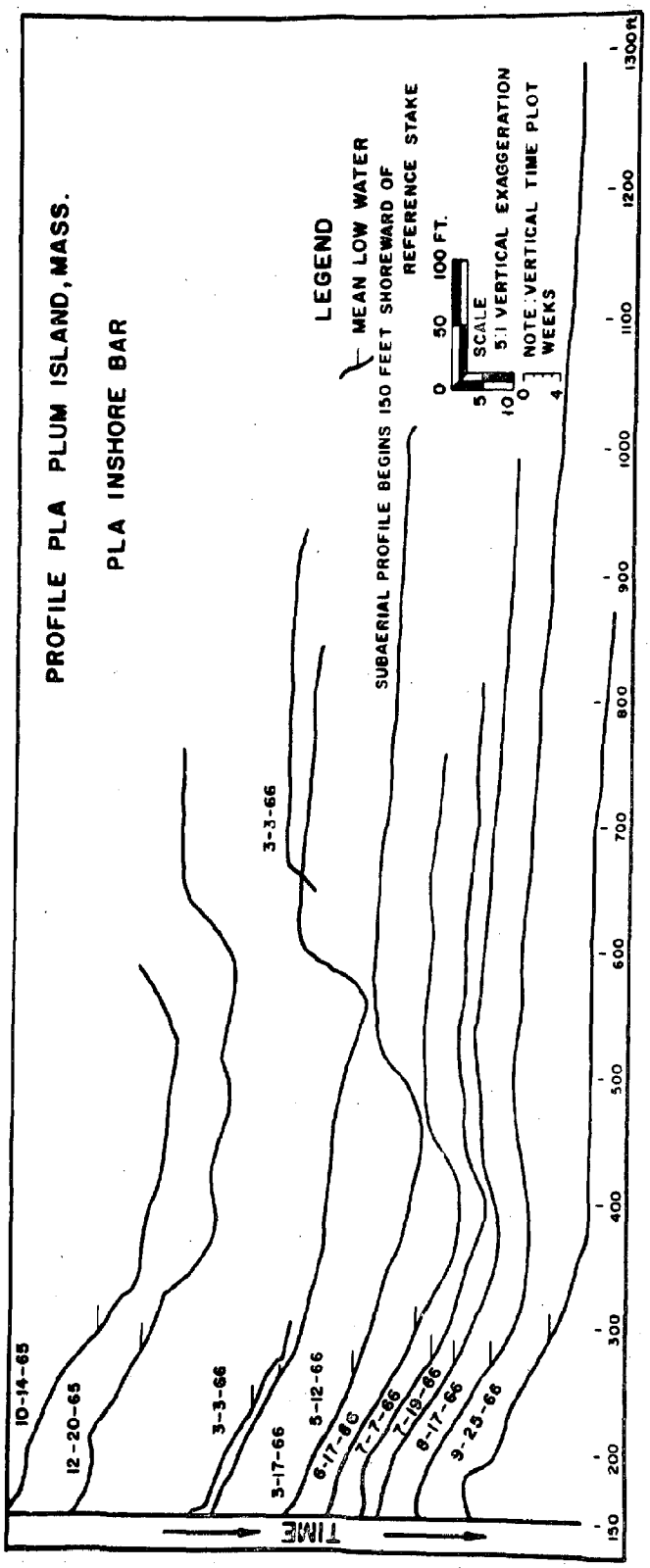


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC

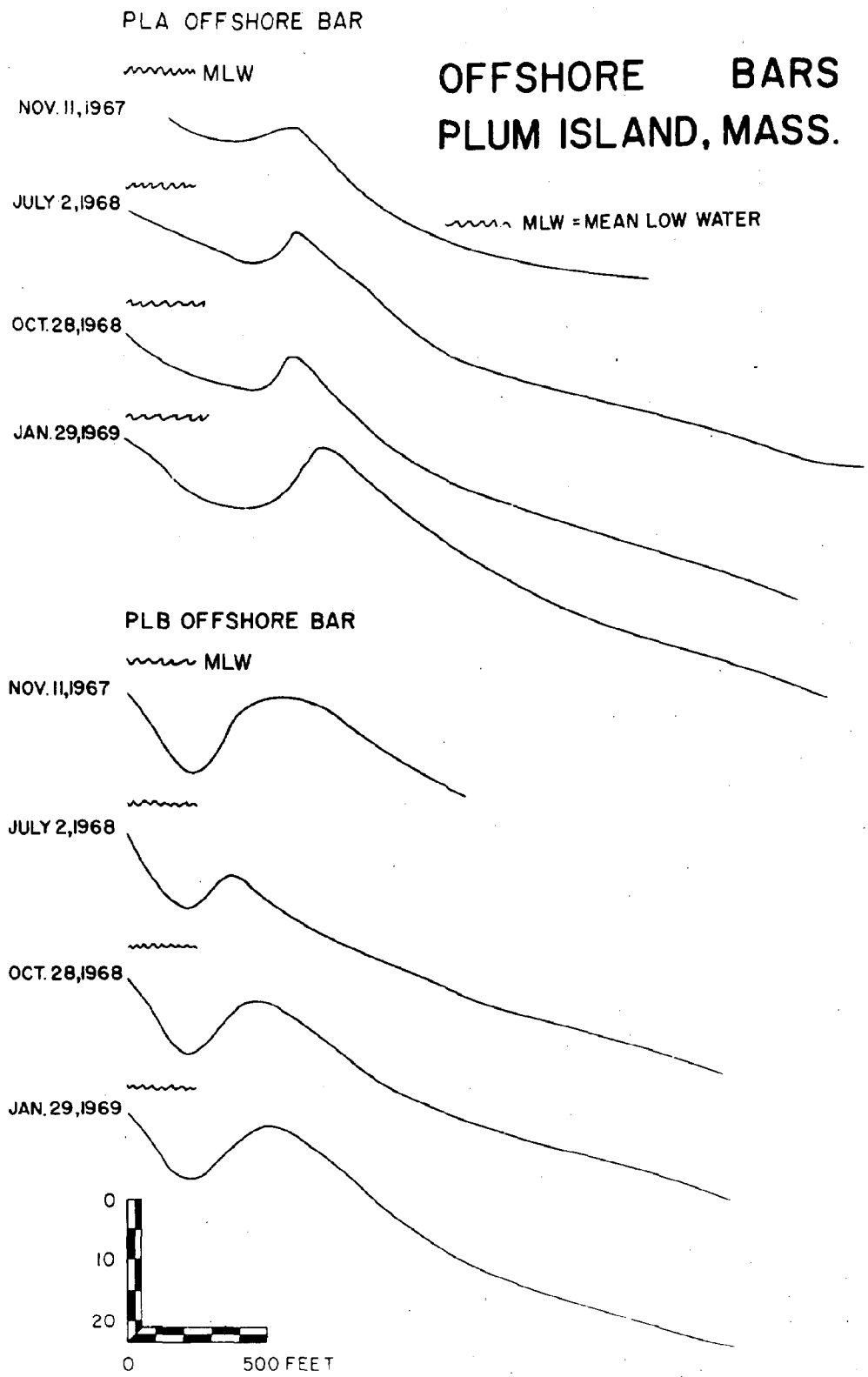
FIGURE 5-30

Bedform Distribution - Circulation Pattern - Merrimack River Inlet, Mass. (Hayes, et al., 1973)



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

TRIGOM PARC	FIGURE 5-31	Onshore Migration of the Inshore Bar - Plum Island, Northern End (Goldsmith, 1969)



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

TRIGOM PARC	FIGURE 5-32	Offshore Bar Profile Changes - Plum Island-Northern Offshore Portion (Goldsmith, 1969)

The beach along this length of the island has been the subject of intensive study by the Coastal Research Group of the University of Massachusetts. Storm and post-storm changes along the shorefront have been mentioned earlier in this report with references to the work of Hayes and Boothroyd (1969) and Abele (1973) See Figure 5-33). The active beach is about 170 m wide along the entire mid-portion of the island and the dune-beach transition zone is variously characterized by a high foredune scarp, large dune lobes, or blowouts where washovers transport beach sand to the interdune area.

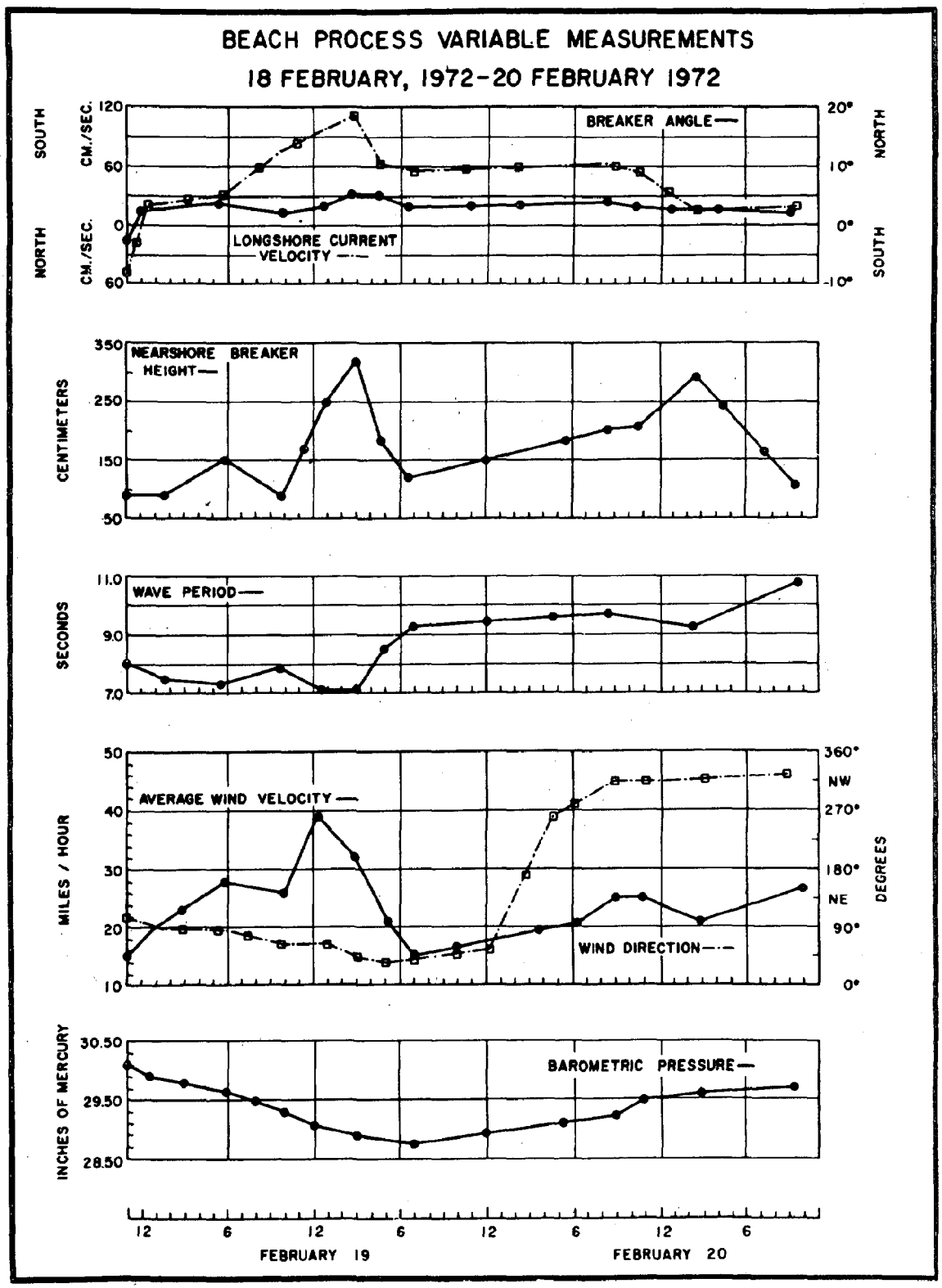
The dune morphology of Plum Island has been studied by Larsen (1969). He divides the barrier into six morphological subzones trending parallel to the present shoreline (pp. 356 & 358) (See Figure 5-34):

> "The zones are: (1) the present beach, with its berm, beach face, and low-tide terrace; (2) a foredune ridge 30 to 35 feet in elevation with gaps formed by blow-outs, slipfaces, and new dunes; (3) an interdune area; (4) a discontinuous backdune ridge, partially stabilized, with elevations over 50 feet in places; (5) a low-wooded area with small stabilized dunes; and (6) a tidal salt-marsh flat with some windblown sand."

The foredune ridge is an erosional remnant of a line of phytogenic dunes, assymetrical in shape with a steep east-facing foredune scarp and a gentle, west-facing slope. The low interdune area displays a strong northwest-southeast lineation defined by the long axes of blowouts due to deflation by northwest winds. Active dune lobes which are building into the northwest sides of depressions; low, rounded phytogenic dunes, and conical erosional dunes are the types of dunes characteristic of the interdune area. The backdune ridge is discontinuous and contains the highest dunes on Plum Island which are actively migrating west into forested areas. The higher dunes are stabilized by bushes and trees. Larsen hypothesizes that where backdunes are absent, washover fans occur. Sand movement in the dunes is mainly accomplished by west, northwest, north, and northeast winds. Northeast winds build up the backdune ridge while northwest winds are responsible for foredune ridge accretion. The presence of buried soil horizons in the dune field suggests dune re-activation which Larsen contends probably occurred during the middle of the 17th Century when early settlers used the island for animal grazing.

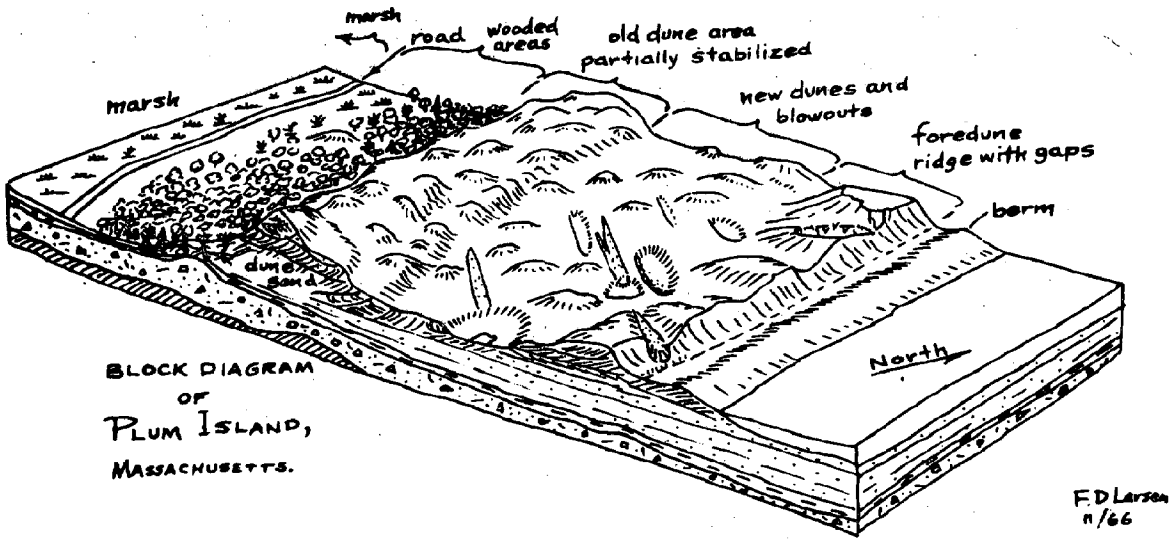
Beach grain size decreases from about 0.46 mm at the northern end of the Plum Island mid-portion to about 0.30 mm at the southern end. Sorting values average .50 along the entire beach (Hayes, 1969). Dune sands show no discernable increase or decrease of grain size along the island. Median diameter of the dune sands average about 0.37 mm., in the medium sand range as are the beach sands (Anan, 1971).

The southern portion of Plum Island can be subdivided into three sedimentation provinces (Farrell, 1969b): (1) a rock-cored drumlin and



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

TRIGOM PARC	FIGURE 5-33	Beach Process Variable Measurements - Plum Island (Hayes et al., 1973)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-34	Dune Morphology - Plum Island (Larsen, 1969)

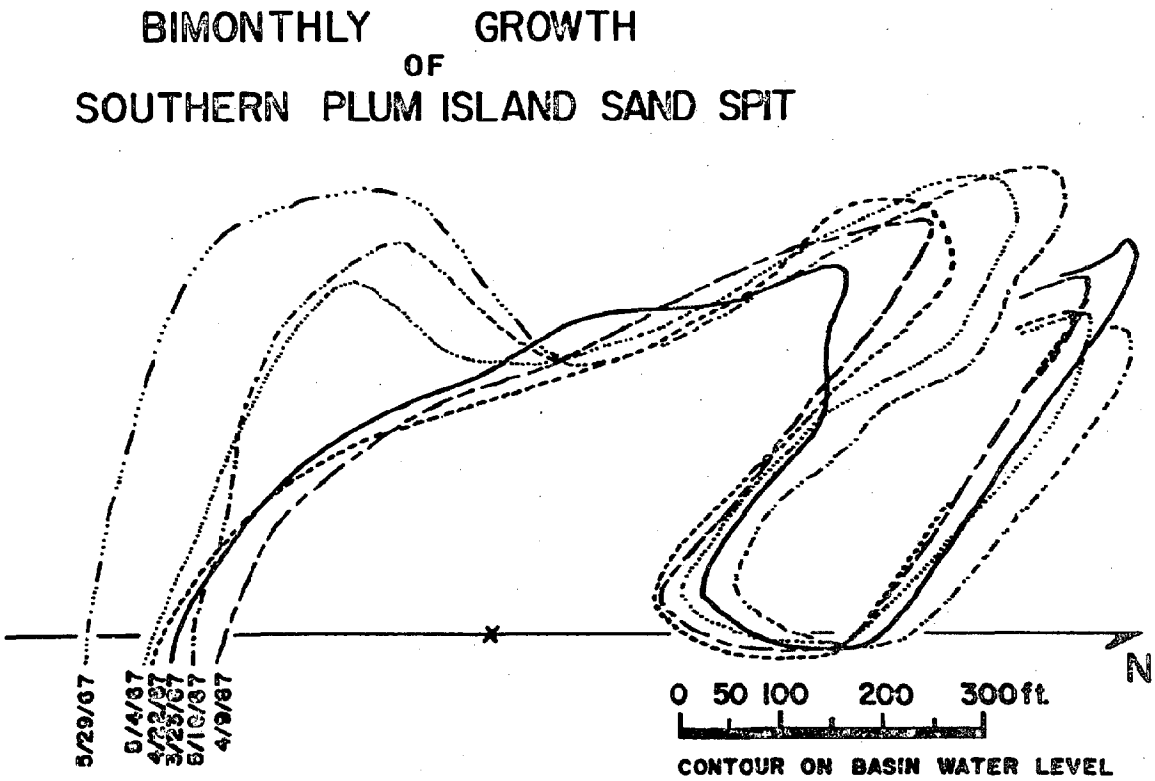
southwest-trending beach; (2) a foreland cusp; and (3) a recurved sand spit and basin.

The southern portion of Plum Island terminates at the Bar Head Drumlin. A section of the drumlin (Hartshorn, 1969) reveals that two tills comprise most of the sediment of the drumlin. The upper till consists of variable sediment types, but probably is the source for much of the beach and spit sand along this section of Plum Island. The southwest trending beach is about 720 m long. The northeast beach portion lies at the base of the drumlin, is coarse-grained, contains numerous boulders and pebbles eroded from the till, and is relatively narrow. The remainder of the beach forms the eastern leading edge of a cuspate foreland which is covered by a low, vegetated dune flat in front of a low dune field. The dune flats are over-washed and bared during northeast storms. The remaining edge of the cuspate foreland is defined by the recurved spit.

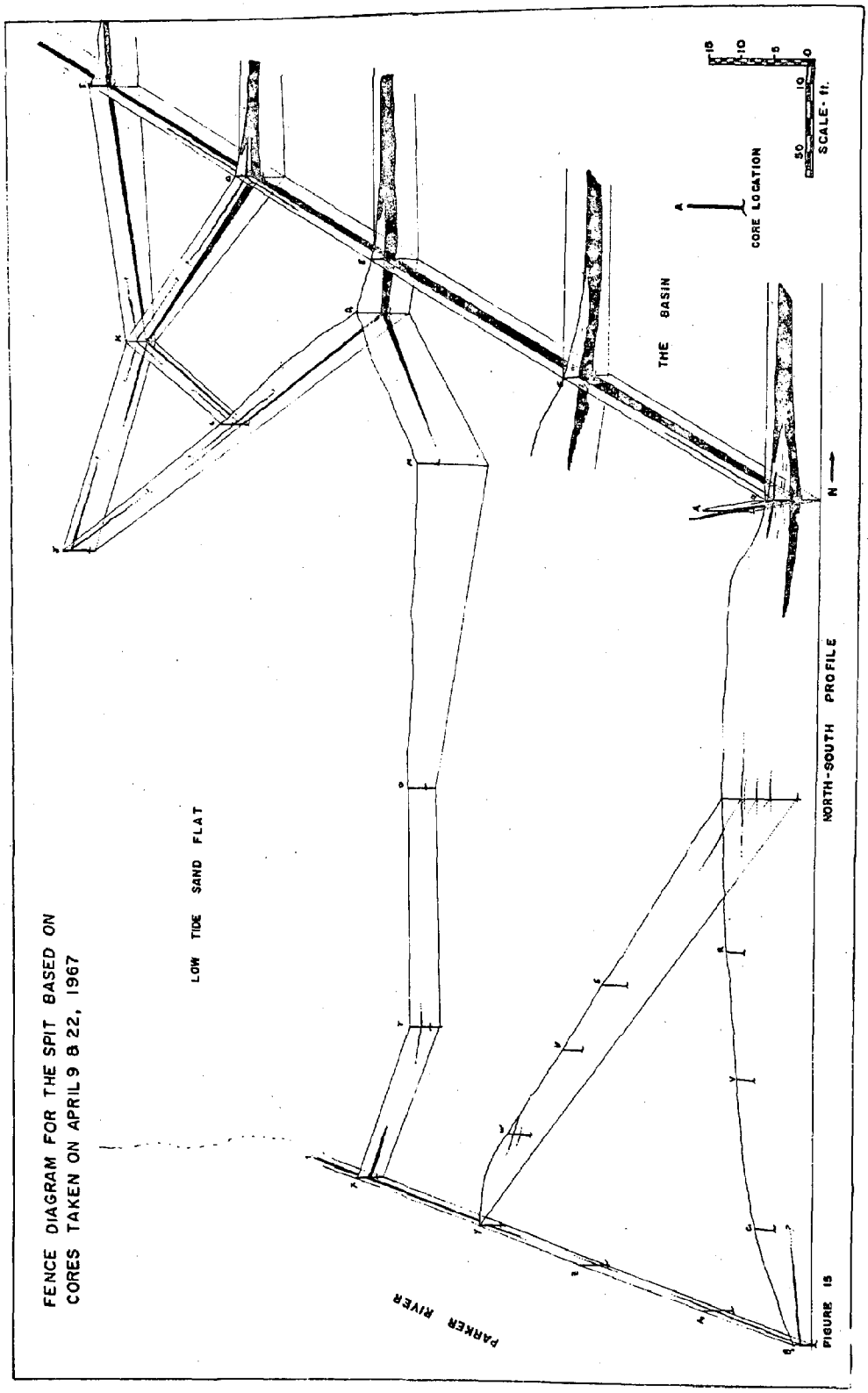
The spit formed during the winter of 1965-66 and increased in size to form a double hooked spit by 1969. The spit accretion represents a volume accumulation of 281,338 cu m over a four-year period. Farrell (1969) has documented the growth of the spit and concludes that spit growth is a result of the amount of sediment delivered to the spit, beach waves and littoral drift, tidal currents, and tidal range. Spit growth rates are highest during storms and spring tides. The rate of growth increases approximately in the ratio of 1:2:10x for neap tides, spring tides, and storms, respectively. An accretion cycle of this spit follows the sequence: (1) spit growth by wave refraction and tidal currents into the Parker River Inlet parallel to the Plum Island beach trend; (2) lateral migration of the spit toward the back of Plum Island, forming and engulfing an intertidal, organic mud-filled lagoon; (3) welding of the leading edge of the spit to the back of Plum Island; and (4) spit heightening and lagoon filling by storm washover and eolian accretion (See Figures 5-35 and 5-36).

Sediments on the spit are bimodal indicating deposition by wave and eolian processes. Grain size increases toward the nose of the spit from about 0.25 mm at the spit base to 0.55 mm at the leading edge of the spit. The grain size increase along the spit is due to selective sorting of larger grains by upper flow regime conditions on the spit.

Farrell speculates that the cyclical nature of spit accretion at Plum Island is the result of the dynamic equilibrium between the tidal water prism volume of the Parker River estuary and the sedimentation rates in the estuary proper. As the estuary fills with sediment and marsh growth, the tidal volume decreases with an attendant decrease in the cross-section of the inlet channel needed to carry the flow. Spit growth occurs during tidal-prism volume decrease and welds onshore when the channel width increases in response to an increase in tidal volume. Farrell fails to explain, however, the cause for periodic tidal-prism increase and decrease.



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-35	Sequential Growth of a Recurved Spit - Plum Island (Farrell, 1969)



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

TRIGOM PARC	FIGURE 5-36	Fence Diagram-Recurved Spit - Plum Island (Farrell, 1969)

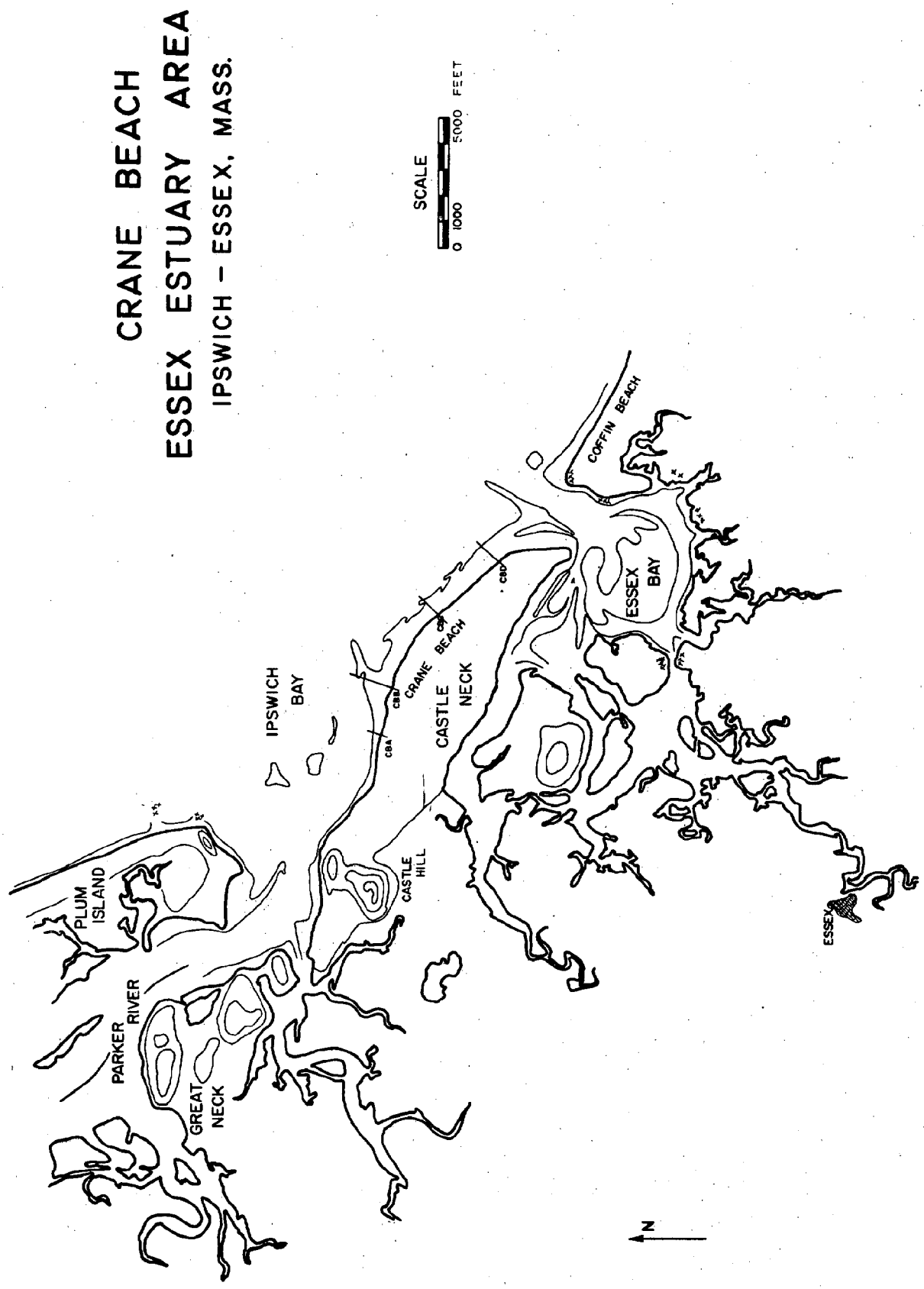
CRANE BEACH, IPSWICH AND ESSEX - ESSEX COUNTY

Castle Neck is the southernmost barrier island of the Merrimack Embayment barrier system. The beach portion of the island is named Crane Beach (See Figure 5-37). The barrier trends southeast for a distance of about 5 km from two rock-cored drumlins, Castle Hill and Steep Hill, which lie just southwest of the end of Plum Island. The drumlins are separated from the spit of Plum Island by the inlet of the Parker River estuary. The inlet is approximately 650 m wide. Castle Neck barrier encloses the Essex River estuary, the inlet of which exists between the southeast end of Crane Beach and the northwest end of Coffin Beach, the next beach south.

Boothroyd (1969) has divided Crane Beach into five distinct constructional phase zones on the basis of beach morphology (See Figures 5-38 and 5-39). The five zones are, from north to south along the barrier: (1) a northern ridge zone characterized during accretional stages by 65 meter-wide ridges and a small berm in front of a scarped foredune ridge. This beach zone faces N 20° E and is influenced strongly by the ebb tidal delta of the Parker River estuary; (2) an accretion zone marked by a salient of the beach protruding seaward. This zone exhibits swashbars, a sand flat, and a large berm-ridge lying over 200 m seaward of the dune line of the barrier. This zone, as well as the first zone, receives sediment from the Parker River ebb tidal delta as waves proceed over the delta toward the beach. Tidal currents generated in the inlet affect this second zone by controlling swash bar orientation; (3) a southern ridge zone characterized by cuspate ridges up to 400 m long and 65 m wide, a small berm, and wide low-tide terrace. This beach from this zone south faces N 45° E and is finer-grained than the first two zones. The foredune backing this beach zone is unscarped and exists just landward of the berm; (4) the Essex delta zone affected by tidal currents generated near the Essex River inlet to the south. Ridges of the southern ridge zone diminish in size and disappear in zone 4 but a complex swashbar-ridge system begins just south of this zone. The low-tide terrace is up to 270 m wide while the berm is of moderate size (1.5 m high) backed by a scarped-foredune; and (5) a swashbar ridge complex strongly affected by the Essex ebb-tidal delta and inlet. This beach zone faces southeast, turning into Essex Bay.

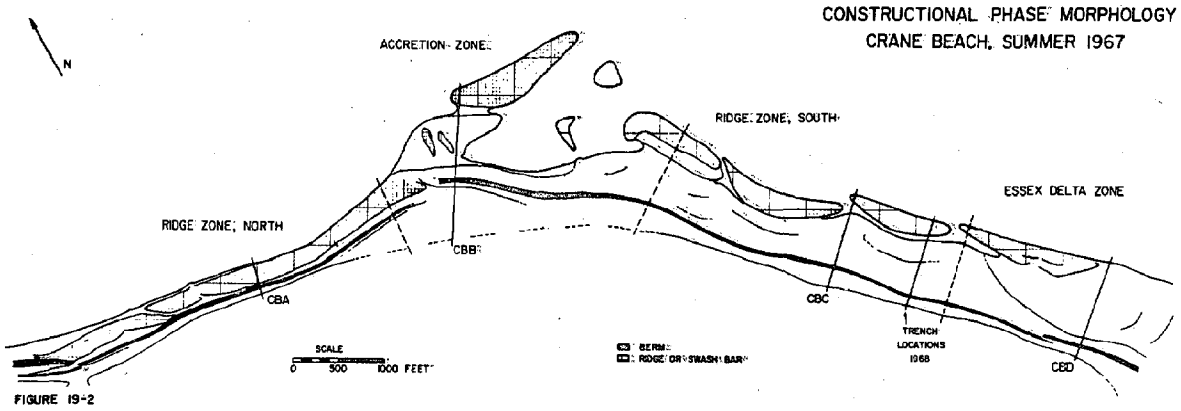
Longshore drift is from north to south along the Castle Neck barrier. Sand eroded from the drumlins at the northern end of the barrier and at the southern end of Plum Island and sand transported from the beaches of Plum Island are the probable sources for Crane Beach sediment, but the barrier is more dependent upon rates of erosion, transport, and morphology changes of the Parker River ebb tidal delta, the immediate source of sand for the Crane Beach area.

