1976-12

PB 284 002

Summary of Environmental Information on the Continental Slope Canadian/U.S. Border to Cape Hatteras N.C

CHAPTER 7.0

BIOLOGICAL OCEANOGRAPHY

7.1 PHYTOPLANKTON

STANLEY CHENOWETH

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

CHAPTER 7.0 TABLE OF CONTENTS

Page

Chapter 7.1 Phytoplankton

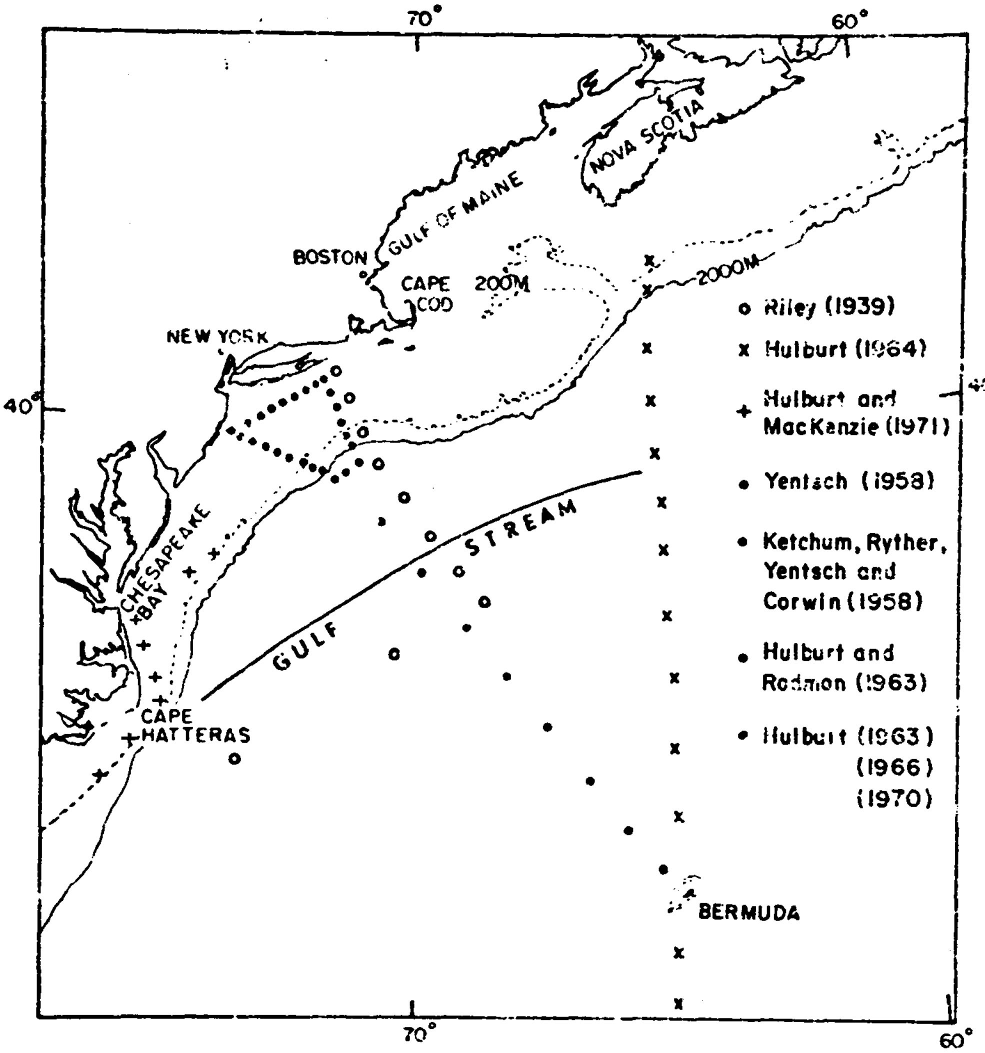
7.1 PHYTOPLANKTON

7.1.1 INTRODUCTION

The phytoplankton components of the continental slope area consist of free-floating algae. As the ocean's primary producers, they are the basic source of organic matter upon which the rest of the marine food chain is built. The phytoplankton consist of autotrophic algae that have representatives from the taxonomic groups: Baccillariophyta, Pyrrophyta, Cyanophyta, Coccolithophoridaceae, Chlorophyta, and Euglenophyta. The algal cells are commonly found in combinations of single, filamentous, or colonial units of varying size in the euphotic zone (upper 100 m) and require sunlight, nutrients, and certain conditions of temperature and salinity in order to synthesize organic matter. The various combinations of those factors in the euphotic zone dictate the floral characteristics of the waters at any particular time or place. Generally speaking, the major groups of phytoplankton are the diatoms, which dominate the shallow shelf areas and cooler waters of northern latitudes, and the flagellates (coccolithophores and dinoflagellates) which are dominant in warmer oceanic waters. Included in the plant plankton are a number of heterotrophic forms such as bacteria, fungi, and some free-floating algal groups which are capable of existing independent of light in the lower euphotic zones (Fournier, 1967). These forms are important in regenerating organic matter into usable nutrients.

What is known of the phytoplankton in the slope water results from the occupation of a few stations in that region during investigations of larger areas of the northwest Atlantic; furthermore, this has been used primarily for comparative purposes. Most of the stations were occupied off the southern New England shelf on standard cruise transects (Figure 7-1). Consequently, most of the information concerning phytoplankton applies to these sampling regions and not necessarily to the slope water from Cape Hatteras to Georges Bank.

Early, extensive plankton survey work which spanned the years 1914-1940 (Bigelow 1914, 1914b, 1915, 1917, 1922, 1926; Braarud 1934; Gran and Braarud 1935; Lillick 1938, 1940; and Bigelow, Lillick and Sears, 1940) was carried out primarily in the continental shelf waters and only occupied a few stations beyond the shelf break. These works have limited application to the slope water. Transects across the northwest Atlantic reported by Riley (1939) and Riley and Gorgy (1948) provided information on productivity and ecology in the slope water. Subsequently, Riley, Stommel, and Bumpus (1949) summarized the information on the plankton of the northwest Atlantic which had been collected up to that point. Productivity studies by Ketchum, Ryther, Yentsch, and Corwin (1958) and Ryther and Yentsch (1958) included slope stations and provide some valuable comparative data between shelf and slope waters. Hulburt (1963, 1964, 1966, 1970, 1975), Hulburt and Rodman (1963) and Hulburt and MacKenzie (1971) have done extensive floristic work in the northwest



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | FIGURE 7-1 | Station Locations of Major Phytoplankton Studies in the Northeast Atlantic

Atlantic from samples taken on station transects; however, in some cases, the information from the samples in the slope water was included with that from other coastal or oceanic areas and therefore is not applicable specifically to the slope. The task, then, in summarizing data regarding the phytoplankton of the continental slope area was to retrieve small amounts of information from diverse studies and describe the phytoplankton by piecing them together.

Two distinct floras are commonly recognized in the northwest Atlantic (Hulburt, 1963) and are referred to as the neritic and the oceanic phytoplankton. The species within these floral groups have either physical, nutritional, or physiological characteristics which suit them to either a coastal or oceanic existence. Some of these characteristics are:

1. Formation of resting spores (meroplanktonic)
2. Body form
3. Size
4. Salinity preference
5. Minimum nutritional requirements
6. Optimum light requirements

Smayda (1958) has cautioned against using the terms neritic and oceanic in a strict biogeographic sense, because the uniqueness of a particular flora can result as much from the nature of the organism as from its geographical location. In fact, under the proper conditions, many species that are termed neritic are found in the open ocean, while many oceanic species are found in coastal areas. The transition does exist, however, between a diatom dominated flora of the relatively shallow, cool coastal areas and a coccolithophore dominated flora of the warmer, deeper oceanic areas (Hulburt, 1963, 1970). Furthermore, the greatest transition between these floras probably occurs within the boundaries of the slope water because this is where the change from the shallow shelf to the deep ocean environment occurs.

The highly variable nature of the slope water creates the conditions for mixing of the phytoplankton species. Riley, Stommel, and Bumpus (1949) considered this as a region of confused hydrography with great chemical and biological variability. The eddies from the Gulf Stream and mixing from the coastal waters within a slow counterclockwise circulation pattern contribute to this variability. The nutrient conditions necessary for moderately good growth that exist in slope waters encourage the high productivity and low diversity characteristics of shelf phytoplankton; however, deep water and high salinity encourage the low productivity and high diversity of open ocean phytoplankton. This results in a highly variable situation.

7.1.2 COMPOSITION AND ABUNDANCE

COMPOSITION

Composition of the slope water phytoplankton consists of shelf diatoms and oceanic flagellates, principally coccolithophores and dinoflagellates. Generally speaking, there is a 50 percent mixture of these two floral groups (Dr. Edward M. Hulburt, personal communication), although this is variable and a function of location and season. A representative sample of the phytoplankton composition at two slope stations is shown in Table 7-1.

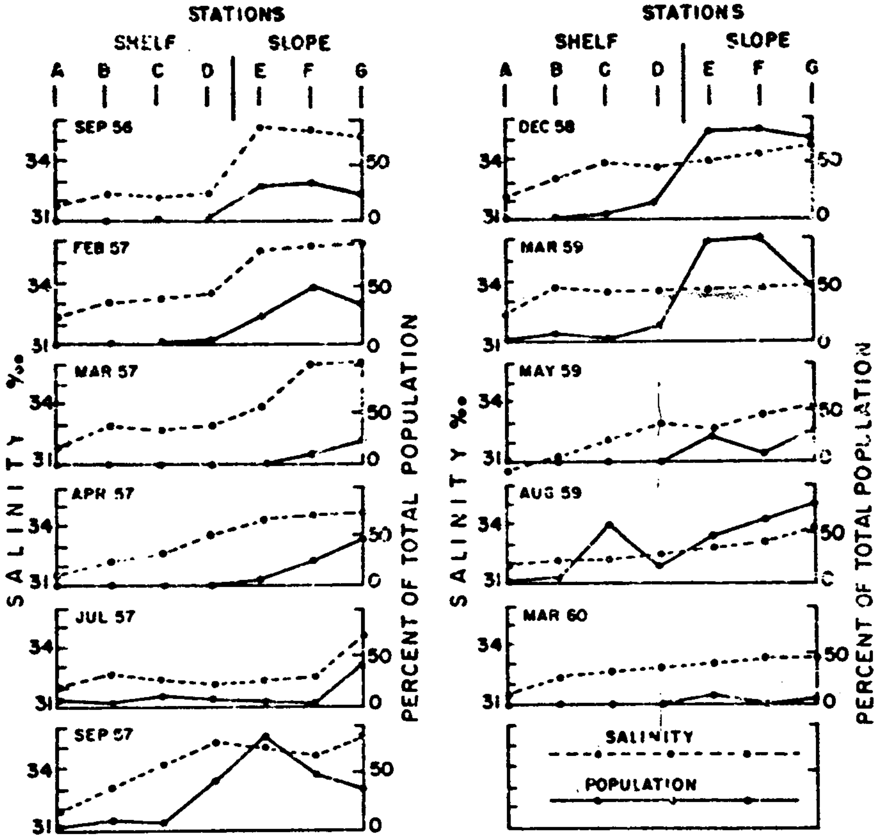
The species change between shelf and slope stations, based on 21 samplings between December of 1956 and August, 1963, has been summarized by Hulburt (1966). A representative number of his data are shown in Figure 7-2 and illustrate the change in percentage of oceanic species with distance from the southern New England coast. His oceanic group included coccolithophores and dinoflagellates from the genus Oxytoxum; all other species were considered coastal. An increase in oceanic flora can be seen at about the shelf break and continues until the oceanic group comprises 25 to 75 percent of the total flora of the outer slope station. Important species in the coastal and slope areas were the coastal diatoms: Rhizosolenia alata, Thalassionema nitzschioides, Asterionella japonica, Skeletonema costatum, and Chaetoceros socialis and the open ocean coccolithophore, Coccolithus huxleyi which is an important component of the winter flora (Hulburt, 1963).

Some species of phytoplankton have salinity preferences which probably serve to limit their distribution. Observations from a number of stations between southern New England and Bermuda (Hulburt and Rodman, 1963) showed that beyond the 183 m line salinities were never below 34.5 o/oo. The distribution of phytoplankton species showed that a majority were most frequently found in low salinity water. The common coastal forms Skeletonema costatum, Coscinosira oestrupi and Prorocentrum micans were not found in salinities of 34.5 o/oo or higher. Diatoms generally had a higher frequency of occurrence at low salinities but were found occasionally at salinities higher than 34.5 o/oo. Species such as Nitzschia closterium, Nitzschia delicatissima, Rhizosolenia stolterfothii, Katodinum rotundatum, Oxytoxum variabile and Syracosphaera pulchra were widely distributed. Only three species were clearly associated with higher salinities: Syracosphaera mediterranea, Coccolithus huxleyi, and Dicosthaera tubifer. Fifty-six species were observed at lower salinities (primarily diatoms) and thirty-one species were observed at salinities greater than 34.5 o/oo.

Hulburt and Rodman's observations bore out the general neritic and oceanic characteristics assigned to many species; however, during periods of blooms in the open ocean, many neritic species were present, especially neritic diatoms. This again demonstrates that neritic species are not completely restricted to the coastal waters and will

Table 7-1. Phytoplankton species taken in single samples from inner and outer slope waters (From Hulburt 1966).

Inner Slope Station	Lat.	Long.	November 1956
	40°00'	71°19'	
Thalassionema nitzschioides			
Nitzschia closterium			
Prorocentrum micans			
Coscinodiscus excentricus			
Thalassiosira nordenskioldii			
Nitzschia delicatissima			
Asterionella bleakleyi			
Coscinodiscus marginatus			
Streptotheca tamensis			
Gyrosigma sp.			
Chaetoceros afinis			
Oxytoxum variable			
Rhizosolenia imbricata *v.* *shrubsolei*			
Dictyocha fibula			
Thalassiosira decipiens			
Leptocylindrus minimus			
Coscinosira oestrupi			
Corethron hystix			
Distephanus speculum			
Rhizosolenia alata			
Ceratium fusus			
Coscinosira polychorda			
Chaetoceros glandazi			
Katodinium rotundatum			
Distephanus speculum			
Skeletonema costatum			
Syracosphaera mediterranea			
Outer Slope Station	38°46'	70°20'	
Discosphaera tubifer			
Coccolithus huxleyi			
Katodinium rotundatum			
Oxytoxum variable			
Trichodesmium thiebautii			
Cyclococcolithus leptoporus			
Rhizosolenia setigera			
Climacodium frauenfeldianum			
Nitzschia closterium			
Mesoporus perforata			
Rhizosolenia alata			
Syracosphaera mediterranea			
Syracosphaera pulchra			
Peridinium trochoideum			
Oxytoxum sphacroideum			
Ceratium fusus			
Prorocentrum rostratum			
Umbellosphaera irregularis			
Gymnodinium punctatum			



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-2	Changes in Percentage of Oceanic Phytoplankton (Coccolithophores and Dinoflagellates) With Distance From the New England Coast (Hulburt, 1966)

appear in any location where the conditions necessary for its flowering exist.

There is little data on how far into the slope waters the shelf diatom flora extend their influence. Presumably, the increased abundance of oceanic species with distance from the shelf (Figure 7-2) would imply a decreased diatom flora. However, as Hulburt (1970) points out, in coastal and open ocean waters there appears to be no competition between phytoplankton species for nutrients, and, therefore, the change to an open ocean dominated plankton from a neritic dominated plankton is not the result of the one group inhibited by the other. It follows, then, that the increased coccolithophore dominated flora in the slope waters does not, in itself, imply a decreased diatom flora.

Hulburt (1964) has examined the spacial succession, species diversity, and dominance that occurred on a transect of stations from the Nova Scotia shelf to St. Thomas (Figure 7-1). Four of the stations in the transects were in slope water. The data showed the northern forms dropping out and the southern forms appearing as the transect crossed the Gulf Stream (Table 7-2).

SPECIES SUCCESSION

The species succession throughout the year in the slope water has not been well defined, although the waters closest to the coast probably follow a pattern of dominance by successive populations of diatom species. Some of the important species can be identified with certain seasons (Hulburt,1963, 1970); Rhizosolenia alata is uniformly distributed in the summer, as is Thalassionema nitzschioides in winter. Other winter species include Skeletonema costatum, Asterionella japonica and Chaetoceros socialis.

VERNAL FLOWERING

The phytoplankton of the slope water does exhibit a brief, but intense, vernal flowering. Average plant pigment concentrations tabulated seasonally (Riley, Stommel, and Bumpus, 1949) for the slope water from data which span the years 1939 to 1947 are shown in Figure 7-3. The phytoplankton maintain a fairly stable monthly abundance except for April, when an intense bloom occurs. The April bloom exceeds the second-ranking month (March) by six times; undoubtedly, the species involved in the bloom were vernal flowering diatoms common to the shelf waters. However, Riley, et al. (1949) did not identify them, nor have these species been clearly identified in other reports. Riley, et al. (1949) point out that the April peak in the slope water was only slightly less than that of Georges Bank and the mid-winter minimum may not be as severe. A relatively high plant pigment value and possibly sporadic summer flowering, which are common to the coastal waters, were recorded in the slope water during the summer of 1947 (Riley and Gorgy, 1948).

Table 7-2. Succession of phytoplankton species, across and transect from the Nova Scotia Shelf to Bermuda (modified from Hulburt, 1964).

	Shelf and Slope						Gulf Stream-Bermuda				
Latitude	42°30'	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°
Temperature °C	1.57	3.45	7.86	9.35	13.82	13.79		18.80	18.65	18.94	18.82
NH_4, µg. at./l	0.90	2.45		1.20	0.71	0.60		0.50	0.41	0.53	1.61
$NO_2 + NO_3$, µg. at./l	3.28	2.81		2.50		4.02		1.18		1.01	
PO_4 µg. at./l.	0.74	0.53		0.33		0.32		0.10		0.09	
Number per cc.	330.2	118.4	1068.0	35.6	109.5	97.0		9.6	21.9	13.8	23.5

Distribution of Diatoms

	42°30'	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°
Lauderia borealis Gran	6										
Chaetoceros debilis Cleve	37	13									
Chaetoceros socialis Lauder	228										
Thalassiosira gravida Cleve	136	37									
Tropidoneis antarctica v. *polyplasta* Gran & Angst	5	11	118	79	136	74		1	1		
Chaetoceros atlanticus Cleve	7	5									
Skeletonema costatum (Grev.) Cleve	14	4				9					
Coscinosira polychorda Gran	6										
Leptocylindrus minimus Gran	6					2					
Chaetoceros convolutus Castracane	13										

Table 7-2. (Cont.)

Latitude	Shelf and Slope 42°30'	42°	41°	40°	39°	38°	Gulf Stream-Bermuda 37°	36°	35°	34°	33°
Chaetoceros compressus Lauder	6	28									
Thalassiosira decipiens (Grun.) Jorg.	12	16				1					
Nitzschia closterium (Ehb.) W. Smith	2	1			2	2			3	3	
Chaetoceros subsecundus (Grun.) Hustedt	14										
Coscinodiscus concinus W. Smith	1										
Thalassiosira nordenskioldii Cleve	57										
Leptocylindrus danicus Cleve	5				1						
Shroederella sp.	17										
Chaetoceros laciniosus Shutt	8										
Nitzschia seriata Cleve	2	1	27		6				3	1	
Rhizosolenia alata Brightwell	4										
Nitzschia delicatissima Cleve					32	10					9
Rhizosolenia stolterfothii H. Peragallo								3			
Rhizosolenia delicatula Cleve											22
Chaetoceros glandazi Mangin											2

Table 7-2. (Cont.)

		Shelf and Slope					Gulf Stream-Bermuda				
Latitude	42°30′	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°
Cerataulina bergonii H. Peragallo											2
Hemiaulus hauckii Grunow											
Chaetoceros pendulus Karsten											
Rhizosolenia imbricata v. *shrubsolei* (Cleve) Schroder											
Cyclotella nana Hustedt											
Hemiaulus membraneus Cleve											
Dactyliosolen mediterraneus H. Pergallo											
Undetermined pennate diatoms	40					2		1	1		

Table 7-2. (Cont.)

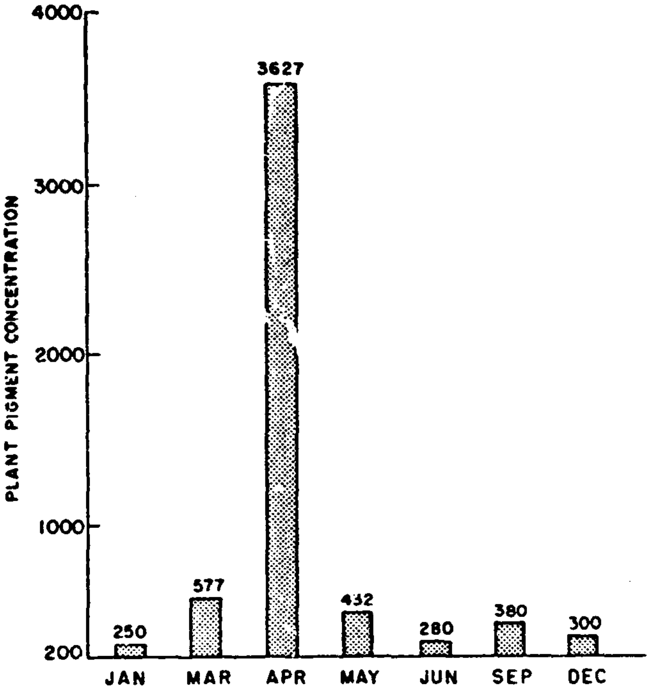
DISTRIBUTION OF FLAGELLATES

Number of cells counted. C indicates coccolithophore and D dinogflagellate

Latitude		42°30′	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°
Gymnodinium splendens Lebour	D		1									
Chilomonas marina (Braarud Halldall)			3									
Cyclococcolithus leptoporus (Murray) & Blackm.) Kamptner				10	2	12	1		3	2	2	4
Ceratium minutum Jorgensen	D			1			1					
Coccolithus huxleyi (Lohm.) Kamptner	C			3	1	4	9		39	84	68	89
Carteria sp.				2	1					5		
Mesoporus perforatus (Gran) Lillick	D			4	1							
Ceratium longipes (Bailey) Gran	D				1							
Oxytoxum variable Schiller	D				1	2	6				2	
Eutreptia marina (da Cunha) Perty						1	2					
Gymnodinium punctatum Pouchet	D					3	1		4	18	6	
Coccolithus pelagicus (Wallich) Schiller	C					4	12					
Rhodomonas sp.						1						
Dictyocha fibula Ehrenberg						1	3			1	1	
Pontosphaera syracusana Lohmann	C					1					L	
Prorocentrum obtusidens Schiller	D						6					
Amphidinium longum Lohmann	D						1					
Distephaus speculum (Ehb.) Haeckel							1		1			
Ceratium tripos (O. F. Miller Nitzsch	D						1					
Acanthoica acanthifera Lohmann	C						3					
Umbilicosphaera mirabilis Lohmann	C								1			

Table 7-2. (Cont.)

		42°30′	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°
Syracosphaera mediterranea Lohmann	C								3		1	2
Gyrodinium wulfii Schiller	D								1			
Katodinium rotundatum (Lohmann) Fott	D								1	3	3	
Pphiaster hydroideus (Lohmann) Gran	C								1	1		
Undetermined Crysophycean flagellate, 4-7μ, single sp.										30	6	14
Thoracosphaera heimii (Lohmann) Kampt.	C									5	2	
Najadea gloriosa Schiller ?	C									1		
Michaelsarsia elegans Grans	C										1	
Oxytoxum scolopax Stein	D											1
Rhabdosphaera tubulosa Schiller	C											
Ceratium fusus (Ehb.) Dujardin	D											
Ceratium teres Kofoid	D											
Prorocentrum lebourae Schiller	D											
Undeterminable		9	42	36	19	18	31		12	6	6	6
Undetermined dinoflagallate		6		3		1	9					9
Undetermined coccolithophore						1			1	1		17



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-3 Seasonal Flowering of Phytoplankton from Average Plant Pigment Concentrations Measured Between 1939 and 1947 (Riley, et al., 1949)

DOMINANCE AND DIVERSITY

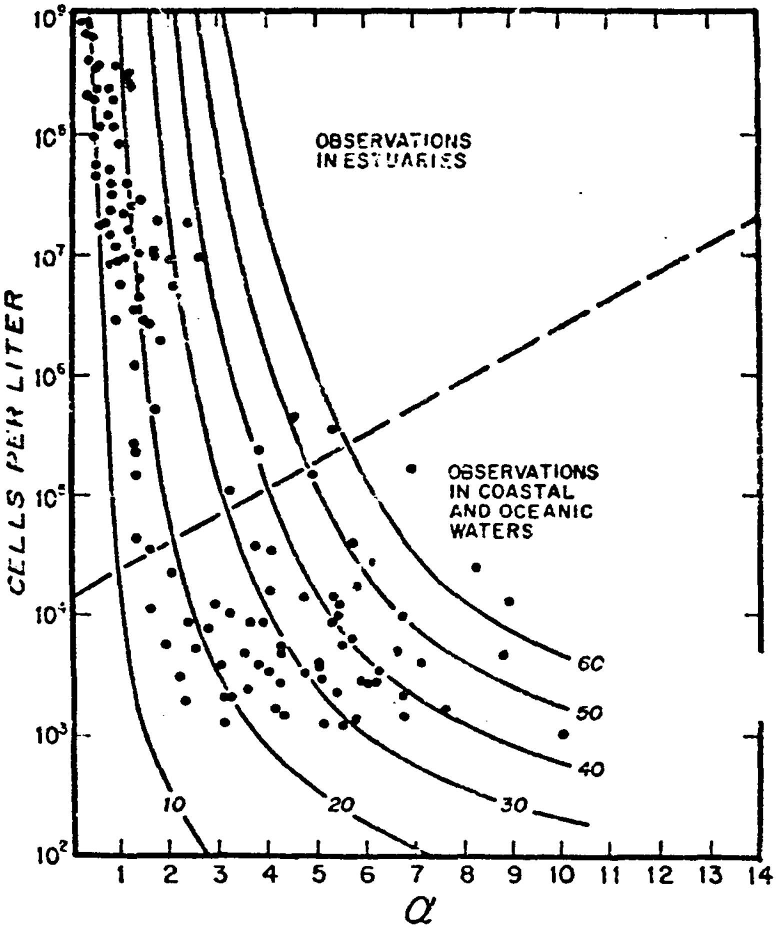
Dominance and diversity of phytoplankton in the northwest Atlantic are interrelated phenomena that have been studied extensively by Hulburt (1963, 1964, 1970). Generally, the estuarine regions provide excellent growing conditions for a few species which tend to be extremely sucessful and dominate the plankton. In open ocean areas, the growing conditions are poorer; but the greater water depth and higher salinity encourage a larger number of species. Therefore, the inshore areas favor low diversity and high populations, while the open ocean favors high diversity and low populations (Figure 7-4). The slope and coastal waters offer an intermediate situation; here there is a pronounced dominance in small samples of populations and a relatively high diversity in larger samples.

STANDING CROP

The standing crop of phytoplankton is a balance at any point in time between the growth of the population through the photosynthetic process and its decimation through the sinking of cells below the euphotic zone or grazing by predators. Abundance values for phytoplankton are usually derived from either counts of net phytoplankton, i.e., cells per cc, or the measurement of the concentration of plant pigment in the water, i.e., Harvey units per m^3.

The abundance of cells in the surface zone of the slope water was summarized by Riley, Stommel, and Bumpus (1949) from all studies previous to that time and from more recent sampling by Hulburt (1966). This data is given in Table 7-3 along with comparative data from the shelf and open ocean (Sargasso Sea). In all cases, the abundance of surface phytoplankton in the slope water was noticeably lower than that of the shelf water and higher than that of the open ocean waters of the lower latitudes. The larger, highly variable quantities of phytoplankton typical of the surface zone in continental shelf waters is somewhat modified in the slope water, probably through the influence of the smaller, less variable quantities of phytoplankton found in the open ocean. Hulburt (1966) has illustrated the difference in frequency distribution of phytoplankton concentration in the upper ten m of water between shelf and slope sampling locations off southern New England. The higher frequency of lower cell counts indicates the lower abundance found in the slope waters (Figure 7-5).

Riley (1939) has shown the vertical distribution of phytoplankton from a slope water station adjacent to the continental shelf and a station near the outer boundary (Figure 7-6). The inner station shows more shelf characteristics having higher surface abundance (8300 Harvey units per m^3) with the phytoplankton disappearing at about 100 m. The outer slope station has relatively fewer surface phytoplankton (3200 Harvey units per m^3) but cells are found at a greater depth (200 m). This



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-4 Population Size and Diversity from Estuarine, Coastal, and Oceanic Populations (Hulburt, 1963)

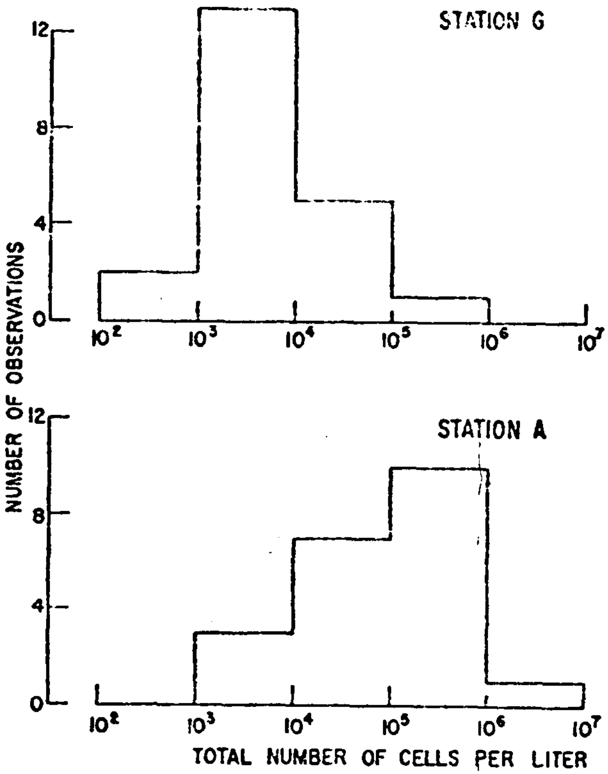
Table 7-3. Abundance values recorded for continental slope stations using net phytoplankton and plant pigment concentrations

Net Phytoplankton Cells/cc

	Shelf	Slope	Oceanic	
Average	230	20	3.45	Hulburt (1966)
Range	6.5-1886	0.14-209	-	21 Samplings (1956-1963)

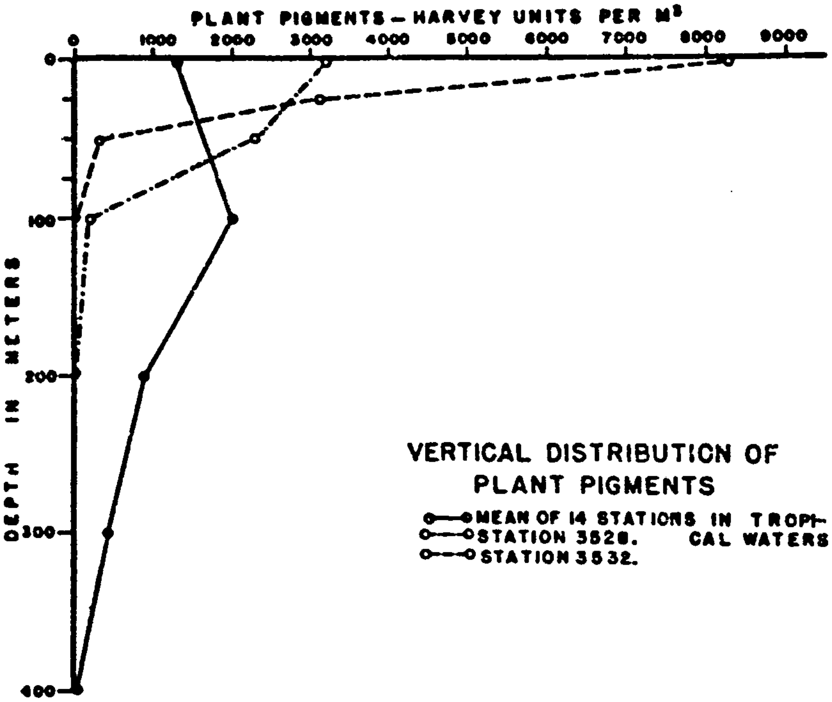
Plant Pigments/m^3 (Harvey Units)

	Shelf	Slope	Oceanic	Riley et al. (1949) Seasonal Averages
Range	2500-45,000	1000-23,000	140-1900	



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-5 Distribution of Phytoplankton Concentrations in Coastal (A) and Slope Water (G) Stations Off Southern New England (Hulburt, 1966)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-6 Depth Distribution of Plant Pigments for Two Slope Stations: 3532, Inner Slope Center; 3528 Outer Slope Water (Riley, 1939) illustrates the transition in terms of vertical abundance between coastal characteristics and open ocean characteristics within the slope water.

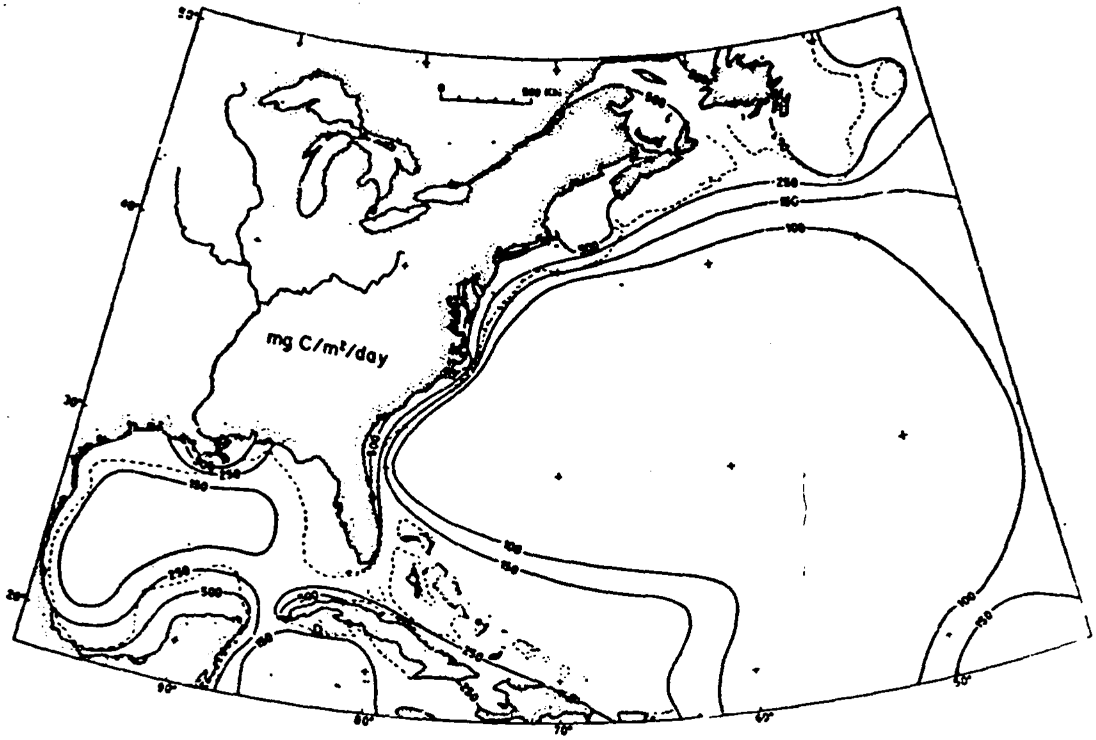
Riley, Stommel, and Bumpus (1949) have suggested that, excluding short vernal flowering periods, the total phytoplankton crop under a square meter of water in the offshore, lower latitude waters of the western North Atlantic are not much different from the rich boreal areas, such as the Gulf of Maine. Although the average numbers per cubic meter for the surface concentration were less in the offshore waters, the production depth was greater. Their data show that the total population for the year is about the same between the slope water and Georges Bank.

7.1.3 PRODUCTIVITY

Primary productivity is the rate at which photosynthesis occurs in phytoplankton populations; it reflects the dynamic qualities of growth and production, as opposed to the static qualities of standing crop. Productivity is measured in a variety of ways: the quantity of carbon dioxide used in photosynthesis, the amount of oxygen released, the removal of dissolved nutrients, the assimilation of carbon, or the quantity of chlorophyll in the water. A number of interrelated factors determine productivity: the amount and intensity of subsurface illumination affects the photosynthetic rate, as does the amount of available nutrients; temperature is important when it establishes a thermocline, which in turn controls the flow of nutrients from deeper waters to the euphotic zone.

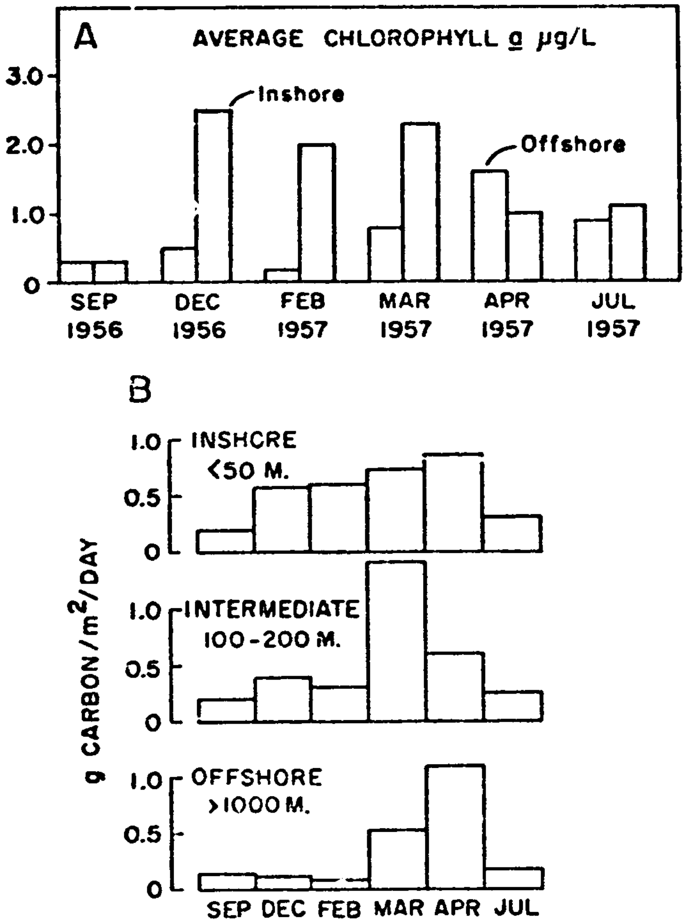
Emery and Uchupi (1972) summarized productivity values for the western North Atlantic in terms of milligrams of carbon per square meter per day (Figure 7-7). Their data show a gradient of productivity values from over 500 milligrams per meter squared per day in the highly productive Gulf of Maine area to less than a hundred in the open ocean. The slope water values fall between 150 and 250 mg of carbon per square meter per day.

Ryther and Yentsch (1958) and Ketchum, Ryther, Yentsch, and Corwin (1958) examined productivity of phytoplankton in the shelf and slope areas off the New York Bight, primarily by relating chlorophyll A concentrations to the photosynthetic rate. Figure 7-8 shows the seasonal productivity rate for inshore and offshore slope stations from Ryther and Yentsch (1958) and Yentsch (1963) as presented by Smayda (1973). These authors demonstrated that the range of daily primary production beneath a square meter of sea surface was not much different between the coastal (0.20 to 0.85 gc/m^2/day) and slope (0.10 to 1.10 gc/m^2/day) stations and that during the flowering in April, slope productivity can exceed that of the shelf waters. Ryther and Yentsch point out, however, that total production over a year would be considerably higher in the inshore waters because of the higher production rates sustained seasonally. The offshore waters, occasionally enriched with nutrients and



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-7	Primary Production in the Western North Atlantic (Emery and Uchupi, 1972)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-8 Primary Production in Shelf and Slope Water Off New York (Ryther and Yentsch, 1958; Yentsch, 1963) with a relatively deep euphotic zone, can sustain relatively high carbon production for short periods. However, constant enrichment of inshore waters and a greater and longer spring flowering gives a greater total amount of production. Comparison of total annual production rates for various waters in the northwest Atlantic are given in Table 7-4.

7.1.4 ECOLOGICAL RELATIONSHIPS

LIGHT

Light, almost exclusively, regulates the vertical distribution of phytoplankton by regulating the depth of the photosynthetic zone (Smayda, 1958). The rapid absorption and scattering of light with depth limits the production of phytoplankton to a relatively shallow surface band which will vary in depth according to the intensity of radiation, turbidity, latitude, and season. The photosynthetic zone may extend down to 100 m in tropical waters, while in northern latitudes it may go down less than 50 m in the summer and only a few meters in the winter (Raymont, 1963). Production of phytoplankton is limited to waters above the compensation depth; that is, the depth at which the rate of photosynthesis equals the rate of respiration. Below this depth the cells loose more through respiration than they gain by photosynthesis and production does not take place.

In the northwest Atlantic, the photosynthetic zone and compensation depth increase with distance from shore. Average transparency values (Table 7-5) for the shelf, slope, and open ocean waters, given by Riley, Stommel, and Bumpus (1949), show the increased transparency of the waters as one goes seaward. As it is in other respects, the slope water is an intermediate region with greater transparency and photosynthetic depth than the shelf waters and less than the oceanic waters. From Figure 7-3, the vertical distribution of plant pigments in the slope water indicates that phytoplankton may be found in 100 to 200 m in depth. However, maximum photosynthetic activity occurs at a shallower depth. Yentsch (1974), using chlorophyll (micrograms per liter) and nitrate-nitrogen to indicate photosynthetic activity, demonstrated that on a transect from Cape Cod to Bermuda in July, the depth of maximum photosynthetic activity in the slope water was about 50 m (Figure 7-11).

NUTRIENTS

The role of nutrients in the production of phytoplankton geographically and seasonally is well documented (Raymont, 1963; Ketchum et al., 1958; Yentsch, 1963). Phosphorus, nitrogen, iron, and manganese in usable form have been demonstrated as limiting factors for cell growth (Yentsch, 1963; Ryther and Kramer, 1961). In the offshore areas, phytoplankton obtains the nutrients necessary for growth through the return of nutrients from deep water, enriched by the oxidation of sinking organic matter, into the depleted photosynthetic zone. In contrast to

Table 7-4. Total annual production rates (carbon fixation) for various waters in the northwest Atlantic in grams per square meter of sea surface (after Ryther and Yentsch 1958)

	Depth (Meters)	m^2/Yr.
Long Island Sound	25	380
Continental Shelf	25 - 50	160
Continental Slope	50 - 100	135
Continental Slope	1000 - 2000	100
North Central Atlantic Sargasso Sea	75,000	78

Table 7-5. Transparency in terms of extinction coefficients (K) of visible light area as summarized by Riley, Stommel, and Bumpus (1949)

	K(Range)
Continental Shelf Water	.110 - .150
Continental Slope Water	.050 - .100
Sargasso Sea	.042 - .066

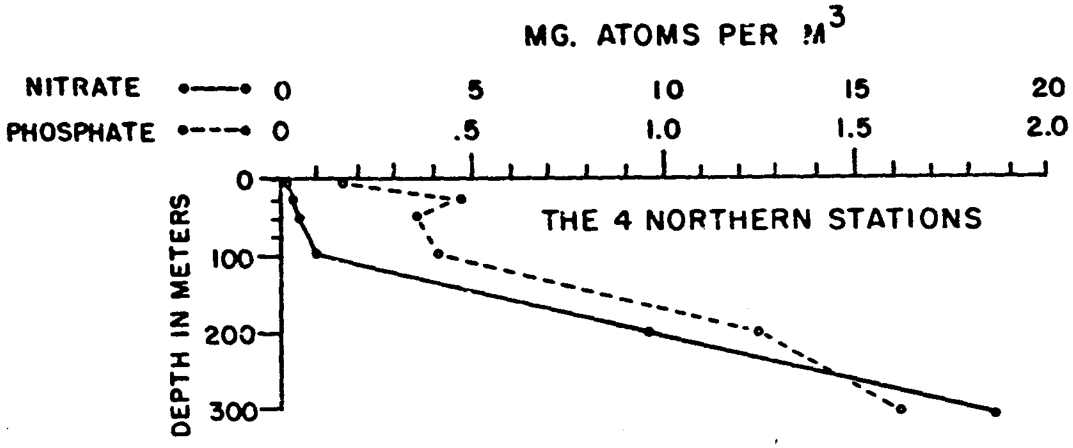
the shelf areas, where nutrients are continually being added and mixed into shallow, turbulent waters, the deeper water of the slope and open ocean generally have lower nutrient concentrations.

Riley (1939) showed the characteristic depth distribution of nutrients from two shelf and two slope stations (Figure 7-9). The depleted surface zone where active photosynthesis was taking place is in contrast with the nutrient rich deeper waters. In slope waters, the site of maximum decomposition of organic matter is about 250 m (Redfield, 1936). Ketchum, et al., (1958) have indicated that the nutrient impoverished offshore areas (slope water) result in physiological differences between inshore and offshore phytoplankton. Results of their light and dark bottle experiments (Figure 7-10) show differences in the ratio of net to gross photosynthesis; high ratios in September and December indicated healthy, growing populations while lower ratios in December and March indicated less healthy populations. Geographically, the low ratio of offshore populations indicates poorer physiological conditions. Ketchum, et al., (1958) suggest that this variation of net:gross photosynthesis ratios may be the result of nutrient deficiencies, particularly in the offshore waters.

UPWELLING

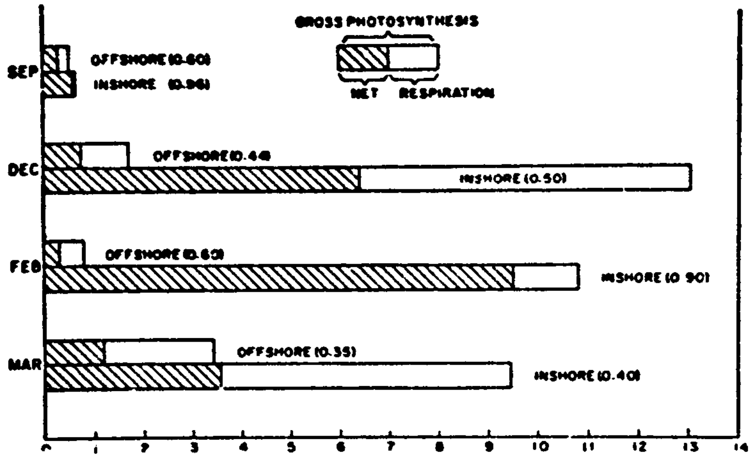
The coastal processes that return nutrients to the surface zone, i.e., wind, tides, and seasonal breakdown of thermoclines, are ineffective beyond the shelf break. The continual sinking of organic matter below the euphotic zones and its decomposition builds up nutrient concentrations at depths of from 200 m (Figure 7-9) to 800 to 1,000 m (Redfield, 1936). In order for production to continue in the surface zone, some process of nutrient renewal is necessary. In the northwest Atlantic, a possible process by which this might take place was suggested by Redfield (1936), who recognized the significance of Rossby's (1936) theories of water movement resulting from the action of the Gulf Stream. The effect of the Gulf Stream on the Northern Hemisphere water mass, Rossby theorized, was to absorb water into the right hand side of the stream and to eject it into the slope water on the left hand side, contributing a large volume of water to the slope area. Because this movement would follow along lines of equal density, which angle sharply towards the surface across the Gulf Stream, the effect would be to draw deep Sargasso Sea water into the surface zone of the slope water. Redfield recognized that this could provide a potential pathway by which nutrients from the deep water of the Atlantic basin would be transported to slope and shelf waters.

Pursuing this idea, Yentsch (1974) presented evidence that correlated the distribution of primary production, nitrate-nitrogen, and density (Sigma T) at the "cold wall" - the sharp temperature gradient between the slope water and the Gulf Stream. He presented the vertical distribution of temperature, salinity, density, nitrate-nitrogen, and



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-9	Vertical Distribution of Nitrate and Phosphate at Two Shelf and Two Slope Stations (Riley, 1939)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-10	Comparison of Gross and Net Photosynthesis Between Inshore and Offshore Stations (Ketchum, et al., 1958)

chlorophyll from a cruise that transected the waters from Cape Cod to Bermuda in July, 1963 (Figures 7-11 through 7-13). The surfacing of lines of equal density (i.e., Sigma T26.0) allowed the relatively high values of nitrate-nitrogen (5 to 10 microgram atoms per liter) that lay in the water of 200 to 600 m to the right of the Gulf Stream to move up to about 50 m in the slope water. Correlated with high nitrate-nitrogen values at 50 m were relatively high concentrations of chlorophyll, indicating high phytoplankton production.

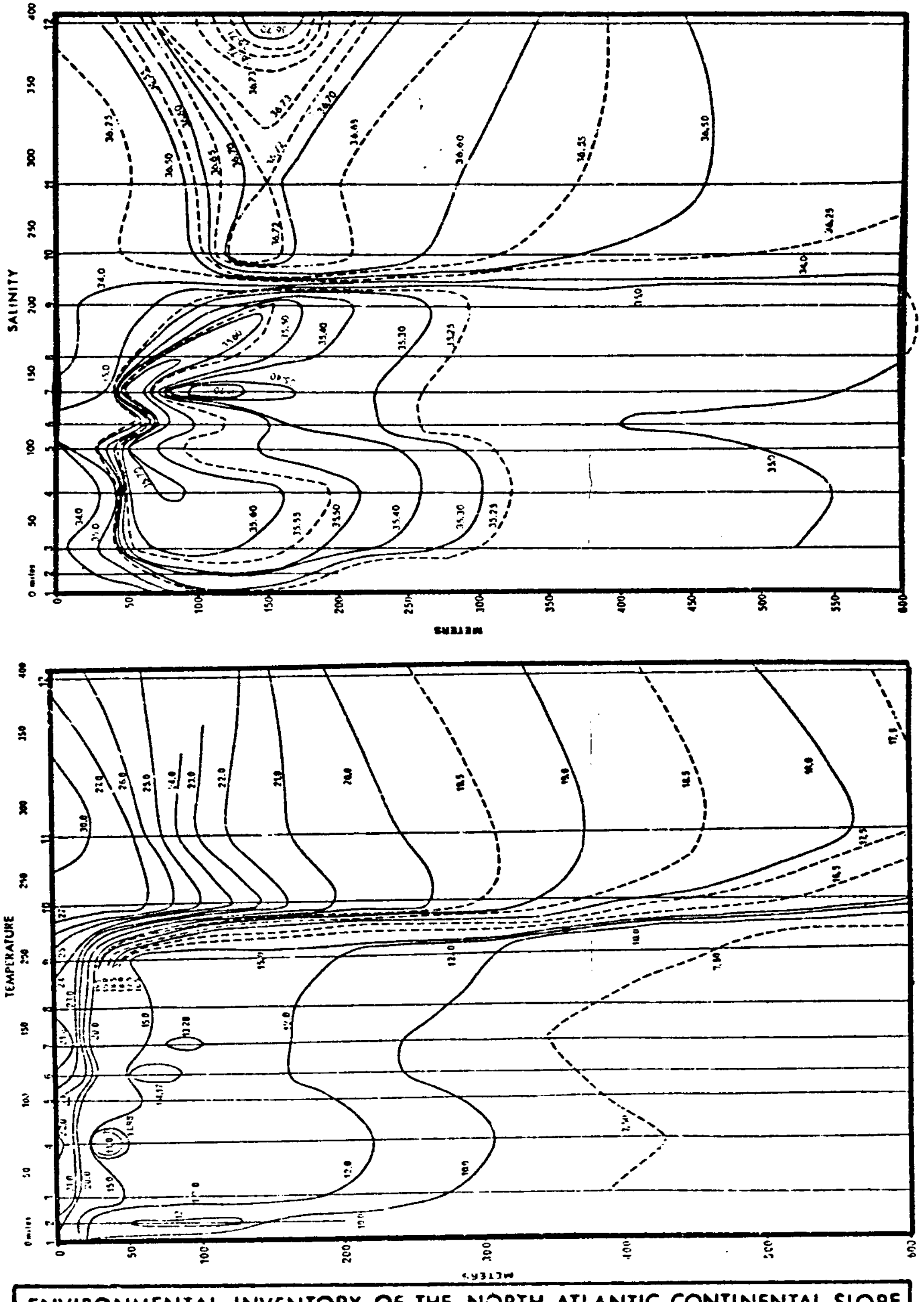
Yentsch contrasts this phenomenon, which he terms geostrophic upwelling, with the wind-driven upwelling that is common in other parts of the world. The characteristics of geostrophic upwelling are the slow surfacing of nutrient rich water into the euphotic zone with maximum production occurring below the surface; whereas wind-driven upwelling creates a sudden reservoir of nutrient rich water at the surface. Yentsch considers geostrophic upwelling to be the most important factor in transporting nutrient-rich deep ocean water into the euphotic zone of the slope and shelf areas.

An interesting corollary is the effect of cold, upwelled water on the species composition of the phytoplankton in the slope waters south of the Grand Banks. Hulburt (1975) observed a marked change in the distribution of phytoplankton species in a cold tongue of low salinity water adjacent to a southeastward bending portion of the Gulf Stream. The change was characterized by a group of species produced in the cold tongue and a group produced in the warmer oceanic currents on either side. Hulburt suggests one of the conditions necessary for such a change was the penetration of deep water with high nutrient value (in this case 10 to 19 and 1.27 to 1.65 microgram atoms of nitrate-nitrogen and phosphate was likely contained in the cold water) from depths of 400 to 500 m into the surface zone. It is obvious that the upwelling of nutrient rich water in the slope area is of great significance to the phytoplankton there.

7.1.5 POLLUTION EFFECTS

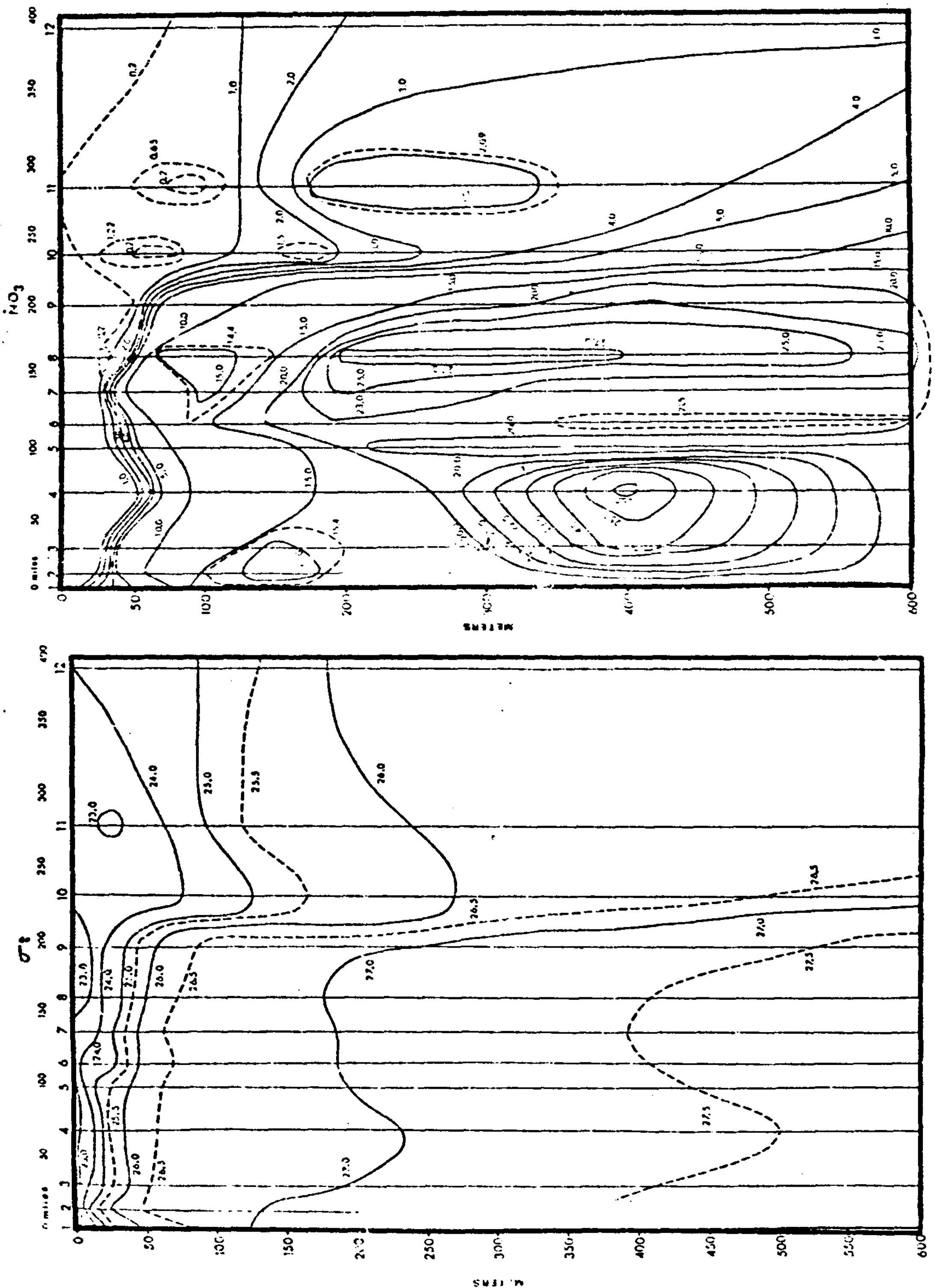
The response of natural populations of phytoplankton to actual or potential pollutants in the northwest Atlantic area is not clearly understood. This is particularly true in the slope water where the phytoplankton has not been systematically studied and where the nature and concentrations of pollutants is not well documented.

Marshall (1974) has reviewed what is known of the relations between phytoplankton and oil pollution in the continental shelf area. He describes two pathways by which oil pollution may have an impact on phytoplankton communities: by direct toxic effect on the flora or, theoretically, by entry into the organism, later resulting in incorporation into the food chain. The toxic effect of oils may reduce the photosynthetic rate, act as a screen to certain light waves, or damage



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-11	Distribution of Temperature and Salinity Across the Gulf Stream Between Cape Cod and Bermuda July, 1963 (Yentsch, 1974)

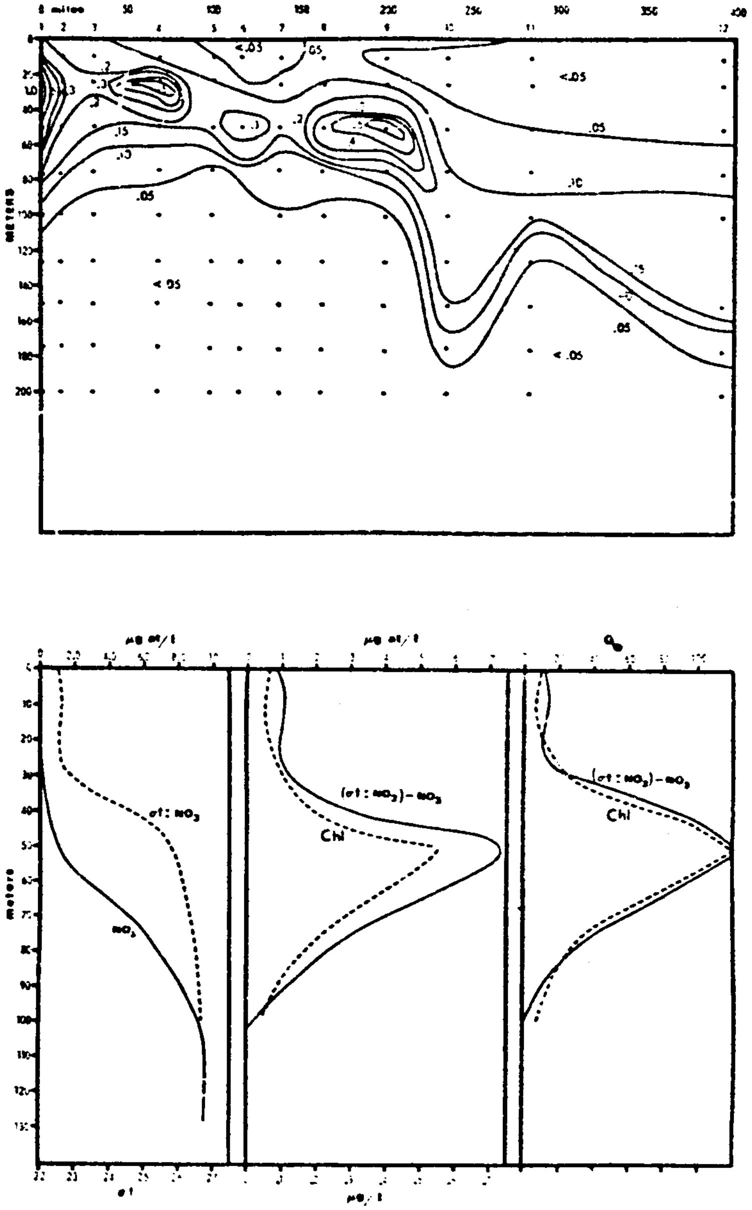


ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-12

Distribution of Density and Nitrate-Nitrogen Across the Gulf Stream Between Cape Cod and Bermuda (Yentsch, 1974)



The slope water/Gulf Stream boundary is at station 9 (200 miles).

FIGURE 7-13 Distribution of Chlorophyll and its Relationship to Nitrate-Nitrogen Across the Cape Cod Bermuda Transect (Yentsch, 1974) cell membranes or internal structures. He notes that the presence of various hallogenated hydrocarbons has been documented in the north Atlantic waters; however, neither in situ data nor laboratory controlled experiments are far enough along to clearly indicate the impact of concentrations on the phytoplankton flora.

Even though no solid data exists concerning pollution impacts on slope water phytoplankton, there is a theoretical consideration for which some evidence does exist, and this should be taken into account when considering pollution impacts in any of the waters beyond the continental shelf. Fisher, Graham, and Carpenter (1973) have noted that while it has been generally demonstrated that the phytoplankton are sensitive to chlorinated hydrocarbons (i.e., DDT and PCB's), little is known of the capacity of organisms from various plankton communities to adapt to contamination. There are indications of physiological races within species of phytoplankton and these races may have ecological adaptations which are quite different between oceanic areas (i.e., continental shelf and Sargasso Sea). There is also evidence to suggest that organisms adapted to a conservative environment (i.e., Sargasso Sea) should be more sensitive to environmental stress. Fisher, et al., (1973) tested the sensitivity of three phytoplankton isolates of the species, Bellerochia sp., Fragiliara pinnata, and Thalassiosira pseudonana (from estuarine, outer shelf and open ocean locations); their results show that growth of cells in all experiments diminished with PCB treatment, and that algal sensitivity (in terms of reduced growth) increased with distance from shore. They suggest that estuarine-coastal phytoplankton may be better equipped to cope with abiotic environmental stresses than those found in the open ocean.

Beyond this point, discussion of the relation of the relative sensitivity of slope water phytoplankton to environmental stress becomes more speculative. However, considering the mixed nature of the slope water communities and assuming the hypothesis of increased sensitivity with distance from shore, the slope phytoplankton community, at least the ocean component, must be considered more sensitive and, therefore, more vulnerable to hydrocarbon contamination.

7.1.6 DATA GAPS

The lack of a broad sampling program that covers the slope water area on a seasonal basis is the reason for some limitations to the information available concerning phytoplankton. Temporal sampling has produced some seasonal analysis of productivity and abundance, but even here the collection of data was limited to small areas of the slope. Further, there is still much to be learned concerning nutrient recycling and renewal in oceanic waters.

The floristic work that has been so ably accomplished by Hulburt and others has been carried out in the northwest Atlantic in general and has not emphasized the slope region, nor has it been carried out on a seasonal basis.

Therefore seasonal information on the variations, diversity and succession of phytoplankton in the slope water in the study region is largely lacking.

Considering the variable nature of pelagic conditions in the slope water region: the high degree of species mix, the wide range in hydrographic conditions and the variable inputs from regions outside the slope water (see Chapter 4.0, Physical Oceanography; Chapter 6.0, Chemical Oceanography; and Chapter 7.2 Zooplankton), it is obvious that a complete analysis of species composition, diversity and succession of phytoplankton and its productivity and nutrient cycles on both an aerial and a seasonal basis will only result from intensive sampling programs designed for that specific purpose.

7.1.7 REFERENCES

Bigelow, H.B. 1914. Oceanography and plankton of Massachusetts Bay and adjacent waters, Nov. 1912, May 1913. Bull. Mus. of Comp. Zool. Harvard College, 58(10): 385-419. Cambridge.

________. 1914b. Explorations in the Gulf of Maine, July and August, 1912, by the U.S. Fishery Schooner GRAMPUS: Oceanography and notes on the plankton. Bull. Mus. of Comp. Zool. Harvard College, 58(2): 29-147. Cambridge.

________. 1915. Exploration of the coast water between Nova Scotia and Chesapeake Bay, July and August 1913 by the U.S. Fisheries Schooner GRAMPUS: Oceanography and plankton. Bull. Mus. of Comp. Zool. Harvard College, 59: 149-360. Cambridge.

________. 1917. Exploration of the coast water between Cape Cod and Halifax in 1914 and 1915 by the U.S. Fisheries Schooner GRAMPUS: Oceanography and plankton. Bull. Mus. Comp. Zool. Harvard College, 61: 161-358.

________. 1922. Exploration of the coastal water off the northeastern United States in 1916 by the U.S. Fisheries Schooner GRAMPUS. Bull. Mus. Comp. Zool., Harvard College, 65(5): 87-188.

________. 1926. Plankton of the offshore waters of the Gulf of Maine. Bull. Bur. Fisheries, 40: 1-509.

Bigelow, H.G., L.C. Lillick, and M. Sears. 1940. Phytoplankton and plankton protozoa of the offshore waters of the Gulf of Maine, Part I: numerical distribution. Trans. Amer. Philos. Soc., 31: 149-191.

Braarud, T. 1934. A note of the phytoplankton of the Gulf of Maine in the summer of 1933. Biol. Bull., 67: 76-82.

Emery, K.O. and E. Uchupi. 1972. Western North Atlantic Ocean: topography, rocks, structure, water life and sediments. Amer. Ass. Petrol. Geol. Mem. 17. 532 p.

Fisher, N.S., L.B. Graham, E.J. Carpenter and C.F. Wurster. 1973. Geographic differences in phytoplankton sensitivity to PCB's. Nature, 241: 548-549.

Fournier, R. 1967. North Atlantic deep sea fertility. Ph.D. Diss. Univ. of Rhode Island, Kingston.

Gran, H.H. 1933. Studies of the biology and chemistry of the Gulf of Maine, II: distribution of phytoplankton in August 1932. Biol. Bull, 64: 159-182.

Gran, H.H. and T. Braarud. 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry, and turbidity) J. Biol. Bd. Can., 1(5): 279-467.

Hulburt, E. M. 1963. The diversity of phytoplankton populations in oceanic coastal and estuarine regions. J. Mar. Res., 21(2): 81-93.

________. 1964. Succession and diversity in the plankton flora of western North Atlantic. Bull. Mar. Sci. Gulf and Caribbean, 14(1): 33-34.

________. 1966. The distribution of phytoplankton and its relationship to hydrography between southern New England and Venezuela. Sears Found. J. Mar. Res., 24(1): 67-81.

________. 1967. A note on regional differences in phytoplankton during a crossing of the southern North Atlantic Ocean. Deep-Sea Res., 14(6): 685-690.

________. 1970. Competition for nutrients by marine phytoplankton in oceanic, coastal, and estuarine regions. Ecology, 51: 475-484.

________. 1975. Necessary and sufficient conditions for phytoplankton changes in the vicinity of the Grand Banks. Bull. Mar. Sci., 25(1): 1-8.

Hulburt, E.M. and R.S. MacKenzie. 1971. Distribution of phytoplankton species at the western margin of the North Atlantic Ocean. Bull. Mar. Sci., 21(2) 603-612.

Hulburt, E.M. and J. Rodman. 1963. Distribution of phytoplankton species with respect to salinity between the coast of southern New England and Bermuda. Limnol. Oceanogr., 8: 263-269.

Iselin, C. O'D. 1936. A study of the circulation of the western North Atlantic. Pap. Phys. Oceanogr. Meteorol., 4(4): 1-101.

Ketchum, B.H., J.H. Ryther, C.S. Yentsch, and N. Corwin. 1958. Productivity in relation to nutrients. Rapp. Proc.-Verb. Cons. Int. Explor. Mer., 144: 132-140.

Lillick, L.C. 1938. Preliminary report of the phytoplankton of the Gulf of Maine. Amer. Midl. Natur., 20: 624-640.

________. 1940. Phytoplankton and planktonic protozoa of the offshore waters of the Gulf of Maine. Part II: qualitative composition of the plankton flora. Trans. Amer. Phil. Soc., 31(part 3): 149-191.

Marshall, H.G. 1974. Phytoplankton studies in the coastal waters between Cape Hatteras and the Gulf of Maine. In: Marine environmental implications of offshore oil and gas development in the Baltimore Canyon region of the mid-Atlantic coast. Proceedings of Estuarine Research Federation Outer Continental Shelf Conference and Workshop, p. 265-276.

Raymont, J.E. 1963. Plankton and productivity in the oceans. MacMillan Co., New York. 660 p.

Redfield, A.C. 1936. An ecological aspect of the Gulf Stream. Nature, 128(2303): 1013.

Riley, G.A. 1939. Plankton studies, II: the western North Atlantic, May-June, 1939. J. Mar. Res., 2: 145-162.

Riley, G.A. and S. Gorgy. 1948. Quantitative studies of summer plankton populations of the western North Atlantic. J. Mar. Res., 7(2): 100-121.

Riley, G.A., H. Stommel, D.F. Bumpus. 1949. Quantitative ecology of the plankton of the western North Atlantic. Bull. Bingham Oceanogr. Collect., 12(3): 1-169.

Rossby, C.G. 1936. Dynamics of steady state ocean currents in the light of experimental fluid mechanics. Pap. Phys. Oceanogr. Meteorol., 5.

Ryther, J.H. and C.S. Yentsch. 1958. Primary production of continental shelf waters off New York. Limnol. Oceanogr., 3: 227-235.

Ryther, J.H. and D.D. Kramer. 1961. Relative iron requirement of some coastal and offshore plankton algae. Ecology, 42: 444-446.

Smayda, T.J. 1958. Biogeographical studies of marine phytoplankton. Oikos, 9: 158-191.

________. 1973. A survey of phytoplankton dynamics in the coastal waters from Cape Hatteras to Nantucket. In: Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. Univ. of R.I., Kingston, p. 3-1 to 3-100.

Yentsch, C.S. 1963. Primary production. Oceanogr. Mar. Biol. Annu. Rev., 1: 157-175.

________. 1974. The influence of geostrophy on primary productivity. Tethys, 6(1-2): 111-118.

CHAPTER 7.0

BIOLOGICAL OCEANOGRAPHY

7.2 ZOOPLANKTON

STANLEY CHENOWETH

CHAPTER 7.2 TABLE OF CONTENTS

7.2 ZOOPLANKTON

7.2.1 INTRODUCTION

The floating animal portion of the plankton includes a wide variety of phyla and practically all of them make a contribution to the zooplankton of the slope waters. In this region, the zooplankton is dominated by herbivorous crustacea (copepods, euphausiids, amphipods, and decapods) that graze on the cells of the plant plankton, thereby representing the second trophic level of the food chain. Of the crustaceans, the copepods are the dominant group. Other principal zooplankton groups are: protozoans (especially the planktonic foraminifera), chaetognaths, coelenterates, molluscs, nemerteans, and chordates.

The zooplankton are probably more easily defined biogeographically than the phytoplankton. Many species are planktonic only during their larval stage and are closely identified with coastal areas. They are better known taxonomically and are therefore more easily identified geographically. Further, several groups (i.e., foraminifera, copepods) are known to be closely associated with physical characteristics of the water mass and are considered as indicator species. The terms neritic and oceanic, as applied to plankton communities, are particularly applicable to the zooplankton. Raymont (1963) summarizes the characteristics of both groups as:

Neritic - Composed of many meroplanktonic forms that are restricted to the shelf waters within the 200 m isobath.

Oceanic - Mostly holoplanktonic with widely distributed species. Usually restricted to water masses, with temperature the main factor controlling their distribution.

There are two distinct zooplankton communities in the northwest Atlantic which are separated by the Gulf Stream. The sharp pressure gradient between the slope waters and the Sargasso Sea (Iselin, 1936) maintains the unique hydrography of each area and results in a sharp break in zooplankton communities between boreal-temperate and subtropical species. The marked faunal change that occurs as the temperate species of the shelf-slope waters are replaced at the cold wall by the Gulf Stream-Sargasso Sea assemblages may represent one of the most distinct faunal boundaries in the North Atlantic (Cifelli, 1962). The Calanus community predominates north of the Gulf Stream. It is dominated by various species of calanoid copepods in an area from the slope cold wall bordering the Gulf Stream to the inshore areas of the continental shelf and from Cape Hatteras to the northern boreal regions of the Atlantic.

To the north there is a less definite boundary at the shelf break. The neritic zooplankton community, with many meroplanktonic forms characteristic of the shallow shelf, changes gradually to an oceanic community across the slope waters. Thus, the slope water is a transition zone for the zooplankton communities as it is for other animal and plant groups.

The literature that concerns the zooplankton of the slope waters is somewhat less fragmented than that of the phytoplankton. There have been several fairly comprehensive studies that detail the species composition, abundance and biomass, vertical distribution, diversity and dominance in the deeper water beyond the shelf break.

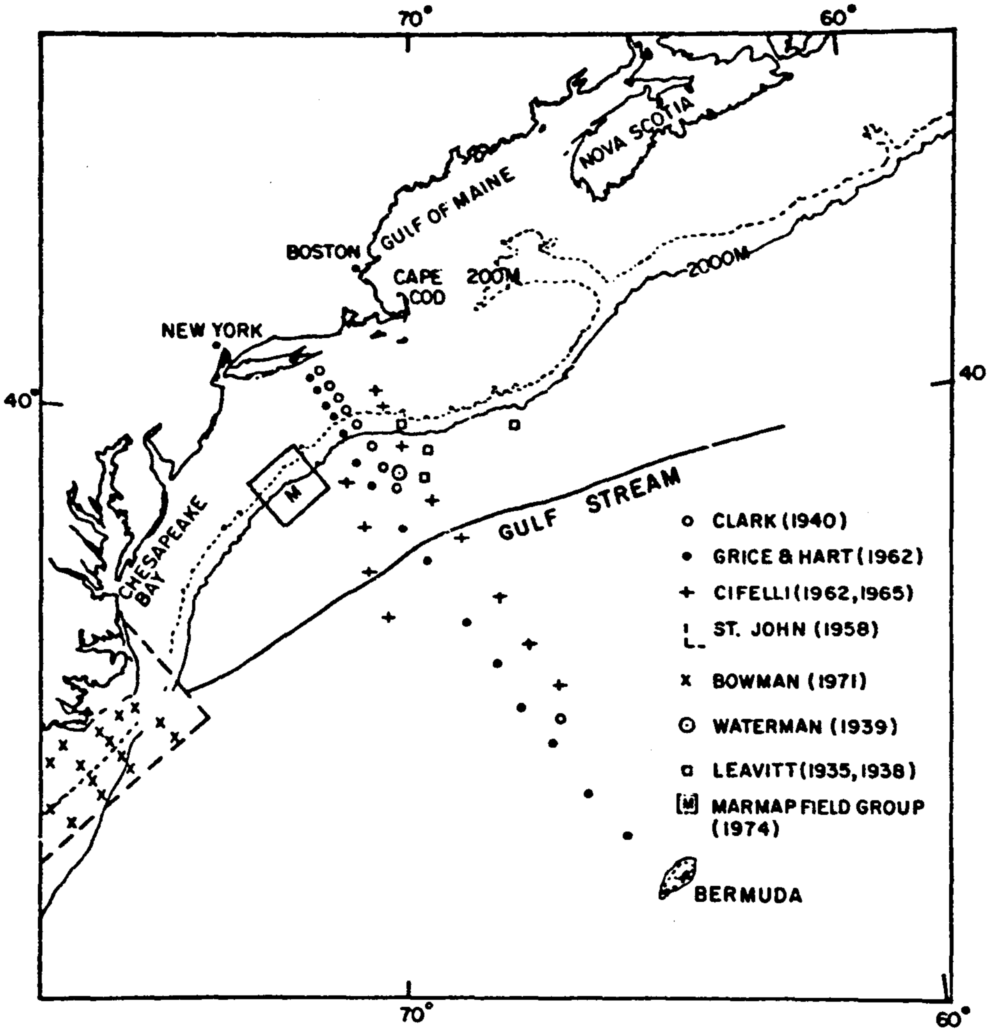
The early work of Bigelow and others that spanned the years 1914 to 1940 identified many of the species that are found in the slope water, but was concerned primarily with the shelf area and its neritic zooplankton.

Clarke (1940) presented the first comprehensive picture of seasonal and geographical abundance of the slope water zooplankton. He compared the richness of coastal and offshore zones on a volumetric basis from data collected on ten transect cruises between Long Island, New York, and Bermuda (Figure 7-14). In the slope water, he made oblique tows with a scrim net down to 275 m. Later, Riley and Gorgy (1948) compared zooplankton abundance on a transect from southern New England to the Mid-Atlantic ridge, which included two slope stations. These data were summarized by Riley, Stommel, and Bumpus (1949) in their consideration of the plankton of the northwestern Atlantic.

The most recent and comprehensive information on the abundance, distribution, and composition of the zooplankton in the slope waters has been presented by Grice and Hart (1962). They used the data collected by an open 3/4 m net towed to a depth of 200 m during four transect cruises between New York and Bermuda and one cruise between New York and the Gulf Stream (Figure 7-14). From a similar series of cruises, Cifelli (1962, 1965) described the planktonic foraminifera of the western North Atlantic, including the slope.

At the southern extreme of the study area, St. John (1958) reported the distribution of zooplankton biomass in the shelf waters and beyond at Cape Hatteras, while Bowman (1971) described the distribution of calanoid copepods from Cape Hatteras to Florida. His northermost transects were also taken from beyond the shelf off Cape Hatteras.

In all of the previously mentioned studies, only the surface zones (about 275 m) were sampled in the slope water. Information on the vertical distribution, diurnal migration, and characteristics of the deepwater zooplankton is available from several special studies. Leavitt (1935, 1938) made vertical tows at a series of stations, including six in the slope water, using a one and a two meter closing net. Waterman, Nunnemacher, Chace, and Clarke (1939) carried out extensive sampling at one slope water station in July, 1939, using nets similar to Leavitt's and



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-14	Principal Zooplankton Surveys in the Northwest Atlantic

described the diurnal vertical migrations of the deepwater plankton. With the development of more sophisticated sampling gear, recent attention (Grice, 1972) has been turned to describing the deepwater, planktobenthic copepods found near the slope bottom.

Very recent zooplankton work in the slope waters has been done off the New York Bight as a part of an environmental study of a potential ocean dumping site. The study, conducted by the Fisheries Oceanography Department, New York Ocean Science Laboratory for the MARMAP Field Group, is at this writing about to be released in a report. These data are from a report issued by NOAA in February 1976 on the Deepwater Dumpsite 106. The data result from an intensive sampling of 23 stations (Figure 7-15) during 1 to 23 May, 1974, using the standard MARMAP Bongo (.333 and .505 mesh) and Neuston nets. The Bongo tow was double oblique to a maximum depth of 200 m. The Neuston tow was at the surface. The report describes the composition and abundance of zooplankton and ichthyoplankton and is particularly useful for its description of the faunistic change that occurs at the shelf break and inner slope areas. For consistency, only the data that resulted from the .505 Bongo net tows is described in this report.

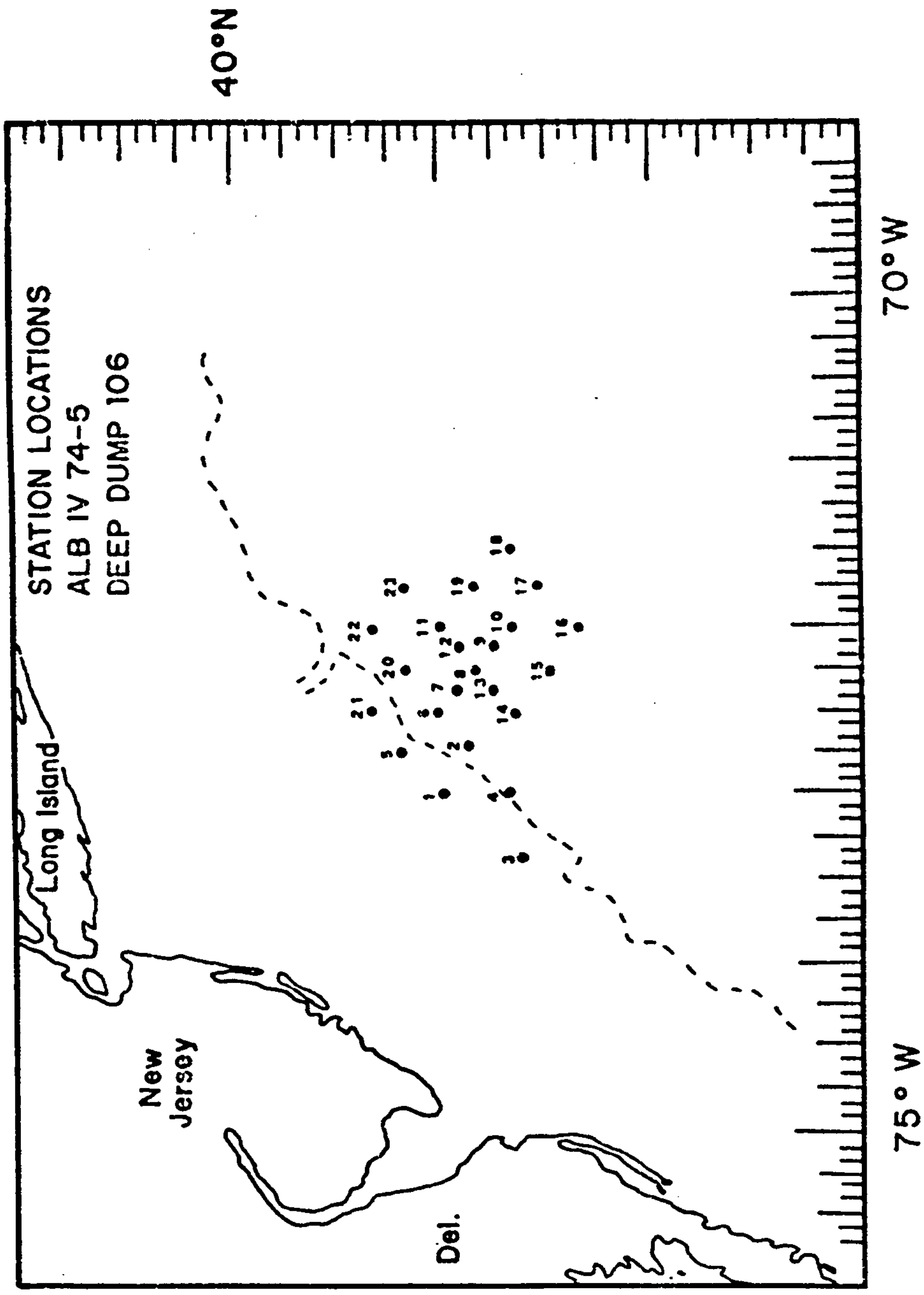
7.2.2 COMPONENTS

The studies of Grice and Hart (1962) and the sampling at the MARMAP deep water site 106 revealed the abundance and occurrence of the major zooplankton taxa of the slope waters. There was general agreement between the two studies on the relative importance of the major groups. Copepods were the largest group in terms of displacement volume, numerical abundance, and species representation (Grice and Hart, 1962). They were followed by chaetognaths, euphausiids, amphipods, siphonophores, and various other less important taxa.

The relative importance of the major taxa at the deep water dump site is shown in Table 7-6.

COPEPODS

The mean percentage displacement volume of copepods in slope water samples, with the exception of July samples, was 35-74 percent of the total volume (Grice and Hart, 1962). In July the samples taken at the slope stations had a high percentage (99 percent at one station) of salps and less than three percent of copepods. The copepods made up an average of 45 percent of all the slope samples in spite of the low July volumes. Their data also indicates an increased diversity of copepods with distance from shore. About twice as many species (79) were recorded in slope water than the shelf water (42). Slope waters had small copepod populations with no consistently dominant species. The comparison of common shelf and slope species (Table 7-7) indicated the lack of strong dominance between slope species.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-15	Deep Water Dump Site Station Locations (New York Ocean Science Laboratory, 1975)

Table 7-6a. Standing crop (No./1000m^3) of major zooplankton at Deepwater Dump-site 106. (modified from N. Y. Ocean Science Laboratory unpublished report). Double oblique tows to 200 meters using 61 cm Bongo net with .505 mesh.

	SHELF STATIONS			
Taxa	1	3	5	21
Siphonophora				351
Chaetognatha	29,943	32,203	11,659	23,558
Polychaeta	4,098	149	142	70
Gastropoda (L)				
Pteropoda	35,798	2,460	5,900	29,728
Heteropoda				70
Cephalopoda	84			
Cladocera	962		569	280
Ostracoda		199	213	280
Mysidaceae				
Amphipoda	42	2,882	355	911
Isopoda				
Euphausiacea	15,055	31,209	12,974	5,539
Decapoda (Caridian) (L)	293	199		280
Decapoda (Brachyura) (L)	10,371	1,938	2,026	16,266
Copelata	836	199	178	70
Salpida		50	284	70

Table 7-6a. (Cont.)

Taxa	INNER SLOPE STATIONS 2	4	6	7	8	9	11	12	13	14	20	22	23
Siphonophora				140	2,404			207	767			481	134
Chaetognatha	3,173	7,502	16,499	10,636	18,431	8,408	8,721	6,198	11,727	17,675	2,520	4,006	5,224
Polychaeta	419	268		220	501	65	30	30	137	271	70	64	
Gastropoda (L)				160	250			885	110	18,775		64	45
Pteropoda	1,498	1,250	1,043	1,459	4,407		718	2,036	1,973	1,623	410	3,076	861
Heteropoda					200	43			55			32	74
Cephalopoda													
Cladocera												208	
Ostracoda	837	804	427	140	2,755	173	90	207	685	1,713	173	144	89
Mysidaceae													
Amphipoda	639	759	1,707	620	3,456	282	448	1,800	548	1,713	1,181	240	668
Isopoda	66	45	95	22	97			30		90	16		
Euphausiacea	1,080	2,143	6,590	3,959	6,010	1,582	4,002	4,575	2,466	5,411	4,395	7,307	2,196
Decapoda (Caridian) (L)	1,080	670	47	1,439	250	217		89	548	631	284	32	104
Decapoda (Brachyura (L)	1,124	625	1,090	1,559	1,803	433	119	59	1,918	2,886	441	288	74
Copelata		1,161	284	320	4,858	108		30	2,850	1,353	221	176	15
Salpida	441	625		780	1,052	87			521	1,353	299		15

Table 7-6a. (Cont.)

	OUTER SLOPE STATIONS					
Taxa	10	15	16	17	18	19
Siphonophora				674		277
Chaetognatha	10,204	5,312	10,889	7,097	14,669	12,465
Polychaeta	875	244	116	180	539	
Gastropoda (L)			185			
Pteropoda	729	804	2,703		3,236	3,509
Heteropoda						
Cephalopoda		24			108	92
Cladocera						
Ostracoda	340	195	579	1,392	2,912	1,847
Mysidaceae						
Amphipoda	1,409	804	1,738	1,392	5,177	1,939
Isopoda					647	
Euphausiacea	5,782	1,389	4,055		5,070	10,249
Decapoda (Caridian) (L)	243	244	1,158	9,971	1,510	831
Decapoda (Brachyura) (L)	1,846	1,218	2,278	90	4,099	1,570
Copelata	1,409	122	193		539	
Salpida	826	97	77	719	1,402	

Table 7-6b. Standing crop (%) of major taxa at Deep Water Dump-site 106. (modified from N. Y. Ocean Science Laboratory unpublished report). Double oblique tows to 200 m using 61 cm Bongo net with .505 mesh.

Taxa	SHELF STATIONS 1	3	5	21
Siphonophora				.45
Chaetognatha	30.69	45.05	33.99	30.41
Polychaeta	4.2	.21	.41	.09
Gastropoda (L)				
Pteropoda	36.69	2.10	17.20	38.37
Heteropoda				.09
Cephalopoda	.08			
Cladocera	.99		1.66	.36
Ostracoda		.28	.62	.36
Mysidaceae				
Amphipoda	.04	4.03	1.03	1.18
Isopoda				
Euphausiacea	15.43	43.66	37.83	7.15
Decapoda (Caridian) (L)	.30	.28		.36
Decapoda (Brachyura) (L)	10.63	2.71	5.91	21.00
Copelata	.86	.28	.52	.09
Salpida		.07	.83	.09

Table 7-6b. (Cont.)

Taxa	INNER SLOPE STATIONS												
	2	4	6	7	8	9	11	12	13	14	20	22	23
Siphonophora				.65	5.18			1.28	3.15			2.99	1.41
Chaetognatha	30.64	47.33	59.39	49.63	39.74	73.63	61.73	38.39	48.20	50.65	25.15	24.93	55.00
Polychaeta	4.05	1.69		1.03	1.08	.57	.21	.19	.56	.78	.79	.40	
Gastropoda (L)				.75	.54			5.48	.45			.40	.47
Pteropoda	14.46	7.89	3.75	6.81	9.50		5.08	12.61	8.11	4.65	4.09	19.14	9.06
Heteropoda					.43	.38			.23			.20	.78
Cephalopoda													
Cladocera												1.29	
Ostracoda	8.08	5.07	1.54	.65	5.94	1.51	.64	1.28	2.82	4.91	1.73	.90	.94
Mysidaceae													
Amphipoda	6.17	4.79	6.14	2.89	7.45	2.47	3.17	11.15	2.25	4.91	11.79	1.49	7.03
Isopoda	.64	.28	.34			.19		.19		.26	.16		
Euphausiacea	10.43	13.52	23.72	18.47	12.96	13.85	28.33	28.34	10.13	15.50	43.87	45.47	23.12
Decapoda (Caridian) (L)	10.43	4.23	.17	6.71	.54	1.9		.55	2.25	1.81	2.83	.20	1.09
Decapoda (Brachyura (L)	10.85	3.94	3.92	7.27	3.89	3.79	.84	.37	7.88	8.27	4.40	1.79	.78
Copelata		7.32	1.02	1.49	10.48	.95		.19	11.71	3.88	2.21	1.10	.16
Salpida	4.26	3.94		3.64	2.27	.76			2.14	4.39	2.98		.16

Table 7-6b. (Cont.)

	OUTER SLOPE STATIONS					
Taxa	10	15	16	17	18	19
Siphonophora				1.67		.84
Chaetognatha	42.95	50.82	45.78	17.61	36.76	37.71
Polychaeta	3.68	2.33	.49	.45	1.35	
Gastropoda (L)				46.60		.56
Pteropoda	3.07	7.69	11.36		8.12	10.62
Heteropoda						
Cephalopoda		.23			.27	.28
Cladocera						
Ostracoda	1.43	1.87	2.43	3.45	7.30	5.59
Mysidaceae						
Amphipoda	5.93	7.69	7.31	3.45	12.97	5.87
Isopoda	.41				1.62	
Euphausiacea	24.34	13.29	17.05		12.70	31.00
Decapoda (Caridian) (L)	1.02	2.33	4.87	24.75	3.78	2.51
Decapoda (Brachyura) (L)	7.77	11.65	9.58	.22	10.27	4.75
Copelata	5.93	1.17	.81		1.35	
Salpida	3.48	.93	.32	1.78	3.51	

Table 7-7. Common copepod species and their average abundance from shelf and slope stations (Grice and Hart, 1962)

Shelf	Mean No./m^3	Slope	Mean No./m^3
Pseudocalanus minutus	559	*Centropages typicus*	76
Centropages typicus	450	*Pseudocalanus minutus*	16
Oithona similis	151	*Oithona similis*	14
Temora longicornis	59	*Metridia lucens*	15
Paracalanus parvus	39	*Clausocalanus pergens*	19
Calanus finmarchicus	32	*C. arcuicornis*	13
Metridia lucens	16	*Pleuromamma borealis*	6
Candacia armata	9	*Oithona atlantica*	6

The slope samples from Grice and Hart's transect consisted of a mixture of species from the shelf and the Gulf Stream-Sargasso Sea, as well as 14 species that were found only in the slope water. Of the 14, eight occurred more than twice and are listed in Table 7-8, and also species that were found in other areas as well as the slope waters. Four of the restricted species were offshore, cold water forms that have rarely been reported in shelf areas, and where reported, are probably the result of offshore intrusion of water onto the shelf. One of them (Calanus hyperboreus), a typical cold water form, has been reported by the authors as abundant in deep water (1800 m) below the Gulf Stream.

In the deep water dump site area off the New York Bight, the most common copepod genera were Centropages, Calanus, Oithona, Euaugaptilus, Rhincalanus, and Pleuromamma. Centropages and Calanus predominated in the shelf and also in areas where shelf water intrusions occurred in the slope water. Calanus was least abundant in the offshore areas where water column stability suggested an oceanic origin. An examination of transects between coastal and slope waters (Clarke, 1940), showed that both Calanus finmarchicus and Centropages typicus, that were so dominant in the coastal areas, were found only in small numbers beyond the shelf break, indicating the strongly neritic characteristics of these species.

Mixing of waters was demonstrated by the presence of Gulf Stream water in the center of the dumpsite study area (stations 11 and 12) as evidenced by the abundance of Rhincalanus, Euaugaptilus, Oithona, and Pleuromamma. A copepod common to deep waters of the northwestern Atlantic, Euchirella rostrata, was also found at all the stations.

Table 7-9 lists the copepod species taken at the deep water dump site and their abundance in terms of standing crop and composition.

The diversity indices of copepod species in the dump site area varied between shelf and slope water and further illustrates the degree of mixing that occurs in the slope area. The contour of diversity indices was such that a differentiation could be made between shelf and slope waters. The boreal faunal composition of copepods, characterized by high abundance and few species, was indicative of the shelf waters, while the slope waters contained a mixture of subtropical and boreal assemblages that resulted in lower abundance and more species.

The species association of copepods at Cape Hatteras in the southern extreme of the study area has been discussed by Bowman (1971). The southern shelf copepod fauna that occurs from the Florida to Cape Hatteras coasts remains fairly constant seasonally. Just north of Cape Hatteras the coastal fauna changes with northern forms dominating in the winter. The oceanic faunal group found south of Cape Hatteras is unchanged north of the Cape, but it moves offshore and follows the Gulf Stream. The slope water region in between that commences at Cape Hatteras contains a mixture of shelf and the oceanic copepods.

Table 7-8. Common species (appearing more than twice in the samples) restricted to slope waters and those found widely distributed. (Grice and Hart, 1963).

Widespread	Restricted to Slope
Calanoida	Slope Calanoida
Acartia danae	*Aetideus armatus*
Calanus tenuicornis	*Calanus hyperboreus*
Calocalanus pavo	*Clausocalanus pergens*
Clausocalanus arcuicornis	*Gaidius tenuispinus*
C. furcatus	*Heterprjabdis mprvegocis*
Eucalanus attenuatus	*Paraeuchaeta norvegica*
E. pileatus	*Pleuromamma robusta*
Euchaeta marina	*Scolecithricella minor*
Labidocera acutifrons	
Mecynocera clausi	
Nannocalanus minor	
Paracalanus parvus	
Temora stylifera	
Undinula vulgaris	
Cyclopoida	
Oithona plumifera	
Harpacticoida	
Macrostella gracilis	

Table 7- 9a Standing crop (no./1000m^3) of copepods from Deepwater Dump-site 106. (modified from N. Y. Ocean Science Laboratory unpublished report). Double oblique tows to 200 m using 61 cm Bongo net with .505 mesh.

	SHELF STATIONS			
Species	1	3	5	21
Rhincalanus coronatus	4895	9615	12332	4277
Temora stylifera	240	497	355	561
Temora longicornis	240	273	569	351
Centropages spp.	50080	50952	14465	61350
Pleuromamma gracilis	293	1590	213	90
Pleuromamma borealis	42	199	71	210
Pleuromamma robusta				
Pleuromamma xiphias				
Corycaeus sp.	42	348	36	491
Oithona spp.	42	422	284	561
Calanus spp.	202405	2460	27010	113655
Euchirella rostrata	240	1764	833	421
Eucalanus spp.	795	2211	1244	561
Acartia longicornis		25	71	
Sapphirina sp.			36	
Euaugaptilus sp.	2007	6286	4514	2384
Euchaeta marina		174	71	70
Uaetideus giesbrechti				
Metridia lucens	39979	6708	838	33585
Saphirella sp.				140
Candacia armata	2258	2385	6077	5890
Aetideus armatus		75	178	
Heterrorhabdus abysalis				70
Unknown no. 1	795	447	782	1262
Unknown no. 2				70
Unknown no. 3				
Pontella pennata			36	
Chirundina sp.				
Undinopsis bradyi				

Table 7-9a. (cont.)

	INNER SLOPE STATIONS												
Species	2	4	6	7	8	9	11	12	13	14	20	22	23
Rhincalanus coronatus	2137	7591	4361	6558	9815	2752	14638	5489	1260	9280	583	2772	7761
Temora stylifera	1366	1295	901	220	3806	672			1397		756	208	460
Temora longicornis	44	89	521	600	250	130	179	59	27	1600	16		74
Centropages spp.		4599	11862	4379	11818	1668	179	59	3699	320	1701	8924	8681
Pleuromamma gracilis		89	6210		3055	3055	747	266	548	32640	1780	1746	89
Pleuromamma borealis		89	2560		601	758	926	6197	986	2560	331	1346	5
Pleuromamma robusta			5452	20	801	22				320		52	5
Pleuromamma xiphias					50					271	16	16	
Corycaeus sp.	991	804	237	220	601	390	179	118	438		347	48	178
Oithona spp.	507	625	521	2180	551	563	538	28506	1151	902	110	48	30
Calanus spp.	353	1518	664	1080	8613	3250	418		2000	1600	583	2532	148
Euchirella rostrata	1036	1786	759	1900	2203	412	448	118	849	1280	2079	3336	638
Eucalanus spp.	3966	8127	1517	3419	2203	867	179	3600	1233	1714	662	192	178
Acartia longicornis	66	45		600		43				1714			
Sapphirina sp.	132	45	47					30				12	3169
Euaugaptilus sp.	4010	4466		4039	4407	1928	5825	2213	4247		5277	2115	141
Euchaeta marina	1719	1340	237	860	1803	108		69	1096	5953	866	112	
Uaetideus giesbrechti										960			45
Metridia lucens	22		427		551			797	55		16	513	
Saphirella sp.	88			20	50			472		960	16	16	312
Candacia armata	859	2635	427	740	801	130		69	823	180	378	401	15
Aetideus armatus	176	447	237	360	50	65				1600	6	112	
Heterrorhabdus abysalis			237	160	50	65	179	1535				32	401
Unknown no. 1		179	190	280	200		30	118	274		725	785	15
Unknown no. 2	441		47	60	250				82	320	284		
Unknown no. 3			284							180		48	
Pontella pennata						22			1180				
Chirundina sp.						22							
Undinopsis bradyi						22							

Table 7-9a. (Cont.)

Species	OUTER SLOPE STATIONS 10	15	16	17	18	19
Rhincalanus coronatus	5247	2656	888	1168	3991	13943
Temora stylifera	1555	49	386	943	3560	2031
Temora longicornis	583	49	154	45	108	
Centropages spp.	3984	7189	9228	12937	11650	21792
Pleuromamma gracilis	3207	24		9568	324	11466
Pleuromamma borealis	680	49		3324	216	33549
Pleuromamma robusta	49			2830		4802
Pleuromamma xiphias				494		554
Corycaeus sp.	534	390	425	539	4531	646
Oithona spp.	875	266	618	1392	3668	
Calanus spp.	1701	366	154	314	1618	1939
Euchirella rostrata	826	609	695	1527	8522	6648
Eucalanus spp.	1992	926	1004	1078	7120	1754
Acartia longicornis		49		135	863	92
Sapphirina sp.	49		39	45	216	
Euaugaptilus sp.	4130	2291	5019	7861	19740	10434
Euchaeta marina	1360	955	1544	1123	5070	1108
Gaetideus giesbrechti				450		
Metridia lucens	340			2066	108	2216
Saphirella sp.	97		39	180	216	92
Candacia armata	534	1145	1042	1437	4315	4432
Aetideus armatus	680	97	39	135	108	
Heterrorhabdus abysalis	49		77	270	216	185
Unknown no. 1	292	268	463	719	3775	1570
Unknown no. 2	49	24				462
Unknown no. 3	49		116	270		
Pontella pennata	49			90		
Chirundina sp.				45		
Undinopsis bradyi				45		

Table 7- 9b. Percent composition of copepods from Deepwater Dump-site 106 (modified from N. Y. Ocean Science Laboratory unpublished report). Double oblique tows to 200 m using 61 cm Bongo net with .505 mesh.

Species	SHELF STATIONS 1	 3	 5	 21
Rhincalanus coronatus	16	145	176	19
Temora stylifera	01	07	05	02
Temora longicornis	01	04	08	02
Centropages spp.	165	467	206	270
Pleuromamma gracilis	01	24	03	04
Pleuromamma borealis	01	03	01	01
Pleuromamma robusta				
Pleuromamma xiphias				
Corycaeus sp.	01	05	01	02
Oithona spp.	01	06	04	02
Calanus spp.	665	37	385	501
Euchirella rostrata	01	27	12	02
Eucalanus spp.	02	33	17	02
Acartia longicornis		03	01	
Sapphirina sp.			01	
Euagaptilus sp.	07	95	64	18
Euchaeta marina		03	01	03
Jaetideus giesbrechti				
Metridia lucens	131	101	13	148
Saphirella sp.				01
Candacia armata	07	36	87	26
Aetideus armatus		01	03	
Heterrorhabdus abysalis				03
Unknown no. 1	03	07	11	06
Unknown no. 2				03
Unknown no. 3				
Pontella pennata			01	
Chirundina sp.				
Undinopsis bradyi				

Table 7- 9b. (Cont.)

	INNER SLOPE STATIONS												
Species	2	4	6	7	8	9	11	12	13	14	20	22	23
Rhincalanus coronatus	74	212	113	240	230	161	597	108	63	145	35	123	335
Temora stylifera	47	36	23	08	89	39			39	25	46	09	20
Temora longicornis	02	02	14	22	06	08	07	01	01	07	01		03
Centropages spp.	218	129	308	160	277	97	07	01	183	501	103	395	375
Pleuromamma gracilis		02	61		72	178	30	05	27	41	107	77	04
Pleuromamma borealis		02	67		14	44	38	122	49	06	20	60	01
Pleuromamma robusta			142	01	19	01				04		01	01
Pleuromamma xiphias					01						01	01	
Corycaeus sp.	34	22	06	08	14	23	05	02	22	14	21	02	08
Oithona spp.	18	17	14	80	13	33	22	560	53	25	07	02	01
Calanus spp.	12	42	17	40	202	180	17		99	23	35	112	06
Euchirella rostrata	36	50	22	69	52	24	18	02		26	125	15	28
Eucalanus spp.	137	227	39	125	32	31	07	71	61	26	40	09	08
Acartia longicornis	02	01		22		03							
Sapphirina sp.	05	01	01					01				01	
Euaugaptilus sp.	130	125		148	103	113	238	44	212	91	318	104	168
Euchaeta marina	59	37	06	31	42	06		02	54	15	52	05	15
Uaetideus giesbrechti													
Metridia lucens	01		11		13			16	03	15	01	23	02
Saphirella sp.	03			01	01			09		03	01	01	
Candacia armata	30	74	11	27	19	08		02	41	25	23	18	13
Aetideus armatus	06	12	06	13	01	04					01	05	01
Heterrorhabdus abysalis			06	06	01	04	07	30				01	
Unknown no. 1		05	05	10	05		01	02	14	06	44	35	07
Unknown no. 2	15		01	02	06				04	03	17		01
Unknown no. 3			07									02	
Pontella pennata						01							
Chirundina sp.						01							
Undinopsis bradyi						01							

Table 7-9b. (Cont.)

	OUTER SLOPE STATIONS					
Species	10	15	16	17	18	19
Rhincalanus coronatus	181	145	40	21	50	63
Temora stylifera	31	03	18	17	45	09
Temora longicornis	20	03	17	01	01	
Centropages spp.	137	392	421	232	146	98
Pleuromamma gracilis	110	01		172	04	612
Pleuromamma borealis	23	03		60	03	150
Pleuromamma robusta	02			51		22
Pleuromamma xiphias				09		02
Corycaeus sp.	18	21	19	10	47	03
Oithona spp.	30	20	28	25	46	
Calanus spp.	59	20	07	06	20	09
Euchirella rostrata	28	33	32	27	107	30
Eucalanus spp.	69	50	46	19	89	08
Acartia longicornis		03		02	11	04
Sapphirina sp.	02		02	01	03	
Euaugaptilus sp.	142	125	229	141	247	47
Euchaeta marina	47	41	70	20	63	05
Uaetideus giesbrechti				001		
Metridia lucens	12			37	01	10
Saphirella sp.	03		02	03	03	04
Candacia armata	18	62	48	23	54	20
Aetideus armatus	23	05	02	02	01	
Heterrorhabdus abysalis	02		02	05	03	01
Unknown no. 1	10	15	21	13	47	07
Unknown no. 2	02	01				02
Unknown no. 3	02		05	05		
Pontella pennata	02			02		
Chirundina sp.				01		
Undinopsis bradyi				01		

Recent sampling has shown that there is a calanoid copepod fauna living in proximity to the bottom (planktobenthic copepods) that is distinct from the pelagic zooplankton community. Using newly developed collection techniques aboard the submersible Alvin, Grice (1972) has identified 14 species that occur near the bottom at depths greater than 1,000 m. The copepods were noted in 1800 m of water in the slope south of Woods Hole. They were typical of benthic species, having small size, plump bodies and long spines, and were found in small numbers. Grice concludes that these forms represent a distinct calanoid copepod fauna near the bottom in the deeper slope waters.

FORAMINIFERA

The faunal characteristics and the distribution of the planktonic foraminifera in the northwest Atlantic has been described by Cifelli (1962, 1965) from four seasonal cruises transecting the shelf to the Sargasso Sea. The distribution of the faunal groups and their abundance is illustrated in Figure 7-16 and 7-17.

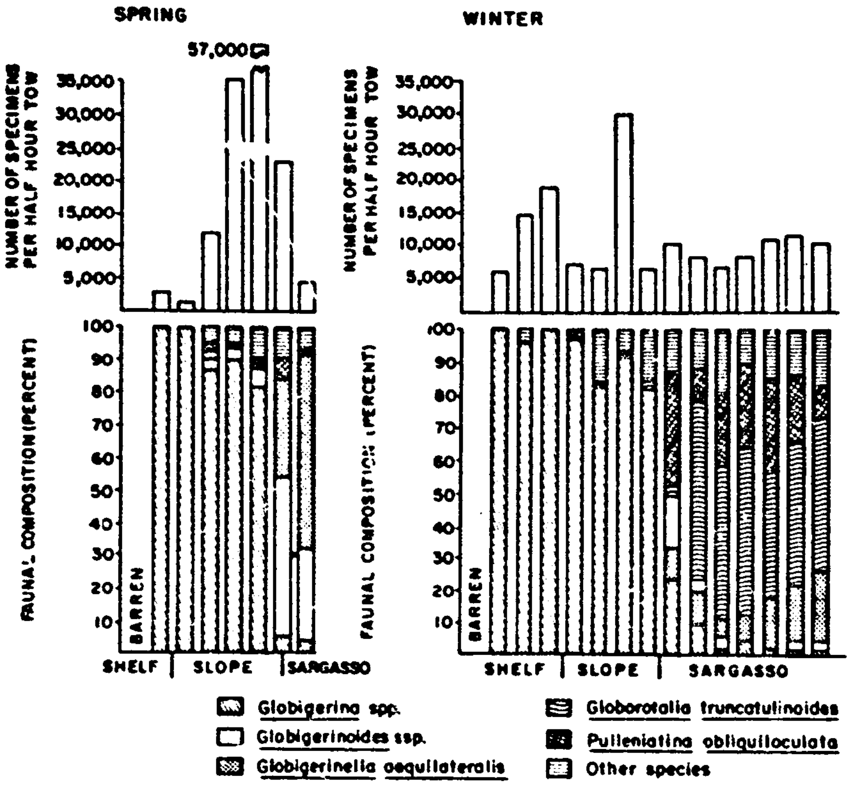
The foraminifera are of particular interest because they are more closely associated with the hydrographic characteristics of water masses than any other zooplankton groups and therefore show most clearly the transitional character of the slope water region. The faunal composition of foraminifera included 20 recognizable species. The shelf and inner slope was characteristically temperate throughout the year and was dominated by species of *Globigerina*. Important species were *Globigerina bulloides*, *Globigerina pachyderima incompta*, *Globigerina inflata*, and *Globigerina* aff. *quinqueloba*. Towards the Gulf Stream, the temperate fauna was gradually replaced by a diverse southern group dominated by *Globigerinoides ruber*, *Globigerinoides trilobics*, *Globigerinella aequilateralis*, *Globorotalia truncatulinoides*, and *Pulleniatina obliquiloculata*.

A fairly distinct boundary existed between these two faunal groups to the north of the Gulf Stream which fluctuated seasonally, being closest to the shore in the fall and furthest offshore between winter and spring.

The slope water yielded the highest abundance of foraminifera all year with the seasonal peak in the fall and the spring (Figures 7-16 and 7-17). The poorest concentration was found in the summer.

CHAETOGNATHS

Chaetognaths were the second most abundant numerically and volumetrically in Grice and Hart's (1962) transect study. However, they were concentrated in the shelf areas. In the four regions studied (shelf, slope, Gulf Stream, Sargasso Sea) they found the slope waters to contain the smallest chaetognath population. (Mean displacement volume 8.3 percent

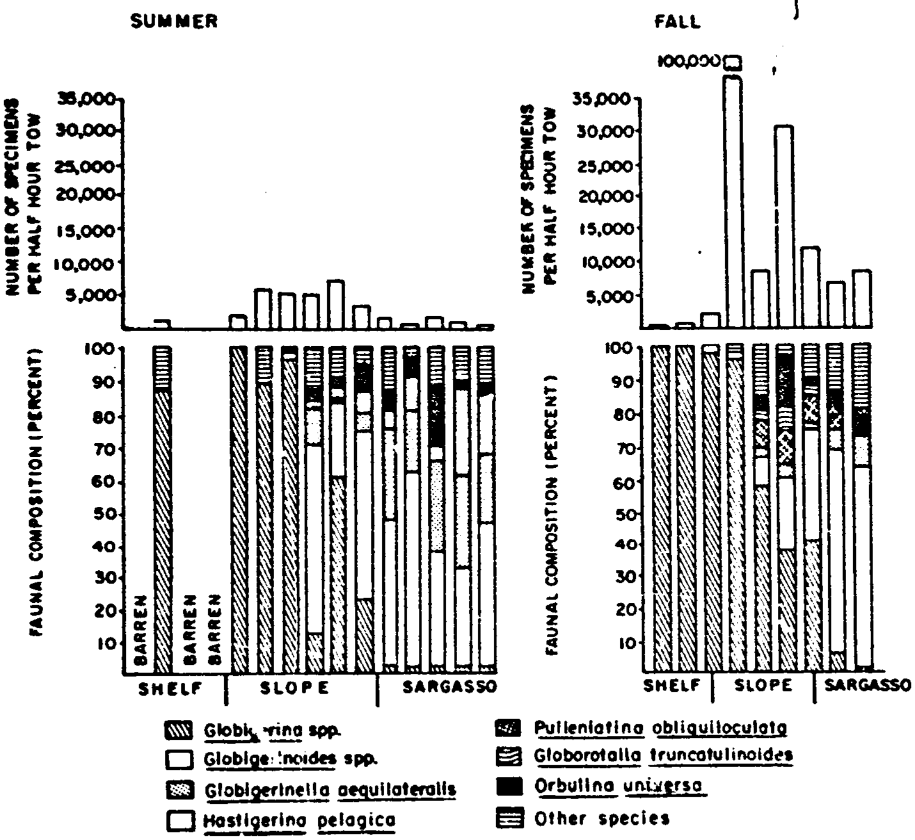


ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-16

Foraminifera Composition and Abundance in the Northwestern Atlantic (Cifelli, 1962)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-17	Foraminifera Composition and Abundance in the Northwestern Atlantic (Cifelli, 1962)

and numerical abundance 3/m^3). The 12 species of chaetognaths found in the slope water (Figure 7-18) were of three distributional types: shelf species, Gulf Stream-Sargasso Sea species, and endemic slope water species. Sagitta elegans was the most abundant form in the slope water, as it was on the shelf. The two species endemic to the slope water (Sagitta maxima and Eukrohnia hamata) were found at a number of stations, mostly in March. They were cold water forms that have been reported at a number of cold, (approximately 7.4°C) deep water slope areas along the East Coast. Grice and Hart (1962) concluded that these species were indicative of cold waters in general and slope waters in particular.

The chaetognaths of the deep water dump site were again, mostly abundant over the shelf (greater than 23,000 per 1,000 m^3) and least abundant beyond the shelf break (less than 10,000 per 1,000 m).

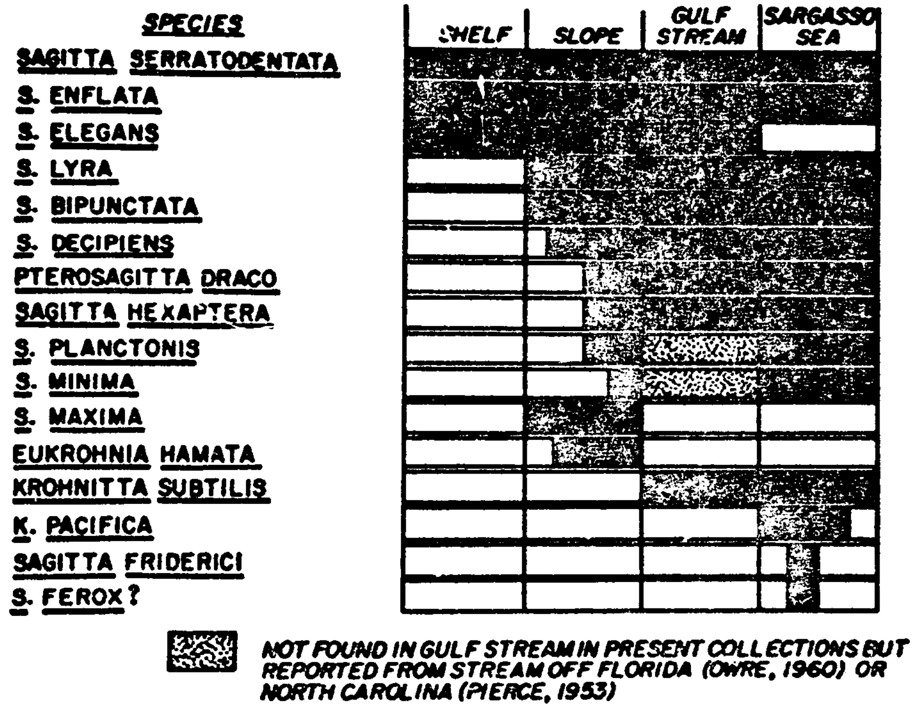
EUPHAUSIIDS

Euphausiids were not an important part of the total zooplankton collection of Grice and Hart, ranking fifth in mean displacement volume. However, they were a relatively important component in the slope waters (8.3 percent of the zooplankton volume with an average numerical abundance of 2.2/m^3).

A succession of species indicated seasonal changes in the euphausiid population. September and December collections were characterized by a large number of diverse forms. Of the 11 species recorded, six were most typical of warmer Gulf Stream and Sargasso Sea water and indicated a mixing of these warmer waters in the slope area (Euphausia tenera, Stylocheiron abbreviatum, Stylocheiron affine, Stylocheiron carinatum, Stylocheiron submii, and Nematoscelis microps). Two species were from neritic waters (Meganyctiphanes norvegica, and Thysanoessa gregaria). Three species were practically endemic to the slope area (Nematoscelis megalops, Euphausia krohnii, and Euphausia pseudogibba). N. megalops was found to be breeding at most of the stations during March.

The March and July samples produced few species and lower abundance. In March the colder waters probably prevented the six warm water species from occurring, and in July large collections of salps may have affected euphausiid abundance.

At the deep water dump site, the mixture of boreal-arctic and subtropical species was also evident. The dominant species was Nyctiphones couchii, which is a cold water form, and was found in greatest numbers at stations 3 and 5. Warm water species of the Euphausia and Stylocheira genera and the tropical Thysanopoda aequalis were dominant at stations 2, 6, 10, 18 and 22. Mixing in the slope region was indicated by combinations of the genera Nyctiphanes (boreal) and Stylocheirion (subtropical) that were found at most stations.



▨ NOT FOUND IN GULF STREAM IN PRESENT COLLECTIONS BUT REPORTED FROM STREAM OFF FLORIDA (OWRE, 1960) OR NORTH CAROLINA (PIERCE, 1953)

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-18	Distribution of Chaetognath Species in the Northwest Atlantic (Grice and Hart, 1962)

AMPHIPODS

Grice and Hart (1962) show that although the amphipods represented relatively low volumes and numbers, they were second only to the copepods in the number of species present. The number of species increased seaward with eight recorded for the shelf, 15 for the slope water, 26 for the Gulf Stream, and 46 for Sargasso Sea. They were, however, relatively more abundant in the shelf waters than offshore. The most frequently occurring shelf and slope species were Paraphemisto gaudichaudii and P. gracilipes. These were seasonally augmented by the occurrence of Gulf Stream and Sargasso Sea species.

OTHER GROUPS

Siphonophores were found to have more representation offshore. Of the 30 species recorded by Grice and Hart (1962), 17 were found in slope waters and only 4 in shelf waters. Volumetrically they were more important in the Gulf Stream and Sargasso Sea.

The molluscs are represented pelagically by the pteropods and heteropods. The pteropods were represented by a combination of boreal and subtropical species in slope waters at the deep water dump site. The location of various species combinations is shown in Table 7-10. Grice and Hart (1962) reported ten heteropod and 19 pteropod species from their transect, with very few found in the neritic environment.

Of the cephalopods, squid larvae were a widely distributed group of the oceanic component at the deep water dump site. However, their abundance never exceeded 6.2 per 1,000 m^3.

A complete listing of the zooplankton species was recorded by Grice and Hart (1962). From this, those species found in the slope water portion of their transect are listed in Table 7-11.

7.2.3 BIOMASS AND ABUNDANCE

The distribution of total zooplankton biomass (displacement volume) and abundance (numbers of organisms) in the slope water relative to other water masses in the northwest Atlantic has been of interest to a number of authors because it pertains to the question of the relative productivity of these waters. Biomass and abundance are not necessarily correlated. Low volumes of zooplankton can accompany high numbers because of the wide range in size of many organisms that comprise the zooplankton (Figure 7-19).

Grice and Hart (1962), Clarke (1940), Riley and Gorgy (1948) and Emery and Uchupi (1972) all recognized the spacial relationship in terms of biomass and abundance that exists from the coastal areas to the open ocean. Table 7-12 summarizes their data and, while not directly

Table 7-10. Distribution of pteropod species at the Deep Water Dump-Site (from N. Y. Ocean Science Laboratory unpublished report).

Faunal Group	Stations Represented
Boreal *Limacina retroversa* *L. helicina*	3, 9, 10, 21, 23
Subtropical *Limacina trachiformis* *L. inflata* *Cresis virgula* *Cavolina spp.* *Clio spp.* *Diacria trispinosa*	6, 7, 8, 14, 19
Mixture with Boreal Predominating	6, 7, 8, 13, 16

Table 7-11 List of zooplankton species taken at slope water station by Grice and Hart (1962). Taken from vertical tows to 200 meters with 3/4 meter open net of no. 6 mesh netting (.023 mm).

	September	December	March	July
PROTOZOA				
Radiolaria			x	
Foraminifera	x	x		x
CNIDARIA				
Siphonophoras				
Abylopsis eschscholtzii	x	x		x
A. tetragona	x	x		
Agalma elegans				x
A. okenii			x	x
Bassia bassensis		x		
Celophyes appendiculata		x		
Dipyes bojani	x	x		x
D. dispar	x			
D. sp.	x			
Ennegonum hyalinum		x		
Eudoxoides mitra		x		
E. spiralis		x		x
Galetta chuni		x		
Hippopodius hippopus				x
Lensia conoidea	x		x	x
L. sp.			x	
Nanomia bijuga				x
N. cara			x	x
Stephanomia rubra		x		
Vogtia serrata			x	
Unident.	x	x	x	x
MEDUSAE				
Aglantha digitale			x	x
Nausithoe punctata		x		
Obelia sp.				x
Rhopalonema valatum			x	
Solmundella bitentaculata			x	x
Unident.	x	x	x	x
CTENOPHORA				
Pleurobrachia brunnea				x
PHYLLODOCIDAE				
Lophadorhynchus (P.) henseni		x		
Maupasia caeca		x		

Table 7-11. (Cont.)

	September	December	March	July
ALCIOPIDAE				
Rhynchonerella petersii		x		
R. sp.		x		
Vanadis minuta		x		
TOMOPTERIDAE				
Enapteris euchaeta		x		
Tomopteris (J.) helgolandica			x	x
T. (T.) cavallii			x	
T. spp.		x		x
INCERTAE SEDIS				
Unident. annelids	x	x	x	
MOLLUSCA				
Heteropoda				
Atlanta sp.	x			
Protatlanta souleyeti				x
PTEROPODA				
Clione sp.				x
Hyalocyclix striata	x			
Limacina inflata	x			
L. retroversa			x	
L. trochiformis			x	
Unident.	x			
CLADOCERA				
Evadne nordmanni				x
OSTRACODA				
Conchoecia acuticosta		x	x	
C. atlantica				x
C. borealis		x		
C. curta		x		
C. elegans		x		
C. spinifera		x		
C. spp.	x	x	x	x
Halocypris globosa				x
COPEPODA				
Calanoida				
Acartia danae	x	x		
A. longiremis				x

Table 7-11. (Cont.)

	September	December	March	July
Candacia bispinosa		x		
C. pachydactyla	x			
C. simplex		x		
Centropages bradyi	x	x		x
C. hamatus	x		x	
C. typicus	x	x	x	x
Chiridius gracilis			x	
Chirundina streetsi		x		
Clausocalanus arcuicornis	x	x	x	
C. furcatus	x	x		
C. pergens	x		x	x
Ctenocalanus vanuas	x			
Eucalanus attenuatus	x	x	x	
E. elongatus		x		
E. pileatus		x		
E. marina		x		
E. media		x		
Euchirella amoena		x		
E. messinensis	x	x	x	
E. rostrata			x	x
Gaetanus minor		x	x	
Gaidus pungens		x		
G. tenuispinus		x	x	
Haloptilus longicornis		x	x	
Heterrorhabdus norvegicus		x	x	
H. papilliger			x	
H. spinifrons			x	
Heterostylites longicornis			x	
Labidocera acutifrons	x			
Lopthothrix latipes			x	
L. flavicornis	x	x	x	x
Mecynocera clausi	x	x	x	x
Metridia lucens	x	x	x	x
Nannocalanus minor	x	x	x	x
N. robustior		x		
Paracalanus parvus	x	x		x
P. pygaeus				x
Paraeuchaeta norvegica	x	x	x	
Pleuromamma abdominalis f. *typica*		x		
P. borealis	x	x	x	
P. piseki	x			
P. robusta	x	x	x	
P. xiphias	x	x	x	
Pontella securifer	x			
Pontellina plumata	x			
Pseudocalanus minutus	x		x	x
Rhincalanus cornutus	x			

Table 7-11. (Cont.)

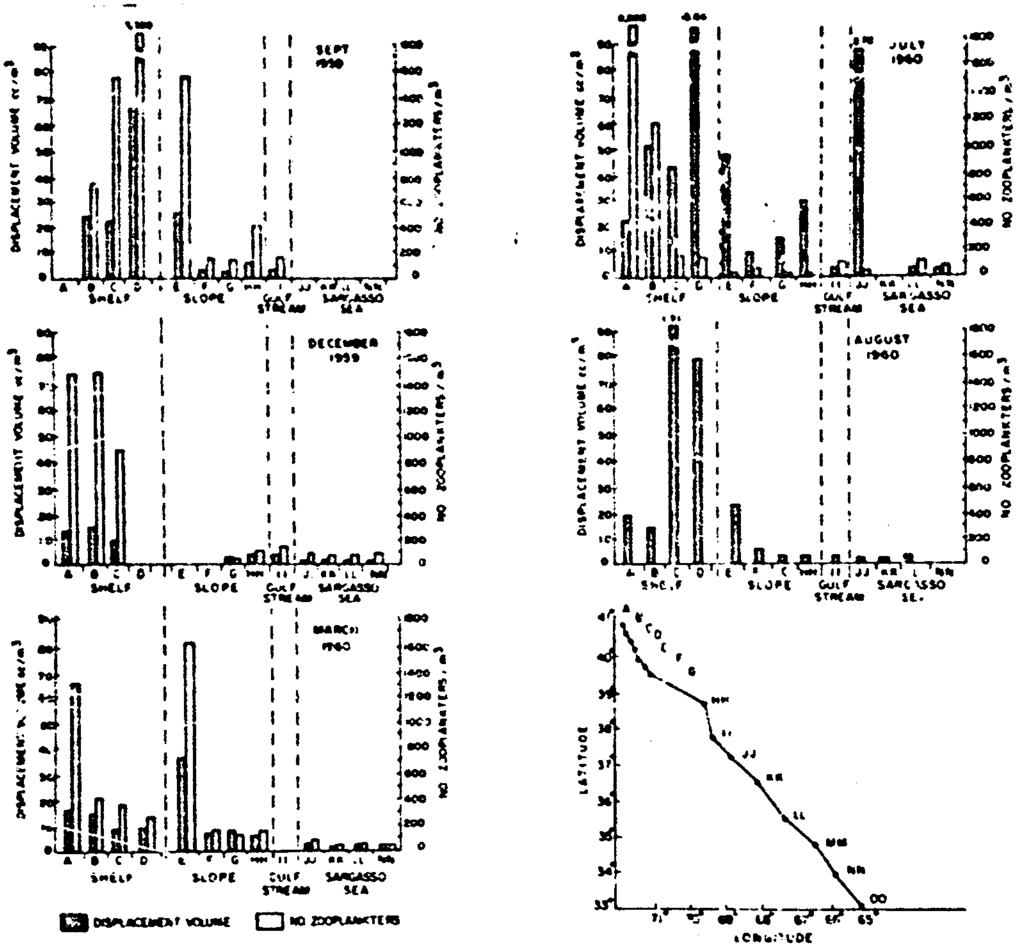
	September	December	March	July
Aetideus armatus	x		x	x
Anomalocera patersoni				x
Calanus finmarchicus				x
C. tenuicornis	x	x	x	x
C. pavo	x			
C. plumulosus		x		
C. styliremis	x	x	x	x
C. tenuis	x		x	x
Candacia ethiopica		x		
C. armata	x	x	x	x
Rhincalanus nasutus	x	x	x	x
Scolecithricella minor				x
S. ovata	x			
S. danae	x	x	x	
Scottocalanus securifrons		x	x	
Temora longicornis	x			x
T. stylifera	x	x		
Undeuchaeta major	x	x		
U. plumosa	x	x	x	
Undinula vulgaris		x		
Juvenile calanoids	x	x	x	x
CYCLOPOIDA				
Coryaeus spp.	x	x		
Farranula carinata	x	x		
Lubbockia squillimana		x	x	
Oithona atlantica	x	x	x	x
O. plumifera		x		
O. similis			x	x
Oncacea conifers			x	
O. spp.	x	x	x	x
HARPACTICOIDA				
Clytemnestra rostrata	x	x		
C. scutellata	x			
Macrosetella gracilis	x	x		
Maricia efferata	x			
Sapphirina spp.				x
MYSIDACEA				
Unident.			x	

Table 7-11. (Cont.)

	September	December	March	July
AMPHIPODA				
Gammaridea				
Cyphocaris anonyx			x	
Hyperiidea				
Anchylomera blossevillei		x		
Brachyscelus rapacoides				x
Eupronoë maculata	x			
Hyperia (P.) atlantica	x			
H. (P.) fabrei	x			
H. (P.) macrophthalma	x			
Hyperioides longipes	x			
Lycaea pulex	x			
Parathemisto (E.) gaudichaudii	x		x	x
P. (E.) gracilipes	x		x	
P. gracilis	x			
Phronima atlantica		x		x
P. stebbingi				x
Phrosina semilunata		x		
Themistella sp.	x			
Vibilis armata	x			x
V. stebbingi				x
Unident. hyperiids			x	
EUPHAUSIACEA				
Euphausia krohnii	x	x	x	
E. mutica			x	
E. pseudogibba		x		
E. tenera	x			
Meganyctiphanes norvegica	x		x	x
Nematoscelis megalops	x	x	x	x
N. microps		x		
Stylocheiron abbreviatum		x		
S. affine	x	x		
S. carinatum	x			
S. submii	x	x		
Thysanoessa gregaria	x	x	x	x
T. longicaudata			x	x
Juveniles	x	x	x	x
DECAPODA				
Penaeidae			x	
Gennadus				

Table 7-11. (Cont.)

	September	December	March	July
Sergestidae				
Lucifer faxonii	x	x		
L. typus	x			
Brachyura				
Unident. larvae	x	x		x
Other Decapoda				
Unident. larvae	x	x		
Unident. adults	x			
STOMATOPODA				
Erichthus larvae	x			
Chaetognatha				
Eukrohnia hamata	x	x	x	
Pterosagitta draco	x			x
Sagitta bipunctata	x			
S. decipiens			x	
S. elegans			x	x
S. enflata	x	x		x
S. hexaptera	x	x	x	x
S. lyra			x	x
S. maxima		x		
S. planctonis		x	x	
S. serratodentata	x	x	x	x
Juvenile and unident.	x	x	x	x
CHORDATA				
Larvacea				
Oikopleura labradoriensis			x	
O. parva		x		
O. spp.		x	x	x
Unident.		x	x	
Pyrosomatida				
Pyrosoma sp.				x
Salpida				
Salpa fusiformis			x	x
S. maxima	x			
Thalia democratica	x	x		
Unident.				x
Doloilida				
Doliolum nationalis		x		
D. (Dolioletta) mirabilis				x
Unident.	x			
Vertebrata				
Unident.			x	x
Fish eggs			x	x



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-19	Biomass and Density of Zooplankton from Transects Across the Northwest Atlantic (Grice and Hart, 1962)

Table 7-12. Relative comparison of zooplankton volumes, numerical abundance and species diversity, in northwest Atlantic (from Grice and Hart 1962, Clarke 1940, Riley and Gorgy 1948, Emery and Uchupi 1972).

Volumes and Numerical Abundance

Shelf	Slope	Open Ocean (Gulf Stream and Sargasso Sea)	
1.07 cc/m^3	.27 cc/m^3	.02-.03 cc/m^3	Grice and Hart (1962)[1]
1540 NO/m^3	310 NO/m^3	71-134 NO/m^3	Grice and Hart (1962)
194 cc	52 cc	12 cc	Clarke (1940)[2]
0.840 gm^3/m^3	0.137-1576 gm^3/m^3	.034-.148 gm^3/m	Riley and Gorgy (1948)[3]
57 ml/m^3	0.36 ml/m^3	.007 ml/m^3	Emery and Uchupi (1972)
0.11-0.25 ml/m^3	0.06-0.09 ml/m^3	-------	Deepwater Dump-site[4] (.505 Bongo)

Diversity (Species)

81	169	157-268	Grice and Hart (1962)

1 3/4 meter net, 6 mesh, vertical to 200 m
2 paired oblique with open scrim net 10 strands/cm
3 Clark Bumpus samplers #10 silk ½ m oblique tow
4 double oblique 200 m 61 cm Bongo .505 mesh

comparable because of different sampling methods, shows the consistently larger quantities of zooplankton in the shelf waters and progressively lesser amounts seaward.

Grice and Hart (1962) determined that the mean zooplankton standing crop in the shelf waters was about three times greater than the slope waters, and in the slope water it was three to four times greater than that of Gulf Stream and Sargasso Sea area. If salps were included in the measurements, the slope zooplankton were four times less abundant than those of the shelf and nine to ten times more abundant than the zooplankton of the oceanic areas. This compares with Clarke's estimates (salps included) of the slope water zooplankton four times less abundant than the shelf zooplankton and four times more than oceanic areas.

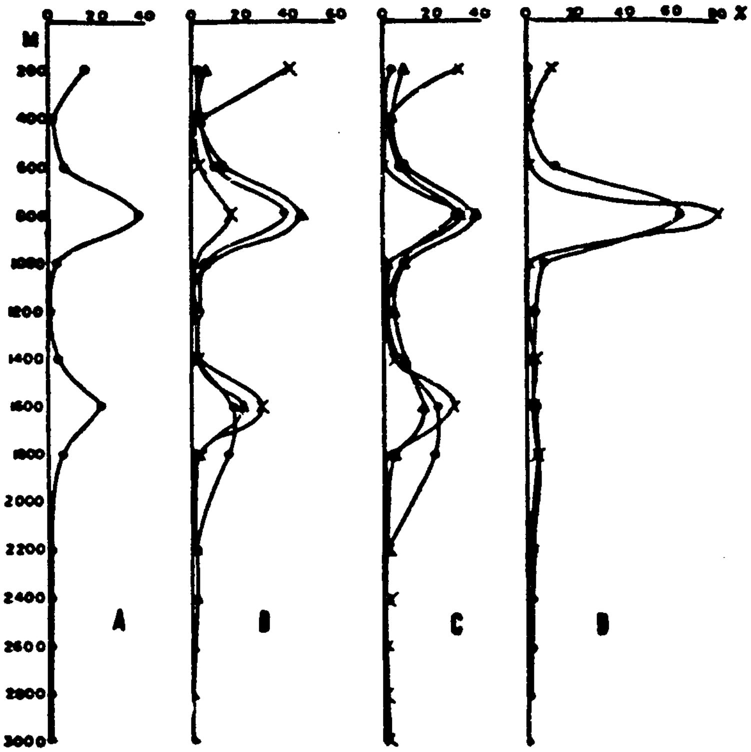
Several authors have noted that the most productive area for zooplankton seems to be near the edge of the continental shelf. Grice and Hart's (Figure 7-19) data show the most consistent peaks of either biomass or numbers to be at the outer shelf or inner slope stations. During March the inner slope exceeded, in biomass and abundance, that of any other area. Riley, Stommel and Bumpus (1949) also noted from their summary of existing data that the water at the edge of the shelf was unusually rich in zooplankton.

7.2.4 VERTICAL DISTRIBUTION

At this point, the vertical distribution of zooplankton in the slope waters becomes an important consideration. In all previous surveys, the maximum sampling depth was no more than 275 m and, therefore, the biomass and abundance relationships from coastal to oceanic areas applies only to the surface zone of the slope and oceanic areas. If there are significant numbers of zooplankton in deeper water, total production (numbers or biomass under a square meter of sea surface) of the offshore waters might be quite a bit higher.

Examination of the vertical distribution and diurnal migration of zooplankton in the slope waters indicated that there was indeed a significant number of organisms below the surface zone (Leavitt, 1935, 1938; Waterman, et. al., 1939). Leavitt's data (Figure 7-20) show a series of peaks down to 2000 m, the largest occurring at 600 to 800 m. He determined that between 40 and 90 percent of the animals were in depths less than 800 m; however, only 1/2 to 1/5 of the total volume occurred above 200 m. Waterman, et al. (1939) determined that the malacostian crustacea of the slope water exhibited diurnal migrations 200 to 600 m vertically in response to light stimulus. The result of this implies that there is a large number of zooplankton unaccounted for by the surface surveys.

Leavitt (1938) concluded that deep water zooplankton maxima was not due to the occurrence of a well-developed bathypelagic fauna, but was



Percentages of catch, at different levels at Station 2216. *A.* Percentage of total catch. *B.* Percentage of fish (●), copepods (▲), and euphausiids (X). *C.* Percentage of decapods (●), chætognaths (▲), and salps (X). *D.* Percentage of cœlenterates (●), and "residue" (X).

FIGURE 7-20

Vertical Distribution of Zooplankton in Slope Water (Leavitt, 1938) comprised of species such as *Calanus finmarchicus* and *Metridia longa* that are abundant in boreal surface waters. He suggested that the deepest maxima resulted from the intrusion of water masses that originated in shallow waters of higher latitudes.

7.2.5 TOTAL PRODUCTIVITY

The question arises as to the total production of zooplankton in the slope water. Riley, Stommel, and Bumpus (1949) and Emery and Uchupi (1972) reviewed data from various sources and both consider the slope water, particularly the area near the shelf break, to be particularly productive. Riley, *et al*., (1949) presented the mean annual zooplankton crop under a square meter of sea surface (Figure 7-21) which indicated the highest values were in the inner slope region. Emery and Uchupi (1972) using a ratio of 1/3 above and below 200 m concluded that the slope water displacement volume is about 200 ml under a square meter of sea surface, and that the slope water contains exceptional amounts of zooplankton. From this, they suggest annual production values of:

22 million tons from shelf waters
21 million tons from slope and open ocean waters

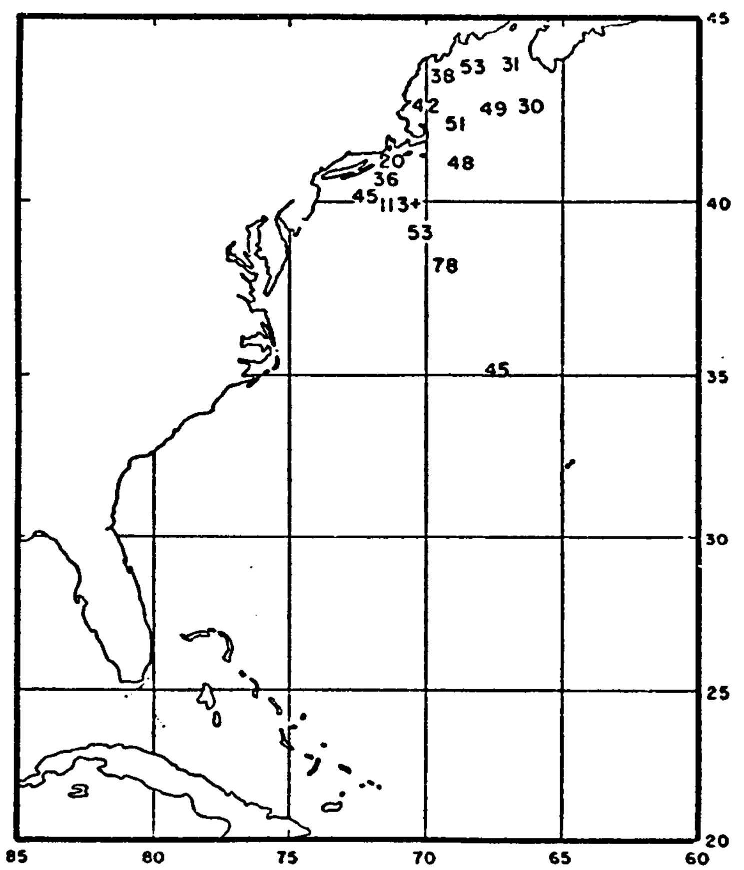
Although they point out that the lack of knowledge of zooplankton life spans makes these estimates very rough, probably, in spite of high total volume, the production of zooplankton on an annual basis in the offshore areas is less than that of the shelf because of the slower growth rates in the deeper, colder waters.

7.2.6 SEASONAL FLUCTUATIONS

The zooplankton volumes in the slope waters demonstrate a seasonal cycle of abundance (Figure 7-19) similar to that of the shelf waters but with not as pronounced a cycle. Grice and Hart (1962) noted that maximum displacement volume occurred in July (.76 cc per m^3) and a minimum displacement in December (.04 cc per m^3), a twenty-fold difference. Clarke (1940) reported a ten-fold difference; however, Grice and Hart (1962) considered their December values low because of a missing station and felt it should be closer to 10 cc per m^3, which would be comparable to Clarke's value. The shelf water exhibited a much greater seasonal fluctuation (20 to 40-fold) while the Sargasso Sea volumes showed little seasonal variation.

Likewise, the numerical abundance of zooplankton varied seasonally in the slope water, but with lesser magnitude than neritic areas. Maximum average values (571 per m^3) occurred in September and minimum values (36 per m^3) in July. The March average (504 per m) was similar to that of the shelf waters (585 per m^3).