The median diameter of Crane Beach sand ranges from 0.32 mm to 0.22 mm; dune sands average from 0.25 to 0.22 mm (Schalk, 1946). Boothroyd (1969) has noted that an abrupt decrease in grain size occurs at the



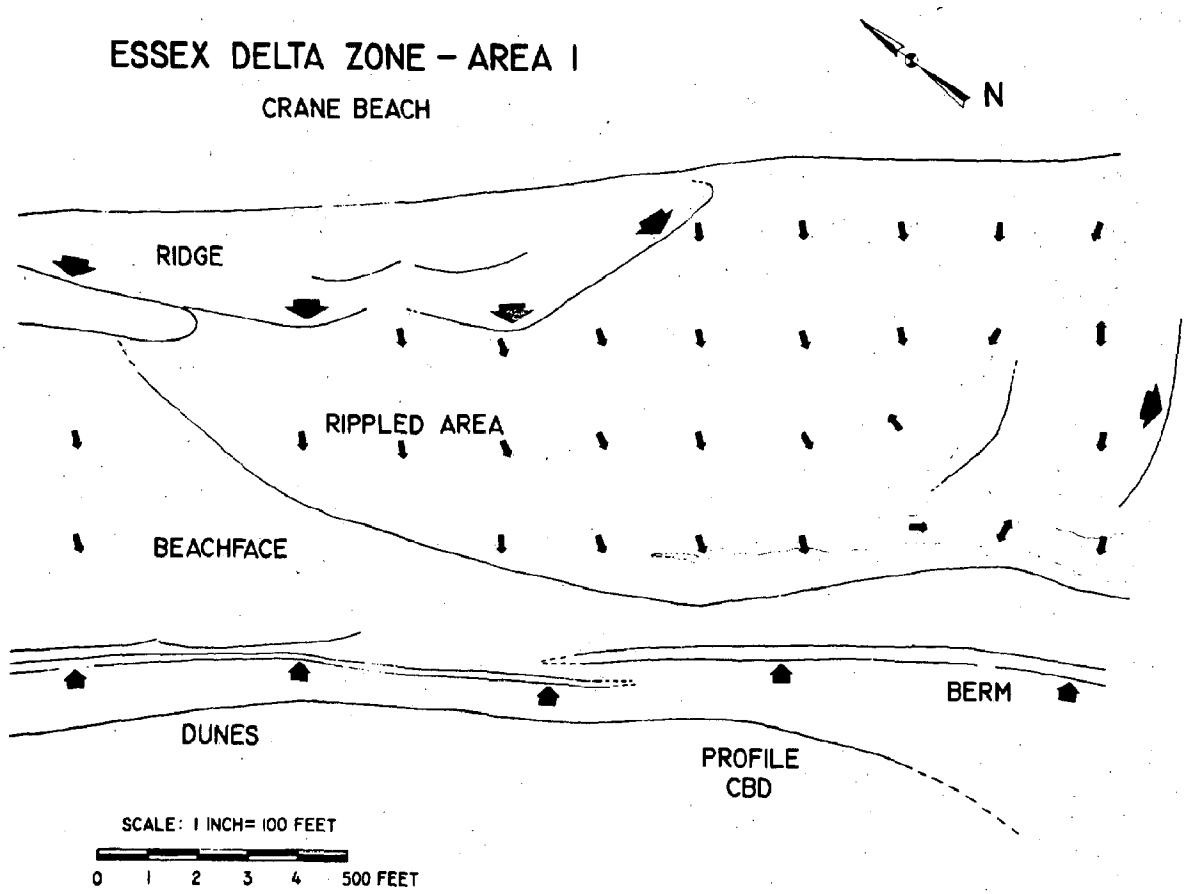
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-37	Crane Beach Area (Boothroyd, 1969)



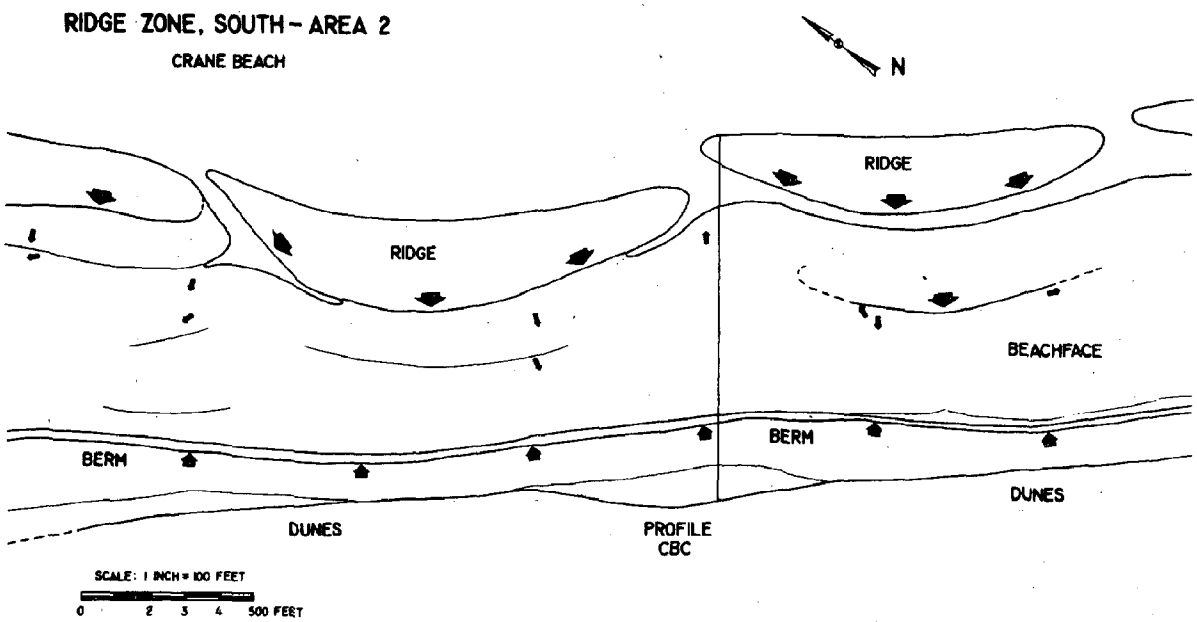
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-38	Crane Beach 4 Accretional Zones (Boothroyd, 1969)



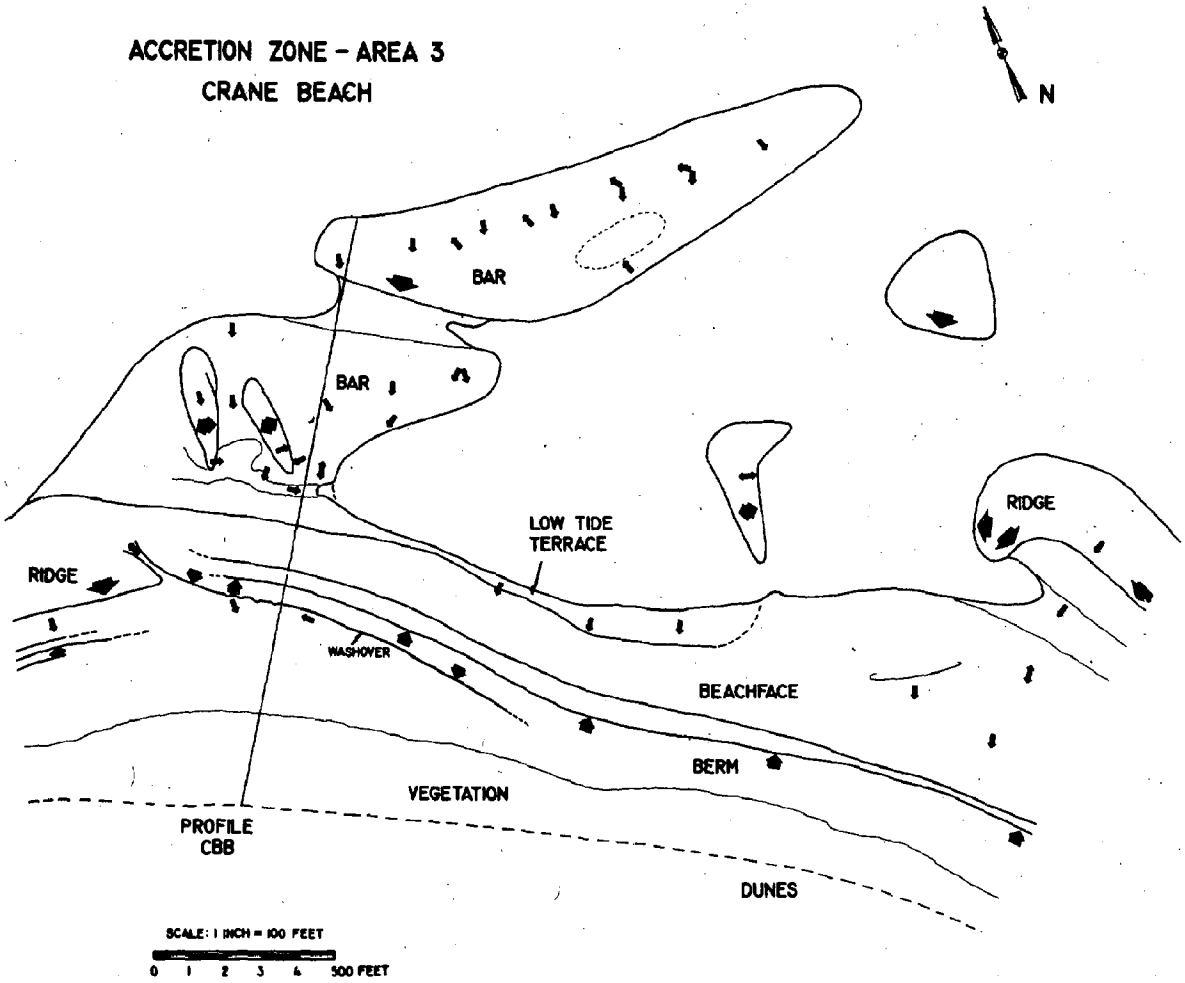
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-39a	Crane Beach-Individual Constructional Zones-Essex Delta (Boothroyd, 1969)



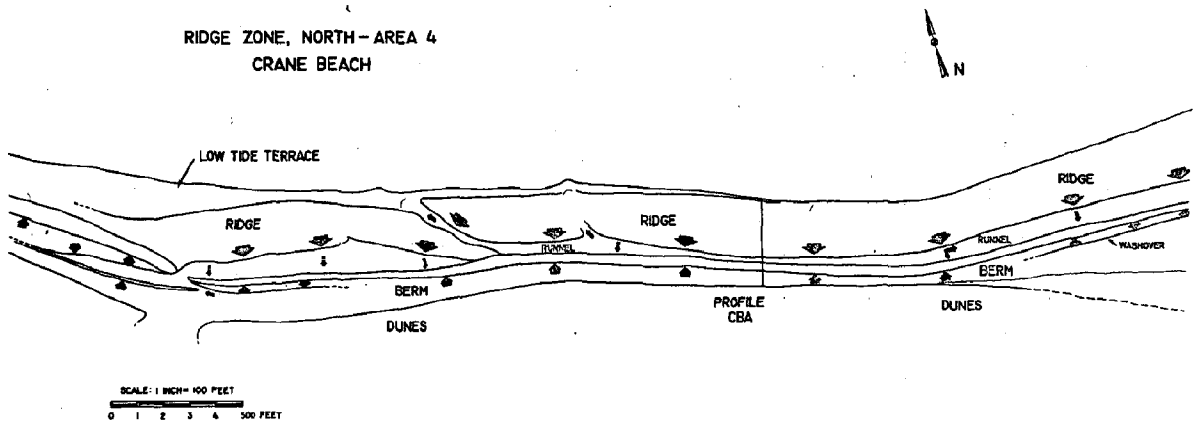
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-39b	Crane Beach Individual Constructional Zones- Ridge Zone South (Boothroyd, 1969)



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

TRIGOM PARC	FIGURE 5-39c	Crane Beach-Individual Constructional Zones-Accretion Zone (Boothroyd, 1969)



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

TRIGOM PARC	FIGURE 5-39d	Crane Beach Ridge Zone North (Boothroyd, 1969)

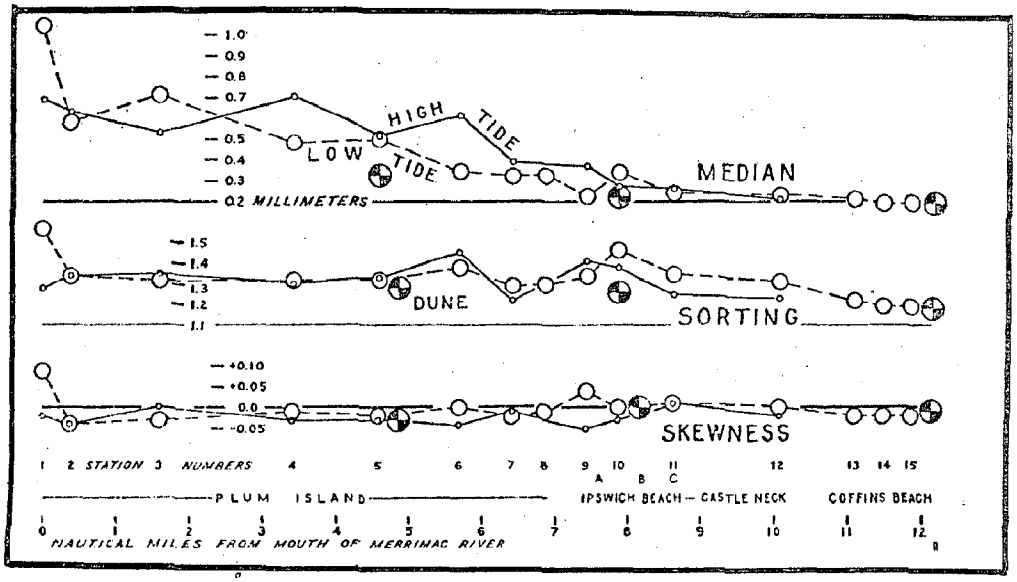
transition of zone 2 and zone 3. This observed change is probably due to the winnowing of the finer grains from the northern beach by the cumulative effect of waves and tidal currents near the Parker River inlet.

The barrier island varies in width from .67 km at either end to 1.25 km. at its mid-section. The large width at the island's center is due to the addition of sand to the barrier at the zone 2, the accretion zone where sand is delivered to the beach from the distal portion of the Parker River ebb-tidal delta. A dune field, of which about 30 percent is unvegetated, covers the rest of the island. Schalk (1946) has briefly described the Ipswich area dunes. Several preserved foredune ridges rim the front edge of the barrier and curve southward around to Essex Bay revealing a southerly progradation of the barrier. Irregular dunes up to 20 m in height mask relict foredune ridges over the rest of the dune field except along the northern portion of the field where Bryan and Nichols (1939) cite evidence for the dunes directly overlying till deposits.

COFFIN BEACH, ESSEX - ESSEX COUNTY

Coffin Beach is a strandplain shoreline marking the southernmost sandy beach of the Merrimack Embayment. The ends of the beach bend into the inlets of the Essex River estuary (Essex Bay) to the northwest and into the Annisquam River inlet to the southeast. The beach is approximately 3.7 km long and faces the N 30° E direction. The beach is fine-grained with grain sizes averaging 0.19 mm on the active beach as well as on the 27 m high dunes backing the beach (Schalk, 1946). Grain size trends indicate that Coffin Beach is the southern end of the Merrimack littoral basin; the beach receives most of its sediment from the Plum Island - Castle Neck barriers (See Figure 5-40).

Both Castle Neck and Coffin Beach are sheltered from easterly storm waves by Cape Ann, but fully exposed to northeast waves. Extensive storm erosion along the beaches of the southern border of the Merrimack Embayment is limited to Boothroyd's (1969) zone 3, the southern ridge zone, where the beach is relatively narrow and the berm a short linear distance from the dune ridge. This lack of erosion is apparently due, in part, to the shield effect of Cape Ann to easterly storm waves, a high rate of sediment supply from the mid-portions of the embayment barriers, and the high dunes backing the active beaches which act as natural storm-wave bulkheads. Portions of Crane Beach exposed to easterly storm waves are protected from extensive erosion by the swash bars associated with the Parker River ebb-tidal delta (Boothroyd, personal communication). Storm waves break and expend their energy on the delta sand body rather than on the subaerial beach.



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

TRIGOM PARC

FIGURE 5-40

Median Diameter, Sorting and Skewness - Plum Island to Coffins Beach (Schalk, 1946)

CAPE ANN BEACHES, GLOUCESTER & ROCKPORT - ESSEX COUNTY

The prominent resistant headland of Massachusetts, Cape Ann, is characterized by a rocky strand, but several small beaches occur in indentations along the coastline. The southeast coastline of Cape Ann contains four small beaches which have been studied by Cunningham and Fox (unpublished material) (Figure 5-41).

Pebbly Beach is the northernmost beach extending southwesterly from Emerson Point for about 1 km. The beach is dominated by a cobble ridge extending 5.5 m above mean low water. The storm ridge is fronted by a sandy terrace extending below mean low water at the northern end and backed by an isolated saltmarsh with a large salt panne.

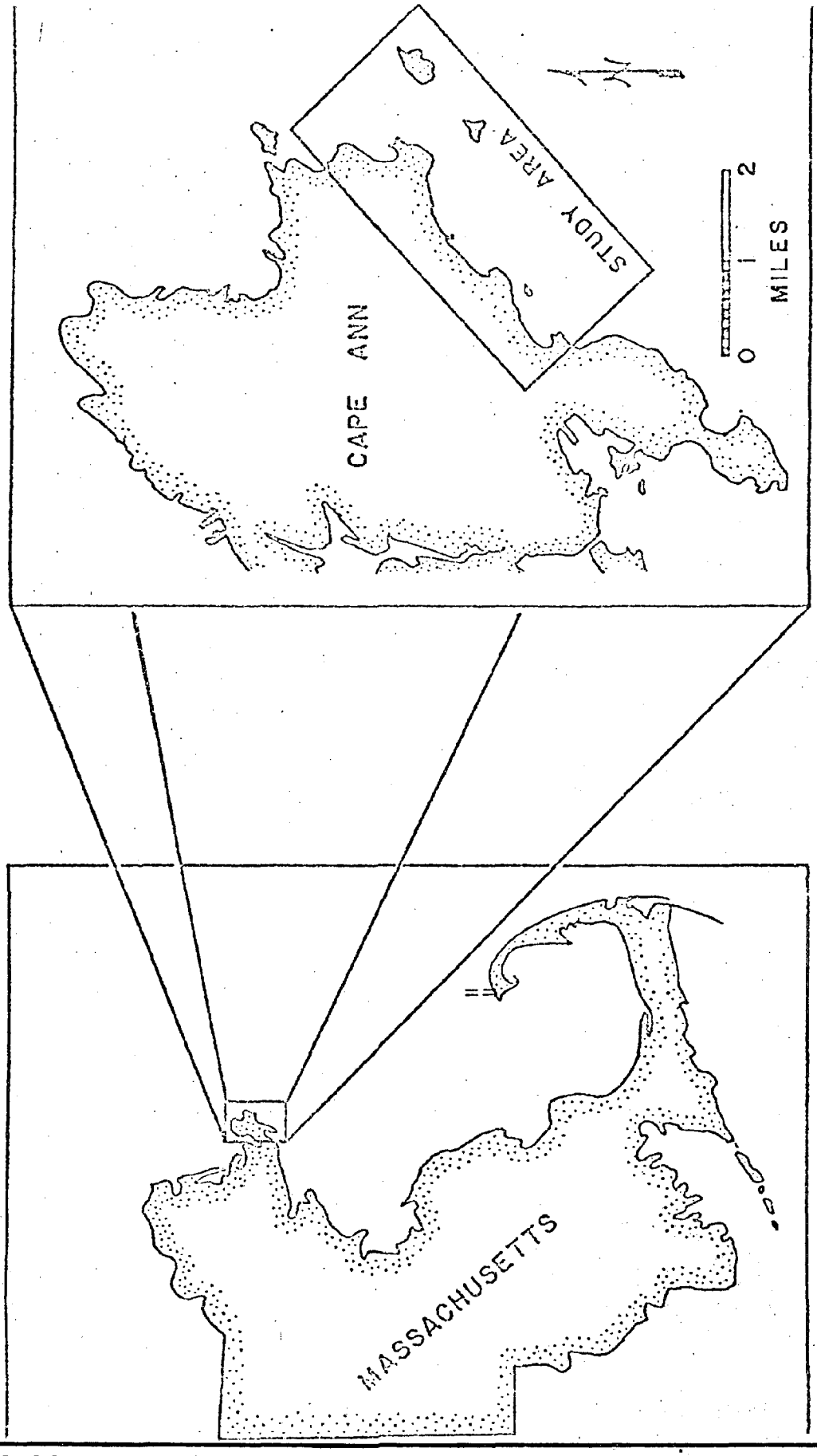
Grain-size decreases in a northerly direction along the beach. The southern ridge is composed of cobble particles whereas the northern segments are dominated by particles in the pebble-size range. Medium sand occurs on the low intertidal beach, but decreases in size to mostly fine sand below mean low water. The beach sediments are all well-sorted except at the northern end where pebbles are mixed with sand on the lower beach. The coarseness of the constituent particles controls the steepness of the beach profile. Beach gradients range from 1:11 at the southern end of Pebbly Beach to 1:22 at the northern end.

The source of the beach sediment on Pebbly Beach is a glacial moraine intersecting the coastline at Cape Hedge about 2 km south of the beach (Sears, 1905).

The cobbles making up the beach ridge are of the same composition and of approximately the same composition variability as the charts comprising the coarse fraction of the moraine material.

Waves approach Pebbly Beach from the south and northeast, the prevailing and dominant wind directions, respectively, of the Cape Ann area. Cunningham and Fox have constructed wave refraction diagrams for this portion of the Cape Ann coastline and found that 10-second period waves generated during northeast storms refract around Thatcher and Milk Islands to the north and offshore of Pebbly Beach to intersect the beach at a right angle (wave orthogonal orientation) while six-second period waves from the south-southwest strike the beach at an angle generating northerly-transporting long-shore drift (See Figure 5-42a).

Cape Hedge Beach extends one km. southwesterly from a small rocky headland to the south of Pebbly Beach to Cape Hedge. This beach, in general, is identical to Pebbly Beach as it is subject to the same sediment source and wave characteristics. Cape Hedge Beach, however, has a higher storm ridge (6.3 m) and a wider forebeach (0.3 km) because of a larger volume of sand-sized material delivered to it from the glacial moraine



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

TRIGOM PARC	FIGURE 5-41	Cape Ann, Massachusetts (Cunningham & Fox)

source at Cape Hedge.

Long Beach lies south of Cape Hedge and extends 1.8 km southwest to Brier Neck. The beach is a baymouth barrier enclosing a tidal active lagoon behind it; a small inlet exists at the northern end of the strand. The backbeach is developed and a seawall runs the length of the barrier to protect building structures from wave damage.

The beach is composed of medium sand and develops a mature berm and ridge-and-runnel system during the summer months. The beach exhibits gradients of about 1:33 for most of its length.

Long Beach is similar to Cape Hedge and Pebbly Beaches in that longshore drift is only set up during wave approach from the south-southwest. Cunningham and Fox indicate that a slight northerly decrease of particle median-diameter along the beach corroborates the net drift direction determined by wave refraction diagrams.

Good Harbor Beach is the southern most beach along the south-eastern margin of Cape Ann. The beach is 2.8 km long extending from Brier Neck on the north to Bass Rocks headland to the south. The northern portion of the beach is characterized by a tombolo extending outward from the beach in an easterly direction to Salt Island. The sand comprising the tombolo spit is fine, whereas the rest of Good Harbor Beach is uniformly medium sand over its entire width (0.8 km) (See Figure 5-42b).

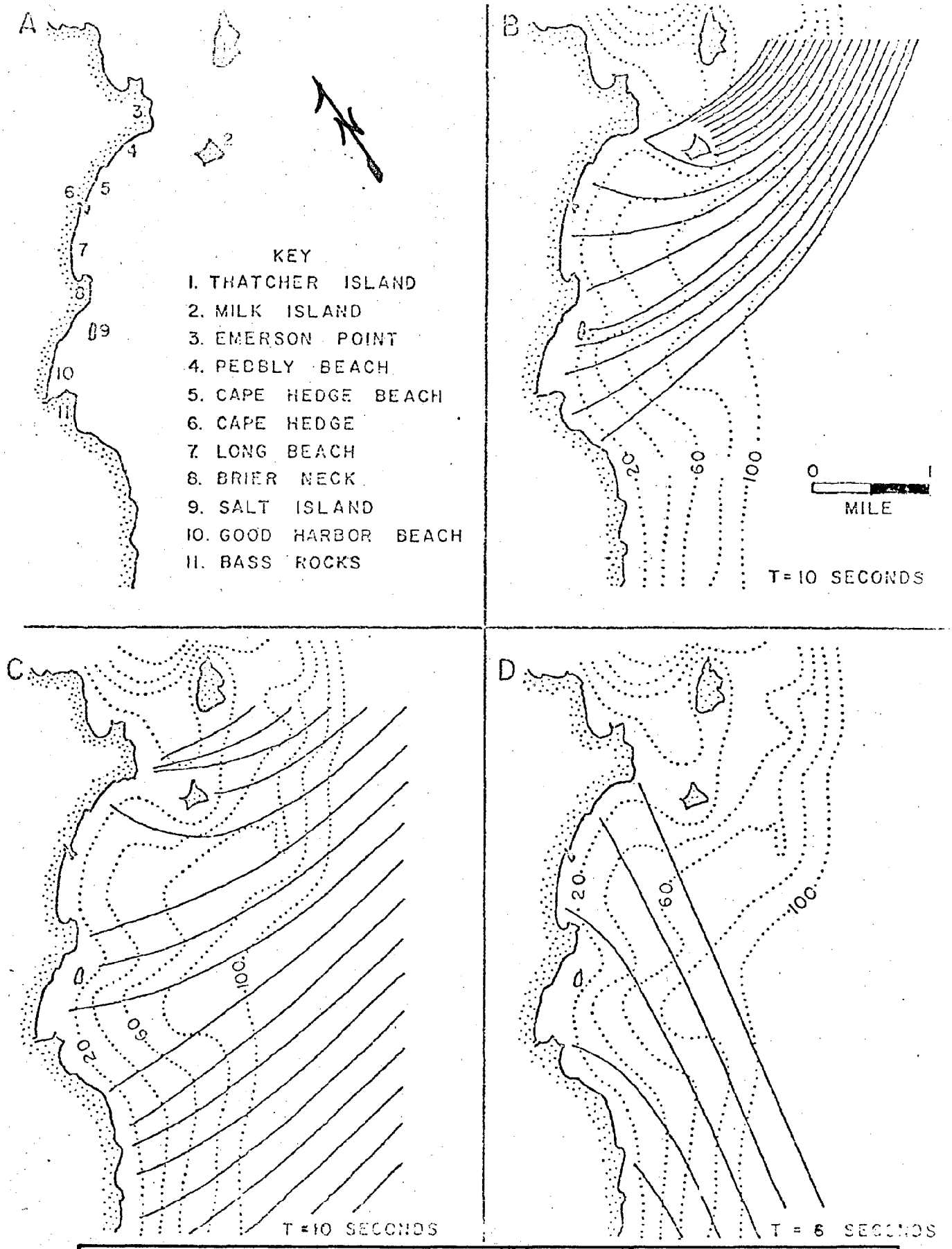
The beach is a baymouth barrier which is prograding in a south-westerly direction to enclose a large, marsh-filled lagoon. A sizable inlet still drains the lagoon behind the barrier (See Figure 5-42c).

Beach gradients are gentle along Good Harbor Beach. The average gradient is 1:53 but is steeper at the northern end near Brier Neck and gentler at the beache's southern end. The forebeach exhibits the typical post-storm accretion stages defined on Plum Island.

Unlike the three beaches to the north, Good Harbor Beach is oriented at right angle to south-southwest waves. Northeast waves approach the beach at an angle to generate southwesterly littoral currents as evidenced by the southerly progradation of the barrier spit. A slight grain-size decrease from Brier Neck southward also indicates that the net drift direction along this beach is to the southwest.

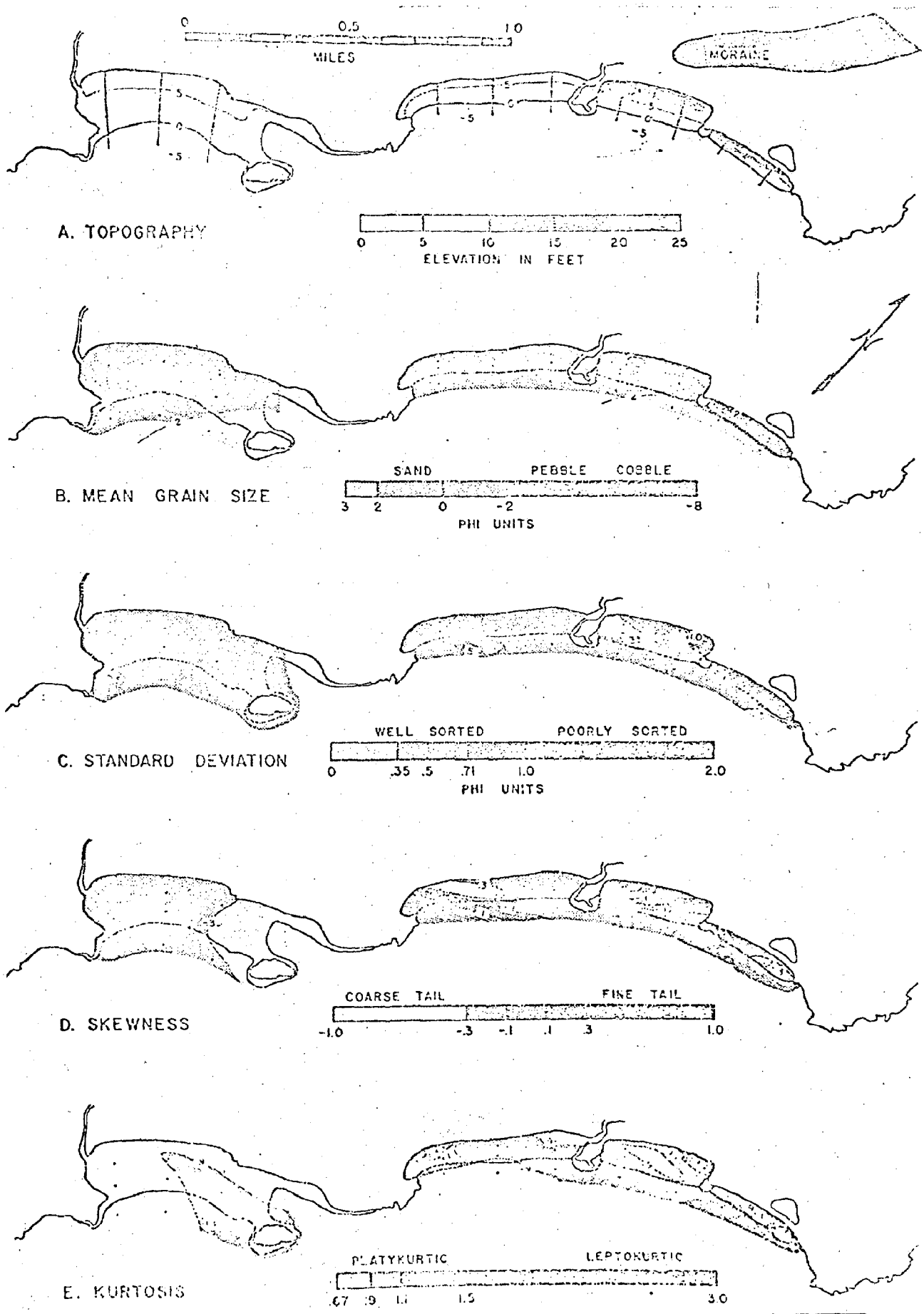
BOSTON BASIN BEACHES, BOSTON - ESSEX, MIDDLESEX, SUFFOLK, AND NORFOLK COUNTIES

Boston Harbor and the inner portions of Massachusetts Bay exhibit numerous submerged drumlins and drumlin remnants (Johnson, 1925). Submergence with subsequent wave erosion of the till-veneered drumlins has formed a complex of spits, tombolos, and beach-rimmed islands. (See Figure 5-43).



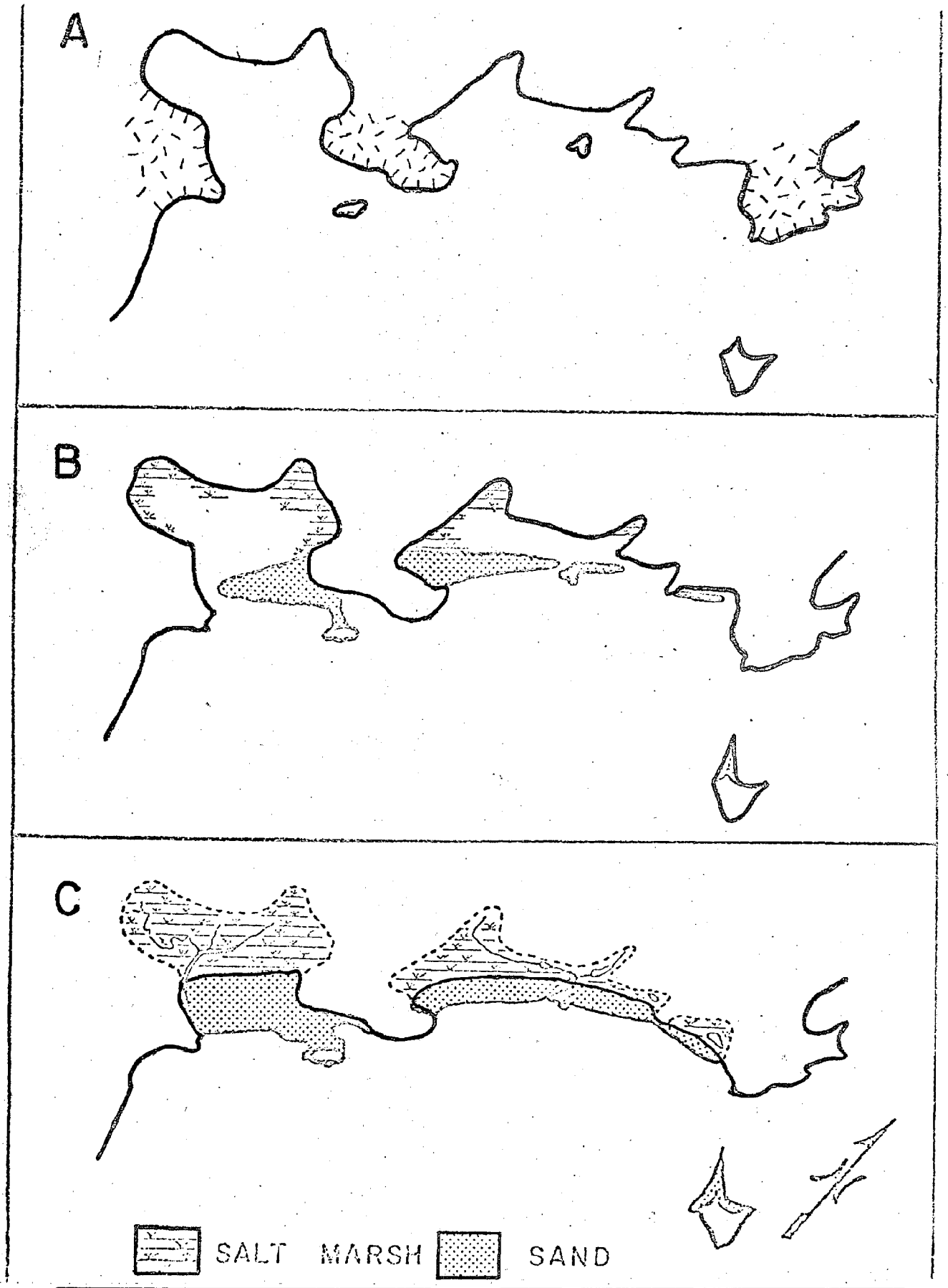
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 5-42a | Cape Ann Beaches-Wave Refraction Diagrams (Cunningham & Fox)



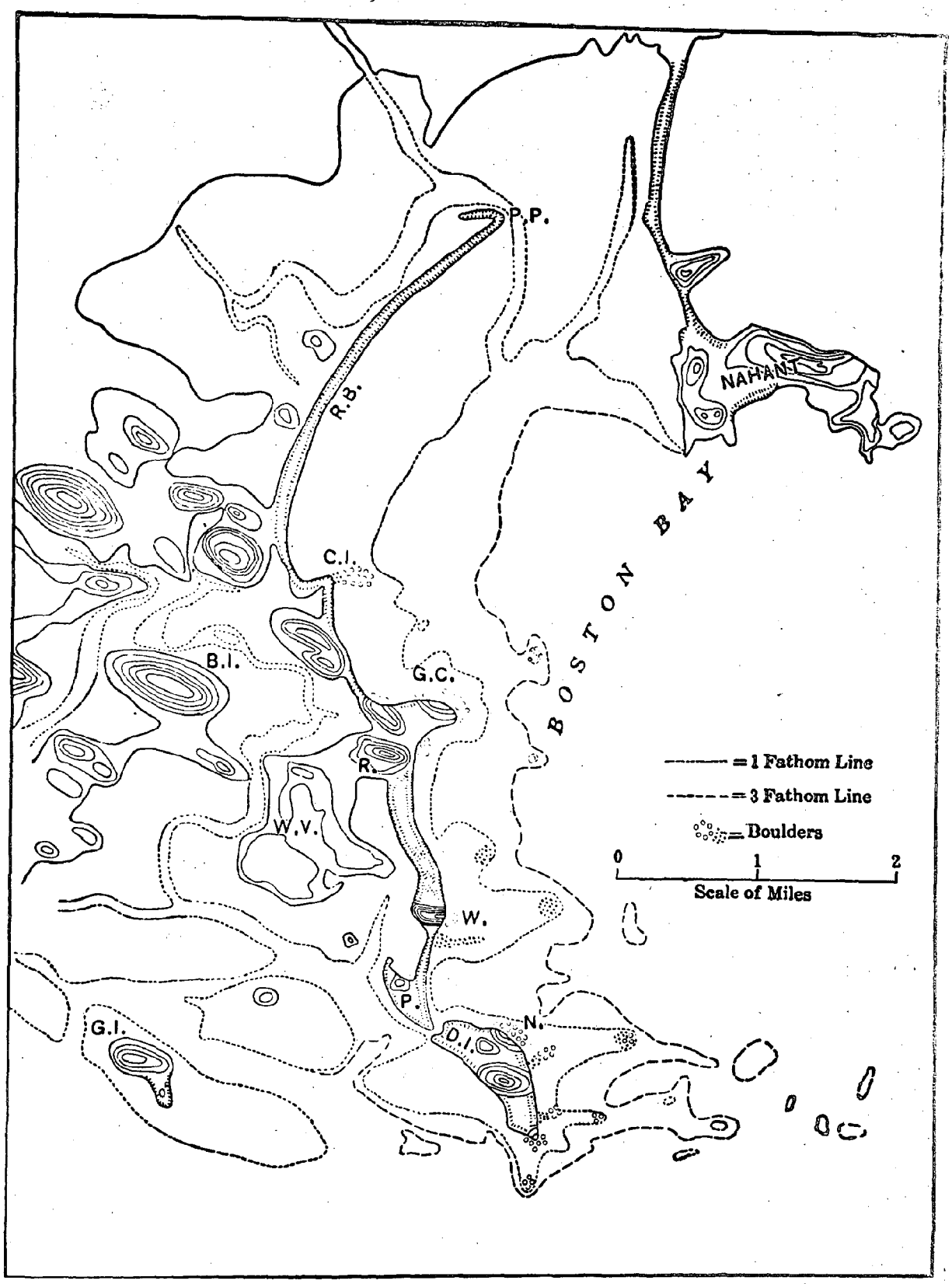
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM | FIGURE | Topography and Textural Parameters of Beach Sediment



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

TRIGOM PARC	FIGURE 5-42c	Spit Development - Cape Ann Beaches (Cunningham & Fox)



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

TRIGOM PARC	FIGURE 5-43	Tombolo Physiography Boston Harbor (Johnson, 1925)

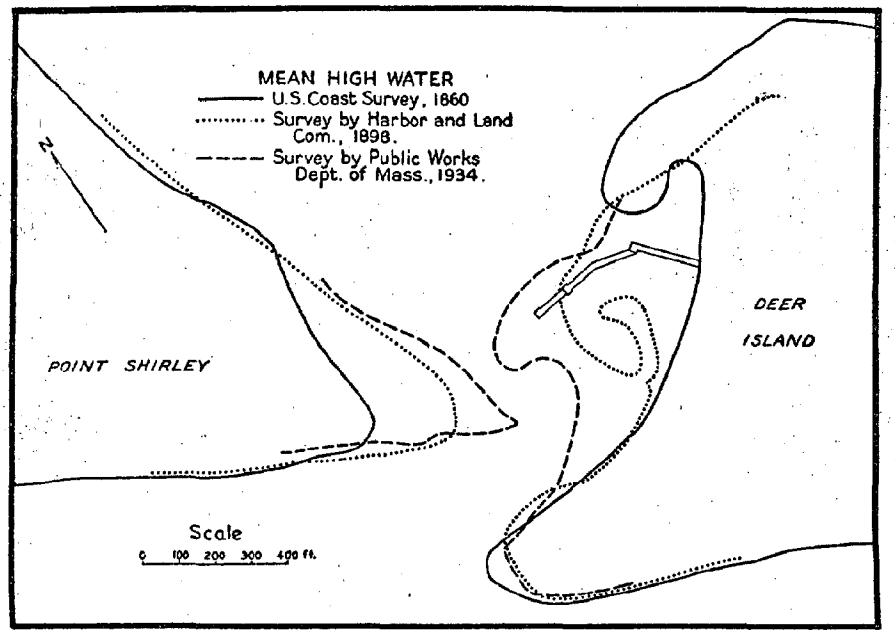
Boston Harbor is protected from the open Gulf of Maine by a series of tombolos extending from the margins of the upland toward the center of the outside of Boston Harbor. The Lynn-Nahant Beach and Winthrop Beach tombolos extend south from Lynn and Winthrop to Nahant and Deer Island.