The seasonal succession of copepod species has been described by Grice



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-21

Estimated Mean Annual Zooplankton Crop, cc. Displacement Volume Per m^2 of Sea Surface (Riley, Stommel, and Bumpus, 1949) and Hart (1962). The September collections included 45 species. Twelve of these were widely occurring forms, while a large number of warm water species and only one cold water species were present. The most abundant species were Centropages typicus and Clausocalanus pergens.

The December samples contained 49 species with over half represented in the September collections and many of the warm water species still present. The most abundant species were Clausocalanus arcuicornis and Pleuromamma borealis.

In March, only 39 species were present with the loss of 12 of the widely occurring forms. The remaining warm water species were found only at the outermost slope stations, and the cold water species, Calanus hyperboreus, appeared at all stations. The most abundant species belonged typically to the shelf region: Pseudocalanus minutus and Oithona similis.

The July collections contained the fewest (24) species with three widely ranging forms and with most of the shelf species that were previously present in slope waters, only in reduced numbers.

7.2.7 TROPHIC RELATIONSHIPS

The trophic relationships in slope waters are confused because they result from a mixture of communities having two somewhat different trophic structures. These two basic differences in the trophic relationships of zooplankton occur between coastal-shelf waters and Gulf Stream-Sargasso Sea waters (Grice and Hart, 1962; Riley, Stommel, and Bumpus, 1949; Riley and Gorgy, 1948).

The composition of zooplankton in the shelf water consisted of a few highly abundant and largely herbivorous species (Grice and Hart, 1962). Although the copepods predominated, salps, which are obligate herbivores, were at times present in large numbers. The Sargasso Sea fauna, again predominantly copepods, was made up of fewer herbivores and more omnivore-carnivores. Only 1/2 by volume of the Sargasso Sea zooplankton consisted of herbivores.

Riley and Gorgy (1948) noted that there was a difference in percent of organic matter in zooplankton collected from shelf and Sargasso Sea water. They suggested that the higher content of organic matter in the shelf zooplankton reflects the greater quantity of stored lipids resulting from higher phytoplankton concentrations.

It appears that the offshore communities completely utilize the available phytoplankton so that there can be no excess in herbivorous groups. Grice and Hart (1962) suggest that the trophic structure of the offshore region suggests a highly efficient, stable and possibly delicate relationship between the primary and the secondary trophic levels. The trophic structure of the shelf is probably less efficient and highly changeable, with constant fluctuations between surplus and scarcity of phytoplankton food supply. The slope water represents a somewhat intermediate situation in that it contains the components of both systems.

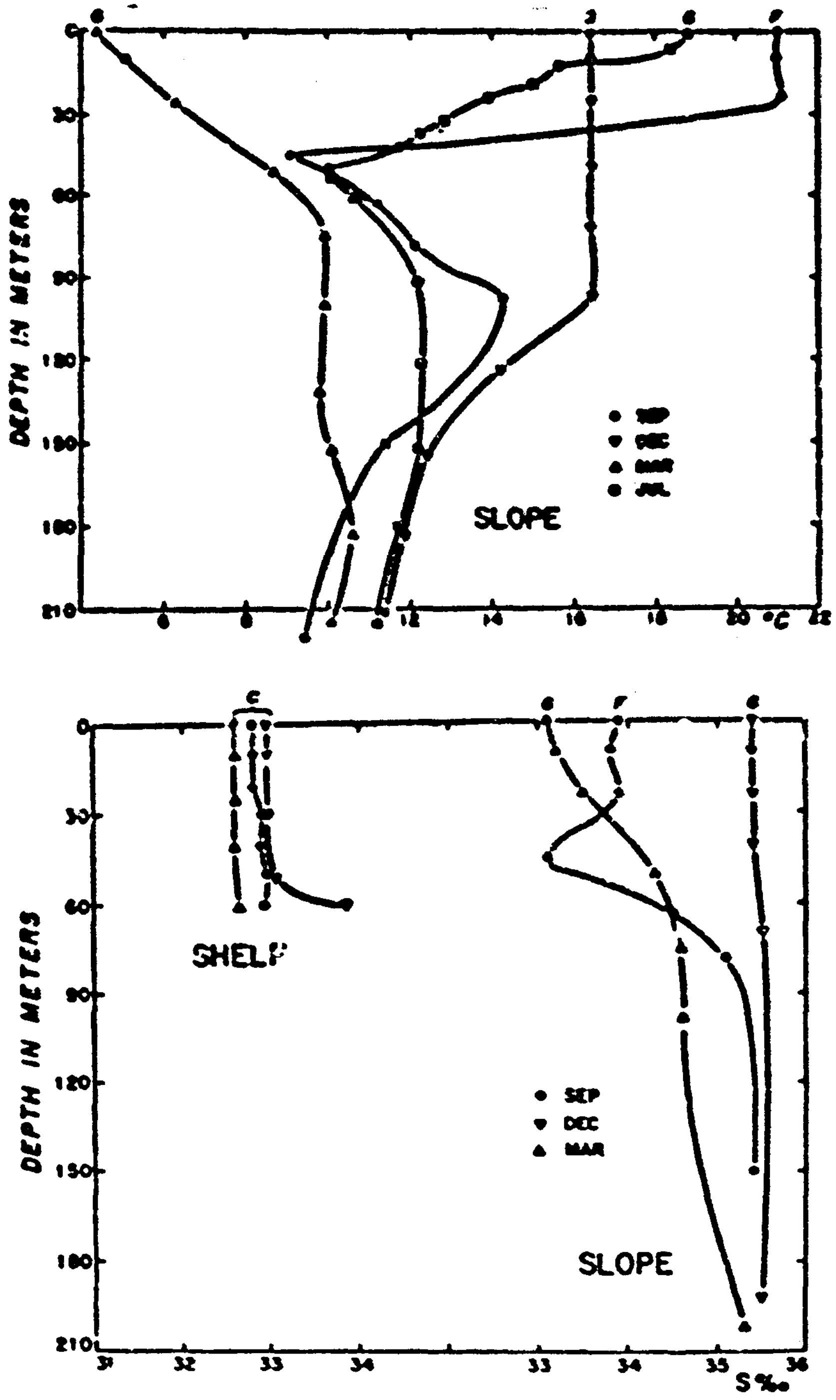
7.2.8 RELATIONSHIP TO HYDROGRAPHY AND OTHER PHYSICAL FACTORS

The relationship between the zooplankton and temperature, salinity, and other features of the water mass is of special interest because many components of the zooplankton community are known to correlate very closely to hydrography and are, therefore, useful in identifying hydrographically related processes in the ocean.

The slope water region, with its wide variation in hydrographic conditions, presents a very dynamic and changing situation for the zooplankton community. A number of authors have illustrated the typical temperature and salinity structure of the slope water that was present during their collections (Grice and Hart, 1962; Cifelli, 1962, 1965; and Clarke, 1940). Grice and Hart's data summarize the temperature and salinity variations for the four seasons (Figure 7-22). The wide variation in temperature and salinity of the surface water is obvious and reflects the neritic-ocean mix occurring in the slope water. Below 200 m there was little change. September and July show thermoclines between 10 and 40 m with temperature inversions, probably related to shelf water intrusions. In December the waters were practically isothermal to 70 m. The slope water salinities were variable but generally higher than the shelf.

Both copepod (Grice and Hart, 1962) and foraminifera (Cifelli, 1962) species are useful indicators of the intrusions and movements of water masses within the slope water region. Grice and Hart (1962) have indicated the seasonal and areal distribution of various copepod indicator species (Table 7-11). Cifelli (1962) noted that the foraminiferal fauna in the slope water was intermediate between coastal and oceanic species and reflected the mixing of surface water between the Sargasso Sea-Gulf Stream and the slope water. He also noted that stations with intermediate foraminiferal faunas had intermediate subsurface temperatures. He suggests that dissipating eddies from the Gulf Stream meanders might be the cause of this type of mixing.

The movement of waters in the form of eddies, rings, or intrusions from the Gulf Stream into the slope and shelf waters brings a characteristic fauna typical of subtropical regions. This had been noted by a number of authors and is at present the subject of major studies at the Woods Hole Oceanographic Institution. The well-known eddies that break away from the Gulf Stream and form a ring of swiftly moving Gulf Stream water around a core of Sargasso Sea water with its expatriate fauna are the means by which the slope and shelf waters may be "invaded" by subtropical species.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-22

Seasonal Temperature and Salinity Variations in the Slope Water (Grice and Hart, 1962)

The process of nutrient renewal by geostrophic upwelling that has been suggested by Rossby (1936), Redfield (1936), and Yentsch (1974), whereby nutrient rich deep water surfaces along the lines of equal density into the slope and shelf waters, is of interest in respect to zooplankton. Several authors have noted the abundant zooplankton fauna in the inner slope and outer shelf region and have suggested that this might result from an abundant phytoplankton food supply resulting from the upwelling process. However, the lack of strong evidence of unusually high phytoplankton production at the shelf break and the fact that the peak in zooplankton production should occur after April, when the slope flowering occurs, a fact that has not yet been established, would indicate that these answers await further investigation.

7.2.9 RELATIONSHIPS TO POLLUTANTS

As with the phytoplankton, there is little in the way of in situ studies from which conclusions can be drawn about the effect of pollutants on zooplankton populations in the slope water. In his review of the relationship between zooplankton and oil, as it relates to the mid-Atlantic shelf, Forns (1974) draws the following conclusions from existing laboratory and field data:

(1) Crude oil seems less toxic to zooplankton than does cleaning dispersants.

(2) Different types of crude oil have different effects on plankton.

(3) Zooplankton populations seem to recover from catastrophic oil spills within one seasonal cycle with sufficient flushing.

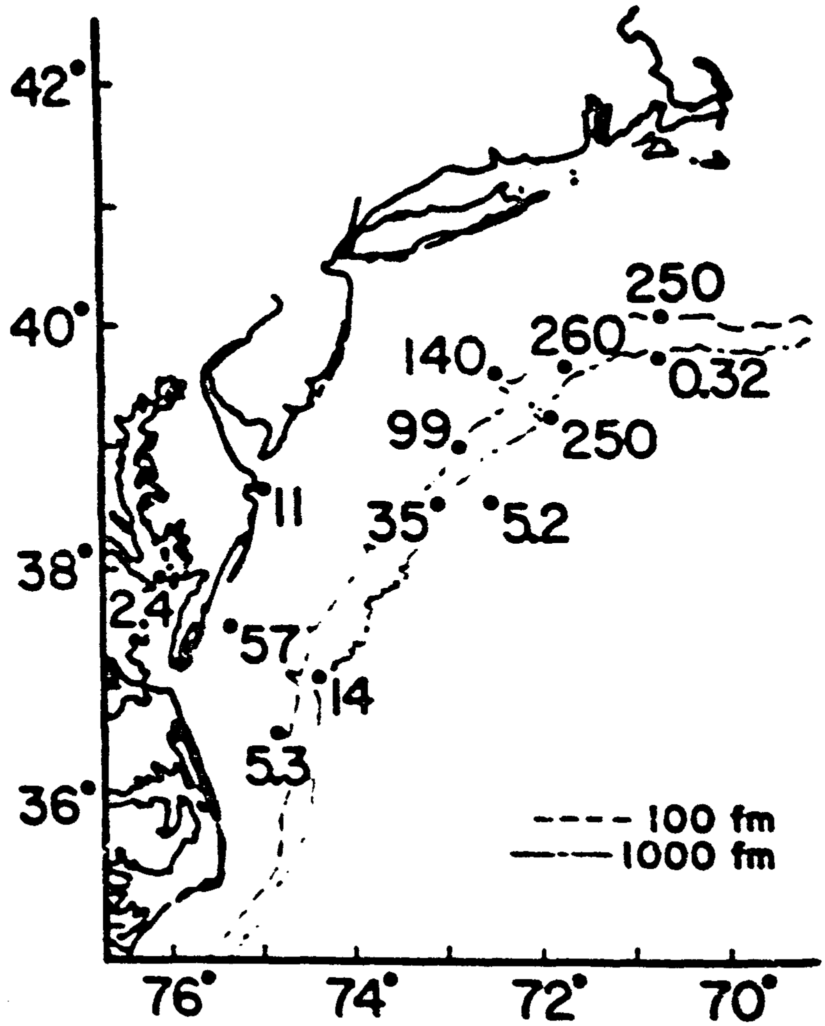
(4) Larval forms are more sensitive to oil than adult forms.

(5) Relative size affects resistance: large animals seem to be more resistant.

Polychlorinated biphenyls in the marine ecosystem have been of interest because of their widespread distribution. Riseborough, Vreeland, Harvey, Miklas, and Carmignani (1972) determined the content of PCB residues in the tissue of zooplankton taken in shelf and slope waters on a series of three cruises. The distribution of the PCB concentrations is shown in Figure 7-23. The concentrations were relatively high, comparable to the levels found in fish off Long Island Sound, and the highest were centered around the slope and shelf off southern New England and New York Bight.

7.2.10 ICHTHYOPLANKTON

Although the ichthyoplankton are an integral component of zooplankton, they have unique features that cause them to be considered more as components of fish populations than as part of the plankton. The



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE		
TRIGOM	FIGURE 7-23	Distribution of PCB Concentrations in Zooplankton of the Northwest Atlantic Shelf, Parts Per Million of the Lipid Weight (Riseborough, et al., 1972)

eggs and larvae of any particular species are only temporary members of the plankton community and because their fate during the planktonic stage has significant effects on adult stocks, they have received most attention from those interested in the fish populations.

Our knowledge of the ichthyoplankton of the slope water is very limited and many of the offshore species are not yet identified. To date there has been no complete survey of the outer slope waters in terms of fish larvae. Past surveys have dealt with coastal and shelf areas which have been summarized in the previous report (Chenoweth, 1974).

At present, the MARMAP program carries out extensive ichthyoplankton sampling in coastal and shelf waters with stations that overlap the shelf edge to about 1,000 m. Their data, when it becomes available, will give a better understanding of the components and abundance of the ichthyofauna of the inner slope regions and the role that the slope water plays in the reproduction of various fish species. The most recent information on slope water ichthyoplankton is from the previously mentioned deep water dump site 106 study (N. Y. Ocean Science Laboratory, 1975) in which a small area of the inner slope was sampled for fish eggs and larvae.

COMPONENTS

There are probably a number of fish communities that contribute to the ichthyofauna of the slope water areas. These communities all overlap, as adults, in the transitional zone that is the slope region. They are:

(1) Species abundant in the shelf areas but whose reproductive products move into the slope area.

(2) Demersal slope species, such as macrourids, that reproduce primarily in these waters.

(3) Mesopelagic fishes, such as myctophids, that are abundant in the deeper slope water.

(4) Possibly the products of bathal fishes, common below 2,000 m, that drift into the slope zone.

The species of fish larvae taken from the slope area of the deep water dump site study are listed with standing crop values in Table 7-13, and show the general representation of the various groups mentioned above. Over 50 identifiable species, most of tropical origin, were found in the Neuston net samples and almost an equal number of species were taken with a .505 Bongo net. The dominant forms in the Bongo .505 samples were larval myctophids and bothids.

The species with the highest standing crops were those inhabiting the shelf areas. Diversity increased with distance offshore to the

Table 7-13. Fish larvae and standing crops taken with .505 Bongo net at the Deep Water Dump-site 106 (from N. Y. Ocean Science Laboratory unpublished report). Double oblique tows to 200 meters using 61 cm Bongo net with .505 mesh.

Station 2-1	Number	No./1000m^3
Muraenidae leptocephalus	1	2.8
Diogenichthys atlanticus	1	2.8
Moridae	8	22.0
Macrouridae	1	2.8
Holocentridae	1	2.8
Bothus sp.	1	2.8
Citharichthys sp.	1	2.8
Monacanthus ciliatus	1	2.8
Tetraodontidae A	1	2.8
Station 4-1		
Nettodarus brevirostrus	1	2.8
Myctophidae	2	6.6
Gonostomatidae	1	2.8
Serranidae	2	6.6
Etropus microstomus	1	2.8
Syacium sp.	1	2.8
Bothidae	3	8.4
Monacanthus hispidus	1	2.8
Unknown D	1	2.8
Unknown E	1	2.8
Station 6-1		
Lepidophanes guentheri	1	3.0
Myctophum asperum	1	3.0
Macrouridae	1	3.0
Peprilus tricanthus	1	3.0
Bothidae	1	3.0
Unknown D	1	3.0
Station 7-1		
Anchoa sp.	1	2.5
Clupeiformes	1	2.5
Maurolicus meulleri	1	2.5
Trachinocephalus myops	1	2.5
Synodontidae	1	2.5
Myctophidae	37	92.5
Urophycis sp.	3	7.5
Lophius americanus	1	2.5
Scorpaenidae	1	2.5
Bothidae	1	2.5
Cyclopsetta fimbriata	1	2.5
Etropus microstomus	1	2.5

Table 7-13. (Cont.)

Station 7-1 (Cont.)	Number	No./1000m^3
Syacium sp.	2	5.0
Symphurus sp.	1	2.5
Tetraodontidae A	1	2.5
Unknown D	2	5.0
Unknown 6	4	10.0
Station 8-1		
Bonapartia pedaliots	1	3.1
Centrobranchus sp.	1	3.1
Ceratoscopelus maderensis	3	9.4
Myctophidae	7	21.9
Moridae	1	3.1
Macrouridae	3	9.4
Holocentridae	1	3.1
Centropristis striatus	1	3.1
Cyclopsetta fimbriata	1	3.1
Tetraodontidae A	2	6.3
Station 9-1		
Clupeiformes	1	2.7
Paralepididae	1	2.7
Myctophidae	11	29.8
Citharichthys arctifrons	1	2.7
Cylopsetta fimbriata	1	2.7
Syacium sp.	1	2.7
Tetraodontidae A	1	2.7
Unknown H	1	2.7
Unknown J	1	2.7
Unknown L	1	2.7
Station 10-1		
Gonostomatidae	2	6.1
Myctophidae	2	6.1
Urophycis sp.	2	6.1
Moridae	1	3.0
Exocoetidae	1	3.0
Pomatomus saltatrix	1	3.0
Peprilus triacanthus	1	3.0
Citharichthys arctifrons	2	6.1
Syacium sp.	1	3.0
Unknown D	2	6.1
Unknown K	2	6.1
Unknown L	1	3.0

Table 7-13. (Cont.)

Station 11-1	Number	No./1000m^3
Myctophidae	24	39.6
Unknown D	2	7.5
Station 12-1		
Gonostomatidae	1	3.7
Myctophidae	6	22.1
Sciaenidae	1	3.7
Unknown D	1	3.7
Station 13-1		
Nettastomatidae leptocephalus	1	3.4
Brevoortia tyrannus	1	3.4
Clupeiformes	1	3.4
Synodontidae	2	6.8
Myctophidae	12	41.1
Pomatomus saltatrix	1	3.4
Peprilus triacanthus	1	3.4
Bothidae	2	6.8
Tetraodontidae A	1	3.4
Unknown G	1	3.4
Unknown R	1	3.4
Station 14-1		
Argyropelecus hemigymnus	1	2.8
Synodontidae	1	2.8
Myctophidae	13	36.6
Histrio histrio	1	2.8
Antigonia sp.	1	2.8
Bothidae	1	2.8
Syacium sp.	1	2.8
Monacanthus hispidus	2	5.6
Unknown K	1	2.8
Unknown L	1	2.8
Station 15-1		
Gonostomatidae	1	3.0
Myctophidae	2	6.1
Bothidae	2	6.1
Unknown O	1	3.0

Table 7-13. (Cont.)

Station 16-1	Number	No./1000m^3
Brevoortia sp.	2	4.8
Synodontidae	1	2.4
Myctophidae	8	19.3
Urophycis sp.	1	2.4
Pomatomus saltatrix	3	7.2
Stenotomus chrysops	1	2.4
Scombridae	1	2.4
Peprilus triacanthus	1	2.4
Prionotus sp.	1	2.4
Syacium sp.	1	2.4
Bothidae	6	14.5
Unknown D	1	2.4
Unknown H	1	2.4
Unknown P	2	4.8
Station 17-1		
Paralepididae	1	2.8
Gonostomatidae	1	2.8
Trachinocephalus myops	1	2.8
Evermannellidae	1	2.8
Diaphus dumeril	4	11.2
Hygophum hygomi	1	2.8
Lobianchia dolfleini	1	2.8
Myctophum affine	1	2.8
Myctophidae	8	22.4
Macrouridae	1	2.8
Pomatomus saltatrix		
Serranidae	2	5.6
Peprilus triacanthus	1	2.8
Bothidae	3	8.4
Tetraodontidae A	2	5.6
Unknown H	1	2.8
Unknown L	1	2.8
Station 18-1		
Myctophidae	25	42.2
Histrio histrio	1	1.7
Urophycis sp.	4	6.7
Macrouridae	3	5.1
Serranidae	1	1.7
Apogonidae	1	1.7
Gempylidae	1	1.7
Peprilus triacanthus	1	1.7

Table 7-13. (Cont.)

Station 18-1 (Cont.)	Number	No./1000m^3
Stromateidae	1	1.7
Cyclopsetta fimbriata	3	5.1
Syacium sp.	14	23.6
Bothidae	33	55.6
Unknown D	16	27.0
Unknown H	1	1.7
Unknown K	2	3.4
Unknown L	6	10.1
Station 19-1		
Congridae leptocephalus	1	1.4
Paralepididae	1	1.4
Valenciennellus tripunctulatus	2	2.9
Vincigerria poweriae	1	1.4
Benthosema suborbitale	3	4.3
Ceratoscopelus maderensis	2	2.9
Diaphus dumerili	1	1.4
Hygophum hygomi	2	2.9
Lampanyctus alatus	1	1.4
Lepidophanes guentheri	1	1.4
Myctophum asperum	3	4.3
Myctophidae	32	46.2
Laphius americanus	2	2.9
Urophycis sp.	2	2.9
Melamphaeidae	1	1.4
Syngnathus elucens	1	1.4
Pomatomus saltatrix	1	1.4
Peprilus triacanthus	1	1.4
Stromataeidae	1	1.4
Citharichthys arctifrons	1	1.4
Bothidae	5	7.2
Unknown H	2	2.9
Unknown Q	1	1.4
Station 20-1		
Congridae leptocephalus	1	2.0
Ceratoscopelus maderensis	3	5.9
Myctophidae	12	23.6
Moridae	1	2.0
Stromateidae	1	2.0
Bothidae	2	3.9
Tetraodontidae B	1	2.0
Unknown D	4	7.9
Unknown R	1	2.0

Table 7-13. (Cont.)

Station 22-1	Number	No./1000m^3
Paralepididae	1	2.0
Synodontidae	1	2.0
Myctophidae	4	8.0
Scomber scombrus	13	26.1
Bothidae	1	2.0
Unknown D	1	2.0
Unknown L	1	2.0
Station 23-1		
Muraenidae leptocephalus	1	1.9
Urophycis sp.	21	39.0
Pomatomus saltatrix	4	7.4
Peprilus triacanthus	1	1.9
Limanda ferruginea	1	1.9
Monacanthus hispidus	1	1.9
Unknown A	1	1.9

southeast, accompanied by higher temperatures and salinities.

Although larvae of shelf species seem to be well represented at the deep water dump side, the slope waters are probably not a nursery ground for these species and it is likely that it harbors shelf species that have drifted away from more desirable areas. Colton and Temple (1961) have discussed the significance of the drift of fish larvae off Georges Bank into slope water and suggest that normally most shelf-spawned larvae drift off the Bank and are lost in the fishery. The role the slope water plays in the reproductive activities of the commercially important shelf species is still not clear.

7.1.11. DATA GAPS

The several studies reported in this chapter have provided information on the species composition, the distribution and the seasonal cycle of abundance of zooplankton as a whole in the surface zone (upper 200 m) of the study area. The zooplankton of the slope water, however, consists of a diverse group of organisms, many of which are not common to the shelf waters where most research has been done. Certainly the life history aspects and autoecology of many kinds of zooplankton in this region have yet to be described. Very little is known about the zooplankton communities below the surface zone.

The inner waters of the slope region are thought to be fairly productive for zooplankton and the waters close to the continental shelf appear to be important forage areas for many animals of the higher trophic levels including the higher invertebrates, fishes, and mammals. There are unanswered questions concerning the productivity and the trophic relationships of zooplankton in this area. Estimates of reliable total zooplankton production require such determinations as life spans of important components of the slope zooplankton and the contributions of populations below the surface zone to total production. The role of the zooplankton as grazers on phytoplankton and as forage for the higher invertebrate and vertebrate animals has yet to be clearly defined.

Some information concerning the relationship of various members of the zooplankton to hydrography in the slope water is available and has been discussed in this chapter. However, there is little data concerning specific tolerances or preferences of individual kinds of zooplanktors to ranges of salinity, temperature, or other physical properties. Programs at the Woods Hole Oceanographic Institution now in progress are designed to examine the relationships of zooplankton communities to the Gulf Stream eddies and should help to clarify the relationship of zooplankton communities to hydrographic features.

Almost nothing is known of the in-situ response of zooplankton to contamination by pollutants although there have been some studies on the distribution of PCB residues in zooplankton tissues.

The ichthyoplankton forms a somewhat separate category of zooplankton because of its relationship to fishery interests. Of particular concern is the movement of fish larvae of important commercial species from the shelf waters where conditions are assumed to be optimal for their survival, into the deep slope water where their survival and recruitment to the adult stocks is less assured. Significant loss of reproductive stock to the open ocean could affect the success of year classes of commercial fish species.

Of course basic information concerning slope water ichthyoplankton belonging to fish species of the deeper oceanic waters is generally lacking to the extent that many of these species are not yet identifiable.

7.2.12 REFERENCES

Bigelow, Henry B. 1914. Oceanography and plankton of Massachusetts Bay and adjacent waters, Nov. 1912, May 1913. Bull. Mus. of Comp. Zool., Harvard College, v. 58, no. 10: 385-419. Cambridge.

__________. 1914b. Explorations in the Gulf of Maine, July and August, 1912, by the U.S. fishery schooner GRAMPUS: oceanography and notes on the plankton. Bull. Mus. Comp. Zool., Harvard College, v. 58, no. 2: 29-147.

__________. 1915. Exploration of the coast water between Nova Scotia and Chesapeake Bay, July and August 1913 by the U.S. fisheries schooner GRAMPUS: oceanography and plankton. Bull. Mus. of Comp. Zool., Harvard College, v. 59: 149-360. Cambridge, Mass.

__________. 1917. Exploration of the coast water betweeen Cape Cod and Halifax in 1914 and 1915 by the U.S. fisheries schooner GRAMPUS: oceanography and plankton. Bull. Mus. Comp. Zool., Harvard College, v. 61: 161-358.

__________. 1922. Exploration of the coastal water off the northeastern United States in 1916 by the U.S. fisheries schooner GRAMPUS. Bull. Mus. of Comp. Zool., Harvard College, v. 65, no. 5: 87-188.

__________. 1926. Plankton of the offshore waters of the Gulf of Maine. Bull. Bur. Fish., v. 40: 1-509.

Bigelow, H. B., L.C. Lillick, and M. Sears. 1940. Phytoplankton and plankton protozoa of the offshore waters of the Gulf of Maine. Part I: numerical distribution. Trans. Amer. Philos. Soc., v. 31: 149-191.

Bowman, T.E. 1971. The ditribution of calanoid copepods of the eastern United States between Cape Hatteras and southern Florida. Smithson. Contrib. Zool., v. 96. 58 p.

Chenoweth, S. 1974. Fishes. In: A Socio-Economic and Environmental Inventory of the North Atlantic Region. TRIGOM/PARC for the Bur. of Land Manage., Washington, D.C.

Cifelli, R. 1962. Some dynamic aspects of the distribution of planktonic foraminifera in the western North Atlantic. Sears Found. J. Mar. Res., v. 20, no. 3: 201-212.

__________. 1965. Planktonic foraminifera from the western North Atlantic. Smithson. Misc. Collect., v. 148, no. 4: 1-36.

REFERENCES (cont.)

Clarke, G.L. 1940. Comparative richness of zooplankton in coastal and offshore areas of the Atlantic. Biol. Bull., v. 78: 226-255.

Colton, J.B., Jr. and R.F. Temple. 1961. The enigma of Georges Bank spawning. Limnol. Oceanogr., v. 6, no. 3: 280-291.

Emery, K.O. and E. Uchupi. 1972. Western North Atlantic Ocean: topography, rocks, structure, water, life and sediments. Amer. Ass. Petrol. Geol. Mem. 17.

Furns, J.M. 1974. Mid-Atlantic zooplankton: an overview with consideration of potential impacts by offshore oil. In: Estuarine Res. Fed., Marine environmental implications of offshore oil and gas development in the Baltimore Canyon region of the mid-Atlantic coast. Proc. Estuarine Res. Fed., Outer continental shelf conf. and workshop, Dec. 2, 3, 4, 1974.

Grice, George D. 1972. The existence of a bottom-living calanoid copepod fauna in deepwater with descriptions of five new species. Crustaceana, v. 23, Part 3: 219-242.

Grice, George D. and Arch D. Hart. 1962. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. Ecol. Monogr., v. 32, no. 4: 287-309.

Iselin, C. O'D. 1936. A study of the circulation of the western North Atlantic. Pap. Phys. Oceanogr. Meteorol., v. 4, no. 4: 1-101.

Leavitt, B.B. 1935, A quantitative study of the vertical distribution of the larger zooplankton in deep water. Biol. Bull., v. 68: 115-130.

__________. 1938. The quantitative vertical distribution of macrozooplankton in the Atlantic Ocean Basin. Biol Bull., v. 74: 376-394.

New York Ocean Science Laboratory. 1975. An analysis of plankton from the New York Bight deep water dump site number 106. MARMAP Contrib., v. 77, Nat. Mar. Fish. Serv.

Raymont, J.E. 1963. Plankton and productivity in the oceans. MacMillan Co., New York.

Redfield, A.C. 1936. An ecological aspect of the Gulf Stream. Nature, v. 128, no. 2302: 1013.

REFERENCES (cont.)

Riley, G.A. and S. Gorgy. 1948. Quantitative studies of summer plankton populations of the western North Atlantic. J. Mar. Res., v. 7, no. 2: 100-121.

Riley, G.A., H. Stommel, and D.F. Bumpus. 1949. Quantitative ecology of the plankton of the western North Atlantic. Bull. Bingham Oceanogr. Collect., v. 12, no. 3: 1-169.

Riseborough, R.W., V. Vreeland, G.R. Harvey, H.P. Miklas, and G.M. Carmignani. 1972. Residues in Atlantic zooplankton. Bull. Environmental Contamination Toxicology, v. 8, no. 6: 34-355.

Rossby, C.G. 1936. Dynamics of steady state ocean currents in light of experimental fluid mechanics. Prop. Phys. Oceanogr. Meteorol., 5.

St. John, P.A. 1958. A volumetric study of zooplankton distribution in Cape Hatteras area. Limnol. Oceanogr., v. 3: 387-397.

Waterman, T.H., R.F. Nunnemacher, F.A. Chace, and G.L. Clarke. 1939. Diurnal vertical migrations of deep water plankton. Biol. Bull., v. 76, no. 2: 256-279.

Yentsch, C.S. 1974. The influence of geostrophy on primary productivity. Tethys, v. 6, no. 1-2: 111-118.

CHAPTER 7.0

BIOLOGICAL OCEANOGRAPHY

7.3 BENTHOS

PETER F. LARSEN

STANLEY CHENOWETH

CHAPTER 7.3 TABLE OF CONTENTS

Chapter 7.3 Benthos

7.3 BENTHOS

7.3.1 THE BENTHIC INVERTEBRATES OF THE CONTINENTAL SLOPE: A REVIEW

INTRODUCTION

Benthic marine ecological studies have been carried out along the northwestern Atlantic coast, especially in the New England region, for well over a century. Only recently, however, has interest been directed towards the deeper waters which include the continental slope. The initial studies of significant magnitude were launched in the early sixties. Work at these depths has been continuing at an accelerating rate with increasing sophistication as our fundamental knowledge of these areas increases, and as the technological maturity to carry out such studies develops. Investigations of the benthos of the continental slope have usually centered around a limited number of people; principal among them are such ecologists as Sanders, Hessler, Rowe, Menzies and Wigley. We drew heavily upon the contributions of these people in compiling this report.

Retrieving samples from deep water remains difficult to this day. The process is basically the same as it was a hundred years ago, that is, lowering a sampling device to the bottom on the end of a line. There have been modifications in the sampling devices, however, which make them more efficient. The advent of deep-sea photography and research submarines has made visual inspection of the bottom possible. Indeed, much of the information on faunal densities and distributions on the continental slope has been generated using these visual methods.

Today four basic methods are used singly or in combination to gain information on the continental slope benthos. They are: 1) grab samples; 2) dredges and trawls; 3) bottom photographs; and 4) observations from submersibles. Each method has advantages and disadvantages. The reliability of grab sampling has been increased with the development of spring-loaded grabs such as the Smith-McIntyre grab (Smith and McIntyre, 1954) which must be in contact with the bottom to close. Many grabs, designed to close when the support line slackens at bottom contact, will close prematurely when a roll of the ship causes the line to slacken. Grab samplers are very quantitative, at least for infauna (the organisms living in the sediment), but the sample size is relatively small so that only a limited number of specimens will be recovered in areas of low density.

Dredges and trawls have the advantage of covering a much larger area than grabs. They are, however, often selective in what they recover. Devices such as the otter trawl or beam trawl are principally used to capture epifauna, i.e., the fauna living on the substrate. Due to the avoidance reaction of the motile epifauna and to the inherent inefficiency of most dredges and trawls, they are considered to be qualitative samplers, although they are often used to establish relative abundances of dominant species. A dredge called the epibenthic sled, developed by Howard Sanders of the Woods Hole Oceanographic Institution, has overcome many of the shortcomings of previous dredges and has greatly advanced our sampling capability in deep water (Hessler and Sanders, 1967). This dredge reliably skims off the top few centimeters of sediment where the great majority of the organisms are found and it has collected a vast number of species and individuals from the ocean bottom.

Field sampling with a grab or dredge is only the beginning of the difficulty of producing data on the continental slope benthos. The samples must be sieved on fine screens to remove the finer sediment fractions, then they must be properly preserved. In the laboratory the fauna must be manually removed from the remaining sediment, identified to species and counted before a rigorous analysis of the data can be started. This laboratory analysis is a long, tedious job. Some benthic ecologists estimate that an hour of field collecting will take 40 hours in the laboratory to work up the information properly. Considering the present lack of systematic knowledge of many continental slope taxa, this estimate may be conservative.

Visual methods of sampling the deep benthos have the advantages of being able to cover a large area of bottom quickly and of being relatively simple to process. The obvious disadvantages are that only the larger epifauna can be seen and identified in the photographs and the animals are not returned to the laboratory for study. If it is possible to assume, however, that the smaller epifaunal and infaunal organisms respond in the same way to controlling ecological factors, as the large epifauna visible in the photographs, it may be possible to define relative abundance and zones of distribution by this method. A more complete discussion of the values and limitations of photographic sampling can be found in McIntyre (1956), Owen, Sanders and Hessler (1967) and Wigley and Theroux (1970).

As mentioned above, it is possible and advantageous to use some of these methods in combination. Grabs are often lowered with attached cameras that photograph the bottom just before impact. Campbell grabs have been equipped with cameras inside the jaws to snap a picture at the exact impact point (Wigley and Emery, 1967). This arrangement allows the recovery of the identical specimens photographed. Dredges and trawls can be outfitted with rapidly recycling cameras on the bridle of the sampling device (Allen Paul, personal communication). This gives an estimate of the percentage of species and individuals in the path of the trawl that are not captured by it.

Special techniques can also contribute valuable information about continental slope benthos. Dayton and Hessler (1972) showed, by taking a timed series of photographs of bait placed on the ocean floor, that motile deep-sea animals apparently are attracted to a food source from a considerable distance. The use of baited traps often recovers species missed by grab or dredge sampling (Paul, 1973) and recruitment in deep-sea communities can be studied by placing boxes of abiotic sediment on the ocean floor and monitoring the settlement and migration of fauna into it (J. Frederick Grassle, personal communication).

The reader wishing more detailed information on benthic sampling and its attendant problems and limitations should consult Holme and McIntyre (1971).

The following account of the benthos of the continental slope is based primarily on published literature. As many pertinent references to the literature as possible are included for easy back refference. Knowledge of the benthos on the slope is still fragmentary, so it is not possible to produce a comprehensive report. The extent and detail of each section below reflects the amount of absolute information known on the subject. For example, the depth distributions of some major epifaunal components are well known, whereas physiological information is almost totally lacking.

There are two areas within the study region of Georges Bank to Cape Hatteras which have been heavily sampled (Figure 7-24). The first is to the south of Martha's Vineyard, Massachusetts. This area is part of the well-known Gayhead-Bermuda transect and it has been studied by several investigators, mostly from the Woods Hole community. Considering all aspects of benthic biology, it probably represents the best known piece of continental slope on the eastern seaboard.

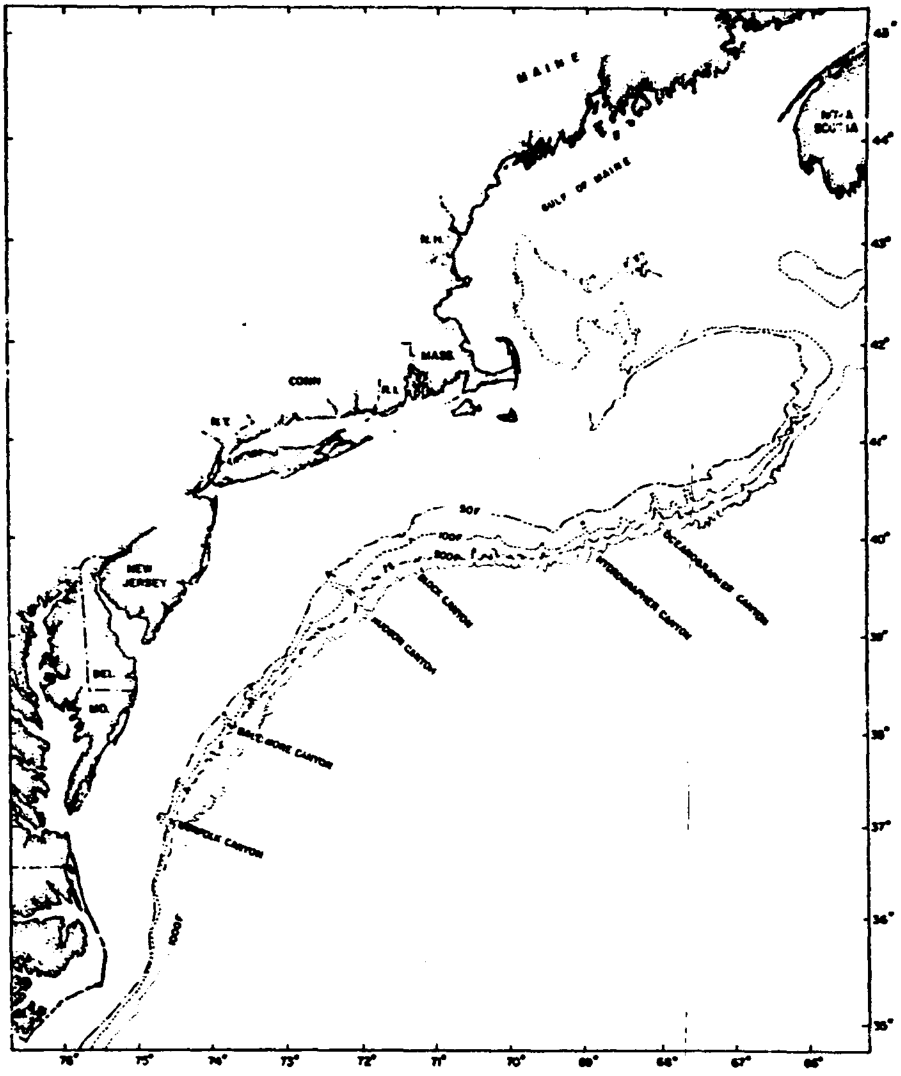
The continental slope off the Carolinas has been heavily studied by scientists previously centered at Duke University. This area, in conjunction with the northern area described in the preceding paragraph, gives us most of the data base upon which this report is written.

The slope in the New York Bight near Hudson Canyon has been examined to a limited extent.

COMMUNITY STRUCTURE

Composition

The taxonomic composition of the marine benthos is very diverse. Stickney (1974) reports that 20 of the 22 accepted animal phyla are represented in the benthos. On the continental slope, certain groups are numerically important, among them the polychaetes, peracarid crustaceans (amphipods, isopods, etc.), bivalve molluscs and often sipunculids in the infauna (Sanders, et al., 1965) and echinoderms (sea cucumbers, brittle stars and sea urchins), polychaetes and coelenterates (sea anemones) in the epifauna (Rowe and Menzies, 1969). Which group is dominant in abundance or biomass depends largely on the depth sampled and the type of sampling gear used. The faunal composition of a typical epibenthic sled haul is illustrated in Table 7-14. This sample was taken



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-24	The Continental Slope from Georges Bank to Cape Hatteras

Table 7-14. Results of a single epibenthic sled haul at 39°46.5'N, 70°43.3'W in from 1330-1470 m (modified from Hessler and Sanders, 1967).

	Spp.	Ind.
Porifera	2	+
Coelenterata	16	171
Nemertina	4	180
Priapulida	1	37
Pogonophora	3	13
Annelida	91	10804
Archiannelida	1	26
Oligochaeta	1	13
Polychaeta	89	10765
Sipunculida	8	85
Echiurida	-	-
Arthropoda	127	4393
Pycnogonida	2	45
Arachnida	1	1
Crustacca	124	4347
Ostracoda	3	25
Copepoda	+	+
Cirripedia	1	1
Malacostraca	120	4321
Leptostraca	1	2
Cumacea	20	794
Tanaidacea	23	891
Isopoda	30	1538
Amphipoda	43	1005
Decapoda	3	91
Mollusca	84	6713
Aplacophora	14	1086
Pelecypoda	28	4493
Gastropoda	35	608
Scaphopoda	7	526
Echinodermata	20	2715
Crinoidea	-	-
Ophiuroidea	6	1327
Asteroidea	3	44
Echinoidea	5	7
Holothuroidea	6	1337
Ectoprocta	-	-
Brachiopoda	-	-
Chordata	3	26
Urochordata	2	22
Vertebrata	1	4
Incertae Sedis	6	105
Total	365	25,242+

by Hessler and Sanders (1967) off southern New England at between 1330-1470 m. Trends in taxonomic composition of the benthic community at various depths will be discussed in the section on zonation.

The number of separate species potentially inhabiting the ocean at slope depths is immense. Hartman listed 266 polychaete species in 50 families from the Gayhead-Bermuda transect (Sanders, et al., 1965). Many of these species occur on the continental slope. For example, in May 1961 three samples were taken at continental slope depths off southern New England using an anchor dredge. From these samples, Hartman identified 50, 51 and 66 species of polychaetes at depths of 2000 m, 1500 m and 823.5 m, respectively (Hartman, 1965). The largest of the three samples covered only 1.01 m^2 of bottom, indicating that this extremely high diversity at slope depths is real and is not an artifact caused by the dredge integrating species across several habitats, i.e., it represents within and not between-habitat diversity. The cumaceans along this transect were studied by Jones and Sanders, (1972) using the epibenthic sled. They report the average number of species per haul to be 15 between 68-1000 m, 18 between 1000-2000 m and 13 between 2000-3000 m. The maximum number of species of cumaceans in a single sled haul was 37 at 587 m. Isopods are a common slope taxon and indeed, because of their abundance, their lifelong benthic habit and the relatively advanced nature of their systematics, they are often chosen as environmental indicators (Menzies, et al., 1973). Menzies, et al. (1973) report finding 41 species of isopods on the Carolina slope between 200 and 2635 m.

It is, therefore, manifest that the continental slope benthos between Georges Bank and the Carolinas is highly diverse. This diversity is reflected not only in the large numbers of species inhabiting the slope but also in the diversity of the higher taxonomic levels from genus to phylum.

Zonation

Zonation can be defined as large scale heterogeneity of faunal distributions. Smaller scale heterogeneity within a species' normal distributional range is called patchiness and it is caused by physical and biological irregularities in the environment. Discussion here will be limited to zonation per se, as the extent and actual causes of patchiness on the continental slope are not well understood.

Within the study area, zonation can take place in two planes - a horizontal plane measured in latitude and a vertical plane measured as depth. Assuming other ecological factors, such as current and distance from land, are constant, there is a change in the pattern of zonation based on latitude. The principle is called tropical submergence and in its simplest form it states that a species is found at increasingly greater depths as one moves from the poles toward the equator. The most pronounced and better known examples occur in shallow water where a species such as the gastropod Buccinum undatum may be characteristic of the intertidal zone in Maine, but is strictly a subtidal organism in southern New England. The operating ecological factor is, of course, the latitudinal gradient in temperature which is reflected in water temperatures. The sum effect of many species exhibiting this phenomenon would cause the same or similar biological communities to be found at greater depths in the southern section of the study area than in the Georges Bank area. Menzies, et al., (1973) (pg. 250) graphically depict this phenomenon. Its relevance to this report is twofold: 1) that different faunal zones occur at different depths in different parts of the ocean so that no generalization about the depth distribution of faunal communities is valid over a large geographic area; and 2) there is no reason to believe that the discontinuity between the communities typical of the continental shelf and those found in deeper water should be found at the shelf break or at any other topographic feature.

One would have to consider a much greater length of continental slope before the phenomenon of tropical submergence would have overriding importance. In our study region, other factors, such as current and sediment distributions are more important, but these factors being equal, the depth distribution of several species, and even whole communities, would be deeper at the southern end than at the northern end.

Within the scale of our study area, depth zonation is much more pronounced than latitudinal zonation and it is perhaps the best studied aspect of the ecology of continental slope benthos. Depth zonation of the faunal communities of the northwestern Atlantic continental slope has been reported as marked (Rowe and Menzies, 1969) and nonexistent (Sanders and Hessler, 1969). Discrepancies between the various reports are in part related to geography and in part to the segment of the fauna being examined.

Zonation on the continental margin is dependent on several interrelated abiotic and biotic factors. It is usually described in terms of depth but it is as dependent on currents, sediments, temperature, topography and, of course, on species interactions. These factors will be discussed separately in later sections, but in reading the following pages these causal factors will be referred to and their interrelationship should be kept in mind.

The depth zonation of isopods and large epifauna animals on the continental slope off the Carolinas has been investigated and summarized by Rowe (1968, 1971), Rowe and Menzies (1968, 1969), Menzies and Rowe (1969) and Menzies, et al. (1973). A large part of the sampling was done photographically. Wigley and Emery (1967) also used photographs to analyze the distribution of benthic animals of the slope from Georges Bank to North Carolina and Southward and Brattegard (1968) examined the zonation of Pogonophora off North Carolina.

Based on the above knowledge, Menzies, *et al*. (1973) conclude that the topographic Carolina slope contains three faunal provinces, where a faunal province is defined (pg. 78) as "a major division of a realm". The realm in this case is the entire aphotic benthic habitat. A province can include one or more faunal zones which are defined (pg. 78) as "a subdivision of a province" that "is distinguished by the rate of change of species along a bathymetric scale within a faunal province".

The faunal province at the highest elevation of the slope is the continental shelf province. This province extends to a depth of at least 246 m off the Carolinas. The significant point here is that the discontinuity between shelf and abyssal fauna does not occur at the shelf break, but at a point where the sediment and other physical parameters change. At about this depth the sediments change from a coarse, motile sediment to a finer, more stable one. Also, the shelf province is subject to marked seasonal changes in temperature, dissolved oxygen, productivity and variations in intensity of the Florida current. Menzies, *et al*. (1973) use isopods as indicators of faunal variation. They state that there is only a five percent overlap on isopod species between the shelf province and the next lower area, the archibenthal zone of transition, and zero percent overlap with the abyssal faunal province. This indicates that the shelf faunal province is definitely distinct from the others mentioned and that, indeed, a faunal discontinuity occurs at about 250 m.

The faunal province below the continental shelf province is called the archibenthal zone of transition (Menzies, *et al*., 1973). This zone runs from near the top of the slope to the zone of constant temperature at about 800-1000 m. In the region of the Carolinas, a good part of this area is swept by the Florida current which leaves the bottom rippled. Both the level of temperature and dissolved oxygen are variable in this area and both are somewhat unpredictable. The seasonal change in temperature can be as great as 5°C and the level of dissolved oxygen can drop to 3.0 ml/l in June as water from the Gulf Stream comes in contact with the bottom (Rowe and Menzies, 1968). On the generic level, the upper part of the archibenthal zone of transition has a faunal affinity to the shelf province while the lower archibenthal zone of transition has a faunal affinity to the abyss. There is much less affinity in either direction at the species level. Taking the fauna of this zone *in toto*, however, it would appear that the archibenthal zone of transition has the greatest faunal affinity for the abyssal province (Ekman, 1953, Menzies, *et al*., 1973).

Menzies, *et al*. (1973) report the large invertebrate animals at this depth range off the Carolinas as being the polychaete *Hyalinoecia artifex*, the anemones *Ceriantheomorpha braziliensis*, *Actinauge rugosa*, *Bolocera tuediae* and *Actinoscyphia saginata*, the decapod crustaceans *Parapagurus pilosomanus*, *Catapagurus sharreri*, *Munida valida*, *Rochinia crassa*, *Bathyplax typhla* and *Geryon quinquedens* and the solitary coral *Flabellum goodei*.

Below the archibenthal zone of transition, beginning at about 1000 m, Menzies, et al. (1973) identify the abyssal faunal province. This province is characterized by little, if any, seasonal temperature change. The temperature at its upper border is between 3.5°C to 4.0°C and it drops slowly with depth to about 2.1°C at the beginning of the abyssal plain. Only about 16 percent of the isopod genera of the abyssal faunal province are found in the archibenthal zone of transition and there are no species in common with the shelf fauna.

There is an increase in abundance of large epifaunal animals between the depths of 1000 and 2000 m followed by a decrease in density with increasing depth (Rowe, 1968; Rowe and Menzies,1969).

Animals in this zone begin to show morphological adaptations to life in the deep sea. Many lack functional eyes, have reduced pigmentation, molluscs show reduced calcification compared to shelf species and some gigantism is exhibited when comparisons are made in the other members of a genus or family (Zenkevich and Birstein, 1956; Menzies, et al.,1973).

Within the abyssal faunal province there are two defined faunal zones which occur on the topographic continental slope. They are the upper abyssal zone and the mesoabyssal zone.

The upper abyssal zone encompasses the depth range of 940-2635 m in the Carolina region. Its sediments are of fine Globigerina ooze and it underlies the Western Boundary Undercurrent (Menzies, et al., 1973). Again, using isopods as being representative of the faunal in general, the upper abyssal zone is distinct from the archibenthal zone of transition in 95 percent of the species and from the mesoabyssal zone in 82 percent of the species.

The upper abyssal zone is characterized by large invertebrates such as the sea urchins Echinus affinus, Phormosoma placenta, Pleisiodiadema antillarum and Hygrosoma petersii; the brittle stars Ophiomusium lymani, O. spinigerum, Ophiacantha stimulans and Bathypectinura heros; and the sponge Cladorhiza sp. (Rowe, 1968; and Rowe and Menzies, 1969).

The mesoabyssal zone is centered at the break between the continental slope and rise, and includes the lower part of the slope. Faunistically, it is more closely related to the upper rather than the lower abyssal zone (Menzies, et al., 1973). There is a species maximum for isopods in this zone (Menzies, et al., 1973) as was previously postulated by Menzies and George (1967).

Large animals characteristic of the mesoabyssal zone in this region include the brittle star Ophiomusium lymani; the sea cucumbers

Pseudostichopus villosus and *Euphronides cornuta*; the soft coral *Anthomastus grandiflorus*; the sea pen *Pennatula aculeata*; the decapod *Parapagurus pilosomanus* and the glass sponges *Hyalonema boreale* and *Euplectella suberea* (Menzies, *et al.*, 1973).

It is evident from the above discussion that the epifauna of the continental slope off the Carolinas occur in definite depth strata. This phenomenon is well-illustrated by a figure from Rowe and Menzies (1967) which is reproduced in Figure 7-25. Although the zonation off the Carolinas is largely defined by epifaunal distributions, there is evidence to indicate that these patterns are exhibited by the benthic fauna in general. First, the faunal break points shown by the epifauna are also evident in the well-studied isopods (Menzies, *et al.*, 1973). Secondly, an analysis of the distributional patterns of several species of Pogonophora indicates a similar vertical zonation pattern (Southward and Brattegard, 1968).

The zonation of epifauna population has been recently studied using observations and photographs from the submersible *Alvin* (Grassle, *et al.*, 1975) and from trawl samples (Haedrich, *et al.*, 1975). Grassle, *et al.* (1975) made several dives on the slope between 500 and 1900 m. Five dives were made at about 1800 m, so detailed descriptions of this depth zone are available. Three large epifaunal species(megafauna) were dominant at this depth. They were the brittle star *Ophiomusium lymani*, a cerianthid anemone, and the sea urchin *Echinus affinis*.

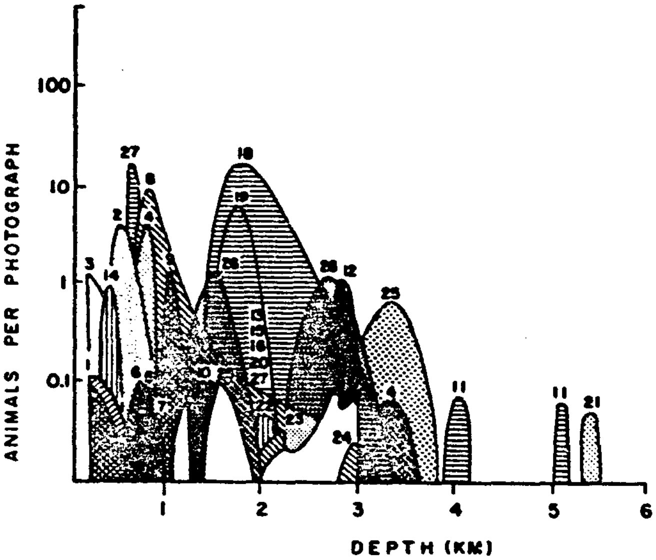
Ophiomusium lymani was ubiquitous at this depth with densities of between 0 and 4.5 per m^2. The cerianthid anemone was seen almost as often as *O. lymani*, as was the urchin *Echinus affinis*.

Other epifaunal species were rare relative to the above species, but Grassle, *et al.* (1975) note seeing the following species: the sea cucumbers *Pelopatides gigantea* and *Mesothuisa lacten*; the sea urchins *Hygrosoma petersii* and *Phormosoma placenta*; starfish of the genus *Solaster*; and, the pycnogonid or sea spider *Colossendeis colossea*.

A few individuals of crustaceans and gastropods were seen, but these were difficult to identify.

Grassle, *et al.* (1975) report seeing many rocks at the 1800 m depth, which supported a different faunal community than that on the unconsolidated sediments which were described above. Organisms found on the rocks include a brittle star of the genus *Ophiacantha*, glass sponges, serpulid polychaetes, the sea cucumber *Psolus*, three species of anemone, gorgonians and crinoids. They also note some motile animals were more common around rocks.

The area examined at 1300 m was generally topographically similar to



Quantitative distribution of epifaunal animals in relation to depth off North Carolina: (1) Cancer borealis; (2) Munida valida; (3) Catapagurus sharrei; (4) Parapagurus pilosomanus; (5) Actinauge longicornis; (6) Actinoscyphia saginata; (7) Bolocera tuediae; (8) Cerianthidae; (9) Flabellum goodei; (10) Pennatula aculeata; (11) Umbellula lindahli; (12) Anthomastus grandiflorus; (13) Echinus affinus; (14) Cidaris abyssicola; (15) Phormosoma placenta; (16) Hygrosoma petersii; (17) Astropecten americanus; (18) Ophiomusium lymani; (19) Ophiacantha simulans; (20) Bathypectinura heros; (21) Amphiophiura bullata; (22) Pseudostichopus villosus; (24) Euphronides depressa; (25) Euplectella suberea; (26) Hyalonema boreale; (27) Hyalinoecia artifex; (28) Lopohelia sp.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE		
TRIGOM	FIGURE 7-25	Epifaunal Zonation on the Continental Slope off the Carolinas (Rowe and Menzies, 1969)

the 1800 m depth, but the dominant epifaunal animals were different (Grassle, et al., 1975). The only abundant species was the sea urchin Phormosoma placenta. Other species characteristic of this area include the glass sponge Hyalonema, the crabs Geryon quinquedens, Lithodes agassizii and hermit crabs. Several observed organisms could not be identified to the species level in this area.

Some fauna occurred at both depths. Hygrosoma, Solaster, Colossendeis, Pelopatides and Actinoscyphe are examples.

Based on their observations, Grassle, et al. (1975) conclude that epifaunal slope species are "markedly zoned by depth". This is especially true for the five numerically dominant species which accounted for 97 percent of the individuals counted, but in most cases the less abundant species also exhibited depth zonation.

Haedrich, et al. (1975) examined depth zonation in the same area as Grassle, et al. (1975) using a 16-foot semiballoon trawl. They captured 46 species of invertebrates between 141 and 1928 m. Breaking this depth range into three depth zones they found that the starfish Astropecten, the crustacean Munida, and the brittle star Amphilimna were the most abundant species at less than 285 m. The polychaete Hyalinoecia artifex and the red crab Geryon quinquedens were most numerous at mid-depths and in the deepest water the brittle stars Ophromusium lymani, and Homalophiura inornata, the urchins Echinus affinus, E. alexandri and Phormosoma placenta, and the starfish Porcellanaster caeruleus were all abundant. These results are summarized in Table 7-15.

Haedrich, et al. (1975) interpret their data as showing faunal boundaries for the epifauna at about 300-400 m and 1000-1100 m. This zone on the upper continental slope corresponds closely to the archibenthal zone of transition defined by Menzies, et al. (1973) for the Carolina region.

It is evident from the results of these several studies from North Carolina and southern New England that large epifaunal animals indeed exhibit depth zonation. Furthermore, the upper and lower depth boundaries are similar for many species, so that the epifaunal assemblage changes strikingly at certain depths, especially at 300-400 m and 1000-1100 m. Many of the dominant organisms are the same at both ends of the study area; for example, the brittle star Ophiomusium lymani and the urchins Echinus affinus and Phormosoma placenta.

The question of depth zonation of the benthic infauna on the continental slope has received less attention than epifaunal zonation. This is because of the difficulty in processing infaunal samples that often contain over 300 species and thousands of individuals (see Table 7-14). The slope off southern New England on the Gayhead-Bermuda transect is the most heavily studied in this regard. Sampling has been done using Smith-McIntyre grabs, anchor dredges and the epibenthic sled. Wigley and McIntyre (1964) included two slope depth stations in their study of the macrobenthos and meiobenthos of the area. Sanders, et al. (1965), Hessler and Sanders (1967) and Sanders and Hessler (1969) occupied several stations on the slope as part of their study of the Gayhead-Bermuda transect. Specific taxonomic infaunal groups from the transect have been studied by Hartman (1965) (polychaetes), Jones and Sanders (1972) (cumaceans) and Rex (1973) (gastropod molluscs).

Wigley and McIntyre (1964) directed most of their effort to the continental shelf environment and two of the three faunal groups they identify pertain to the shelf. The three zones are (pg. 487): "1) an inner continental shelf group characterized by amphipods and polychaetes, 2) an outer continental shelf group characterized by echinoderms and mollusks, and 3) a continental slope group characterized by a general paucity of fauna but dominated by polychaetes and including small numbers of certain miscellaneous groups." Their slope stations were at depths of 366 and 567 m, so their finding of a unique slope group at this depth seems to be consistent with the conclusions of Menzies, et al. (1973) and Haedrich, et al. (1975), that the discontinuity between shelf and slope faunal zones occurs at about 300-400 m.

The extensive studies of Sanders and his colleagues show a different situation for the infauna than for the epifauna (Sanders, et al., 1965; Hessler and Sanders, 1967; and Sanders and Hessler, 1969). These investigators do not find abrupt faunal boundaries at continental slope depths. Indeed, the only major faunal boundary that they identify is that between the shelf and slope fauna in the area of 200 m. Below this depth and continuing to the deepest parts of the ocean, they emphasize that there is a gradual and continuous change in the fauna. There is no evidence indicating that faunal change with depth is faster at certain places than others, except at the top of the slope. Hence, the faunal zones described for the epifauna (Menzies, et al., 1973) are not valid for the infauna (Sanders and Hessler, 1969).

These conclusions should not be interpreted as meaning that individual infaunal species are not confined to specific depths. On the contrary, the evidence suggests that many infaunal species have quite narrow depth ranges. Jones and Sanders (1972) concluded (pg. 737) "The cumacea have narrow and discrete depth ranges and are sharply zoned by depth." Sanders and Hessler (1969) are of the opinion that, at the least, the bivalve composition of a deep sea sample is more dependent on depth than on geographic location. They cite the example of a station at 1400 m on the Gayhead-Bermuda transect being more similar to bivalve composition to a station at 1700 m off the coast of West Africa than it was to other stations on the transect separated from it in depth by as little as 800 m (Sanders and Hessler, 1969).

ABUNDANCE - DENSITY AND BIOMASS

The presence of a species in a quantitative survey is usually recorded as its abundance, that is, the number of individuals, and sometimes the weight, per unit area. This is important because such information, in combination with data on its size, life cycle, feeding habits, etc., allows an ecologist to draw inferences on the importance of the species in the community and on the nature of the community as a whole. The literature contains much more information on the abundance of infaunal animals than on epifaunal species because the concept of density is more meaningful in terms of the infauna since they are collected with quantitative gear. Trawl sampling programs produce data in terms of relative abundance or catch per unit effort and usually greatly underestimate absolute abundance (Haedrich, et al., 1975).

Photography has been used to estimate the abundance of slope epifauna (Grassle, et al., 1975; Rowe and Menzies, 1969; and Wigley and Emery, 1967). This method is, of course, limited because only those organisms that are large enough to be both seen and identified can be counted. The most extensive coverage of the bottom at continental slope depths is that provided by Haedrich, et al. (1975). Densities of identifiable epifaunal animals in their study varied from 0.38 to 2,445 individuals/ 1,000 m^2 for the urchin (Hygrosoma petersii) and the brittle star (Ophiomusium lymani), respectively. A summary of their results regarding abundance is provided in Table 7-15. These authors conclude that their density figures do not greatly deviate from those produced by Rowe (1968) for the North Carolina continental slope.

Menzies, et al. (1973) note that there is an increase in the density of large epifaunal animals in the abyssal faunal province from 1,000 to 2,000 m. Below 2,000 m, however, there is a progressive decline in density.

Quantitative data on the density of infaunal specimens is provided in the area of southern New England by Sanders, et al. (1965); Wigley and McIntyre (1964); and Rowe, et al. (1974), and around Hudson Canyon by Pearce, et al. (1974). Wigley (1963) discusses the occurrence and density of Pogonophora on the New England slope.

Very high densities of organisms were encountered on the continental slope by Sanders, et al. (1965). These investigators state that each area supports a characteristic number of animals. For example, they found between 6,000 and 13,000 individuals per square meter on the outer continental shelf; 6,000 to 23,000 on the upper continental slope, and 1,500 to 3,000 at lower continental slope depths. These numbers agree fairly well with newer data provided by Rowe, et al. (1974) for the same area (Table 7-16).

Table 7-15. Dominant epifaunal invertebrates by numbers and percent on each depth zone. (modified from Haedrich, *et al.*, 1975).

	Shallow 141-285 m		Middle 393-1095 m		Deep 1270-1928 m	
	Number	Percent	Number	Percent	Number	Percent
Astropecten americanus	352	53.6	-			
Munida valida	158	24.1	4	1.0		
Amphilimna olivaceo	146	22.2				
Hyalinoecia artifex			236	56.3		
Geryon quinquedens			177	42.2	22	0.9
Ophiomusium lymani			2	0.5	1468	58.4
Echinus affinis					355	14.1
Homalophiura inornata					232	9.2
Phormosoma placenta					182	7.2
Echinus alexandri					147	5.8
Porcellanaster caeruleus					107	4.2

Table 7-16. Densities of benthic infauna per meter square off southern New England (modified from Rowe, et al., 1974)

Depth (m)	Number of Organisms
550	6,405
1,110	3,070
1,180	4,430
1,900	2,020
2,080	700
	$\bar{x}$ = 3,325

Wigley and McIntyre (1964) included two stations at 366 and 567 m in their survey. The faunal densities were 1,695 and 730 individuals/m^2, respectively. These investigators used a 1.0 mm screen upon which to sieve their samples, as opposed to the 0.42 mm screen used by Sanders, et al. (1965) and Rowe, et al. (1974), so a lower recovery of individuals would be expected. Pearce, et al. (1974) recovered from 190 to 480 individuals/m^2 using a 0.5 mm screen in the Hudson Canyon area. Unfortunately, the station depths were not reported, although they are probably all at continental slope depths.

Densities of the most commonly occurring higher taxa are presented by Sanders, et al. (1965). The polychaetes were present in numbers of about 2,000/m^2 on the upper continental shelf, from 4,700-14,000/m^2 on the upper continental slope, from 1,400-2,200/m^2 on the lower continental slope. The crustaceans occurred in densities of 300/m^2 on the outer shelf, from 450-750/m^2 on the upper slope and 240-330/m^2 on the lower slope. The bivalve molluscs were represented by 825/m^2 on the outer continental shelf, 500-2,000/m^2 on the upper continental slope and 100-220/m^2 on the lower continental slope.

Wigley (1963) reported on the densities of two species of Pogonophora, Siboglinum ekmani and Siboglinum sp., on the New England continental slope. He found their combined densities to be 30 per square meter at 366 m and 25 per square meter at 567 m.

Biomass is used in conjunction with density to analyze benthic communities. It is a measure of the weight or standing crop of the fauna and can be considered to be a gross measure of productivity. It is variously measured as wet weight, dry weight, and ash-free dry weight. It is important to know what methods were used in its determination before comparisons are made between two studies.

Trawl sampling is not quantitative enough to produce representative epifaunal samples and biomass data usually cannot be produced by photographic techniques, so good estimates of epifaunal biomass do not exist. When consistant trawl sampling is used, however, it is possible to use relative biomass for comparative purposes. Haedrich, et al. (1975) provide data in weight caught per hour for major taxa on the New England continental slope. This information is presented in Table 7-17.

Table 7-17. Catch per hour (in grams wet weight of major invertebrate taxa in three depth cores (modified from Haedrich, et al., 1975)

	Shallow 141-285 m	Middle 393-1,095 m	Deep 1,270-1,928 m
Echinoderms	158.2	66	3,848.7
Arthropods	448.3	1,785	265.1
Coelenterates	46.1	206.9	59.5
Polychaetes	-	106	-
Molluscs	-	160.2	-

Menzies, et al. (1973) report that, like abundance, the biomass of large epifaunal animals increases between 1,000-2,000 m off the Carolinas and then decreases constantly with increasing depth.

Data on the biomass of infaunal organisms on the northwestern Atlantic continental slope is found in Wigley and McIntyre (1964) and Rowe, et al. (1974). At 366 m and 567 m, Wigley and McIntyre (1964) found 31.98 and 21.09 g wet weight/m^2 of infauna, respectively. Somewhat lower values are reported by Rowe, et al. (1974) (Table 7-18). These differences are even a little greater than the absolute weights because Rowe, et al. (1974) used a smaller sieve size (0.42 vs. 1.0 mm).

Table 7-18. Biomass of benthic infauna per meter square off southern New England (modified from Rowe, et al., 1974)

Depth (m)	Wet Weight (g/m^2)
550	11.975
1,110	0.845
1,180	1.216
1,900	15.600
2,080	0.325

As a generality, it can be stated that both density and biomass decrease with depth and distance from land (Sanders, et al., 1965; Rowe, 1971; Menzies, et al., 1973). Rowe, et al. (1974) subjected their density and biomass data to a regression analysis against depth. They conclude that the decrease in density and biomass with depth is significant.

There are a few studies which attempt to compare the density and biomass of infauna and epifauna. Wigley and Emery (1967) compare both of these parameters by depth and by geographic zone. A summary of their results is presented in Table 7-19. They arbitrarily divided the continental slope from Georges Bank to North Carolina into three zones: a northern zone from approximately Rhode Island eastward; a central zone between Rhode Island and Virginia; and a southern zone including the Virginian and North Carolinian slope. Epibenthic biomass is based on photographic interpretation.

Table 7-19. Comparison of density and biomass of epibenthos and total benthos (modified from Wigley and Emery, 1967)

	Epibenthos (photographs)				Total Benthos (grab sampler)			
	200-500m	500-1,000m	1,000-2,000m	>2,000m	200-500m	500-1,000m	1,000-2,000m	>2,000m
				Individuals/m^2				
Northern	59	15	8	2	422	66	92	58
Central	14	8	4	10	261	413	94	30
Southern	272	2	213	1	156	41	67	24
Average	48	8	58	3	302	233	86	46
				Biomass (gm/m^2)				
Northern	34.2	69.7	10.8	0.3	8.8	5.8	5.8	3.7
Central	9.0	17.9	4.9	1.6	17.4	8.8	7.5	3.7
Southern	187.2	1.3	46.5	6.2	10.1	5.8	3.3	3.8
Average	30.5	26.7	17.3	1.7	14.2	7.3	5.9	3.7

It can be seen from Table 7-19 that both density and biomass decrease with depth and the total benthic density is much higher than the epibenthos.

Grassle, et al. (1975) compared their epibenthic densities derived from photographs with anchor dredge samples from the same area of the continental slope (Sanders, et al., 1965). The density of the infauna is three to five orders of magnitude higher than that of the epifauna (Table 7-20).

Table 7-20. Densities of infauna and epifauna on the continental slope south of New England (modified from Grassle, et al. 1975).

	Depth (m)	Number per 1,000m^2
Infauna	487	8,033,000
	824	2,411,000
	1,500	1,335,000
	2,086	2,156,000
Epifauna	495- 499	1,550
	992-1,000	31
	1,298-1,360	184
	1,465-1,550	705
	1,778-1,882	2,463
	1,798-1,803	3,551

Haedrich, et al., (1975) agree that the density of the epifauna on the slope is three to four orders of magnitude less than the infauna. They believe, however, that the biomass of the epifauna is at the same order of magnitude as the infauna, which raises the question of how such a mass of epifauna is supported.

TEMPORAL VARIATION

The range of temporal variation, or changes in distribution or density over time, is essential to know when evaluating a potential environmental impact. Invertebrate communities are known for their dramatic variations (Coe, 1956) especially in shallow water. A community must be effectively monitored over a respectable period of time to document natural seasonal and inter-annual changes in abundance or species composition. Only then can a sudden change in community structure be assigned to a natural or pollutional cause.

Unfortunately, because of the time and money required to process them, only a few samples have been collected in any one part of the slope (Sanders, et al., 1965). Whereas, recently some areas, such as the slope off southern New England, have received increased attention, no long term studies at specific sites have been carried out. In the foreseeable future, it may be possible for some of the investigators in this area to comment on changes that may have occurred, but at this time there is nothing significant published on the temporal variation of the slope benthos of the northwestern Atlantic. One thing to keep in mind, however, is that the deeper one samples in the ocean the more constant are the conditions and the less important seasonal programming will be. Although breeding periodicity has been shown for some deep sea groups (Schoener, 1968), it is safe to assume that temporal variations do not occur at the same frequency or magnitude as they do in shallow marine waters.

TROPHIC CONSIDERATIONS

There are four feeding types which are significant on the continental slope. These are suspension feeders, deposit feeders, omnivores, and carnivores. Due to the absence of living plant material the herbivorous feeding habit is poorly developed.

The single dominant feeding type is deposit feeding. Deposit feeders engulf all, or certain fractions, of the sediment to utilize the organic content of the contained detritus. Sanders and Hessler (1969) reported the following percentages of detritus feeders in the most diverse groups at a station 2,891 m deep: 60 percent polychaetes; over 90 percent tanaids; 90 percent isopods; over 50 percent amphipods; and 45 percent bivalves. These species represented 47 percent of the species in the sample. After a stomach analysis of 83 deep-sea species Sokolova (1959) concluded that 55 percent of the deep-sea fauna are deposit feeders, 25 percent are suspension feeders and 20 percent are carnivores.

Suspension feeders can only become numerous where currents are such as to bring in an adequate supply of suspended material. This requires a supply of organic material and a current strong enough to carry sufficient quantities past the sessile suspension feeders. These conditions occur on the continental shelf and upper slope and at the base of the slope (Sokolova, 1959). Menzies, et al. (1973) state that detrital sea grasses concentrate at the break between the Carolina slope and rise and that there is also a marked increase in the waterborne suspended material in this area. Even in these areas the deposit feeders usually outweigh the suspension feeders. On the upper slope the dominance, by weight, of deposit feeders over suspension feeders might be by as much as 3.5 to 1 and on the lower slope by a factor of 21 to 1 (Sokolova, 1959). Likewise, carnivores usually account for much less of the biomass than the deposit feeders.

Density and biomass of deep-sea organisms are considered to be principally controlled by the abundance of food (Sanders and Hessler, 1969). This means that the density patterns discussed above are in large part a reflection of the availability of organic carbon. In general, then, high values of organic carbon, density, and biomass can be expected on the shelf and upper slope with values of all three declining as the ocean floor is approached.

The source of the organic material utilized by deep water organisms remains an intriguing question. For many years, it was thought that the fallout from the primary production of the phytoplankton was the primary source since primary production is highest near land and decreases seaward just as benthic density and biomass do. The very dramatic decrease in density over the continental slope, however, would indicate depth as a more important factor than distance from land since density on the slope drops several orders of magnitude in a very short lateral distance (Sanders and Hessler, 1969) and there is little change in surface productivity over this limited distance. At continental slope depths most of the sinking organic matter is consumed by bacteria or pelagic scavengers before it ever reaches the bottom.

How, then, does the benthos on the continental slope receive utilizable organic matter? Those individuals living at the upper limits of the slope receive an adequate supply from surface productivity. As one proceeds down the slope less and less of the products and by-products of surface productivity reach the bottom. There is the possibility, however, that enough material does reach the deeper bottoms to support the very low biomass found there (Sanders and Hessler, 1969). Vinogradov (1961) proposed a vertical ladder of zooplankton as a method of transport of nutrient material to the bottom. Under this scheme surface plankters are eaten by organisms living in the water mass below them and these in turn are devoured by still deeper species, etc., until the bottom is reached. This hypothesis has been discounted by Sanders and Hessler (1969) because of the energy loss that would be incurred at every change in trophic level, and by Menzies, et al. (1973) because the biomass of zooplankton over the bottom is not sufficient to support the larger benthic biomass.

Turbidity currents have been considered by Sanders and Hessler (1969) to be insufficient to explain downslope movement of organics because of their infrequency and destructive nature. On the other hand, Menzies, et al. (1973) believe that "fallout" from the continental shelf is transported to the deeper benthos by turbidity currents, and support their argument by noting that the highest concentrations of abyssal benthos occur near continental margins and not at similar depths at a distance from a continent.

Recently, many investigators have advanced the idea that larger, faster sinking masses of organic matter might supply a significant amount of organic material to the deep benthos. Dayton and Hessler (1972) cite the possibility of very large chunks of organic matter reaching the bottom in the form of dead fishes and mammals from the surface waters. Pieces of the pelagic algae Sargassum and the tropical sea grass Thalassia have been photographed and recovered from the continental slope (Schoener and Rowe, 1970; Menzies, Zaneveld, and Pratt, 1967; Menzies and Rowe, 1969). Other particles that have a potential of reaching the bottom are fecal pellets (Smayda, 1969; Fowler and Small, 1972), and the olive-green bodies (Fournier, 1972).

Whereas, there is not general agreement among deep-sea biologists on just what is the most significant route of organic material to the bottom, it is safe to assume that each proposed method probably plays some role. Further research will undoubtedly elucidate both the actual pathways and the rates of transport to various depths.

SPECIES INTERACTIONS

Observations on species interactions at continental slope depths are very limited. Rowe, et al. (1974) observed a worm foraging in fresh crab tracks in the Hudson Canyon. Grassle, et al. (1975) observed three examples of species interactions from a submersible on the slope off southern New England. At 1,800 m the brittle star *Asteronyx leveni* was found exclusively and constantly in the branches of a gorgonian. At 1,300 m two associations were noted. Hermit crabs were most abundant where a trochid gastropod was found and the large individuals of the crab *Lithodes agassizii* were seen in aggregations of the sea urchin *Phormosoma placenta*.

There is some speculation that species interactions occur only at a reduced level in deep water relative to levels on the shelf and in nearshore environments. This is discussed by Sanders and Hessler (1969) who state that since density is low and diversity is high, and because individual organisms are of small size and limited mobility, an individual is capable of interacting with only a small number of competing species.

MEIOBENTHOS

An often neglected group of organisms is collectively known as the meiofauna or meiobenthos. This diverse assemblage is principally defined on the basis of size and is often regarded to be that group of organisms which will pass through a 0.5 mm sieve but will be retained on a 0.044 mm sieve. Although many of the meiobenthic organisms are juvenile forms of the macrobenthos, most are meiobenthic creatures throughout their life. Among the groups which often comprise a meiobenthic assemblage are nematodes, harpactacoid copepods, foraminifera, polychaetes, ostracods, Gastratricha, rotifers, turbellarians, nemerteans, archiannelids, tardigrades, kinorhyncha, Halicaridae, hydrozoans and lamellibranchs. On the basis of abundance, the nematodes and harpactacoid copepods comprise 90 percent of the marine meiobenthos.

Consideration of the meiobenthos is important for several reasons. For one, their sheer abundance is overwhelming. It is not unusual to find 1,000,000 meiobenthic organisms per meter square and up to 110,000 meiobenthic individuals per meter square have been reported at abyssal depths in the Indian Ocean (Thiel, 1966). Their biomass is often significant especially in areas with low macrobenthic biomass. At slope depths, meiobenthic biomass has been reported as 0.4-1.2 g per meter square off Iceland and the nematodes alone accounted for 2 g per meter square between 1,500 m and 1,800 m in the Norwegian Sea (Thiel, 1971). While these biomasses might not seem astounding in themselves, they take on significance when the high metabolic rate and short generation time of the meiobenthic species are considered. Using oxygen consumption as a measure of metabolism, Gerlach (1971) reports that meiobenthic animals are consuming between 200 and 2,000 mm^3 O_2/h/g wet weight while small macrobenthic organisms are consuming 200-500 $mm^2O_2/h/g$ and the larger macrobenthos only 10-100 $mm^3O_2/h/g$. In other words, the metabolic rate of the meiobenthos is about five times greater than the macrobenthos. Generation times are commonly reported, based on laboratory experiments, to be as short as three to six weeks, but even using a more conservative estimate of three generations per year (Gerlach, 1971) it can be seen that a lot of energy is cycled through the meiobenthos. It is assumed that much of this energy is being transferred to the macrobenthos through grazing, but nothing is known about natural mortality of meiobenthos species (Gerlach, 1971).

Ecological studies of the meiobenthos at continental slope depths are rare, but three have occurred along the eastern seaboard. Coull (1972) sampled harpacticoid copepods along a transect between North Carolina and Bermuda. Tietjen (1971) investigated the meiobenthos, with emphasis on the nematodes, on the Carolina shelf and slope and Wigley and McIntyre (1964) compared meiobenthic and macrobenthic community parameters south of Martha's Vineyard.

The harpacticoid copepods are the most abundant arthropod in the benthos and their diversity increases with increasing depth (Coull, 1972). Coull found a distinct slope fauna with a sharp discontinuity at the shelf break similar to the one reported by Sanders and Hessler (1969). In the Carolina region this is the area of greatest temperature variation. Coull's samples also indicated the same type of narrow zonation in some species as was reported by Rowe and Menzies (1969) for the large epifaunal invertebrates.

Tietjen (1971) recorded 21 taxonomic groups in his meiobenthic samples. Maximum densities occurred at about 250 m and there was a density minimum at 400-500 m. The nematodes were the dominant group between 50-500 m and the benthic foraminifera were most abundant below 500 m. Maximum diversity of species and higher taxa was found between 50 and 500 m. A marked change in density was detected between 400 and 600 and only seven groups or less were found at depths below 800 m (Table 7-21).

Focusing on the nematodes, Tietjen (1971) identified 212 species belonging to 23 families. Some depth zonation was obvious as 79 species were found in depths of 500 m and less, 59 species were restricted to depths greater than 500 m and only 24 species, or 11 percent of the total nematode fauna, were found to occur from the outer shelf to the lower slope. A similarity analysis divided the nematodes into two groups, a 'shallow' water fauna from 50-500 m and a 'deep' water fauna from 1,000-2,500 m. The intermediate area shared several species and represented a zone of transition.

In general, Tietjen (1971) found the densities of meiobenthic animals to be an order of magnitude less on the slope than above 250 m. Densities and species compositions are largely controlled by the sediment type, so the above variation in density may be a function of sediment

Table 7-21. Numbers of meiofauna per 100 cm^3 of sediment for transect stations across the North Carolina shelf and slope. (modified from Tietjen, 1971)

Meiofauna group	DEPTH (m)									
	50	100	250	400	600	800	1,000	1,500	2,000	2,500
Nematoda	593	445	1,026	87	140	134	71	84	33	45
Harpactacoidea	72	93	53	22	5	2	9	2	3	2
Foraminifera	63	37	22	13	230	270	326	536	384	169
Polychaeta	59	62	35	5	10	7	4	2	2	3
Ostracoda	13	7	9	2	4	2	1	1	2	4
Gastrotricha	43	34	20	7						
Rotifera	6	7	1	1	2	1	30	10		
Turbellaria	3	4	1	1						
Nemertea	12	19	15	2	3	3				
Archiannelida	4	1	1	2						
Kinorhyncha	7	3	1	1						
Tardigrada	1	1	1	1						
Halicaridae	17	6	7	1						
Hydrozoa	2	1	1	2						
Gnathostomulida	8	10	1							
Lamellibranchiata	4	4	1	1						
Cumacea	1									
Echiurida					1					
Nauplii	4	8	1	3	1		6	1	1	1
Total meiofauna	912	742	1,196	151	396	419	447	636	425	224

changes rather than depth changes. No correlation could be found between total meiofauna abundance and the sediment levels of organic carbon.

Nematode feeding types change with depth probably due to changes in sediment and concomitant changes in food availability (Tietjen, 1971). Deposit feeding nematodes were most abundant at all depths but were especially dominant below 500 m (Figure 7-26).

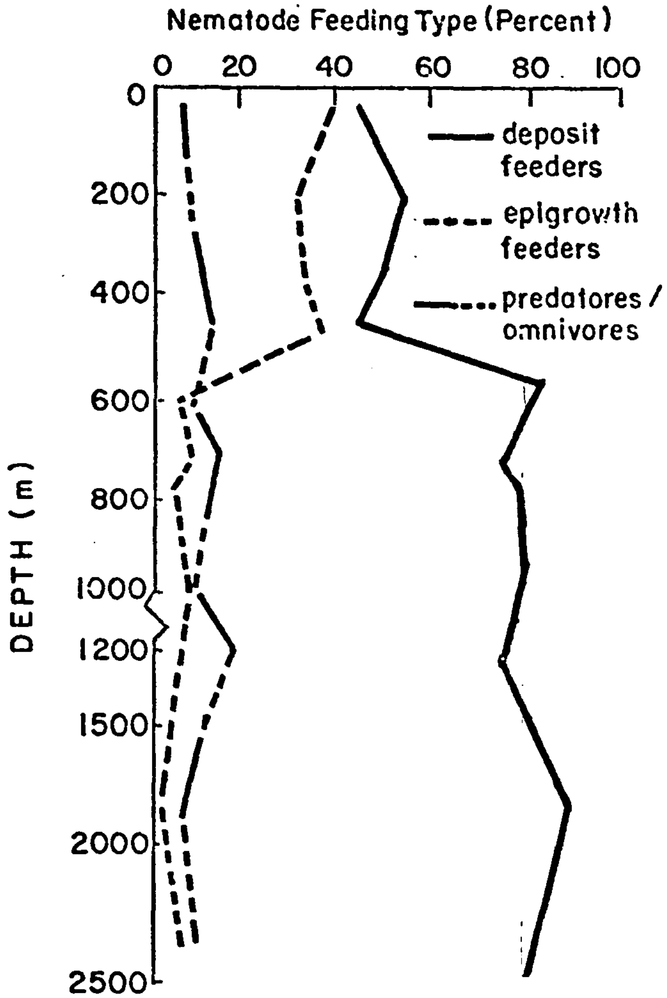
The survey of Wigley and McIntyre (1964), which was discussed more fully in previous sections, contained two slope stations at 366 and 567 m. These investigators found that the number and biomass of meiobenthos decreased with increasing depth as did the macrobenthos, and that the nematodes were the dominant meiobenthic taxon. Summaries of their findings pertinent to our purposes are expressed in Tables 7-22 and 7-23.

MICROBENTHOS

A freak discovery, made possible by an expensive accident, greatly advanced interest in, and experimentation with, the marine microbenthos, principally the bacteria. In late 1968 the research submersible "ALVIN" was lost from its tender and sank in 1,540 m of water on the continental slope off Massachusetts. Its hatch was open. When the vessel was recovered ten months later, the crew's lunch was amazingly well preserved. The sandwiches, apples, and soup all looked, smelled and tasted normal and passed bacteriological tests. At that time (1969) there was absolutely nothing known about qualitative and quantitative microbial decomposition processes in deep water (Jannasch and Wirsen, 1969). The implication of the "ALVIN" incident was that microbial activity in the deep sea is extremely slow.

Experiments were devised to test the hypothesis of slow, deep sea microbial activity (Jannasch and Wirsen, 1969). These experiments were placed in the deep sea (5,000 m) with laboratory controls and showed that, depending on the substrate used, bacterial decomposition took place from 666 to 8.2 times more slowly in the deep sea. This proved that the "ALVIN" incident was not anomalous and that, indeed, life processes are greatly slowed in the deep sea. A temperature-pressure relationship was thought to be responsible for the decline in activity. It was theorized that increased hydrostatic pressure increases the minimal growing temperature of a bacterial strain and that with enough pressure the minimal growing temperature may exceed the environmental temperature, resulting in the elimination of bacterial growth and biochemical activity. Holm-Hansen (1971) observed a continual decrease in microbial life with depth.

A very important implication of these findings is that organic material dumped into the deep sea will not be degraded by bacteria and hence may accumulate.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-26 Distribution of Nematode Feeding Types With Respect to Depth off North Carolina (Modified from Tietjen, 1971)

Jannasch and Wirsen (1973) completed a series of enrichment experiments at 1,830 m. They determined that, even substrate left in situ for one year did not produce any substantial activity of the indigenous microflora. This confirms their earlier conclusion that "the deep sea must be considered extremely inefficient with respect to recycling of organic wastes". They believe that an "active, adapted microflora" is not to be found in the deep sea and that the high levels found, when deep sea sediments are streaked on neutral agar, are the result of bacterial cells that sank to the bottom on detrital particles, but were not able to function there. Significant levels of microbial activity may occur in the intestinal tracts of macrobenthic organisms as is suggested by the longer gut of some species (Allen and Sanders, 1966) and deep sea wood-boring activities (Turner, 1973) which require bacteria for the digestion of cellulose.

Extensive laboratory experiments at controlled temperatures and pressures using a number of bacterial isolates and substrates again confirmed the hypothesis that low temperature and high pressure decrease the incorporation and respiration of substrates by bacterial isolates at low substrate concentrations (Wirsen and Jannasch, 1975). These are the conditions that would be expected on the slope and in deeper water.

Further in situ experiments are planned which should answer many of the questions about microbial activity and decomposition in the deep sea (H. W. Jannasch, personal communication). These experiments will take place on the New England continental slope along the Gay Head-Bermuda transect and will be accomplished using the recovered submersible "ALVIN" which was so instrumental in opening up the productive field of research.

Table 7-22. Meiobenthos wet weight (mg/10cm^2) and number of individuals (per 10 cm^2) at two depths (Modified from Wigley and McIntyre, 1964).

	Depth	
Number	366	567
Nematoda	117	110
Foraminifera	6	4
Copepoda	-	1
Polychaeta	4	1
Lamellibranchia	-	1
Total	127	117
Weight		
Nematoda	0.243	0.359
Foraminifera	0.053	0.038
Polychaeta	0.453	0.105
All other Groups	-	0.105
Total	0.749	0.607

Table 7-23. Density of macrobenthos and meiobenthos expressed as numbers of individuals and weight per meter square (modified from Wigley and McIntyre, 1964).

	Depth	
Number of Individuals	366	567
Macrobenthos	1,695	730
Meiobenthos	127,000	117,000
Ratio	1:75	1:160
Weight (g)		
Macrobenthos	31.98	21.09
Meiobenthos	0.75	0.61
Ratio	43:1	35:1

LIFE HISTORY OF KEY SPECIES

Geryon quinquidens

Geryon quinquidens, the deep-sea red crab, is the basis of a limited commercial fishery in southern New England. The abundance of red crabs was studied to determine the feasibility of a commercial fishery (Schroeder, 1959; McRae, 1961; and Holmsen, 1968). A comprehensive survey of red crabs was recently completed by Wigley, et al. 1975. They estimated the number of commercial size red crabs at 43 million and the standing crop biomass at 27 million kg in the area along the slope from eastern Georges Bank to offshore Maryland.

Red crabs inhabit depths from 40 to 2,155 m and range primarily along the continental slope from Halifax, Nova Scotia to Cuba, the Gulf of Mexico and possibly Brazil. They also are inhabitants of the Gulf of Maine (Rathbun, 1937; Chace, 1940; and Schroeder, 1959).

Red crabs were found to be most abundant in depths between 366 and 549 m in the region between Cape Ann, Massachusetts, and offshore Virginia (McRae, 1961). Meade (1970) and Meade and Gray (1973) reported the greatest catches between Veatch and Atlantis canyons. The National Marine Fisheries Service (Anonymous, 1971) fished in the areas of Block, Hudson, and Baltimore Canyons and the highest concentrations were between 457 and 914 m. Highest densities between 265 and 512 m were found in the vicinity of Norfolk Canyon (Haefner and Musick, 1974). Between Georges Bank and offshore Maryland, Wigley, et al. (1975) caught the greatest number and biomass between 320 and 914 m. There is some indication, based on catch per trawl, that red crabs are more abundant on the slope than in canyons (Haefner and Musick, 1974). On a geographical basis, red crabs are sparse in most of the Georges Bank region and common from western Georges Bank to offshore Maryland (Wigley, et al., 1975).

In the depths where red crabs are most abundant (302-503m), female crabs are about twice as numerous as male crabs (Wigley, et al.). Males were more abundant in both the deeper (503-1,280 m) and shallower water (229-320 m). Numerically, females were more abundant than males in the entire survey region by a factor of 1.24. Females were more abundant than males in the region off New Jersey, Delaware, and Maryland (1.96:1) whereas males were more abundant in the area along the slope off Rhode Island and Cape Cod (0.71 females to 1 male).

Red crabs have been reported to grow to a carapace width at 178 mm and to over 1,130 g in weight (Wilder, 1966). A size range from 8 to 142 mm (carapace width) and damp weights of 0.1 to 964 g were reported by Wigley. et al. (1975) in the survey which covered an area from Georges Bank to offshore Maryland. In the Norfolk Canyon region, Haefner and Musick (1974) found red crabs ranging in size from 44 to 160 mm with a mean width of approximately 114 mm and weights ranging from 28 to 1,136 g.

Male crabs, which have an average carapace width at 99 mm (modal width 112.5 mm) and average weight of 413 g (modal weight 520 g), are larger than female crabs which have an average size of 90 mm (modal width 92.5 mm) and average weight of 244 g (modal weight 260 g) (Wigley, et al., 1975).

No techniques for aging Geryon have been developed nor have any rearing studies been completed in which age-size determinations have been made.

Variations in size were found to correlate with depth and latitude (Wigley, et al., 1975). Both male and female crabs had smaller average carapace widths (49 mm for females, 33 mm for males) at depths between 914 and 1,280 m than in shallower water between 229 and 320 m where the average carapace width was 104 mm for females and 116 mm for males. Weights for both males and females follow the same trend. Since the size of red crabs increases progressively from deeper water to shoaler water, and since young crabs were found only at depths greater than 640 m, Wigley, et al. (1975) deduced that there is a size-related upslope migration.

Latitudinally, Wigley, et al. (1975) found that red crabs generally were smallest (in terms of average size and weight) in the region offshore of New Jersey, Delaware, and Maryland, intermediate in size between Hudson Canyon and southwestern Georges Bank, and largest in the Georges Bank region.

Densities of Geryon were determined photographically by Wigley, et al. (1975). In shallow water (229-320 m) 13 to 28 crabs were found per hectare (2.5 acres); 128-382 crabs per hectare at intermediate depths (320-640 m); 11-112 crabs per hectare in deep water (640-1,1280 m); and 10.9 crabs per hectare in the deepest water examined (1,280-1,646 m). Obviously, the greatest density of crabs occurs at intermediate depths.

The greatest biomass (average 75 to 95 kg/ha) also occurred at intermediate depths (Wigley, et al., 1975). Biomass in the shallower water was 10 kg/ha and between 1.3 and 27 kg/ha in water deeper than 640 m.

Information on the reproduction of red crabs is very sketchy. Wigley, et al. (1975) postulate, based on the proportion of egg-bearing females by water depth and the stage of development of the eggs (as interpreted from their color), that the spawning season of Geryon begins in late winter or before and ends in early summer. They also found that the spawning period was shorter and commenced earlier in shallower water than in deep water in the mid-slope region. No egg-bearing females were found at depths below 640 m. They suggest that the eggs mature faster in shallower waters, possibly due to temperature and/or depth.

There are six larval stages of Geryon (Perkins, 1973). The following are the sizes and average number of days the larvae were at each stage when reared under laboratory conditions at 18-21°C:

Prezoea	2.8 mm	total length	1 hour-1 day
Zoea I	0.83 mm	carapace length	7 days
	3.71 mm	total length	
Zoea II	1.07 mm	carapace length	6 days
	4.97 mm	total length	
Zoea III	1.42 mm	carapace length	5 days
	6.13 mm	total length	
Zoea IV	1.74 mm	carapace length	7 days
	8.31 mm	total length	
Megalops	3.16 mm	carapace length	14 days
	6.46 mm	total length	

The mortality of Geryon larvae is probably greater than 99 percent. There are no mortality figures available for adult crabs. Mortality due to fishing would be expected to be low since fishing for red crabs has been limited in effort and duration (Wigley, et al., 1975).

Wigley, et al. (1975) found adult red crabs at temperatures between 4.2 and 12.7°C which were the coldest and warmest temperatures in which the survey was conducted. There are records of red crabs being caught in temperatures as low as 3.1°C and being maintained in an aquarium in temperatures as high as 21.1°C. They feel that, because the temperature tolerance of these animals is so great, their pattern of abundance is more related to depth than to temperature. Temperature also plays a role in increasing the speed of development of eggs and larvae (Perkins, 1973).

Red crabs prefer substrates into which they can burrow. The young have been found on smooth surface silt-clays (Wigley, et al., 1975). Red crabs are scavengers. Their diet consists of fish and invertebrates, alive or dead. They are probably preyed upon by cod, skates, or sharks, as are lobsters.

Homarus americanus

The lobster fishery is one of the most important fisheries in the northwestern Atlantic. Lobster fishing has historically been concentrated in the inshore waters, but in the last decade exploitation of populations on the continental margin has developed.

Homarus americanus occurs from Labrador to Cape Hatteras in depths from the low intertidal to over 700 m. Many studies have been undertaken to determine whether the offshore lobsters are a different stock from the inshore population. There is some indication, based on biochemical-genetic studies, that the offshore population may be a separate stock (Sherburne and Ridgway, in preparation). Cooper and Uzman (1971) reported that some individuals tagged and released on the continental slope migrated into coastal waters.

Lobsters living along the continental slope grow larger and live longer than inshore lobsters. Skud (1966) reported offshore lobsters with carapace lengths of 5 to 21 cm and weights of 0.2 to 13 kg. The mean carapace length of offshore lobsters is 13 cm and the mean weight is 3 kg, whereas the mean carapace length of inshore lobsters is 9 cm and the mean weight is less than 1 kg.

After settling to the bottom, the juvenile lobsters usually molt four more times before their growth is arrested by the low winter temperatures. Although the size at this stage varies considerably, depending on nutrition, etc., the carapace length is usually about 15 mm. Juveniles molt two to three times annually and adults molt about once a year. Table 7-24 presents the mean carapace lengths at the end of each growing season as reported by Hughes and Matthiessen (1962) for laboratory-reared animals.

Skud (1966) found that 60 percent of the lobsters captured in offshore waters were females. Those individuals with carapace lengths between 14-16 cm had the greatest percentage of females. Fifty percent of the females caught which had a carapace length of between 12-17 cm were carrying eggs in the summer and fall. Few of the larger females (over 18 cm) were found to be egg-bearing. Perkins and Skud (1966) showed that offshore lobsters mature at smaller carapace lengths than inshore lobsters. They reported that the smallest egg-bearing lobster recovered was 8.8 cm.

Lobsters breed during the summer. Immediately after the female molts copulation occurs. The sperm are stored in the seminal receptacle of the female and are released to fertilize the eggs as they are extruded onto the pleopods. The eggs may be extruded shortly after mating but some do not extrude their eggs until the following year. Hatching of offshore lobsters occurs in June and July of the year following extrusion.

The number of eggs produced by an individual female lobster varies with her age and size. Approximately 10,000 eggs are produced by a one-pound individual and about 130,000 eggs are produced by an 18-pound lobster. About 35 percent of the eggs die while they are being carried on the female. After hatching the pelagic larvae molt through four instars before they achieve the characteristic lobster appearance and settle to the ocean floor. Under laboratory conditions the fifth stage is reached in three weeks at 20°C and five to six weeks at 15°C. Larvae and small juveniles have a very high mortality which is probably greater than 99 percent.

Lobster prefer habitats which provide shelter. They either hide in crevices provided by irregular bottoms or burrow into sand and mud.

Table 7-24. Mean carapace lengths of lobsters at the end of the growing season (modified from Hughes and Matthiessen, 1962)

Year	Length
1st	13.5 mm
2nd	29.0
3rd	45.7
4th	63.2
5th	82.2
6th	94.4
7th	104.0
8th	113.8
9th	127.7
10th	153.0

They are territorial by nature and often show aggression towards one another. Lobsters are involved in both inter- and intraspecific competition for space.

Stomach analyses show that lobsters eat the following things (in order of importance): fish, dead or alive; crustaceans, chiefly isopods and decapods; molluscs, largely small gastropods, algae, echinoderms, and hydroids. Circolana concharum, an isopod, is eaten frequently and abundantly. Lobsters also eat their own eggs and each other. Intraspecific competition for food is intense.

Lobsters are preyed upon by surface feeding fish; small lumpfish, hiding in floating seaweed, are known to feed on lobster larvae. Cunners and other small bottom feeding fish prey upon early juveniles. Wolffish are known to eat the larger juveniles. Cod, skates, and sharks prey upon larger lobsters. Lobsters are particularly subject to predation following molting when their exoskeleton is soft.

Older juveniles and adults have a lower natural mortality but the fishing mortality is heavy. Wigley, et al. (1975) found that there were fewer and smaller lobsters caught in their survey than in former surveys of the offshore waters.

Other Dominant Species

Besides the two benthic commercial species, Geryon quiquedens and Homarus americanus, the following would be considered to be key species: Ophiomusium lymani, Echinus affinis, Phormosoma placenta, Hyalinoecia artifex, and ceriantbid anemones. These five species constituted over 97 percent of the animals counted in a survey conducted by Grassle, et al. (1975).

Ophiomusium lymani, a brittle star, is found in the eastern and western North Atlantic and in the Pacific. The large ones are from 1.5 to 2.5 cm in disc diameter with arms which are 10 to 15 cm long (Wigley and Emery, 1967). Schoener (1968) reported that some are as large as 3.5 cm in disc diameter. In the western North Atlantic, O. lymani has been found in the following depth ranges: between 443 and 3,781 m by Verrill (1885), between 1, 968 and 3,987 m off North Carolina (Rowe, 1968), and between 1,480 and 2,150 m by Wigley and Emery (1967). Ninety-one percent of the brittle stars were found between 1,705 and 2,170 m (Grassle, et al., 1975).

Grassle, et al. (1975) reported densities between 0 and 4.5 per meter square at 1,800 m. Wigley and Emery (1967) found densities of 0.8 per meter square at stations between Cape Hatteras and Nantucket Island. The highest density and biomass in this survey was 11 individuals and 31 gm per meter square. When O. lymani are in dense groups they space themselves in a regular way just a few centimeters from one another (Wigley and Emery, 1967; and Grassle, et al., 1975). Fifty-eight percent of the 8,284 animals observed by Grassle, et al. (1975) and 56 percent of the 9,311 animals sampled by Rowe and Menzies (1969) along the continental slope were O. lymani.

Ophiomusium lymani bears its young in July and August (Schoener, 1968). This species probably has free-floating larvae since they do not brood their young (Schoener, 1967).

The polychaete, Hyalinoecia artifex or quill worm, has a cosmopolitan distribution (Pettibone, 1963). They are widely distributed in all oceans except the Antarctic and are found at depths between 13 and 4,379 m (Ekman, 1953). In the western North Atlantic, they have been reported between 274 and 1,170 m by Verrill (1885) and between 300 and 564 m by Hartman (1965) Wigley and Emery (1967) and Hartman and Fauchald (1971). In the area off North Carolina, Rowe (1968) found that 97 percent of the quill worms were between 390 and 505 m.

Wigley and Emery (1967) reported that the average density at stations in which one or more Hyalinoecia artifex were present was 46 per meter square, and the greatest density found was 272 per meter square. They found there is an inverse relationship between latitude and density.

The polychaete lives in a tube on silty sand, foraminiferal silt or other unconsolidated sediment (Wigley and Emery, 1967). Wigley and Emery (1967) provided information on the worm tubes and worm activity. Eighty percent of the tubes were occupied and ten percent of the worms were emerged from the tubes probably looking for food. This would indicate that the worms are relatively inactive. The tube length is 6-15 cm although most of the worms have a tube length between 8 and 12 cm. The tube is tapered and the diameter of the larger anterior end is between 3 and 8 mm. Smaller worms have a more tapered tube than larger worms. They have a habit of stacking with the anterior end resting on top of the tube of another worm. They apparently scrape detritus off the other tubes.

Wigley and Emery (1967) cite Ophiomusium lymani as a possible predator on Hyalinoecia curtifex.

There is very little life history material available about the sea urchin, Echinus affinus and Phormosoma placenta, and the cerianthid anemone. Cerianthids and Echinus affinis are less abundant than Ophiomusium lymani but almost as ubiquitous (Grassle, et al., 1975). Both species were found at depths greater than 1,550 m although Echinus affinis was also found in lesser densities between 1,465 and 1,550 m (Grassle, et al., 1975). Grassle, et al. (1975) reported that Phormosoma placenta was the only abundant epifaunal species at 1,300 m. Echinus affinus congregate in small dense feeding groups which feed on plant remains (Grassle, et al., 1975). They disperse when not feeding. Phormosoma placenta, however, is a deposit feeder which forms small dense groups that move slowly en masse while working the sediments (Grassle, et al., 1975).

ABIOTIC FACTORS

Abiotic factors do not have the same overriding importance in deeper water that they do in coastal waters. The unique characteristic of the deep sea, including most of the continental slope environment, is its uniformity and constancy. Seasonal changes in temperature, dissolved oxygen, turbidity, etc., are all felt on the continental shelf, but these are quickly dampened with increasing depth. For example, Menzies, et al. (1973) report that the seasonal temperature variation in the archibenthal zone of transition (445-940 m) is about 4°C, while on the lower slope the variation is less than 0.1°C. This is in great contrast to the littoral and shallow water environments in the same geographic region which may change over 30°C in the course of a year. Sanders and Hessler (1969) write "The abundance of food is generally assumed to control density and biomass in the deep sea. Oxygen concentration, sediment type and temperature either do not show correlated changes or never reach levels regarded as limiting." In the next few paragraphs the major abiotic factors will be considered briefly in turn. The briefness is a function of a lack of knowledge about their specific influence or of their relative unimportance in the deep sea environment.

Depth per se is an important ecological factor. Depth potentially effects the continental slope benthos in two ways: 1) by creating a great hydrostatic pressure and 2) by separating the benthos from the zone of organic production. Many authors doubt that pressure is a factor of ecological significance and believe that temperature is more important (Flügel, 1972). Sanders, et al. (1965) are also of the opinion that the difficulty in recovering live organisms from deep water is due to temperature shock rather than pressure changes. The one direct physiological effect of high pressure might be its influence on bacterial respiration which was discussed with the microbenthos. The effect of depth on food availability was considered in the section entitled Trophic Considerations. In general, the greater the depth the less food reaches the bottom because it has more time in which to be utilized in the water column. This is undoubtedly the greatest effect depth has on the deep sea benthos.

The reduced seasonal temperature variation in deep water is one of the most important features that sets the continental slope environment apart from surface and coastal waters. The boundary between the continental shelf and slope fauna is found at the depth where temperature variation decreases significantly rather than necessarily at the topographic shelf break (Menzies, et al., 1973; Coull, 1972; Tietjen, 1971; and Sanders and Hessler, 1969). In these zones of limited temperature variation, the small changes which do occur probably are not of ecological significance.

The levels of organic matter and dissolved oxygen are fairly constant throughout the ocean basins (Menzel, 1967 and Craig, 1971). The seasonal drop to 3.0 ml/l of dissolved oxygen on the upper continental slope off the Carolinas (Rowe and Menzies, 1968) is unusual. Dissolved oxygen levels are usually not limiting (Sanders and Hessler, 1969). Several investigators report a failure to find a correlation between benthic distributions and levels of organic carbon (Sanders and Hessler, 1969; Tietjen, 1971; Menzies, et al., 1973; and Rowe, et al., 1974). This is usually attributed to the refractory nature of the majority of the carbon in much of the sediment. This means that although a certain carbon level exists, it is in a form which is not readily utilizable by the benthos. The lack of a developed microfauna (Jannasch and Wirsen, 1969) insures that most of this material will be kept out of the general carbon cycle. Dumping of dredge spoils and sewage sludge may cause enrichment and result in increased macrobenthic abundance on the slope. A similar phenomenon has been observed on the continental shelf and it is possible that some of this material might be transported off the shelf (Rowe, 1972).

Variations in turbidity levels apparently occur on the slope. Increased abundances of suspension feeders have been noted in certain areas by Sokolova (1959), Rowe and Menzies (1969) and Menzies, et al. (1973). This indicates that in these areas there is an increased amount of suspended sediment upon which the animals can feed. An extreme case of increased turbidity is a turbidity current. Under such a circumstance an organism must be motile enough to avoid it or be able to burrow well enough to dig out of it, or he will succumb. Less drastic unpredictable turbidity flows have been observed (Rowe, et al., 1974) but their influence on slope benthos is open to speculation. They obviously transport material down the slope but they also are a stress in that they require additional energy expenditures for burrow maintenance and cleansing of gills and feeding apparatus.

Very little is known about the effects of toxic materials on slope organisms. There is some evidence that the slope fauna can be impacted. Bourcier (1968) reported the effect of an aluminum processing plant down to 1,800 m in the Mediterranean. There is no such evidence along our Atlantic coast. In an investigation of community structure and heavy metal concentration Pearce, et al. (1974) could find no effect of the dumping in the New York Bight on slope benthos.

All benthic animals depend on water movement to supply food material and respiratory gases and to remove wastes. Water movements also influence the nature of the sediment and the dispersion of larvae. In order for a population of suspension feeders to develop, a current must be present that is swift enough to carry a minimal amount of organic matter past the individuals. Deposit feeders are not as directly dependent on constant currents but on the slope they still must depend on organics from outside areas. Currents effect the nature of the substrate in various ways. Relatively strong currents cause erosion and the removal of small sediment particles and weak currents allow the deposition of silt and clay size particles. Currents are also responsible for ripple marks and sand waves on the bottom which may effect the nature of the faunal assemblage present. Most deep sea currents are constant in nature and the variable current conditions, as seen on the upper Carolina slope (Menzies, et al., 1973) caused by variations in the Gulf Stream, are not common.

One of the most important ecological factors in shallow water is the sediment type. In the deeper water, however, its influence on the macrobenthos has been questioned (Sanders and Hessler, 1969). Most deep sea sediments are very fine (Menzies, et al., 1973) and studies of macrobenthic distribution and sediment types have shown no relationship (Sokolova, 1968). Obviously, an encrusting or attached form needs a suitable substrate, for attachment and encrusting assemblages will only develop where a substantial amount of such a substrate is available. Several authors suggest that the induration of sediments might limit the development of certain populations in canyons but there is no hard evidence to prove this.

The most significant relationship between sediments and benthos appear to be the effect that the benthos has on sediments. In Chapter 8, Submarine Canyons, the dominant role that benthos plays in erosion is discussed. Deep sea animal-sediment relationships have recently been reviewed by Rowe (1974). He presents a table that summarizes the possible interactions to stimulate further consideration of this phenomenon. This self-explantory table is presented as Table 7-25.

DATA GAPS

The gaps in our knowledge of the continental slope benthos are large; indeed, much of the work completed to date can be considered to be preliminary in nature. There is no aspect of the continental slope benthos that is known satisfactorily. Fundamentally, more sampling is necessary over a wider geographic range and basic taxonomic work needs to be done for several groups. This is especially true for the infauna which is less well known then the epifauna. Sampling over a period of time in a limited area would add useful information on temporal variation.

Significant contibutions are needed in the field of natural history, i.e. better information on feeding types, population size and age structure and the reproductive strategies of a multitude of species. This would help produce a better comprehension of species interactions.

We are only beginning to understand the time spans involved in continental slope and deep sea life. Many species do not reach maturity for 50 years. This slow motion life style raises many questions about the rate of energy flow, the predictability of food sources, and the role of microfauna.

In summary, our data base on continental slope benthos is small. Workers in the field have only recently had enough information to ask meaningful questions. Much more effort will be needed to answer these questions.

Table 7-25. The effects of the benthos on sediments.

				Examples	Occurrence in the Deep Sea
B. Weaken, disperse or unconsolidate	Feeding	Non-selective	Deposits	Ingest sediments whole, removes organic matter, produces castings	Common*
		Selective	Filter	Filters or sieves bottom water, produces both pellets and pseudofeces	Uncommon*
			Deposit	Removes biota or detritus from surface (10 cm) sediments, produces pellets and castings	Common (?)*
	Locomotion		Swimming	Fishes, some holothurians and crustaceans, smooth surface	Common
			Crawling	Crustaceans and echinoderms, may either smooth or cut sediments	Common
			Burrowing	Bivalves and polychaetes, infaunal worms (*Glycera*, etc.) and mollusks (*Mya*, etc.), accounts for most bioturbation	Common
				Homarus in Gulf of Maine, *Geryon* in Hudson Canyon	Less common, but often in canyons or steep topography
	Habitation		Burrowing Construction	Mostly decapod crustaceans *Nephrops*, *Goneplax* in shallow sand and mud	
A. Strengthen or consolidate	Escape			Response to catastrophic burial-success depends on the taxon	Not common Unknown
	Tube Construction	Inorganic		Calcium carbonate tubes - Polychaetes	Uncommon
				Onuphids (polychaete) use of *Globigerina* tests	Common above $CaCO_3$ compensation depth
				Pectinaria (polychaete) quartz sand tubes	Uncommon
		Organic		Pogonophoran tubes	Common
				Cerianthis anemone tubes	Common at slope depths
				Chitinous polychaete tubes, *Hyalinoecia*, chaetopterids, onuphids, etc.	Patchy remains remineralized

* Although much work has been done on deep-sea feeding (Sokolova, 1968), how and on what animals feed is still an open question (Dayton and Hessler, 1972).

REFERENCES

Allen, J. A. and H. L. Sanders. 1966. Adaptations to abyssal life as shown by the bivalve Abra profundorum (Smith).Deep-Sea Res. 12:1175-1184.

Anonymous. 1971. Shellfish resource assessment. Cruise Rept. Delaware II Cruise 70-8. December 18, 1970 - February 26, 1971. Nat. Mar. Fish. Woods Hole. 10 p.

Barnes, H. 1972. Aspects of temperature in the marine environment. Sym. Effects Temp. on Organisms. Obergurgl, 1-17.

Boolootian, R. A., ed. 1966. Physiology of Echinodermata. Interscience Publishers, N.Y. 822 pp.

Bourcier, M. 1968. Ecoulement des boues-roques dans le canyon de la Cassidaigne. Tethys, 1: 779-782.

Bruun, A. F. 1957. Deep Sea and abyssal depths. In: J. Hedgpeth (ed.), Treatise on marine ecology and paleoecology, Vol. 1, Mem. Geol. Soc. Amer., 67.

Bruun, A. F. and T. Wolff. 1961. Abyssal benthic organisms: Nature, origin, distribution and influence on sedimentation, pp. 391-397. In: M. Sears (ed.), Oceanography. Amer. Ass. for the Adv. of Sci. Publ., 67.

Carey, A. G., Jr. 1972. Food sources of sublittoral, bathyal and abyssal asteroids in the northeast Pacific Ocean, 10: 35-47.

Chace, F. A., Jr. 1940. Reports on the scientific results of the Atlantis expedition to the West Indies, under the joint auspices of the University of Havana and Harvard University. The Brachyuran crabs. Torreia, no. 4: 1-67.

Clark, A. H. 1954. Some mollusks from the continental slope of northeastern North America. Breviora, no. 40. 1-11.

Coe, W. R. 1956. Fluctuations in populations of littoral marine invertebrates. J. Mar. Res., 15: 212-232.

Cooper, R. A. and J. R. Uzmann. 1971. Migrations and growth of deep-sea lobsters, Homarus americanus. Science, 171: 288-290.

Coull, B. C. 1972. Species diversity and faunal affinities of meiobenthic copepoda in the deep sea. Mar. Biol., 14: 48-51.

Craig, H. 1971. The deep metabolism: oxygen consumption in abyssal ocean water. J. Geophy. Res. 76: 5078-5086.

Dall, W. H. 1882. On certain limpets and chitons from the deep waters off the eastern coast of the United States. Proc. U.S. Nat. Mus., 81: 400-414.

Dayton, P. K. and R. R. Hessler. 1972. Role of biological disturbance in maintaining diversity in the deep sea. Deep-Sea Res. 19: 199-208.

Dillon, W. P. and H. B. Zimmerman. 1970. Erosion by biological activity in two New England submarine canyons. J. Sediment. Petrology, 40: 542-547.

Ekman, S. 1953. Zoogeography of the sea. Sidgwick and Jackson, Ltd., London. 417 p.

Flügel, H. 1972. Animals. Section 8.3 in Cnapter 8, Pressure. In: O. Kinne (ed.), Marine ecology, A comprehensive, integrated treatise on life in oceans and coastal waters. Wiley-Interscience, N.Y. p. 1407-1450.

Fournier, R. O. 1972. The transport of organic carbon to organisms living in the deep oceans. Proc. Roy. Soc. Edinborough, 73(21): 203-211.

Fowler, S. W. and L. F. Small. 1972. Sinking rates of euphausiid fecal pellets. Limnol. Oceanogr., 17: 293-296.

Gerlach, S. A. 1971. On the importance of marine meiofauna for benthos communities. Oecologia, 6: 176-190.

Grassle, J. F. and H. L. Sanders. 1973. Life histories and the role of disturbance. Deep-Sea Res., 20: 543-59.

Grassle, J. F., H. L. Sanders, R. R. Hessler, G. T. Rowe and T. McLellan. 1975. Pattern and zonation: a study of the bathyal megafauna using the research submersible ALVIN. Deep-Sea Res., 22: 457-481.

Griggs, G. B., A. G. Carey and L. D. Kulm. 1969. Deep-sea sedimentation and sediment-fauna interaction in Cascadia Channel and on Cascadia abyssal plain. Deep-Sea Res. 16: 157-170.

Haedrich, R. L., G. T. Rowe and P. T. Polloni. 1975. Zonation and faunal composition of epibenthic populations on the continental slope south of New England. J. Mar. Res., 33(2): 191-212.

Haefner, P. A., Jr. and J. A. Musick. 1974. Observations on distribution and abundance of red crabs in Norfolk Canyon and adjacent continental slope. Mar. Fish. Rev., 36(1): 31-34.

Hartman, O. 1965. Deep water benthic polychaetous annelids off New England to Bermuda and other North Atlantic areas. Allan Hancock Found. Publ. Occas. Pap., 28: 1-378.

Hartman, O. and K. Fauchald. 1971. Deep-water benthic polychaetous annelids off New England to Bermuda and other North Atlantic areas. Part II. Allan Hancock Monogr. Mar. Biol., 6: 1-327.

Heezen, B. C. and C. D. Hollister. 1971. The face of the deep. Oxford Univ. Press., N.Y. 659 p.

Hessler, R. R. and H. L. Sanders. 1965. Bathyal Leptostraca from the continental slope of the Northeastern United States. Crustaceana, 9: 71-74.

____________. 1967. Faunal diversity in the deep-sea. Deep-Sea Res., 14: 65-78.

Holme, N. A. and A. D. McIntyre. 1971. Methods for the study of marine benthos. IBP Handbook no. 16. Blackwell Scientific Publications, Oxford. 334 p.

Holm-Hansen, O. 1971. Determination of microbial biomass in deep ocean profiles. *In*: Fertility of the Sea, J. D. Costlow, Jr., (ed) Gordon and Breach, p. 197-207.

Holmsen, A. 1968. The commercial potential of the deep sea red crab. Occas. Pap. Univ. R.I. 68-138: 1-17.

Holmsen, A. A. and H. McAllister. 1974. Technological and economic aspects of red crab harvesting and processing. Univ. R.I. Mar. Tech. Rept. 28. 35 p.

Hughes, J. and G. Matthiessen. 1962. Observations on the biology of the American lobster, *Homarus americanus*. Limnol. Oceanogr. 7: 414-421.

Jannasch, H. W. and C. O. Wirsen. 1969. Microbial degradation of organic matter in the deep sea. Science, 171: 672-675.

____________. 1973. Deep-sea micro-organisms: In situ response to nutrient enrichment. Science, 180: 641-643.

Jones, N. S. and H. L. Sanders. 1972. Distribution of Cumacea in the deep Atlantic. Deep-Sea Res., 19: 737-745.

Kinne, O. (ed). 1970. Marine ecology. Wiley-Interscience, N.Y., 1, Parts 1-3. 1774 p.

Limbaugh, C. and F. P. Shepard. 1957. Submarine canyons. Chapter 21, pp. 633-639. In: J. Hedgpeth (ed.). Treatise on marine ecology and paleoecology. v. 1. Mem. Geol. Soc. Amer. 67.

Mangum, C. P. 1972. Temperature sensitivity of metabolism in offshore and intertidal onuphid polychaetes. Mar. Biol., 17: 108-114.

McIntyre, A. D. 1956. The use of trawling, grab, and camera in estimating marine benthos. J. Mar. Biol. Ass. U.K., 25: 419-429.

McRae, E. D., Jr. 1960. Lobster explorations on the continental shelf and slope off the northeast coast of the United States. Commer. Fish. Rev., 22(9): 1-7.

____________. 1961. Red crab explorations off the northeastern coast of the United States. Commer. Fish. Rev., 23(5): 5-10.

Meade, T. L. 1970. Red crabs in your future. Rhode Island Resour., 16(1): 1-3.

Meade, T. L. and G. W. Gray, Jr. 1973. The red crab. Mar. Tech. Rept. Series no. 11, Univ. R.I. 21 p.

Menzel, D. W. 1967. Particulate organic carbon in the deep-sea. Deep-Sea Res., 14: 229-238.

Menzies, R. J. and R. Y. George. 1967. A re-evaluation of the concept of hadal or ultra-abyssal fauna. Deep-Sea Res., 14: 703-723.

Menzies, R. J., R. Y. George and G. T. Rowe. 1973. Abyssal environment and ecology of the world oceans. Wiley-Interscience, N.Y. 488 p.

Menzies, R. J. and G. T. Rowe. 1969. The distribution and significance of detrital turtle grass Thallassia testudinata, on the deep-sea floor off North Carolina. Int. Revue. ges. Hydrobiol., 54(2): 217-222.

Menzies, R. J., J. S. Zaneveld and R. M. Pratt. 1967. Transported turtle grass as a source of organic enrichment of abyssal sediment, off North Carolina. Deep-Sea Res., 14: 111-112.

Owen, D. M., H. L. Sanders and R. R. Hessler. 1967. Bottom photography as a tool for estimating benthic populations. Johns Hopkins Oceanogr. Studies, 3: 229-234.

Paul, A. Z. 1973. Trapping and recovery of living deep-sea amphipods from the Arctic Ocean floor. Deep-Sea Res., 20: 289-290.

Pearce, J. B., J. Thomas and R. Greig. 1974. A preliminary investigation of the benthic resources at deep water disposal site 106. NMFS, Sandy Hook. (Ecosystems Investigations) Informal Report 37. 11 p

Perkins, H. C. 1973. The larval stages of the deep sea red crab, Geryon quinquedens Smith, reared under laboratory conditions (Decapoda: Brachyrhyncha). Fish. Bull., 71: 69-82.

Perkins, H. C. and B. E. Skud. 1966. Body proportions and maturity of female lobsters. Amer. Zool., 6(4): 615 p.

Pettibone, M. H. 1963. Marine polychaete worms of the New England region. I. Aphroditidae through Trochochaetidae. Bull. U.S. Nat. Mus., 227: 1-356.

Rathbun, M. J. 1937. The Oxystomatous and allied crabs of America. Bull. U.S. Nat. Mus. 166: 1-278.

Rex, M. A. 1973. Deep-sea species diversity: decreased gastropod diversity at abyssal depths. Science, 181: 1051-1053.

Rowe, G. T. 1968. Distribution patterns in populations of large, deep-sea benthic invertebrates off North Carolina. Doctoral Thesis. Duke Univ., Durham, N.C. 296 p.

Rowe, G. T. 1971. Benthic biomass and surface productivity. In: Fertility of the sea, J. D. Costlow, Jr., (ed.), Gordon and Breach 2: 441-454.

____________. 1971. Observations on bottom currents and epibenthic populations in Hatteras submarine canyon. Deep-Sea Res., 18: 569-581.

____________. 1972. The exploration of submarine canyons and their benthic faunal assemblages. Proc. Roy. Soc. Edinborough. 73: 159-169.

____________. 1974. The effects of the benthic fauna on the physical properties of deep-sea sediments. Deep sea sediments, H. L. Inderbitzen, ed., Plenum. p. 381-400.

Rowe, G. T., G. Keller, H. Edgerton, N. Staresinic and J. MacIlvaine. 1974. Time-lapse photography of the biological reworking of sediments in Hudson submarine canyon. J. Sediment. Petrology, 44(2): 549-552.

Rowe, G. T. and R. J. Menzies. 1968. Deep bottom currents off the coast of North Carolina. Deep-Sea Res., 15(6): 711-719.

___________. 1969. Zonation of large benthic invertebrates in the deep-sea off the Carolinas. Deep-Sea Res., 16: 531-537.

Rowe, G. T., P. T. Polloni and S. G. Horner. 1974. Benthic biomass estimates from the northwestern Atlantic Ocean and the northern Gulf of Mexico. Deep-Sea Res., 21: 641-650.

Sanders, H. L. 1968. Marine benthic diversity: A comparative study. Amer. Natur. 102: 1-40.

___________. 1969. Benthic marine diversity and the stability-time hypothesis. Brookhaven Symposia in Biol. 22: 71-81.

Sanders, H. L. and J. F. Grassle. 1971. The interactions of diversity, distribution and mode of reproduction among major groupings of the deep-sea benthos. Proc. Joint Oceanogr. Assembly (Tokyo) p. 260-262.

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

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

Schoener, A. 1967. Post-larval development of five deep-sea ophiuroids. Deep-Sea Res., 14: 645-660.

___________. 1968. Evidence for reproductive periodicity in the deep-sea. Ecology, 49: 81-87.

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

Schroeder, W. C. 1955. Report on the results of exploratory otter-trawling along the continental shelf and slope between Nova Scotia and Virginia during the summers of 1952 and 1953. Deep-Sea Res., 3: 358-372.

___________. 1959. The lobster, Homarus americanus, and the red crab, Geryon quinquedons, in the offshore waters of the western North Atlantic. Deep-Sea Res., 5: 266-282.

Serafy, D. K. 1971. Intra-specific variation in the brittle star Ophropholis aculeata (Linnaeus) in the northwestern Atlantic (Echinodermata; Ophiuroidea). Biol. Bull., 140: 323-330.

Sherburne, S. and G. Ridgway. In prep. Phosphoglucomutase polymorphism in populations of the American lobster, Homarus americanus.

Skud, B. E. 1966. Size composition, sex ratio and maturity of offshore lobsters. Amer. Zool., 6: 362-363.

Slobodkin, L. B. and H. L. Sanders. 1969. On the contribution of environmental predictability to species diversity. Brookhaven Symposia in Biology. 22: 82-95.

Smayda, T. J. 1969. Some measurements of the sinking rate of fecal pellets. Limnol. Oceanogr. 14: 621-625.

Smith, K. L., Jr., and J. M. Teal. 1973. Deep-Sea benthic community respiration: An in situ study at 1,850 m. Science, 179: 282-283.

Smith, W. and A. D. McIntyre. 1954. A spring-loaded bottom sampler. J. Mar. Biol. Ass. U.K. 33: 257-264.

Sokolova, M. N. 1959. On the distribution of deep-water bottom animals in relation to their feeding habits and the character of sedimentation. Deep-Sea Res., 6: 1-4.

____________. 1968. Relationships between feeding groups of bathypelagic macrobenthos and the composition of bottom sediments. Oceanology, 8: 141-151.

____________. 1972. Trophic structure of deep-sea macrobenthos. Mar. Biol. 16: 1-12.

Southward, E. C. and T. Brattegard. 1968. Pogonophora of the northwest Atlantic: North Carolina region. Bull. Mar. Sci., 18(4): 836-875.

Stanley, D. J. 1971. Bioturbation and sediment failure in some submarine canyons. Vie Milieu Suppl., 22: 541-555.

Stickney, A. P. 1974. Benthic invertebrates. Chapter 10. In: A socioeconomic and environmental inventory of the North Atlantic region. TRIGOM for the Bur. of Land Manage. 4,900 p.

Thiel, H. 1966. Quantitative untersuchungen über die meiofauna des Tiefseebodens. Veröff. Inst. Meerestorsch. Bremerh. Sonderband, 2: 131-148.

____________. 1971. Häufigkeit und verteilung der meiofauna in Bereich des Island-Färöer-Rückens. Ber. dt. wiss. Kommn. Meeresforsch., 22.

Tietjen, J. H. 1971. Ecology and distribution of deep-sea meiobenthos off North Carolina. Deep-Sea Res., 19: 941-957.

Turner, R. 1973. Wood-boring bivalves, opportunistic species in the deep sea. Science, 180: 1377-1379.

Verrill, A. E. 1885. Results of the explorations made by the steamer Albatross off the northern coast of the United States in 1883. Rept. U.S. Comm. Fish and Fisheries (1883), 503-699.

Vinogradov, M. E. 1961. The feeding of deep-sea zooplankton. In: J. H. Fraser and J. Corlett, Rapp. Proc. Verb. Reunion Cons. Perm. Int. 'Explor. Mer., 153: 114-120.

Warme, J. E., T. B. Scanland and N. F. Marshall. 1971. Submarine canyon erosion: Contribution of marine rock burrowers. Science, 173: 1127-1129.

Wigley, R. L. 1963. Pogonophora of the New England continental slope. Science, 141: 358-359.

Wigley, R. L. and B. R. Burns. 1971. Distribution and biology of mysids (Crustacea, Mysidacea) from the Atlantic coast of the United States in the NMFS Woods Hole collection. Fish. Bull., 69: 717-746.

Wigley, R. L. and K. O. Emery. 1967. Benthic animals, particularly Hyalinoecia (Annelida) and Ophiomusium (Echinodermata), in seabottom photographs from the continental slope. In: J. B. Hersey (ed.) Deep-sea photography, Johns Hopkins Oceanogr. Stud., 3: 235-249.

Wigley, R. L. and A. D. McIntyre. 1964. Some quantitative comparisons of offshore meiobenthos and macrobenthos south of Martha's Vineyard. Limnol. and Oceanogr. v. 9, no. 4: 485-493.

Wigley, R. L. and F. C. Stinton. 1973. Distribution of macroscopic remains of recent animals from marine sediments off Massachusetts. Fish. Bull. 71: 1-40.

Wigley, R. L. and R. B. Theroux. 1970. Sea-bottom photographs and macrobenthos collections from the continental shelf off Massachusetts. U.S. Fish. Wildl. Serv. SSR-Fish. 613. 12 pp.

Wigley, R. L., R. B. Theroux and H. E. Murray. 1975. Deep-Sea red crab, Geryon quinquedens, survey off northeastern United States. Mar. Fish. Rev., 37: 1-21.

Wilder, D. G. 1966. Canadian Atlantic crab resources. Fish. Res. Bd. Canada. Biol. Stn., St. Andrews, N.B. Gen. Ser. Circ. no. 50, 4 p.

Wirsen, C. O. and H. W. Jannasch. 1975. Activity of marine psychrophilic bacteria at elevated hydrostatic pressures and low temperatures. Mar. Biol., 31: 201-208.

Zenkevich, L. A. and J. A. Birstein. 1956. Studies of the deep-water fauna and related problems. Deep-Sea Res., 4: 54-64.

7.3.2 BENTHIC FISHES

INTRODUCTION

The most characteristic feature of the fish fauna inhabiting the shoal waters of the northwest Atlantic is the abundance of benthic and benthopelagic species. These are species primarily dependent on the bottom for their food and concealment. In many cases morphological adaptation to the benthic environment has also occurred. The main components of this fauna consist of flatfish (flounders, halibut, plaice, and sole), flattened laterally and lying with either their left or right side pressed to the bottom; cartilaginous fishes (skates, rays, and torpedoes) flattened dorso-ventrally; and "roundfish" (cod, haddock, hake and cusk). The diet of these groups consists mainly of bottom dwelling animals such as crustaceans, mollusks, echinoderms, and worms, although a number of the "roundfish" are predaceous on other fish and shrimp. Spawning activity generally occurs near the bottom but in some cases the eggs, and in many instances the larvae, are pelagic. Furthermore, the type of substrate is important to many of these species and their distribution patterns can often be mapped according to bottom topography and materials. This species-substrate relationship may either be protective or the result of an association of food organisms with the bottom type.

The choice between classifying a particular species of fish as pelagic or benthic can be arbitrary. Fish are generally mobile and many of the so-called benthic species spend considerable time up in the water column (Chenoweth, 1974); conversely, a large number of species which have pelagic habits (i.e., they range widely and feed on pelagic animals) are found near the bottom and are considered groundfish inasmuch as they are readily captured with a bottom trawling gear. Examples include: dogfish, silver hake, scup, and butterfish. In this report, fishes whose bottom habits make them susceptible to capture by bottom trawls are considered to be benthic species.

Benthic fishes of the continental slope fall into three broad categories:

(1) Species that are widely distributed over the shelf and slope area as adults usually have changing seasonal distributions, and comprise a large portion of the commercial catch (silver hake, red hake, butterfish, skates, and dogfish).

(2) Species that are found in deeper water beyond the shelf edge are endemic to the slope, and are members of larger groups which are widely distributed over the deep ocean (macrourids, morids, and synaphobranchids).

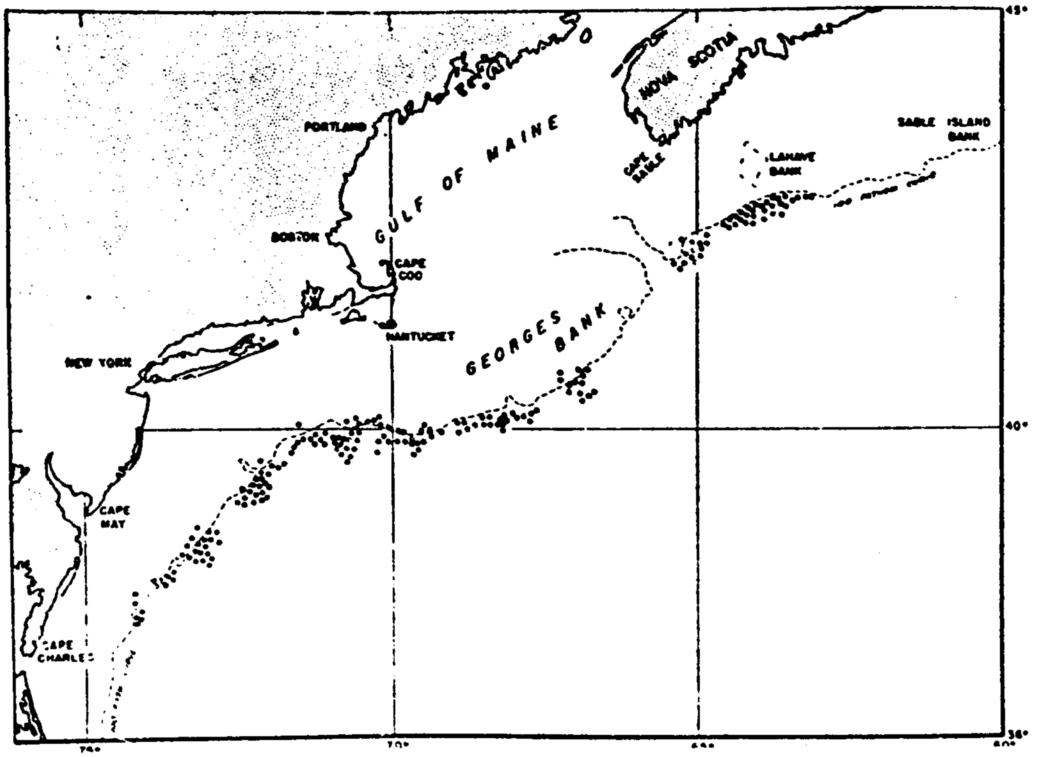
(3) Species that use the slope region as nursery grounds and are an important part of the slope fauna as juveniles (witch flounder).

For the benthic fishes, as for other floral and faunal groups, the continental slope presents a transition zone with marked environmental changes. As a result, the abundant temperate and boreal shelf fishes give way to sparse populations of deep water species at the ocean depths. For this reason, it would be expected that the benthic fishes of the slope would be sharply zonated in terms of kinds and abundance as one traverses the region vertically from the shelf edge to the continental rise.

To some extent, all fishes on the slope have adapted to the particular conditions presented by the deep sea environment: rapidly increasing depth, decreasing food supply, and increasing stability of environmental conditions. The widely distributed benthic fishes of the first of the previously mentioned three categories are probably less adapted to these conditions and generally are not found a great distance below the shelf edge. The fishes that can be considered slope species seem to be able to cope with increased conservatism of the slope environment; although in many cases they are found most abundantly only at certain levels downslope.

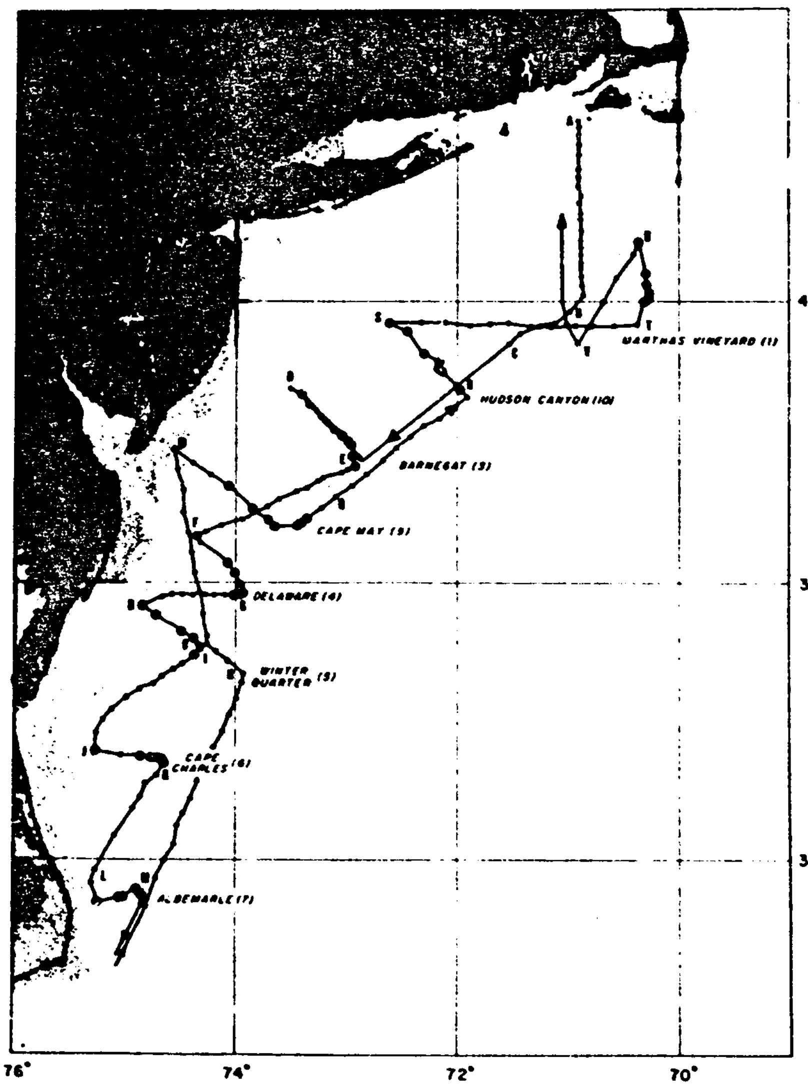
Existing knowledge of the fish fauna of the slope region, particularly their ecology, is still in a primitive state relative to what is known about fishes of more coastal waters. Only a limited amount of scientific exploration has been carried out beyond the outer shelf, most of which has been done during the last few years. The results of exploratory cruises in the 1880's by the "FISH HAWK", "ALBATROSS", and "BLAKE" using bottom trawls down to about 1,200 to 1,000 m off southern New England, represented the extent of knowledge about the slope fishes for the next 70 years (Schroeder, 1955). These explorations resulted in the basic taxonomic work of Goode and Bean (1896) which has subsequently been augmented for particular groups by Beebe (1929); Parr (1932); Bigelow and Schroeder (1954); and Castle (1964). Extensive treatment of the fishes found primarily below 2,000 m was given by Grey (1956). Most of these works are essentially systematic studies.

Beginning in the mid-1950's, trawl surveys of benthic fishes began along the slope paralleling the north and mid-Atlantic coast. The intent of these surveys was to determine the distribution and abundance of potential commercial quantities of fish. This distributional information began with Schroeder (1955), who conducted an extensive trawl survey of the upper slope region (914 to 1,280 m) from the Nova Scotian slope to Cape Charles during June and July, 1952-1953 (Figure 7-27). Later, Edwards, Livingstone and Hamer (1962) reported the results of a winter cruise track from Cape Cod to Cape Hatteras down to about 500 m on the slope (Figure 7-28). During the cruise, they recorded the sea temperature and the winter distribution of many commercially important species. Other than this survey, very little data exist for the winter months. Recently, Markle and Musick (1974) discussed the faunal composition of the deep water fishes along the slope. Their work is the result of an August survey of fishes conducted from southern New England to Cape



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	**FIGURE** 7-27	Sampling Areas, June-July, 1952, 1953 (Schroeder, 1955)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | **FIGURE** 7-28 | Sampling Areas (Edwards, Livingstone, and Hamer, 1962)

Hatteras at a depth of 900 m (Figure 7-29).