Nichols (1949) has studied the evolution of the Winthrop Beach tombolo by historical chart comparisons. Prior to 1936 Deer Island existed as an island with the tip of Winthrop Beach, the spit of Point Shirley, prograding toward the north end of the island and a spit prograding from Deer Island north. The spits were separated by a channel, Shirley Gut. Continued attack by northeast waves on Winthrop Beach and Deer Isle added material to the spits which joined in 1936, closing Shirley Gut (See Figure 5-44). The beaches are composed of a mixture of sand and gravel with pebble-and cobble-sized materials concentrated near the drumlin headlands and medium-sized sand toward the centers of the tombolos. The seaward-facing beaches of the tombolos are generally coarser than their harbor-facing counterparts. Apparently the latter beaches receive refracted and diminished wave energy spectra only capable of transporting sand-sized materials from the eroded scarps of the drumlins (Farquhar, 1967). Both beaches, Lynn-Nahant and Winthrop Beach are extensively developed and the thin tombolos are stabilized by rip-rap protected roads.

Revere Beach is an arcuate barrier spit extending north from the northern end of Winthrop Beach. The beach is about 7 km long and is entirely developed with dwellings, commercial buildings, and an amusement center. The beach has prograded across a bay to leave a tidal inlet. The bay has been partially filled by artificial means. Revere Beach consists mostly of fine quartz sand transported from the source at Winthrop Head and Grovers Cliff, drumlin remnants (Trowbridge & Shepard, 1932). The Lynn-Nahant tombolo shields Revere Beach from easterly storm waves so that only diminished refracted and southerly waves affect the Beach. These low-energy waves are only capable of transporting the finer sand particles from the glacial sediments at Winthrop Head.

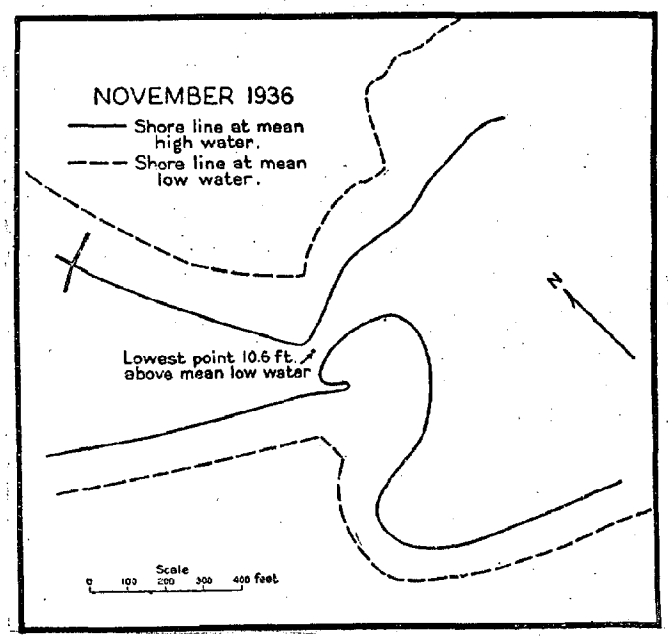
Nantasket Beach encloses the southern portion of Boston Harbor from Massachusetts Bay. The beach is a tombolo complex consisting of a north-northwest trending, 5 km long beach ridge complex from the upland to Little Hill, a drumlin, and a shorter, 2.8 km long "tombolo arm" extending westerly from Little Hill to Nantasket Hill and Telegraph Hill, also submerged drumlins. Johnson (1925) has reconstructed the stages of origin of the Nantasket tombolo which exhibits multiple, low beach ridges of varying orientations (See Figures 5-45 a-f).

Presently, Nantasket Beach is developed and protected from storm waves by seawalls and exists as a single continuous beach. Prior to recorded history the beach consisted of several arcuate spits between four drumlins. When spit growth finally incorporated the segregated spits with Atlantic Hill, Hingham, the rate of sediment supply from mainland glacial deposits was increased to aid an unbroken series of beach ridges



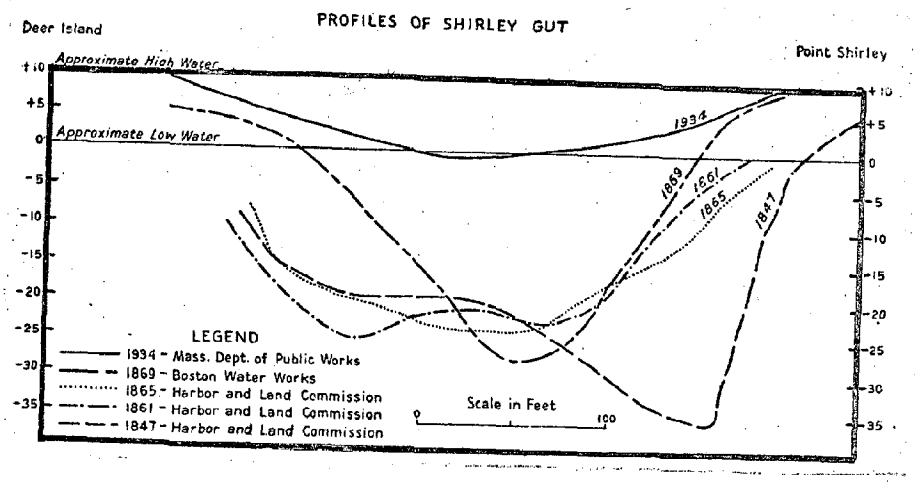
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-44a	Shirley Gut - Progressive Channel Closing by Spit Growth (Nichols, 1949)



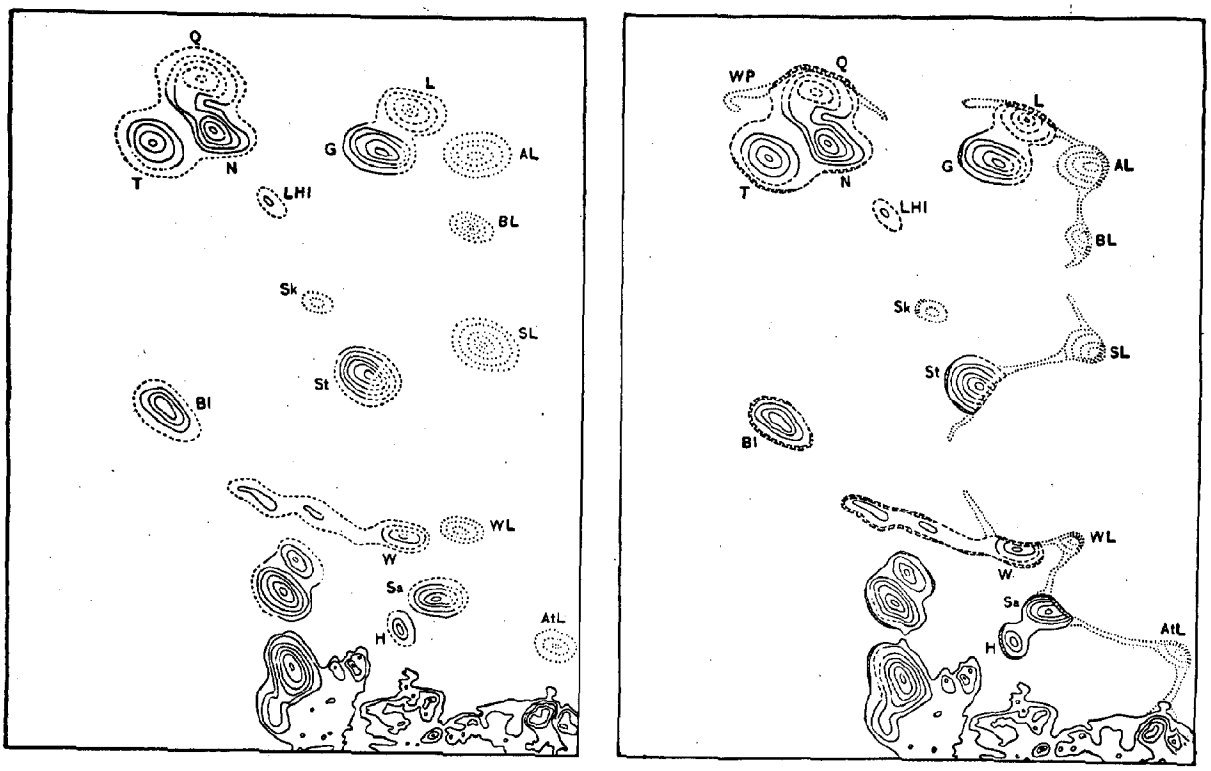
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-44b	Shirley Gut - After Closure of the Channel (Nichols, 1949)



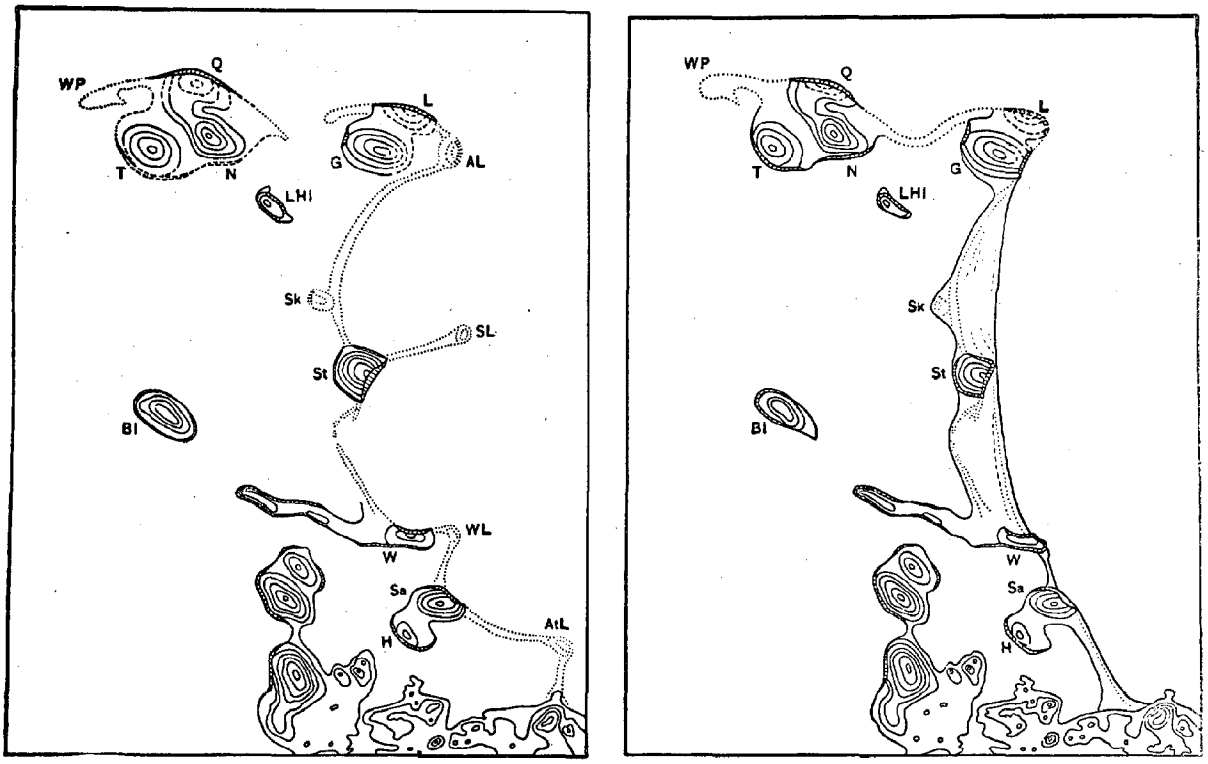
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-44c	Shirley Gut - Bottom Profiles (Nichols, 1949)



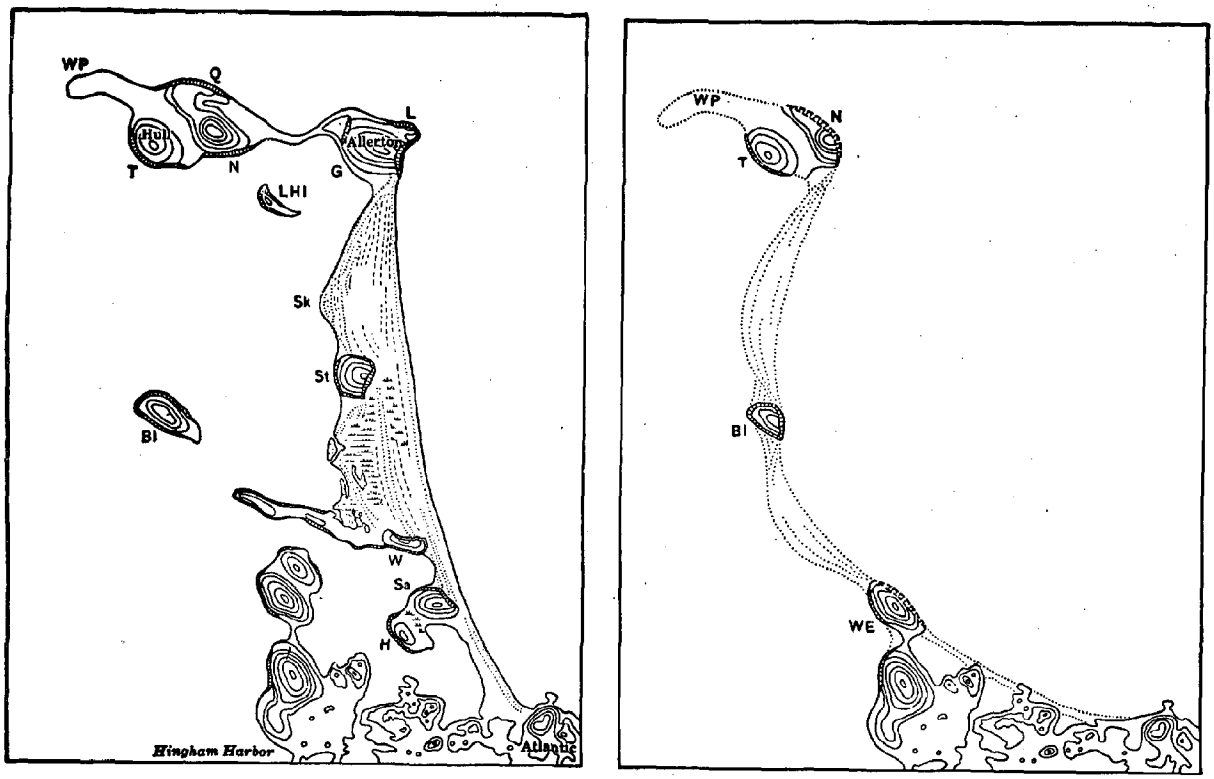
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-45a/b	Nantasket Beach Progressive Development (Johnson, 1925



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

TRIGOM PARC	FIGURE 5-45c/d	Nantasket Beach Progressive Development (Johnson, 1925



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

TRIGOM PARC	FIGURE 5-45e/f	Nantasket Beach Progressive Development (Johnson, 1925)

to prograde the length of the segregated beach arcs.

Nantasket Beach is composed of fine sand averaging .20 mm in median diameter (Stetson & Schalk, 1935). The beach probably receives sediment from Little Hill drumlin on the north during northeast storms and from the south at Atlantic Hill during prevailing southerly winds.

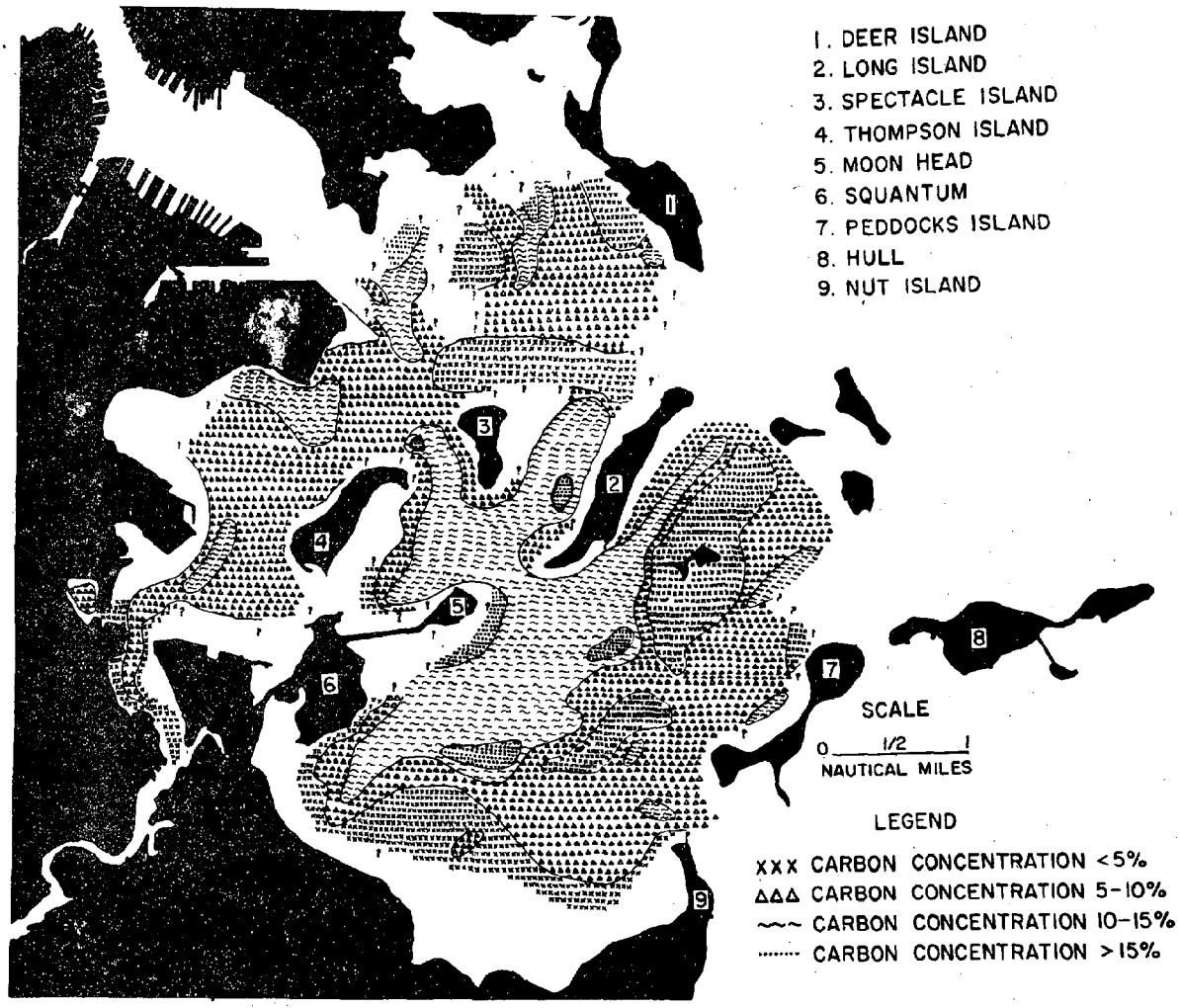
More than 15 isolated, submerged drumlin islands exist within and outside of Boston Harbor. Each island is rimmed with coarse-grained beaches of sand, pebbles, and cobbles eroded from the exposed scarps of the drumlin till immediately landward of the beaches.

Kaye (1967) indicates that cliff recession of the glacial till by rain wash and mass wasting delivers sediment to the base of the scarps to form talus accumulations. Storm waves rarely directly erode the cliff face, but rework the talus to supply sediment to the beaches.

Kaye found that the yearly mean erosion (recession) of drumlin faces is 8 to 15 cm per year on the sheltered cliffs within Boston Harbor, while Corps of Engineer studies in the 1920's indicated that cliff recession averaged 23 cm. per year on the more exposed faces of Winthrop Hill (Johnson, 1925).

Erosion of the beaches surrounding Boston Harbor has been an historical problem of considerabe magnitude (Johnson, 1925) and has continued to the present day (Corps of Engineers, 1971). Urbanization of the drumlin hills has necessitated construction of retaining walls along the scarp bases. Subsequent lack of erosion of the till and delivery of sediment to the beaches has increased erosion along tombolo and spit beaches which rely on the drumlin till sediments as a source of nourishment.

Investigations of inner Massachusetts Bay by Trowbridge and Shepard (1932) and Stetson and Schalk (1935) reveal that sand eroded from the beaches and drumlins protecting Boston Harbor by storm waves is transported seaward for a distance of about four to five km. A steady decrease of median diameter from medium sand (.28 mm) to fine sand (.17 mm) occurs off the major tombolo beaches. Where the Bay bottom is not interrupted by abrupt bathymetric changes representing ledge or relict glacial sediment outcrops, the fine sand extends to depths of 35 m. Seaward of this depth course, relict glacio-fluvial sediments exist as the bottom sediment. Elsewhere the fine sand derived from the beaches stops abruptly at bathymetric highs which act as dams to prevent wave-borne sediment from transport further seaward. Mencher, Copeland, and Payson (1968) have found that sand and gravel-size material surround the inner Harbor Islands up to distances of 1 km from the shoreline. The sand and gravel is transported to deeper portions of the Harbor by storm waves and tidal currents from the drumlin beaches. Organic-rich silts and clays occur elsewhere over most of the Harbor bottom areas which are over 1 to 1.5 km distant from any drumlin. (See Figure 5-46)



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

TRIGOM PARC	FIGURE 5-46	Grain Size Distribution of Recent Sediments in Boston Harbor (Mencher, et al., 1968)

WHITE CLIFFS TO NOBSCUSSET POINT AREA, PLYMOUTH, SANDWICH, BARNSTABLE-PLYMOUTH AND BARNSTABLE COUNTIES

The southwestern and southern coast of Cape Cod Bay is a continuous littoral sediment system extending from White Cliffs, Plymouth, to the Barnstable Harbor Inlet (Hobbs, 1972) (See Figure 5-47). East of the Barnstable inlet is a 5 km stretch of coastline which, in itself, is an isolated sediment transport system.

Hobbs has defined six shoreline morphological zones within the larger system: White Cliffs Beach, Scusset Beach, Town Beach, Springhill Beach, Scorton Neck, and Sandy Neck (See Figure 5-48).

White Cliff's Beach is a strandplain beach lying at the base of a scarp eroded into the Wareham Pitted Outwash Plain. White Cliffs is the southern section of the Manomet Point Headland which separates the barrier beaches of the inner Cape shore from Plymouth Bay to the north.

The cliff scarp is from 20 m to 30 m high and serves as the source for most of the beach sediment to the south. The southerly drift is driven by waves impinging on the beach from a northeast direction. These waves are generated during northeast storms and times of northwest winds. The prevailing winds of Cape Cod, southwest winds, blow offshore reducing wave heights of northerly waves propagating into Cape Cod Bay.

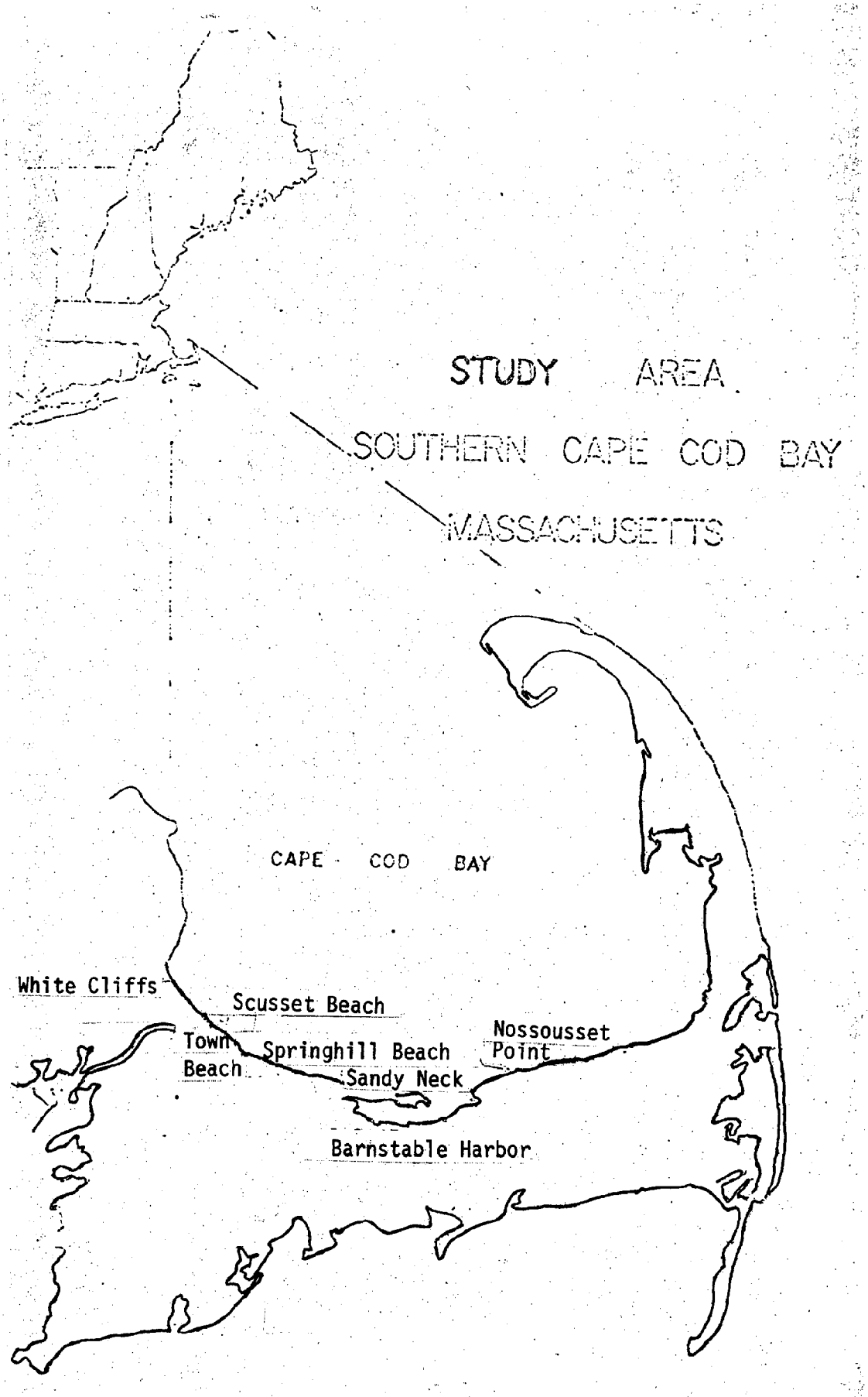
The beaches of White Cliffs are relatively narrow (75 m) with narrow berms. Accretional stages exhibiting ridge-and-runnel formation are absent; an increase in the height and width of the berm marks accretion. Hobbs postulates that the narrowness of the beach is due to the rapid removal of sediment to the south. (See Figure 5-49)

Much of the beach is revetted and groins exist along the beach to prevent loss of beach sand by littoral drift.

Scusset Beach is a 4 km long barrier island extending from the Sagamore Highlands to the Cape Cod Canal jetty. The beach trends northwest-southeast in an attempt to face the northeast-approaching waves. An intertidal spit at the southern end of the barrier has formed to further direct the beach to parallel the northeast waves.

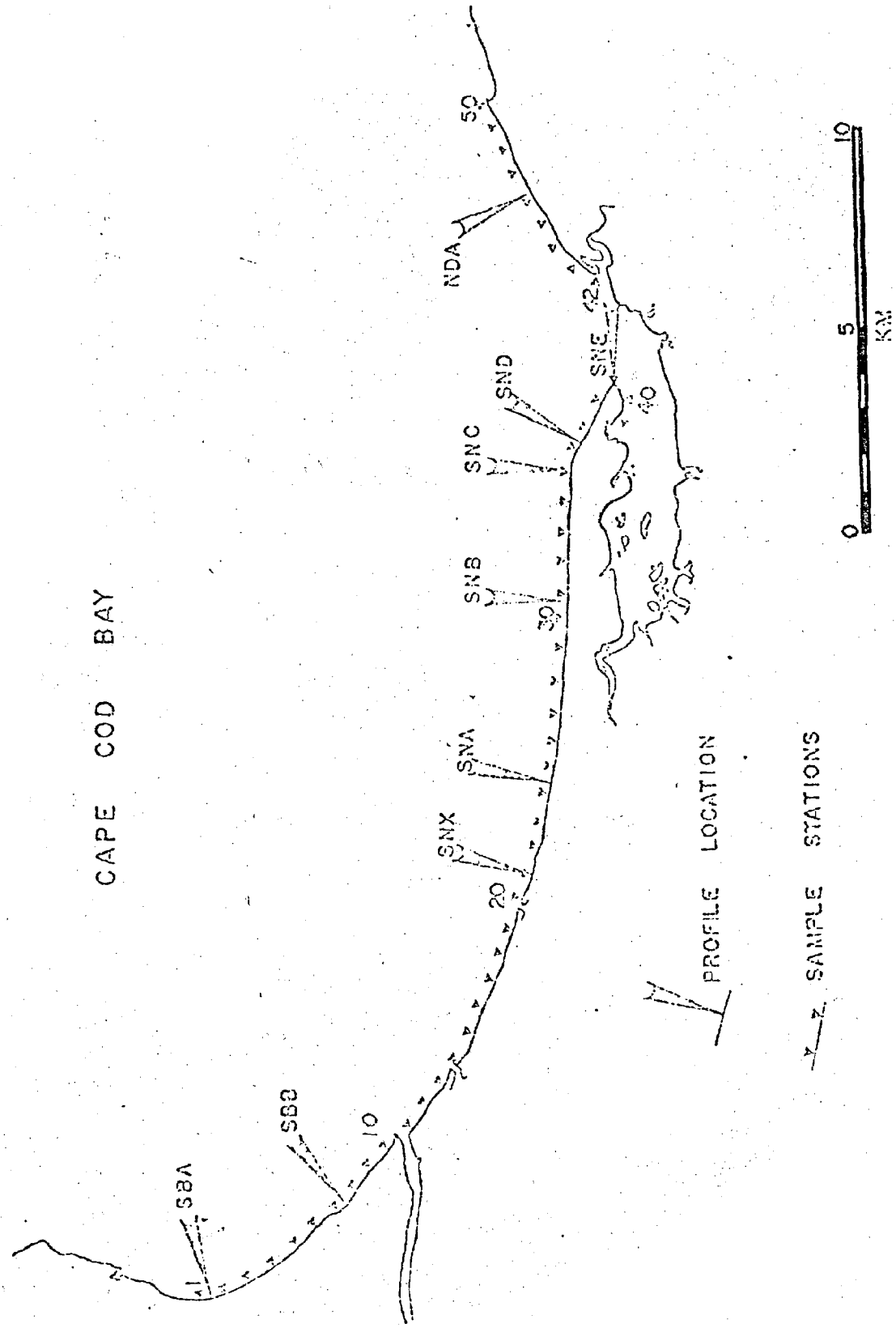
Scusset Beach is somewhat narrower than the beaches of White Cliff and an accretion - erosion cycle is marked only by berm growth and retreat. Seawalls extend over much of the length of the barrier and several groins have been erected to retard beach erosion.

The Scusset Barrier encloses a large saltmarsh tract and supports an active dune field. The dunes and intervening blowouts exhibit a strong northeast-southwest lineation, the directions of the dominant and prevailing winds.



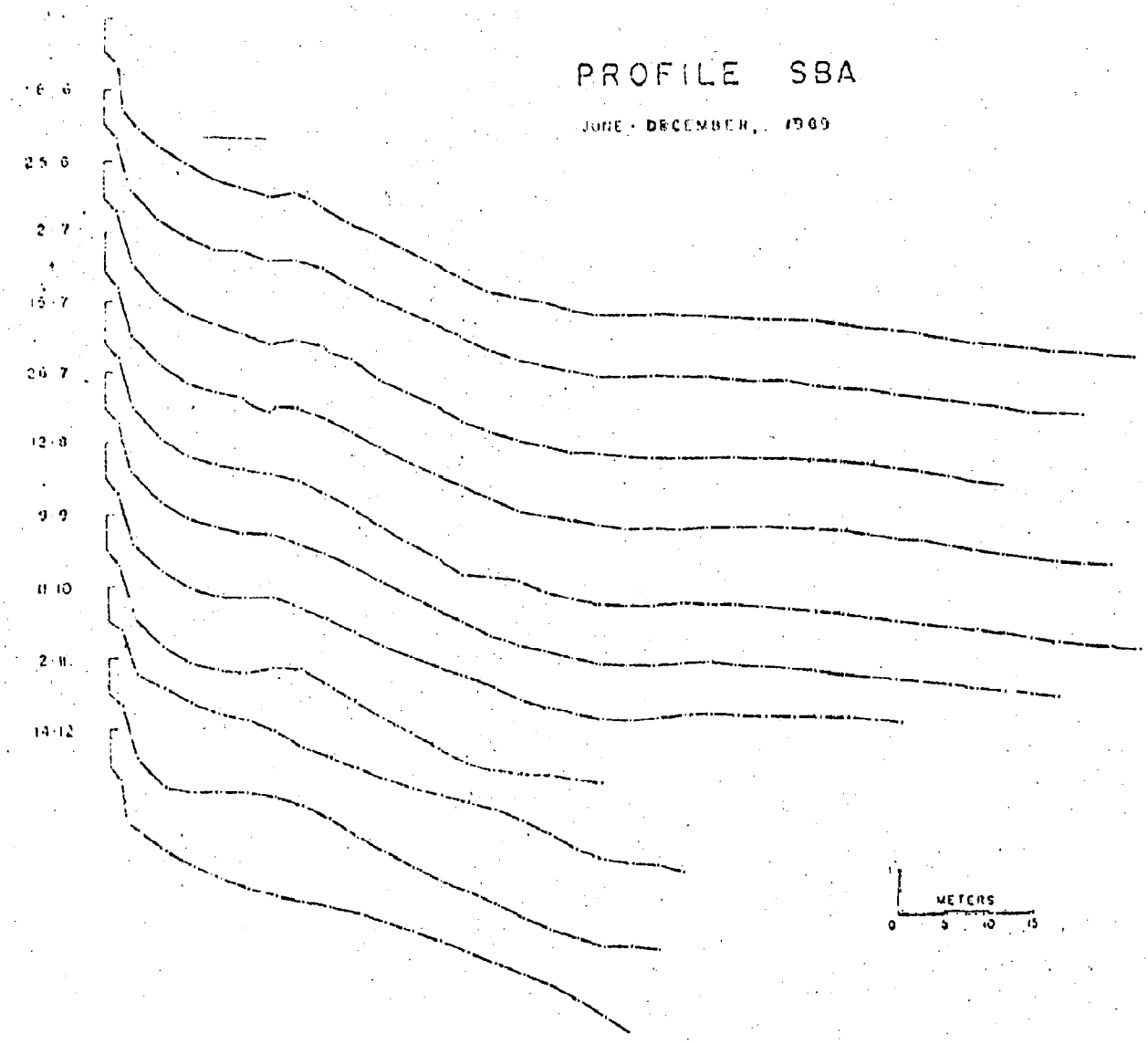
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC | FIGURE 5-47 | Southern Cape Cod (Hobbs, 1972)



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

TRIGOM PARC	FIGURE 5-48	Profile Locations-Sample Stations (Hobbs, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-49	Beach Profiles-White Cliffs-Plymouth (Hobbs, 1972)

Town Beach is a small barrier extending from the Cape Cod Canal to the mouth of Sandwich Harbor. The beach is narrow (60 m) and sediment deficient because the Canal jetties prevent sand from White Cliffs to be transported to the southern side of the Canal. The beach is extensively developed; seawalls have been built to impede erosion of the backbeach area, groins have been built to slow littoral drift and the beach is artificially nourished periodically with coarse sand.