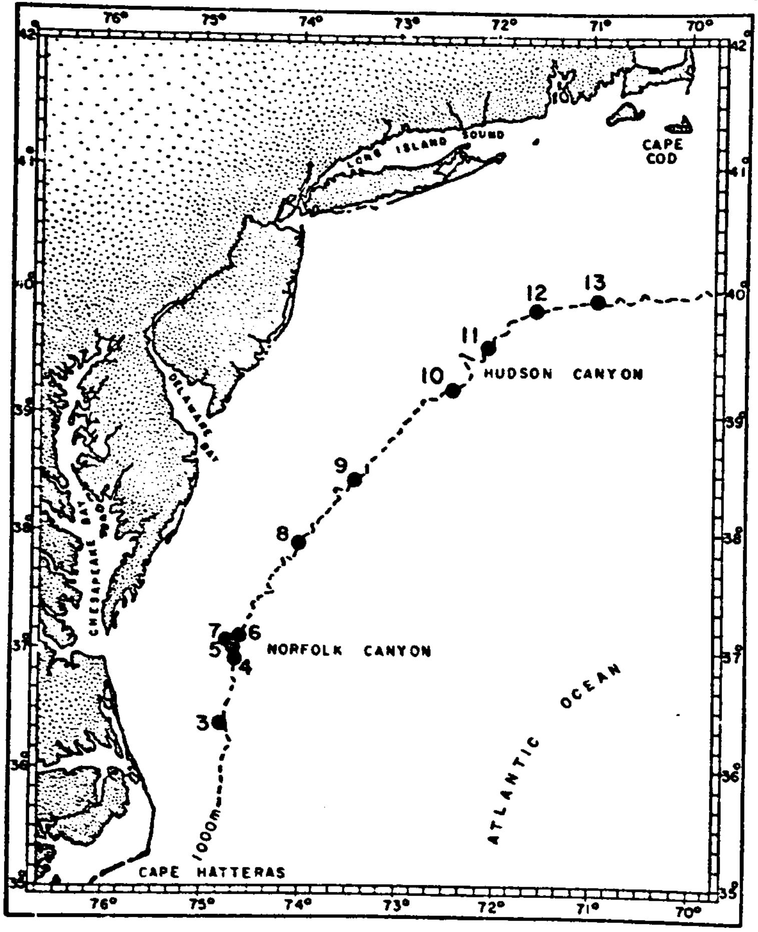
Perhaps the most extensive survey data for the upper slope level is generated by the annual quantitative inventory of continental shelf fish populations conducted by the National Marine Fisheries Service Northeast Fishery Center (Figure 7-51). This inventory extends from the Gulf of Maine to Cape Hatteras and has been at its present level of effort since 1969. The survey consists of a fall and a spring sampling of the shelf and upper slope areas by bottom trawl, the area is divided into basic sampling units (depth strata) with a number of 30-minute random tows made in each strata. Grosslein (1974) describes the sampling design in detail. For our purposes, the two outer depth strata are useful. One parallels the upper slope at depths from 200 to 400 m and the other bridges the shelf edge from 120 to 200 m. Summary printouts giving the weight and number of fish caught per tow in these outer two strata have been obtained for this report and cover the years 1969-1974. These data are particularly useful as a gross inventory of the benthic fishes common to the shelf that have also been found at the upper slope levels. The within-year variations and the statistical significance of these data have not been analyzed in this presentation. Therefore, any generalizations made concerning trends in the numbers or weights of the catches result from qualitative judgments and should be treated as such pending statistical analysis.

Until recently, ecological treatment of the slope fishes has been scanty and questions of dominance, zonation, and diversity in relation to increasing depth were left largely unanswered. Schroeder (1955) discussed the distribution of fish fauna to about 1,300 m, but his was primarily a group-by-group account emphasizing commercially important species. Faunal changes along the slope between 800 and 900 m were studied by Markle and Musick (1974). Recent interest in the downslope faunal changes have led to discussion regarding the zonation of fishes on the slope off the Carolinas (Menzies, George, and Rowe, 1973). Epifaunal studies have resulted from both bottom photography by the submersible, "ALVIN" (Grassle, Sanders, Hessler, Rowe, and McLellan, 1975) on the slope near the standard Gay Head-Bermuda transect and from bottom trawl tows (Haedrich, Rowe and Polloni, 1975).

FAUNAL COMPOSITION

Along-Slope Components

The summer cruises of Schroeder (1955) extended for a distance of some 600 km parallel to the slope from Nova Scotia to Cape Charles and seaward from the shelf edge in a band from 5 to 20 km wide and to a depth of about 1,300 m (Figure 7-27). He took a total of 75 species of benthic fishes (Table 7-12) in his study region which he divided into four zones: Nova Scotia to Georges Bank (A), to the offing of Nantucket (B), to the Hudson Canyon (C), and to Cape Charles (D). Of the more important



TRIGOM FIGURE 7-29 Sampling Areas, August, 1969 (Markle and Musick, 1974)

Table 7-26. Composition of slope fish fauna to a depth of 1300 m in the summer from Nova Scotia to Cape Charles (after Schroeder, 1955).

Species	Fathoms - 200	Fathoms + 200	Caught In 1-10 Hauls	Caught In 11 + Hauls	Number of Fish: Aggregate Catch 1-10	Number of Fish: Aggregate Catch 11-100	Number of Fish: Aggregate Catch 101+
Myxine glutinosa	D		X		X		
Petromyzon marinus		A	X		X		
Scyliorhinus retifer	B-C-D		X			X	
Apristurus profundorum		A-B-C-D		X		X	
Mustelus canis	D		X		X		
Centroscymnus coelolepis		B-C-D	X		X		
Centroscyllium fabricii		A-B-C-D		X		X	X
Etmopterus princeps		A-B-C		X		X	
Raja bathyphila		B	X		X		
Raja erinacea	B		X		X		
Raja fyllae		A-B		X		X	
Raja garmani	B-C-D			X		X	
Raja jenseni		A D	X		X		
Raja laevis	C	A-B-C	X		X		
Raja mollis		A	X		X		
Raja ocellata	B		X		X		
Raja radiata	B-C	A-B-C-D		X		X	
Raja senta	B-C-D	A-B-C-D		X		X	
Raja spinicauda		A-B	X		X		
Harriotta raleighana		A-B-C-D		X		X	
Rhinochimaera atlantica		A-B D	X		X		
Argentina silus		A		X		X	
Argentina striata	A-B-C-D		X			X	
Notacanthus phasganorus		A C	X		X		
Polyacanthonotus rostratus		A	X		X		
Simenchelys parasiticus		A-B-C-D		X		X	
Conger oceanica	D		X		X		

Table 7-26 (Cont.)

	Fathoms		Caught In		Number of Fish: Aggregate Catch		
Species	- 200	+ 200	1-10 Hauls	11+ Hauls	1-10	11-100	101+
Synaphobranchus pinnatus		A-B-C-D		X			X
Chlorophthalmus chalybeius	B-C-D	B-C-D		X			X
Chlorophthalmus truculentus	B-C		X		X		
Merluccius bilinearis	A-B-C-D	A-B-C		X			X
Merluccius albidus	B-C-D	B-C-D		X			X
Gaidropsarus ensis		A	X		X		
Enchelyopus cimbrius	C		X		X		
Pollachius virens	A		X		X		
Melanogrammus aeglefinis	A-B D		X				X
Antimora rostrata		A-B-C-D		X			X
Urophycis regius	B-C-D			X			X
Urophycis tenuis	B-C-D	A-B-C-D		X			X
Urophycis chuss	A-B-C-D			X			X
Urophycis chesteri	B-C-D	A-B-C-D		X			X
Laemonema barbatulum		D	X		X		
Brosme brosme		A	X		X		
Gadus (Micromesistius) poutassou	----	A-B	X		X		
Macrourus bairdii	B-C-D	A-B-C-D		X			X
Macrourus berglax		A-B		X		X	
Coelorhynchus carminatus	B-C-D	B-C-D		X			X
Coryphaenoides rupestris		A-B-C-D		X			X
Citharichthys arctifrons	B-C-D			X			X
Monolene sessilcaudata	C-D		X			X	
Reinhardtius hippoglossoides		A-B		X		X	
Hippoglossus hippoglossus		A	X		X		

Table 7-26. (cont.)

	Fathoms		Caught In		Number of Fish: Aggregate Catch		
	- 200	+ 200	1-10 Hauls	11 + Hauls	1-10	11-100	101+
Hippoglossoides platessoides	A	A	X		X		
Paralichthys oblongus	B-C-D	B		X			X
Glyptocephalus cynoglossus	B-C-D	A-B-C-D		X			X
Zenopsis ocellatus	D		X		X		
Polymyxia nobilis	C-D		X			X	
Poronotus triacanthus	B-C-D		X			X	
Lopholatilus chamaeleonticeps	C		X		X		
Sebastes marinus	A	A-B-C		X			X
Helicolenus dactylopterus	B-C-D	B-C-D		X			X
Myoxocephalus octodecemspinosus	A		X		X		
Cottunculus microps		A-B		X		X	
Cottunculus thompsoni		A-B-C-D		X		X	
Paraliparis copei		A-B	X			X	
Peristedion miniatum	B-C-D			X			X
Tautogolabrus adspersus	B		X		X		
Macrozoarces americanus	B		X		X		
Lycodes esmarkii		B	X		X		
Lycodes frigidus		A-B-C	X		X		
Lycenchelys paxillus	A		X		X		
Dicrolene intronigra		B-C-D		X		X	
Lepohidium cervinum	C-D		X		X		
Lophius americanus	A-B-C-D	A-B-C-D		X		X	
Dibranchus atlanticus	B-C-D	A-B-C-D		X			X

species, the black dogfish (Centroscyllium fabricci), a deep water eel (Synaphobranchus pinnatus), and the redfish (Sebastes marinus) were found primarily in Zone A. The macrourids, dominated in weight by Coryphaenoides rupestris were also most abundant in Zone A, but were found in lesser quantities throughout. The cod and hake families were represented by a number of important species; most plentiful were the longfinned hake (Phy cis chesteri) and the blue hake (Antimora rostrata), both most numerous in Zone A. The offshore hake (Merluccius albidus) ranked third in abundance with the greatest catches occurring in Zones C and D, but with no representatives in Zone A. Catches of the commercially important silver hake (Merluccius bilinearis), red hake (Urophycis chuss), and white hake (U. tenuis) were scattered. The flounder tribe was represented only by the witch flounder (Glyptocephalus cynoglossus), which were widespread as juveniles (one-fourth to one pound in size). Schroeder noted the absence of commercially important species in quantity and concluded the slope region was much less productive of commercial fishes than the bank areas.

The results of Markle and Musick (1974) are of particular interest because their faunal associations concern species predominantly considered fishes of the deeper waters and for which there are very little ecological data. Their sampling was done during the summer along the mid-slope region, Nantucket to Cape Hatteras, and the catch reported for seven successful slope hauls included 29 species and 17 families of benthic and benthopelagic fishes. Their species list is included in Table 7-27. These data, when analyzed using a dominance-affinity index, show areas of high species affinity to the north and south of Station 9, near Wilmington Canyon (Figure 7-29). These two areas of association were attributed partly to differences in species composition between the two areas and partly to the dominance of Synaphobranchus kaupi. Dominant in their catches were Glyptocephalus cynoglossus and Phycis chesteri at Stations 4, 6, and 8; and Synaphobranchus kaupi at Stations 11, 12, and 13. The species contributing to the difference between the two groups of stations are shown in Table 7-28. Diversity indices and species richness values were highest at intermediate Station 9 and the two adjacent stations, with the lowest values at the most northerly and the most southerly stations. The dominant species of the mid-Atlantic Bight were the synaphobranchid eel (Synaphobranchus kaupi), the macrourids (Mezumia spp.), the hake (Phycis chesteri), and the flatfish (Glyptocephalus cynoglossus). Southwest of the Wilmington Canyon the latter two species dominated, while the synaphobranchid eel dominated to the northeast. Markle and Musick noted that most C. kaupi were in spawning condition and their abundance may have resulted from spawning assemblages. The Wilmington Canyon stations were summarized as: (1) having the highest diversity value, (2) being intermediate in position between the two areas of faunal association, and (3) containing the three dominant species in almost equal abundance.

Table 7-27. Composition of slope fish fauna at 900 meters in August from Nantucket to Cape Hatteras (after Markle and Musick, 1974)

Species	Total
Centroscyllium fabricii	6
Hariotta raleighana	1
Ariosoma perturbator	1
Ilyophis brunneus	4
Synaphobranchus kaupi	400
Simenchelys parasiticus	13
Halosaurus guntheri	2
Aldrovandia phalacra	25
Alepocephalus agassizi	1
Bajacalifornia drakei	1
Bathypterois viridensis	1
Lophius americanus	1
Dibranchus atlanticus	1
Antimore rostrata	15
Phycis chesteri	173
Dicrolene intronigra	20
Monomitopus agassizi	1
Melanostigma atlanticum	27
Lycodonus mirabilis	1
Lycenchelys verrilli	2
Lycenchelys paxillus	6
Lycodes atlanticus	5
Trachonurus sulcatus	1

Table 7-28. Percent occurrence of benthic species on the slope north and south of the offing off Delaware Bay (after Markle and Musick, 1974).

Species	Percent Occurring South of Station 9	Percent Occurring North of Station 9	Percent Occurring At Station 9
Centroscyllium fabricii	0	100	0
Harriotta raleighana	0	100	0
Ariosoma perturbator	0	100	0
Alepocephalus agassizi	0	100	0
Bajacaliformia drakei	0	100	0
Lycodonus mirabilis	0	100	0
Coryphaenoides rupestris	3	97	0
Synaphobranchus kaupi	2	94	4
Simenchelys parasiticus	8	77	15
Ilyophis brunneus	25	75	0
Melanostigma atlanticum	26	70	4
Anitomora rostrata	0	67	33
Lycenchelys paxillus	0	67	33
Dicrolene intronigra	15	65	20
Paraliparis copei	0	50	50
Halosaurus guntheri	50	0	50
Aldrovandia phalacra	24	48	28
Glyptocephalus cynoglossus	71	18	11
Phycis chesteri	76	15	9
Lycodes atlanticus	80	20	0
Bathypterois viridensis	100	0	0
Lophius americanus	100	0	0
Monomitopus agassizi	100	0	0
Trachonurus sulcatus	100	0	0
Coryphaenoides colon	100	0	0
Nezumia cyrano	100	0	0

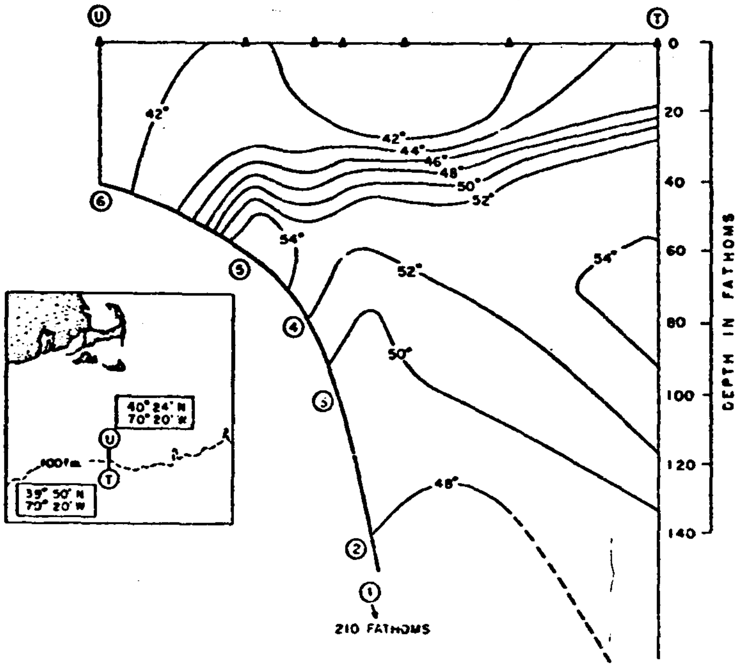
At the opposite seasonal extreme, Edwards, Livingstone and Hamer (1962) conducted a winter survey of the upper slope waters from the offing of Nantucket to Cape Hatteras down to a maximum depth of 500 m. The principal species taken on a series of transects crossing the shelf-break onto the upper slope at eight points along the shelf edge are shown in Figures 7-30 to 7-37. The hakes dominated the slope catches on every transect; other principal species included several that are abundant on the continental shelf at other times of the year. Silver hake was by far the most abundant on the slope with the offshore hake (their American hake), red hake, and white hake also plentiful. Other shelf species, such as butterfish and scup, are most abundant close to the shelf edge at the northern transects below Long Island. The witch flounder (grey sole), as juveniles, are also abundant on the slope. A number of other species not shown here and considered fishes of the deeper slope waters were also taken. The dominance of the hakes, especially those that are also found on the shelf, over the deeper water species during this time of year is noteworthy.

Down-Slope Components

There have been several studies focusing on changes in the faunal composition of benthic fishes with increased depth: Schroeder, 1955; Haedrich, et al., 1975; and Grassle, et al., 1975. Vertically, sharp changes in particular physiographic and hydrographic conditions occur, resulting in corresponding breaks in the faunal composition; these have been noted on the Oregon slope by Day and Pearcy (1968) and off of North Carolina by Rowe and Menzies (1969). A sharp faunal break at about 1000 m was evident off the Carolinas which leads to a proposed zonation by depth as follows: 1) a shelf faunal province (5-246 m), 2) an archibenthal zone of transition (445-940 m), and 3) an upper abyssal zone (940-2635 m) (Menzies, et al., 1973). The zonation of benthic fish species is probably universal all along the north and middle Atlantic slope; however, the particular depth at which faunal changes occur may differ.

Schroeder (1955) has listed the species he caught by occurrence above and below 400m Table 7-29A). Among his more important species, the black dogfish Centrosyllum fabricii was taken principally from 600 to 1100 m, and the eel Synaphobranchus pinnatus from 800-1000 m. Of the hakes, the long-finned hake was the most plentiful between 400-900 m, the blue hake between 600-1400 m, and the offshore hake between 200-500 m. The macrourids were widespread between 600 m and his deepest tows. Likewise, the witch flounder was found in the shallowest to the deepest tows.

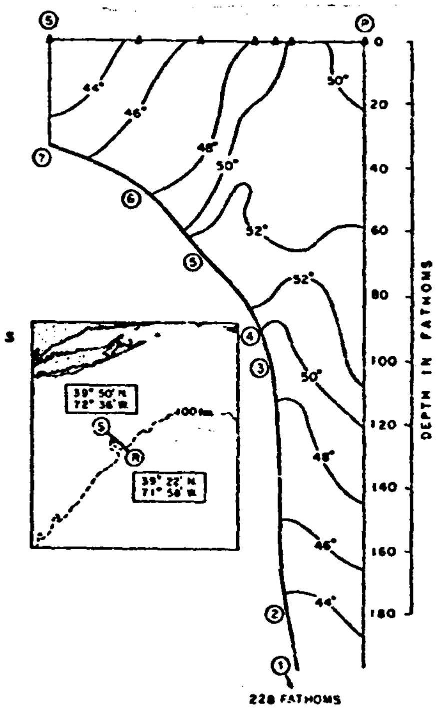
Haedrich, et al. (1975) made twenty-five August trawl collections of the epifauna (both fish and invertebrates) along the slope gradient between 200 and 1900 m (Figure 7-33). Their results provide a fresh look at the nature of the benthic fish fauna of that region. Based on several analyses they were able to detect three faunal zones within which certain



Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]					
	6 (46.5)	5 (64)	4 (82.5)	3 (99)	2 (146)	1 (210)
Spiny dogfish:						
Male	48	---	14	423	---	2
Female	11	---	353	5	---	---
Barndoor skate	---	---	---	---	2	2
Silver hake	17	---	---	---	300	280
American hake	---	---	---	---	130	72
White hake	---	---	---	---	1	26
Red hake	2	---	---	---	105	---
Long-finned hake	---	---	---	---	1	68
Fluke	---	4	---	---	---	---
Four spot	1	---	---	3	4	---
Grey sole	---	---	---	---	4	34
Butterfish	---	---	277	1,500	---	---
Black-bellied redfish	---	---	---	---	9	3
Armored sea robin	---	---	---	9	---	---
Angler	4	1	---	7	5	11

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | FIGURE 7-30 | Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)

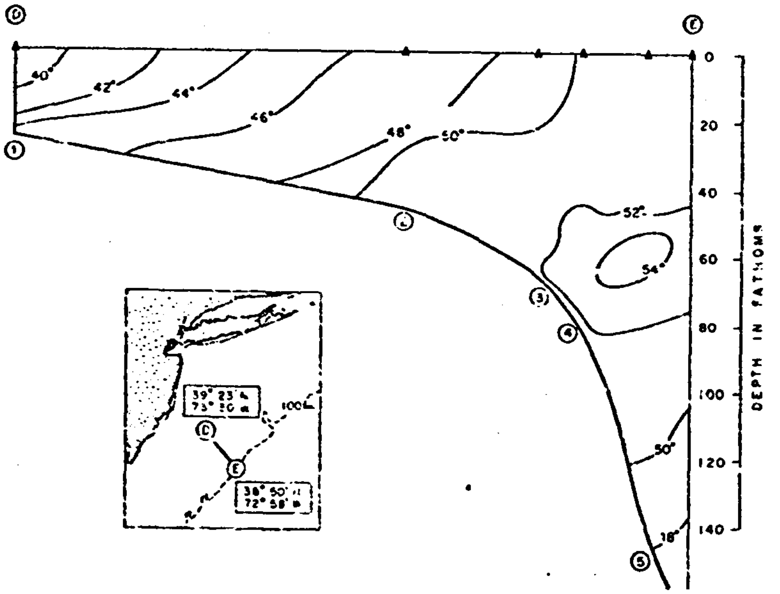


Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]						
	7 (32)	6 (46)	5 (67)	4 (92)	3 (103)	2 (178)	1 (228)
Spiny dogfish:							
Male	10	40	5	---	---	---	---
Female	---	2	5	---	---	---	---
Barndoor skate	---	16	2	---	1	---	---
Leopard skate	---	---	2	---	---	---	---
Silver hake	[1] 13	---	29	---	---	280	---
American hake	---	---	---	---	---	360	62
White hake	---	---	---	---	---	16	5
Red hake	---	176	---	---	---	36	---
Long-finned hake	---	---	---	---	---	16	8
Fluke	1	---	---	---	---	---	---
Grey sole	---	---	---	---	---	1	11
Butterfish	---	41	149	---	---	---	---
Scup	---	90	387	---	---	---	---
Black-bellied redfish	---	---	---	---	4	17	2
Armored sea robin	---	---	---	---	21	---	---
Angler	---	8	---	---	---	1	2

[1] Young-of-the-year and immature fish

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

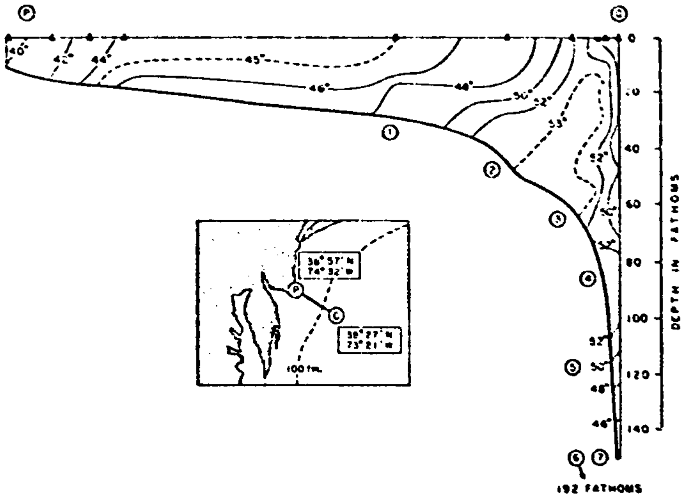
TRIGOM | **FIGURE** 7-31 | Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)



Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]				
	1 (25)	2 (45)	3 (62)	4 (80)	5 (159)
Big skate......................	---	2	2	---	---
Leopard skate..................	---	---	---	1	---
Silver hake....................	---	1	23	12	407
Red hake.......................	---	---	1	---	54
Four spot......................	---	---	2	---	---
Grey sole......................	---	---	---	---	2
Butterfish.....................	---	8	17	---	---
Mackerel.......................	1	12	2	---	---
Scup...........................	---	---	1	---	---
Black-bellied redfish..........	---	---	---	---	7
Angler.........................	---	3	1	---	8

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

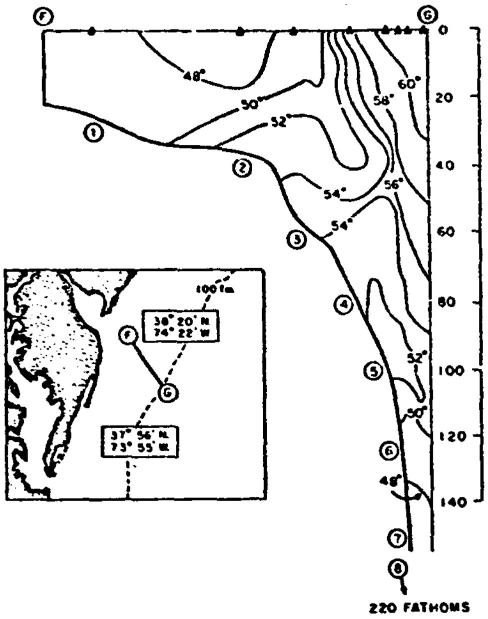
TRIGOM	FIGURE 7-32	Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)



Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]						
	1 (32)	2 (43)	3 (62)	4 (86)	5 (117)	7 (153)	6 (180)
Spiny dogfish:							
Male	53	144	251	---	---	---	---
Female	4	138	466	---	---	---	---
Brier skate	1	---	---	---	---	1	1
Leopard skate	---	---	---	6	6	---	---
Silver hake	17	---	---	80	±1,125	850	415
American hake	---	---	---	---	---	27	+125
White hake	---	---	---	---	---	15	21
Red hake	1	---	---	1	49	17	---
Spotted hake	---	1	---	6	---	---	---
Long-finned hake	---	---	---	---	---	---	4
Fluke	2	1	---	3	1	---	---
Four spot	1	1	1	1	2	---	---
Grey sole	---	---	---	---	5	3	3
Butterfish	52	1,120	---	5	1	---	---
Sea bass	---	23	5	---	---	---	---
Scup	3	121	2	1	---	---	---
Black-bellied redfish	---	---	---	---	1	30	13
Common sea robin	105	11	---	---	---	---	---
Armored sea robin	---	---	---	---	1	1	---
Angler	5	1	---	---	4	13	13

FIGURE 7-33

Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)

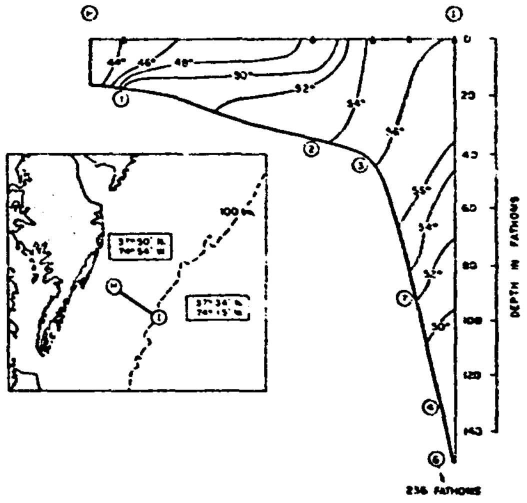


Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]							
	1 (30)	2 (42)	3 (65)	4 (80)	5 (100)	6 (125)	7 (150)	8 (220)
Spiny dogfish:								
Male............	14	53	2	1	---	---	---	---
Female..........	---	66	1	1	---	---	---	---
Barndoor skate....	---	---	---	---	---	---	1	---
Big skate.........	1	2	---	---	---	---	---	---
Brier skate.......	---	1	2	1	---	---	---	---
Leopard skate.....	---	---	---	---	3	1	---	---
Silver hake.......	[1] 10	6	1	11	113	72	72	---
American hake.....	---	---	---	---	---	---	---	127
White hake........	---	---	---	---	---	---	---	46
Red hake..........	1	---	1	4	15	5	36	---
Spotted hake......	---	---	---	2	1	---	---	---
Long-finned hake..	---	---	---	---	---	---	---	6
Fluke.............	1	4	---	---	---	---	---	---
Four spot.........	---	---	---	1	---	---	---	---
Grey sole.........	---	---	---	---	---	2	2	3
Butterfish........	3	10	53	4	---	---	---	---
Sea bass..........	---	5	15	1	3	---	---	---
Scup..............	1	30	3	1	---	---	---	---
Black-bellied redfish.........	---	---	---	---	---	2	4	7
Common sea robin..	---	4	1	---	---	---	---	---
Armored sea robin.	---	---	---	---	2	---	4	1
Angler............	6	1	1	1	1	2	9	30

[1] Young-of-the-year

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | **FIGURE 7-34** | Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)

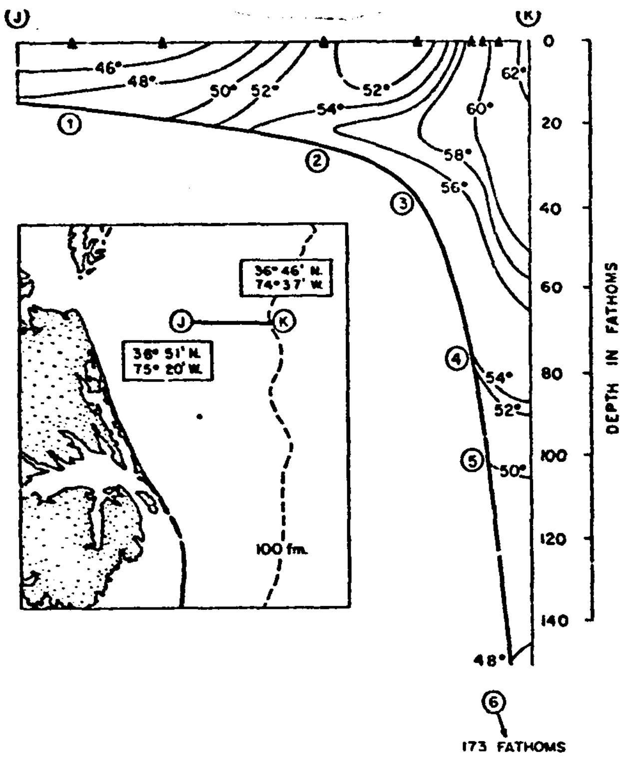


Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]					
	1 (18)	2 (37)	3 (48)	7 (92)	4 (130)	6 (238)
Spiny dogfish:						
Male................	58	4	1	17	---	---
Female..............	1	1	---	8	---	---
Big skate.............	1	---	---	---	---	---
Brier skate...........	---	---	2	2	---	---
Leopard skate.........	---	2	---	2	---	---
Silver hake...........	2	---	---	[1] 334	[1] 230	---
American hake.........	---	---	---	---	---	66
White hake............	---	---	---	---	---	49
Red hake..............	---	---	---	61	---	---
Spotted hake..........	2	---	---	6	---	---
Long-finned hake......	---	---	---	---	---	29
Fluke.................	---	2	---	4	---	---
Four spot.............	---	---	1	6	---	---
Grey sole.............	---	---	---	---	---	2
Butterfish............	6	1	---	---	---	---
Sea bass..............	---	2	6	---	---	---
Scup..................	1	399	4	---	1	---
Black-bellied redfish.	---	---	---	---	---	2
Angler................	3	---	---	2	3	17

[1] Mostly immature fish

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | **FIGURE** 7-35 | Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone and Hamer, 1962)



Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]					
	1 (17)	2 (24)	3 (42)	4 (77)	5 (107)	6 (173)
Spiny dogfish:						
Male	---	25	---	---	---	---
Female	---	56	1	---	---	---
Barndoor skate	---	---	---	---	---	1
Brier skate	---	---	1	---	---	---
Silver hake	[1] 5	---	---	6	450	540
American hake	---	---	---	---	---	24
White hake	---	---	---	---	1	4
Red hake	---	---	---	---	33	2
Spotted hake	---	---	1	1	12	2
Long-finned hake	---	---	---	---	---	16
Fluke	1	2	2	---	1	---
Grey sole	---	---	---	---	---	1
Butterfish	7	---	---	---	---	---
Sea bass	---	3	4	15	8	---
Scup	---	---	46	8	---	---
Black-bellied redfish	---	---	---	---	2	2
Common sea robin	---	6	45	6	1	---
Angler	---	---	---	---	15	45

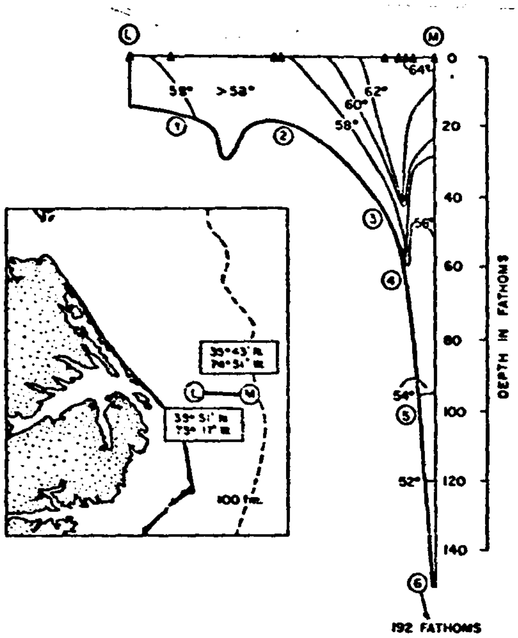
[1] Young-of-the-year

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-36

Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone, and Hamer, 1962)



Species	Number taken at station -- [Average depth of tow (in fathoms) in parentheses]					
	1 (19)	2 (26)	3 (45)	4 (64)	5 (80)	6 (192)
Brier skate..........	1	5	4	1	---	---
Leopard skate........	---	---	1	1	---	---
Silver hake..........	---	---	---	3	123	[1] 332
American hake........	---	---	---	---	---	4
Red hake.............	---	---	[2] 1	---	---	7
Spotted hake.........	---	---	---	---	7	4
Long-finned hake......	---	---	---	---	---	4
Fluke................	---	3	---	1	---	---
Four spot............	---	---	1	---	1	---
Butterfish...........	---	---	---	---	6	---
Black-bellied redfish.	---	---	---	---	---	2
Angler...............	2	---	---	---	2	1

[1] Mostly immature fish.
[2] Small red hake in scallop.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-37 Winter Distribution of Benthic Fishes, Shelf and Slope, on Transects off Cape Cod and Cape Hatteras (Edwards, Livingstone, and Hamer, 1962)

Table 7-29.

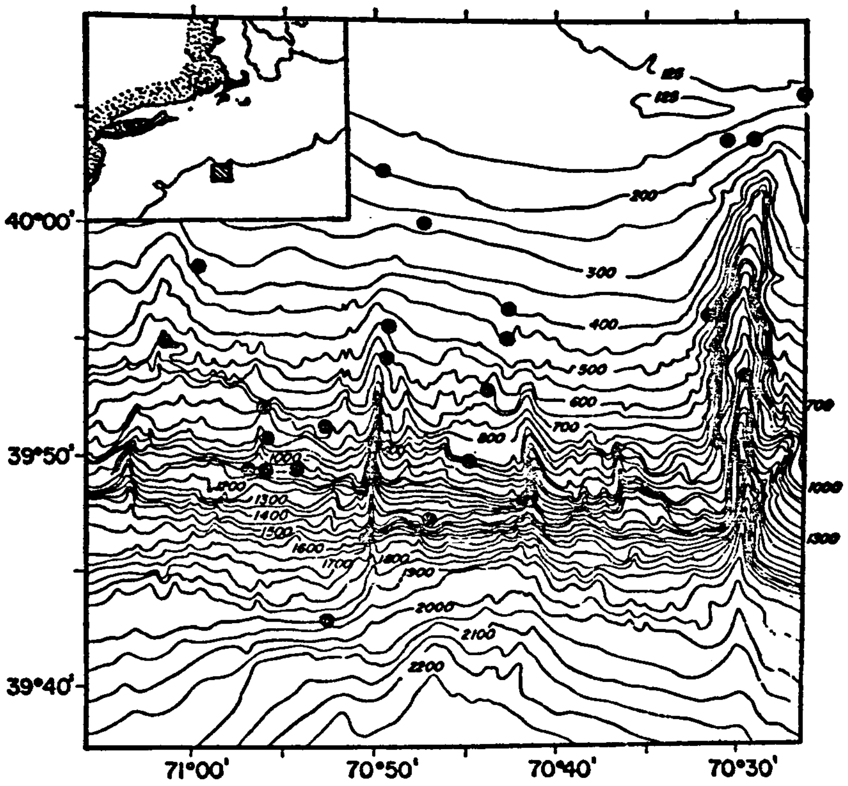
Numbers and weight of benthic fishes taken down-slope on two trawl surveys.

A. (Schroeder, 1955)

	Nova Scotia			Georges Bank			To Hudson Canyon			To Cape Charles			Average		
Fathoms	Hauls	Number	Pounds	Hauls	Number	Pounds	Hauls	Number	Pounds	Hauls	Number	Pounds	Hauls	Number	Pounds
101-200	(0)			(8)	216	107	(13)	371	207	(9)	386	185	(30)	333	168
210-300	(10)	900	1013	(9)	408	192	(9)	261	180	(5)	450	258	(33)	522	447
301-400	(16)	1053	710	(2)	321	180	(5)	273	204	(5)	180	90	(28)	705	471
401-500	(9)	929	480	(2)	200	113	(0)			(4)	338	150	(15)	674	345
501-730	(6)	283	488	(3)	135	105	(2)	230	165	(8)	158	93	(19)	327	226
Average	(41)	933	700	(24)	285	150	(29)	311	190	(31)	300	153			

B. (Haedrich, *et al.*, 1975)

	Shallow, 141-285 m		Middle, 393-1095 m		Deep, 1270-1928 m	
Hours	3.82		11.24		6.35	
	Number	Weight	Number	Weight	Number	Weight
Fish - total	381	5202.1	420	17827	66	9796.0
- per hour	99.8	1363.0	37.4	1586	10.4	1542.7



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

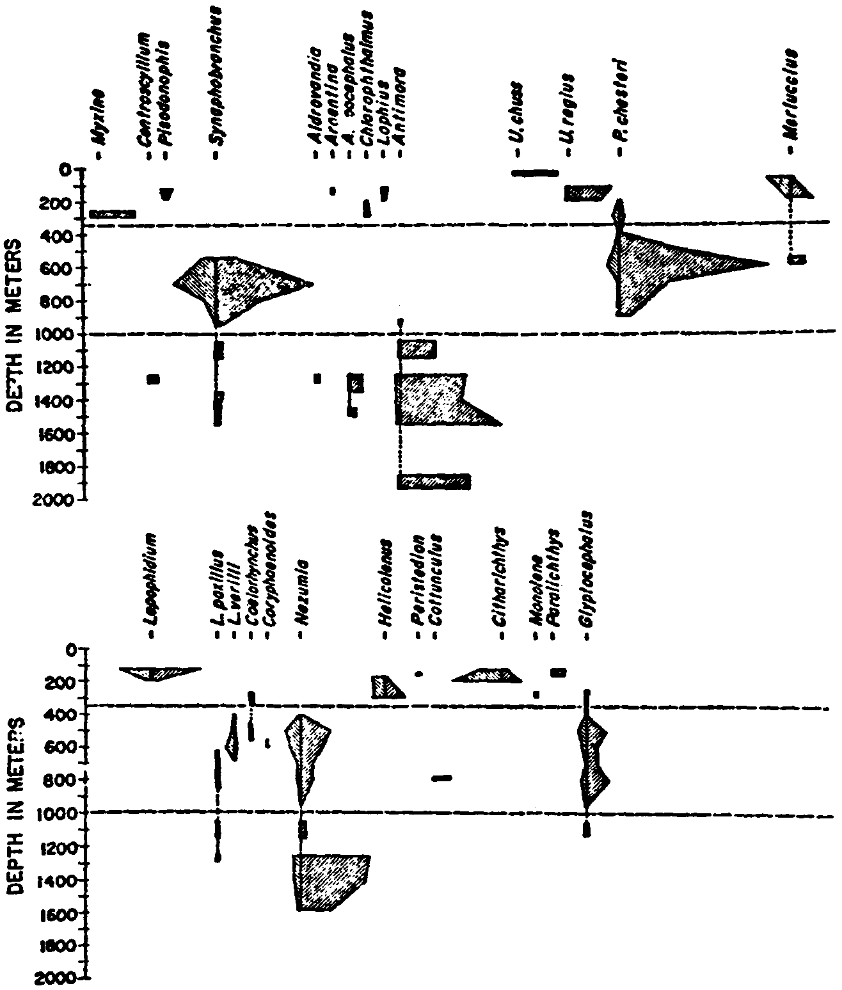
TRIGOM FIGURE 7-38 Trawl Locations (Haedrich, et al., 1975) faunal groups tended to cluster: shallow (141-285 m), middle (393-1095 m), and deep (1270-1928 m). In all zones 26 species of fish were taken (Table 7-30). This group, along with the echinoderms, represent the dominant taxa. The overall dominant fish species was Synaphobranchus kaupi with the rank order of the top several species agreeing closely to that of Markle and Musick (1974). The number of fish declined with depth, but individual weight remained fairly uniform throughout, since bigger specimens were caught at lower levels. In contrast, the number of echinoderms increased with depth. Four fish species were dominant in the shallow zone: Citharichthys arctifrons, Lepophidium cervimum, Merluccius albidus, and Helicolenus dactylopterus; five were dominant in the middle zone: Synaphobranchidae kaupi, Mezumia bairdii, Phycis chesteri, Lycenchelys sp. and Glyptocephalus cynoglossus; with no abundant species of fish found in the deeper zone. Thus, the fishes were important members of the shallow and middle zones but yielded to the echinoderms in the deeper zones. The absence of widely distributed shelf species, such as silver hake, in the shallow zone during this season is noteworthy. The fishes decreased in density and diversity with depth, while the invertebrates increased. The depth range and relative abundance of fishes on the slope, according to Haedrich, et al., is shown in Figure 7-39.

A somewhat parallel study, involving epifaunal analysis from bottom photographs, was done by Grassle, et al. (1975). The photographs were taken between June and September in the slope region off the Gay Head-Bermuda transect at depths ranging from 124-1900 m; however, their observations were confined primarily to the 1300 and the 1800 m depths. At 1800 m they found fish to be the most diverse of the megafauna but no fish species had as high a numerical dominance as the echinoderms. The most abundant fishes belonged to the Macrouridae, Synaphobranchidae, Moridae Halosauridae, and the Alepocephalidae. The blue hake, Antimora rostrata, the eel Synaphobranchus kaupi, and the macrourid Coryphaeniodes carapinus were most frequently encountered. At the 1300 m depth, fish were relatively more abundant with the Halosaurid Aldroandia affinis and the macrourids predominating.

Listed in the following tables are the composition of the fish fauna at the different times and locations of these studies. Tables 7-26 and 7-30 represent summer catches and include the fish composition at the lower slope levels; most of these species are deepwater benthic fishes that are common to the continental slope and rise. In Table 7-31 are the species of megafauna (fish and large invertebrates) caught during the National Marine Fisheries Service Groundfish Surveys conducted at the shelf edge and upper slope (to about 400 m). This list represents the species composition during the fall and spring and is comprised of a relatively large number of species, many of which are benthic invertebrates and some of which are pelagics caught in the trawl along with the benthic fishes. The total kinds of animals caught averaged 52 per strata for the shelf edge and 60 per strata for the upper slope. However, this is only

Table 7-30. Composition of slope fish fauna to a depth of 1900 meters in August off Southern New England (after Haedrich *et al.*, 1975)

	Shallow 141-285 m		Middle 393-1095 m		Deep 1270-1928 m	
	Number	Weight	Number	Weight	Number	Weight
Argentina straiata	2	13.0	-	-	-	-
Coelorinchus carminatus	3	51.0	2	99.0	-	-
Chlorophthalmus agassozo	7	59.0	-	-	-	-
Citharichthys arctifrons	144	482.0	-	-	-	-
Glyptocephalus cynoglossus	1	45.0	45	1510.0	-	-
Helicolenus dactylopterus	44	394.0	-	-	-	-
Lepophidium cervinum	68	1027.0	-	-	-	-
Lophius piscatorius	3	116.0	-	-	-	-
Merluccius albidus	55	430.1	1	486.0	-	-
Monolene sessilicauda	1	31.0	-	-	-	-
Myxine glutinosa	15	652.0	-	-	-	-
Paralichthys oblongus	2	196.0	-	-	-	-
Peristedion miniatum	1	42.0	-	-	-	-
Phycis chesteri	14	93.0	61	8517.0	-	-
Pisodonophis cruentifer	14	160.0	-	-	-	-
Urophycis regius	7	1411.0	-	-	-	-
Antimora rostrata	-	-	3	572.0	27	6245.0
Coryphaenoides rupestris	-	-	2	3.0	-	-
Cottunculus thompsoni	-	-	3	377.0	-	-
Lycenchelys paxillus	-	-	5	65.0	1	15.0
Lycenchelys verrilli	-	-	50	175.0	-	-
Nezumia bairdii	-	-	84	1975.0	30	2882.0
Synaphobranchus kaupi	-	-	164	4048.0	3	161.0
Aldrovandia affinis	-	-	-	-	1	23.0
Alepocephalus agassizi	-	-	-	-	3	355.0
Centroscyllium fabricii	-	-	-	-	1	115.0



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-39 Depth Range and Relative Abundance of Slope Fishes (Haedrich, *et al.*, 1975)

Table 7-31. Species of Epibenthic Megafauna Taken on the Shelf Edge and Slope by the Groundfish Survey of the National Marine Fisheries Service. (See Figure 7-40 for Strata Location).

Species		Strata																	
Scientific Name	Common Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Carcharhinus obscurus	dusky shark	x																	
Centroscyllium fabricii	black dogfish	x	x	x															
Shark unclassified		x	x																
Mustelus canis	smooth dogfish	x	x		x	x													
Scyliorhinus retifer	chain dogfish	x	x	x	x	x	x	x	x	x	x	x							
Squalus acanthias	spiny dogfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Squatina dumerili	angel shark	x	x	x	x														
Raja eglanteria	brier skate clear nose	x			x	x							x						x
Raja gamani	leopard skate	x	x	x	x	x	x		x	x	x	x							
Etrumeus sadina	round herring	x	x	x		x		x	x		x	x	x						
Ceratoscopelus maderiensus	horned lantern fish	x	x		x		x		x		x				x			x	x
Myctophidea unident	deep water	x	x	x			x		x		x		x				x		x
Conger oceanicus	Amer. conger eel	x	x	x		x				x		x		x					
Nemichthys scolopaceous	deep sea snipe eel	x	x	x	x		x	x	x	x	x					x		x	x
Merluccius albidus	offshore hake black	x	x	x	x		x		x	x	x	x	x		x	x	x	x	x
Merluccius bilinearis	silver hake whiting	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Urophycis chuss	red hake squirrel	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Urophycis regius	spotted hake	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Macrourus bairdii	common grenadier - marlin spike	x	x	x	x		x	x	x		x		x	x	x	x	x	x	x
Paralichthys dentatus	fluke	x		x	x	x		x		x		x		x		x	x		
Paralichthys oblongus	four spotted flounder	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Citharichthys arctifrons	Gulfstream flounder	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Macrorhamphosus scolopax	long spine snipe fish	x	x			x		x	x		x	x	x	x					
Zenopsis ocellata	John Dory	x		x	x	x	x	x	x	x	x	x			x	x			
Poronotus triacanthus	butterfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Vomer setapinnis	moon fish	x	x																
Cheilodipterus spp.		x	x		x		x	x											
Centropristes striatus	sea bass	x	x	x	x	x		x		x									

Table 7-31 (Cont.)

Species		Strata																	
Scientific Name	Common Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Stenotomus chrysops	scup	x	x	x	x	x	x	x	x	x		x		x		x			
Cynoscion ragalis	weakfish	x								x									
Sebastes marinus	redfish, rosefish	x							x				x		x	x	x	x	x
Helicolenus dactylopterus	black bellied redfish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Antigonia capros	boarfish	x						x	x							x			
Prionotus carolinus	northern sea robin	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Prionotus evolans	striped sea robin	x	x	x	x	x	x	x											
Peristedion miniatum	armored sea robin	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		
Lepophidium cervinum	cusk eel	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sphaeroides maculatus	northern puffer	x																	
Lophius americanus	American goosefish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Monacantnus hispidus	plane head file fish	x	x		x							x	x			x	x	x	x
Balistes carolinensis	trigger fish	x								x									
Ogcocephalus vespertilio	batfish	x	x	x	x		x		x		x	x	x	x	x		x		
Decapterus macarellus	mackerel scad	x	x								x	x	x						
Lantern fish unclassified		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Symphurus sp.	tongue fish	x	x		x						x		x		x	x	x		
Maurolicus muelleri	pearlsides	x							x		x	x	x						
Maurolicus pennanti	pearlsides	x	x			x	x		x		x		x		x	x	x	x	x
Chloropthalmus agassizii	green eye	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x
Benthodesmus atlanticus		x									x								
Chauliodus sloani	viper fish	x	x		x		x							x					
Stomiatoidea unident.	deep water	x	x		x	x	x		x		x	x	x	x	x	x	x	x	x
Polyipnus asteroides	hatchet fish	x	x		x		x		x		x		x		x		x		x
Polymixia nobilis	stout beard fish	x	-		~~x~~				x		x			x	x		x		
Malacocephalus occidentalis	American straptail grenadier	x	x						x		x								
Homarus americanus	lobster	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cancer unclassified	cancer crab unclassified	x	x	x	x		x	x		x	x	x		x	x				x

Table 7-31 (Cont.)

Species Scientific Name	Common Name	Strata 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cancer borealis	Jonah crab	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cancer irroratus	rock crab	x	x	x	x	x	x	x	x	x	x				x	x		x	
Sphyma lewini	scalloped hammerhead	x																	
Placopecten magelanicus	sea scallop	x		x	x	x		x	x	x	x	x				x		x	
Ophidiidae unclassified		x		x	x			x		x		x							
Illex illecebrosus	short finned squid	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Loligo pealei	long finned squid	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Petromyzon marinus	sea lamprey			x				x							x	x		x	
Clupea harengus	sea herring			x						x						x		x	x
Urophycis tenuis	white hake		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Glyptocephalus cynoglossus	witch flounder-grey sole		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Scomber scombrus	mackerel		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stomias affinis				x	x				x										
Chloropthalmus chalybeius			x	x	x		x				x		x						
Argyropelecus aculeatus	silver hatchet fish		x	x			x		x										
Polymixia lowei	beard fish		x	x	x														
Bothidae unclassified			x	x	x	x		x	x	x	x		x						
Myxine glutinosa	hagfish		x		x	x	x		x		x		x		x		x		
Raja erinacea	little common skate					x		x	x	x	x	x		x	x	x	x	x	x
Argentina silus	Argentine		x		x	x	x		x	x	x	x	x	x	x	x		x	x
Omochelys cruentifer	snake eel		x		x	x		x	x	x	x	x	x	x	x		x		
Urophycis chesteri	long finned hake		x		x	x	x		x		x		x		x	x	x	x	x
Hake unclassified			x		x	x	x	x	x	x	x					x	x	x	x
Limanda ferruginea	yellowtail flounder					x		x		x		x	x			x	x	x	x
Trachurus trachurus	saurel		x			x													
Lagocephalus laevigatus	deep sea puffer-smooth puffer					x													
Raja ocellata	big skate-winter skate							x								x		x	x
Alosa pseudoharengus	alewife		x					x	x	x	x	x	x	x	x	x		x	

Table 7-31 (Cont.)

Species		Strata																	
Scientific Name	Common Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Alosa sapidissima	shad		x	x	x			x		x	x	x	x	x		x		x	
Macrozoarces americanus	ocean pout-eel pout							x	x	x					x	x	x	x	x
Shrimp unclassified			x				x	x	x				x		x	x	x		x
Squid unclassified			x		x			x	x				x		x				x
Alosa aestivalis	blueback		x							x	x								
Eel unclassified							x		x	x		x		x					
Lolliguncula brevis	brief squid						x		x		x								
Lopholatilus chamaeleonticeps	tile fish		x				x			x		x	x	x					
Myoxocephalus octodecemspinosus	long horned sculpin									x		x			x	x	x	x	x
Hypsicometes gobioides										x									
Selar crumenopthalmus	big eye scad									x									
Ophichthyidae unclassified										x	x		x						
Scorpaenidae unclassified										x			x						
Anchoa hepsetus	striped anchovy											x							
Physiculus fulvus	hakeling											x		x					
Hippoglossoides platessoides	American dab											x		x	x	x	x	x	x
Sea robin unclassified											x	x			x				
Etropus sp.											x	x	x						
Hemitripterus americanus	sea raven													x	x	x	x	x	x
Dibranchus atlanticus	frogfish Atlantic batfish										x			x	x				
Geryon quinquedens	red crab				x		x		x		x		x	x	x	x	x	x	x
Torpedo nobiliana	torpedo		x				x				x		x			x		x	
Raja senta	smooth-tailed or prickly skate						x				x				x	x	x	x	x
Raja radiata	thorny skate														x	x	x	x	x
Melanogrammus aeglefinus	haddock															x		x	x
Scophthalmus aquosus	sand flounder windowpane															x		x	
Raja laevis	barndoor																	x	x
Osmerus mordax	smelt																	x	

Table 7-31 (Cont.)

Species: Scientific Name	Common Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Gadus morhua	- cod																	x	x
Pollachius virens	- pollock																	x	x
Brosme brosme	- cusk																x	x	x
Flounder unclassified	-		x		x													x	
Hippoglossus hippoglossus	- halibut																	x	
Artediellus uncinatus	- hook-eared sculpin																	x	x
Triglops ommatistius	- mailed sculpin																	x	x
Aspidophoroides monopterygius	- alligator fish																	x	
Neoliparis atlanticus	- sea snail																	x	
Olvaria subbifurcata	- radiated shanny																	x	
Anarhichas lupus	- wolf fish																	x	x
Diaphus dumerilli-Aethoprora metopoci	- headlight fish		x															x	
Antimora rostrata	- blue hake										x								
Cyclopterus lumpus	- lump fish																		x
Enchelyopus cimbrius	- four-bearded rockling		x						x		x		x				x		
Grenadier unclassified	-		x		x		x		x		x		x		x				x
Trichiurus lepturus	- Atlantic cutlass fish				x						x								
Gonostoma elongatum	- long tooth angle mouth				x						x		x						
Carangidae unclassified	-		x																
Herring unclassified	-				x														
Promethichthys prometheus	-				x														
Palinurichthys perciformis	- barrel fish				x														
Paralepis borealis Atlantica	-				x														
Hoplostethus mediterraneus	-				x								x						
Synodus poeyi	- offshore lizard fish				x						x								
Dogfish unclassified	-						x												
Simenchelys parasiticus	- slime eel						x		x		x								
Menidia menidia	- Atlantic silverside						x												

Table 7-31 (Cont.)

Species		Strata																	
Scientific Name	Common Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Priacanthus arenatus	- big eye						x												
Anchovy unclassified	-						x				x		x						
Chloropthalmid	-								x										
Coelorhyochus carminatus	- long-nosed grenadier								x				x				x		
Gasterosteus aculeatus	- three-spined stickleback								x										
Octophidium omostignum	- polka dot cusk eel								x						x				
Macrourus berglax	- Right-headed grenadier										x								
Monolene sessilicauda	- deepwater flounder										x		x				x		
Cryptacanthodes maculatus	- wrymouth										x								
Anarhichas lupus	- wolf fish										x								
Careproctus ranulas	-										x								
Mystriophis sp.	-										x								
Melanostigma atlanticum	- soft pout														x				
Synodus foetens	- inshore lizard fish														x				
Myctophum punctatum	- spotted lantern fish																x		x

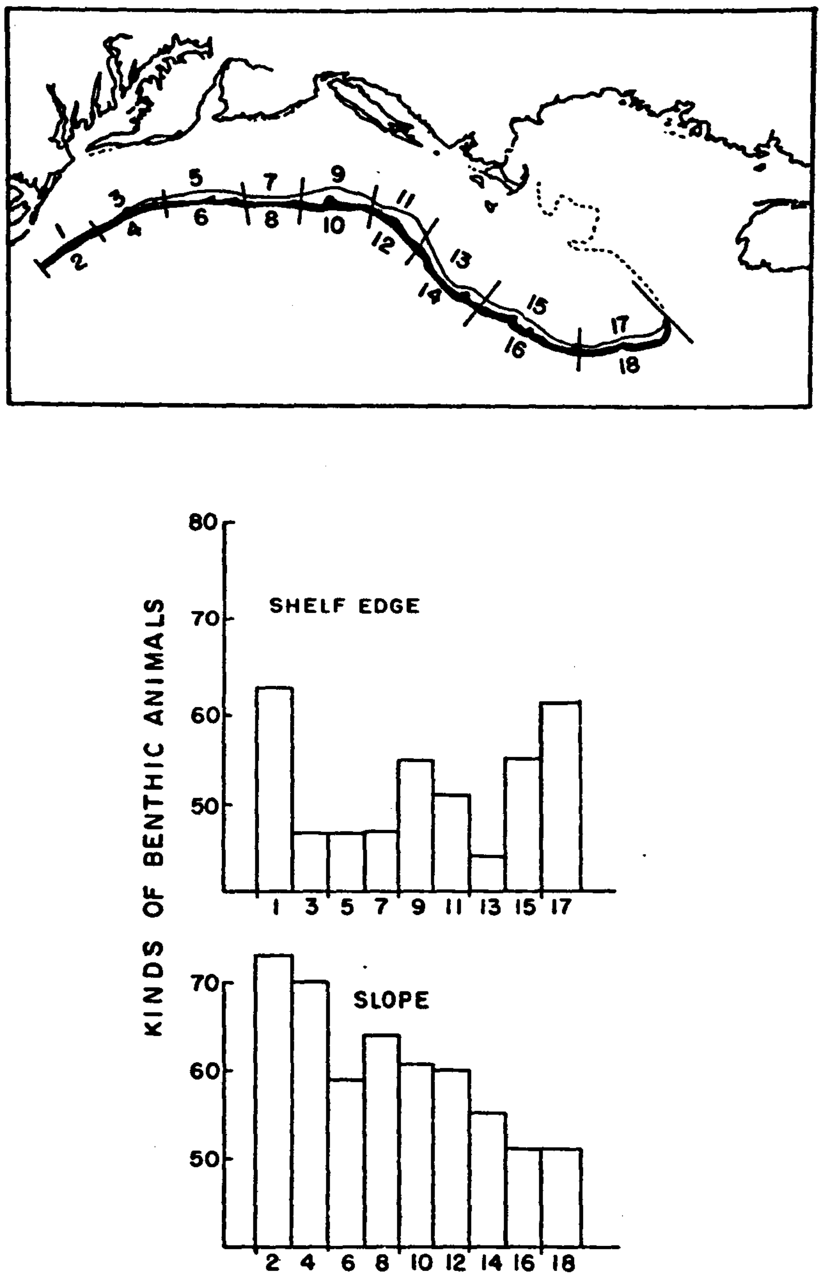
approximate since, in some cases, unidentified species were lumped into groups. Relatively high counts of species occurred at the southern extreme of the study area (Cape Hatteras), gradually decreasing in the slope strata toward the northern extreme (Georges Bank) (Figure 7-40). The result of overlapping distribution of the shelf species onto the upper slope can be seen from the list, which includes many forms that cannot be considered fishes exclusively of the continental slope.

BIOMASS AND ABUNDANCE

Variations in the numerical abundance and biomass of benthic fishes occur down-slope from the edge of the shelf to the beginning of the continental rise; along-slope from Georges Bank to Cape Hatteras; and in the upper slope according to the season of the year. The surveys of Schroeder (1955); Haedrich, *et al.* (1975); and Grassle, *et al.* (1975), are particularly suited for examining down-slope variation. The groundfish surveys of the National Marine Fisheries Service provide the most complete information along the upper slope.

According to Schroeder, numbers and weights of fish caught increased between 400 and 1000 m, then decreased to low values at the deeper slope levels. He found (Table 7-29A) his most abundant hauls to be between 400 and 800 m with the species contributing the most to be redfish, *Sebastes marinus* (in Nova Scotia slope only); the macrourid *Corypheanoides*, the offshore hake, *Merluccius albidus*, and the long-finned hake, *Phycis chesteri*. The upper 200-400 m produced the smallest yield in weight of fish per haul, while catches in the region from 800-1400 m declined from the peak with the macrourides, long-finned hake and witch flounder contributing most to the catch. Haedrich, *et al.*, on the other hand, show a maximum catch at their depth zone of 141-285 m (Table 7-29A) and then a declining catch in numbers with depth, although the weight of the catch remained constant. Grassle, *et al.* indicated that benthic fishes became relatively more important in terms of numbers (density) than the invertebrate members of the epibenthic macrofauna at about 1000 m, but were by far numerically inferior at other depths. They noted that the epibenthic macrofauna in general (Figure 7-41) were numerically inferior to the infauna by 10^3 to 10^4, but that their biomasses are of the same order of magnitude. In any event, the slope levels below 1000 m seem to be regions of reduced abundance, biomass, and diversity for the benthic fishes, 1000 m being the point at which a significant change occurs.

The biomass and abundance of the more representative species of benthic fishes, as well as a few species of pelagic and benthic invertebrates, were recorded from fall and spring tows made along the shelf edge and upper slope between Georges Bank and Cape Hatteras and represented average values for the years 1969-1974. The data are presented as (1) mean weight and numbers per tow for all species combined (Table 7-32 and Figure 7-50); (2) mean weight and numbers per tow for selected species (Table 7-33, Figures 7-42 to 7-50);

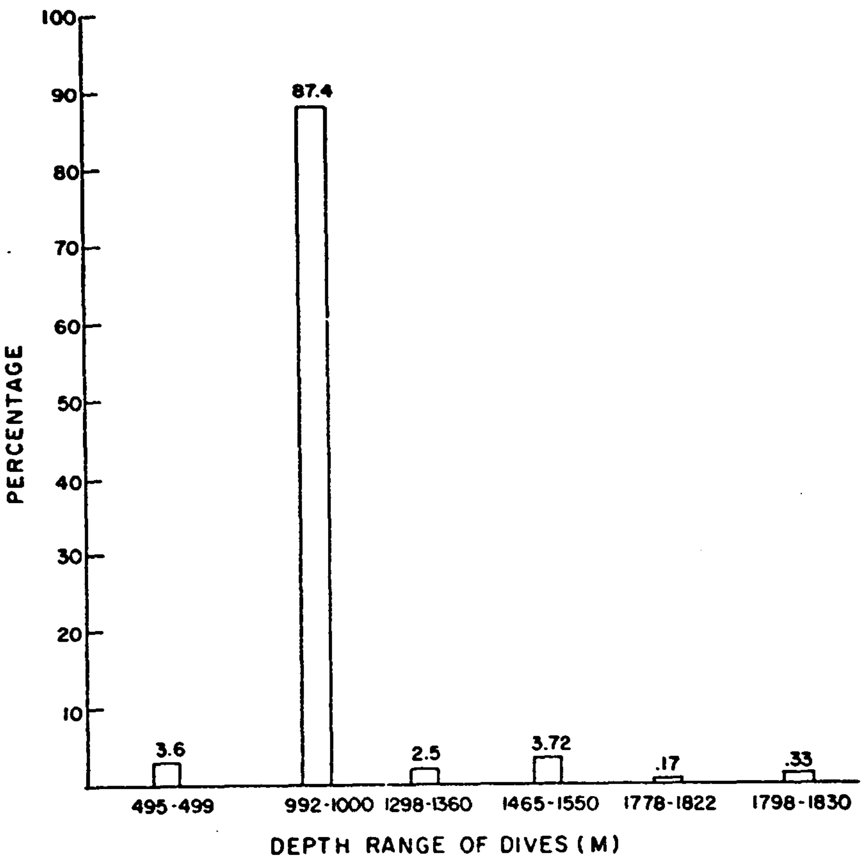


ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-40

Kinds of Benthic Animals Caught at Slope and Shelf Edge Depth Strata on NMFS Groundfish Surveys, 1969-1974

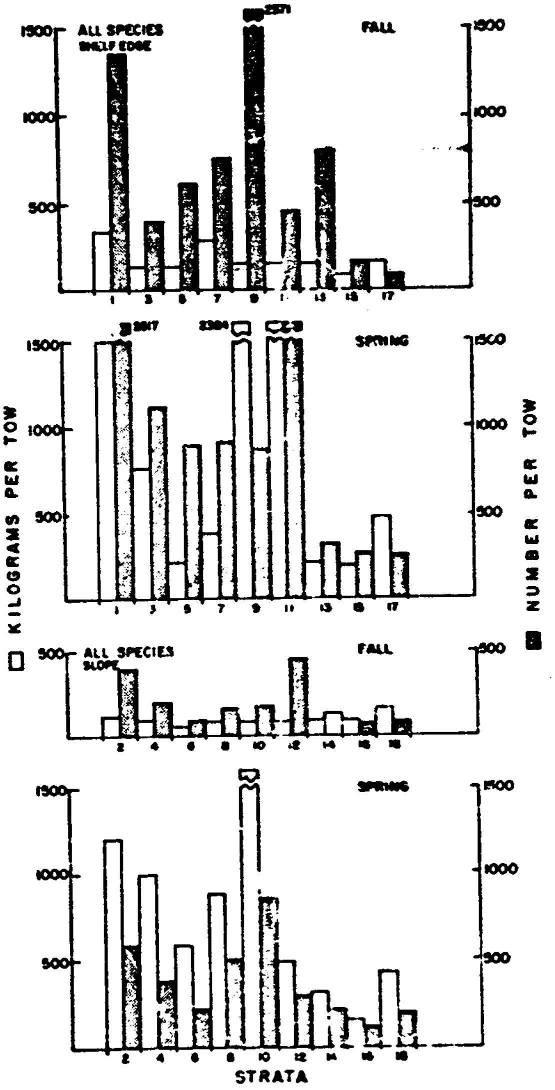


TRIGOM	FIGURE 7-41	Relative Density of Fish to Other Epibenthic Megafauna at Various Depths on the Slope (Grassle, et al., 1975)

Table 7-32. Average number and weight of all epibenthic macrofauna taken at the shelf edge and upper slope during fall and spring trawl surveys, 1969-1974.

ALL SPECIES

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	346	1,356.25	1,536	2,517.00	2	120	419.17	1,172	597.54
3	140	487.08	757	1,128.10	4	100	202.33	993	387.73
5	140	591.08	209	941.00	6	64	98.00	581	215.54
7	299	756.77	399	958.25	8	91	165.75	882	507.67
9	156	2,371.11	2,324	860.00	10	87	152.61	1,794	847.89
11	128	467.89	1,835	1,631.45	12	92	461.61	474	295.28
13	151	808.11	214	323.09	14	89	135.70	302	216.26
15	82	156.50	196	258.78	16	99	81.85	167	138.00
17	162	84.46	473	299.85	18	167	86.00	438	199.53



Data includes fall and spring surveys at the slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	**FIGURE** 7-42	Mean Weight and Numbers Per Tow For All Species From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-1974)

Table 7-33. Average number and weight of selected species of epibenthic macrofauna taken at the shelf edge and upper slope during fall and spring trawl surveys, 1969-1974.

SILVER HAKE-*Merluccius bilinearis*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	3	7.67	14	21.27	2	1	6.58	85	132.00
3	2	6.54	34	48.00	4	3	7.33	34	48.27
5	1	10.08	6	7.77	6	1	3.50	51	74.00
7	1	17.15	21	21.08	8	<1	1.50	85	108.42
9	1	20.83	30	40.28	10	1	5.61	86	71.84
11	2	6.95	29	27.25	12	<1	2.39	85	77.50
13	2	8.44	16	12.75	14	8	19.41	73	73.31
15	11	28.04	36	35.52	16	8	10.75	52	50.83
17	6	9.08	40	59.04	18	17	15.94	44	46.82

Table 7-33 (Cont.) RED HAKE-*Urophycis chuss*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	.083	<1	.82	2	<1	1.58	9	12.09
3	2	2.61	5	6.29	4	-	.083	16	20.18
5	<1	.33	2	2.31	6	<1	.58	14	12.64
7	-	.077	4	4.92	8	<1	.58	66	122.67
9	-	.055	12	9.00	10	<1	1.11	55	51.42
11	<1	.37	18	12.00	12	<1	.83	80	68.44
13	2	1.72	5	3.35	14	1	1.06	23	18.74
15	7	5.21	22	19.78	16	4	1.95	17	12.11
17	7	5.12	9	6.35	18	2	1.05	10	9.76

Table 7-33. (Cont.) SPINY DOGFISH-*Squalus acanthias*

SHELF BREAK STRATA	Fall		Spring		SLOPE STRATA	Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	None	680	88.18	2	-	None	830	115.18
3	-	None	142	23.09	4	-	None	724	77.82
5	-	None	61	10.77	6	-	None	386	33.64
7	-	None	84	102.00	8	-	None	593	133.67
9	<1	.39	2,009	313.64	10	<1	.11	1,410	300.31
11	-	None	16	6.85	12	-	None	113	19.22
13	<1	.055	54	21.35	14	-	.059	17	8.95
15	3	4.79	9	43.56	16	-	.050	21	10.78
17	<1	2.37	97	11.56	18	-	.11	115	10.88

Table 7-33 (Cont.) OFFSHORE HAKE-*Merluccius albidus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	None	-	18	2	2	1.75	17	19.91
3	-	.077	<1	.099	4	1	2.92	7	8.45
5	-	None	-	None	6	<1	1.42	1	1.00
7	-	None	-	None	8	2	2.25	3	2.33
9	<1	.17	-	None	10	6	8.94	8	3.89
11	<1	.16	-	.099	12	3	3.33	18	6.33
13	-	None	-	None	14	4	3.41	10	5.42
15	<1	.37	<1	.043	16	4	2.40	4	1.83
17	-	None	<1	.13	18	<1	.28	2	1.23

Table 7-33 (Cont.) LONG FINNED SQUID-*Loligo pealei*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	28	72.17	125	688.18	2	12	42.75	20	57.00
3	60	214.08	<1	270.89	4	30	88.58	37	86.36
5	24	61.92	100	842.54	6	1	5.75	18	39.00
7	53	127.85	137	572.92	8	19	66.83	19	58.83
9	56	481.50	63	244.61	10	6	62.72	23	41.37
11	61	304.00	61	120.25	12	35	354.67	9	14.94
13	103	646.22	49	180.50	14	10	32.59	22	47.21
15	10	48.12	49	81.35	16	5	12.55	11	19.11
17	<1	2.79	7	13.74	18	-	.11	6	11.82

Table 7-33 (Cont.) SHORT-FINNED SQUID-*Illex illecebrosus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	26	38.92	10	56.27	2	14	16.92	8	32.54
3	3	4.31	1	5.79	4	14	19.42	4	12.36
5	<1	2.00	<1	1.77	6	12	11.17	2	4.54
7	3	5.69	1	7.92	8	13	18.00	<1	1.17
9	2	4.22	<1	1.25	10	10	11.78	5	15.95
11	6	20.79	<1	.40	12	7	9.28	<1	1.39
13	5	11.89	-	.15	14	6	7.35	<1	1.00
15	2	3.87	<1	1.35	16	5	3.70	<1	.78
17	1	.87	<1	.26	18	1	1.44	-	.70

Table 7-33 (Cont.) MACKEREL-*Scomber scombrus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	None	-	None	2	-	None	2	1.18
3	-	None	2	1.70	4	-	None	<1	.91
5	-	None	8	8.15	6	-	None	22	13.91
7	-	None	15	11.92	8	-	None	<1	.42
9	-	None	32	19.07	10	<1	.33	26	16.21
11	1	1.42	1,298	810.45	12	-	None	10	6.00
13	<1	.22	5	3.85	14	-	.059	6	4.05
15	4	2.12	24	13.96	16	<1	.15	-	.33
17	-	None	42	21.69	18	-	.055	1	.53

Table 7-33 (Cont.) BUTTERFISH-*Poronotus triacanthus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	198	905.25	37	171.82	2	17	102.42	33	145.00
3	19	93.69	107	189.80	4	-	None	8	16.55
5	92	471.42	7	22.15	6	2	16.33	<1	1.00
7	216	538.00	17	54.17	8	<1	2.17	9	24.83
9	59	230.50	37	111.36	10	<1	2.00	92	287.37
11	<1	3.37	269	537.75	12	<1	1.11	13	33.00
13	15	111.72	24	49.89	14	<1	2.12	<1	1.68
15	4	9.33	16	31.87	16	-	.099	<1	1.05
17	<1	.29	-	None	18	-	None	5	6.65

Table 7-33 (Cont.) WHITE HAKE-*Urophycis tenuis*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	None	-	None	2	-	None	6	1.54
3	<1	.077	<1	.099	4	-	None	34	3.82
5	-	None	-	.077	6	-	None	5	1.27
7	-	None	-	None	8	-	None	10	1.25
9	-	None	1	.36	10	1	.28	15	2.21
11	-	None	<1	.45	12	2	.61	28	4.28
13	1	.17	4	1.20	14	2	.35	16	2.26
15	7	.92	4	1.09	16	14	3.15	13	1.83
17	4	.46	2	.43	18	9	1.50	14	2.53

Table 7-33 (Cont.) AMERICAN GOOSEFISH-*Lophius americanus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	1	1.25	15	.05	2	<1	0.83	93	3.36
3	4	3.23	7	1.09	4	11	6.66	45	3.64
5	1	.83	1	.23	6	11	4.58	25	1.09
7	1	7.69	13	.75	8	14	1.92	61	2.83
9	1	.11	15	.57	10	18	1.28	34	1.16
11	6	.79	29	1.09	12	12	1.00	56	2.17
13	3	.44	23	.70	14	23	1.47	55	2.21
15	11	.79	7	.39	16	24	.96	8	.55
17	<1	.13	1	.087	18	9	.55	18	.86

Table 7-33 (Cont.)

SEAROBINS

NORTHERN SEA ROBIN-*Prionotus carolinus*
STRIPED SEA ROBIN-*Prionotus evolans*
ARMORED SEA ROBIN-*Peristedion miniatum*
SEA ROBIN- *Unclassified*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	<1	1.08	358	1,188.45	2	<1	1.58	1	2.64
3	-	.31	52	82.09	4	<1	.58	2	4.45
5	-	.083	2	2.15	6	<1	.83	<1	.82
7	-	None	92	141.75	8	-	None	<1	2.42
9	<1	.78	12	22.82	10	<1	2.00	<1	3.16
11	<1	.37	88	83.59	12	-	.28	1	2.33
13	<1	.33	<1	.099	14	-	.059	<1	.21
15	-	None	<1	.17	16	-	.099	-	None
17	-	None	-	None	18	-	None	-	None

Table 7-33 (Cont.) DEEPWATER FISHES

BATFISH-*Ogcocephalus vespertilio*
PEARLSIDES-*Maurolicus muelleri*, *Maurolicus pemartti*
GREENEYE-*Chloropthalmus aggasizii*
SILVER HATCHET FISH-*Argyropelecus aculeatus*
HATCHET FISH-*Polyipnus isteroides*
LANTERN FISH-*Stamiatoidea* unident. unclassified

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	<1	58.83	<1	8.54	2	<1	102.58	1	15.64
3	-	4.61	-	2.20	4	-	13.75	<1	27.18
5	-	1.08	-	.38	6	<1	16.67	-	4.73
7	-	5.46		6.58	8	-	22.75	-	7.33
9	10	1,579.28	-	.28	10	-	6.39	-	2.95
11	-	.21	-	4.45	12	<1	19.33	<1	9.28
13	-	1.72	-	.35	14	<1	20.41	-	3.84
15	<1	27.71	-	.65	16	-	13.80	-	6.22
17	-	1.33	-	.17	18	-	3.67	-	3.35

Table 7-33 (Cont.) RED CRAB-*Geryon quinquedens*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	-	-	-	2	-	-	-	-
3	-	-	-	-	4	-	-	<1	.091
5	-	-	-	-	6	-	.083	-	-
7	-	-	-	-	8	1.28	.67	2.20	1.00
9	-	-	-	-	10	6.24	2.17	-	-
11	-	-	-	-	12	7.10	3.72	5.14	1.72
13	-	.055	-	.050	14	3.64	1.82	35.85	.58
15	-	.042	-	-	16	2.31	1.05	-	.055
17	-	.042	-	-	18	<1	.28	-	-

Table 7-33 (Cont.) LOBSTER-*Homarus americanus*

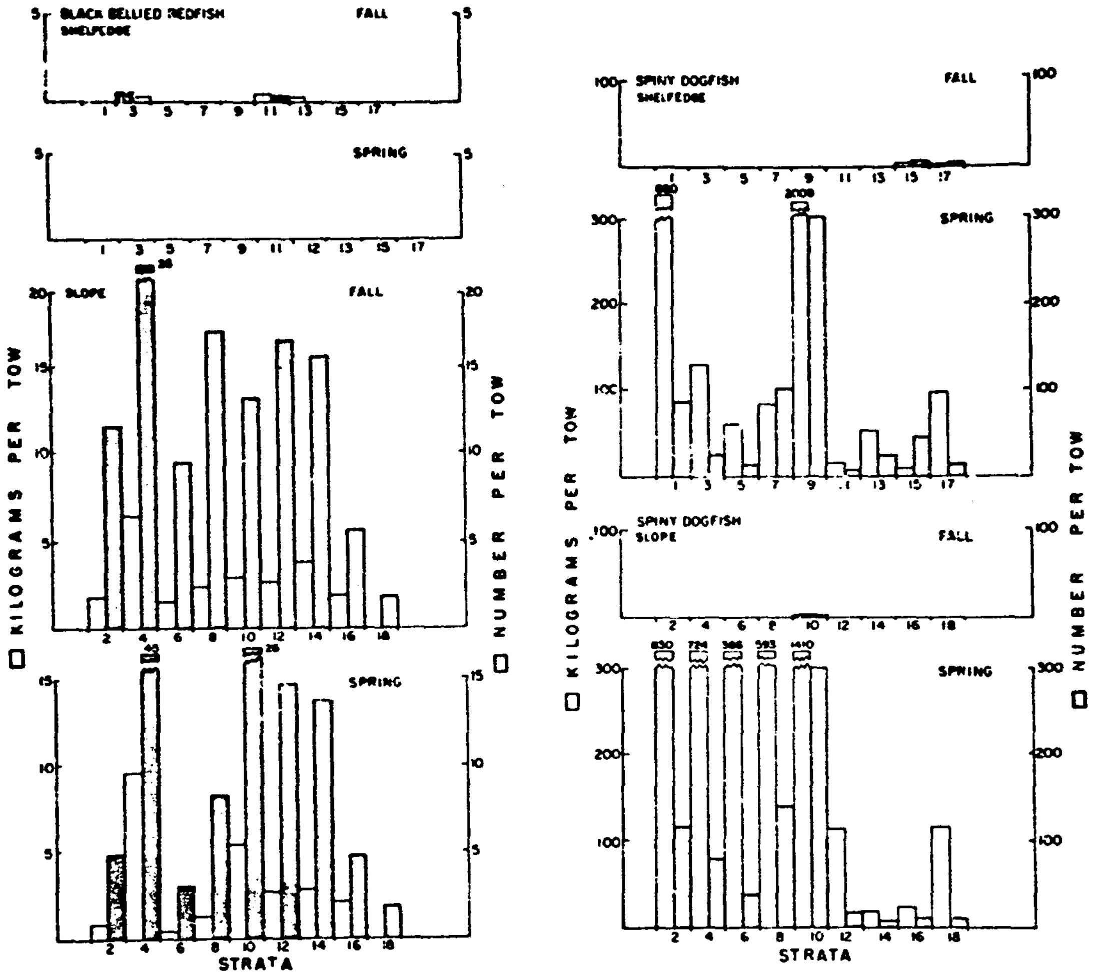
SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	11.57	1.25	7.80	.82	2	20.94	3.50	8.82	2.09
3	12.37	3.92	6.61	1.29	4	25.90	3.58	52.51	10.09
5	8.09	2.17	1.34	.23	6	28.66	3.53	38.47	7.45
7	9.32	1.85	3.13	.58	8	33.07	5.50	25.73	4.75
9	9.30	3.11	4.17	.78	10	28.53	12.78	24.93	8.10
11	10.32	5.58	2.20	.90	12	11.64	7.67	29.28	14.28
13	10.40	2.17	3.64	1.15	14	18.67	7.88	29.58	11.24
15	13.69	1.67	2.98	.74	16	8.27	1.25	18.25	2.83
17	3.57	<1	6.04	.65	18	11.26	1.05	37.70	3.76

Table 7-33 (Cont) WITCH FLOUNDER-*Glyptocephalus cynoglossus*

SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	None	-	None	2	-	.083	<1	.18
3	-	None	-	.20	4	-	.17	4.00	3.54
5	-	.083	<1	.31	6	-	.92	5.00	5.09
7	-	None	-	.17	8	<1	.42	2.00	5.33
9	-	.055	<1	.11	10	-	.28	1.00	1.79
11	-	None	<1	.050	12	-	.33	3.00	4.00
13	<1	.11	-	None	14	<1	.47	1.00	2.47
15	<1	.12	<1	.13	16	<1	.65	2.00	2.05
17	<1	.17	<1	.30	18	<1	.67	5.00	3.23

Table 7-33 (Cont.) BLACK BELLIED REDFISH-*Helicolenus dactylopterus*

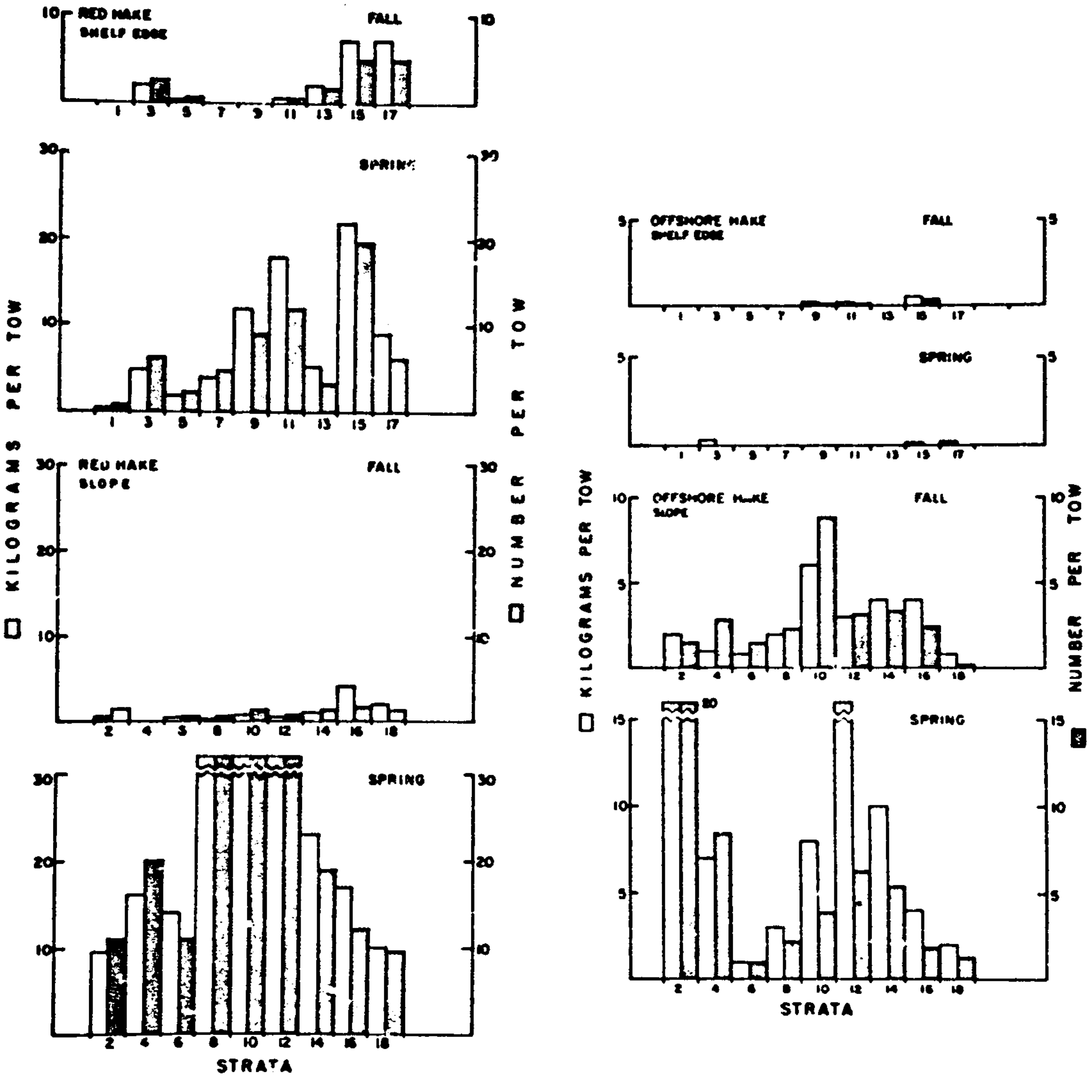
SHELF BREAK STRATA					SLOPE STRATA				
	Fall		Spring			Fall		Spring	
Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.	Strata	Ave.Wt. (Kgs)	Ave.Nos.	Ave.Wt. (Kgs)	Ave.Nos.
1	-	2.50	-	.45	2	1.83	11.50	<1	4.73
3	<1	3.46	-	.80	4	6.44	26.50	9.61	44.73
5	-	2.25	-	2.38	6	1.48	9.50	<1	3.00
7	-	7.69	-	2.17	8	2.30	17.17	1.28	8.25
9	-	1.39	<1	.64	10	2.93	13.33	5.22	26.00
11	<1	.79	-	.050	12	2.58	16.61	2.69	14.17
13	<1	.89	-	.35	14	3.75	15.65	2.78	13.26
15	<1	2.17	-	.043	16	1.76	5.59	2.07	4.72
17		.87	-	.35	18		1.28		1.94



Data includes fall and spring surveys at slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

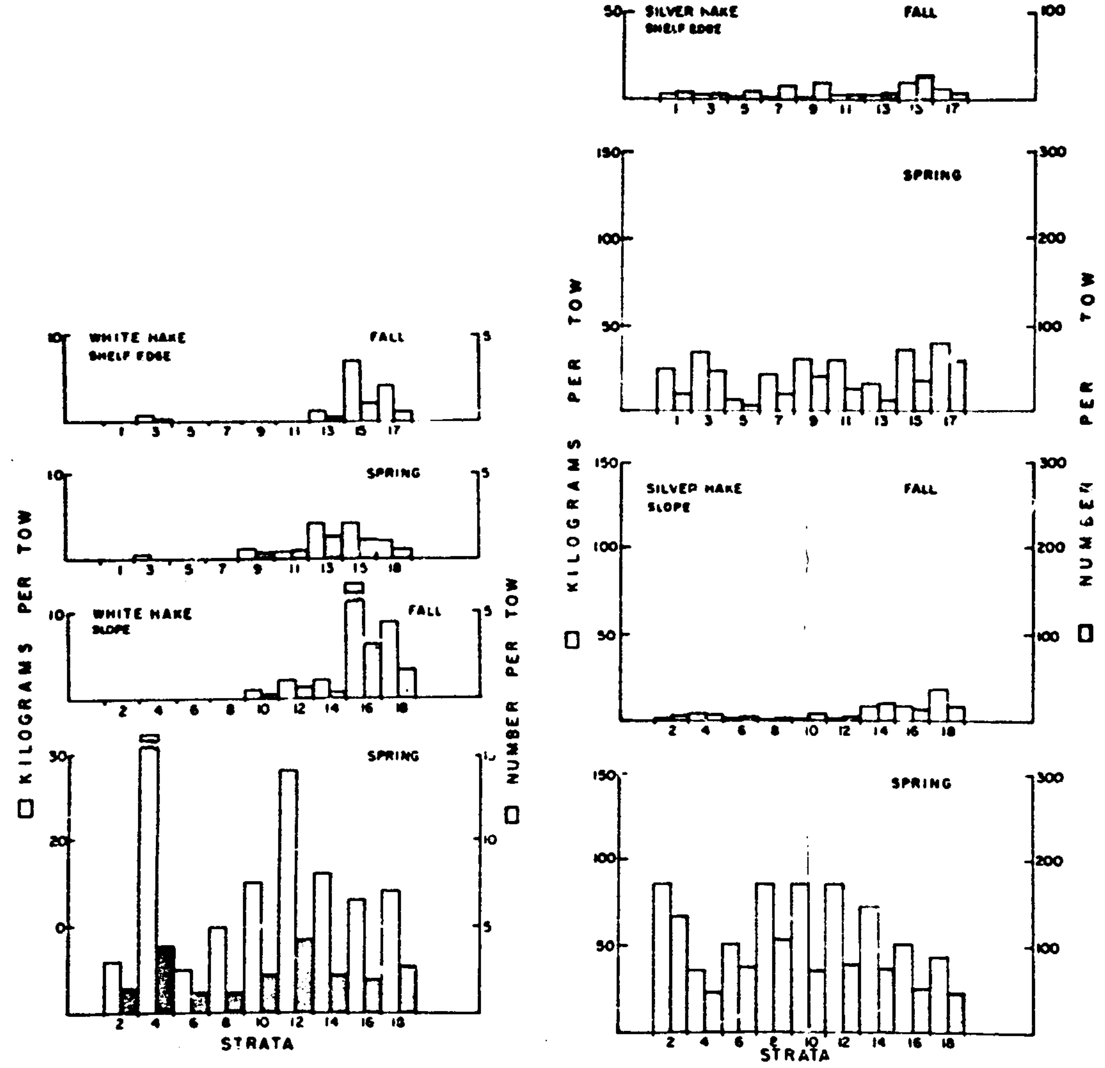
TRIGOM	FIGURE 7-43	Mean Weight and Numbers Per Tow For Black Bellied Redfish and Spiny Dogfish From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-74)



Data includes fall and spring surveys at the slope and shelf edge depth strata

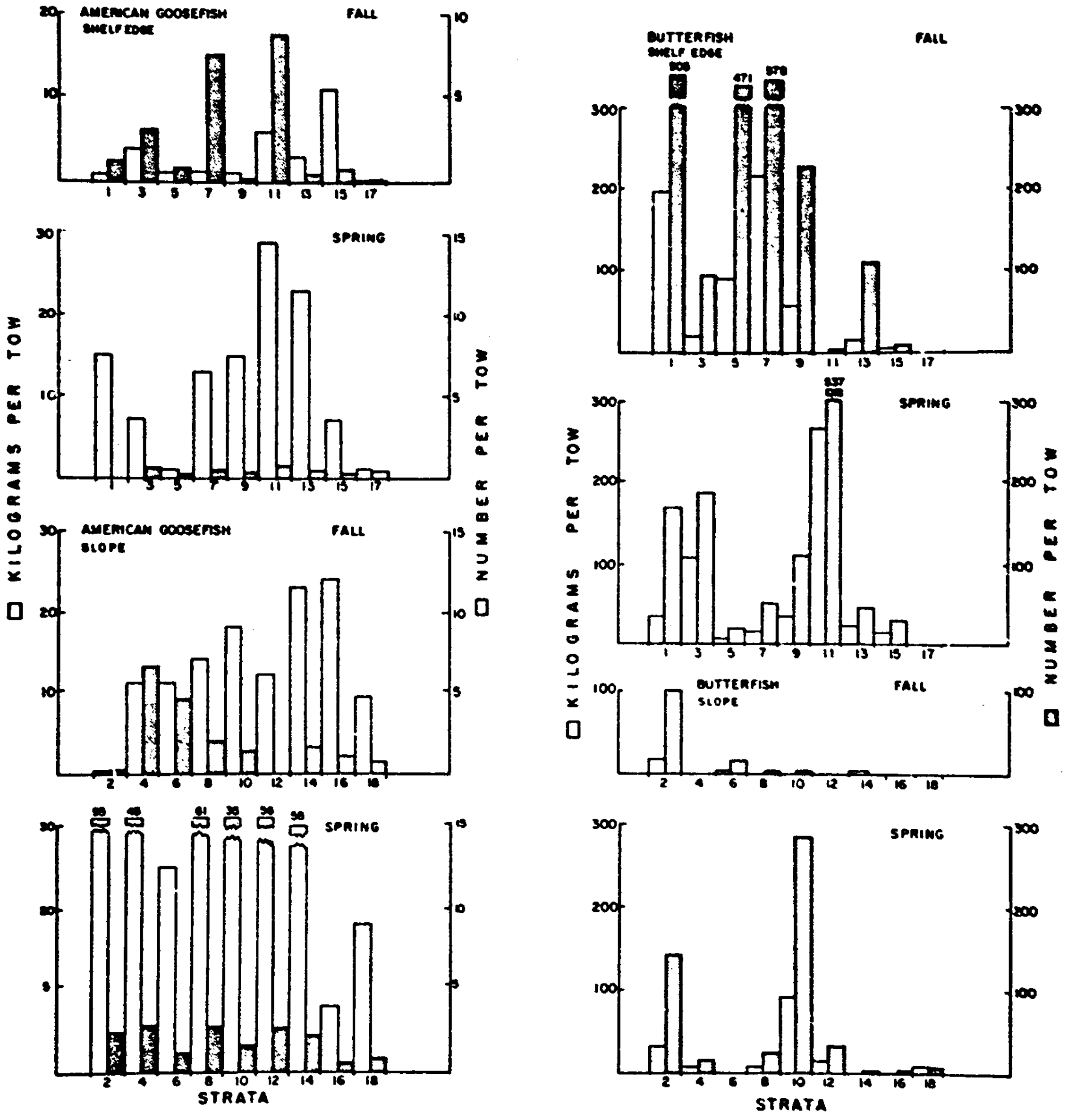
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-44	Mean Weight and Numbers Per Tow For Red Hake and Offshore Hake From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-1974)



Data includes fall and spring surveys at the slope and shelf edge depth strata.

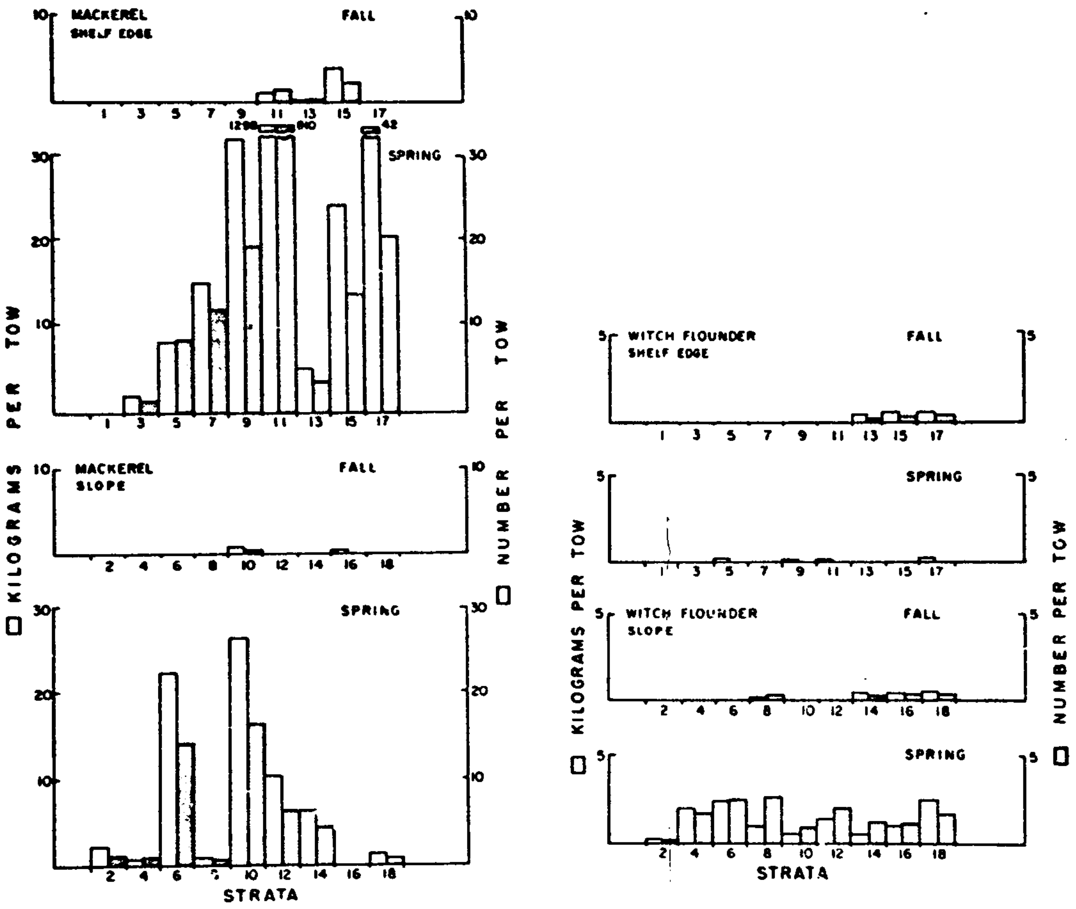
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE		
TRIGOM	FIGURE 7-45	Mean Weight and Numbers Per Tow For White Hake and Silver Hake From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-1974)



Data includes fall and spring surveys at the slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

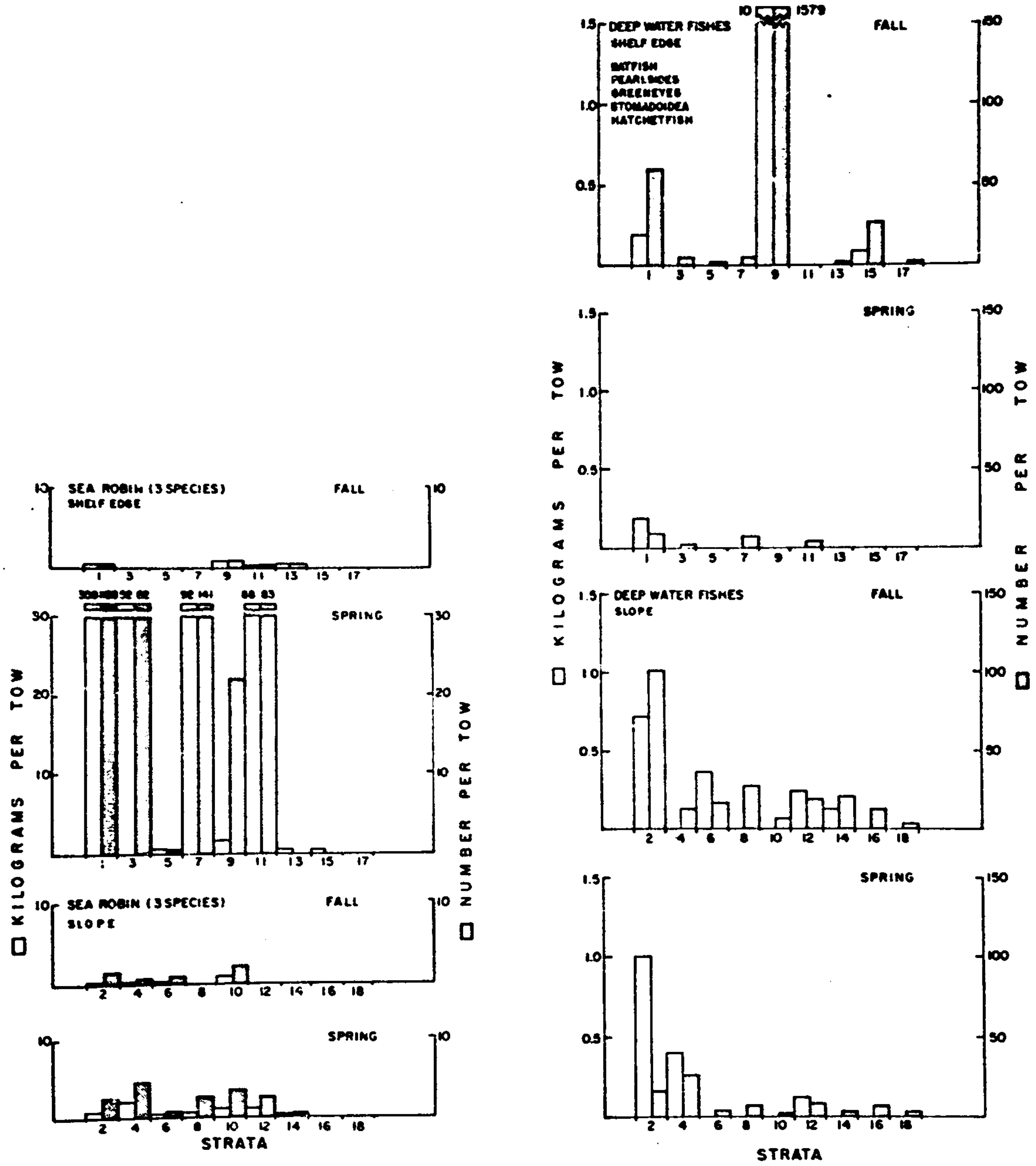
TRIGOM	FIGURE 7-46	Mean Weight and Numbers Per Tow For American Goosefish and Butterfish From Georges Bank ~~to~~ Cape Hatteras (NMFS Groundfish Surveys, 1969-74)



Data includes fall and spring surveys at the slope and shelf edge depth strata.

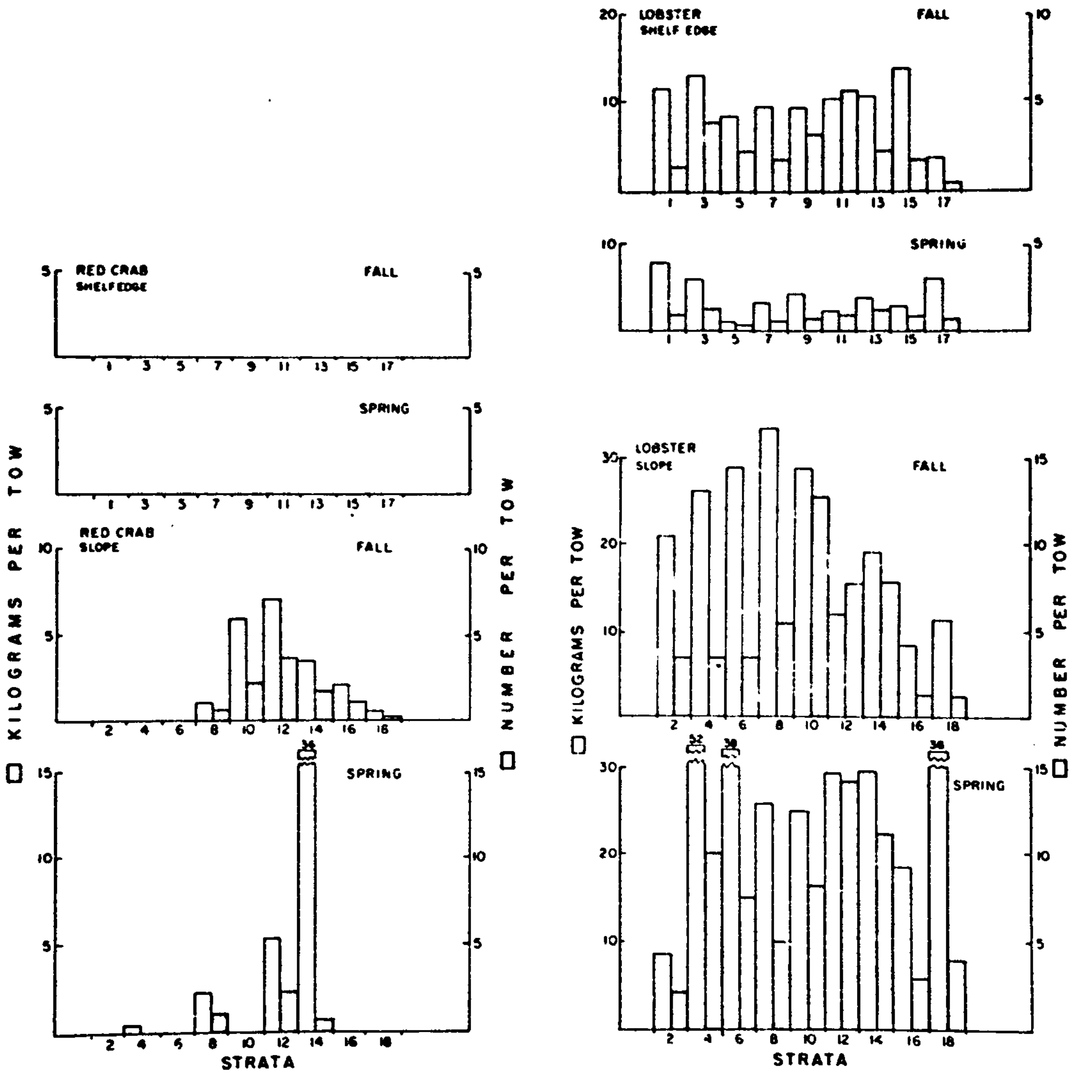
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | FIGURE 7-47 | Mean Weight and Numbers Per Tow for Mackerel and Witch Flounder From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-1974)



Data includes fall and spring surveys at the slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE		
TRIGOM	FIGURE 7-48	Mean Weight and Numbers Per Tow For Sea Robin (Three Species) and Deep Water Fishes From Georges Bank to Cape Hatteras (NMFS, 1969-1974)



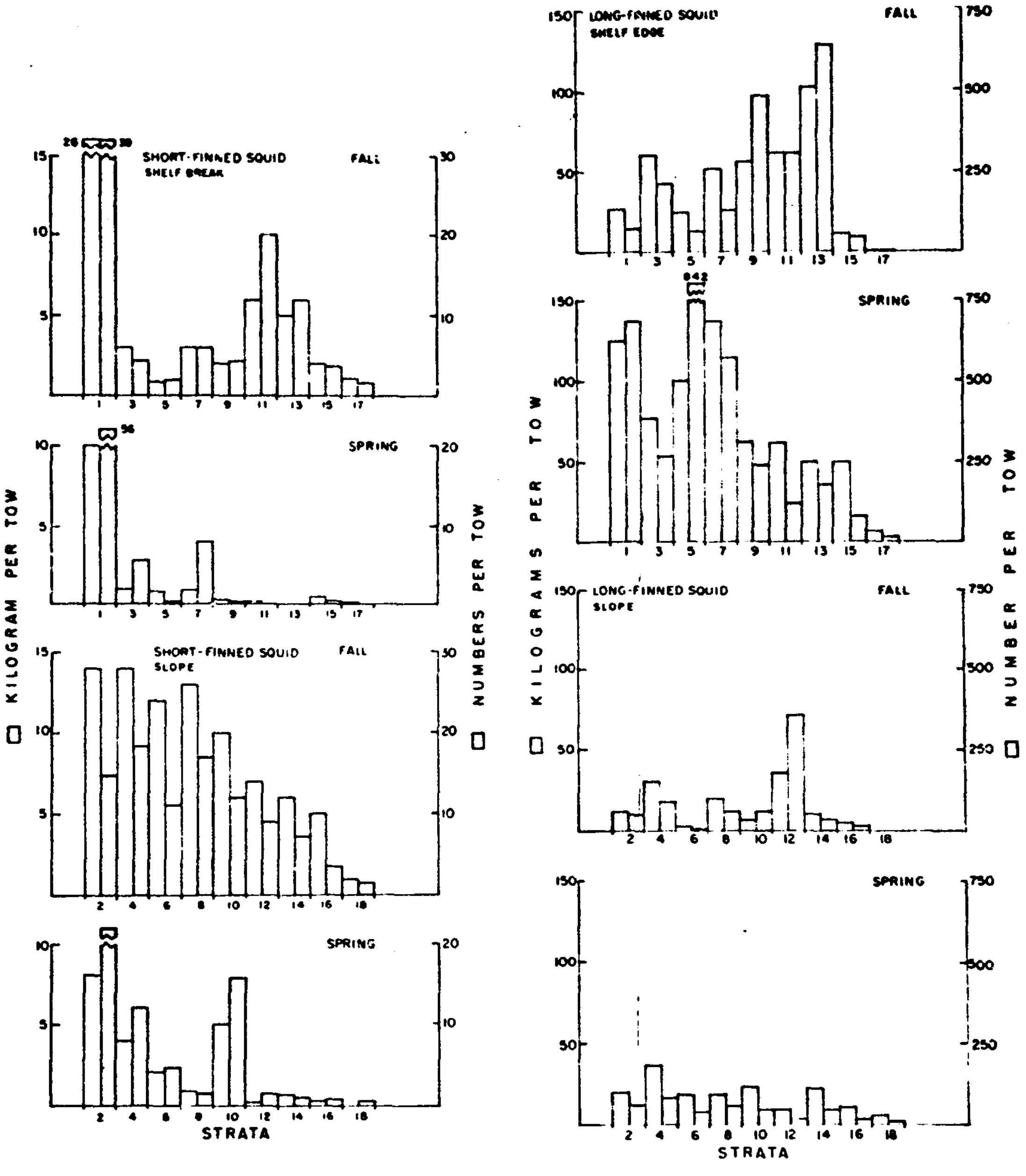
Data includes fall and spring surveys at the slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-49

Mean Weight and Numbers Per Tow For Red Crab and Lobster From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-1974)



Data includes fall and spring surveys at the slope and shelf edge depth strata.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-50	Mean Weight and Numbers Per Tow For Short-Finned Squid and Long-Finned Squid From Georges Bank to Cape Hatteras (NMFS Groundfish Surveys, 1969-74)

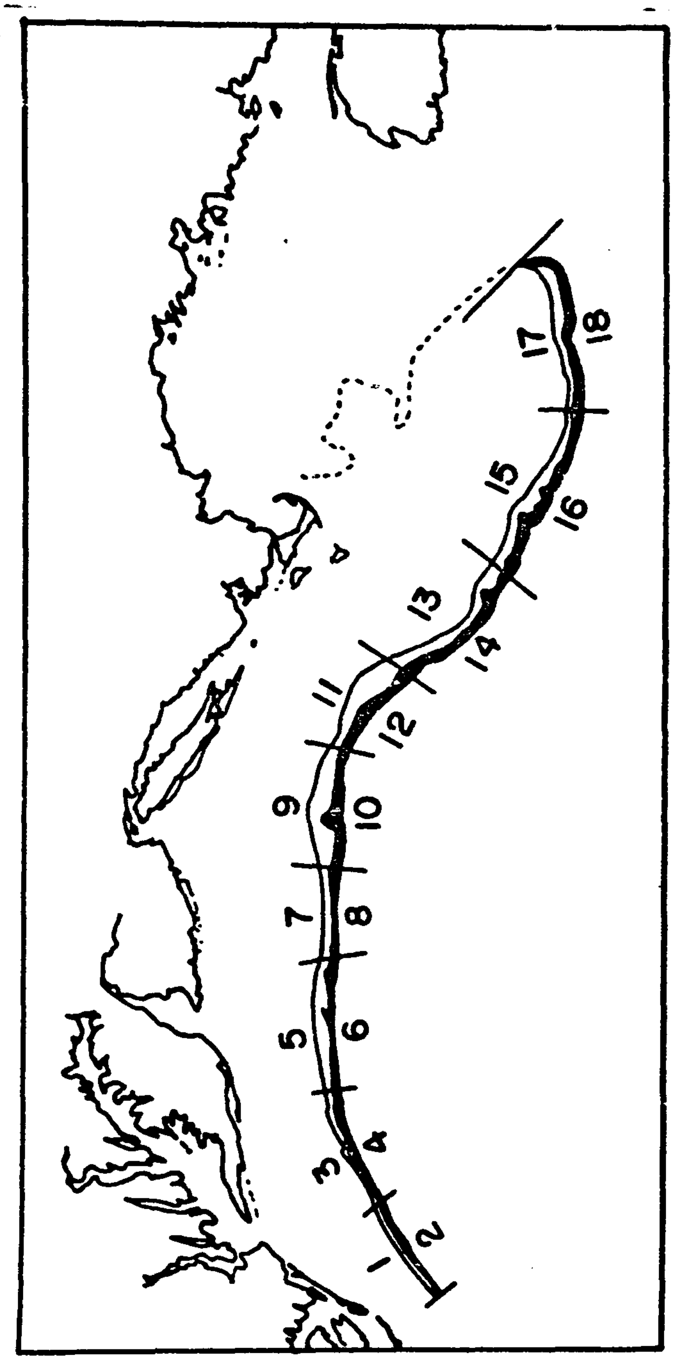


FIGURE 7-51 Shelf Edge and Slope Depth Strata of the NMFS Groundfish Survey

and 3) average bottom temperature and depth (Table 7-34). The data are presented by depth strata (Figure 7-51) for the shelf edge, the upper slope, and for spring and fall.

From these data some features concerning the quantities of benthic fishes are evident. During the spring, along the shelf edge and upper slope the weight and numbers of fishes are far greater than they are in the fall. This is particularly true of highly migratory forms such as silver hake, spiny dogfish, and red hake. The overall average of numbers of fish caught and their weight per tow in the spring were 684 and 819 kg, respectively, as opposed to 374 and 140 kg in the fall. The shelf break strata yielded higher catches in terms of average numbers per tow (990 in the spring, 786 in the fall) and weight per tow (882 kg in the spring, 178 kg in the fall) than did the slope strata (numbers = 278 in the spring, 200 in the fall; weight = 775 kg in the spring, 101 kg in the fall). Along the slope (Figure 7-42),the overall catch varied considerably between strata. In the spring, both weight and numbers again tended to be high at the southern most strata and in the area between the Hudson Canyon and Southern New England; the fall catches do not show as clear a trend. Schroeder (1955) noted the summer catches were highest on the slope off Nova Scotia, with lesser and somewhat equal amounts in the other three zones from Georges Bank to Cape Charles (Table 7-29A).

Sixteen species, or groups of related species, were selected as being of particular significance on the slope. Their quantities are indicated in Table 7-33. Generally, the deeper water forms, such as the macrourids (Grenediers), offshore hake, batfish, hatchet-fish, stomiatoids, and lantern fish were found in low quantities scattered throughout the area. These species are probably never as abundant as the shallower water forms that are found in the upper slope levels.

The silver hake, red hake, spiny dogfish, butterfish, and long-finned squid were some of the most abundant species in terms of numbers and weight per tow. They dominated the catches, particularly in the spring. These are all wide-ranging, inhabit the upper 200 m and are common in the shelf waters. The slope edge and down to about 400 m is probably the limit of the distribution for many of these species.

The biomass and abundance of a number of these species (Figures 7-43 to 7-50) show different distribution patterns. In examining these illustrations it should be noted that a variable scale was used to plot numbers and weight of different species because they range so widely in abundance and size. It should also be noted that in some cases the variation between numbers and weight for any species may indicate the location of different size or age groups.

The four abundant, widely ranging species spiny dogfish, red hake, white hake and silver hake show similar characteristics, being more strongly distributed along the slope strata during the spring. During this time,

Table 7-34. Average bottom temperature and depth of tow for trawl hauls made at the shelf edge and upper slope during fall and spring surveys, 1969-1974.

SLOPE

Fall				Spring			
Strata	Ave.Temp.	Ave.Depth	Stratum Time	Strata	Ave.Temp.	Ave.Depth	Stratum Time
2	11.1	143.8	60	2	11.4	137.9	60
4	10.6	154.8	52	4	10.4	143.5	52
6	11.0	137.0	105	6	10.7	134.8	105
8	10.1	146.9	60	8	10.1	148.4	60
10	10.6	150.8	188	10	10.9	142.2	188
12	9.6	148.9	230	12	10.9	150.3	230
14	9.3	151.8	176	14	10.4	144.3	176
16	9.3	143.9	230	16	10.3	146.0	230
18	8.3	135.1	172	18	8.2	148.1	172

Table 7-34.(Cont.)

SHELF BREAK

Fall				Spring			
Strata	Ave.Temp.	Ave.Depth	Stratum Time	Strata	Ave.Temp.	Ave.Depth	Stratum Time
1	12.4	80.6	86	1	11.1	81.4	86
3	12.8	82.7	86	3	11.4	77.4	86
5	12.5	68.0	281	5	12.2	69.3	281
7	12.9	67.3	139	7	11.5	66.7	139
9	12.7	73.6	566	9	11.5	72.6	566
11	11.9	78.3	514	11	11.8	77.6	514
13	12.2	72.4	622	13	11.4	75.0	622
15	11.7	75.7	656	15	11.0	76.0	656
17	9.3	77.4	360	17	8.0	77.3	360

the red and silver hake tend to be centered most abundantly off the New York Bight, spiny dogfish centered from the New York Bight to Cape Hatteras and the white hake less abundantly along the slope. Both the mackerel and butterfish, which are pelagic species, are more strongly oriented to the shelf edge, their occurrence in the slope strata being limited more to the area around Hudson Canyon. The deep water fishes should probably be considered mesopelagic and are only irregularly found in the relatively shallow levels of the sampling region. There seems to be an abundance of these species in the Hudson Canyon area of the shelf strata during the fall; however, this could be the result of a few unusual catches. The highly variable vertical distribution of these species would make sampling with bottom trawls unreliable. For the invertebrates, the red crab is probably at the limit of its range in the upper slope strata, but was taken in some quantities in the spring and fall off southern New England. The lobster is widely distributed in the slope strata in both fall and spring. Two species of squid show similar distribution although the long finned squid is considered more strongly abundant south of the Georges Bank slope. The remaining species consists of four strongly benthic species. The black belly redfish is widespread in the slope strata, the witch flounder, probably made up largely of juveniles, are widespread on the slope during the spring, but probably more abundant in the deeper levels (see life history description). The sea robins are primarily restricted to the shelf edge and to the more southern waters and the American goosefish shows a size distribution which indicates that younger, smaller individuals are distributed along the shelf edge strata, while larger, older fish are more abundant along the slope strata.

ECOLOGICAL RELATIONSHIPS

Reproduction

Mead, Bertelsen, and Cohen (1964) discuss the means by which fishes of the deeper slope waters accomplish successful reproduction in an environment that produces sparse populations, scattered individuals, and offers little support to the development of the young. The discussion was in relation to deep sea fishes below 2000 m, but since these same groups are found in the deeper slope regions, where conditions for reproduction are similar, their observations are pertinent.

The proper balance between fecundity and survival of progeny which insures adequate recruitment to the adult population can be accomplished by the mode of reproduction and by egg development. The mode of reproduction can be similar to that of the fishes of shallower water - large numbers of small eggs are produced with the young developing in the surface zone (epipelagic) where abundant food is available and parental care is minimal. This is found among certain of the deepwater eel, such as the synaphrobranchids. Another mode is the development of few large eggs that produce large, well-developed young in the deepwater with a tendency for some form of parental assistance, insuring that the progeny are able to cope with the more hostile environment of deepwater. This type of reproduction is most common in the slope area and is characteristic of the macrourids and other groups. The successful fertilization of gametes depends on successful mate location, a problem that becomes important in areas where the population is sparse and the environment dark and unchanging. Most fish species are dioecious and require adaptations with which to locate mates; sound production and reception is common in many groups of deepwater fishes, as is bioluminescence. There are several fishes of the Iomoni that are monoecious and may be functional hermaphrodites.

Food

The amount and kinds of food encountered by benthic fishes of the deeper slope waters are somewhat different than those of their brethren in the shallower shelf regions. These conditions probably influence the type of fish fauna found at deeper levels. In general, the density of benthic organisms important as food items in the shelf areas, i.e., crustaceans, molluscs, and worms decreases rapidly below the euphonic zone. Haedrich, *et al.* (1975) estimated that the biomass of infauna in deep sea was nearly the same order of magnitude as that of the epifauna. Consequently, unless turnover rates of infauna are very high, they are not sufficient alone to support the epifauna. It is apparent that available food is one of the major limiting factors in the abundance of benthic fishes below the shelf edge and that those inhabiting these depths require slightly different food habits.

Several authors (Pearcy and Ambler, 1974; Haedrich and Henderson, 1974) have noted that certain of the slope fishes, particularly the macrourids, derive a major portion of their diet from the overlying mid-waters. Pelagic food items in the stomachs of trawl caught *Coryphaenoides armatus* in the Hudson Canyon (Haedrich and Henderson, 1974) suggested that such organisms as cephalopods, euphausiids and small fishes comprised a significant part of the diet of the larger individuals. The capture of a large number of macrourid species in mid-water trawl nets (Haedrich, 1974) indicates that pelagic excursions into the overlying waters in search of prey is a common occurrence with these fishes.

The general mobility of fishes means that they are less dependent on the bottom and can respond more to food availability. In the deeper water (approximately 2600 m), where fish diversity is low compared to the slope regions above, fishes are quite generalized feeders, consuming both animal and detrital material (Haedrich and Henderson, 1974). At the higher levels of the slope, a relative increase in food abundance results in greater food specialization (Pearcy and Ambler, 1974), allowing for an efficient use of food resource through the increase in diversity of feeding types.

Another characteristic of fishes in the deeper waters seems to be reduced respiration. In situ respiration measurements (Smith and Hessler, 1974) off San Diego of a species of macrourid and a myxiniid from 1230 m show respiration rates significantly lower than those of comparable shallow water species. In the case of one species, *Coryphaenoides acrolepis*, respiration was reduced by two orders of magnitude. These results correspond with other findings and indicate a general decrease of metabolic activity in the deep sea as a response to food availability, pressure, and temperature. Smith and Hessler note the possibility that fishes at these depths exist in a quiescent state until food becomes available.

Temperature and Seasonal Movements

The general relationship of temperature to fish distribution in the North Atlantic region has been discussed in a previous report (Chenoweth, 1974). In the open ocean, temperature primarily controls fish distribution. Consequently, seasonal changes in distribution result from the movement of fishes to maintain themselves within their range of temperature preference. In the upper 200 m of the western North Atlantic water, seasonal temperature changes are extreme (Hutchins, 1947) leading to extensive migrations of many fish species on the continental shelf (Chenoweth, 1974).

On the slope below 200 m, there is little seasonal change. For a detailed description of temperature characteristics of the slope water, the reader is referred to Chapter 4 of this report. Essentially, seasonal temperature changes occur most widely in the upper 50 m decreasing to about 4°C change at 100 m. At 120 m on the shelf edge there is a warm band of water about 40 to 80 m thick; after which there is a sharp reduction in temperature of about one degree in 80 m to a depth of 500 to 600 m. A gradual reduction of temperature then occurs to a minimum of 2.2°C at 4000 m.

Below the main thermocline, the role of temperature in the seasonal changes of kinds and abundance of benthic fishes is probably minimal, since conditions appear to be very stable. Investigations that produce a time series of samples from the slope are lacking and the studies mentioned previously were, for the most part, carried out in the summer. It would be reasonable to assume that the seasonal distribution of those species of benthic fishes characteristic of the deeper slope water (below 400 m) does not change significantly.

Down-slope, the major changes in benthic taxa suggest a faunal boundary at 300 to 400 m (Haedrich, et al., 1975). The region inshore of this boundary is shallow enough to be influenced by the seasonal thermocline. Below about 400 m slowly decreasing, stable temperatures probably have less affect on the kinds and numbers of benthic fishes than factors such as food supply and sediment type.

Depth

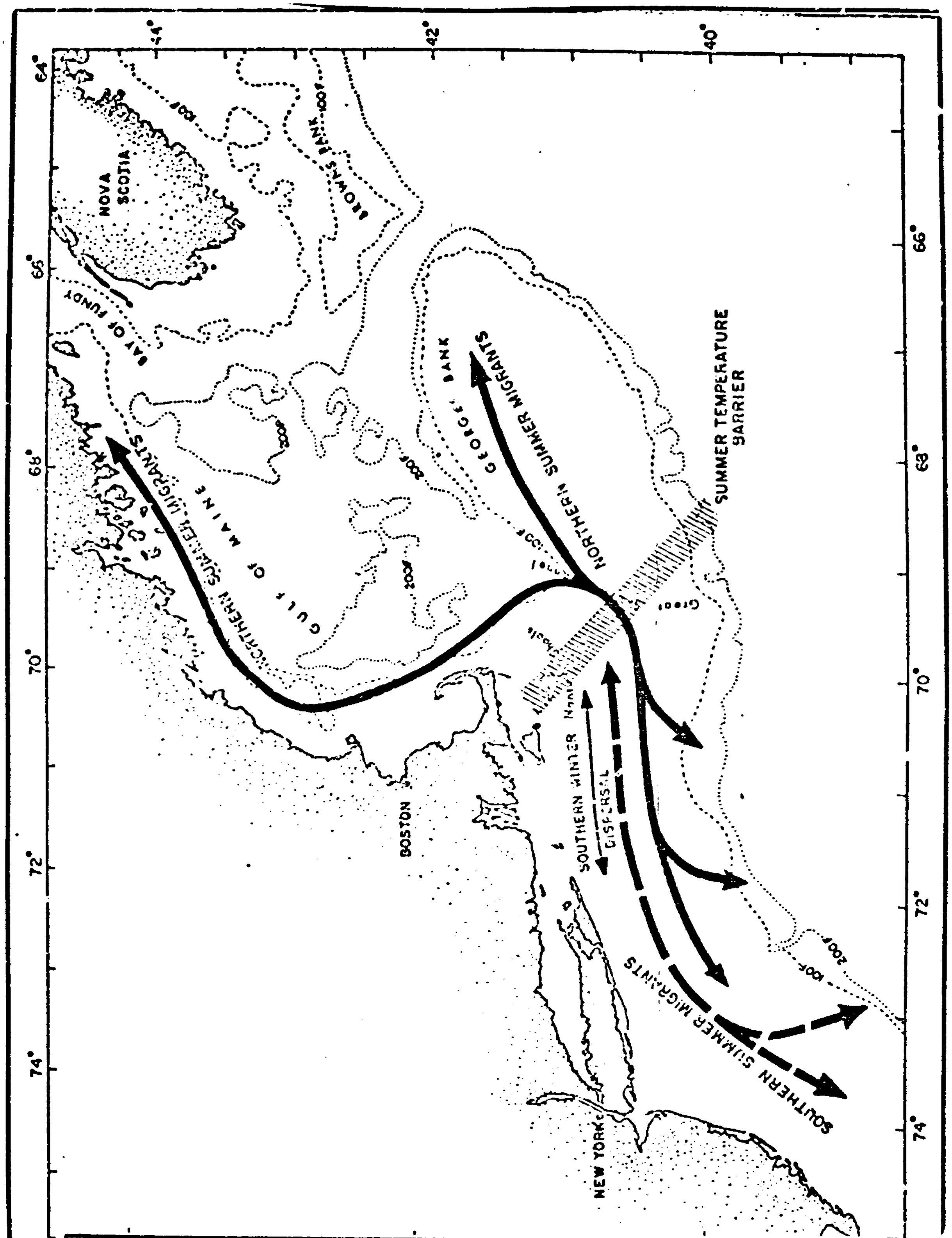
The general influence of increasing depth on the distribution and zonation of the kinds and quantities of benthic fishes have been treated in the previous section. Actually, it is the factors associated with increasing depth that influence fish directly, i.e., changes in pressure, temperature, sediment type, food type, and quantity.

Sediment Type

The physiography and type of bottom material is known to influence the distribution of benthic fishes, at least those species of the shallower coastal water for which there is ecological information. Below the shelf edge, our knowledge of the relation of benthic fishes to bottom type is very limited. MacIlvaine (1973) described a small section of the slope off southern New England in detail and from this Haedrich, et al. were able to establish a relationship to their faunal boundary at 1000 m. This boundary corresponds approximately to the transition from the upper to the lower continental slope. Above the boundary, the gradient is 1.4° and characterized by a sediment rate of 15 cm per 1000 years. Below the boundary, the gradient is 7.6° and the sedimentation rate is only 2 cm per 1000 years. This results in different bottom characteristics above and below 1000 m. Haedrich, et al. consider this to be an important influence on the different benthic communities on either side of the faunal boundaries. Above the boundary there was medium scale slumping and bottom materials are only partially removed. Below the boundary there was no accumulation of materials resulting in a consolidated, erosion resistant surface with a stiff, clay silt sediment and little suspended material.

SIGNIFICANCE OF SLOPE TO SHELF FISHES

The seasonal movements of the fishes inhabiting the relatively shallow water of the continental shelf in response to annual temperature fluctuations was considered with some detail in the previous report (Chenoweth, 1974). For a number of very abundant fishes the outer continental shelf and slope have a particular significance. The shelf of the mid-Atlantic Bight contains very few permanent residents. It is composed primarily of continuously shifting populations that move north, many into the Gulf of Maine, during the very warm months, and retreat south during the cold months (Figure 7-52). It has been noted (Edwards, 1964; Edwards, Livingstone, and Hamer, 1962) that during their autumnal retreat many important species (such as silver hake, red hake, scup, butterfish, goosefish, and spiny dogfish) move into the warmer, deeper waters of the outer continental shelf in response to declining water temperatures elsewhere. The band of warm water that exists year round at the shelf break beginning at about 120 m (Chapter 4) represents a winter habitat of significant proportions to these shelf fishes.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	**FIGURE** 7-52	General Movement of Migratory Fish Species (TRIGOM, 1974)

From the data of Edwards, Livingstone and Hamer (1962) (Fig. 7-30 - 7-37) and National Marine Fisheries Service Groundfish Survey (Figures 7-43 to 7-50) the populations of these species seem to be distributed from about 100 m to somewhere below the 200 m depth along the outer shelf from Georges Bank to the mid-Atlantic region during the colder months (January to April). They appear to be located at slightly shallow waters at the southern part of the study region, probably in response to slightly warmer shelf waters. Exactly how far down slope these populations extend is not clear from this data. However, considering the decreasing temperatures and food supply that were being counted very far down the slope, it is unlikely that these shelf species are found in quantity much below 300 to 400 m.

Along the slope, distribution of these species is not even (Figure 7-42.) It would appear that at the shelf edge and upper slope, the Cape Hatteras and the Hudson Canyon regions south of Long Island, are areas where these species are found most abundantly in terms of both number and weight. The differences in weight and numbers of fish taken at the shelf edge and slope strata indicate that the main area of their concentration is at the edge of the continental shelf. It is interesting to consider the possible interrelationship between species under these conditions, although at this point it is most speculative. Obviously, in addition to presenting optimum winter temperatures, this particular region must also provide an adequate food supply to support these expatriate shelf species in addition to any existing resident populations. Unless there is an insignificant resident population or a corresponding movement down-slope of resident species, there must be increased competition for available food during this period. More information on the productivity of this area of the outer shelf edge and slope area is obviously needed.

Assuming that a large portion of the abundant shelf fish stocks winter over in the relatively narrow band of water at the shelf edge and upper slope, this region is an extremely important one to the ecology of the continental shelf fish populations in general and to commercial fishing interests in particular.

LIFE HISTORY OF KEY SPECIES

Considering the relatively narrow band of bottom area constituting the continental slope, it is not surprising that most of the benthic fishes found there have ranges overlapping into either the shallow shelf waters or the deeper abyssal zones. Nevertheless, there are species groups which stand out as being important constituents of the slope habitat. For some of these, a brief synopsis of what is known of their life history follows.

Macrourids

Fishes of the family Macrouridae (grenediers, rattails) are of the order Anacanthini and, therefore, are closely similar to the gaddids and related groups. They have well developed swim bladders luminescent organs, and a long, tapering posterior portion of the body. These are fishes primarily of the continental slopes of the world where they are fairly abundant in localized populations. The systematics and biology of this group have been given extensive treatment by Parr (1946); Mead, Bertelson, and Cohen (1964); and Marshall (1965, 1973). In our study area the group is represented by a number of species, notably Nezumia bairdii and Coryphaenoides rupestris.

Reproduction

Of particular interest is the means by which endemic slope species reproduce themselves. This must be done in such a way as to insure that the products of reproduction remain in a restricted area providing recruits to the adult population. How the macrourids accomplish this is not clear. They are not viviporous, but lay externally fertilized eggs. Although the exact breeding time on the northwest Atlantic slope is not well documented, they breed in other areas from February to September, implying a fairly long spawning season. Ripening gonads indicated that they breed off of New England during the summer and autumn (Bigelow and Schroeder, 1953). The swim bladder operates as a sound producer as well as a hydrostatic organ and is considered to relate in some way to mate attraction in the deeper slope waters.

Fecundity and Larval Life

Macrourids lay relatively large eggs (1-4 mm in diameter), which are free floating (Marshall, 1973). The fecundity of Coryphaenoides rupestris ranged from 10,000 to 16,500 eggs per individual (Mead, et al., 1964). From the collections of the ship DANA in other areas, a tentative reconstruction of macrourid early life history has been made (Marshall, 1965, 1973). The eggs are likely shed and fertilized near the bottom and develop as they float slowly upward. The larvae lie not far below the thermocline, gradually returning to the bottom as they grow. The development to metamorphosis is probably very rapid because of the necessity to recruit to populations confined to the relatively narrow slope.

Growth and Longevity

Age and growth of C. rupestris in the northwest Atlantic (Savvatimsky, 1971) showed fish of commercial size (age 9-14 years) increased their length 3-4 cm per year. Weight increased by 68-80 gm for males and 80-100 gm for females. At 19 years, males reach a length of 84 cm and a weight of 1,010 gm, females were 88 cm and 550 gm.

Migration Characteristics and Distribution

There are over 300 species of macrourids, over 90 percent of which live close to the continental slopes between depths of about 200-2,000 m

(Marshall, 1965). They are considered benthopelagic in that they spend a significant part of their time up in the water column. Haedrich (1974) noted the occurrence of C. rupestris in mid-water trawl collections in the Denmark straits. The macrourids of the western north Atlantic have a restricted distribution with only four species, among them C. rupestris, recorded for the slope waters of the eastern north Atlantic (Marshall, 1965).

Locally, macrourids probably do not range widely. C. rupestris is reported to exhibit some seasonal movement up and down the slope in response to the vertical distribution of prey and migratory movements of 1 to 200 m off of the bottom (Pechenik and Troyanovskii, 1970).

Population Densities

In all probability, the macrourids of the study area are fairly abundant fishes, although good density figures are lacking. Marshall (1965) reports the density of one fish to about 160 m^2 at 2600 m depth in an area south of Nova Scotia. Pechenik and Troyanodskii (1970) reporting on exploratory fishing of the slopes from Newfoundland to Baffin Island found C. rupestris in commercial quantities of from 120 to 200 centners per 15 minute trawl.

Food

The feeding habits of macrourids in the Hudson Canyon to a depth of 2600 m have been reported by Haedrich and Henderson (1974). The major categories of food eaten by Coryphaenoides armatus are shown in Table 7-35. The food included benthic animals, pelagic animals and items of terrestrial or neritic origin. The amount of pelagic food taken, which included cephalopods and small fishes, was significant and increased with the size of C. armatus. The larger fish were obviously more prone to capture pelagic prey. Haedrich and Henderson concluded that C. armatus derives a major portion of this prey from the overlying waters.

Predation and Competition

At the upper slope level, young macrourids might be the prey of such shelf fish as silver hake during the winter. Competitive relationships are not known but are of interest in relation to the seasonary immigrating species in the upper slope levels. Generally, there is very little information.

The Hakes

The hakes, as a group, all have different degrees of affinity to the continental slope. The life history of the silver hake (Merluccius bilinearis) has been treated previously (Chenoweth, 1974) and will not be included here. The white hake (Urophycis chuss) and the red hake (Urophycis tenius) are both shelf and slope species. However, Musick

Table 7-35. Food items found in Coryphaenoides armatus by size. Entries are number of stomachs in which an item occurred (after Haedrich and Henderson, 1974).

	69-99 mm	100-139 mm	140-179 mm	180-229 mm
Stomachs with food	4	12	20	5
Empty stomachs	-	4	3	1
Everted stomachs	1	14	13	2
Cumacea	2	6	3	1
Tanaidacea	2	6	3	1
Isopoda	3	3	1	-
Amphipoda	2	7	7	1
Mysidacea	1	-	1	-
Polychaeta	3	7	6	-
Pycnogonida	-	-	1	-
Copepoda	1	4	3	1
Euphausiacea	-	1	2	-
Decapoda	-	3	4	-
Crustacean parts	-	4	7	2
Cephalopoda	-	2	16	5
Chauliodus	-	1	6	2
Serrivomer	-	1	3	-
Other fishes	-	5	10	3
Sargassum	-	2	-	1
Things from surface	-	2	7	2

(1974) has shown that the red hake is much more strongly oriented to the slope. The red hake would be the most representative of the hakes for the purpose of this report, however, since these two species (red and white hake) are not easily distinguished, they are treated together. Several other species (Antimora rostrata the blue hake, Phycis chesteri the long-finned hake, Urophycis regius the spotted hake, and Merluccius albidus the offshore hake) are also fish of the deeper slope waters. Their life history is not well known, although Bigelow and Schroeder (1955) reported on the occurrence of the latter species off the north and middle Atlantic coasts.

The white hake and red hake are cold water bottom fishes of the cod family. They are treated together because they are so similar in appearance and habit and they cannot be easily distinguished. The white hake is slightly larger and has a more northern distribution than the red hake. They are both commercially important.

Reproduction

The spawning behavior of hakes is not well known. It occurs over an extended period during the summer both north and south of Cape Cod. There is evidence that hake from southern grounds spawn somewhat earlier, indicating temperature probably effects the time of spawning. South of Cape Cod, spawning occurs from May to August. Hake eggs were collected in Narragansett Bay from May to November and in Block Island Sound from June to September. Red hake probably reach sexual maturity at age three. The majority of stations in the Gulf of Maine at which hake eggs were collected were well inside 800 m isobath. Probably spawning among hake occurs in relatively shallow water. Musick (1974) states that after inshore migration during spring in southern New England, red hake migrate offshore in the summer to spawn. Sexually mature red hake were heavily concentrated during the summer in depths shoaler than 110 m on the southwest part of Georges Bank and off Block Island. These concentrations were probably spawning aggregations because ripe fish were taken quite frequently. The immigration of red hake from shallow southern New England waters to offshore spawning grounds is probably correlated with temperature. Red hake were found not to be abundant within temperature intervals higher than 12°C.

Fecundity and Larval Life

The eggs and larvae of the hake are pelagic. Eggs range from 0.63-0.97 mm in diameter. They are spherical, transparent, and contain one oil globule. At hatching, red hake prolarvae are 1.76-2.29 mm long. The pelagic larvae of the red hake descend to the bottom at a length of about 35-40 mm. The young then live within the mantle cavity of the sea scallop Placopecten magellanicus. The pelagic larvae of the white hake descend to the bottom at a length of about 80 mm.

Growth and Longevity

Hake spawn in the summer. Young of year taken in November off New York were 49-65 mm. Young hake judged to be approaching one year old ranged from 60-110 mm. An analysis of length frequency data for hake from the Bay of Fundy (Bigelow and Schroeder, 1953) revealed the following age-growth data:

Age	Males	Females
1	200 mm	200 mm
2	330 mm	360 mm
3	405 mm	480 mm

The growth of females out-strips that of males in fish over two years old. The white hake is the larger of the two species attaining a maximum length of 122 cm and weight of 18 kg. The red hake reaches 75 cm and weight 2.5-3.5 kg. The white hake matures at about 500 mm in length and the red hake becomes mature at 290 mm in length.

Migration Characteristics and Distribution

Musick (1974) summarized the seasonal distribution and movements of the red and white hake. The distribution patterns of the two species are not coincidental but complementary. The red hake is more abundant in the mid-Atlantic Bight, whereas the white hake is more abundant on the Scotian shelf, Gulf of St. Lawrence, and the Grand Banks. They occur together most often in the Gulf of Maine.

The red hake is considered by Musick to be a fish of the continental slope. He found this species to be occurring over the shelf in small numbers and to be most concentrated in water deeper than 200 m at all seasons. The National Marine Fisheries Service Ground Fish Survey data (Figure 7-44) also indicate a preference by the red hake for the upper slope waters and a distribution that is centered on the shelf below Long Island.

The seasonal distribution (Musick, 1974) of the red hake is as follows: During fall, juveniles are most abundant in southern New England waters shoaler than 120 m, their distribution coinciding with their host, the sea scallop; the winter distribution of immature hake is in water deeper than 200 m; the adults migrate inshore in spring, then slightly offshore in summer in spawning concentrations; in fall they are dispersed over the entire area. In the winter there is a strong offshore movement, with the fish concentrating on the edge of the continental shelf from southwest Georges Bank to Hudson Canyon. South of Nantucket they seem most abundant between 200-500 m and between 8.3°C and 10.0°C.

These two species have a preference for sand and mud bottoms and rarely occur over rock and gravel bottoms. The red hake generally occurs on the slope in areas of muddy or silty bottom.

Food

The red hake feeds chiefly on shrimps (Pandalus), amphipods, and other small crustacea that they find on the bottom. Larger individuals also eat squid and a variety of small fish such as alewives, butterfish, eels, flatfishes, tautog, herring, mackerel, menhaden, launce, silversides, silver hake, sculpins, sea robins, smelt, and tom cod. Small crabs are also eaten. In the northeastern part of the Gulf of Maine, they feed far enough off bottom to capture pelagic shrimps (Meganyctiphanes and Thysanoessa) (Bigelow and Schroeder, 1953).

Glyptocephalus cynoglossus

The witch flounder is a flatfish inhabiting the deeper waters of the continental shelf. It has an extensive range, occurring between Cape Lookout, North Carolina and the strait of Belle Isle. It is a species of growing commercial importance. The witch flounder is of interest because its life history is complicated and occupies three largely discrete ecological niches, one of them on the continental slope.

Reproduction

A spring-summer spawning season is inferred from the capture of eggs between April and August and the pelagic larvae that occurred from May to early November (Markle, 1975). Bigelow and Schroeder (1953) considered that there was no significant spawning south of Cape Cod.