Springhill Beach extends 4 km from Sandwich Harbor to Scorton Neck, a slightly seaward protruding headland of Pleistocene kame delta sediment. The beach faces just east of north, is narrow and characterized by small neap berms after accretional periods. It is backed by a thin dune ridge which acts as a storm barrier to the many summer homes on the beach.

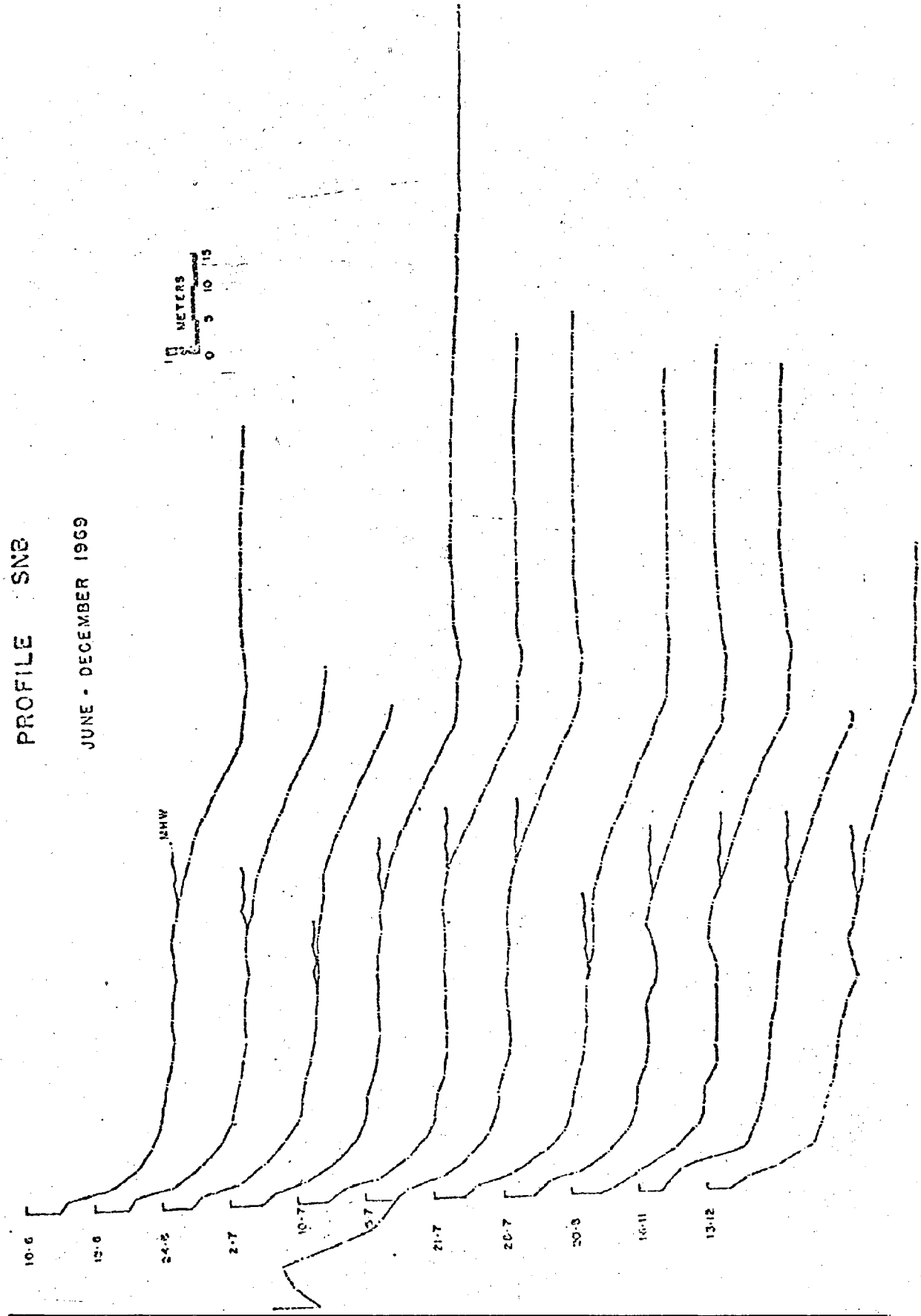
Scorton Neck is about 2 km long and anchors the western end of Sandy Neck. Hobbs indicates that winter storms may cut back the front scarp of the headland but that post-storm accretion is dominated by shoreward migrating ridges and wide berms.

The headland acts as a source of sand for Sandy Neck and allows sediment from the west to bypass to the Sandy Neck spit. The erosion of the scarp has prompted the residents of a small colony on the eastern flank of the headland to erect revetments and several groins to abate sediment removal.

Sandy Neck is a 9 km long barrier spit that separates Barnstable Harbor from Cape Cod Bay. Redfield (1965, 1967) has detailed the eastward growth of the spit by documenting the growth of marsh within the harbor. The barrier spit has prograded eastward by 7 periods of spit growth since about 3300 BP. An eighth accretion period is currently active forcing the inlet of Barnstable Harbor further to the east.

Hobbs has defined three morphological units characterizing the forebeach area of the barrier: 1) a north-facing 3.5 km section of the spit; 2) a northeast-facing 2 km zone affected by tidal currents generated in the vicinity of the tidal inlet; and 3) a short segment which acts as the channel margin of the inlet.

The first zone, the westernmost beach, is characterized by a very wide berm and a continuous ridge-and-runnel system. (See Figure 5-50). The second zone exhibits a steeper, narrower beachface than zone one. A dune scarp exists only a short distance from the berm crest. Ridges characterize a narrow low-tide terrace but are assymetrical in plan with the leading edges of the bulk of the ridge facing toward the inlet. Southeast migrating bedforms on the ridges indicate that flood tidal currents aid littoral drift in transporting sediment from west to east. Protuberances form and migrate along the beachface from west to east toward the inlet. The third zone exhibits a convex-upward profile, only 30 m long, plunging steeply to the inlet channel. Tidal currents generated in the inlet maintain a steep, narrow beachface.



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

TRIGOM PARC	FIGURE 5-50	Profile Changes-Sandy Neck (Hobbs, 1972)

Sandy Neck is covered by a stabilized dune field with dunes extending to heights of six meters. Southwest winds transport dune sand to the beach by eroding blowouts and forming dune lobes at the leading margin of the field. Northeast and northwest winds blow sand from the beach to the dune field and advance the dunes over the Barnstable marshes. Dune sands are medium-sized sands and decrease in size from west to east (≃ .40 mm to .31 mm) along the length of the dunes.

The sediments of the southwestern shoreline of Cape Cod range from medium sand to pebbles. Gravel exists on the back beach along most of the shoreline but decreases in median diameter from about 60 mm at White Cliffs to about 30 mm at the end of Sandy Neck. Grain-size trends from west to east demonstrate downdrift fining, improved sorting, and an approach toward a more nearly symmetrical grain-size population distribution indicating a tendency for the sediment to approach a population of grains at equilibrium with littoral processes active along the inner Cape Cod shoreline. (See Figures 5-51 and 5-52)

NORTH DENNIS BEACHES, DENNIS - BARNSTABLE COUNTY

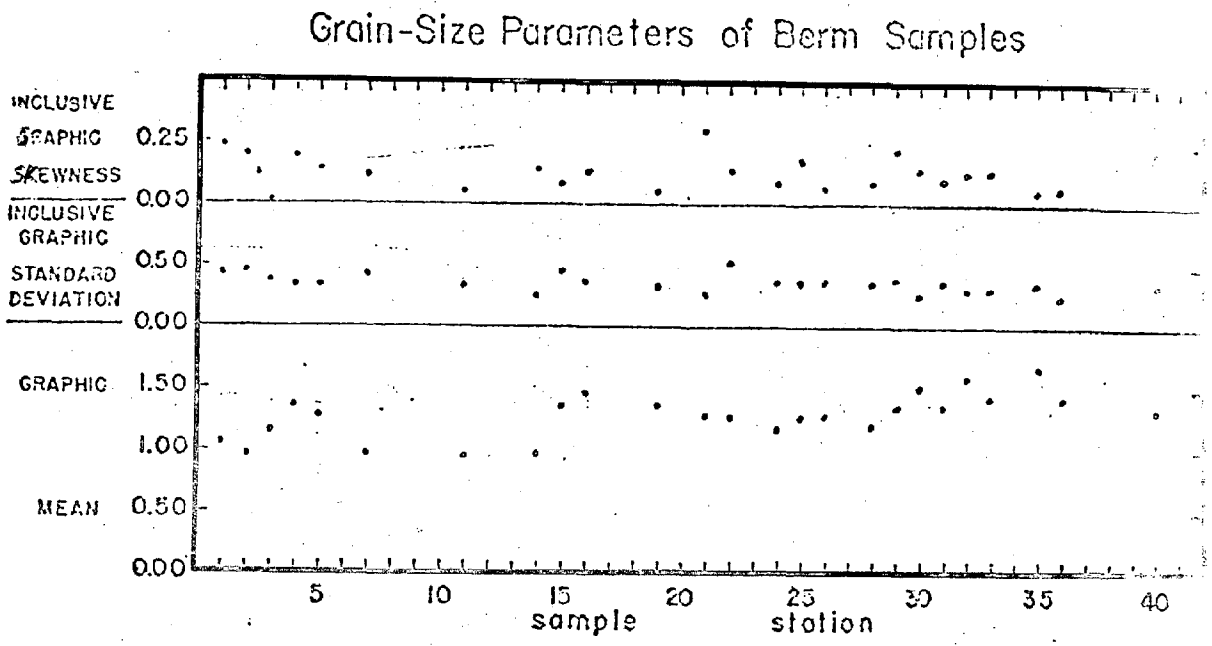
East of the Barnstable Harbor inlet is a 5 km stretch of beaches extending to Nobscusset Point, a resistant headland composed of glacial moraine sediment.

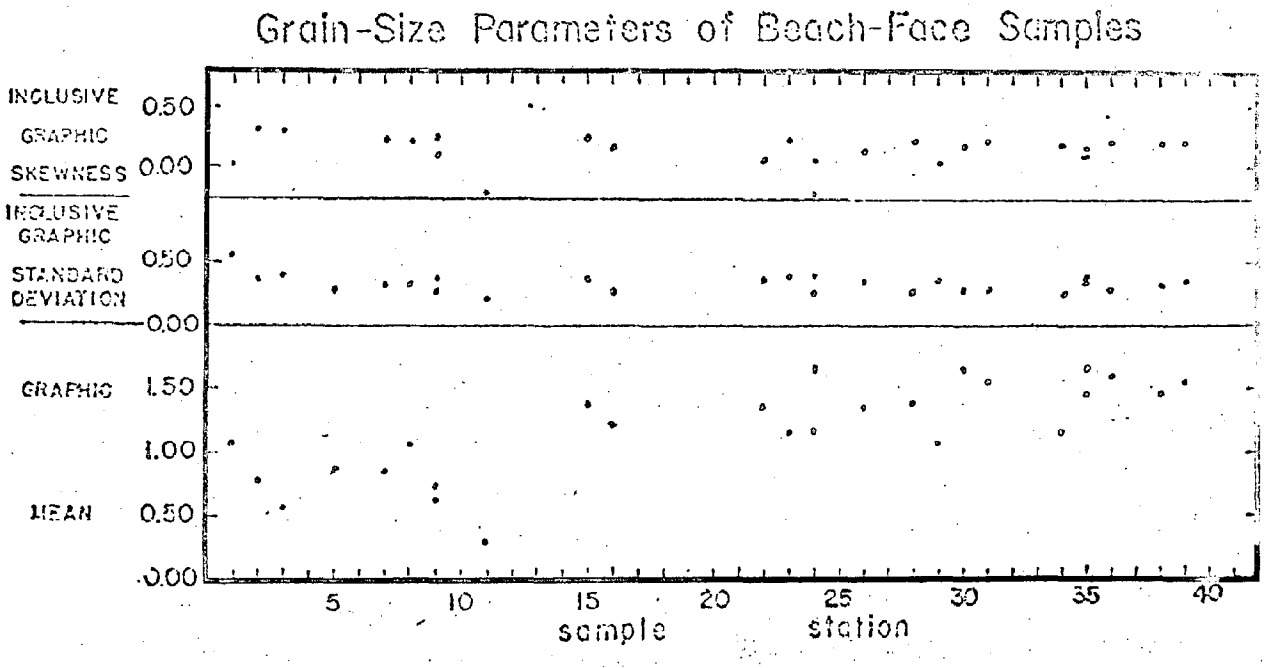
Nobscusset Heights are directly open to northwest waves generated across the entire fetch of Cape Cod Bay. Wave energy concentrates on Nobscusset Point to erode glacial sediment and transport sand and gravel along the shore from east to west toward Barnstable Harbor. The beaches are relatively narrow (30 m) but are fronted by low, sandy tidal flats up to 200 m wide. Most of the sand eroded from the headland is finally transported to the inlet of Barnstable Harbor. Several recurved spits have formed at the free end of the beaches, curving into the harbor.

BREWSTER, EASTHAM, AND WELLFLEET BEACHES, DENNIS, BREWSTER, EASTHAM, AND WELLFLEET - BARNSTABLE COUNTY

The southeast shore of Cape Cod Bay is unique from the rest of the New England strands in that it is characterized by sand tidal flats up to 2 km wide, fronting narrow beaches with diminutive, incipient berms. (See Figure 5-53). For the most part, the narrow beaches are strandplain beaches lying at the base of an eroded outwash plain (the Eastham outwash plain) along the eastern shore and scarped Pleistocene lake deposits (till?) (Oldale, 1969) along the Brewster shoreline to the south.

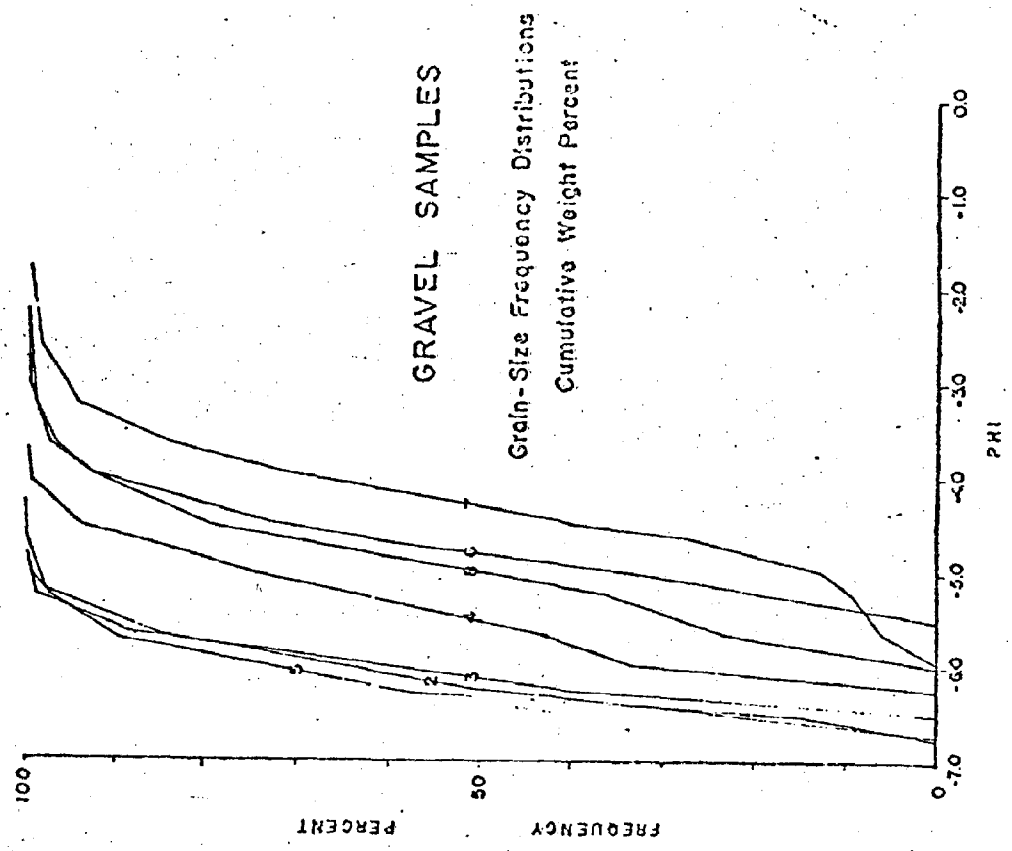
Nilsson (1972, 1973) defines three zones of intertidal and shallow subtidal sand flats on the basis of type, orientation,and numbers of sand bars exhibited on the flats.

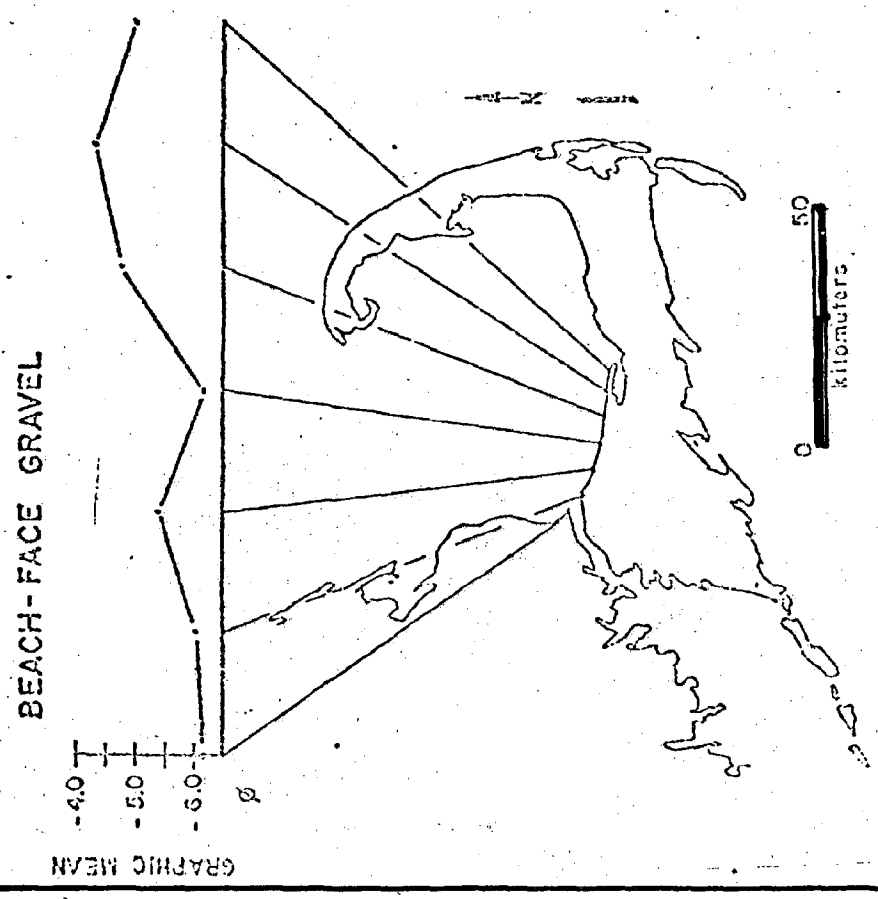




A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-51	Textural Parameters-Berm and Beach Face Sands-S.W. Cape Cod Bay (Hobbs, 1972)



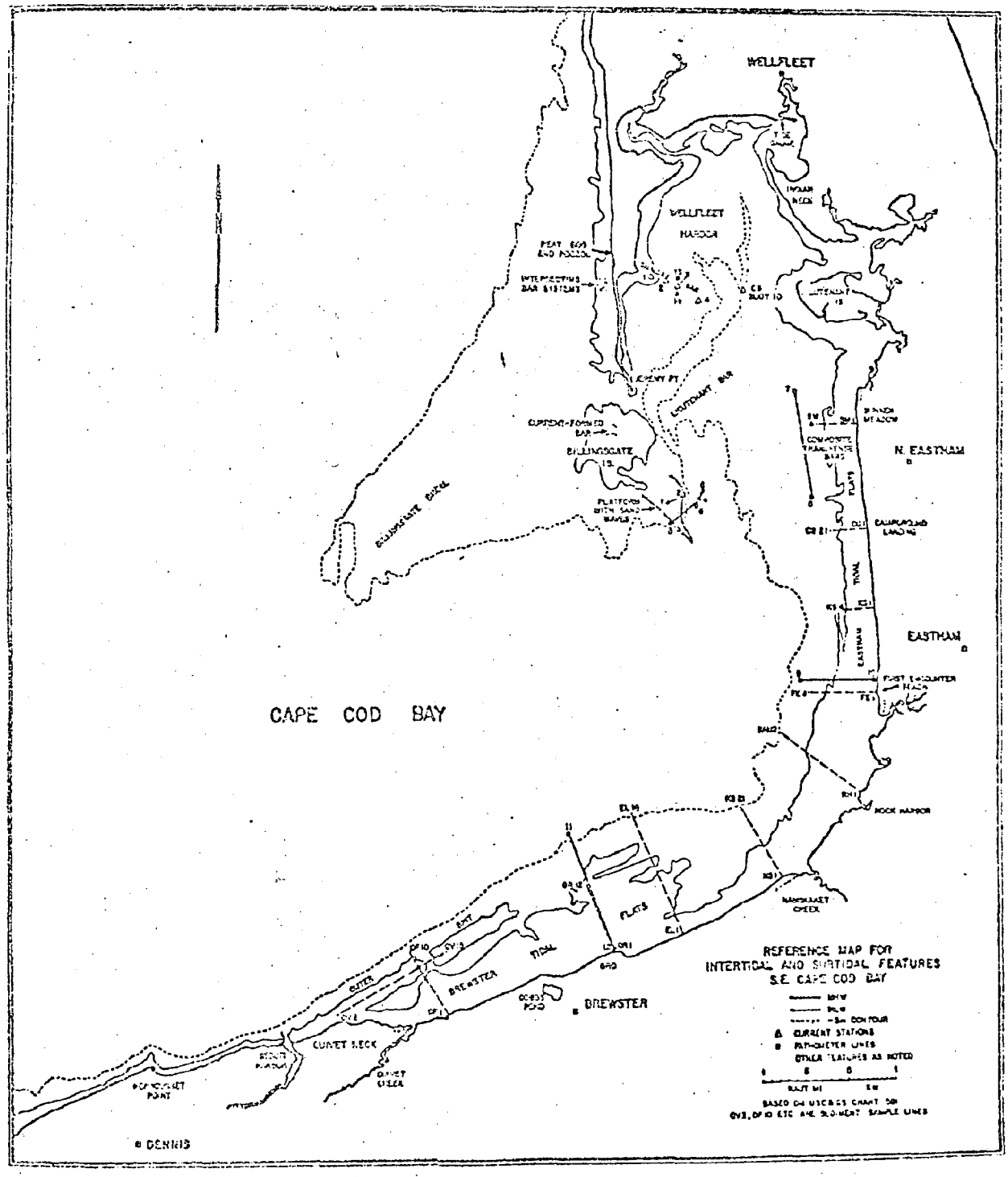


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM INC.

FIGURE 5-52

Down Drift Decrease in Gravel Size (Hobbs, 1972)



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

TRIGOM PARC	FIGURE 5-53	Intertidal and Subtidal Features-S.E. Cape Cod Bay (Nilsson, 1972)

The Brewster shoreline, extending 9 km from Nobscusset northeasterly to Nanskaket Creek, is characterized by convex landward and seaward-shaped swash bars covering the sand flats to a subtidal depth equalling the Cape Cod wave base depth (2-3 m below mean low water). (See Figure 5-54) The swash bars are formed by the action of waves contacting bottom and breaking. Multiple swash bars form where waves break, reform, and break again to deposit sediment on the bar. Nilsson (1973) stipulates that multiple bar formation is favored by conditions and processes indigenous to the inner, protected shores of Cape Cod Bay: gentle slopes not exceeding 0.005; sand-sized sediment; a high tidal range (3 m); and relatively low wave energy (maximum observed waves 1 m high with 4-5 second period induce multiple swash bar formation.)

The Brewster flats exhibit convex symmetrical or assymmetrical swash bars which are influenced by southwest wind-generated currents and tidal currents. The horns of the convex or concave bars are oriented facing the east because the currents proceed from west to east along the southern coast. Northwest wind-generated waves erode the Pleistocene deposits to deliver sediment to the tidal flats and beaches. Southwest wind-generated waves, prevalent during the summer, initiate littoral drift in an easterly direction along the Brewster shoreline.

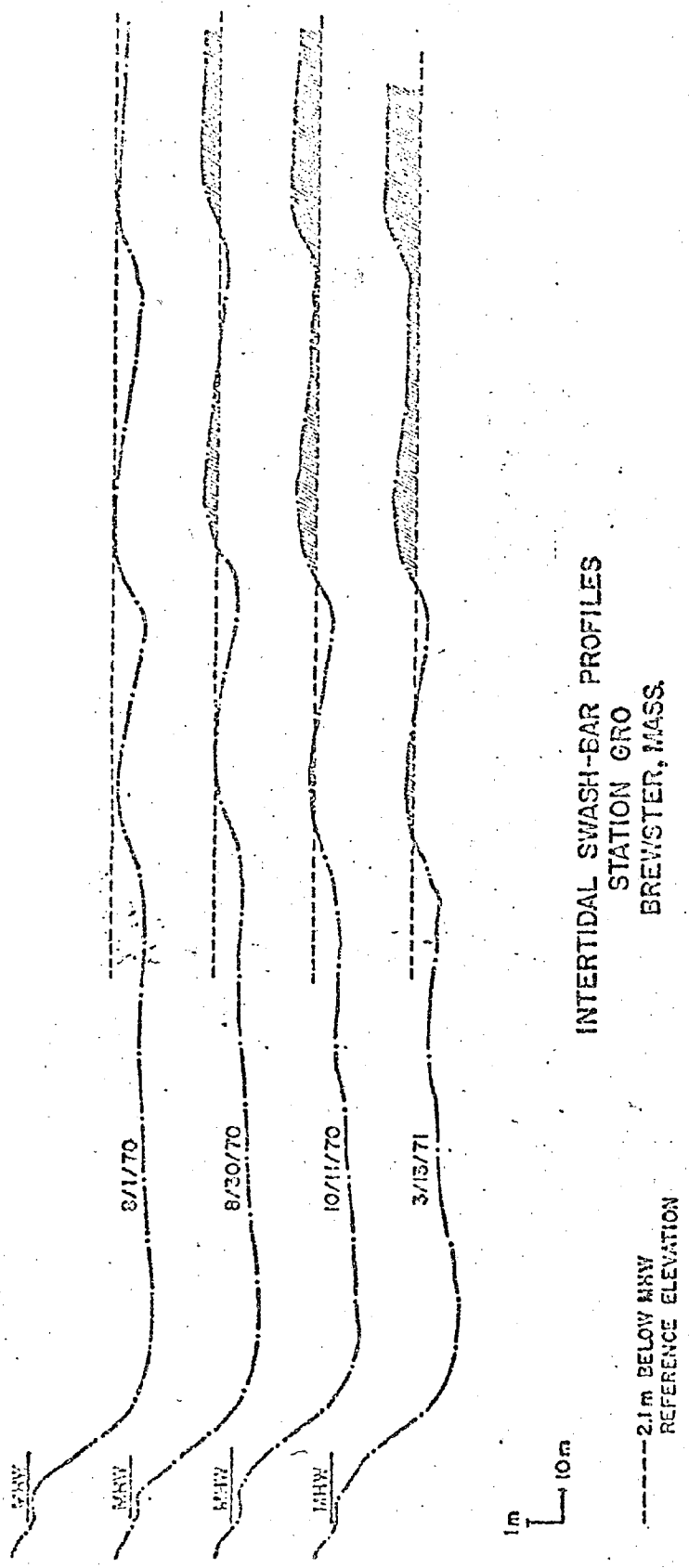
During the summer of 1971 Nilsson (1972) observed no horizontal migration of the swash bars, but observed up to 1 m of vertical growth on the bars. The swash bars are about 1-1.5 m in amplitude and exhibit wave lengths of 60 m.

The Eastham shoreline is a north-south oriented strand extending from Nanskaket Creek to the entrance of Wellfleet Harbor. The tidal flats exposed along this 10 km shoreline are somewhat protected from northwest wave attack by Billingsgate Shoal off Wellfleet, but since westerly and southwesterly waves are parallel to the Eastham shore, the net drift direction is from north to south.

Up to 30 linear swash bars parallel the shoreline and extend 1.6 km seaward from the beaches. The swashbars exhibit an amplitude of from 0.3 to 0.6 m and a wavelength of about 50 m. Seaweeds and other marine algae are commonly found in the troughs of the bars.

Sediment for the beaches and bars is derived from erosion of the Eastham bluffs, exposures of outwash sands and gravels during periods of strong northwest winds.

The Wellfleet shoreline extends north from Jeremy Point, along a spit, north 5 km to narrow beaches fronting bluffs cut into the Wellfleet Plain deposits.



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

TRIGOM PARC	FIGURE 5-54	Near Shore Profile-Swash Bar Topography off Brewster (Nilsson, 1972)

South and southeast of Jeremy Point is an extensive shallow shoal shelf, Billingsgate Shoal. Billingsgate Island lies on this shoal surrounded by current-formed bars and sand waves migrating toward Wellfleet Harbor. North of Jeremy Point, offshore from narrow beaches, are .5 km wide sand flats which act as a platform for both parallel and transverse swash bars. Bars parallel to the shore exist on the outer flats, while transverse bars occupy the inner flats. The bar fields are separated by a featureless zone. The parallel bars are formed by westerly winds, dominant during the winter. Transverse or oblique bars are formed by southwest waves which are dominant in the summer.

The sediments of the southeast shore of Cape Cod Bay range from fine to coarse sand. The beach sands range from 0.80 mm to 0.35 mm in diameter and exhibit sorting values ranging from .35 to .65, well-sorted sands. The sediments of the tidal flats exhibit similar sorting values to the beach sands but are finer in size ranging from 0.4 mm to 0.18 mm , medium to fine sand. Finer-sized sand is moved seaward from the beaches by wave action and current winnowing. The area of the shoreline between Eastham and Brewster, a convergence zone of littoral drift from two directions, is characterized by beach and flat sediment showing size characteristics between the beach and flat sediment of the southern and eastern shores. Sediment sorting is variable at the convergence zone because of the mixing of fine sand delivered by littoral drift and coarse to medium sand eroded directly from the upland bluffs. (See Figures 5-55 and 5-56).

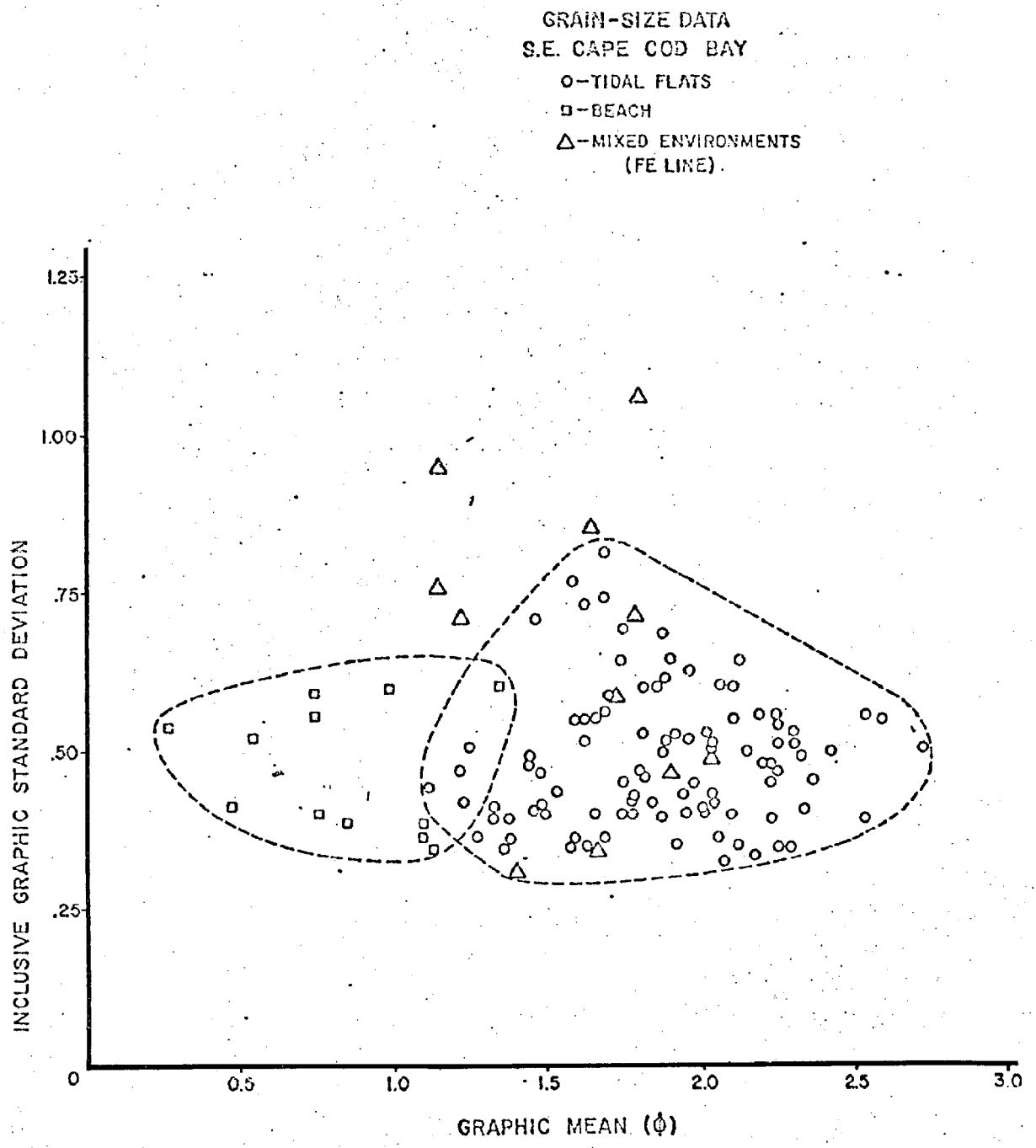
The Wellfleet shoreline has been subject to extensive erosion by waves and storm surge tides. Nilsson (1972) studied historical records and charts and estimates that the Wellfleet shoreline has retreated over 100 m in 73 years. Much of this sediment is transported south to add to the growth of Jeremy Spit. Billingsgate Island has been reduced in size to an intertidal bar over the seventy years.

Seismic data collected by Nilsson indicate that the extensive intertidal flats average 10 m in thickness and overlie an irregular surface eroded into what probably is glacial till or compact glacial sediment. This surface slopes gently toward the center of Cape Cod Bay.

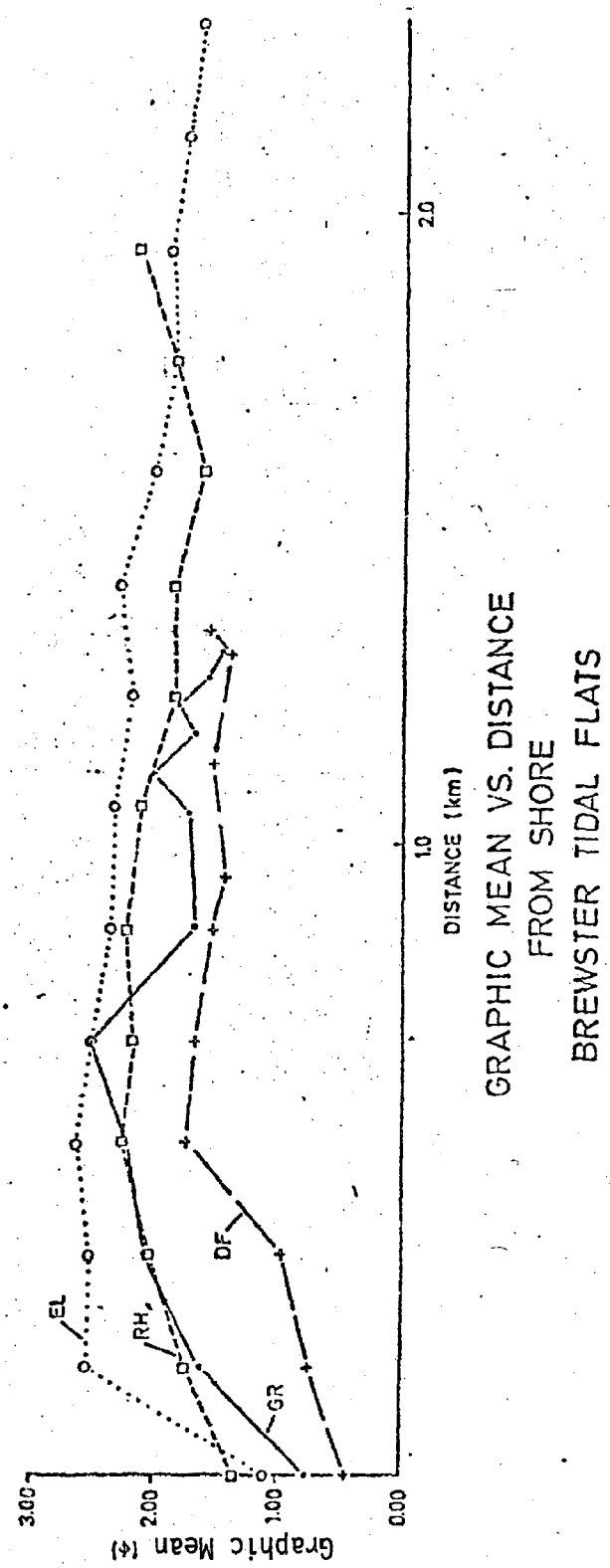
OUTER CAPE COD BEACHES, PROVINCETOWN TO MONOMOY ISLAND - BARNSTABLE COUNTY

Outer Cape Cod is bordered by 60 km of continuous beach broken only by two inlets. All but 3 km of the beaches face north, northeast, or east directly into the Gulf of Maine. The remaining beach faces west and south into Cape Cod Bay.

The outer beaches can be divided into two separate sediment transport zones: a northern section extending from somewhere at the middle of the eastern cliff section between Cape Cod Light and the Nauset Coast Guard Station to Long Point, Provincetown; and a southern portion



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-55	Grain/Size Data-S.E. Cape Cod Bay (Nilsson, 1972)



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

TRIGOM PARC	FIGURE 5-56	Grain-Size Changes Along Profiles from Beaches to Flats (Nilsson, 1972)

extending from the cliff section to Monomoy Point. Littoral sediment transport is to the north and south from the cliff section (Johnson, 1925; Marinden, 1889; Schalk, 1939; Zeigler et al, 1959; Zeigler and Tuttle, 1961; Hartshorn et al, 1969) (See Figure 5-57).

The outer beaches can also be subdivided into three morphological zones: 1) the Provincelands zone where, for the most part, the beaches are backed by an extensive dune field at Provincetown; 2) the Highlands section where narrow beaches lie at the base of a scarp (7 to 40 m high) eroded into Pleistocene outwash sediment; and 3) the Nauset-Monomoy area characterized by baymouth or spit barrier islands.

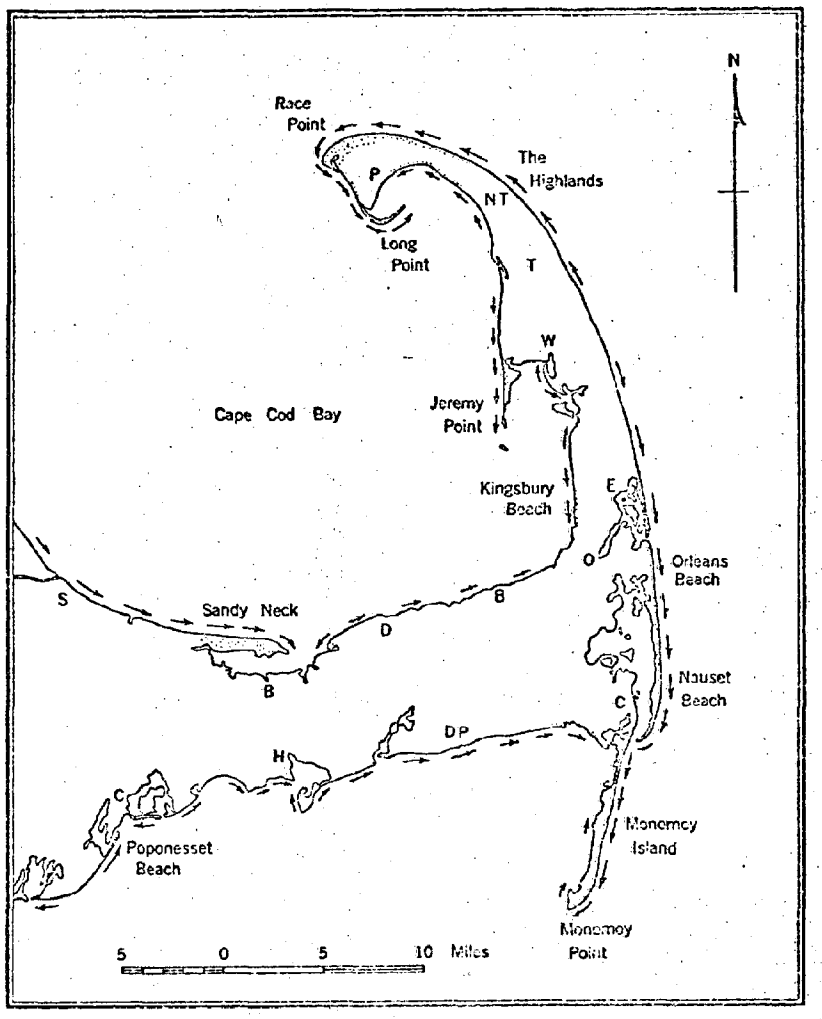
The Provincelands, or the Provincetown Hook, has formed as a series of coalescing beaches providing both a source and a base for several generations of parabolic dunes (Messenger, 1958; Hartshorn, et al., 1967).

The beaches of the Provincetown Hook are characterized by a concave-upward profile after storms and accretional berms after extended quiescent periods. An energy gradient exists all around the hook from Highland Light to Long Point. Storm erosion is greatest at Highland Light and decreases counter-clockwise west around to Long Point. The beaches at Highland are extensively eroded with scarp recession averaging one meter per year (Zeigler et al, 1959) during easterly and northeast storms. The beach at Race Point is constructional during periods of easterly or northeast waves, but erosional during northerly winds; while New Beach, facing southwest, appears to be accretional at all times of the year.

Peaked Hill Bar, an offshore bar, springs from the beach in the vicinity of Highland Light and extends around the Provincetown Hook to Race Point. The offshore bar exists from 300 to 600 m offshore from the beach until it disappears in water of 50 m depths off from Race Point.

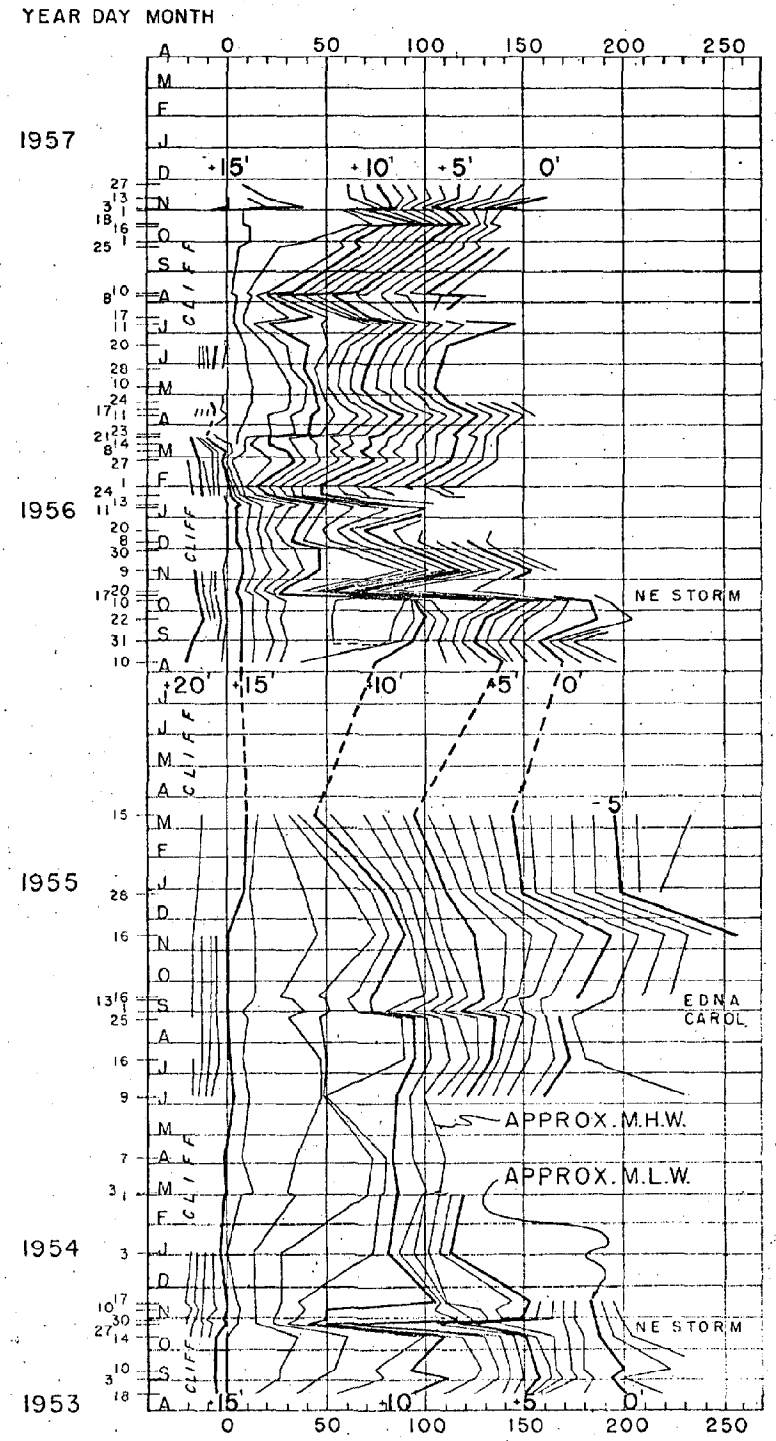
Zeigler et al.(1959) have also observed complex inshore bars extending from Highland Light to Race Point. The complex bars, called sand waves, are probably analogous to protuberances described by Goldsmith (1972) along Monomoy Island. The sand waves migrate in a northerly and westerly direction around the Provincetown Hook. Beach recovery after storms is dependent upon inshore bar existence immediately offshore. Where bars have been removed by storm erosion, beach recovery is very slow, not reaching a mature stage for up to 4 to 5 months after storm erosion. The sand waves extend onshore to weld to the beach. Where welding occurs, the beach is wide; but inter-protuberance areas exhibit a narrow beach. Storm erosion of the scarp is severe where protuberances are non-existent (See Figures 5-58 and 5-59).

Median diameters of beach sediment increase from 0.55 mm. at the northern section of the cliffs to 1.30 mm at Long Point (Schalk, 1939). The increase in median diameter is explained by progressive winnowing of fine



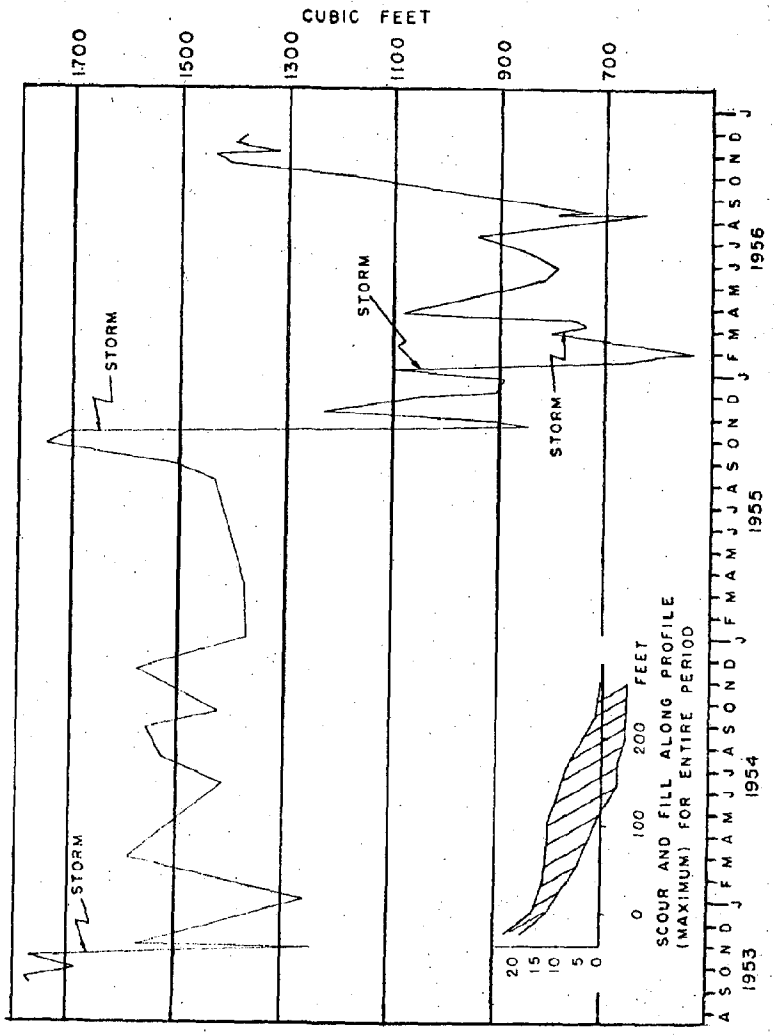
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-57	Longshore Drift of Beach Sediment-Cape Cod (Strahler, 1966)



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

TRIGOM PARC	FIGURE 5-58	Isopleth Diagram of Profile Changes-Highlands (Zeigler et al., 1959)



VOLUME OF BEACH BETWEEN TOE
OF CLIFF AND APPROXIMATE MLW
HIGHLAND "A"

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

TRIGOM PARC	FIGURE 5-59	Volume of Beach Over Time-Highlands (Zeigler et al., 1959)

particles from the sediment. The finer-sized particles are moved offshore. This process appears to be somewhat questionable as an energy gradient decreases in this direction. The source of the beach sediment for the Provinceland beaches are the scarps eroded into the Truro Outwash Plain at Highland Light. Zeigler et al., (1959) and Schalk (1939) have observed the uncovering of coarser particles at the toe of beaches after storms. Sediment from buried glacial sediments may also be supplied to the beach from the shallow offshore during severe storms.

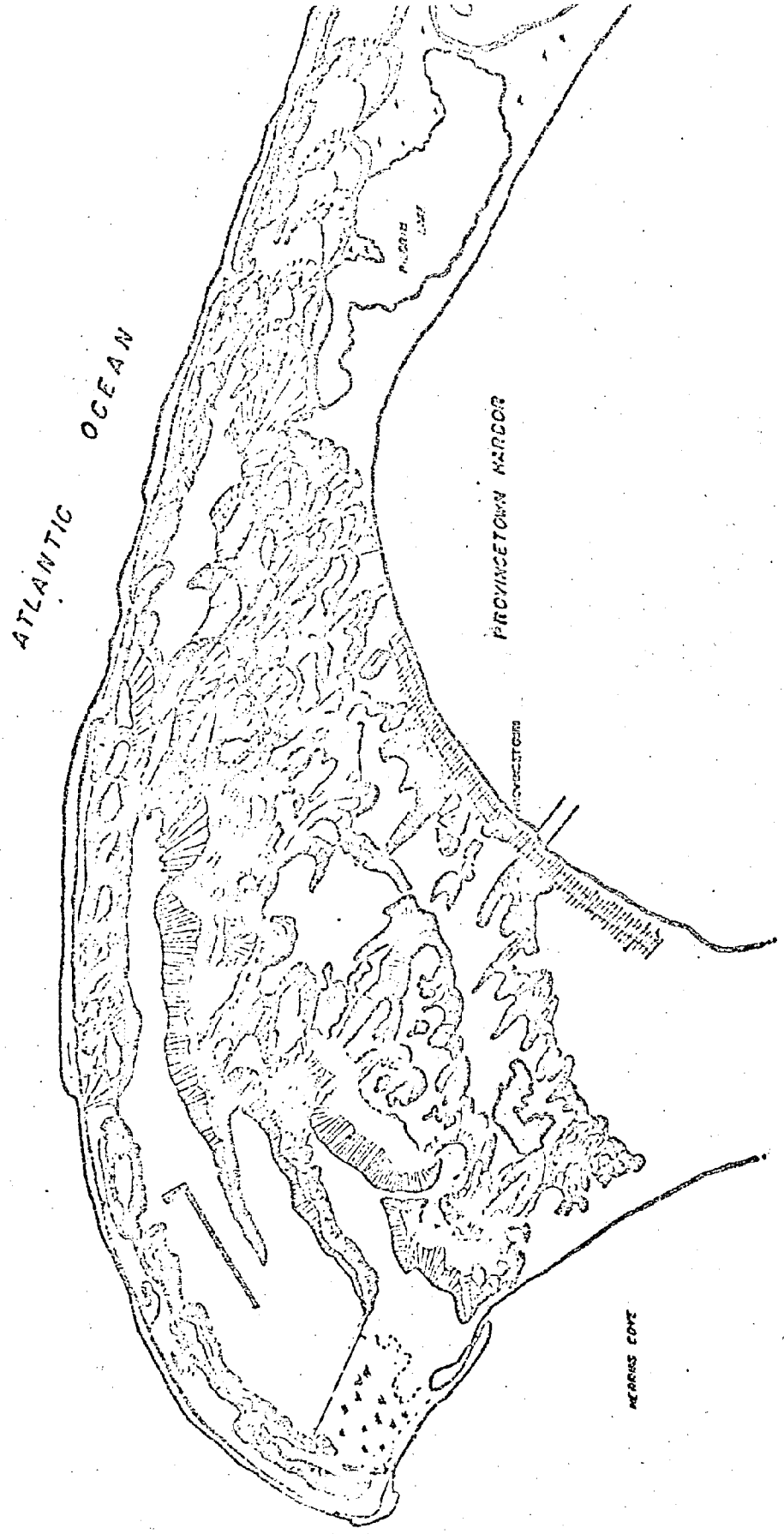
The Provincelands is a large dune field composed of three dune ridges along the outer margin and an irregular dune field on the inner margin (See Figure 5-60). The dunes are parabolic and include both U-shaped and V-shaped forms with the open ends toward the west-northwest wind. The inner dune field is more irregular with complex dunes reaching heights of up to 35 m. The direction of winds that built these large dunes is uncertain. The common occurrence of forms gradational between the complex dune and the parabolic dunes are formed by west-northwest winds (Hartshorn et al, 1967). The dune sands range from fine sand at dune crests to coarse sand on interdune deflation surfaces.

The scarped Highland section extends south-southeasterly from Highland Light to Nauset Light, a distance of about 15 km. The scarp is eroded into the Truro, Wellfleet, and Eastham plains which serve as the source of sediment for the Provincetown Hook and the barrier islands to the south.

Sediment from the scarps is delivered to talus fans at the scarp base by rainwash and mass-wasting. The talus is then removed by storm erosion. Cliff recession is variable along the Highland section but is greatest in the center (Marindin, 1889). Ziegler et al.(1959) observed cliff erosion of from 10 to 15 m at Nauset, 4 m at the central part, and 1.3 m from Highland during a storm in April of 1958 (See Figure 5-61). It is estimated that 648,448 cubic meters of material are supplied to Cape Cod beaches by erosion of the cliffs, one of the highest removal rates recorded (Wiegel, 1964).

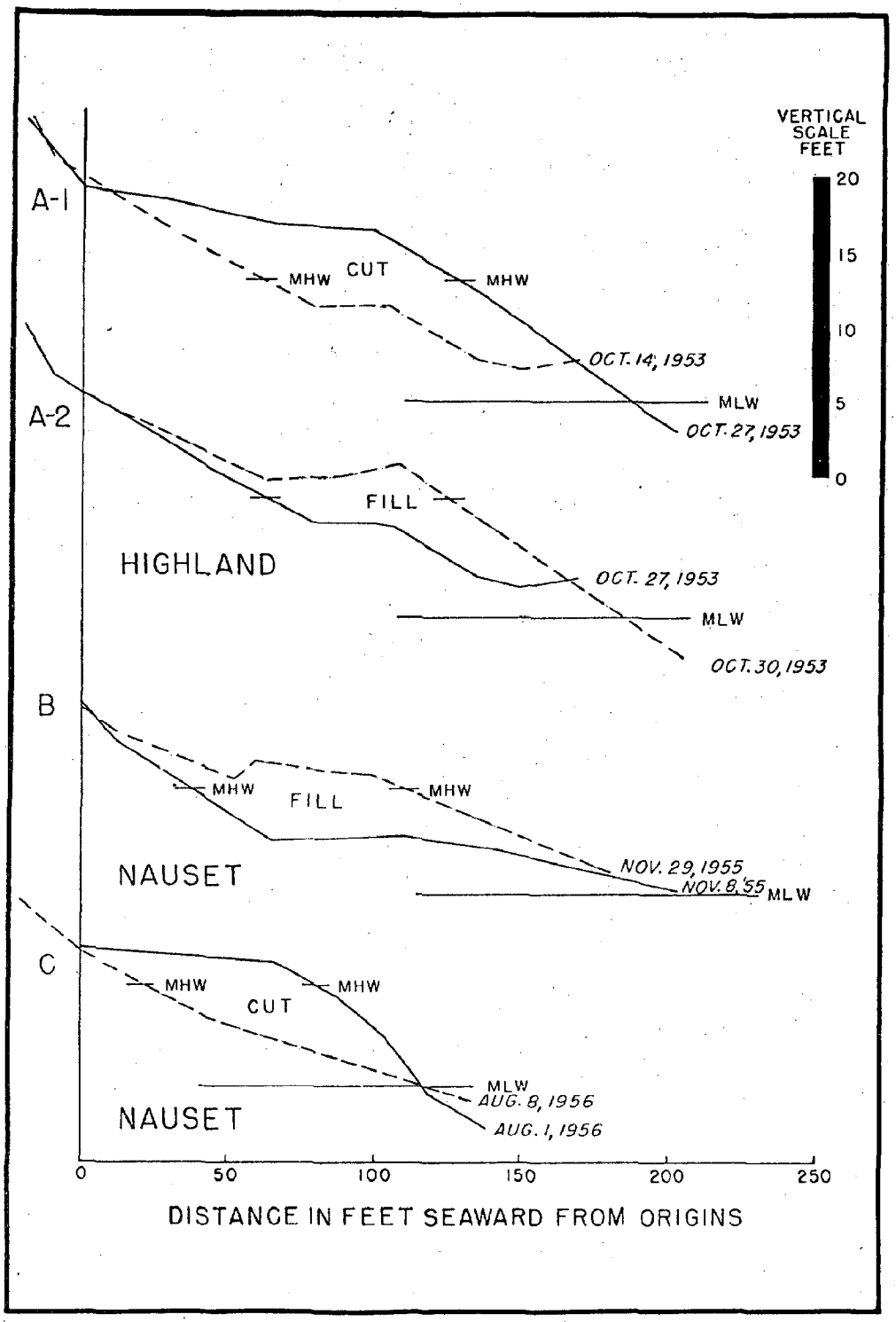
The beaches along this central zone vary in width from 15 to 50 m depending upon accretional stage. Inshore bars, protuberances, are common along this zone; and influence rates of erosion and accretion. Up to 10.5 cubic meters of beach material per profile may be removed and returned within two tides along the central beaches (Zeigler at al (1959).

Median grain-sizes decrease from about 0.55 mm at the northern highlands to 0.30 mm at Nauset Light (Schalk, 1939), but Felsher (1963) contends that this grain-size decrease is non-existent.



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

TRIGOM PARC	FIGURE 5-60	Dunes of Provincetown (Messenger, 1958)



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

TRIGOM PARC	FIGURE 5-61	Cut and Fill at Highland and Nauset-Before and After Storm Conditions (Zeigler et al., 1959)

The southern zone is one of thin barrier islands and barrier spits. From north to south, three barrier islands characterize the coastline. Coast Guard Beach is a 4 km long barrier between the open Gulf and Eastham Bay. Nauset Beach extends 12 km from the inlet of Eastham Bay to the Pleasant Bay inlet, while Monomoy Island extends as an isolated barrier spit springing from a point just south of Chatham and extends 10 km into the Atlantic Ocean toward George's Bank. The barrier of Monomoy separates the Gulf of Maine from Nantucket South.

Hine (1972) divides the Nauset barrier into two zones, a linear beach and a wider recurved spit beach in proximity to the Pleasant Bay inlet. The linear beach is the northern two-thirds portion of the island. The barrier is thin and has formed by progressive progradation of the barrier in a southerly direction. The beach along this segment of the barrier is about 90 m wide and characterized by neap and spring berms formed by the migration of ridges across a low-tide terrace.

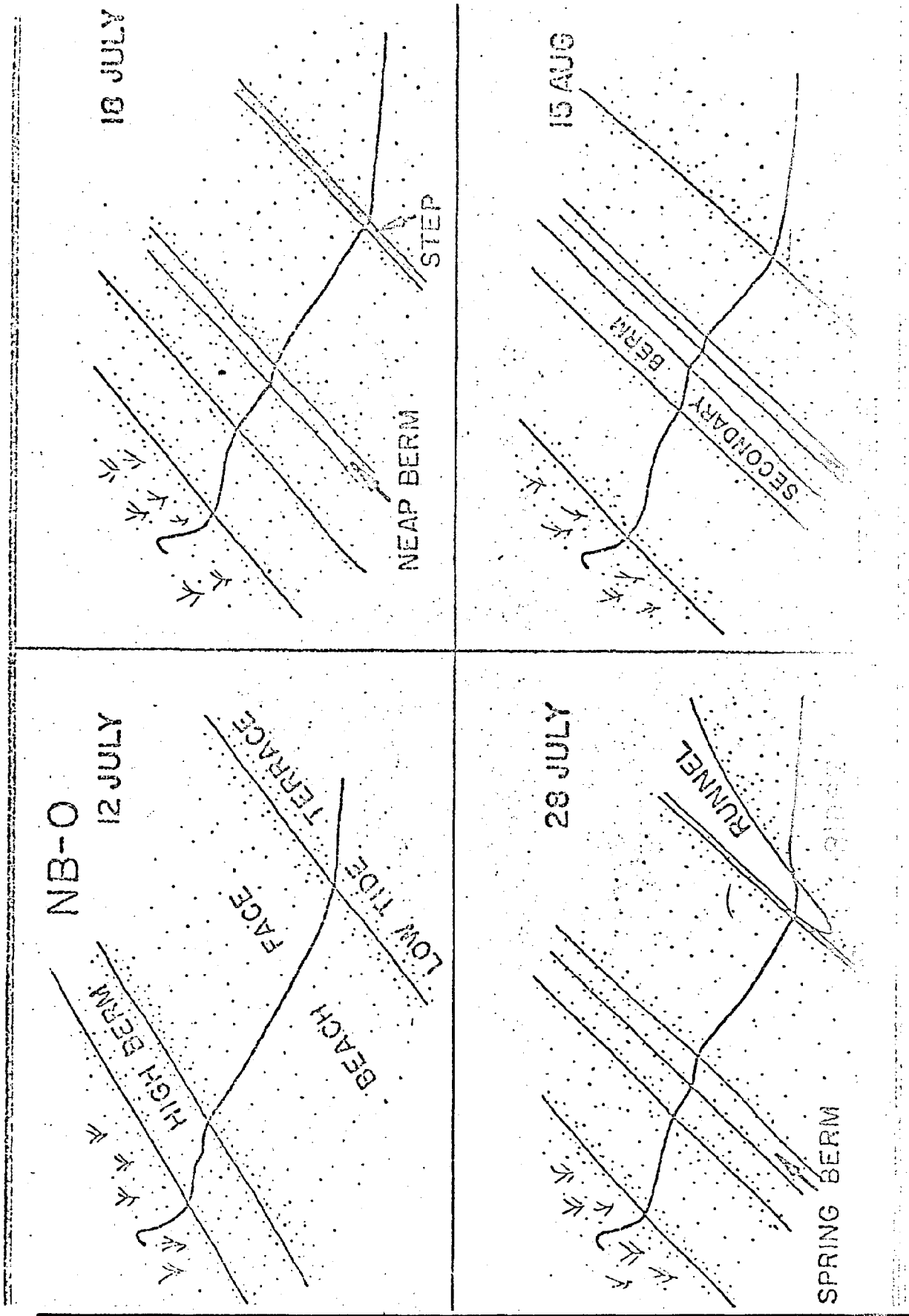
The barrier is narrow (0.5 km) along its northern section. A single dune ridge exists back of the beach, but wider expanses are low vegetated eolian surfaces sitting on arcuate washover fan lobes built into Pleasant Bay (See Figure 5-62).

The southern one km section of the Nauset barrier is bulbous in plan, being the result of recurved spit formation and progradation of the barrier (See Figure 5-63). The southern beach portion is about 180 m wide and characterized by rapid sediment deposition. As a result, secondary berm and ridge growth is rapid after storms. Sedimentation is so rapid that berms may develop on ridge crests before ridges migrate shoreward. The lower portion of the beach (foreshore) exhibits current-formed bedforms oriented toward the inlet mouth indicating strong tidal currents generated in the vicinity of the inlet (See Figures 5-64 and 5-65).

Schalk (1939) found that grain size increases slightly from 0.3 mm at the northern end of Nauset to 0.4 mm at the end of Nauset Spit.

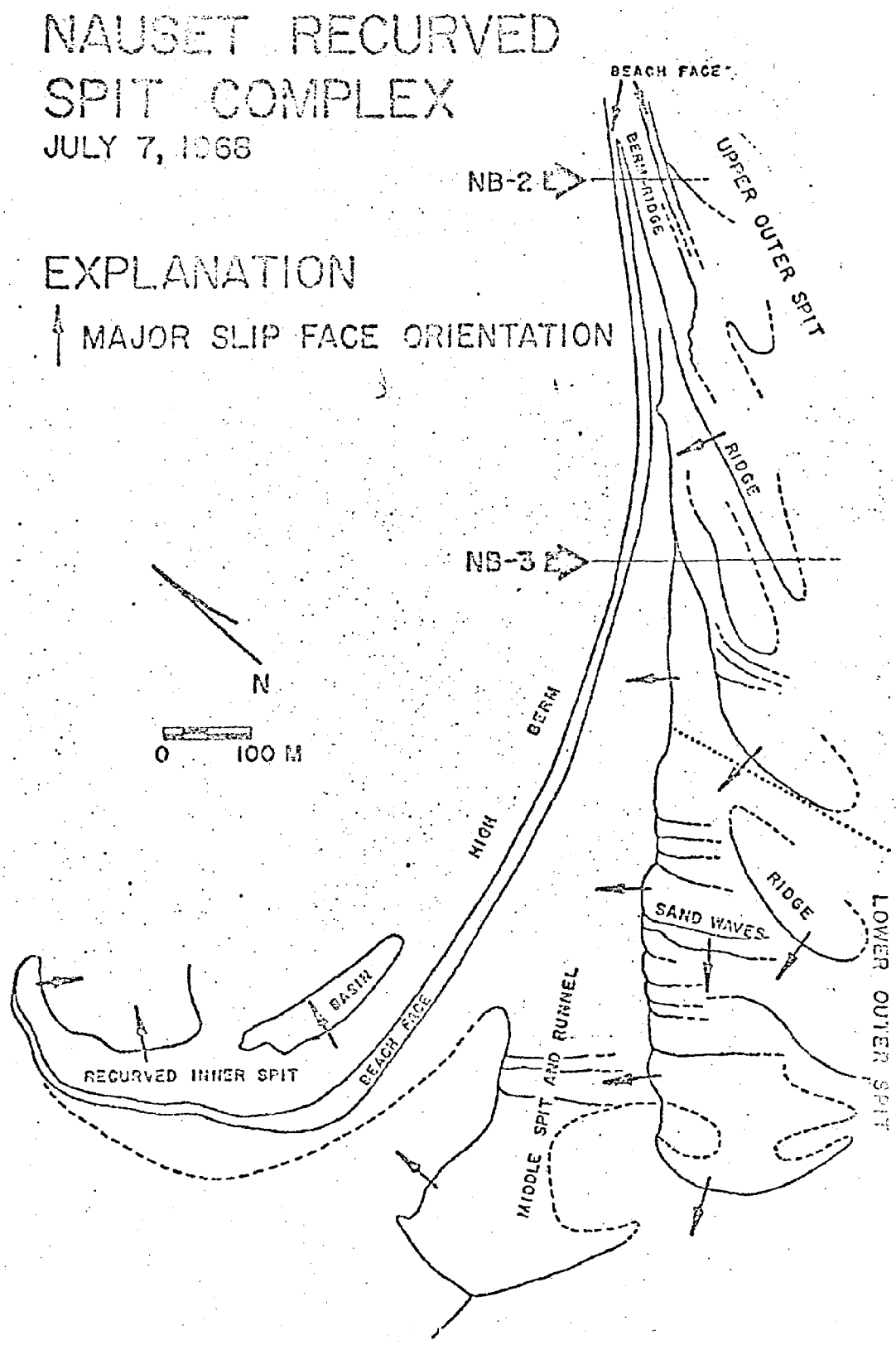
Monomoy Island is a barrier which has undergone dynamic changes over the past century. Goldsmith (1972) has studied the sediment, sedimentary environment, physical processes, and historical changes.

The island consists of two distinctly different portions. The northern third of the island is less than 40 years old and consists of a narrow, rapidly eroding beach with numerous attached intertidal and subtidal offshore bars; an irregular duneline highly dissected by sluice channels; a wide supratidal blue-green algal flat; a fringing marsh; and wide intertidal clam flats. The remainder of the island is wider and consists mostly of low dunes.