The life cycle of the witch flounder is summarized by Powles and Kohler (1970). The egg hatches into a pelagic larval stage that may persist up to a year. These larvae may be concentrated 30-40 m from the surface over deep water. The metamorphosed fish settle to the bottom in deep water (144-450 m in the Maritime Provinces) and are separate from the more shoal adult stock. For the first four to five years of life they are found in the deeper waters, thereafter gradually migrating up onto the shelf. Powles and Kohler suggest that by remaining deep the juveniles avoid direct feeding competition on the main fishing grounds with other abundant species, such as cod and plaice.

Markle (1975) has made further observations on juvenile flounder over the continental slope off Virginia. They were found to be dominant at 900 meters. The narrow size range observed in the collections off Virginia and the strongly bimodal length frequency distribution off the Nova Scotia banks led Markle to infer that the slope off Virginia is a major nursery area for one to three or four year old witch flounder. As the present evidence suggests, spawning occurs quite far to the north and the juveniles may either: 1) Move southward along increasingly deeper isotherms, or 2) arrive as larvae after drifting southwestward along the mid-Atlantic Bight and then eastward into the slope water.

Synaphobranchid Eels

Among the anguilliform eels is a group of species that inhabit the pelagic and benthic environments of the deeper waters. The synaphobranchids belong to such a group. Although they are important components of the slope fauna (Markle and Musick, 1974), their remoteness and adeptness in avoiding or escaping slow moving fishing trawls has resulted in a dearth of existing life history information. Castle (1964) has treated the systematics of the synaphobranchids and Brunn (1937) has dealt with their life history.

The abundance of *Synaphobranchus kaupi* at the middle slope levels has been noted by Haedrich, *et al*. and by Markle and Musick. In the collections by Haedrich, *et al*. the 164 *S. kaupi* taken at the middle depth zone (393-1095 m) represented 18.6 percent of the total catch, which qualified it for consideration as the dominant fish species of that zone. Markle and Musick show the following station catch distribution along-slope at 900 m (stations shown in Figure 7-29):

Stations	3	4	5	6	7	8	9	10	11	12	13	Total
S. kaupi	1	6	-	-	1	1	17	-	116	201	57	400

S. kaupi was most abundant at and below Hudson Canyon (Station 9). Unpublished data from the Virginia Institute of Marine Sciences (Wenner, 1975) indicate that this species is also an important part of the benthic fish community in Norfolk Canyon at about 1000 m. Wenner also notes that two other species, *S. affinis* and *Ilyophis brunneus*, are common on the slope off North Carolina.

Reproduction

Synaphobranchids are among the few species of deep sea fishes that have the high fecundity and epipelagic larval development characteristic of the oceanic fishes of the surface zone (Mead, *et al*., 1964). Brunn (1937) and Mead, *et al*. (1964) both note that the problem of mate selection is reduced by a tendency of synaphobranchids to form relatively dense populations in selected areas during spawning seasons. Markle and Musick noted that dense concentrations of synaphobranchids in their collections had a large percentage of females that appeared to be in a spawning condition and that their patchy distribution indicated seasonal reproductive activity. This suggests a mid-to-late summer spawning season of this species in the study area.

Fecundity and Larval Life

The synaphobranchids have relatively high fecundities with ripe eggs that measured from 0.9-1.1 mm in specimens of S. kaupi hatched by Markle and Musick. The larval life of this species was estimated to be about 18-22 months (Bruun, 1937). The eggs are pelagic and develop into the leptocephali larvae characteristic of the eel group. These Leptocephali are reported to avoid the upper surface layers and have a center of distribution between 100-250 m. The advanced elver stage of 89 S. affinis were taken at depths of from 550-600 m by Wenner (1975) and ranged in size from about 75-105 mm. The leptocephalus stage of the synapobranchids generally reaches 13 cm (Mead, et al., 1964).

Distributions in Migrations

Very little information except spawning migration and patchy distribution are suspected during the summer months. Overall there is some indication that S. kaupi is most abundant on the slope at about 900-1000 m.

DATA GAPS

Deficiencies in the data base result from the lack of deep sea studies on benthic fish on the continental slope. Until very recently few sampling efforts were made beyond the continental shelf and those concerned themselves with defining what species were present in the deep water and in what quantities. The emphasis in many of these studies was on commercially important shelf fishes. For the fishes of the deep water benthic environment, there is a decided lack of basic life history information. Whole groups of species are largely unknown in terms of general abundance, distribution and zonation, growth, reproduction, and trophic relationships. Recent research has just begun to accumulate information on the benthic ecosystem of the continental slope and how the fish fauna relate to it.

The relatively narrow region at the shelf break that is so seasonally productive of commercial species is also an area where research is needed. To what extent this region seasonally supports commercial stocks of fish has implications for the commercial stocks of the whole North Atlantic continental shelf.

The seasonal characteristics of the benthic fishes along the slope is not well understood because there have been no seasonal studies. To identify seasonal changes in community components, distribution, and other temporal cycles requires a time series of examples rather than collecting from a single research cruise.

The benthic fish of the deeper slope waters must be considered in relation to the ecosystem in which they reside. Recently, it has become evident that this ecosystem is quite different from that of shallow shelf waters. The distribution, abundance, reproduction, feeding and metabolism and prey-predator relationships of benthic fishes in the deep water beyond the shelf break are manifestations of a system that operates under great pressure, lack of sunlight, lower, but stable, temperatures, and low productivity - essentially a conservative environment. Much research needs to be done to define the system and evaluate potential future human impacts upon it.

REFERENCES

Beebe, W. 1929. Deep sea fish of the Hudson Gorge. Zoologica, 12(1): 1-19.

Bigelow, H.B. and W. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildl. Serv., Fish Bull., 53(74): 577 p.

________. 1954. Deep water elasmobranchs and chimaercids from the northwestern Atlantic slope. Bull. Mus. Comp. Zool., Harvard Univ., 112(2): 37-87.

________. 1955. Occurrence off the Middle and North Atlantic United States of the offshore hake, *Merluccius albidus* (Mitchell) 1818 and of the blue whiting, *Gadus morhua (Micromesistius)*-Poutassou (Risso) 1826. Bull. Mus. Comp. Zool. Harvard Univ., 113(2): 205-226.

Bruun, A.F. 1937. Contributions to the life histories of the deep sea eels: Synaphobranchidae. Dana Rep. 9. 31 p.

Castle, P.H.J. 1964. Deep sea eels: family Synaphobranchidae. Galathea Rep. 7: 29-42.

Chenoweth, S.B. 1974. Fishes, chapter 12. *In*: A socio-economic and environmental inventory of the North Atlantic region. TRI-GOM for the Bur. of Land Manage., Washington, D.C. 8 v. 4,900 p.

Day, D.S. and W.G. Pearcy. 1968. Species associations of benthic fishes on the continental shelf and slope off Oregon. J. Fish. Res. Bd. Can., 25(2): 2665-2675.

Edwards, R.L. 1964. Relation of temperature to fish abundance and distribution in the southern New England area. ICNAF Environ. Symp. Spec. Publ. 6: 95-110.

Edwards, R.L., R. Livingstone, and P.E. Hamer. 1962. Winter water temperatures and an annotated list of fishes, Nantucket Shoals to Cape Hatteras. *Albatross III* Cruise No. 126. Spec. Sci. Rep. U.S. Fish and Wildl. Serv., Fish. Rep. 397. 31 p.

Goode, G.B. and T.H. Bean. 1896. Oceanic ichthyology: deep sea pelagic fishes of the world. Spec. Bull. U.S. Nat. Mus., 2: 1-553.

Grey, M. 1956. The distribution of fishes found below a depth of 2000 meters. Fieldiana Zool., 36: 73-337.

Grassle, J.F., H.L. Sanders, R.R. Hessler, G.T. Rowe, and T. McLellan. 1975. Pattern and zonation: a study of the bathyal megafauna using the research submersible ALVIN. Deep-Sea Res., 22: 457-481.

Grosslein, M.D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Mass., U.S.A. ICNAF Res. Doc. 74/96.

Haedrich, R.L. 1974. Pelagic capture of the epibenthic rattail, *Coryphaenoides rupestris*. Deep-Sea Res., 21: 977-979.

Haedrich, R.L. and N.R. Henderson. 1974. Pelagic food of *Coryphaenoides armatus*, a deep sea benthic rattail. Deep-Sea Res., 21: 739-744.

Haedrich, R.L., G.T. Rowe, and P.T. Polloni. 1975. Zonation and faunal composition of epibenthic populations on the continental slope south of New England. J. Mar. Res., 33(2): 191-212.

Hutchins, L. 1947. The basis for temperature zonation in geographic distribution. Ecol. Monogr., 17: 325-335.

MacIlvaine, J.C. 1973. Sedimentary processes on the continental slope off New England. Ph.D. Thesis, Mass. Inst. Technol./ Woods Hole Oceanogr. Inst. Ref. 73-58. 211 p.

Markle, D. 1975. Young witch flounder, *Glyptocephalus cynoglossus*, on the slope off Virginia. J. Fish. Res. Bd. Can., 32(8): 1447-1450.

Markle, D. and J.A. Musick. 1974. Benthic slope fishes found at 900 m. depth along a transect in the western North Atlantic Ocean. Mar. Biol., 26: 225-233.

Marshall, N.B. 1965. Systematic and biological studies of the macrouridae fishes, *Anacanthini teleostii*. Deep-Sea Res., 12(3): 299-322.

________. 1973. The family macrouridae. *In:* Fishes of the western North Atlantic. Mem. Sears Found. for Mar. Res., 1(6): 496-662.

Mead, G.W., E. Bertelson, and D. Cohen. 1964. Reproduction among deep sea fishes. Deep-Sea Res., 11: 569-596.

Menzies, R.J., R.Y. George, and G.T. Rowe. 1973. Abyssal environment and ecology of the world oceans. John Wiley and Sons, Inc., New York. 488 p.

Musick, J.A. 1974. Seasonal distribution of sibling hakes, *Urophycis chuss* and *U. tenuis* (Pisces Gadidae) in New England. Fish. Bull., 72(2): 481-495.

National Marine Fisheries Service. Groundfish survey data, 1969-1974. Nat. Mar. Fish. Serv., Woods Hole, Mass.

Parr, A.E. 1932. Deep sea eels: exclusive of larval forms. Bull. Bingham Oceanogr. Collect., 3(5): 1-41.

________. 1946. The marouridae of the western North Atlantic and central American seas. Bull. Bingham Oceanogr. Collect., 10(1): 1-99.

Pearcy, W.G. and J.W. Ambler. 1974. Food habits of deep sea macrourid fishes off the Oregon coast. Deep-Sea Res., 21: 745-759.

Pechenik, L.N. and P.M. Troyanovskii. 1970. Trawling resources on the North Atlantic continental slope. Main Admin. of Industry, Northern Bases, Murwansk. (Israel Program for Scientific Translation). 65 p.

Powles, P.M. and A.C. Kohler. 1970. Depth distribution of various stages of witch flounder (Glyptocephalus cynoglossus) off Nova Scotia and the Gulf of St. Lawrence. J. Fish. Res. Bd. Can., 27(11): 2053-2062.

Rowe, G.I. and R.J. Menzies. 1969. Zonation of large benthic invertebrates in the deep sea off the Carolinas. Deep-Sea Res., 16: 531-537.

Savvatimsky, P.T. 1971. Studies of the age and growth of roundnose grenedier (Macrouris rupestris Gunn) in the North Atlantic, 1967-1970. ICNAF Red Book, Part III: 125-138.

Schroeder, W.C. 1955. Report on the results of exploratory otter-trawling along the continental shelf and slope between Nova Scotia and Virginia during the summers of 1952 and 1953. Pap. Mar. Biol. Oceanogr., Deep-Sea Res., 3(Suppl. 10): 358-372.

Smith, K.L. and R.R. Hessler. 1974. Respiration of benthopelagic fishes: in situ measurements at 1230 meters. Science, 184(4132): 72-73.

TRIGOM. 1974. A socio-economic and environmental inventory of the North Atlantic region. Prepared by TRIGOM for the Bur. of Land Manage., Washington, D.C. 8 v. 4,900 p.

Wenner, C.A. 1975. The occurrence of elvers of Synaphobranchus affinis on the continental slope off North Carolina. Fish. Bull., 73(3): 687-690.

CHAPTER 7.0

BIOLOGICAL OCEANOGRAPHY

7.4 NEKTON

STANLEY CHENOWETH

STEVEN K. KATONA

DIANE S. BRACKETT

CHAPTER 7.0 TABLE OF CONTENTS

Page

Chapter 7.4 Nekton

7.4 NEKTON

7.4.1 INTRODUCTION

The nekton of the slope water is made up of a diversified group of animals which actively move about in the water column, existing independently of the bottom. The group inhabits the region between the surface water and the bottom, which on the continental slope and continental rise can vary in depth between 200-4000 m. The region can be divided into a number of habitats according to depth and the various fauna that inhabit them.

epipelagic zone	upper 200 m
mesopelagic zone	200 to 1000 m
bathypelagic zone	1000 to 4000 m

The nekton that inhabit the epipelagic zone in the upper slope water are generally large, highly developed animals of the higher trophic levels. Many of the fishes (sharks, tunas, marlins, swordfish, and numerous smaller species) inhabit tropical to warm temperate waters and enter the northwest Atlantic slope water only during the summer. The squids, represented abundantly by two species, the short-finned squid Illex illecebrosus and the long-finned squid Loligo pealei, are animals of the continental shelf that winter over in the inner slope water. Practically all species of cetaceans that are found in the temperate waters of the northwest Atlantic at least pass through the slope water at some time during their lives, and the larger oceanic cetaceans are most common there. Several species of sea turtles use the slope waters as a seasonal habitat.

The nekton of the general epipelagic zone have been divided into a number of trophic levels (Parin, 1968) in which the fishes play a most important role (Figure 7-53). Each level represents about a 90 percent reduction of the organic carbon assimilated by animal production from the next lower level (Emery and Uchupi, 1972). The food web is extremely complex and in some cases the lower trophic levels are by-passed. Such is the case with certain cetaceans that feed directly on crustaceans. Complexity of the food associations within the epipelagic nekton makes it difficult to estimate the flow of food energy from the primary producers (phytoplankton) through to the highest trophic levels.

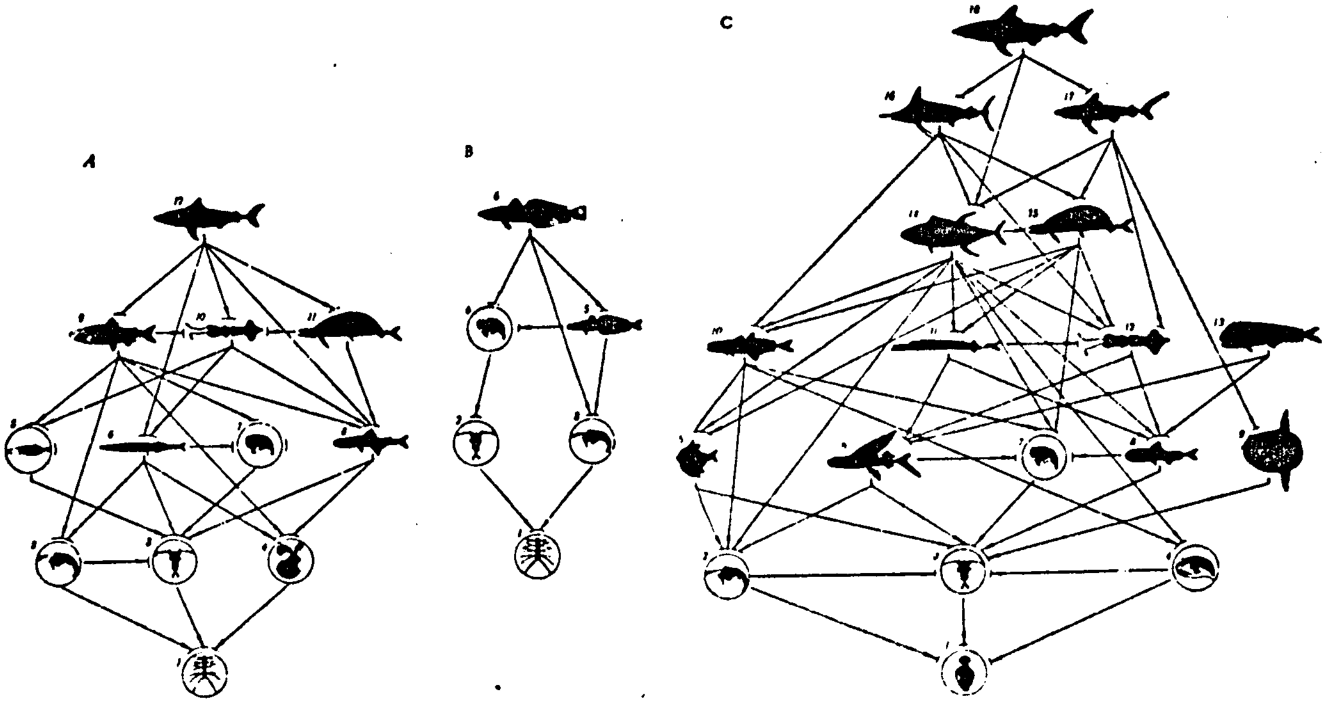
The species composition of the epipelagic nekton in the slope water is probably highly seasonal with few permanent residents. The wide seasonal fluctuations in temperature in the surface zone (upper 200 m) of the slope water with the accompanying seasonal variation in standing crop of the primary and secondary trophic levels (see Chapters 7.1 and 7.2) produce a variation in environmental conditions that encourages

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE
7-53

Trophic Links Among Epipelagic Fishes
(Parin, 1968)



A—subarctic waters; level I—phytoplankton (1); level II—phytophagous zooplankton: euphausiids (2), copepods (3), Pteropoda (4); level III—predatory plankton and planktophagous fishes: fish juveniles (5), saury (6), hyperiids (7), myctophids (8); level IV—nektonic predators: Pacific salmon (9), squid (10), lancetfishes (11); level V—large nektonic predators: mackerel shark (12).

B—antarctic waters: level I—phytoplankton (1); level II—copepods (2), euphausiids (3); level III—hyperiids (4), planktophagous fishes (5); level IV—predatory fishes (6).

C—tropical waters: level I—phytoplankton (1); level II—euphausiids (2), copepods (3), shrimp (4); level III—fishes of the "shifting layers" (5), flyingfishes (6), hyperiids (7), "subsurface" lanternfishes (8), moals (9); level IV—small deepwater ichthyophages (Chiasmodon, etc.) (10), nyctoepipelagic predators (snake mackerel) (11), squid (12), Corphaena (13); level V—tuna (14), lancetfishes (15); level VI—marlins (16), medium-sized sharks (17); level VII—large sharks (18).

temporal fluctuations. Most epipelagic fishes are summer migrants into the slope water, as probably also are a number of cetaceans, that respond to changing food supplies. The squid, reptiles, and some of the pelagic shelf fishes move into the deeper, relatively warm water of the inner slope when the temperature of the water on the shelf off north and middle Atlantic states approach their minimum tolerance levels.

The nekton of the mesopelagic zone is dominated by numerous species of small animals that collectively represent the greatest concentrations of swimming animals in the water column of the ocean. Dominant among these are a group of small mesopelagic fishes that are important links to the food chain, both in the epipelagic zone into which they migrate and in the deeper waters they inhabit. Large groups of schooling fish, such as the myctophids, although widely scattered and little studied, are an important part of the economy of the deep ocean areas.

In this section, we will consider separately several important representatives of the slope water nekton: the tunas and billfishes, mesopelagic fishes, the two most abundant species of squid, sea turtles, and the mammals. In some cases, these animals will be treated as a group and in other cases the life history of individual species will be described.

7.4.2 EPIPELAGIC FISHES AND MESOPELAGIC FISHES

TUNAS AND BILLFISHES

Large, pelagic fishes of open ocean areas include tunas and billfishes (swordfish, marlin, sailfish and spearfish). These fishes feed and reproduce up in the water column and have streamlined bodies suited for migrating long distances at great speeds. Their great mobility is indicated by recorded swimming speeds for tuna of up to 70 km per hour and for swordfish and marlin up to 130 km per hour (Parin, 1968). It is not surprising, then, that these fishes have a circular migratory path in the northwest Atlantic that covers a distance of probably 10,000 km each year (Mather, 1969).

The tunas and billfishes are important seasonal visitors to the slope and shelf waters of the study area. Basically, they are tropical and warm temperate fishes that most commonly inhabit the warm seas south of the Gulf Stream in waters along the permanent thermocline. These species move into the slope water from the south during the summer and are found feeding on the abundant shelf and slope water fishes during the warmer months. At this time, all along the shelf and in the slope from the Gulf of Maine to Cape Hatteras, they are taken by commercial and sport fishermen on the outer shelf, and are particularly concentrated at the heads of submarine canyons.

Knowledge of these fishes in general is somewhat limited because of the difficulty in studying populations of such wide-ranging species. Most of what is known of these species results from an analysis of long line catches from the commercial fishing operations (Wise and Davis, 1973, Sakagawa, 1975), from tagging studies (Mather, 1962 , 1969; Mather, Bartlett, and Beckett, 1967; Mather, Jones and Beardsley, 1972; Mather, Mason and Clark, 1974; and Beckett, 1970), or from exploratory fishing (Mather and Bartlett, 1962, Squire, 1962). These studies have described the general migration paths of these fishes and their relative abundance along the shelf and slope waters. A complete treatment of the life history of several Atlantic species of billfishes was given in the International Billfish Symposium, Kailui-Koma, Hawaii, August 9-12, 1972 Mather, Clark, and Mason, 1974 and 1975.

Components

The large, pelagic oceanic fishes are representatives of the family Scombridae (mackerels and tunas), Xiphidae (swordfish), Istiophoridae (marlins and sailfishes). Being members of the highest trophic levels, they are represented by relatively few species world-wide and because of their affinity for warmer water represented by even fewer in the slope water of the northwest Atlantic. A list of the Atlantic species that occurred in Japanese long-line catches (Wise and Davis, 1973) is provided in Table 7-36, along with a subjective estimate of their relative importance in the study area. Probably the bluefin tuna, Thunnus thynnus and the white marlin, Tetrapterus albidus are the dominant species in the slope waters. Several species (sailfish, spearfish) only stray into the study areas and are centered mainly below Cape Hatteras to the Carribean.

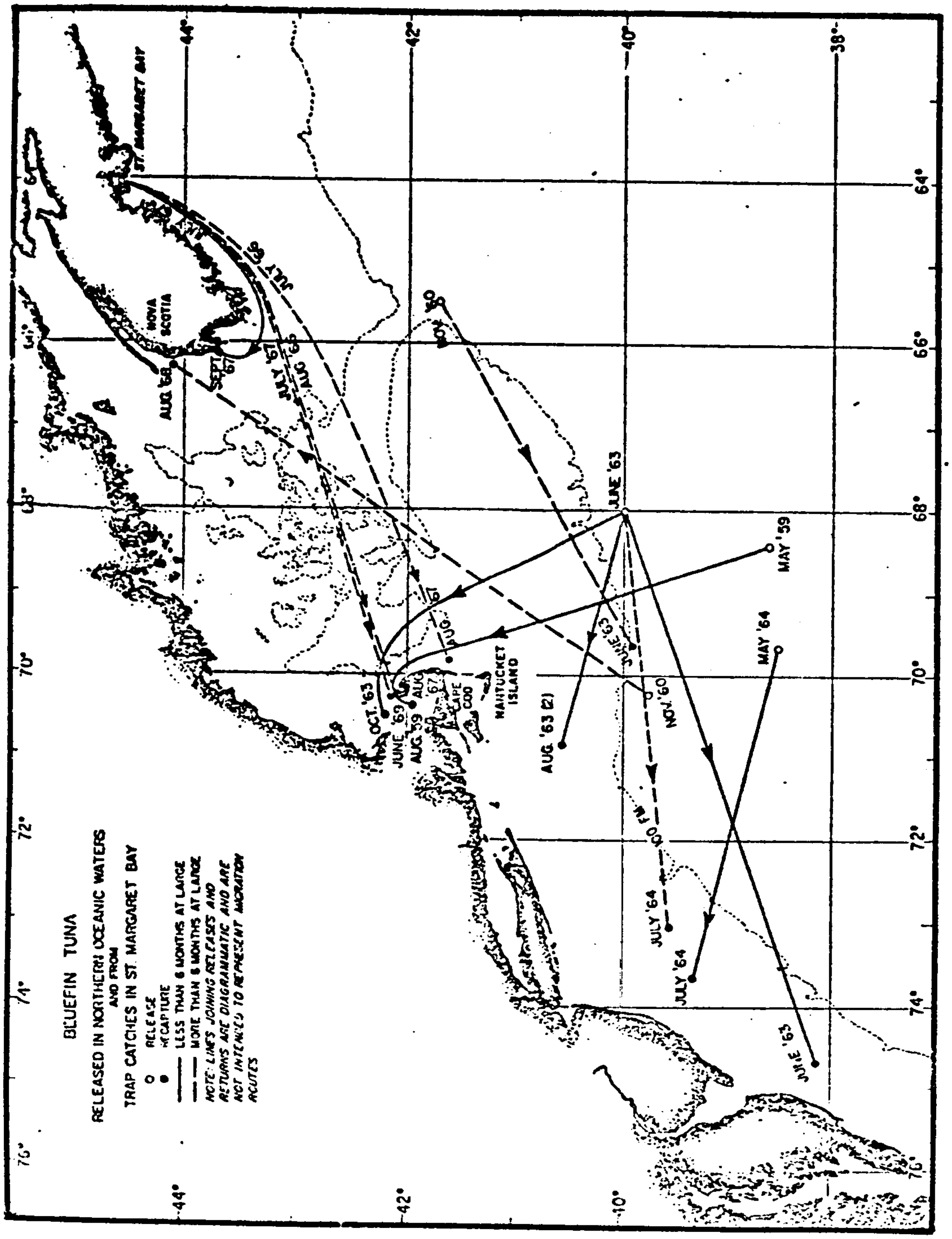
Distribution - Migration - Abundance - Food

Bluefin Tuna

The distribution and migration of bluefin tuna in the Atlantic follows a complicated pattern that suggests migrations by different age components (FAO, 1972). Tagging of bluefin, particularly off the Bahamas, has indicated interrelationships between groups from New England-Nova Scotia, Bahamas, Norway and eastern Brazil. Large bluefin tuna which occur off New England and Nova Scotia (FAO, 1972) appear to constitute a single stock (Figure 7-54). It appears, from tag returns of releases made between the Gulf Stream and the continental shelf from Cape Hatteras to the Newfoundland banks, that large bluefin move seasonally into the mid-Atlantic coast in late spring from the east with a gradual movement northeastward up the coast during the summer. They arrive late in the summer in the Gulf of Maine and Canadian waters. It is generally assumed that this stock belongs to the same group that pass northward along the edge of the Bahama Bank in May and June. Small bluefin also show a tendency to move northeastward from off Delaware Bay to off southern Massachusetts with the advance of the summer season, but then appear to move back to the New York waters late in the season rather than continuing on into the Gulf of Maine.

Table 7-36. Species of tuna and billfishes found in the Atlantic

		Common	Occasional
Bluefin Tuna	Thynnus thynnus	*	
Southern Bluefin	T. maccoyii		
Albacore	T. alalunga	*	
Bigeye Tuna	T. obesus		*
Yellowfin Tuna	T. albacares		*
Blackfin Tuna	T. atlanticus		
Swordfish	Xiphias gladius	*	
White Marlin	Tetrapterus albidus	*	
Blue Marlin	Makaira nigricans		*
Black Marlin	M. indica		
Sailfish	Istiophorus albicans		
Longbill Spearfish	Tetrapterus pfluegeri		
Skipjack Tuna	Euthynnus pelamis	*	



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-54 Recaptures of Bluefin Tuna Tagged From Trap and Longline Catches (FAO, 1972)

In absolute numbers the stocks of bluefin tuna are not large and they have been heavily fished. This is particularly true of the small bluefin which were particularly hard-pressed by the middle-Atlantic Ocean fishery operations that developed early in the 1960's. Exploratory longline fishing (Mather and Bartlett, 1962) carried out between the 200 m depth and the Gulf Stream indicated the distribution and relative abundance of bluefin during November (Figure 7-55). A surprising concentration of bluefin were found distributed along the 2000 m isobath south of New England to New York. The larger catches occurred in waters whose temperature ranged between 13.4°C and 16.8°C, and 15.9 to 17.3°C at 54.86 m and surface salinities of 33.65 o/oo to 35.30 o/oo. All four of the heavy catches were made at the entrance to canyons. Mather and Bartlett note the possibility that the greater mixing of deep and surface waters in these areas produced richer feeding grounds.

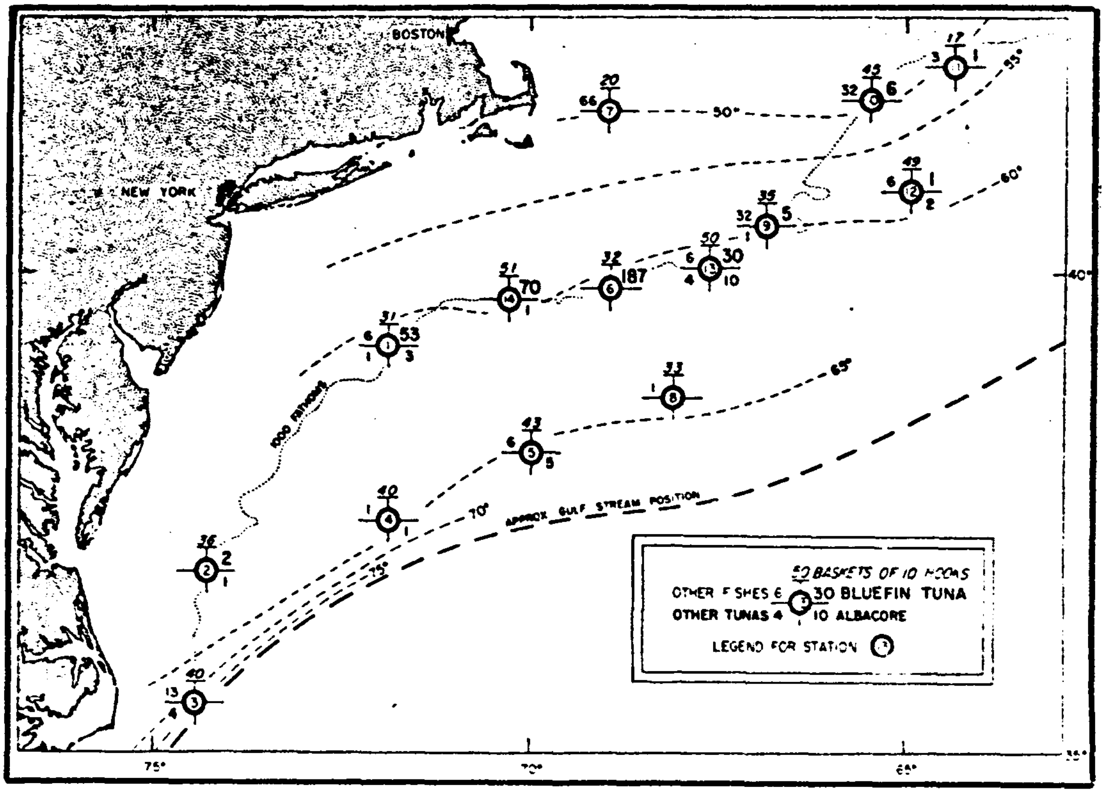
Further indications of seasonal distributions are from purse seine catches (Sakagawa, 1975). The catches for July, August and September for the years 1963, 1966 and 1973 (Figure 7-56) indicate the seasonal movements to northeastward along the coast.

Tuna feed on small pelagic fishes and invertebrates, primarily of the schooling type. The particular species depends on the local supply (Bigelow and Schroeder, 1953). Principal prey include herring, mackerel, squid and to some extent euphausid shrimp.

White marlin. The movement of white marlin follows a similar pattern to that of tunas, in that they move up the Florida current and the Gulf Stream and into the north and middle-Atlantic shelf and slope waters in the summer, then return to the Lesser Antilles through the open ocean in the fall. This general circular clock-wise pattern seems to be characteristic of the tunas and billfishes (Mather, 1969).

White marlin are considered more abundant in the western Atlantic, as indicated by the greater frequency of catches above 0.5 fish per hook in the longline fisheries (Mather, et al., 1972). The greatest summer abundance is off the New Jersey to Maryland coast to about 1829 m (Figure 7-57). These are fish that enter the area from the south about June and July, concentrate in the area during August and then move directly offshore in September and October (Figures 7-58 and 7-59). Because of repeated returns to the same area, the white marlin of this group are considered by Mather, et al. to form a distinct stock (middle Atlantic stock), although they may not be genetically distinct. These summer concentrations of white marlin are the object of a popular sport fishery and a longline commercial fishery.

Mather, Clark, and Mason (1975) attribute spawning and the feeding as the two primary factors controlling the distribution of the white marlin and secondarily environmental conditions. Coastal concentrations in the Caribbean relate to spawning activity, while coastal concentrations



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | **FIGURE** 7-55 | Location of Longline Catches of Bluefin Tuna Made in November on the Continental Slope (Mather and Bartlett, 1962)

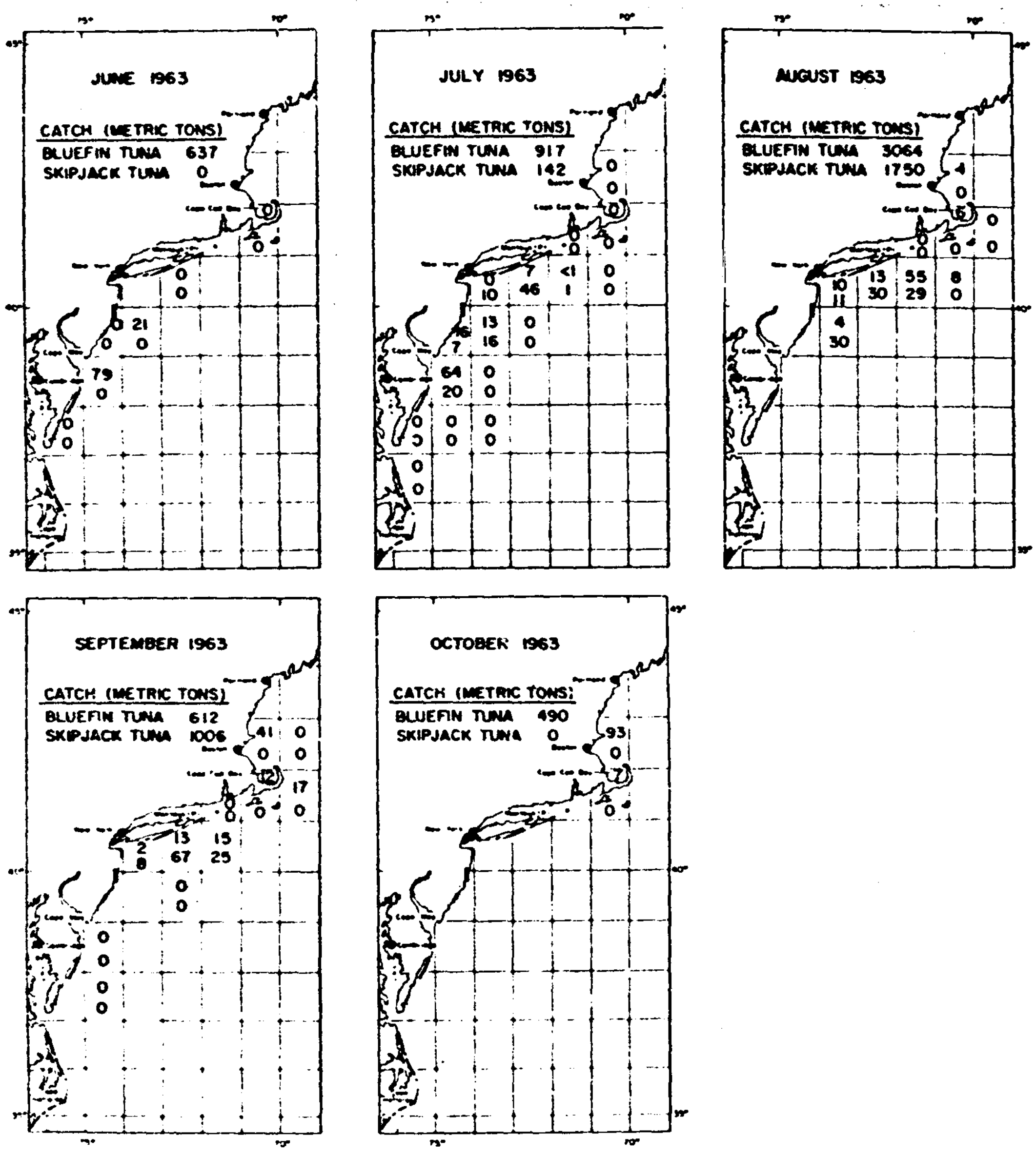
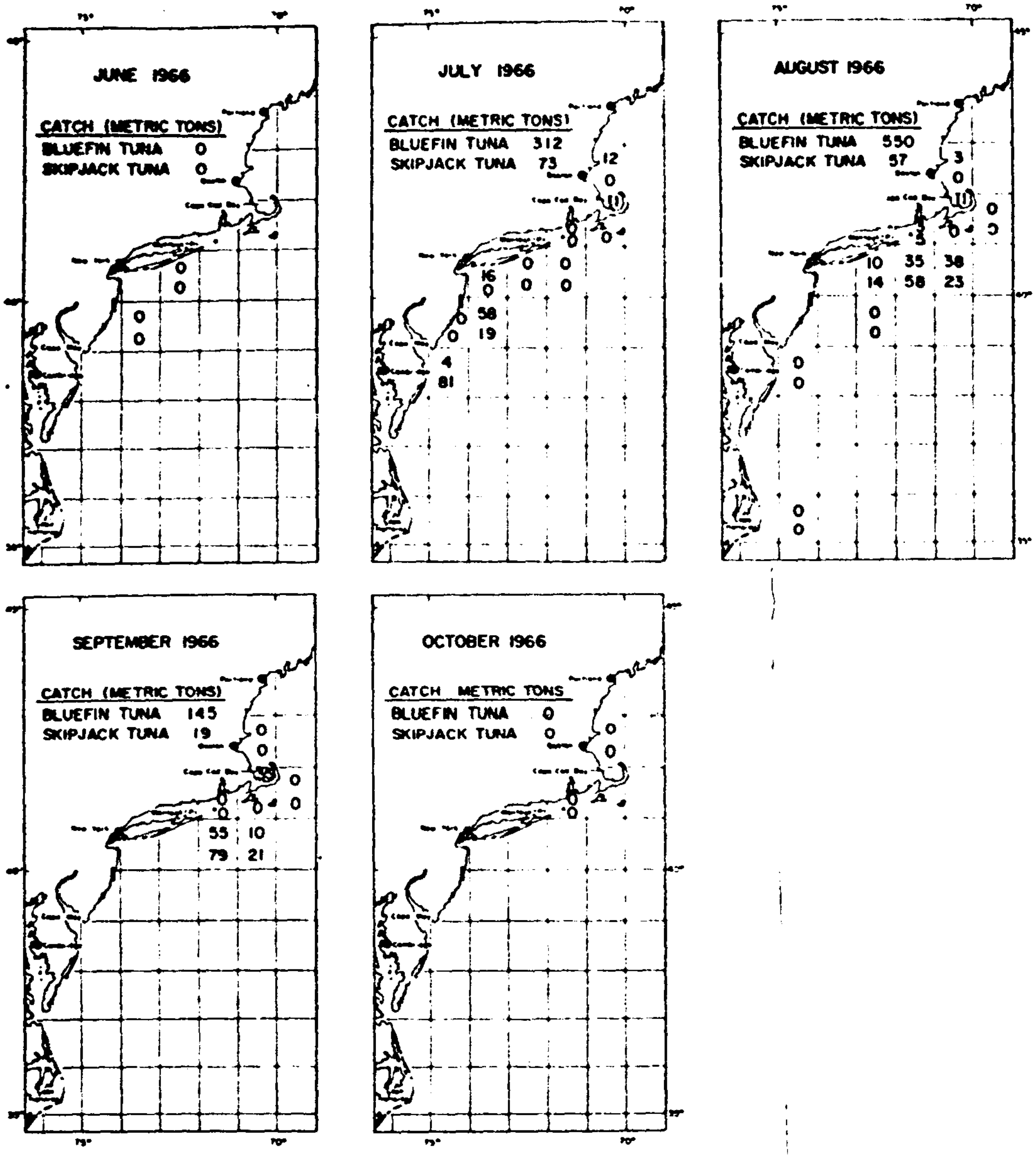


FIGURE 7-56A Percent of Bluefin and Skipjack Tuna by 1° Area and by Month from the Purse Seine Fishery in the Northwest Atlantic, 1963 (Sakagawa, 1975)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM

FIGURE 7-56B

Percent of Bluefin and Skipjack Tuna by 1° Area and by Month from the Purse Seire Fishery in the Northwest Atlantic, 1966 (Sakagawa, 1975)

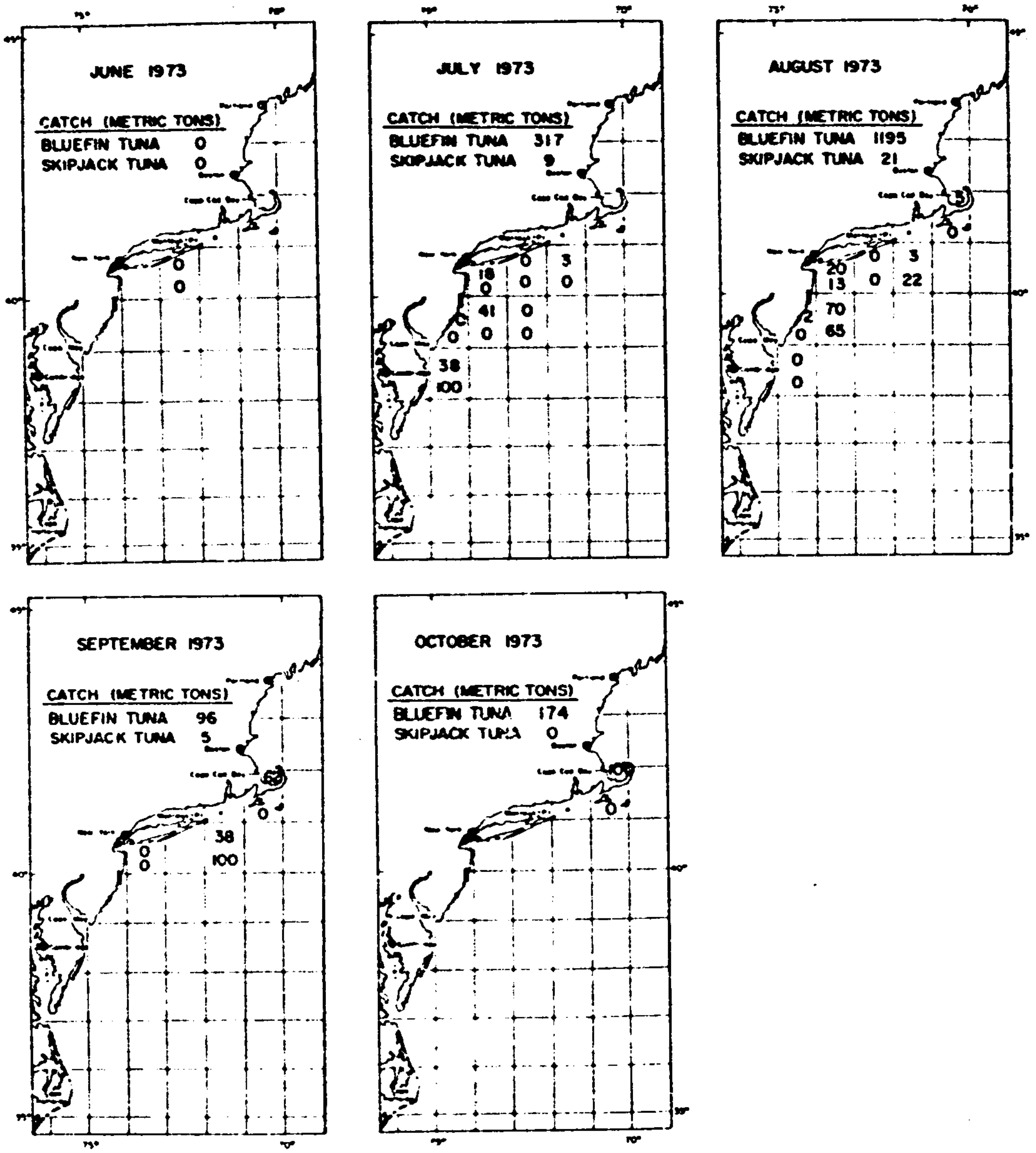
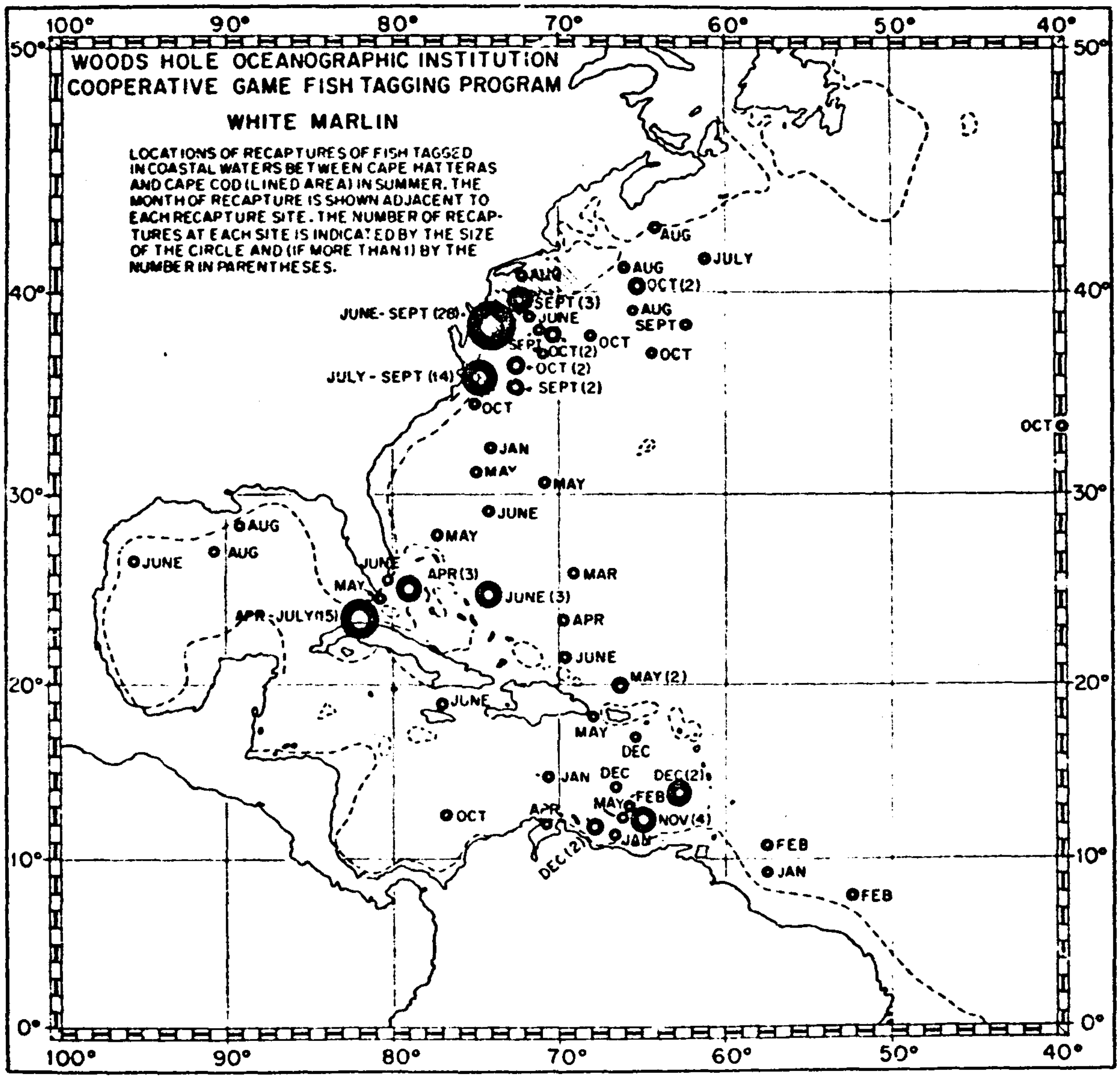
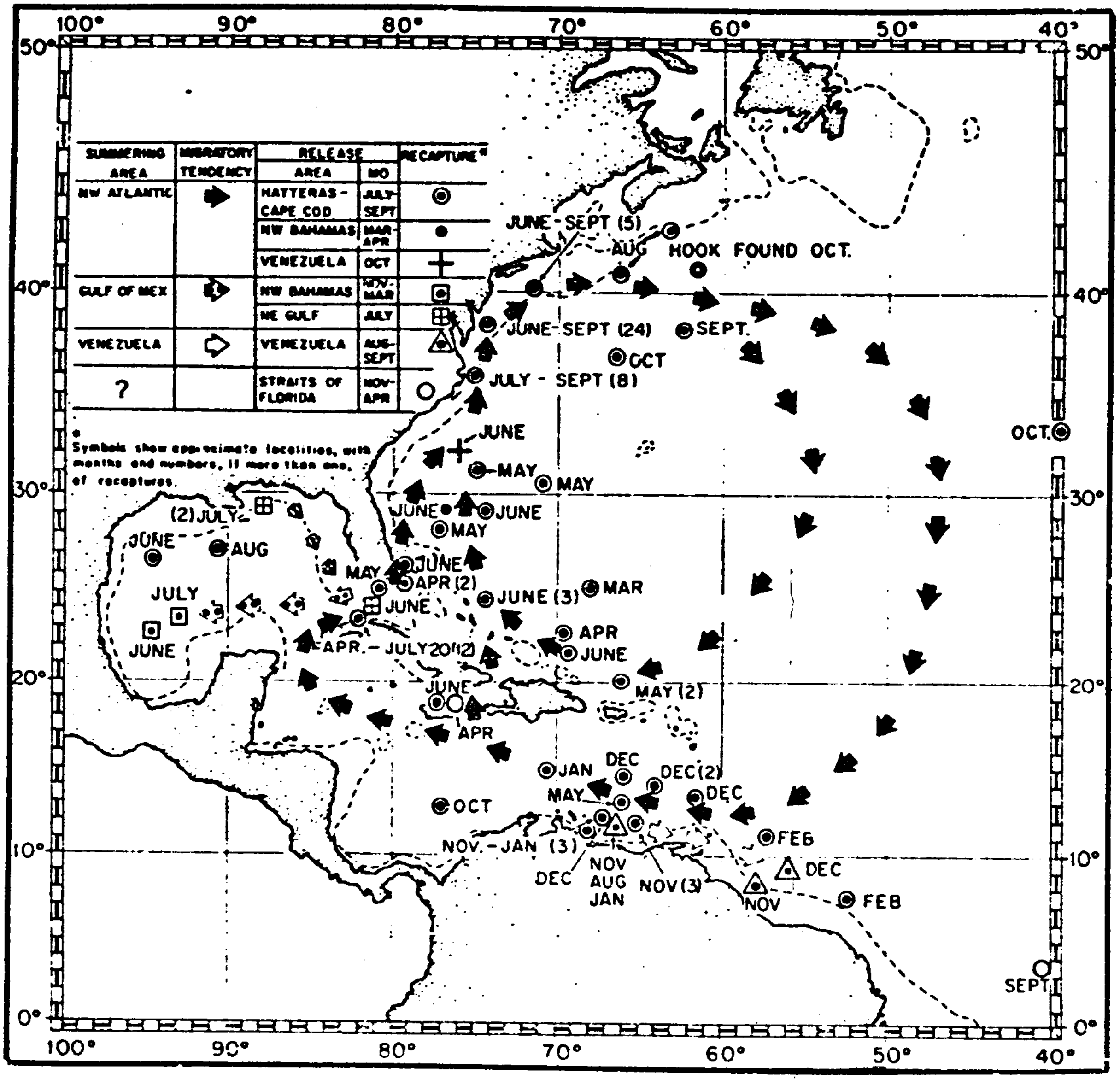


FIGURE 7-56C Percent of Bluefin and Skipjack Tuna by 1° Area and by Month from the Purse Seine Fishery in the Northwest Atlantic, 1973 (Sakagawa, 1975)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-57	Tag Returns from White Marlin Released in Coastal Waters Between Cape Hatteras, N.C. and Cape Cod, Mass. (Mather, Clark and Mason, 1975)

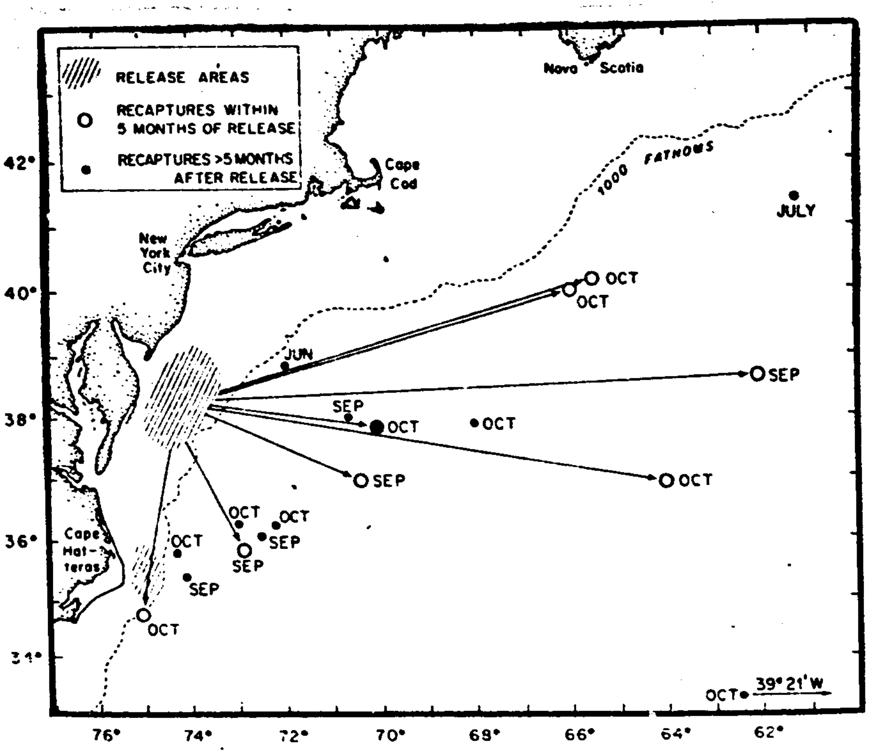


SUMMERING AREA	MIGRATORY TENDENCY	RELEASE AREA	RELEASE MO	RECAPTURE*
NW ATLANTIC	➡	HATTERAS-CAPE COD	JULY-SEPT	◉
		NW BAHAMAS	MAR-APR	●
		VENEZUELA	OCT	+
GULF OF MEX	➡	NW BAHAMAS	NOV-MAR	▣
		NE GULF	JULY	⊞
VENEZUELA	⇨	VENEZUELA	AUG-SEPT	△
?		STRAITS OF FLORIDA	NOV-APR	○

* Symbols show approximate localities, with months and numbers, if more than one, of recaptures.

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-58	Migratory Tendencies of White Marlin From Tag Return Data (FAO, 1972)



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	**FIGURE** 7-59	Recapture Outside 1000 Fathom Contour of White Marlin Tagged During the Summer in Coastal Waters Between Cape Cod and Cape Hatteras (Mather, Mason, and Clark, 1974)

along the middle Atlantic relate to feeding. Within this general framework, water temperatures strongly influence their distribution. Squire (1962) noted that the surface temperatures where white marlin were caught in exploratory longline fishery in the northwest Atlantic were between 21.1°C and 28.3°C, with a weighted mean of 24.8°C, and the temperatures at the estimated fishing depth (52.7 m) were between 10°C and 27°C, with a weighted mean of 20.5°C. It has been noted by several authors (Mather, et al., 1975) that concentrations of white marlin occur in areas where less saline coastal waters mix with more saline oceanic waters. Thus, the white marlin sport fish grounds off southern New Jersey and Maryland were of higher salinity than the surrounding inshore waters and were identifiable by the abrupt change from lower to higher salinity. Areas of white marlin concentrations also show distinctly high plankton volumes. Submarine canyons, when located in areas with suitable water conditions, are locations of feeding concentrations of marlin. This is particularly true of the Norfolk, Washington, Baltimore, Wilmington and Hudson Canyons.

White marlin are feeders on small schooling fishes and invertebrates, and as such, compete with the tunas and sharks for food (Mather, et al., 1975). Squid play a particularly important part in their diet. Important food species are indicated in Table 7-37.

Swordfish. Swordfish also range along the shelf and slope waters of the middle Atlantic coast during the summer months and are of interest to sport and commercial fishermen. Their marked seasonal variation in the northwest Atlantic was noted by Beckett (1974). In the winter, the fish are confined to the water of the Gulf Stream where surface temperatures exceed 15°C. In the warmer months, they range over a much wider area, after following the northern movement of increasing water temperatures in the spring. Their summer range extends along the edge of the continental shelf from Cape Cod to the Grand Banks; occasionally, they are found as far north as the Miramichi River in the Gulf of St. Lawrence. This summer distribution is generally limited by the 13°C isotherm, with only a few fish found below 15°C. There is a relationship between temperatures and several components of the swordfish population. Females and larger, older individuals seem able to better tolerate cooler waters than males or small individuals. Therefore, the population of swordfish at the edge of the continental shelf is likely to consist of large females.

The feeding habits of the swordfish is reported from specimens caught along the 200 m depth from Cape Cod to the Grand Banks (Scott and Tibbo, 1974). The species of primary importance in the diet of swordfish from this sampling were squid (Illex illecebrosus), mackerel, barracudinas (family paralepididae), redfish (Sebastes marinus), lantern fishes (Myctophidae), and silver hake. The fishes contributed a greater volume (78.7 to 94 percent) to the diet than the squid. The sixteen families of fishes identified in the swordfish stomachs are shown in Table 7-38) and reflect a mixture of species from the shelf and deeper slope

Table 7-37. Frequency of occurrence of different organisms in stomachs of 55 white marlin taken by anglers between Ocean City, Md., and Atlantic City, N.J. (after Mather, *et al.*, 1975)

	Number of Times Occurring	
	1959	1960
VERTEBRATES		
Fishes		
Clupeiformes (unidentified)	1	
Clupeidae (Dussumieriinae)		
Atlantic round herring, *Etrumeus sadina*	22	1
Hemiramphidae		
Halfbeak, *Hyporpamphus unifasciatus*	2	1
Carangidae		
Banded rudderfish, *Seriola zonata*	4	1
Round scad, *Decapterus punctatus*	1	1
Jack, *Caranx* sp.	1	4
Unidentified carangids	3	
Scombridae		
Mackerel, *Scomber* sp.	2	
Xiphiidae		
Swordfish, *Xiphias gladius*		1
Dactylopteridae		
Flying gurnard, *Dactylopterus volitans*	1	
Fish remains (unidentified)	9	
INVERTEBRATES		
Mollusca (Cephalopoda)		
Squid, *Loligo pealei*	13	2
OTHER		
Rockweed, *Fucus* sp.		1
EMPTY	10	4

Table 7-38. Species and families of fishes found in swordfish stomachs (Scott and Tibbo, 1974)

Fish	Total Volume (CC)
Scombridae (Mackerels)	
Scomber scombrus (Atlantic mackerel)	18,110
Paralephididae (Barracudinas)	10,017
Scorpaenidae (Scorpionfishes)	
Sebastes marinus (Redfish)	7,355
Myctophidae (Lanternfishes)	3,802
Gadidae (Cods)	
Merluccius bilinearis (Silver hake)	3,485
Alepisauridae (Lancetfishes)	
Alepisaurus ferox (Longnose lancetfish)	1,365
Stromateidae (Butterfishes)	
Centrolophus niger (Black ruff)	1,005
Balistidae (Triggerfishes and Filefishes)	455
Evermannellidae (Saber-toothed fishes)	198
Malacosteidae (Loosejaws)	
Malacosteus niger (Loosejaw)	160
Carangidae (Jacks and Pompanos)	100
Nemichthyidae (Snipe eels)	
Nemichthys scolopaceous (Slender snipe eel)	97
Stomiatidae (Scaled dragonfishes)	
Stomias boa ferox (Boa dragonfish)	40
Gempylidae (Snake mackerels)	
Nealotus tripes	40
Scomberesocidae (Sauries)	
Scomberesox saurus (Atlantic saury)	16
Gonostomatidae (Anglemouths)	
Maurolicus muelleri (Muller's pearlsides)	2
Unidentified fishes	4,219
Total	50,466

waters that would be expected from the area near 200 m isobath.

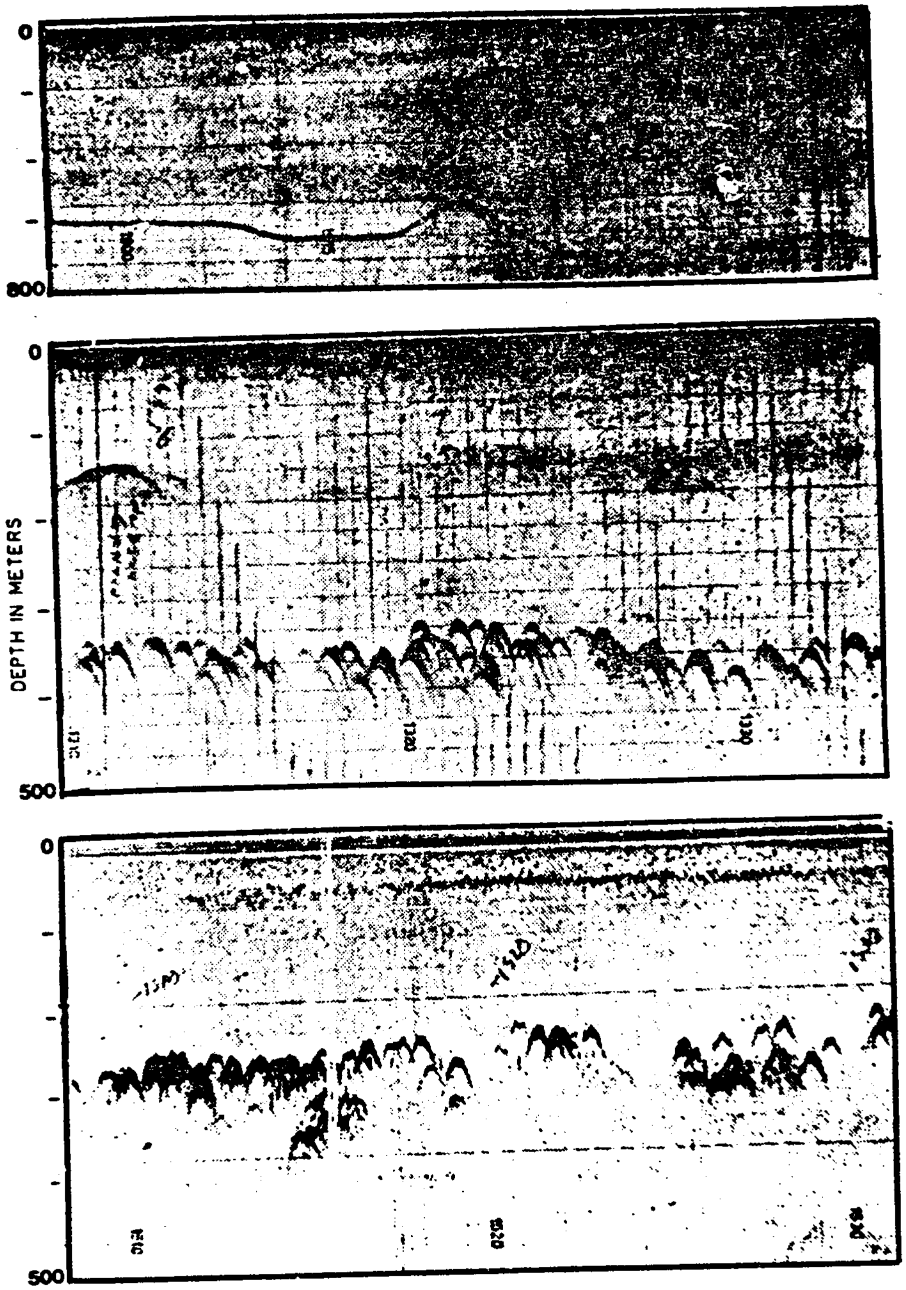
MESOPELAGIC FISHES

One of the least understood fauna inhabiting the pelagic regions of the slope water are a group of small fishes that reside in the dimly lit waters beyond the shelf between 100 to 1000 m, The mesopelagic fishes, that are represented by many species over a wide range of ocean and that continually move vertically in the water column, present a difficult sampling problem. For this reason, very little is known about their life history and distribution; even their taxonomy is not complete.

These animals occur in large schools that are continually shifting their positions diurnally, and are largely responsible for the phenomenon known as "deep sound scattering layer" that was first noted from sonar soundings during World War II. The characteristics of these layers suggest that the reflectors consist of gas-filled swim bladders of small mesopelagic fishes. However, all the species responsible are still not completely identified. Different types of sound scattering layers occur in different regions (Emery and Uchupi, 1972). The slope water has a characteristic pattern of dense hyperbolic sequences (Figure 7-60) that were attributed to schools of fish, but until recently their identity was unknown. Observations by the deep submersible, ALVIN, within the layer, identified the Myctophid fish Ceratoscopelus maderensis as the culprit. This species is restricted in distribution to the slope water and was found within a layer to be in schools of 5 to 10 m thick, 10 to 100 m in diameter and 10 to 200 m apart. Within the schools the fish were concentrated in groups of 10 to 15/m3 (Backus, Craddock, Haedrich, Shores, Teal, Wing, Mead, and Clarke, 1968).

These fishes, although of no commercial importance to man, form one of the major links in the pelagic food chain. Their role is that of forage to the animals of higher trophic levels, such as tuna, billfishes, and sharks, and reduction in their numbers would probably alter the economy of the ocean seriously.

Published accounts of the mesopelagic fishes in the slope waters are few. Some systematic work on particular groups of fishes that are represented in the slope waters have been carried out by a number of authors but this work is by no means complete. Some aspects of the ecology and biology of these fishes have been examined. Backus, Craddock, Haedrich and Shores (1970) presented an extensive treatment of the distribution and faunal assemblages of mesopelagic fishes in the western north Atlantic Ocean. Locally, their faunal characteristics in warm core eddies (Haedrich, 1972) and in western Sargasso Sea thermal fronts (Backus, Craddock, Haedrich, Shores, Teal, Wing, Mead and Clarke, 1968) have been examined. Probably the most recent data of faunal composition in the slope waters is from an examination of mid-water trawl collections from the deep water dump-site sponsored by National Oceanic and Atmospheric Administration



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM | **FIGURE** 7-60 | Deep Scattering Layer Typical of the Northwest Atlantic Slope Water (Emery and Uchupi, 1972)

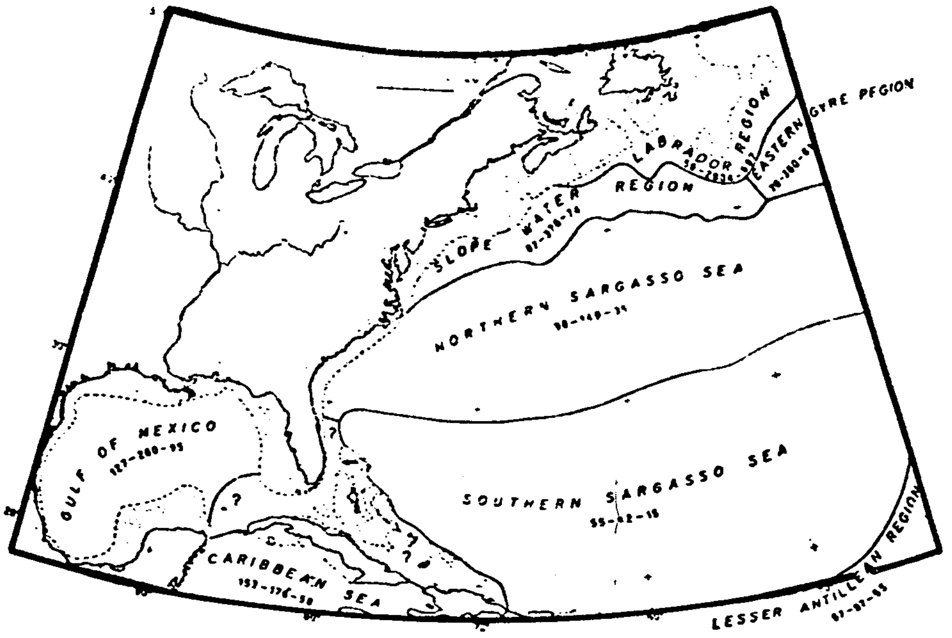
(Krueger, Keene and Keller, 1975).

Composition and Distribution

The general faunal composition of mesopelagic fishes in the western north Atlantic consists of a few abundant and many rare species (Backus, et al., 1970). Dominant in terms of numbers of species and numbers of individuals are the fishes from the families Myctophidae and Gonostomatidae. Backus, et al. found a total of 350 mesopelagic species in the equatorial and western North Atlantic and about 80 species occurring commonly enough for distributional consideration. About three-fourths of these belong to the families mentioned above. They considered the distribution patterns of these fishes in terms of faunal zones (Figure 7-61). The slope faunal region, as defined by Backus, et al., consists of a northern boundary at the continental shelf and the 200 m isotherm of 9°C and a southern boundary at the Gulf Stream following the 200 m isotherm of 15°C. Within this region, the dominant species are shown in Table 7-39. Three groups of primarily myctophid species could be identified with the western North Atlantic region including the slope water. One group had its southern limit at the Gulf Stream and was exemplified by the myctophid Ceratoscopelus maderensis and eight other species. Another group of four myctophid and two stomiatoid species had a boundary between the northern and southern Sargasso Sea, and the third group, including three myctophids, three gonostomatids, and one stomiatoid species had their southern limit in the Gulf of Mexico. They concluded that the variety of overlapping distribution patterns gave each pelagic region a distinct fauna with a characteristic assemblage of species in characteristic proportion and diversity.