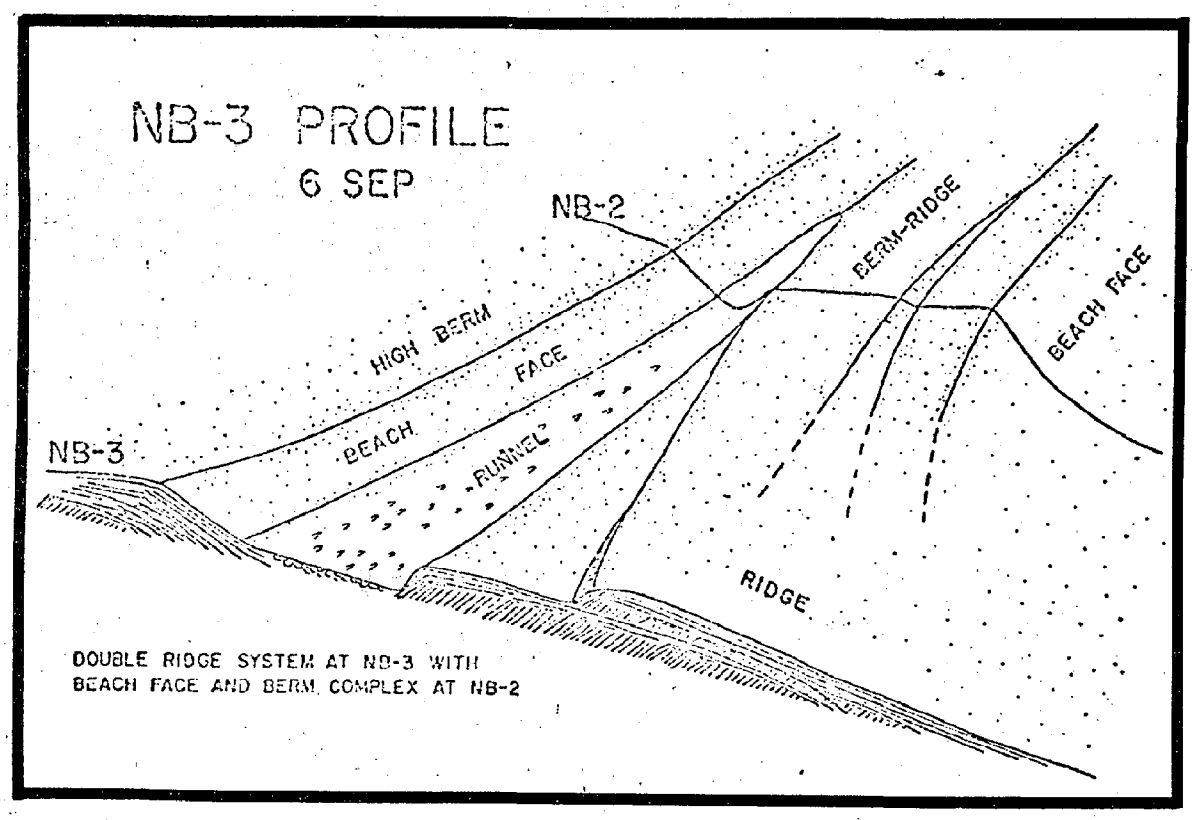
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

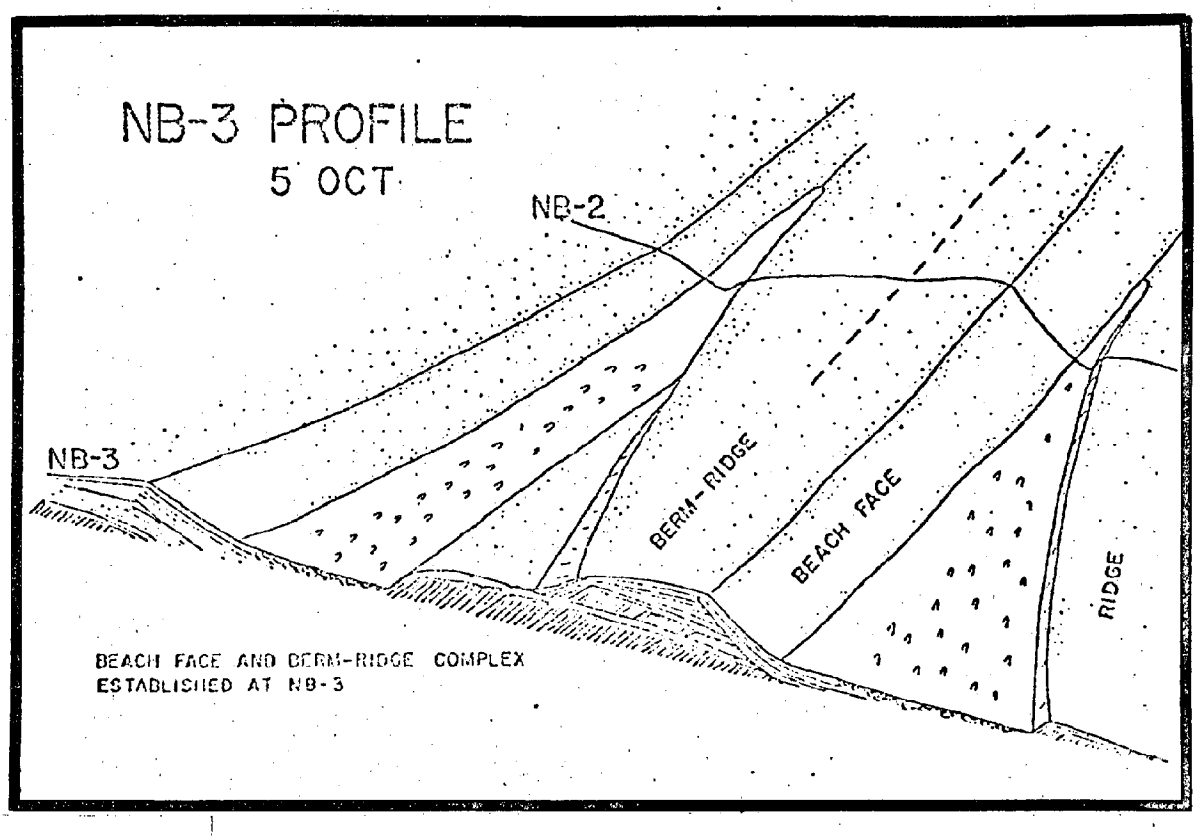
TRIGOM PARC | FIGURE 5-62 | Beach Features and Development-Nauset Beach (Hine, 1972)



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

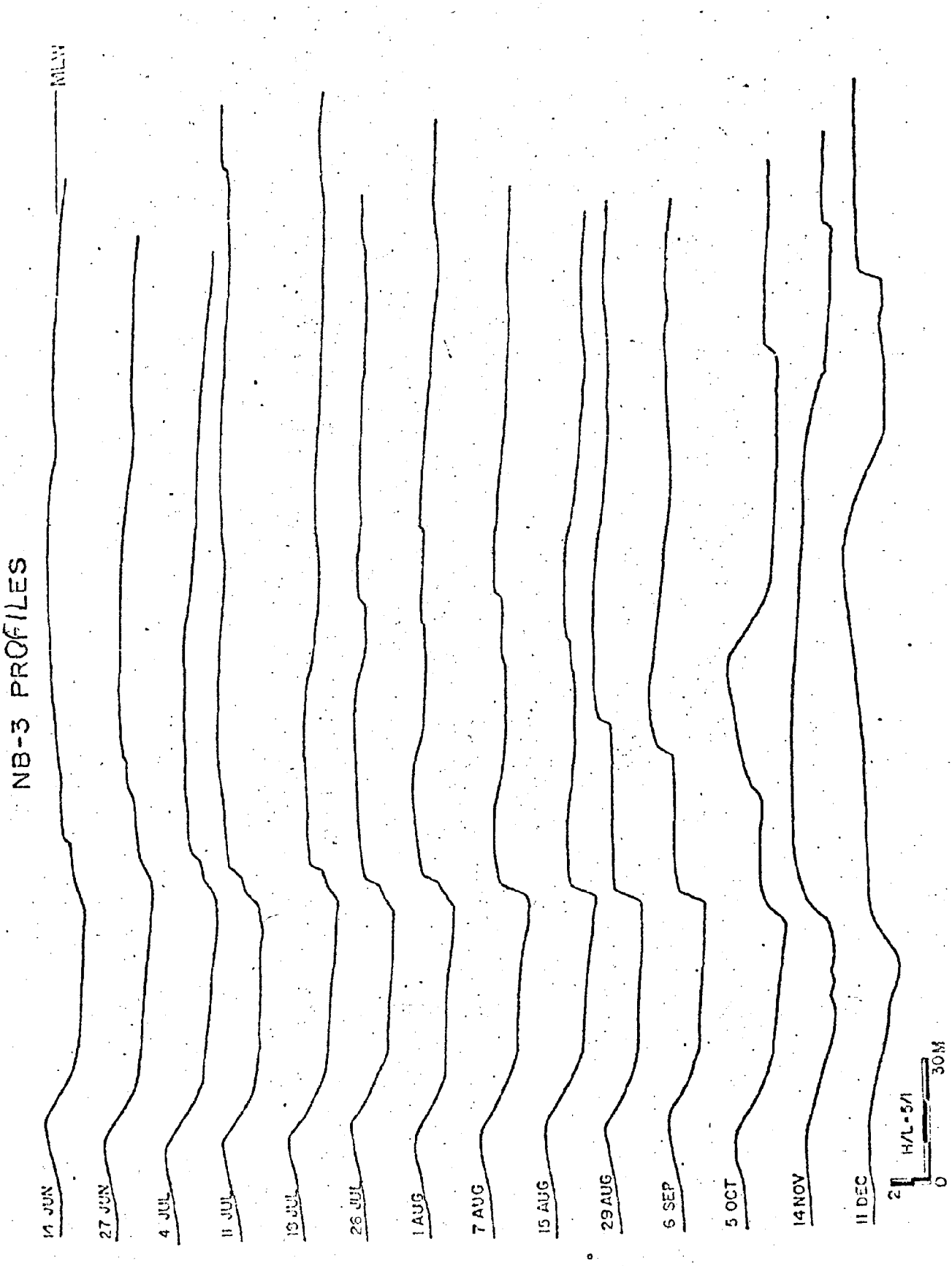
TRIGOM PARC	FIGURE 5-63	Nauset Recurved Spit Complex and Location of Beach Profiles (Hine, 1972)





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

TRIGOM PARC	FIGURE 5-64	Development of a Bermridge and Double Beach Face-Nauset Beach (Hine, 1972)



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

TRIGOM PARC	FIGURE 5-65	Sequential Development of Southern Spit Portion of Nauset Beach (Hine, 1972)

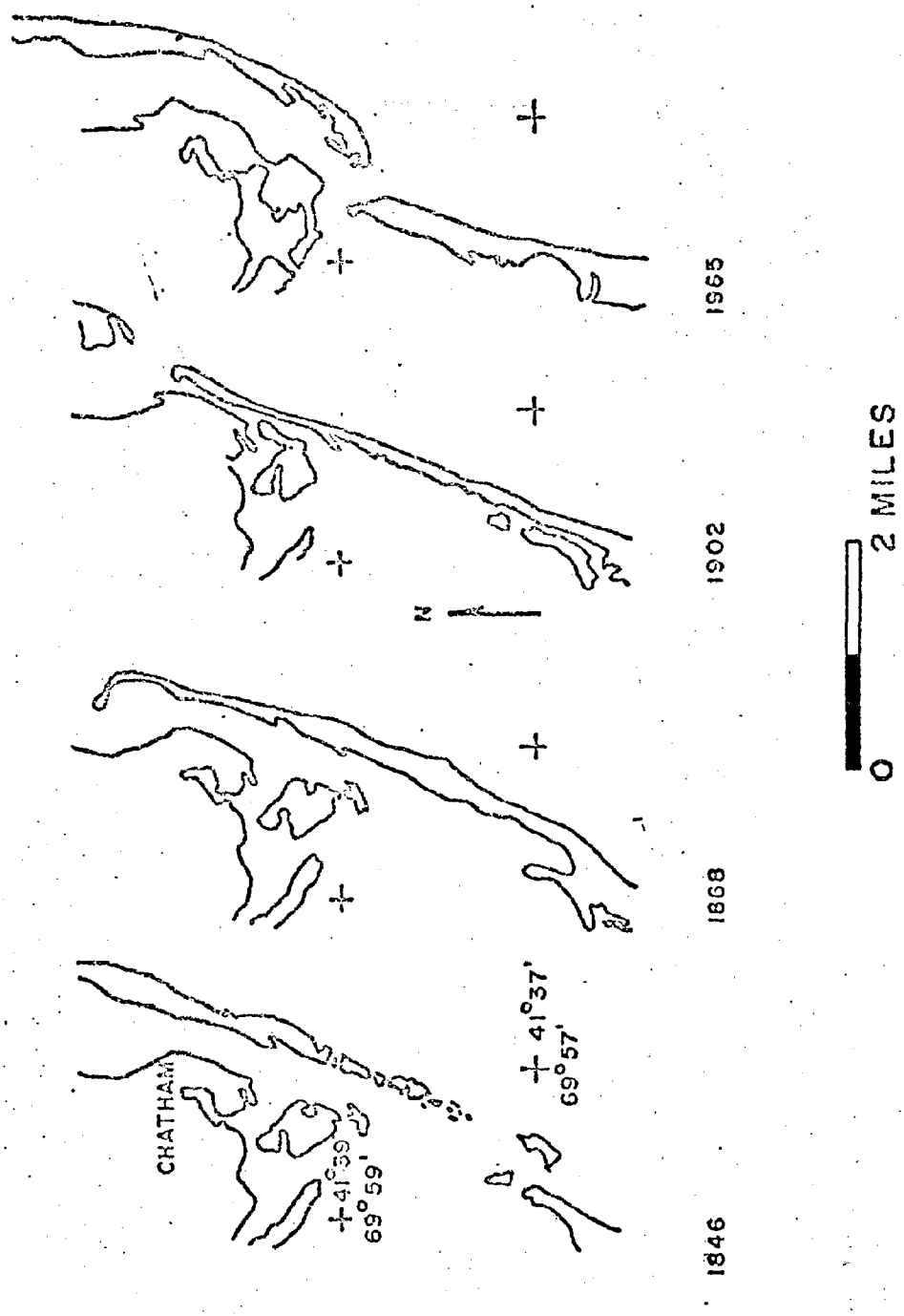
The northern part has accreted rapidly and responded to the southern progradation of the Pleasant Bay inlet. Large-scale inlet migration occurs in a cycle recurring approximately every 130 years, a time period of increased storm frequency (See Figures 5-66 and 5-67).

The rest of the island beaches are narrow, exhibiting erosional or berm-constructional profile. Inshore bars oriented at an angle to the coastline characterize the foreshore and migrate in a northerly direction overtime in front of the beach. Protuberances on the beach migrate with the inshore bars, and erosion of the subaerial beach is directed to the areas updrift of the protuberance axes. Offshore bars parallel to the island face are located about 660 m from the beaches (See Figures 5-68 through 5-70).

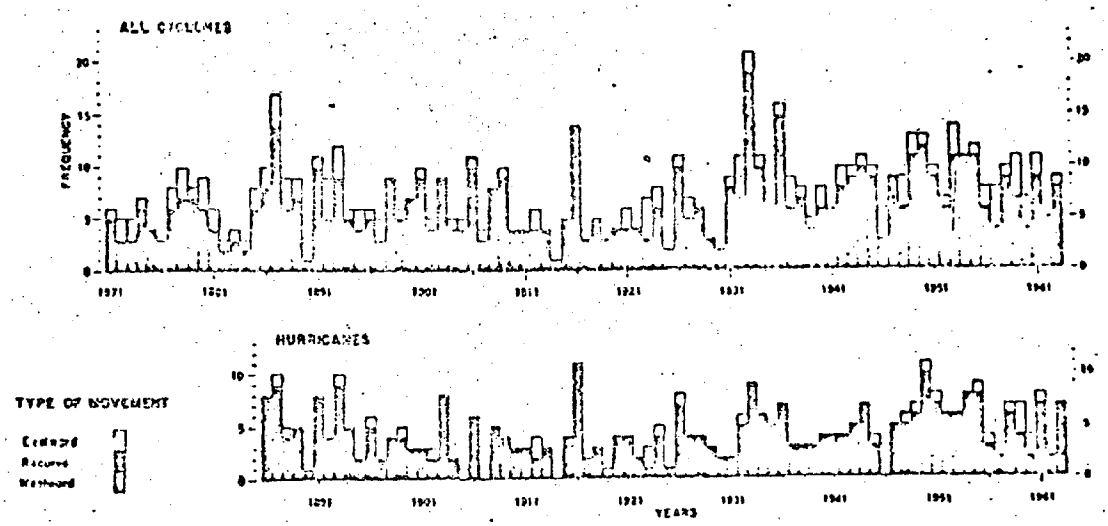
Erosion of the beaches occurs during periods of nonuniform distribution of wave energy from long (8-12 sec) waves of low amplitude generated in the Gulf of Maine during northeast storms. Larger amplitude, long-period waves (height 1.5 m) tend to break on the offshore bars while shorter waves do not refract sufficiently to produce zones of wave-energy concentration on Monomoy (See Figures 5-71 through 5-73).

Beach sediment size is nearly uniform over the entire length of the front of the island. Average grain size is about 0.37 mm. Coarser sediments occur at zones where wave energy is concentrated on the downdrift sides of protuberances. Goldsmith attributes the homogeneity of the sediment to reversing rectlinear tidal currents generated along this portion of the coastline. The reversing currents offset the southerly longshore drift produced by oblique wave approach from the north-northeast (See Figures 5-74 a & b and 5-75).

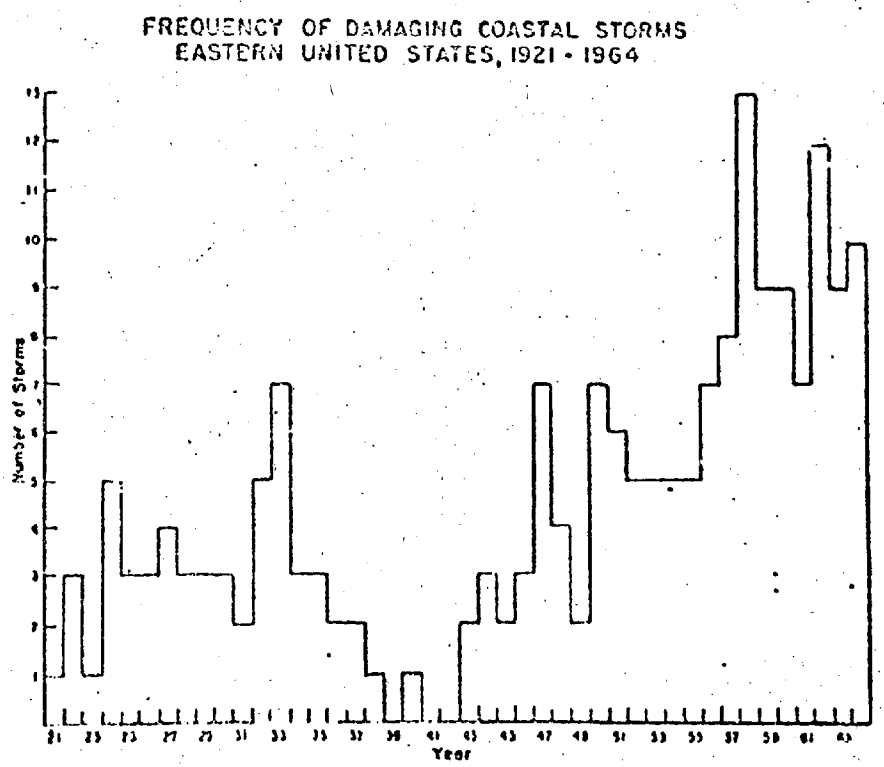
Historically, Monomoy Island has migrated in a westerly direction; a distance of about 1.5 km over the past three centuries. The migration is aided by accretion of sediment on the western side of the island by marsh and algal mat formation and erosion by wave processes on the eastern side. Migration rates would be higher if the low phytogenic dunes of the island were not well-vegetated, but limited access of the island to the public has assumed their stability. The low dunes are maintained by the prevailing winds of the Cape, southwesterly winds. During the winter months when dune grasses are dormant, both the beaches and dunes are frozen by intergranular ice. Extensive erosion during northeast storms in the winter is prevented by this phenomenon.



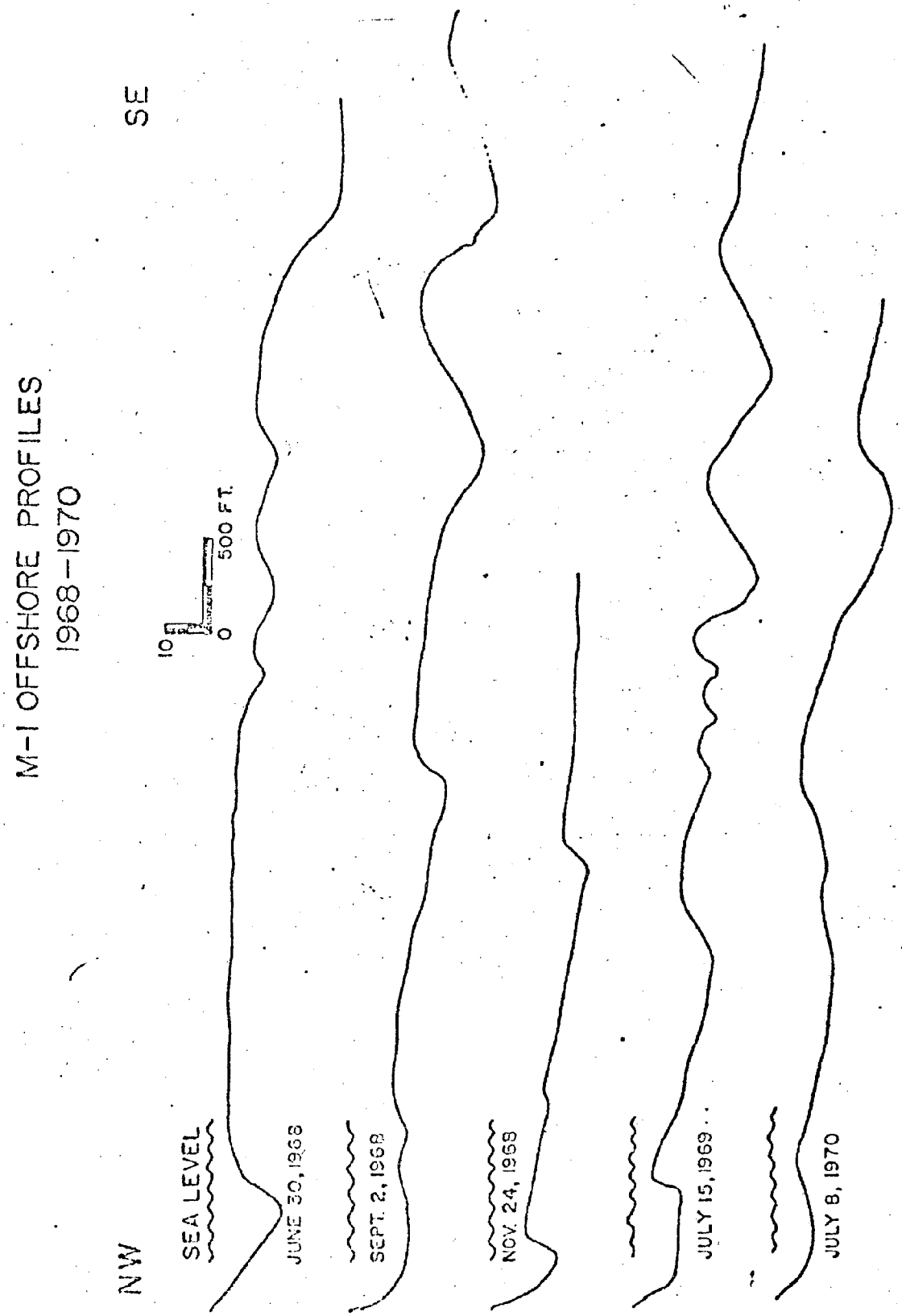
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-66	Monomoy Nauset Inlet-Historical Shoreline Changes (Goldsmith, 1972)



Total annual frequency of North Atlantic tropical cyclones, 1871-1963, and of North Atlantic hurricanes, 1886-1963. General type of movement is indicated by various shadings.

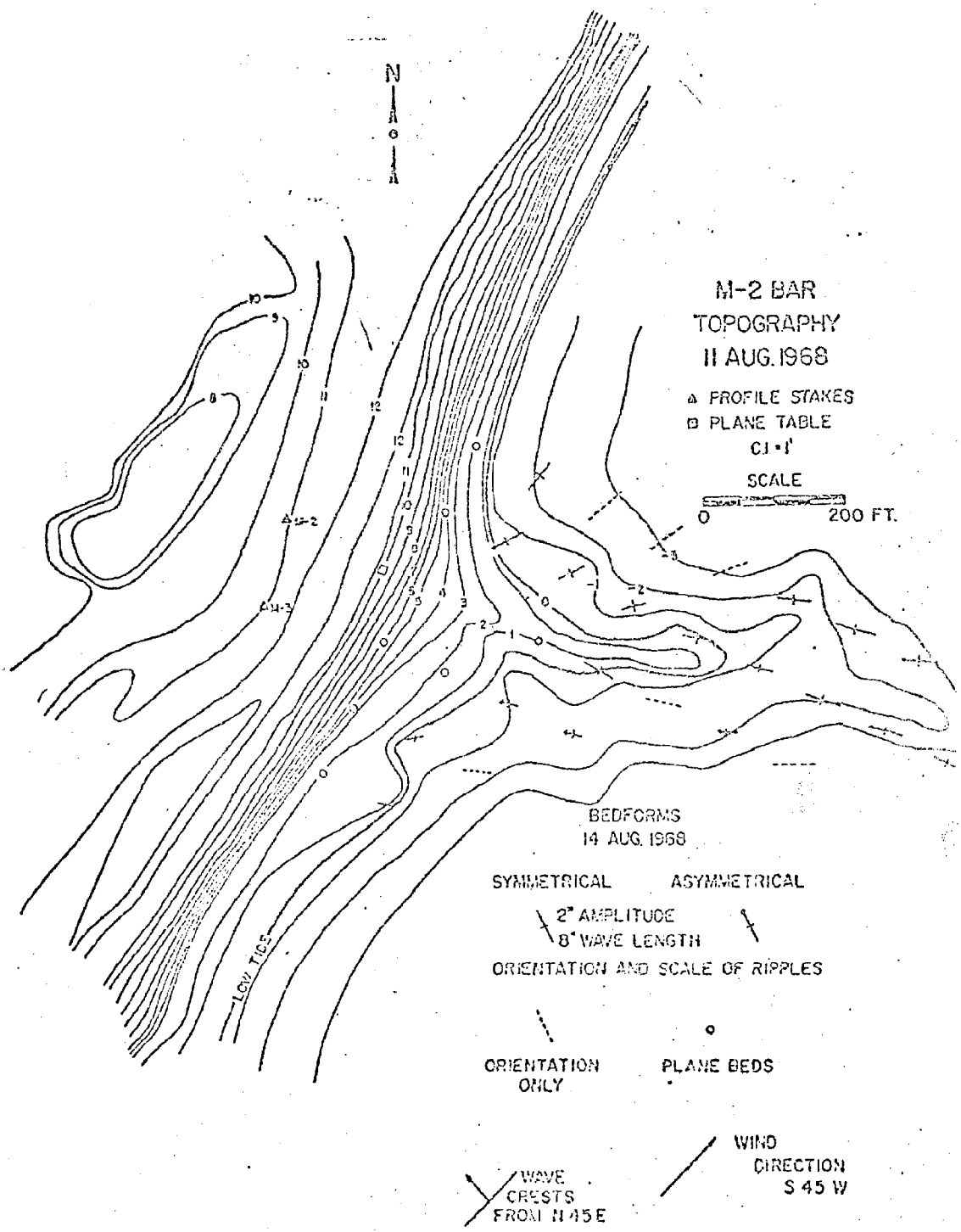


A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-67	Storm Frequency in Monomoy Area (Goldsmith, 1972)



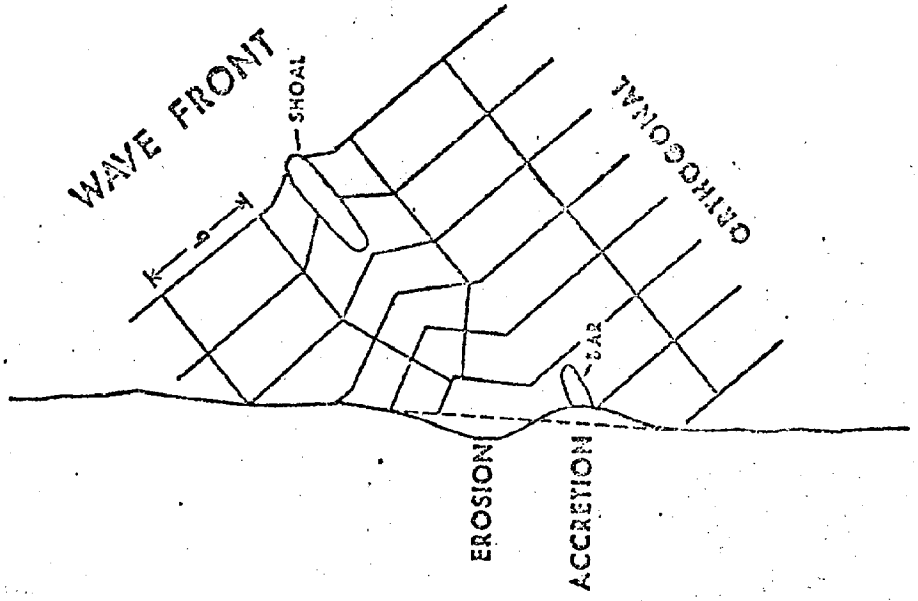
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-68	Offshore Bar Profiles Monomoy Island (Goldsmith, 1972)



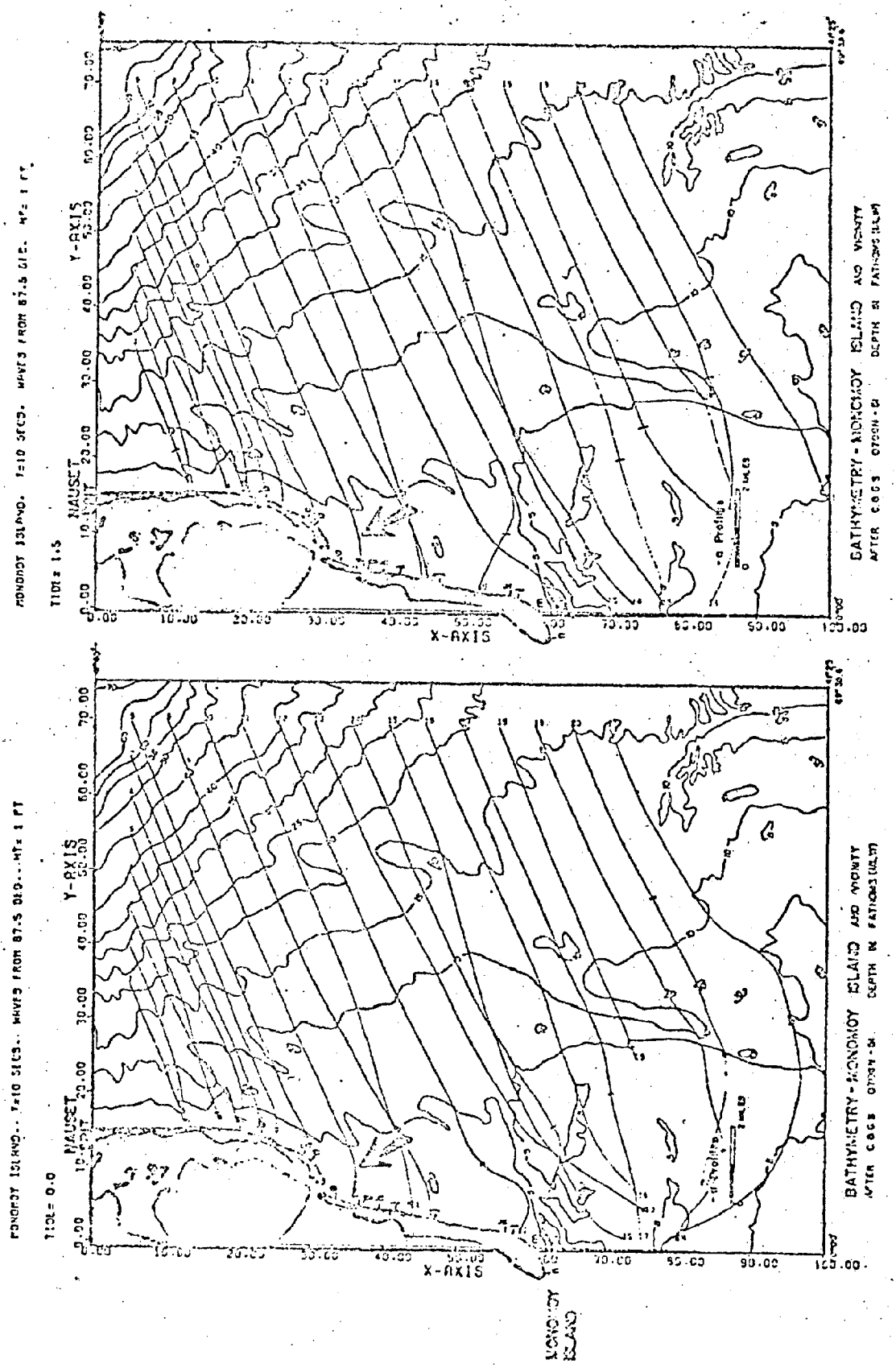
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-69	Topography and Bedforms-Monomoy (Goldsmith, 1972)



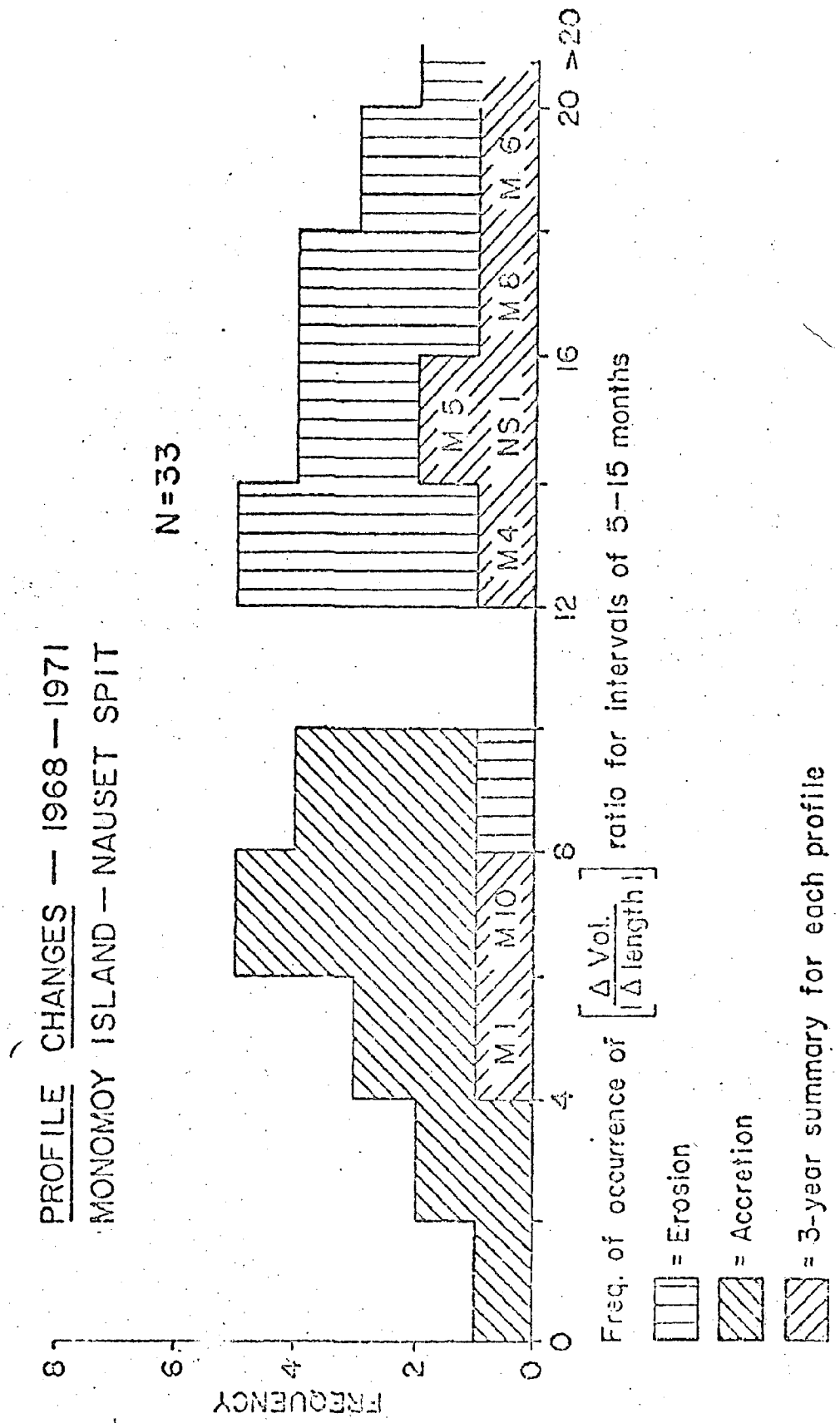
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-70	Hypothetical Wave Refraction Pattern (Goldsmith, 1972)



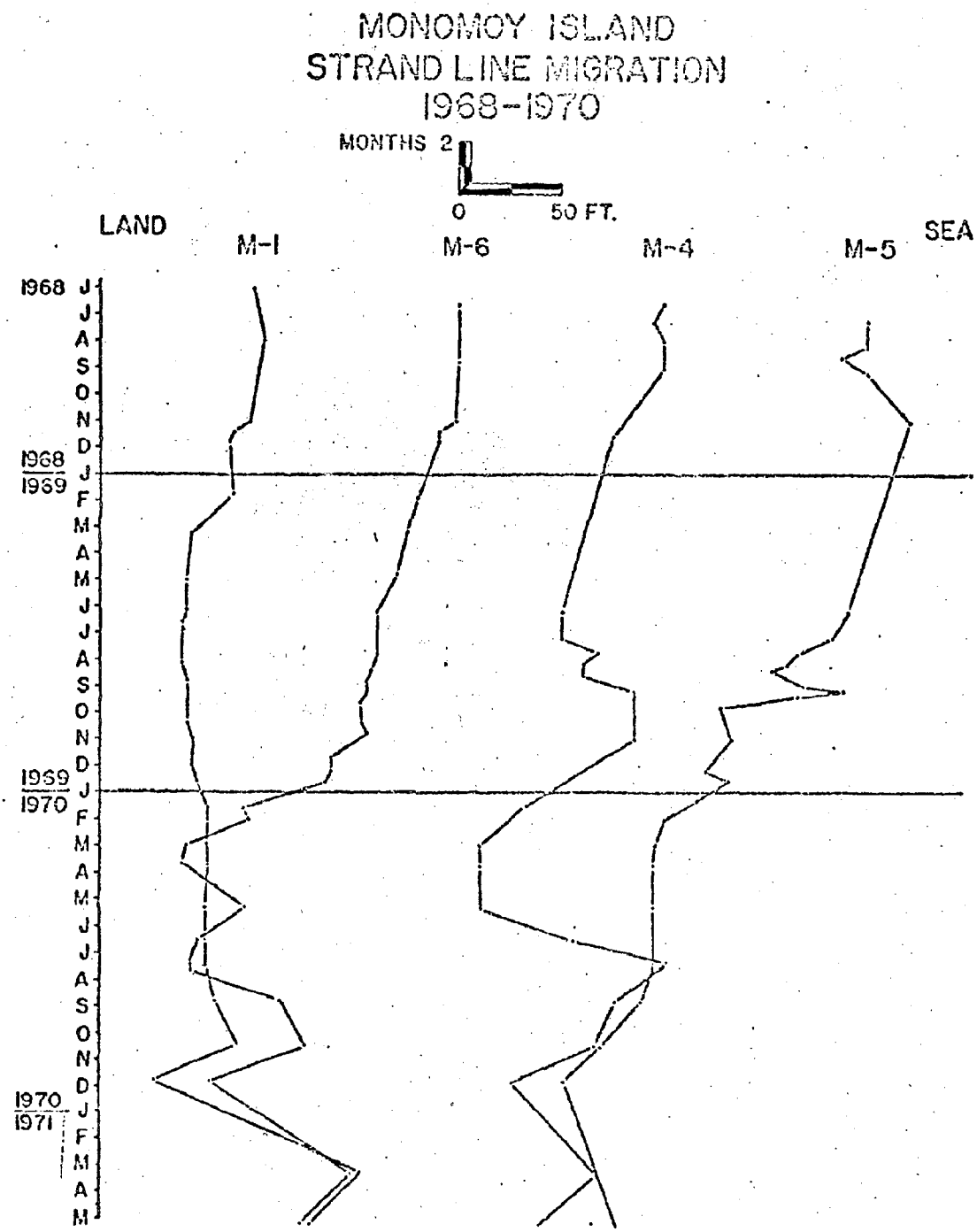
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-71	Wave Refraction - 10 Second Period-Monomoy (Goldsmith, 1972)



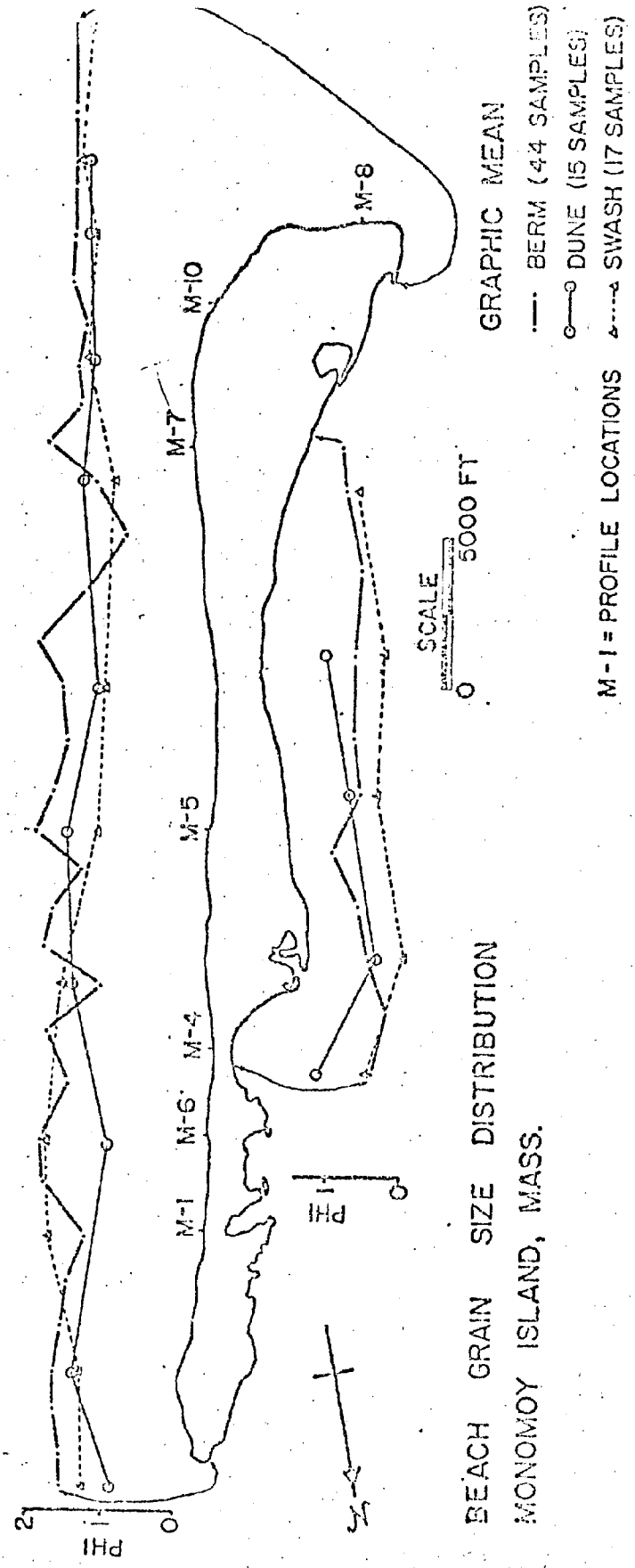
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-72	Erosion and Accretion at Monomoy (Goldsmith, 1972)



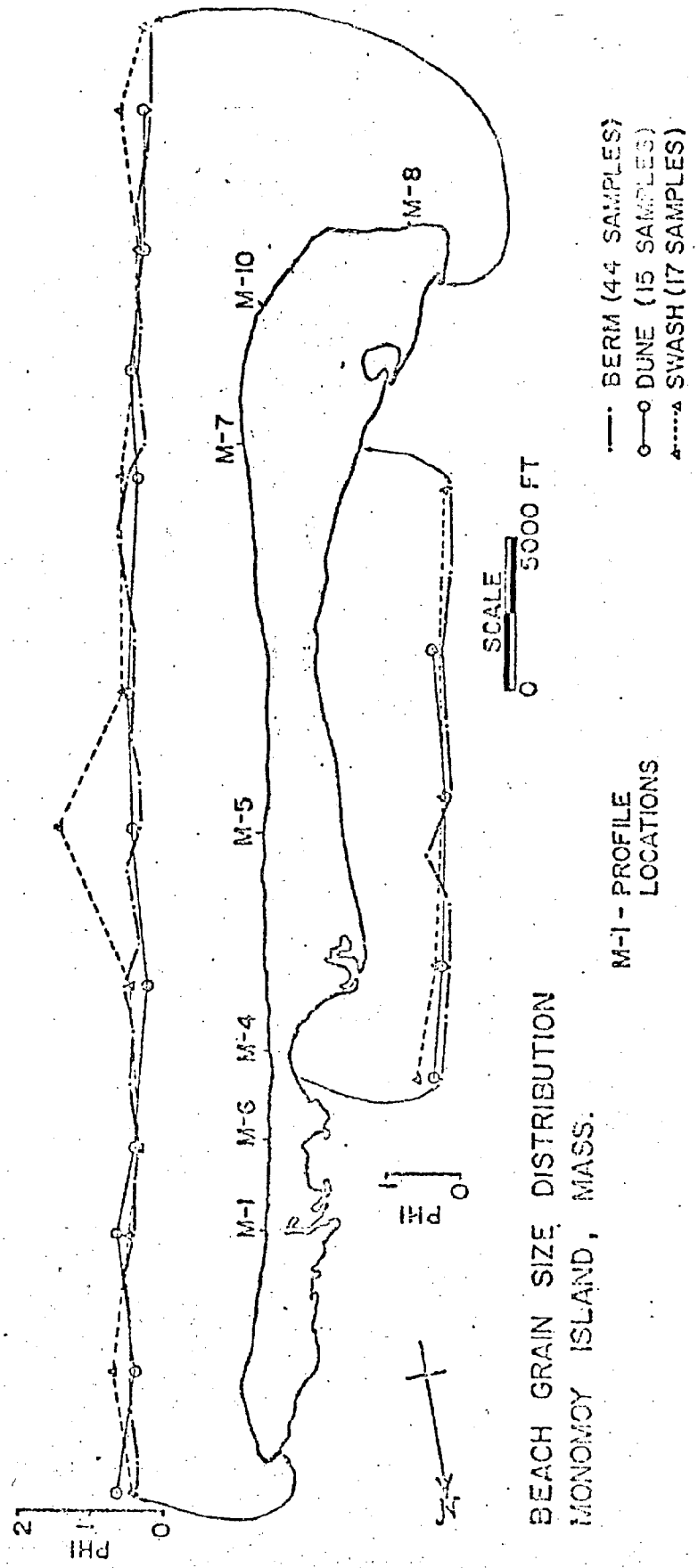
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-73	Monomoy Island Strand Line Migration (Goldsmith, 1972)



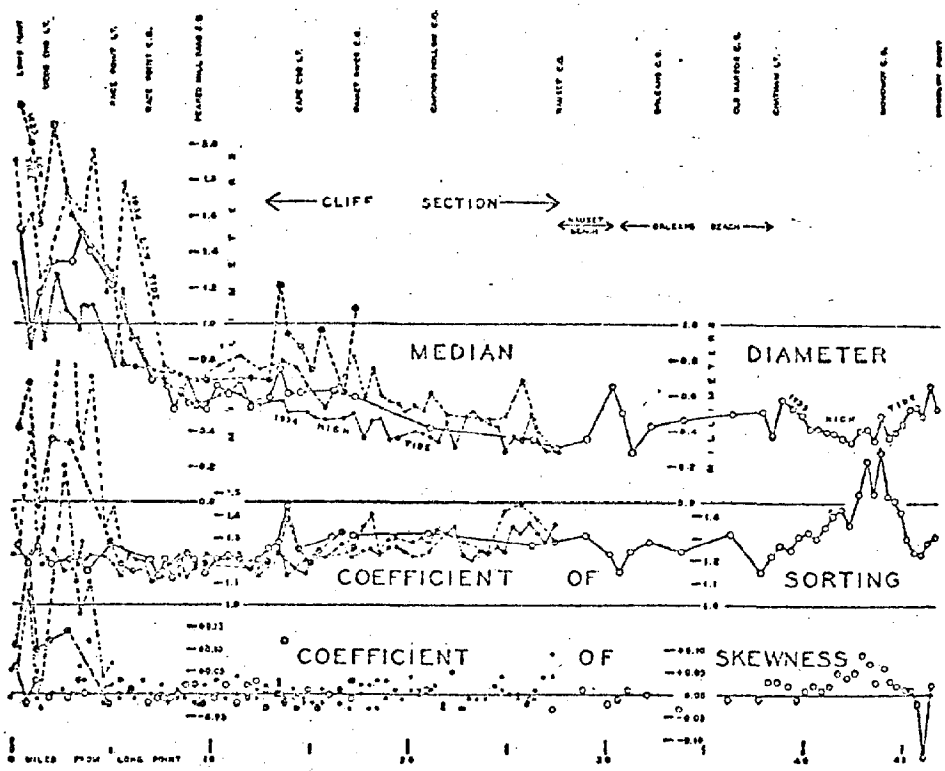
A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION

TRIGOM PARC	FIGURE 5-74a	Beach Grain SRE Distribution-Graphic Mean-Monomoy Island (Goldsmith, 1972)



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

TRIGOM PARC	FIGURE 5-74b	Beach Grain SRE Distribution-Inclusive Graphic Standard Deviation - M.I. (Goldsmith, 1972)



A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-75	Characteristics of Littoral Sands Along Outer Cape Cod (Schalk, 1939)

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5.2 WIND AND WAVE CLIMATE

Waves, more than any other phenomenon, control physical processes along exposed coastlines. Inasmuch as waves are caused by wind, a review of the winds that operate in the Gulf of Maine area will serve as a basis of understanding of the wave climate of New England as well as an understanding of the processes that build, erode and maintain coastal dunes.

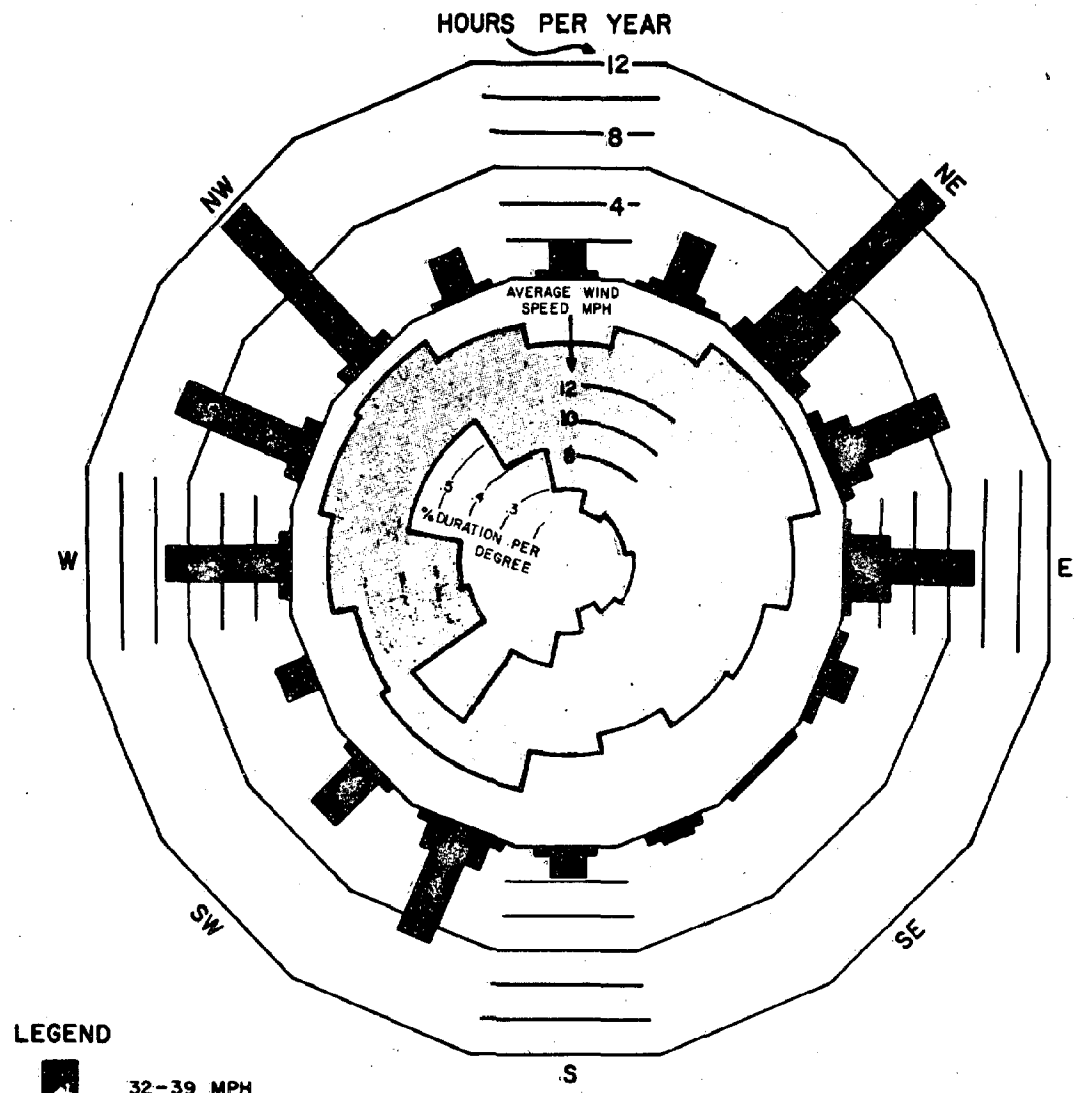
5.2.1 WINDS

The prevailing winds which affect the New England coastline are the northwest, south-southwesterly and south-southeasterly winds. The northwest winds accompany strong high pressure systems moving into New England and predominate throughout the winter months. Inasmuch as the northwesterly winds are offshore they do not generate waves that affect beaches except within Cape Cod Bay which faces the northwest; they generally oppose oncoming waves elsewhere along the New England shoreline, and serve to decrease wave heights coming ashore. These winds, however, do affect coastal dune systems. Extended periods of offshore winds, blowing sand from dune fields behind foredune ridges, will initiate accretion of dune lobes from foredune ridges out onto the back-berm area of the beach. Subsequent erosion of the beach during northeast storms, also frequent during the winter months, removes the original dune sand from the littoral system.

Strong northwest winds also enhance mixing in the surface layers of the estuarine water column of those embayments that are aligned northwest-southeast, an alignment typical of estuaries in Maine.

South-southwesterly and south-southeasterly winds are generated from flow off established high pressure systems (the Bermuda High) during the summer months. Southwest winds generate waves that affect the western coast of the Cape Cod "forearm" (Nilsson, 1972), the western side of Monomoy Island (Goldsmith, 1972), and the south-central and south-eastern coast of Maine. (See Figure 5-76).

Data from the National Weather Service Station at Portland, Maine, indicate that south-southeasterly winds predominate. (See Figure 5-77). These southeast winds, apparently peculiar to the southwest coast of Maine, may be the result of interference of the eastern Massachusetts



LEGEND

32-39 MPH

39-46 MPH

GREATER THAN 46 MPH

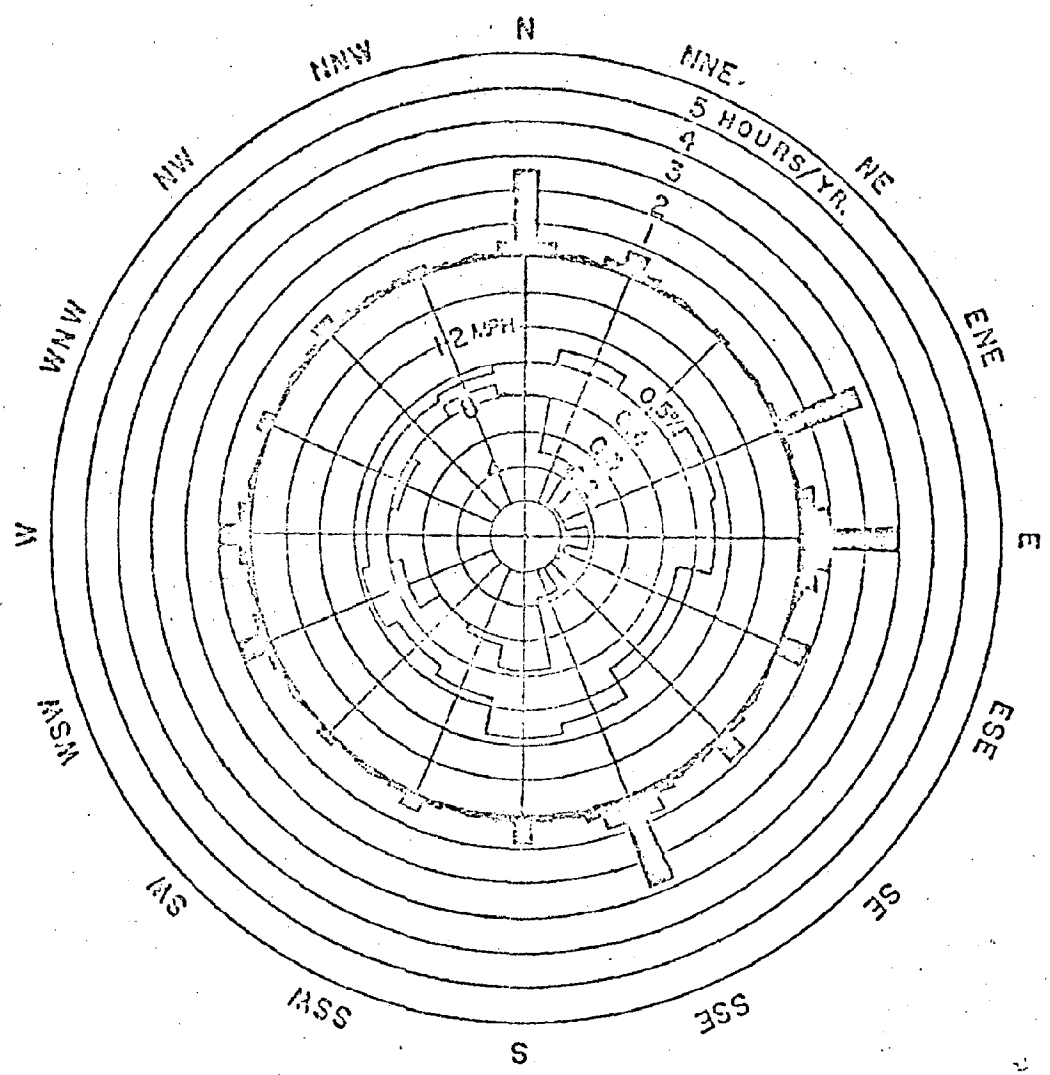
WIND ROSE

LOGAN AIRPORT, BOSTON, MASS.

OCTOBER 1949 – SEPTEMBER 1959

DURATION FOR EACH RANGE OF WIND SPEEDS IS MEASURED OUTWARD FROM TOP OF UNDERLYING BAR GRAPH.

PERCENT DURATION PER DEGREE IS THE AVERAGE PERCENT DURATION OBSERVED FOR EACH 16 POINTS OF THE COMPASS DIVIDED BY 22 1/2 DEGREES.



WIND DIAGRAM
PORTLAND, MAINE

OCTOBER 1949 - SEPTEMBER 1964 INCLUSIVE

MIDDLE ROSE = AVE. SPEED, M.P.H.
INNER ROSE = % DURATION/DEGREE

WINDS > 32 M.P.H.

32 - 38 M.P.H.
39 - 46 M.P.H.
OVER 47 M.P.H.

A SOCIO-ECONOMIC AND ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC REGION		
TRIGOM PARC	FIGURE 5-77	Wind Diagram-Portland, Maine

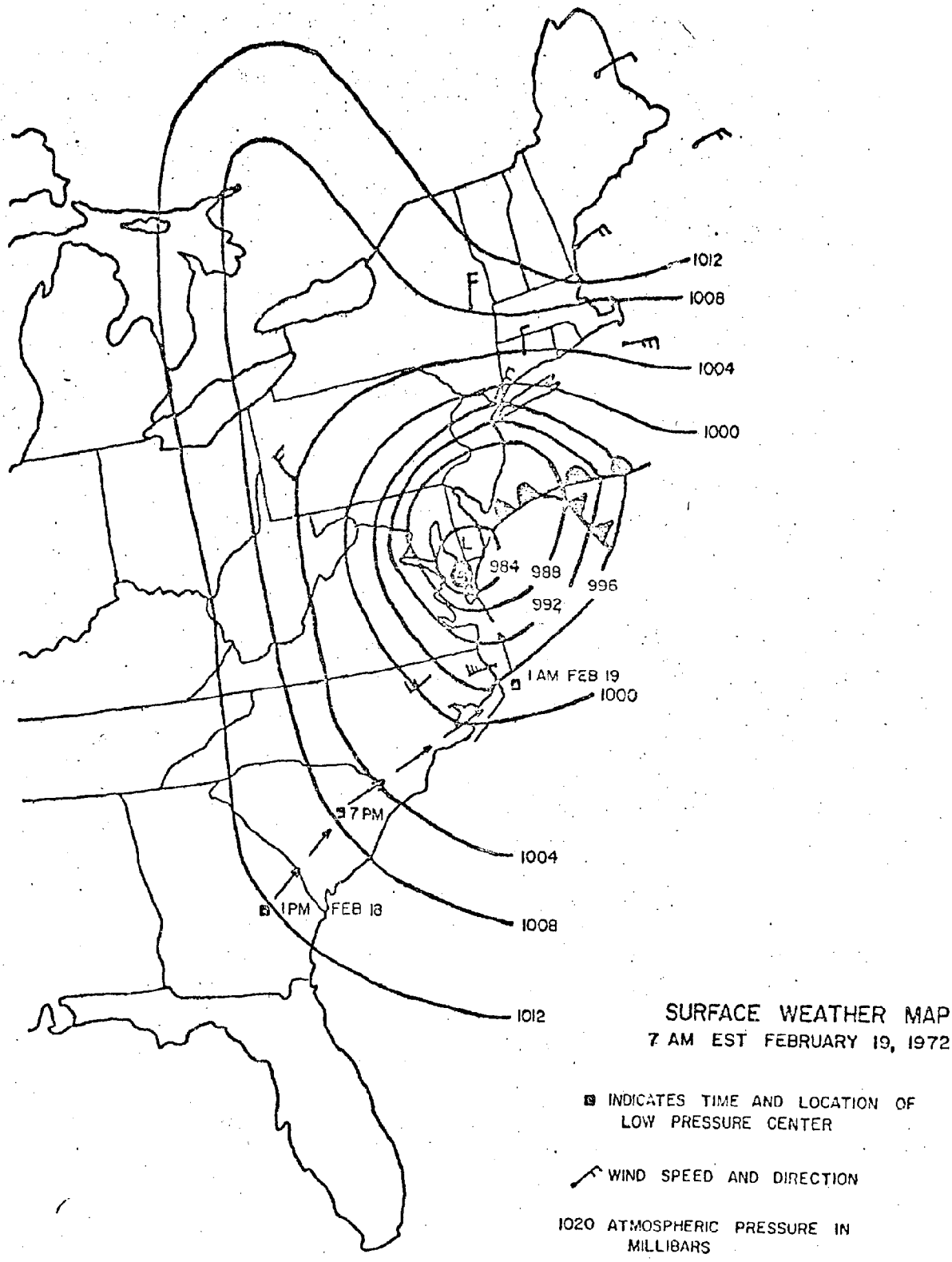
landmass to the south to the prevailing air streams, or to the interference of two barometric highs, one south of Cape Cod and one north of Cape Cod in the Bay of Fundy area. These southeast winds affect littoral drift along the southwestern beaches of Maine.

Northeast and east winds are the dominant winds of the Gulf of Maine. These are the winds associated with the familiar "Nor'easter" storms which traverse the Gulf of Maine along the coast from south to north. Wind velocities of 80 to 90 km are common during storms, and, in many instances, strong winds have a fetch equalling the width of the continental shelf; waves generated by these strong east-northeasterly winds strongly affect beach erosion and coastal damage along the entire New England coast save the protected beaches along the south and southeast margins of Cape Cod Bay.

Northeast storms are extra-tropical cyclonic lows. Winds generated around these low-pressure systems are counter-clockwise in orientation. As the low pressure system passes through the Gulf of Maine, the Northeast winds shift to a northerly and then northwesterly direction. Northwest winds then directly oppose waves generated by northeast winds, initiating rapid storm wave abatement (See Figure 5-78).

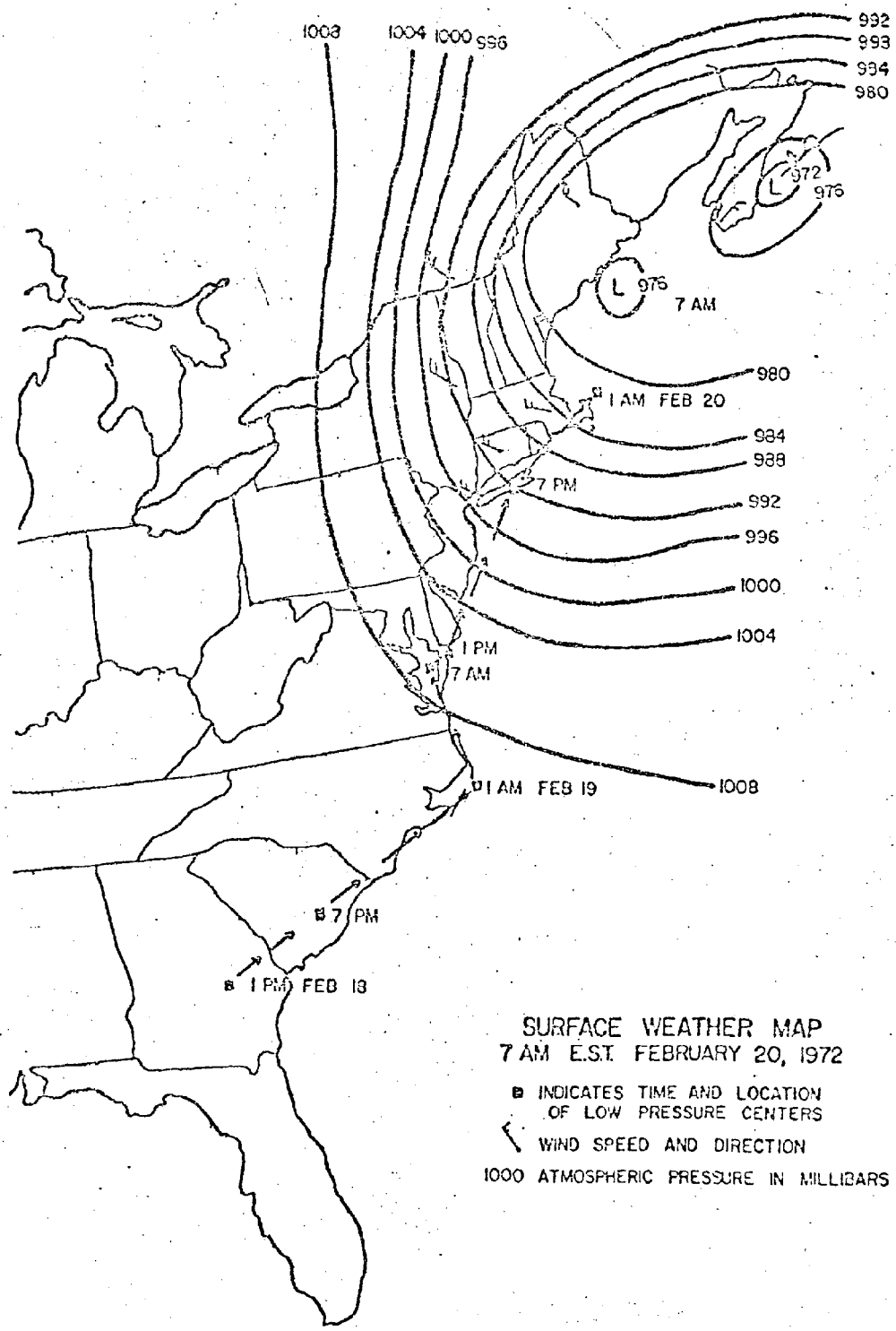
Tropical storms, hurricanes, are generated in the Caribbean Ocean as tropical cyclonic storms with counter-clockwise rotating winds; and move north affecting the Gulf of Maine region as they move onshore in southern New England or offshore before they hit the Canadian Maritimes. Southeasterly winds preceed the passage of the storm center, and, as the center passes over New England, the winds shift through south to a westerly direction. Peak winds accompany passage of the center, coming from the south-southeast as well as the south-southwest. Peak winds may reach 161 km ph velocities. Chute (1946) documented wind velocities of 143 km ph at Hyannis, Massachusetts during the hurricane of 1944. Winds are faster along the right hand side of the storm because they are augmented by the forward movement of the storm.

Waves generated during hurricanes have been responsible for coastal damage exceeding $100 million, but the effectiveness of damaging waves is mostly due to increased water levels accompanying storm centers. Increased levels are caused by extreme barometric pressure lows as well as wind-setup along the coast. Storm sea-levels during hurricanes may exceed normal levels by 1 to 1.5 m (Redfield and Miller, 1957) or by .5 to 1 m during northeast storms.



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

TRIGOM PARC	FIGURE 5-78a	Passage of a Barometric Low Through Gulf of Maine Feb. 19, 1972 (Abele, 1973)



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

TRIGOM PARC	FIGURE 5-78b	Passage of a Barometric Low Through Gulf of Maine FEB 20, 1972 (Abele, 1973)

5.2.2 REFERENCES

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5.3 BIOLOGICAL OCEANOGRAPHY

5.3.1 SANDY SHORES

In this section the biology of the sandy shores habitat is considered. The habitat is defined, its dynamics described, the effect of man-induced stress discussed, its biological components listed and the distribution of the habitat in the study area illustrated. The major components of the habitat are the benthic invertebrates, macrophytes, fishes and birds. For a detailed treatment of the life history and ecology of these taxonomic groups, the reader is referred to chapters 10.0, Benthic Invertebrates, 11.0, Macrophytes, 12.0, Fishes, and 13.0, Birds.

HABITAT DEFINITION/DESCRIPTION

The exposed, sandy shore habitat includes those areas of unconsolidated sediments ranging from cobbles through shingle to fine sand, found from the intertidal to 20 m depth, and exposed to heavy wave action. This habitat generally occurs on the open coast, south of Cape Cod.

HABITAT DYNAMICS

Environmental Conditions

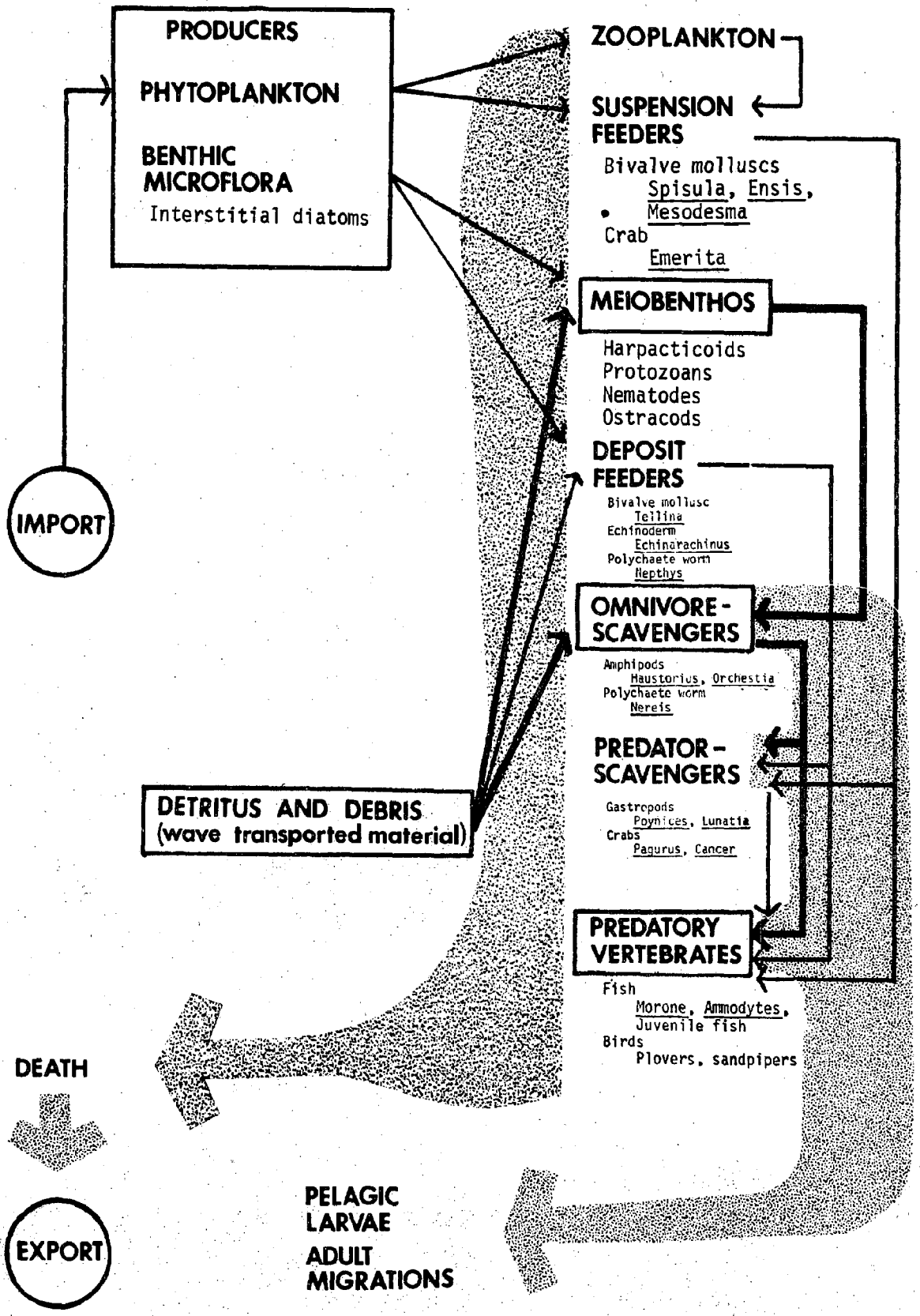
By definition, the most important environmental characteristic is the heavy wave action. Sediment composition and beach shape are determined by wave action. The high energy of the waves, resulting in shifting sediments and constant turbulence, cause the sandy shore to be the most biologically depauperate habitat discussed in this study. Epifauna is essentially nonexistant while the infauna is restricted to a few species specialized to cope with the stressful environment.

Microenvironments

The high-energy sandy shore is found from the intertidal to 20 m depth so that both intertidal and subtidal environments are found. Within these microenvironments, the sediment is sorted according to the dynamics of wave action (e.g. Hedgpeth, 1957) so that an area of coarse sand may lie adjacent to a pocket of fine sand. The aerobic top layer may be up to a meter thick in the upper-intertidal while the lower, anaerobic layer may extend to within 1 cm subtidally (Fenchel and Riedl, 1970). Both sediment composition and oxygen content strongly influence the meiofaunal species composition (Fenchel, 1969).

Nutrient Cycles and Food Webs

As in worm-clam bottoms, of which the sandy shore is in reality only a special sub-type, there is very little primary productivity within the sandy shore habitat. The most important energy sources are the detritus



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

TRIGOM PARC	FIGURE 5-79	Food Web-Sandy Shore Community

and soluble organic compounds washed up by waves and absorbed onto the sand-grains from water percolated through the sand (McIntyre, Munro and Steele, 1970). Since macrofauna are usually not very abundant in this habitat, the major energy flow and nutrient recycling within the sediment is probably through the meiofauna. The meiofaunal food chain outlined in "Worm-Clam" bottoms is thus very important here. Species constituting the major groups indicated in that food web will vary according to season and sediment type (Fenchel, 1969). Another food chain is based on the decomposition of the windrows of Zostera, macroalgae, and dead bodies left by the tide. Shorebird populations are a major route of nutrients out of the habitat although they undoubtedly contribute to the nutrient supply through their waste products.

Seasonal Cycles and Natural Stress

Seasonal cycles are marked and often drastic in the sandy shore. In general, winter storms remove much of a beach, transferring the sand offshore or to locations downshore (Hedgpeth, 1957). During the spring and summer the beach increases in width and height, although a severe storm may again temporarily remove part of the beach.

In addition to this wholesale movement of sand, sand is constantly being shifted and sorted. A constant feature of sandy shores is the formation and movement of cusps. Often segments of populations of burrowers may be smothered by a passing cusp (Hedgpeth, 1957).

As a consequence of both the seasonal removal and constant shifting of sand, most sandy shore species are active burrowers and have annual life cycles. Population densities are also highly irregular, being dependant on the common annual variations in larval success.

Temperature differences between the surface and several centimeters deep in the sediment become more marked during the summer (Hedgpeth, 1957). Because clean sand does not hold water well during low tides, the upper intertidal is often subject to periodic dessication during summer in addition to the higher temperatures. Such stresses lead to the regular migrations of the infauna, especially the merofauna, both vertically and horizontally (Hummon, 1969; Pollock, 1969, 1970).

Relative Productivity

Shingle and cobble beaches are essentially abiotic due to the exceedingly unstable and stressful nature of these sediments (Eltringham, 1971). Sand beaches are only slightly more productive, the 5 g C m^{-2} yr^{-1} primary production of an exposed beach in Scotland (Table 1, Worm-Clam bottom) being less productive than a desert (Eltringham, 1971). Biomass of consumers on the same beach amounted to 1.65 gm dry weight/m^{-2} (1.3 g/m^{-2} macrofauna + 0.35 g/m^2 microfauna, McIntyre, et al., 1970). When this is compared to, for example, the figures for

a salt marsh (Table 1 and 3 in "Salt Marsh"), it becomes clear that the sandy shore is the least productive marine habitat discussed.

EFFECT OF MAN-INDUCED STRESS

One of the most important stresses on the sandy shore is the construction of groins and jetties perpendicular to the shoreline. Most sand beaches are renewed annually by sand carried by longshore currents parallel to the beach. Groins and jetties interrupt this flow causing sand to pile up on the up-current side and beaches on the down-current side to vanish from lack of sand (Schuberth, 1972). Examples of this process can be seen all along the coast of southern New England and are exceptionally obvious at the beaches in Falmouth, Massachusetts (pers. obs.). Sandy shores are by nature dynamic habitats and can exist only in this State. Attempts to "stabilize" them only result in less of the habitat. The National Park Service has recognized this and forbade dune development and construction of jetties both on the Cape Cod and Cape Hatteras National Seashores (Dolan, Godfrey and Odum, 1973).

Another man-induced stress of current concern is the effect of oil spills on this habitat. Surveys of exposed sandy beaches in the Santa Barbara Channel after the 1969 oil well blowout, found very little damage due to oil pollution (Straughan, 1972). Experimental studies in Scotland have, in essence, confirmed this finding. Johnston (1970) found that the microbial rate of oil destruction (at 10 C) in heavily oiled sand was 0.09 g m^{-2} day^{-1}. These rates continued for several months resulting in reduction of approximately 10 percent of the oil. The remaining 90 percent was exceedingly resistant of breakdown, but, in fact, did not appear to be "oily" to touch or smell. Similar studies on sand from a Cape Cod beach (Bloom, 1970) produced similar results and the hypothesis that 300 days would be required to degrade the oil. In both studies microbial and meiofaunal populations did not seem to be affected. However, since rate of decomposition depends on amount of oxygen available, burial of oil spills would delay the ultimate breakdown by reducing available oxygen (Johnston, 1970).

BIOLOGICAL COMPONENTS

General Distribution

As in all intertidal and shallow water habitats, the sandy shore biota are zoned. Unfortunately, relatively little study has been done describing these zones, especially in this study area. At the upper littoral zone, a very high density of talitrid amphipods (beach "fleas" or "hoppers") lives in the detritus left by the retreating tide. The intertidal area is generally inhabitated by one to a few species of very active burrowers (e.g. *Emerita* sp (mole crab) or haustorid amphipods). In the subtidal area, very high densities of *Spisula solidissima* often occur. Depending on conditions, *Echinarachnius parma* (sand dollar) and *Tellina* sp. may occur associated with small polychaete

worms (Hedgpeth, 1957). Study of the zonation and species composition of the meiofauna, probably more important than the macrofauna in energy cycling in this habitat, has only recently begun (Pollock, 1969, 1970; Hummon, 1969, 1971).

Fishes

The following is a list of fishes normally found in the Sandy Shore habitat within the continental shelf area between Sandy Hook, New Jersey, and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases, the criterion has been the extent of the species' impact on a particular habitat, i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance

A. The geographical distribution includes three categories
North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through George's Bank.
South - Primarily distributed south and west to that line
Throughout - Distributed throughout the study area.

B. The relative abundance is indicated by the terms: abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south or throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore, characteristics of the species.

Fresh-water
Brackish water
Nearshore - coastline to 18 m
Coastal - out to 91 m
Offshore - 91 m to the continental slope
Basin - deep basin of the Gulf of Maine
Banks - shallow, offshore bank areas, i.e., George's Bank
Oceanic - pelagic fish of open ocean habit.

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species or a rare or endangered species. The life history of these will be treated in Chapter 12.0, Fishes.

TABLE 5-1
Checklist of Fishes

Sandy Shores

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Sharks			
Sand shark *Odontaspis taurus*	common south	nearshore to coastal, 1.83 m to 183 m.	food-small fish; shallow sand bars
Skates			
Winter skate *Raja ocellata*	common throughout	nearshore to 91 m	food-fish, small invertebrates
Little skate*** *Raja erinacea*	abundant throughout	nearshore to 137 m	food-small fish, invertebrates; sandy-pebbly bottom
Anchovies			
Anchovy *Anchoa mitchelli*	common south	nearshore to coastal	food-copepods; principally mouths of rivers
Smelts			
Capelin *Millotus villosus*	occasional north	coastal	food-small invertebrates; eastern Maine to Bay of Fundy
Killifish			
Striped killifish *Fundulus majalis*	abundant south	nearshore	food-small animals
Silversides			
Silversides*** *Menidia menidia*	abundant south	brackish to nearshore	food-small crustaceans, fish eggs, invertebrate larvae, vegetable matter
Tidewater silverside *Menidia beryllina*	common south	fresh to nearshore	food-small crustaceans, fish eggs, invertebrate larvae.

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Bluefishes			
Bluefish*** *Pomatomous saltatrix*	abundant south	coastal to oceanic	food-fish, squid
Temperate basses			
Striped bass*** *Morone saxatilis*	abundant throughout	nearshore to coastal	food-small fish, invertebrates
Drums			
Weakfish *Cynoscion regalis*	common south	brackish to coastal	food-small schooling fish, invertebrates; sandy bottom
Northern kingfish *Menticirrhus saxatilis*	common south	nearshore to coastal	food-invertebrates, young fish; hard or sandy bottom
Silver perch *Bairdiella chrysura*	occasional south	coastal	sandy bottom
Channel bass *Sciaenops ocellatus*	ocassional south	nearshore to coastal	food-molluscs, crustaceans; sand bottom
Sand lances			
sand lances*** *Ammodytes* sp	abundant throughout	coastal, banks	food-small crustaceans; sand bottom
Flounders			
Winter flounder*** *Pseudopleuronectes americanus*	abundant throughout	brackish to coastal, banks to 128 m.	food-small bottom invertebrates
Windowpane *Scophthalmus aquosus*	common south	nearshore to coastal to 73 m	food-small invertebrates

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Puffers			
Northern puffer *Sphaeroides maculatus*	common south	brackish to nearshore	food-small crustaceans

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5.3.2 ROCKY SHORES

In this section the biology of the rocky shore habitat is considered. The habitat is defined, its dynamics described, the effect of man-induced stress discussed, its biological components listed and the distribution of the habitat in the study area illustrated. The major components of the habitat are the benthic invertebrates, macrophytes, fishes and birds. For a detailed treatment of the life history and ecology of these taxonomic groups the reader is referred to chapters 10.0, Benthic Invertebrates, 11.0, Macrophytes, 12.0, Fishes, and 13.0, Birds.

HABITAT DEFINITION/DESCRIPTION

The rocky shore habitat includes all shores washed by saline waters from the top of the zone wetted by spray to 20 m depth with a rock substrate ranging from solid outcrops of bedrock to broken boulder beaches.

HABITAT DYNAMICS

Environmental Conditions and Microenvironments

The first, and most obvious, characteristic of rocky shores is that the substrate is solid. Thus, in the region covered by this study, the biota are restricted to epiflora and fauna: no species dwell beneath the surface. Competition for space is consequently uniquely important in this habitat.

The second most important enviornmental characteristic is the nature of the water washing the rock. Differences in salinity and temperature from the open coast to upper estuarine reaches have an important overall effect on the composition of the biota in an area. Much more important on the local level is the nature of the water movement. (The following discussion is abstracted from Lewis, 1968). Two types of water movement are recognized: 1) the horizontal flow of tidal currents and 2) the turbulence and violence of wave action.

Areas affected by either breaking waves or strong tidal currents are distinguished by silt-free substrata and, due to the thorough mixing of water masses, an absence of chemical or temperature gradients. On wave-washed shores, probably the most important characteristic limiting the types of species present is the pull or drag of the water on the organism. The violence of such drag eliminates delicate or large species in favor of small or stunted, strongly attached forms. Areas with very turbulent tidal flow share this characteristic and consequently show a similar biota. Where tidal flow is moderate, in contrast, the richest assemblage of forms, especially delicate forms of the Porifera, Hydrozoa, Polyzoa, Bryozoans and Ascidiacea, are found. Lewis postulates that such areas combine the advantages of wave washed coasts with a

lack of violence, creating optimal conditions for sessile, attached forms.

At the end of the spectrum, in sheltered areas lacking currents or waves, the substrate often becomes silt-covered and seasonal or short-term fluctuations in such factors as salinity and turbidity tend to be more severe than in nearby, more "exposed" areas. Other conditions which restrict the type of species that live in sheltered areas include competition for space with the abundant fucoid algae characteristic of such areas and lowered mixing rates reducing the number of larvae coming in contact with the rock surface, reducing the probability of settlement of many species.

Another obvious characteristic of rocky shores is the zonation of plants and animals. The fundamental reasons for this are the gradients of exposure intertidally and of light penetration subtidally. The upper limit of most species zones in the intertidal is determined by the varying physiological tolerances to dessication and lower level by biological interactions. (For very complete discussion of these factors, see, for example, Lewis, 1964; Stephenson and Stephenson, 1972; Doty, 1957). Subtidally, the algal species are zoned according to their differing efficiencies of utilizing light of various wave lengths, since the deeper the water the less light there is with the shorter wave-lengths being eliminated first. The width and height of these zones are determined by the frequency and height of wave action; the more frequent and higher the waves, the wider and higher on the shore the zones are (Lewis, 1968). In very sheltered areas, zones are markedly reduced and often don't extend even to high tide level.

Nutrient Cycles

True nutrient cycles don't exist on rocky shores. The biota of rocky shores are usually dominated by the macroalgae (*Fucus*, *Laminaria*), yet only 10 percent of their production is utilized within the habitat. The remaining 90 percent is exported and becomes the basis of food chains in other habitats where imported detritus forms a significant supplement to indigenous primary production (e.g., pelagic, worm and clam flats, sandy shores) (Mann, 1973).

Seasonal Cycles

Seasonal cycles in environmental conditions occur more markedly the more sheltered the area is. In estuarine areas and salt ponds the rocky shore biota are subjected to all seasonal extremes already discussed under these habitats, compounded in intertidal areas by the bi-monthly cycles of tidal heights (See Natural Stress).

Mann (1973) has demonstrated a seasonal cycle in the rate of primary productivity. Although the macroalgae grow all year round, peaks in

the growth rate occur during the months of March and April (in Nova Scotia) and the lowest rate is found during September and October.

Because the rocky shore biota are dominated by long-lived organisms, seasonal changes in species abundance is not marked. Recruitment of young occurs very irregularly partly because larval success varies from year to year depending on the conditions encountered during their pelagic existence. A second factor is competition for space with already established adult populations. Even in sites cleared of adult populations, re-colonization occurs very slowly, especially for the macroalgae (Lewis, 1968).

Food Webs

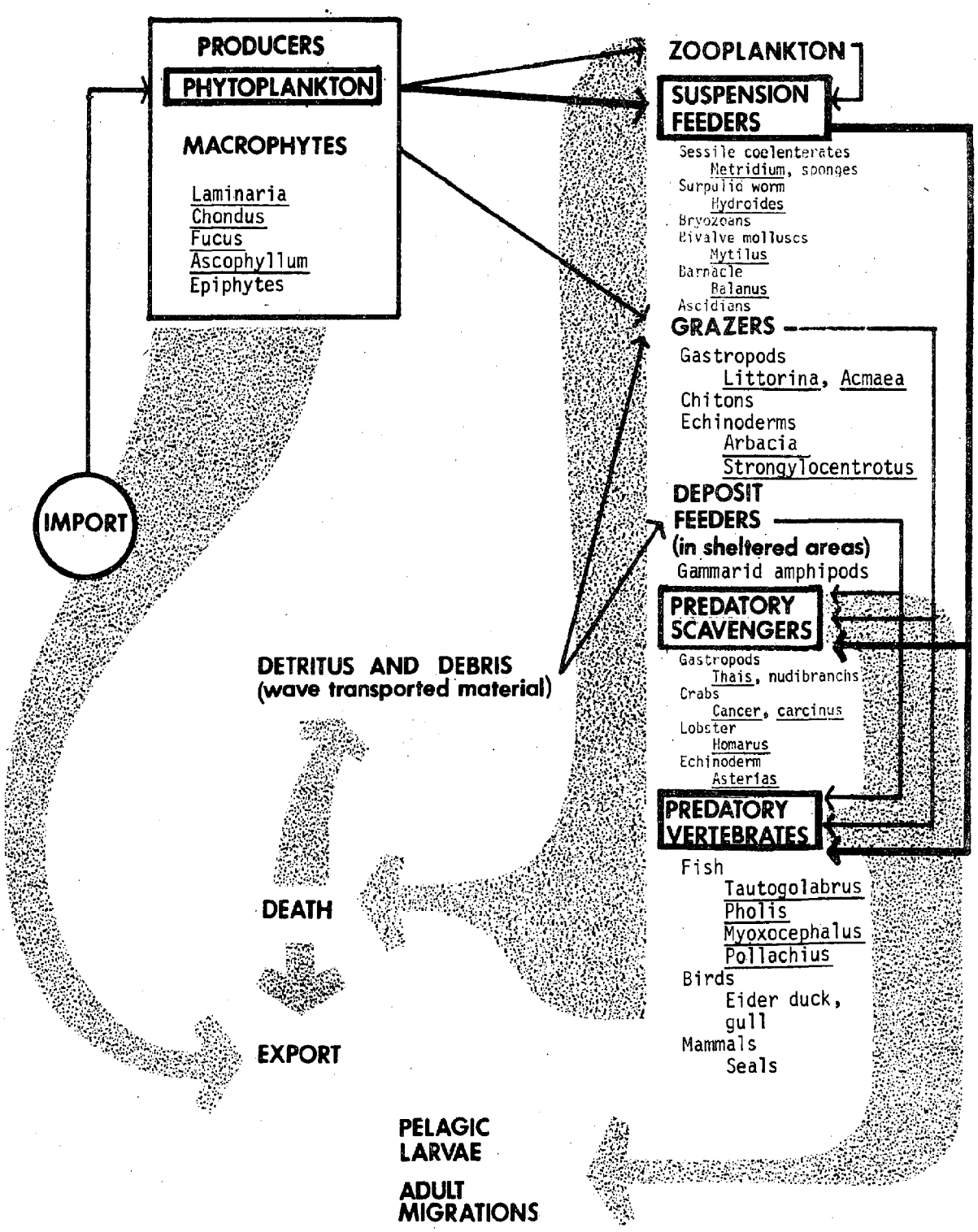
The food web of rocky shores is probably the least complicated of all the marine habitats. This is at least partly due to the fundamentally one-dimensional nature of the substrate. There is no place for nutrients to accumulate becoming available for recycling within the habitat. Thus the food web is solely based on the macroalgae and phytoplankton, their consumers, and the predators of the consumers. Because of this, interactions tend to be simple. As Mann (1973) points out, the key predator on the sea urchin is probably the lobster. The sea urchin in turn is the most destructive grazer on the kelp bed. With the present intense fishing pressure on the lobster, the main control on the sea urchin population is removed, allowing it to expand causing destruction of kelp beds. To put it another way, to increase kelp bed production, fishing pressure on the lobster should be partially released. The increased numbers of lobsters should in turn reduce the sea urchin population.

Relative Productivity

Mann (1973) found that the primary production of the seaweed zone in St. Margaret's Bay, Nova Scotia, was 1750 g C per m^{-2} yr^{-1}. This worked out to three times the production of the phytoplankton in the Bay. Such a level of production ranks the seaweed zone as one of the highest areas of primary production in the marine habitat. For comparison, turtle grass (*Thalassia*) beds in the Caribbean produced around 600-900 g C m^{-2} yr^{-1}, and *Spartina* in the Atlantic North America ranges from 100 to 900 g C m^{-2} yr^{-1}.

Natural Stress

Intertidal populations are especially vulnerable during low tides to extremes of weather. Times of greatest physiological stress occur when low tide falls during the summer mid-day, winter blizzards, or heavy rainstorms. The organisms thus exposed must be able to withstand high temperatures and dessication, freezing, and sudden, prolonged changes in salinity, respectively. Often such extreme conditions are believed to be the limiting factor in the distribution and zonation of a species



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

TRIGOM PARC	FIGURE 5-80	Food Web-Rocky Shore Community

Other natural stresses include scour from winter ice and storm waves. Whole areas of shore may be periodically denuded especially when a bay frequently freezes during the winter.

EFFECT OF MAN-INDUCED STRESS

Largely because of their accessibility and the obviousness of population changes, several types of man-induced changes on rocky shores have been well-documented.

The effects on rocky shores biota of a spill of Bunker C crude oil in Chedabucto Bay, Nova Scotia, were closely studied. In general, the biota were affected most severely where the oil was particularly heavy. In such areas the fauna completely disappeared. In areas of lighter oiling, effects were more variable. The fauna (Balanus balanoides, Littorina spp.) showed no severe reduction in abundance or disruption in recruitment. Fucus spiralis, however, was reduced or eliminated and no evidence of recolonization could be found after two years. The original oiling, however, disappeared fairly rapidly from all rocky shores except in very sheltered areas, leading to the conclusion that clean-up of such spills is not necessary except at heavily oiled sites (Thomas, 1973).

The effects of repeated spillages and the use of oil emulsifiers on biota has been studied at South-west Wales (Colwell, Baker and Crapp, 1972). Most littoral species are resistant to toxic oil spills, the major effect being a mechanical one; snails coated with a heavy layer of oil are most likely to be dislodged by waves. Tests with emulsifiers revealed that most fauna have a seasonally varying resistance to the toxicity. Most snails respond by withdrawing into their shell (especially Littorines) and are consequently then easily rolled off the shore. When the large populations of grazing snails are thus removed or killed by the emulsifier (e.g., limpets and mussels) the area becomes recolonized by first Enteromorpha and then Fucus vesiculosus. The character of the shore then is completely altered.

Borowitzka (1972) studied the effects of an outfall of raw domestic sewage on algal species distribution and diversity. The results of such studies can be applied to any rocky shore because of the worldwide similarity of the rocky shore biota (Stephenson and Stephenson, 1972). In the immediate area of the outfall, animal species and zonation of all species are eliminated. Only immature Enteromorpha and Chaetomorpha thrive, species characteristically "pioneer" species in denuded areas. Borowitzka discovered that both the distance from the edge of the rock platform and distance from the sewer outfall affect algal species diversity. Diversity increases with distance from the outfall and is highest in the lower littoral.

BIOLOGICAL COMPONENTS

General Distribution

The following zones generally constitute the basic pattern of intertidal zonation on rocky shores from the upper to lower limits: lichens above spray, blue-green algae and Littorina saxatilis in spray zone, Fucus spp. competing with barnacles (Balanus sp.) in upper area and mussels (Mytilus edulis) in lower areas of fucoid zone, Ascophylum, perhaps another Fucus sp. grading into Chondrus crispus and Ulvua in the lower intertidal and upper sublittoral. The lichen and blue-green zones are especially affected by wave action, becoming more developed the greater the wave action. The fucoid species and Ascophylum become more developed with greater shelter, while the barnacle and mussel zones predominate in more exposed areas (Lewis, 1968). Other abundant species in this zone are Littorina obtusata, and L. littorea, many amphipods, Thais lapillus, and often Asterias.

Subtidally (1-3m depth) Chorda spp. and filamentous browns occur in sheltered areas, often adjacent to sandy shores, and are replaced by Chondrus crispus on exposed shores and Zostera marina on muddy shores. At 3-13m , Laminaria spp. are dominant; L. digitata occurring in fairly exposed areas and L. longicruris in sheltered sites (4-18 m depth). Agarum cribosum with an understory of Ptilota serrata extends below Laminaria to soft substrates, dominating at 15-20 m depth. In highly exposed sites, Alaria sp. replaces the Laminaria (Mann, 1972).

Species Checklist

The following is a checklist of benthic invertebrates and fishes. These species are considered to be regular inhabitants of the rocky shore habitat.

TABLE 5-2

Benthic Invertebrates

The following benthic invertebrates are found on rocky shores. The codes for their reported occurrence are:

1. Cape Cod, north and west shore
2. Massachusetts Bay to Cape Ann
3. Cape Ann to Cape Elizabeth
4. Cape Elizabeth to Small Point (Casco Bay)
5. Small Point to Port Clyde
6. Port Clyde to Isle au Haut (Penobscot Bay)
7. Isle au Haut to Schoodic Peninsular
8. Schoodic Peninsula to Passamaquoddy Bay
9. Maine coast, location unspecified
10. Georges Bank

Species	Reported Occurrence
Phylum Porifera	
Haliclona oculata	4,5,7,9
Cliona celata (sulphurea)	4,7,9
Grantia ciliata	4,9
Grantia coronata	4
Halichondria panicea	4,7,9
Halisarca sp.	
Leucosolenia cancellata	4,9
Microciona prolifera	7,9
Myxilla incrustans	7,9
Phylum Coelenterata, Class Hydrozoa	
Bougainvillia superciliaris	2,9
Campanularia flexuosa	2,3,4,6,8,9
Clava leptostyla	3,9
Hybocodon prolifer	2,9
Hydractinia echinata	2,3,4,8,9,10
Obelia commissuralis	2,8,9
Obelia geniculata	2,4,8,9
Sertularia pumila	2,3,4,8,9
Tubularia crocea	2,4,8,9
Tubularia larynx	8,9
Phylum Coelenterata, Class Anthozoa	
Bunodea (=Bunodactis) stella	9
Metridium senile	3,4,5,7,9
Tealia crassicornis	4,5,7,9
Phylum Coelenterata, Class Scyphozoa	
Aurelia aurita	
Phylum Platyhelminthes, Class Turbellaria	
Notoplana atomata	4,9
Stylochus ellipticus	9
Phylum Annelida, Class Polychaeta	
Amphitrite brunnea	7
Eulalia viridis	3,9,10
Fabricia sabella	9
Harmathoe acanellae	7,9,10
Lepidonotus squamatus	3,5,7,9,10
Nereis virens	2,3,4,5,6,7,8,9
Spirorbis borealis	5
Spirorbis spirillum	4,9
Phylum Annelida, Class Oligochaeta	
Clitellio arenarius	
Enchytraeus albidus	

Phylum Nemertea	
Amphiporus angulatus	4,9
Lineus viridis (=ruber)	4,8,9
Phylum Arthropoda, Subclass Cirripedia	
Balanus balanoides	mid-low intertidal
Balanus balanus	low intertidal-subtidal
Balanus crenatus	rocks, shells, (subtidal)
Balanus eburneus	rocks, pilings
Balanus improvisus	
Phylum Arthropoda, Order Mysidacea	
Mysis stenolepis	in rockweeds, low intertidal
Phylum Arthropoda, Order Isopoda	
Jaera marina	tide pools, especially upper ones
Idotea baltiea	
Idotea phosphorea	
Phylum Arthropoda, Order Amphipoda	
Calliopius laevuisculus	especially in tide pools
Melita dentata	
Ampithoe rubricata	
Gammarus oceanicus	tide pools
Leptocheirus pinguis	on hydroids, algae
Caprella linearis	
Phylum Arthropoda, Order Decapoda	
Carcinides maenas	
Cancer borealis	low intertidal-subtidal
Cancer irroratus	low intertidal-subtidal
Homarus americanus	
Phylum Arthropoda, Class Insecta	
Anurida maritima	tide pools; under rocks, on algae
Phylum Mollusca, Class Gastropoda (Prosobranchia)	
Acmaca testudinalis	3,5,7,9
Buccinum undatum	3,4,5,7,8,9
Crepidula fornicata	3,7,9,10
Crepidula plana	3,9,10
Lacuna vincta	3,5,7,9
Littorina littorea	3,5,7,8,9
Littorina obtusata	3,5,7,9
Littorina saxatilis	3,5,7,9
Margarites groenlandica	7,8,9,10
Neptunea decemcostata	3,7,8,9
Odostomia seminuda	9
Thais lapillus	3,5,7,9
Urosalpinx cinerea	9

Phylum Mollusca, Class Gastropoda (Opisthobranchia)	
Aeolidia papillosa	2,5,7,9
Coryphella rufibranchialis	2,7,8,9
Onchidoris aspersa	9
Onchidoris fusca	9
Palio lessonii	9
Phylum Mollusca, Class Polyplacophora	
Ischnochiton ruber	9
Ischnochiton albus	9
Tonicella marmorea	
Phylum Mollusca, Class Pelecypoda	
Hiatella arctica	3,5,7,9
Mytilus edulis	1,2,3,4,5,6,7,8,9
Petricola pholadiformis	2,3,9
Modiolus modiolus	3,5,7,9
Zirfaea crispata	2
Phylum Echinoderma, Class Asteroidea	
Asterias vulgaris	5,7,9
Asterias forbesi	5,7,9
Crossaster papposus	7,9
Crossaster endeca	4,7,9
Henricia sanguinolenta	4,5,7,9
Phylum Echinoderma, Class Ophiuroidea	
Amphipholis squamata	9
Ophiopholis aculeata	3,4,5,7,9
Phylum Echinoderma, Class Echinoidea	
Strongylocentrotus droehbachiensis	3,4,5,7,9
Phylum Echinoderma, Class Holothuroidea	
Cucumaria frondosa	5,7,9
Psolus fabricii	4,7,9
Psolus phantapus	4,7,9
Phylum Bryozoa (Ectoprocta)	
Bugula turrita	4,9
Crisea eburnea	4,5,7,9
Electra pilosa	9
Flustrellidra hispida	7,8,9
Gemellaria (=Eucratia) lornicata	3,4,7,9

Phylum Chordata, Class Ascidiacea

Amaroucium glabrum	4,9
Boltenia echinata	9
Boltenia ovifera	4,5,9
Botryllus schlosseri	3,5,9
Ciona intestinalis	4,9
Didemnum albidum	5,9
Halocynthia pyriformis	9
Perophora viridis	9

Fishes

The following is a list of fishes normally found in the rocky shores habitat within the continental shelf area between Sandy Hook, New Jersey and the Bay of Fundy. Because of their mobility, the assignment of a particular species to a habitat has, in some cases, been somewhat arbitrary, especially in assigning a particular species to either a pelagic or a demersal habit. In such cases the criteron has been the extent of the species' impact on a particular habitat, i.e., if a fish species feeds principally on pelagic animals, then it would be considered part of the pelagic community. The scientific names are those published by the American Fisheries Society: A List of Common and Scientific Names of Fishes, 1970 edition.

The species notations in the checklist are defined as follows:

I. Geographical distribution and relative abundance
   A. The geographical distribution includes three categories
      1. North - Primarily distributed north and east of a line from Cape Cod and the Nantucket Shoals through George s Bank.
      2. South - Primarily distributed south and west of that line
      3. Throughout - Distributed throughout the study area.

   B. The relative abundance is indicated by the terms abundant, common, occasional and rare. These are meant to indicate rough, relative indices and are in no way quantitative measures. In each case they refer to the abundance in the area of primary distribution, i.e., north, south, throughout.

II. Depth distribution. The following terms are used to describe the depth or the inshore-offshore characteristics of the species.
   Fresh Water
   Brackish water
   Nearshore - coastline to 18 m
   Coastal - out to 91 m
   Offshore - 91 m to the continental slope
   Basin - deep basin of the Gulf of Maine
   Banks - shallow, offshore bank areas, i.e., Georges Bank
   Oceanic - pelagic fish of open ocean habit

The species marked *** are considered as "key species" in that they are a primary constituent of the habitat, a commercially important species, or a rare or endangered species. The life history of these species will be treated in Chapter 12.0, Fishes.

TABLE 5-3

Checklist of Fishes

Rocky Shores

Species	Geographical Distribution, Abundance	Depth Distribution	Habit
Smelts			
Rainbow smelt*** *Osmerus mordax*	abundant throughout	brackish to nearshore	food-small fish crustaceans; spawns brackish
Codfishes			
Pollock*** *Pollachius virens*	abundant north	coastal, banks to 183 m.	food-small fish, crustaceans
Sticklebacks			
Fourspine stickleback *Apeltes quadracus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Threespine stickleback *Gasterosteus aculeatus*	abundant throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Blackspotted stickleback *Gasterosteus wheatlandi*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Ninespine stickleback *Pungitus pungitus*	common throughout	fresh to nearshore	food-copepods, other small crustaceans, fish eggs and fry
Pipefishes			
Northern pipefish *Syngnathus fuscus*	common north	brackish to nearshore to 31 m.	food-copepods, amphipods, fish eggs and fry
Lined seahorse *Hippocampus erectus*	occasional south	brackish to nearshore	food-copepods, amphipods, fish eggs and fry
Temperate basses			
Striped bass*** *Morone saxatilis*	abundant throughout	nearshore to coastal	food-small fish, invertebrates

Scorpionfishes			
Redfish*** *Sebastes marinus*	abundant north	nearshore to banks, basins to 732 m.	food-crustaceans, other invertebrates
Sculpins			
Grubby *Myoxocephalus aeneus*	common throughout	nearshore to coastal	food-scavenger, fish, invertebrates
Shorthorn sculpin *Myoxocephalus scorpius*	common north	nearshore to coastal	food-scavenger, fish, invertebrates
Longhorn sculpin*** *Myoxocephalus octodecemspinosus*	abundant throughout	brackish to coastal, banks to 183 m.	food-scavenger, fish, invertebrates
Sea raven *Hemitripterus americanus*	common throughout	nearshore to 91 m.	food-scavenger, fish, invertebrates
Lumpfishes			
Lumpfish *Cyclopterus lumpus*	common north	nearshore to coastal	food-crustaceans hard bottom
Seasnail *Liparis atlanticus*	common north	coastal, banks to 91 m.	food-crustaceans, molluscs; hard bottom
Liparis inquilinus	common throughout	coastal, banks 9.1-183 m.	food-crustaceans, molluscs; hard bottom
Cunners			
Cunner*** *Tautogolabrus adspersus*	abundant throughout	nearshore to coastal, banks to 128 m.	food-omnivorous scavenger
Tautog*** *Tautoga onitis*	abundant south	brackish to coastal to 36.6 m.	food-molluscs, other invertebrates
Gunnels			
Rock gunnel *Pholis gunnellus*	common north	nearshore to coastal, banks to 183 m.	food-molluscs, crustaceans; hard bottom

Pricklebacks			
Radiated shanny *Ulvaria subbifurcata*	common north	nearshore to basin to 82 m.	hard bottom
Wolffishes			
Atlantic wolffish *Anarhicus lupus*	common north	coast, banks to 164.7 m.	food-molluscs, echinoderms, crustaceans; hard bottom
Eel pouts			
Ocean pout*** *Macrozoarces americanus*	abundant throughout	nearshore to coastal, banks basin 3.66 - 192 m.	food-molluscs, crustaceans, echinoderms

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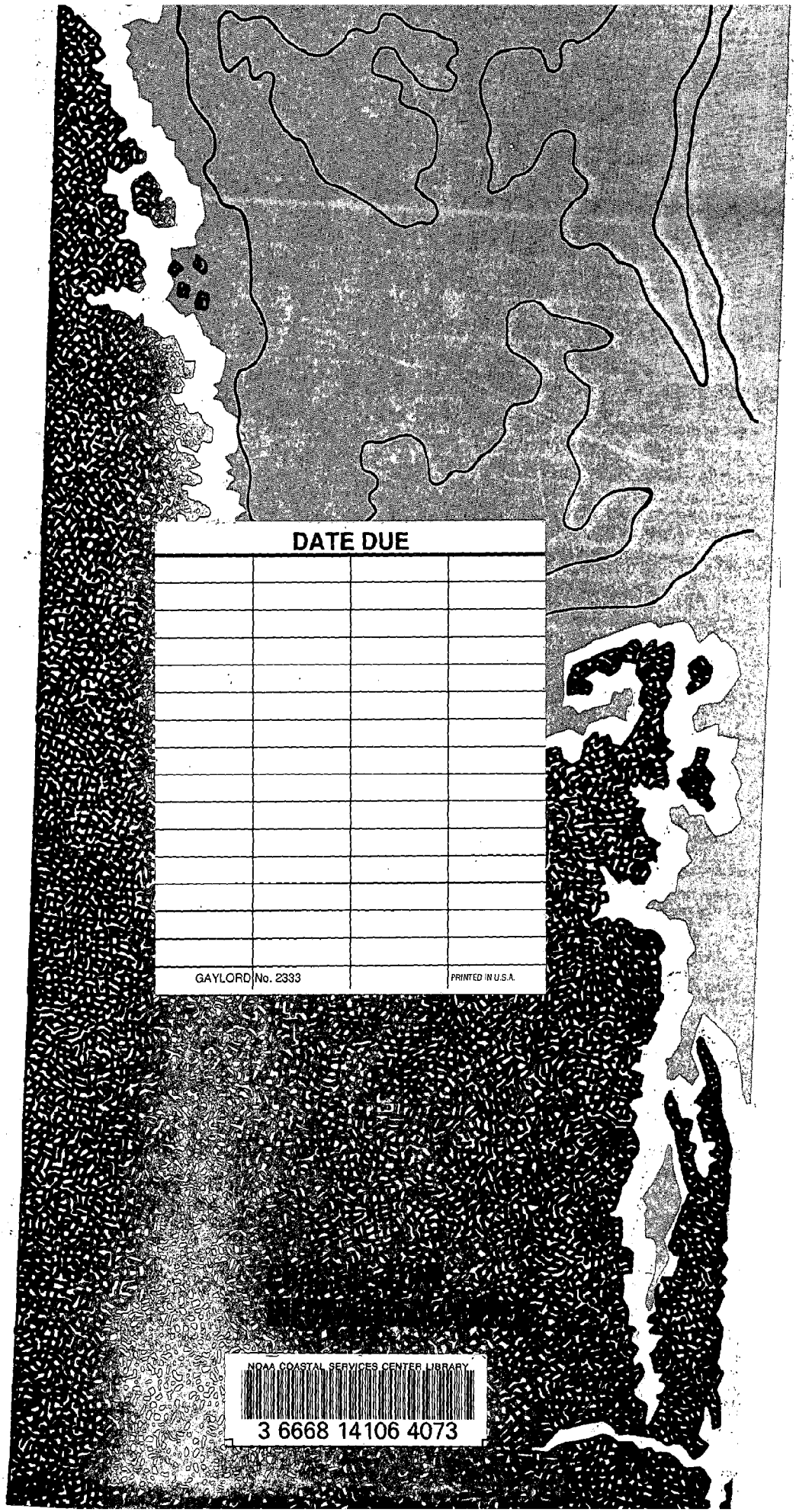

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