In the deep water dump-site sampling region (see Chapter 7.2 for location), off the shelf edge of the New York Bight, Krueger, et al. (1975) examined the faunal assemblage from ten oblique tows made to a maximum depth of 550 to 790 m. The summary from their catch data and the distribution of specimens by depth is shown in Tables 7-40 and 7-41. The 10 trawls captured 4,029 specimens with a total volume of 2523.4 ml. They represented 114 species from thirty families and ten orders. From the comparison of observed and expected catches, they concluded that the distribution of mesopelagic fishes was strongly clumped and that many may have been stratified by species size in the water column, as indicated by decreasing number of specimens and increasing volume with depth. Of the 114 species collected, they considered most of the 73 species that were poorly represented in the catches to be incidental strays from other regions (continental shelf, bathypelagic zone). Most of the remaining species were considered to be important residents and known or suspected spawners in the slope waters. The catch data on these species is given in Table 7-42.

The following synopsis of the major species of mesopelagic fishes from the deepwater dump-site study is taken directly from the report of Krueger, et al. (1975):



Numbers in order refer to total number of species of mesopelagic fishes, average number caught per hour and average volume of catch (cc/hour).

ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-61	Mesopelagic Regions of the Western North Atlantic. (Emery and Uchupi, 1972)

Table 7-39. Dominant species of mesopelagic fishes of the slope water region (modified from Backus, *et al*., 1970)

	Rank Abundance	% of Total No.
Lobianchia dofleini	1	27
Ceratoslopelus maderensis	2	20
Lamphnyctus pusillus	3	6
Benthosema glaciale	4	5

Table 7-40 Summary of catch data at the deepwater dumpsite area (Krueger, et al., 1975). New species are those encountered for the first time. Expected values are based on percentage trawl time. Asterisks indicate observed values significantly different from expected as determined by chi-square analysis (* = .05; ** = .01; d.f. = 1).

	Trawl Number										
	1	2	3	4	5	6	7	8	9	10	Total
Maximum depth (m)	750	675	790	620	720	615	640	630	550	550	---
Trawl time (hours)	3.06	1.21	1.41	2.30	1.60	2.46	2.83	3.26	2.05	1.78	21.96
Number of species	45	34	26	43	47	46	63	54	46	40	114
Species/hour	14.7	27.9	18.4	18.7	29.4	18.7	22.3	16.6	22.4	22.5	---
Number of "new" species	45	9	5	9	11	4	17	8	3	3	114
Number of specimens											
expected	561	222	259	422	294	451	519	598	376	327	4029
observed	456**	170**	42**	333**	469**	497*	556	726**	449**	331	4029
Total volume:											
expected	351.5	139.0	162.0	264.2	184.0	325.3	374.5	235.7	204.6		2523.4
observed	405.6**	119.8	50.6**	259.0	24.94**	425.6**	368.6	215.0	149.2**		2523.4

Table 7-41 Distribution of specimens by maximum trawl depth (Krueger, et al., 1975)

	Maximum Depth (m)		
	501-500	601-700	701-800
Trawl Numbers	9-10	2-4-6-7-8	1-3-5
Total Trawling Time (Hours)	3.83	12.06	6.07
Number of Specimens	780	2282	967
Total Volume (ml)	364.2	1363.6	705.6
Specimens/Hour	203.7	189.2	159.3
Volume/Hour	95.1	113.1	116.2
Mean Volume/Specimen	0.47	0.60	0.73

Table 7-42 Leptocephali and known or suspected spawners in the deepwater dump area

Family	Species	Specimens	Volume (ml)
Muraenidae	*Leptocephalus* sp. A.	25	5.0
Nettastomatidae	*Saurenchelys cancrivcra*	19	5.0
Congridae	*Leptocephalus* sp. I	24	13.0
Ophichthidae	*Leptocephalus* sp.	17	2.7
Serrivomeridae	*Serrivomer beanii*	34	66.8
Nemichthyidae	*Nemichthys scolopaceus*	15	67.4
Gonostomatidae	*Cyclothone alba*	36	1.5
	C. braueri	383	20.4
	C. microdon	1300	111.6
	C. pallida	111	11.8
	C. pseudopallida	126	11.9
	Gonostoma elongatum	37	427.5
	Maurolicus muelleri	361	120.5
	Valenciennellus tripunctulatus	10	1.5
	Vinciguerria nimbaria	30	4.5
Sternoptychidae	*Argyropelecus aculeatus*	27	50.6
	A. hemigymnus	19	8.4
	Sternoptyx diaphana	69	27.0
Chauliodontidae	*Chauliodus sloani*	35	284.6
Stomiatidae	*Stomias boa ferox*	10	27.2
Paralepididae	*Lestrolepis intermedia*	22	2.0
	Notolepis rissoi	48	3.0
	Paralepis corregonoides	18	2.4
Myctophidae	*Benthosema glaciale*	480	335.9
	B. suborbitale	18	1.5
	Bolinichthys indicus	21	10.6
	Ceratoscopelus warmingi	36	14.4
	Diaphus dumerili	165	33.3
	Diogenichthys atlanticus	26	2.6
	Hygophum hygomi	95	76.1
	Lampanyctus pusillus	12	3.5
	Notolychnus valdiviae	30	2.0
	Notoscopelus resplendens	33	21.2
	Total	3692	1778.3

Order Anguilliformes

The four eels taken only as leptocephali represent four families: Muraenidae (*Leptocephalus* sp. A), Nettastomatidae (*Saurenchelys cancrivora*), Congridae (*Leptocephalus* sp. I) and Ophichthidae (*Leptocephalus* sp.). There are conveniently discussed together.

Leptocephalus larvae occur in great numbers in the epipelagic zone, yet their taxonomy is poorly understood; most cannot yet be identified with any known adult. Studies on those species whose life histories are known indicate that leptocephali may travel great distances from their site of origin (Castle, 1969). The skin of leptocephali appears incapable of acting as a barrier to the external environment (Hulet, 1972), and these larvae are actually almost isosmotic with sea water (Hulet, *et al*, 1972). Thus, leptocephali may be particularly susceptible to pollutants, and although their spawning areas are unknown, we include these four species in our list of spawners.

Family Serrivomeridae

Serrivomer beanii. None of the 34 specimens of this species are leptocephali. However, the absence of larvae may be a function of the life history. *S. beanii* spawns in the northern Sargasso Sea, but the leptocephali are abundant only from January through March, and they metamorphose in early spring (Tighe, in preparation). The large number of specimens captured suggests that this species also spawns in the Deepwater Dump area.

Family Nemichthyidae

Nemichthys scolopaceus. The absence of leptocephali of this species is surprising, since *N. scolopaceus* is widely distributed in the western North Atlantic and leptocephali are found throughout the year in the northern Sargasso Sea (Bengtson, 1973). The largest individual taken is within the size range of Bengtson's (1973) mature adults, and we tentatively assign this species to our list of spawners.

Family Gonostomatidae

Cyclothone spp. *Cyclothone* larvae are too small to be retained by the mesh of the IKMT (Bond, 1974) and none were captured. Five species were taken in moderate to large numbers: *C. alba*, *C. braueri*, *C. microdon*, *C. pallida* and *C. pseudopallida*. The size ranges of all five encompass the ranges given for juveniles as well as mature adults by Bond (1974), and we believe that all reproduce in the study area.

Gonostoma elongatum. This is one of the most abundant large predators in the study area. The size range indicates that both larvae and mature adults are present (Bond, 1974), and this species undoubtedly spawns in the Deepwater Dump area.

Maurolicus muelleri. This is the third most abundant gonostomatid in the study area, exceeded only by *Cyclothone braueri* and *C. microdon*. We have sexed and staged each of the 361 specimens. Except for four subadult males and five subadult females, all are postlarvae or juveniles, indicating intensive spawning. The absence of mature adults suggests a one year life cycle. Okiyama (1971) reported that in the waters off Japan *M. muelleri* is most abundant near the edge of the continental shelf. This may also be true in the Atlantic, for in contrast to the present study material only two and four specimens were reported by Beebe (1937) and Bond (1974), respectively, from off Bermuda.

Valenciennellus tripunctulatus. This species is widespread in the North Atlantic (Backus, *et al*., 1970) and spawns throughout the year in the northern Sargasso Sea (Krueger, 1972). Although postlarvae are absent, the ten specimens include juveniles as well as large adults, and we tentatively assign this species to our list of spawners.

Vinciguerria nimbaria. Grey (1964) reported that this species is abundant in the North Atlantic only south of 35°N, and Backus, *et al*. (1970) provisionally considered *V. nimbaria* a tropical species transported to the slope water by the Gulf Stream only as waifs. However, based on the sizes reported from the Indian Ocean (Silas and George, 1969), the present 30 specimens include postlarvae as well as adults, and we tentatively assign *V. nimbaria* to our list of spawners.

Family Sternoptychidae

Three hatchetfishes were taken in sizeable numbers: *Argyropelecus aculeatus*, *A. hemigymnus* and *Sternoptyx diaphana*. Baird (1971) considered the three to form a species assembly in the western North Atlantic, and noted for *Argyropelecus* that "Wherever a species is found in an area in numbers, it seems to represent a breeding population" (p. 106). The present study material includes postlarvae of all three species, and all undoubtedly spawn in the Deepwater Dump area.

Family Chauliodontidae

Chaulidos sloani is one of the most abundant large predators in the study area. One postlarva, 29 mm SL, was taken and the large number of specimens (35) suggests a self-maintaining population.

Family Stomiatidae

Stomias boaferox occurs throughout cooler waters of the western North Atlantic (Gibbs, 1969). Our ten specimens are of postlarval to adult size (32-208 mm SL), and this species almost certainly spawns in the study area.

Family Paralepididae

Three species were common in the study area: Lestrolepis intermedia, Notolepis rissoi and Paralepis coregonoides. The study material includes specimens of postlarval size (Rofen, 1966) for each species, and we assume that all three spawn in the area.

Family Myctophidae

Benthosema glaciale. This is the most abundant lanternfish in the study area, with 480 specimens. These show a strikingly bimodal size distribution, with 202 of the specimens measuring 10-16 mm SL, the rest 29-68 mm. The smaller specimens are comparable to young of the year described from the slope water off Nova Scotia by Halliday (1970), and B. glaciale unquestionably spawns in the Deepwater Dump area.

Benthosema suborbitale. The study material includes several specimens 10-11 mm SL, the size at which postlarvae of this species undergo metamorphosis (Moser and Ahlstrom, 1970). Although the species attains a size of about 30 mm, the largest of our 18 specimens is only 21 mm. However, this may be due to a one year life cycle. B. suborbitale is a broadly tropical species, occurring regularly in the slope water (Backus, et al., 1970), and we tentatively include it in our list of spawners.

Bolinichthys indicus is represented by 21 specimens, 20-38 mm SL. This is the approximate size range of specimens taken in March-April in the northern Sargasso Sea, where the spawning peak is in early summer (Gibbs, et al., 1971), and we tentatively add it to our list of spawners.

Ceratoscopelus maderensis. Although 40 specimens were taken, all are large (48-73 mm SL). Backus, et al. (1970) characterized this as a northern species. Their Figure 13 indicates that C. maderensis is far more abundant to the east and north of the study area, and larvae have been identified from the Georges Bank area (Moser and Ahlstrom, 1970). We suspect that this species does not reproduce in the study area and that the present specimens are expatriates from colder waters.

Ceratoscopelus warmingi. Backus, et al. (1970) characterized this as a broadly tropical species that occurs regularly in the slope water. Our size range (16-60 mm SL) is similar to that in the northern Sargasso Sea, where the species maintains a resident population (Gibbs, et al., 1971), and we include it in our list of spawners in the Deepwater Dump area.

Diaphus dumerili is the second most abundant myctophid, with 165 specimens, 13-46 mm SL. Nafpaktitis (1968) found this species common off the continental slope from the Bahamas to Cape Cod, but recognized only two spawning populations, one in the eastern Caribbean, the other in the Gulf of Guinea. He found no ripe females smaller than 52 mm SL in the

Caribbean, while those in the Gulf of Guinea were mature at a much smaller size (40-42 mm). Examination of the gonads of our four largest specimens (42-46 mm SL) reveals that all are subadults. Three are females, with eggs ca. 0.1 mm in diameter. The single male has small but clearly recognizable testes. These specimens may represent maturing individuals that spawn in summer. At any rate, we cannot dismiss 165 specimens as waifs and suspect that D. dumerili spawns in the study area as relatively small adults, as it does in the Gulf of Guinea.

Diaphus rafinesquei spawns in the eastern Atlantic, and the small size (13-35 mm SL) of our few specimens (15) supports Nafpaktitis' (1968) contention that this species is transported into the western Atlantic as waifs.

Diogenichthys atlanticus is widespread in the North Atlantic (Backus, et al., 1970). This is a diminutive species, and the size range of our specimens (12-21 mm SL) is comparable to that in the northern Sargasso Sea where D. atlanticus is known to spawn (Gibbs, et al., 1971). We consider the present 26 specimens to represent a spawning population in the Deepwater Dump area.

Hyophum benoiti is represented by only ten small specimens, 12-17 mm SL. The peak spawning period in the northern Sargasso Sea is in March (Gibbs, et al., 1971), suggesting that the present specimens are waifs from waters to the southwest.

Hygophum hygomi is the third most abundant myctophid, with 95 specimens, 14-49 mm SL. The size range is very similar to that of specimens taken in March and April in the northern Sargasso Sea, where the species spawns in late fall and winter (Gibbs, et al., 1971), suggesting that it spawns in the study area as well.

Lampanyctus alatus is a tropical species (Backus, et al., 1970), and we consider the present 24 specimens (15-48 mm SL) waifs from waters to the southwest.

Lampanyctus pusillus is represented by 12 specimens, 16-40 mm SL. This is a northern species (Backus, et al., 1970), and the size range of our specimens is very similar to that of individuals taken in April in the northern Sargasso Sea, where L. pusillus spawns year-round (Gibbs, et al., 1971). We tentatively include it in our list of species.

Lepidophanes guentheri is a tropical species (Backus, et al., 1970). Our 34 specimens fall into two size ranges, 15-29 mm SL and 39-62 mm SL, both present in approximately equal numbers. We consider these to represent two year classes of waifs, the smaller specimens consisting of recent arrivals, the larger ones representing individuals which survive in the slope water but are incapable of reproduction.

Lobianchia dofleini is represented by 14 specimens, 16-35 mm SL. O'Day and Nafpaktitis (1967) showed that individuals of *L. dofleini* are expatriated from the eastern Atlantic and fail to develop ripe gonads in waters west of 45 W.

Myctophum affine is represented by 15 small specimens, 15-32 mm SL. The species attains a maximum size of over 60 mm SL (Gibbs, 1957). This is a tropical species (Backus, *et al*., 1970) and probably occurs in the slope water only as waifs.

Notolychnus valdiviae is a diminutive species, represented here by 30 specimens, 10-21 mm SL. The species is widespread in the North Atlantic (Backus, *et al*., 1970) and our size range approximates that of the large spawning population in the northern Sargasso Sea (Gibbs, *et al*., 1971). We include it in our list of spawners.

Notoscopelus resplendens is another species characterized by Backus, *et al*. (1970) as broadly tropical in distribution, occurring regularly in the slope water. Our 33 specimens range from 23-69 mm SL. Twenty-nine of these are in the 23-38 range and probably represent the products of a single spawning, suggesting that *N. resplendens* reproduces in the study area in late fall and winter, as it does in the northern Sargasso Sea (Gibbs, *et al*., 1971).

Family Melamphaidae

Scopelogadus beanii is represented by 13 specimens, 66-114 mm SL. Ebeling and Weed (1963) showed that postlarvae and young were found in warmer waters, and the absence of small specimens indicates that *S. beanii* does not reproduce in the Deepwater Dump area.

Physical factors

Backus, *et al*. (1970) discuss some of the physical factors connected with the distribution of mesopelagic fishes. Very little is known about what factors influence the distribution of these fishes. The "water mass" hypothesis that relates distribution to temperature/salinity relationships is most popular. However, their observations indicate a greater complexity. They note that sound scattering maxima, temperature inversions, bottom thermocline and surface isothermal layers, and transparency mark the areas of concentrations of mid-water fishes. Characteristic changes in faunal assemblages have been noted in warm core eddies that contain warm water of tropical origin which have broken from the Gulf Stream and drifted into the slope waters (Haedrich, 1972) and across thermal fronts in the Sargasso Sea (Backus, Craddock, Haedrich and Shores,1969).

REFERENCES

Backus, R.H., J.E. Craddock, R.L. Haedrich, and D.L. Shores. 1969. Mesopelagic fishes and thermal fronts in the western Sargasso Sea. Mar. Biol., 3(2): 87-106.

________. 1970. The distribution of mesopelagic fishes in the western and tropical North Atlantic Ocean. J. Mar. Res., 28(2): 179-201.

Backus, R.H., J.E. Craddock, R.L. Haedrich, D.L. Shores, J.M. Teal, A.S. Wing, G.W. Mead, and W.D. Clarke. 1968. Ceratoscopelus maderensis: a peculiar sound-scattering layer identified with this myctophid fish. Science, 160(3831): 991-993.

Baird, R.C. 1971. The systematics, distribution, and zoogeography of the marine hatchetfishes (family Sternoptychidae). Bull. Mus. Comp. Zool., 142(1): 1-28.

Beckett, J.S. 1970. Swordfish, shark and tuna-tagging, 1961-1969. Tech. Rep. Fish. Res. Bd. Can., 193: 13 p.

________. 1974. Biology of the swordfish, Xiphias gladius L., in the northwest Atlantic Ocean. Proc. Int. Billfish Symp., Kailua-Kona, Hawaii, 1972. Part 2, NOAA Tech, Rep. NMFS 675.

Beebe, W. 1937. Preliminary list of Bermuda deep-sea fish. Zool., 22(3): 197-208.

Bengtson, D.A. 1973. Vertical distribution and life history of the fish family Nemichthyidae in the Bermuda Ocean Area. M.S. thesis, Univ. R.I.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull., 53(74): 577 p.

Bond, G.W. 1974. Vertical distribution and life histories of the gonostomatid fishes (Pisces: Gonostomatidae) off Bermuda. Rep. to U.S. Navy Underwater Systems Center, Contract No. N00140-73-C-6304. Smithson. Inst., Washington, D. C.

Castle, P.H.J. 1969. An index and bibliography of eel larvae. Spec. Publ. J.L.B. Smith Inst., Ichthyol., 7: 1-121.

Ebeling, A.W. and W.H. Weed. 1963. Melamphaidae III: systematics and distribution of the species in the bathypelagic fish genus Scopelogadus vaillant. Dana Rep. No. 60: 1-58.

Emery, K.O. and E. Uchupi. 1972. The western North Atlantic Ocean: topography, rocks, structure, water, life and sediments. Amer. Ass.

Petrol. Geol. Mem. 17. 532 p.

Food and Agricultural Organization (FAO). 1972. Final report of the working party for the facilitation of tuna research. FAO Fish Rep. No. 118, Suppl. 1. 37 p.

Gibbs, R.H., Jr., 1957. A taxonomic analysis of Myctophum affine and M. nitidulum, two lantern fishes previously synonymized, in the western North Atlantic. Deep-Sea Res., 4: 230-237.

________. 1969. Taxonomy, sexual dimorphism, vertical distribution, and evolutionary zoogeography of the bathypelagic fish genus Stomias (Stomiatidae). Smithson. Contrib. Zool., 31: 1-25.

Gibbs, R.H., Jr., R.H. Goodyear, M.J. Keene, and D.W. Brown. 1971. Biological studies of the Bermuda Ocean Acre, II, vertical distributional and ecology of the lanternfishes (Family Myctophidae). Rep. to U.S. Navy Underwater Systems Center, contract no. N00140-70-C-0307. Smithson. Inst.

Grey, M. 1964. Family Gonostomatidae. In: H.B. Bigelow (ed.), Fishes of the western North Atlantic. Mem. Sears Found. Mar. Res., 1(4): 78-240.

Haedrich, R.L. 1972. Midwater fishes from a warm core eddy. Deep-Sea Res., 19: 903-906.

Halliday, R.G. 1970. Growth and vertical distribution of the glacier lanternfish, Benthosema glaciale, in the northwestern Atlantic. J. Fish. Res. Bd. Can., 27: 105-116.

Hulet, W.H. 1972. Structure and functional development of the eel Leptocephalus (Pisces, Anguilliformes). Ph.D. Dissert. Univ. Miami.

Hulet, W.H., J. Fischer, and B.J. Rietberg. 1972. Electrolyte composition of Anguilliform leptocephali from the Straits of Florida. Bull. Mar. Sci., 22: 432-448.

Krueger, W.H. 1972. Biological studies of the Bermuda Ocean Acre, IV life history, vertical distribution and sound scattering in the gonostomatid fish, Valenciennellus tripunctulatus (Esmark). Rep. to U.S. Navy Underwater Sys. Center, Contract no. N00140-72-C-0315. Smithson. Inst.

Krueger, W.H., M.J. Keene, and A.A. Keller. 1975. Midwater fishes of the deepwater dump-site. Dept. Zool., Univ. R.I., Final Rep. to Nat. Ocean. and Atmos. Admin., Grant no. 04-4-158-49. 38 p.

Mather, R.J., III. 1962. Distribution and migrations of North Atlantic bluefin tuna. Proc. Int. Game Fish., Conf. 7. 7 p.

________. 1969. Long distance migrations of tunas and marlins. Underwater Natur., 6(1): 1-14.

Mather, F.J., III and M.R. Bartlett. 1962. Bluefin tuna concentration found during a longline exploration of the northwest Atlantic slope. Comm. Fish. Rev., 24(2): 1-7.

Mather, F.J., III, M.R. Bartlett, and J.S. Beckett. 1967. Trans-Atlantic migrations of young bluefin tuna. J. Fish. Res. Bd. Can., 24(9): 1991-1997.

Mather, F.J., III, H.L. Clark, and J.M. Mason, Jr. 1975. Synopsis of the biology of the white marlin, *Tetrapterus albidus poey* (1861). *In*: Proc. Int. Billfish Symp. Kailua-Kona, Hawaii, 1972. Part 3. NOAA Tech. Rep. NMFS SSRF-675.

Mather, F.J., III, A.C. Jones and G.L. Beardsley, Jr. 1972. Migration and distribution of white marlin and blue marlin in the Atlantic Ocean. Fish. Bull. U.S. Fish Wildl. Serv., 70: 283-298.

Mather, F.J., III, J.M. Mason, and H.L. Clark. 1974. Migrations of white and blue marlin in the western North Atlantic Ocean - tagging results since May, 1970. *In*: Proc. Int. Billfish Symp. Kailua-Kona, Hawaii, 1972. Part 2, NOAA Tech. Rep. NMFS SSRF-675; 211-225.

Moser, H.G. and E.H. Ahlstrom. 1970. Development of lanternfishes (Family Myctophidae) in the California Current, Part I, species with narrow-eyed larvae. Bull. Los Angeles Co. Mus. Natur. Hist. Sci., 7: 1-145.

Nafpaktitis, B.G. 1968. Taxonomy and distribution of the lanternfishes *Lobianchia* and *Diaphus*, in the North Atlantic. Dana Rep., 73: 1-131.

O'Day, W.T. and B.G. Nafpaktitis. 1967. A study of the effects of expatriation on the gonads of two myctophid fishes in the North Atlantic Ocean. Bull. Mus. Comp. Zool., 136(5): 77-90.

Okiyama, M. 1971. Early life history of the gonostomatid fish, *Maurolicus muelleri* (Gmelin), in the Japan Sea. Bull. Jap. Sea. Reg. Fish. Res. Lab. 23: 21-53.

Parin, N.V. 1968. Ikhtiofauna okeanoskoi epipelagial: (ichthyofauna of the pelagic zone). AKHD. NAUK SSSR Tr. Inst. Oceanol. Moskua. (Trans. by M. Raveh), 1970 Israel Program Sci. Transl. 206 p.

Rofen, R..R 1966. Family Paralepididae. *In*: Y.H. Olsen (ed.), Fishes of the western North Atlantic. Mem. Sears Found. Mar. Res., 1(5): 205-460.

Sakagawa, G. 1975. The purse-seine fishery for bluefin tuna in the northwest Atlantic Ocean. Mar. Fish. Rev., 37(3): 1-8.

Scott, W.B. and S.N. Tibbo. 1974. Food and feeding habits of swordfish, Xiphias aladius Linneaus in the northwest Atlantic Ocean. In: Proc. Int. Billfish Symp. Kailua-Kona, Hawaii, 1972. Part 3. NOAA Tech. Rep., NMFS, SSRF-675.

Silas, E.G. and K.C. George. 1969. On the larval and postlarval development and distribution of the mesopelagic fish Vinciguerria nimbaria (Jordan and Williams) (Family Gonostomatidae) off the west coast of India and the Laccadive Sea. J. Mar. Biol. Ass. India, 11(1-2): 218-250.

Squire, J.L., Jr. 1962. Distribution of tunas in oceanic waters of the western North Atlantic. U.S. Fish. Bull., 62(211): 323-341.

Tighe, K. (in preparation). Systematics, vertical distribution and life history of the serrivomerid eels in the Bermuda Ocean Acre. M.S. thesis, Univ. R.I., Kingston.

Weitzman, S.H. 1974. Osteology and evolutionary relationships of the Sternoptychidae, with a new classification of stomiatoid families. Bull. Amer. Mus. Natur. Hist., 153(3): 329-478.

Wise, J.P. and C. Davis. 1973. Seasonal distribution of tunas and billfishes in the Atlantic. NOAA Tech. Rep. NMFS, SSRF-662.

7.4.3 SQUID

Many species of cephalopods occur in the oceanic waters of the northwest Atlantic and Arctic (Mercer, 1968) and probably a number of these occur on the continental slope from Newfoundland to Cape Hatteras. However, the distribution records of this general group are not complete enough to identify them specifically to the waters of the study area. Two species stand out as important components of the slope fauna and also the commercial fisheries of that area - the short-finned squid Illex illecebrosus and the long-finned squid, Loligo pealei.

The literature on these species is not extensive, particularly references to their population biology, probably because interest has only just recently been focused on them as species with commercial potential. Most information on the biology of Illex illecebrosus is from work in Newfoundland and Nova Scotian waters (Squires, 1957, Mercer, 1970, 1973a, 1973b, 1974, 1975) because of its more northern distribution. Loligo pealei has been studied off the New England and middle Atlantic region (Haefner, 1959, Arnold, 1962, Summers, 1969, 1971 and Lux, Handwork, and Rathjen, 1974).

The ommastrephid squid, Illex illecebrosus is primarily an oceanic species that seasonally migrates inshore, mainly to areas north of Cape Cod. Its winter distribution is offshore along the shelf edge and slope primarily from Newfoundland to Georges Bank. South of Cape Cod, it occurs sporadically on the shelf and slope (Mercer, 1968). The lolignid, Loligo pealei is primarily a species of neritic waters, but it is also distributed on the outer shelf and slope during winter. Its center of distribution is between Cape Cod and Cape Hatteras. The relative abundance and distribution of these two species and the degree to which their ranges overlap within the study area are indicated by the Ground Fish Survey Data of the National Marine Fisheries Service (Chapter 7.3.3, Figure 7-50).

During the winter-spring period, when the squid are concentrated in the band of relatively warm water along the outer shelf and slope, they are particularly vulnerable to commercial fishing. Until recently, these species represented an underdeveloped resource, but within the last few years, with the stocks of other commercial species declining, first foreign fleets and then the U. S. fishermen have turned to the winter distribution of squid as a resource.

The following is a life history synopsis of these two species:

LOLIGO PEALEI

Reproduction

Breeding occurs during the warm months in the shallow inshore waters of the shelf from the Gulf of Maine to Cape Hatteras. Squid are pelagic and gregarious and pair off after a somewhat elaborate mating ritual (Arnold, 1962). The eggs are enclosed in large finger-like cases that are attached to rocks and other bottom substrate in shallow water. Two broods are produced, one ubiquitous July brood is probably delayed north of Cape Cod and the other, a small November brood, originates in the southern middle Atlantic Bight (Summers, 1971).

Fecundity and Larval Life

The fecundity of L. pealei is quite high. Within a few weeks the larvae hatch from the egg cases as exact replicas of the adult. Their growth is rapid with July hatched larvae increasing in mantle length to 4 cm by September and 10 cm by January (Summers, 1971).

Growth and Longevity

Growth of L. pealei is rapid and the stock is basically annual, although a significant portion of the stock may be the product of two year olds (Summers, 1971). Summers (Table 7-43) gives the growth data for L. pealei off the north and middle Atlantic coasts.

Natural Mortality

There are no mortality estimates. However, Mercer (1968) suggests that L. pealei has a high natural mortality corresponding to its high fecundity and that the difference between good and bad year classes is established during the early stages by density-dependent and environmentally related mortality.

Migration Characteristics and Distribution

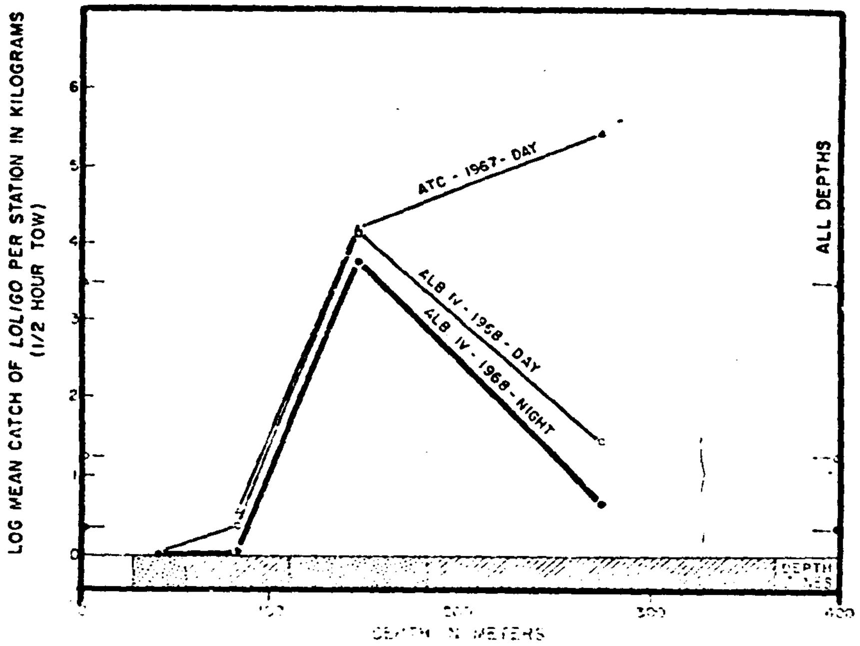
Loligo pealei has two distinct distributions, one during the summer and fall (May-November) in which it ranges from the southern coast of Nova Scotia to Cape Hatteras in the inshore shelf waters, and the other during the winter and spring in which it is concentrated along the outer edge of the continental shelf (Summers, 1969). During the winter, the greatest concentrations of L. pealei occur between 110-183 m (Figure 7-62) in the central middle Atlantic Bight. Summers found that L. pealei was restricted mainly to water temperatures of 8°C or higher. A fairly extensive migration occurs, particularly for larger individuals, as they migrate northward up to 600 miles and inshore to 200 miles to and from their summer breeding grounds (Summers, 1969).

Distributional data from the National Marine Fisheries Service Ground Fish Survey (Chapter 7.3.3, Figure 7-50) and from exploratory trawling (Lux, Handwork and Rathjen, 1974) indicate heavy concentrations of winter squid on the shelf edge off southern New England to just below Hudson Canyon. According to Lux, et al., the squid catch in this area

Table 7-43. Growth of Logigo pealei (Summers, 1971)

Age (Months)	Date, first of month		Mean dorsal mantle length (cm)	
	July brood	November brood	Females	Males
0	July	Nov.	0.2	0.2
2	Sept.	Jan.	4	4
4	Nov	Mar.	7	7
6	Jan.	May	10	10
8	Mar.	July	12	12
10	May	Sept.	14	15
12	July	Nov.	16	18
14	Sept.	Jan.	18	21
16	Nov.	Mar.	20	23
18	Jan.	May	21	25
20	Mar.	July	23	28
22	May	Sept.	25*	30
24	July	Nov.	27*	32
.	.			.
.	.			.
.	.			.
34-36?	May-July	_	_	45

* Extrapolated from the observed data.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	**FIGURE** 7-62	Log Mean Catches of L. pealei Per Two for the Four Depth Zones in 1967 and 1968 (Summers, 1969)

was about 90 percent Loligo pealei with the remaining 10 percent Illex illecebrosus.

Population Density

The several estimates of winter density of L. pealei along the outer shelf indicate a substantial population. Summers (1969) estimates the late winter abundance in the mid-Atlantic Bight to be 3.4 and 2.1 X 10 km, respectively, for the years 1967 and 1968. Lux, et al. (Table 7-44) show the take of their exploratory fishing during January to February 1974.

Food and Predation

There is little data on the food of Loligo pealei or its chief predators. However, there is some information on Illex illecebrosus which, in a general way, can be assumed to apply to L. pealei as well.

ILLEX ILLECEBROSUS

Reproduction

There is very little information concerning reproductive biology of I. illecebrosus. The bi-modal and tri-modal nature of size distributions within a year class suggests a protracted spawning season and area (Mercer, 1973a). Mercer (1973a) and Squires (1957) have suggested that this species spawns in the winter offshore, and that it is presumed to be monotelic and to die after spawning. Reproduction in the study area, if it does occur, is probably confined to the offshore areas north of Cape Cod.

Growth and Longevity

I. illecebrosus appears to live not more than one or two years (Mercer, 1968). Growth (Squires, 1957) is rapid from May to October, the period for which there is data (Figure 7-63). Thereafter, it tapers off, presumably, until the time of spawning in the winter. Sexual maturity is obtained in the fall and appears to quicken with decreasing day length (Mercer, 1973b). No mature males were reported by Squires (1957) before September, but sexual development was observed between September and November.

Migration Characteristics and Distribution

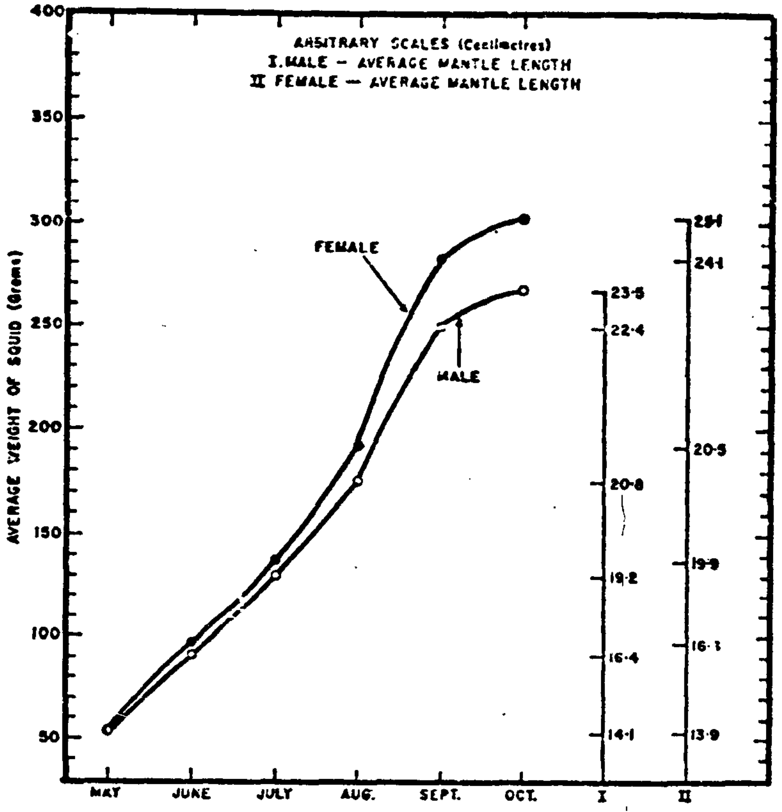
I. illecebrosus is distributed on the slope and shelf edge from Georges Bank to Cape Hatteras, although only scattered below Cape Cod. This species is less strongly distributed in the inshore areas of our study region than is L. pealei. The region they occupy in the shallow water of the continental shelf is restricted by low temperatures. During the spring, they concentrate at the edge of the continental shelf in water

Table 7-44. Landed catch and value of squid from exploratory fishing on the outer continental shelf, Mid-Atlantic Bight, January to February, 1974 (Lux, Handwork, and Rathjen, 1974)

Trip No.	Dates	No. of Tows	Landed Catch Squid	Landed Catch Finfish[1]	Catch Value
			Pounds		Dollars
1	8-13 Jan. 1974	52	37,500	1,975	6,670
2	18-24 Jan. 1974	60	50,200	6,760	8,508
3	29 Jan. - 4 Feb. 1974	55	41,750	3,640	7,416
	10-15 Feb. 1974	51	39,625	3,950	7,206
	Total	218	169,075	16,325	29,800

---

[1] The landed finfish consisted of butterfish (39 percent), summer flounder (28 percent), tilefish (28 percent), goosefish (4 percent), and scup (1 percent).



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-63	Average Weight and Mantle Length of Male and Female Illex Taken at Holyrood, Newfoundland Each Month, 1952 (Squires, 1957)

generally warmer than 5°C, and at this time, in Canadian waters, they are restricted in their vertical and horizontal movements by overlying cold Arctic water (Mercer, 1973). In Canadian waters these squid move inshore, beginning in May and June, and then return offshore in November. The nature of their movement from the edge of Georges Bank in the spring is not clear. However, considering their preference for colder water, it is likely that they move inshore in a northerly direction into the Canadian waters.

Population Densities

Catches in Canadian waters indicate that the abundance of I. illecebrosus is enormous (Mercer, 1968). They are probably less abundant in the waters of the study area where their peak abundance occurs on the southern edge of Georges Bank (Chapter 7.3.3, Figure 7-50).

Food and Predation

In Newfoundland waters (Squires, 1957), the diet of I. illecebrosus seems to consist chiefly of euphausiid crustaceans for the smaller squid. Larger squid take fish, principally the capelin Mallotus villosus, but also redfish, Sebastes marinus; cod, Gadus morhua; and haddock, Melanogrammus aeglefinus.

There appears to be a predator-prey relationship between I. illecebrosus and the pilot whale Globicephala melaena. Their summer distribution and seasonal movements in Newfoundland strongly coincide to the extent that the inshore availability of the pilot whale depends on that of the squid (Mercer, 1975). Apparently, this cetacean feeds almost exclusively on the short-finned squid. Mercer notes that progressively higher peaks in abundance of squid and lower peaks of the pilot whale may be the result of depletion of the whale stocks in Newfoundland waters.

7.4.4 TURTLES

Five species of sea turtles are known to be associated with coastal and slope waters (Table 7-45) along the study area. According to Bleakney (1965), sea turtles are commonly seen off Georges Bank and along the edge of the Gulf Stream in June. The North Atlantic Drift Current, being warmer than surrounding sea temperatures, apparently allows tropical turtles to reach 61°N latitude as far east as Scotland and Norway (Bleakney, 1965). Sea turtles have been reported active in waters as cold as 11.7°C (MacAskie and Forrester, 1962), though the sea turtles in northern coastal waters usually are most numerous from July through October (Table 7-46) at which time the turtles follow their primary food (jellyfish) inshore. Three of the species (hawksbill, leatherback, and Atlantic ridley) are endangered and the remaining two (green and loggerhead) will probably be classified as endangered (see Table 7-47) by the end of 1975 (National

Table 7-45. Summary of records of marine turtles reported from the coastal waters of New England and Eastern Canada.

Species	Conn.	R.I.	Mass.	N.H.	Me.	N.B.	N.S.	Nfld.	Totals
Dermochelys	4	5	16	1	33	2	25	2	98
Lepidochelys	-	-	7	-	1	-	4	1	13
Caretta	1	-	1	-	1	-	2	1	6
Eretmochelys	-	-	1	-	-	-	-	-	1
Chelonia	1	-	2	-	-	-	-	-	3
TOTALS	6	5	27	1	35	2	31	4	112

(From Bleakney, 1965)

Table 7-46. Monthly distribution of reports of marine turtles along the coast from Connecticut to Newfoundland, 1840-1964. (D) represents specimen found dead.

Species	Reports	Jan.	Mar.	June	July	Aug.	Sept.	Oct.
Dermochelys	54	-	-	-	9	29	15	1
Lepidochelys	8	-	1(D)	-	1	3	-	3(D)
Caretta	4	1(D)	-	1	-	2	-	-
Chelonia	3	-	-	-	-	-	2	1
Unidentified	1	-	-	-	-	1	-	-
TOTALS	70	1	1	1	10	35	17	5
Sea surface temp. off Nova Scotia:				48°F	55°F	63°F	63°F	59°F
Sea surface temp. off Georges Bank:				53°F	58°F	63°F	64°F	60°F

(From Bleakney, 1965)

Table 7-47. Threatened and endangered turtles

Common Name	Species Name	Geographic-Bathymetric Range	Habitat	Reason for Decline
+Hawksbill turtle	*Eretmochelys imbricata*	tropical waters, rare in New England waters, nests on Carribean shores and along Atlantic coast to Brazil on undisturbed beaches.	deep ocean	heavily exploited for shell
+Leatherback turtle	*Dermochelvy coriacea*	New England waters summer-autumn. Closely associated with slope waters during migration	highly pelagic, feeds on pelagic jellyfish	some slaughter by fishermen, eggs collection on breeding grounds
*Loggerhead turtle	*Caretta caretta*	New England waters summer-autumn. Migrate Atlantic coast to/from Sargasso Sea	frequently sighted in coastal waters, more littoral than leatherback or hawksbill	predation by racoons and people, egg destruction of breeding beaches due to coastal development
*Green turtle	*Chelonia mydas*	occasionally seen in New England waters in summer. Tropical oceans. Rare north of Cape Cod.	deep slope waters between Gulf Stream and littoral feeding grounds	reduction of breeding grounds and commercial exploitation
+Atlantic ridley	*Lepidochelys kempi*	New England waters during summer months, breeds on more tropical beaches	more littoral than leatherback or hawksbill	eggs plundered on breeding beaches

*proposed threatened status +endangered species

Oceanic and Atmospheric Administration, 1975). The International Union for the Conservation of Nature and Natural Resources (IUCN) has also listed all sea turtles as threatened, endangered, or rare in its worldwide Red Data Book. However, sea turtles may be seen in increasing numbers along the southern U.S. since every southern coastal state has banned the exploitation of the turtles.

Leatherbacks, loggerheads, ridleys and green turtles are regular migrants in East Coast waters and should not be considered strays from warmer Gulf Stream waters (Bleakney, 1965).

HAWKSBILL, *Eretmochelys imbricata*

The hawksbill, *Eretmochelys imbricata*, a tropical turtle, is a rare species in New England waters. One of the species was collected off Cape Cod in 1968 (Lazell, personal communication) which indicates that it still does occur. Lazell assumes the species must occur in deep slope waters, although the only Massachusetts specimen was a dead juvenile washed up on shore. The specimen was probably not an accidental straggler since the species is rare worldwide and there is some evidence that the hawksbill was once more numerous in New England waters (Babcock, 1919). However, according to Lazell (personal communication), Babcock's source may refer to another species, the ridley.

The widely distributed hawksbill is more frequently seen in tropical waters south of New England although there are no reliable figures on the current breeding stock (Barbour, 1976). It nests on Caribbean shores and along the Atlantic Coast to Brazil where it can find undisturbed beaches. *E. imbricata* does not form communal nesting grounds; females come up from the ocean one by one to lay their eggs.

The most colorful sea turtle is the hawksbill with the classical "tortoise shell" (Lazell, 1974). The scutes, or plates of the shell, are streaked with light and dark brown. The shell generally attains a length of about 76 cm. The narrow head allows for feeding on sponges and other species that live in coral reefs. Occasionally the hawksbill feeds on organisms that are poisonous to humans which in turn makes the meat unfit for human consumption (Barbour, 1976).

The U.S. Fish and Wildlife Service (1974) lists the hawksbill as an endangered species. Heavily exploited for its tortoise shell, it is also mounted for the tourist trade.

LEATHERBACK, *Dermochelvy coriacea*

The leatherback, *Dermochelvy coriacea*, is a regular summer/autumn resident in Massachusetts waters (Isgur, 1973). Scattergood and Packard (1960) also report 15 authenticated and 15 probable records of sightings in Maine. Leatherbacks are highly pelagic warm-blooded animals (body temperature about 26. 7°C) and are believed to be closely associated with deep slope waters during migrations (Lazell, personal communication). However, due to the species' deep ocean habitat, little is known of the life history of leatherbacks between hatchling size and breeding adult size (Barbour, 1976). In addition, Barbour states that there are no valid reports of leatherback captures between five and 500 pounds. D. coriacea nests on muddy beaches, usually near the mouths of sediment-laden rivers since the absence of a "shell" would otherwise expose it to injury on rocky beaches and coral (Barbour, 1976).

Leatherbacks are large marine reptiles (occasionally weighing a ton), not related, in any meaningful sense, to any other living turtle (Lazell, 1974). The "shell" is a leathery covering of fatty hide having seven sharp longitudinal ridges on the back. Unlike other turtles, the head and neck do not retract. Leatherbacks feed on pelagic jellyfish (Cyanea), moving inshore as the season progresses and the jellyfish increase.

Human depredation has reduced the leatherback to an endangered species (U.S. Fish and Wildlife Service, 1974) throughout the Mediterranean, Atlantic, Pacific, and Indian Ocean due to egg collecting on breeding grounds and slaughter by fishermen (Isgur, 1973). However, some effort is presently being made to hatch eggs in captivity. The Atlantic population may be fairly stable at present, although there may only be some 29,000 to 40,000 breeding females worldwide (Barbour, 1976), making the species extremely vulnerable to commercial or environmental pressure.

LOGGERHEAD, Caretta caretta

The loggerhead turtle, Caretta caretta, is also a regular summer/fall resident with hundreds, perhaps thousands, inhabiting Massachusetts coastal waters (Lazell, personal communication). Scattergood and Packard (1960) report one record of a loggerhead in Maine waters. It is the most frequently seen sea turtle in Florida waters (Barbour, 1976). C. caretta is usually found where the ridleys are absent since both species feed on crabs. According to Carr (1967), loggerheads mature in Sargasso Sea beds off Bermuda and migrate up the Atlantic coast as far as Massachusetts in June or July, returning southward in September.

The loggerhead is dark brown with a light colored belly and a shoulder scute. Shell length averages over 152.40 cm and a mature loggerhead weighs over 227 kg. An extremely powerful reptile, the loggerhead can easily crush an oar with its jaws (Lazell, 1974).

Due to egg collection and coastal development, the world population of loggerheads is in decline (Isgur, 1973). Along the southeastern U.S., racoons prey on eggs and depredation has increased with the removal of the racoons' natural predators. The United States and Australia legally protect loggerhead eggs along the coasts, but allow importation of turtles. Many loggerheads are drowned in nets of commercial fishermen. Still more die after injesting plastic bags which evidently appear as jellyfish to the loggerhead. In developed coastal areas, some hatchlings are confused by bright lights and highway lights and wander inland where they die (U.S. Dept. of Interior, 1975). A public hearing pursuant to listing the loggerhead as an endangered species will be held on December 3, 1975 (NOAA, 1975). Survival of the loggerhead at present is due in part to the low economic value of its coarse meat and worthless shell.

GREEN, Chelonia mydas

The green turtle, Chelonia mydas, occasionally appears in New England waters, particularly around Nantucket in the summer (Lazell, 1974). The greens that occur there are young and still in the carnivorous phase of their lives. Unlike other sea turtles , the green soon turns to grazing on sea grasses (Barbour, 1976). Lazell states that there is little data concerning the green turtles' early life history, through it is safe to assume that the deep slope waters between the Gulf Stream and their littoral feeding grounds are a regular part of their habitat. Greens are also found worldwide in tropical waters.

C. mydas is mud-colored with a white stomach. There is no shoulder scute and dorsal scutes do not overlap (Lazell, 1974). The shell contains four pairs of lateral shields. Greens in New England waters are small, between 30.5 to 50.8 cm, aged about two years. When mature, the green will obtain a length of over .9 m and weigh 136.08 km (Lazell, 1974). Breeding age is reached in the sixth year and nesting probably occurs every three years, each female averaging approximately 100 eggs.

The green turtle is the most commercially valuable reptile and overexploitation has reduced it to an endangered species. In North America and Europe, 15,000 to 20,000 turtles are killed each year for turtle soup, oil for cosmetics, luxury soap and shoe leather. The appetite for green turtle meat, particularly in Japan and Germany, has expanded significantly since World War II. The meat of the green turtle is reported more succulent than other turtle meat due to its diet of sea grasses. A large green turtle will bring a poacher up to $200 in some areas, so great is the commercial demand for this species (Barbour, 1976).

Breeding grounds are diminishing around the world which further endangers the future of the green turtle. The species is very scarce in the Indian Ocean (Isgur, 1973) due to heavy egg harvests. In addition, commercial fishermen trawling for shrimp accidently catch greens in their nets (U.S. Dept. of the Interior, 1975). However, two important breeding grounds still exist: Toruguero, Costa Rica where a hatchery is also located; and the other on Ascension Island in the South Atlantic. Hatchlings from the Tortuguero hatchery are flown to other areas of the Caribbean (Isgur, 1973) although it is as yet too early to tell whether this effort will be successful (Barbour, 1976). Unfortunately, the Caribbean areas and Costa Rica are hosts to a number of turtle freezing plants which make it economically advantageous for natives to hunt the turtles. Hearings will be held on December 3, 1975, pursuant to listing the green turtle as an endangered species (NOAA, 1975).

ATLANTIC RIDLEY - Lepidochelys kempi

The Atlantic ridley, Lepidochelys kempi, regularly inhabits the waters off the Massachusetts coast during the summer months. Loggerheads and ridleys are more littoral than the leatherback or the hawksbill (Lazell, personal communication). Scattergood and Packard (1960) report one Atlantic ridley seen in Maine waters. Nesting usually occurs on isolated beaches in Mexico near Rancho Nuevo and from Tampico to Soto la Marina.

The ridley is described by Lazell (1974) as pale, concrete-colored above and white below. L. kempi is the smallest sea turtle, reaching less than 76 cm in length. Four or five bridge plates, each containing a small pore and shoulder scute, are present (Lazell, 1974).

Due to massive slaughters on the beaches in the past, breeding habits of the ridley have changed. Whereas the ridleys previously came to the beaches en masse, only part of the herd now arrives, leaving the rest of the females to straggle in one by one (Barbour, 1976). The total breeding population is very low with only 2,200 turtles appearing on the nesting grounds in 1967 (Barbour, 1976). The nesting areas are also continually plundered by people seeking to supplement their diets with animal protein in the form of turtle eggs (Isgur, 1973).

Additional ridleys are killed when caught in shrimp trawlers' nets, which, due to expanded demand for shrimp, now measure 60 feet across and stay down for an hour. Some turtles could be saved with artificial respiration (a foot on the stomach) even after an hour's submergence, but they are usually considered net damagers and are tossed back overboard to die (Barbour, 1976). More turtles are killed through permits which are issued by the Mexican government. The ridley is considered an endangered species by the U.S. Fish and Wildlife Service (1974).

REFERENCES

Arnold, J.M. 1962. Mating behavior and social structure in Loligo pealei. Biol. Bull, 123: 53-57.

Babcock, H.L. 1919. The turtles of New England. Mem. Boston Soc. Natur. Hist., 8(3): 323-432.

Barbour, J. 1976. Up from the sea. Int. Wildlife, 6(1): 4-13.

Bleakney, J.S. 1965. Reports of marine turtles from New England and Canadian waters. Can. Field Natur., 79(2): 120-128.

Carr, A. 1967. So excellent a fish. Anchor, Doubleday. 266 p.

Haefner, P.A., Jr. 1959. Squid: soft-bodied hawks of the sea. Estuarine Bull., 4(3): 3-5.

Isgur, B. 1973. Rare and endangered plants and vertebrate animals of Massachusetts. Mass. Audubon Soc., Public Serv. Inform. 8 p.

Lazell, J.D. 1974. Reptiles and amphibians in Massachusetts. Mass. Audubon. 34 p.

________. (personal communication, Nov. 1975). Scientific Staff, Mass. Audubon Soc., Lincoln, Mass.

Lux, F.E., W.D. Handwork, and W.F. Rathjen. 1974. The potential for an offshore squid fishery in New England. Mar. Fish. Rev., 36(12): 24-27.

MacAskie, I.V. and C.R. Forrester. 1962. Pacific leatherback turtles (Dermochelys) off the coast of British Columbia. Copeia, 3: 646.

Mercer, M.C. 1968. Symposis of the recent cephalopoda of Canada. Proc. Symp. on Mollusca. Mar. Biol. Ass. India, 1: 265-275.

________. 1970. Cephalopod resources and fisheries in the northwest Atlantic. Amer. Malacological Union Annu. Rep.: 30-33.

________. 1973a. Distribution and biological characteristics of the ommastrephid squid, Illex illecebrosus (Le Sueur) on the Grand Banks, St. Peree Bank and Nova Scotia Shelf (subarea 3 and 4) as determined by otter trawl surveys, 1970-to 1972. ICNAF Res. Doc. 73/79. 11 p.

________. 1973b. Sexual maturity and sex ratios of the ommastrephid squid, Illex illecebrosus (Le Sueur). at Newfoundland (subarea 3). ICNAF Res. Doc. 73/71. 14 p.

________. 1974. The interaction between the northern pilot whale, Globocephala melaena, and the short-finned squid, Illex illecebrosus, at Newfoundland with particular reference to stock assessments and production estimates. Sub-Committee on Small Cetacea, Scientific Committee of the Int. Whaling Comm., Montreal, April 1-12, 1974.

________. 1975. Modified Leslie-DeLury population models of the long-finned pilot whale (Globicephala melaena) and annual production of the short-finned squid (Illex illecebrosus) based on their interaction at Newfoundland. J. Fish. Res. Bd. Can., 32(7): 1145-1154.

Mercer, M.C. and G. Paulmier. 1974. Distribution and biological characteristics of the short-finned squid (Illex illecebrosus) on the continental shelf of subareas 3 and 4 in May-June 1973. ICNAF Res. Doc. 74/78.

National Oceanic and Atmospheric Administration. 1975. Listing the green turtle, the loggerhead sea turtle, and Pacific ridley sea turtle as threatened species: public hearing. Fed. Regist., 40(162): 36401.

Scattergood, L.W. and C. Packard. 1960. Records of marine turtles in Maine. Me. Field Natur., 16: 46-50.

Squires, H.J. 1957. Squid, Illex illecebrosus (Le Seur) in the Newfoundland fishing area. J. Fish. Res. Bd. Can., 14(5): 693-728.

Summers, W.C. 1969. Winter population of Loligo pealei in the Mid-Atlantic Bight. Biol. Bull., 137: 202-216.

________. 1971. Age and growth of Loligo pealei, a population study of the common Atlantic Coast squid. Biol. Bull., 141(1): 189-201.

U.S. Department of the Interior. 1975. Sea turtles, proposed "threatened status". Fed. Regist., 40(98): 21974-21977, 21983-21986.

U.S. Fish and Wildlife Service. 1974. United States list of endangered fauna, May 1974. U.S. Dept. of Interior. 22 p.

7.4.5 MAMMALS

INTRODUCTION

Of the mammals, the cetaceans alone are of obvious significance in the slope water region. Considering the wide ranging habit of the cetaceans, one would expect any species known from the North Atlantic Ocean to occur in the slope waters of the western North Atlantic, at least on rare occasions. There is, however, very little solid data on what species are found in the slope water and on what role this region plays in their life history. There presently is a pressing need for such data. Most available information was summarized in the previous report (Katona, 1974) and we will draw upon this information as our primary source.

The habitat preference of the various species known to occur in the northwest Atlantic is shown in Table 7-48. Of these, a small number are probably restricted to coastal waters and are, therefore, not slope water species. These include:

Harbor porpoise
Beluga
Bottlenosed dolphin
Killer whale
Pilot whale

The remainder would be expected to occur fairly frequently in the waters of the continental slope.

Data on the abundance and relative importance of cetacean species in the offshore waters are few. Only scattered reports are now available, most of which have been made incidentally to the pursuance of some other activities, such as fishing or other oceanographic work. The configuration of the coast and bottom between Cape Cod and Nova Scotia suggests the possibility that many more whales might be seen at sea than in the inshore waters. A whale could swim along that path in a direct route and remain near some of the most productive areas in the northwestern Atlantic, namely Georges Bank and Browns Bank. It could then continue north along the Emerald Bank, Horseshoe Bank, and other shoal areas offshore from Nova Scotia, finally reaching the Grand Bank of Newfoundland.

From the very little known of the cetaceans in offshore waters, it appears that the study area is an important one for these animals. There is no data on their abundance there, but Levenson (1972) estimated that 54,000 large whales inhabit the western North Atlantic Ocean. The general inference is that the offshore Gulf of Maine and probably the Middle Atlantic as well, are migratory routes between northern summering grounds and southern wintering grounds (Katona, 1974). If so, the larger, more oceanic species would likely move parallel to the continental shelf. This would allow them to feed on copepods, euphausids, squid, and fish that are so abundant on the outer continental margin.

Several investigators (Dr. Steve Katona and Dr. Howard Winn, personnel communication) have indicated that the area just beyond the continental margin probably is extremely important to cetaceans. The 200 m isobath appears to be the inshore boundary for the distribution of some of the larger species. The sperm whale is known to be limited by this depth contour. The proximity of rich feeding grounds along a north-south migration route would make the slope waters an extremely attractive region to the cetaceans.

The following describes what is known of the life history of species that are likely to occur in the study region. A species summary of these cetaceans is given in Table 7-49.

The life histories of inshore species of cetaceans are not detailed here. Neither are histories provided for species that may occasionally occur at the extreme southern limits of the study area. These species include the California sea lion, Zalophus californianus; Florida manatee, Trichechus manatus latirostris; Bryde's whale, Balaenoptera edeni; rough-toothed dolphin, Steno bredanensis; Atlantic spotted dolphin, Stenella plagiodon; and spinner dolphin, Stenella cf. longirostris.

Table 7-48. Habitat preferences of cetaceans

KNOWN TO ENTER ESTUARIES OR RIVERS	LIKELY TO OCCUR IN SLOPE WATER
Harbor porpoise, *Phocoena phocoena*	
Beluga, *Delphinapterus leucas*	
Bottlenosed dolphin, *Tursiops truncatus*	
Common dolphin, *Delphinis delphis*	*
Killer whale, *Orcinus orca*	
OFTEN FOUND IN BAYS, INSHORE, OR IN COASTAL WATERS	
Harbor porpoise, *Phocoena phocoena*	
Pilot whale, *Globicephala melaena*	
Right whale, *Eubalaena glacialis*	*
Humpback whale, *Megaptera novaeangliae*	*
Fin whale, *Balaenoptera physalus*	*
Minke whale, *Balaenoptera acutorostrata*	*
Beluga, *Delphinapterus leucas*	
Killer whale, *Orcinus orca*	
USUALLY FOUND WELL AT SEA	
Fin whale, *Balaenoptera physalus*	*
Minke whale, *Balaenoptera acutorostrata*	*
Right whale, *Eubalaena glacialis*	*
Blue whale, *Balaenoptera musculus*	*
Sei whale, *Balaenoptera borealis*	*
Sperm whale, *Physeter catodon*	*
Common dolphin, *Delphinis delphis*	*
Gray grampus, *Grampus griseus*	*
White-sided dolphin, *Lagenorhynchus acutus*	*
White-beaked dolphin, *Lagenorhynchus albirostris*	*
HABITAT POORLY KNOWN, BUT USUALLY FOUND WELL AT SEA	
Pygmy sperm whale, *Kogia breviceps*	*
Gray grampus, *Grampus griseus*	*
North Atlantic bottlenosed whale, *Hyperoodon ampullatus*	*
True's beaked whale, *Mesoplodon mirus*	*
Dense-beaked whale, *Mesoplodon densirostris*	*

*Signifies key species, based on present abundance or estimated historical abundance

Reproduced from best available copy.

Table 7-49. Species summary of cetaceans.

Family	Common Name(s)	Species Name	Western Atlantic Range and Distribution	Habitat	Estimated Abundance in Western North Atlantic	Dominance in Gulf of Maine
Phocoenidae	Harbor porpoise	*Phocoena phocoena*	New Jersey to Baffin Bay; Center of population in approaches to Bay of Fundy and inshore Gulf of Me.	Coastal and inshore waters	4,000-10,000	Numerically dominant cetacean
Delphinidae	Pilot whale	*Globicephala melaena*	New York to Greenland; Especially common in Newfoundland	Pelagic (winter) & coastal (summer)	No estimates; Most common whale seen in Cape Cod Bay; Schools of up to 300 on Georges Bank	Frequently seen
● Balaenopteridae	Finback whale	*Balaenoptera physalus*	Population centered between 41°21'N and 57°00'N and from coast to 2000 m contour	Pelagic, but enter bays and inshore waters in late summer	7,200	Dominant large whale; one of most common cetaceans
Balaenopteridae	Minke whale	*Balaenoptera acutarostrata*	Chesapeake Bay to Baffin Island in summer, eastern Gulf of Mexico, northeast Florida and bahamas in winter	Pelagic, but may stay nearer to shore than other rorquals (except humpback)	No estimates	Less common than finback, but sightings are routine
● Balaenopteridae	Humpback whale	*Megaptera novaeangliae*	Common near land, but can be found in deep ocean	Approaches land more closely and commonly than other large whales; also found in deep ocean	800-1,500	Routinely seen but much reduced from past abundance
● Balaenidae	Right whale	*Eubalaena glacialis*	New England to Gulf of St. Lawrence; Possibly found as far south as Florida	Pelagic and coastal; not normally inshore	200-1,000	Much reduced from former importance; rare
Delphinidae	Killer whale	*Orcinus orca*	Tropics to Greenland, Spitzbergen, Baffin Bay	Mainly pelagic and occasional, however they do commonly approach coast	No estimate; apparently not seen as commonly as in more northerly areas	Uncommon
Delphinidae	Common dolphin	*Delphinis delphis*	Caribbean Sea to Newfoundland; very wide ranging; may be most widespread and abundant delphinid in world	Seldom found inside 100 m contour, but does frequent seamounts, escarpments, & other offshore features	Poorly known; probably more common than available records indicate; may be more common in Massachusetts Bay; no estimates	Not known; possibly *Phocoena* is a competitor

- ● Endangered Species

Reproduced from best available copy.

Table 7-49. (cont.)

	Delphinidae	Bottle-nosed dolphin	*Tursiops truncatus*	Argentina to Greenland, but most common from Florida, West Indies, & Caribbean to New England	Usually close to shore & near islands; enters bays, lagoons, rivers	Rare, especially in inshore regions; no estimates	Rare; perhaps Phocoena is a competitor.
	Delphinidae	White-beaked dolphin	*Lagenorhynchus albirostrus*	Massachusetts to Davis Strait, but ranges farther north into Arctic waters than *L. acutus*; rarely seen south of Labrador and Newfoundland	Coastal waters	Rare stray in Gulf of Maine; no estimates	Apparently minimal
	Delphinidae	White-sided dolphin	*Lagenorhynchus acutus*	Cape Cod to Davis Strait	Often schools with pilot whales, but is less common than that species	Not common	Apparently not important by numbers
	Delphinidae	Grey grampus, Risso's dolphin	*Grampus griseus*	Ranges south from Massachusetts	Coastal waters; habitat poorly known	Uncommon, but possibly not rare; no estimates	Much less common than *Phocoena*
	Monodontidae	Beluga	*Delphinapteras leucas*	St. Lawrence River and Gulf to Arctic regions	Prefers estuaries & shallow water areas	Rare visitor from Gulf of St. Lawrence	Rare
●	**Balaenopteridae**	Blue whale	*Balaenoptera musculus*	Gulf of St. Lawrence to Davis Strait; routinely sighted on banks fringing outer Gulf of Maine; Population much reduced from original number of about 1,100 in western N. Atlantic	Pelagic, deep ocean; however occasionally approaches land in deep water regions, e.g., the Laurentian Channel of the St. Lawrence River	Generally not common; some sightings expected in offshore regions; no estimates	Much less common than finback
●	**Balaenopteridae**	Sei whale	*Balaenoptera borealis*	New England to Arctic Ocean	Pelagic, does not usually approach coast	1,570 off Nova Scotia	Much less common than finback
●	**Physeteridae**	Sperm whale	*Physeter catadon*	Equator to 50°N (females & juveniles) or Davis Strait (males)	Pelagic, deep ocean	Estimated 22,000 inhabit North Atlantic Ocean	Uncommon visitor
	Physeteridae	Pygmy sperm whale	*Kogia breviceps*	Tropics to Nova Scotia	Pelagic in warm ocean waters	Very rare; only one record	Minimal
	Ziphiidae	Bottle-nosed whale	*Hyperoodon ampullatus*	Rhode Island to Davis Strait	Pelagic; cold temperate and subarctic waters	Poorly known; between 260-700 taken annually in North Atlantic Ocean, 1958-70	Poorly known
	Ziphiidae	True's beaked whale	*Mesoplodon mirus*	Northern Florida to Nova Scotia	Nothing is known	Extremely rare; poorly known	Minimal
	Ziphiidae	Dense-beaked whale	*Mesoplodon densirostris*	Tropics to Nova Scotia	Probably pelagic in tropical and warm waters	Extremely rare: stray visitor	Minimal

LIFE HISTORY DESCRIPTIONS

FAMILY BALAENOPTERIDAE: FIN WHALE, FINBACK WHALE, RORQUAL, FINNER, PIKE WHALE, Balaenoptera physalus physalus

This is the second largest whale in the Balaenopterine group, reaching a maximum length of about 24.5 m and a weight of perhaps 59 metric tons. It resembles the other whales in the genus quite closely in general form, but may be distinguished by certain characteristics. Most distinctive is the asymmetric coloration of the jaws and the baleen. On the left side both are the same dusky gray as the dorsal part of the body. However, the right side of the lower jaw is white or light gray externally on the anterior quarter, shading to the dark color of the head posteriorly. Correspondingly, the first third of the baleen of the right side is white or slightly yellowish, while the posterior portion and entire left side is dark blue-black. The portion of the external right upper jaw in contact with the light-colored baleen is also white. The coloration of the interior of the right jaw may be reversed from that of the exterior, at least in males (Tomilin, 1957).

The ventral portion of the body is mainly white, including the underside of the flukes and flippers. The body of the fin whale is more slender than that of other balaenopterines. The dorsal fin displays small differences in morphology from that of the sei or minke, but this is not always discernible at sea. While feeding, the fin whale often blows three or four times, at equal intervals, dives for five to ten minutes, then reappears (Mitchell, 1972a). The long period between the blow and the appearance of the dorsal fin (over one second, but less than two or three seconds in the case of the blue whale) may help an experienced observer to recognize the species at sea (in conjunction with an estimate of size and, especially, a glimpse of asymmetric head coloration). The finback does not show flukes when diving. Arnold and Gaskin (1972) saw one finback breach twice in the Bay of Fundy, but this behavior is unusual for the species. Allen's (1916) description of this whale is useful.

(1) Distribution and habitat preference. The range of the fin whale covers all oceans of the world. It is somewhat less numerous in the Northern Hemisphere and somewhat less numerous in the North Atlantic than in the North Pacific. It is not found in the tropics (Tomilin, 1957) and only rarely among pack ice (Pilson and Goldstein, 1973). Within the North Atlantic, the finback is very widely distributed from Spitzbergen and Greenland south to the Azores (Kellogg, 1929). It is the most commonly seen large whale in the Bay of Fundy (Neave and Wright, 1968), along the Maine coast (Norton, 1930), and is the most commonly stranded large whale along the New England coast (Allen, 1916). The latter fact probably stems from the fact that in New England it readily enters inshore shallow waters perhaps in pursuit of small schools of fish, although it normally stays at some distance from the mainland (Allen, 1916).

This is perhaps peculiar to our area because in most other locations the finback is considered to be a creature of the deep sea (Tomilin, 1957; IUCN, 1972). Allen (1916) felt that waters off Cape Ann and in the northwest part of the Gulf of Maine seemed to be favorite haunts of the finback, although Mitchell (1974) indicated that there is some evidence that fin whales of one or more populations concentrate on the Canadian continental shelf. Pilson and Goldstein (1973) state that its range extends south of New England with one possible stranding in Florida (Moore, 1953). Sergeant (1966) and Mitchell (1972d) considered the fin whales in the Gulf of Maine-Grand Banks-Davis Strait areas to be a distinct population group with no interchange with the west Greenland or the east Greenland populations. Mitchell (1974) considered the following populations to be distinct, with little or no interchange: (1) Nova Scotian stock, (3) Laborador stock (ten percent interchange with Nova Scotia), (3) west Greenland stock, (4) east Greenland-Iceland stock. Fin whales in the Gulf of Maine should probably be considered part of the Nova Scotian stock for the time being, however, no data are yet available.

(2) Migration. According to Mitchell (1974), the major population of northwest Atlantic fin whales is centered between about 41° 20'N and 57° 00'N and from the coast to the 1,000 m depth contour. That area can be considered the summer feeding range of northwest Atlantic fin whales. Within that area, fin whales appear to spend summer months in the northern reaches and winter months farther south. However, there appears to be enough latitudinal stratification of discrete fin whale populations along the western Atlantic coastline that grounds occupied by a southern population in the summer are probably occupied by a northern population in the winter (Mitchell, 1972). Although Allen (1916) could find no evidence for a regular migration of finbacks, he nevertheless observed regular periodicities of abundance in which the whales were present in summer but not in winter. On the whole, migrations of this species in the North Atlantic are apparently less regular than in other areas (Tomilin, 1957), and are also less regular and less well known (Kellogg, 1929) than those of the blue or humpback whales. However, Mitchell (1972d) has demonstrated, by tagging returns, a general seasonal migration from Cape Cod in June and July up to and including waters on the central Labrador Coast up to 57°N latitude, although individual whales probably do not make the entire trip. Mitchell (1974) also demonstrated a regular migration parallel to the Nova Scotia coast. Tomilin (1957) thought that the warm water of the Gulf Stream provided favorable breeding conditions not only at low latitudes but also relatively far to the north and allowed some fins to winter on their feeding grounds, because food is still abundant. He listed April through October as the periods of fin whale abundance in the Gulf of Maine, with January and February being times of extreme

rarity. Clark (1887) reported the northward migration of large numbers of finbacks in the Gulf of Maine early in March. During autumn, the bulk of the fin-whale population migrates (pregnant females first) south from summering grounds in the Arctic, or off the coasts of Newfoundland, Iceland, New England, and elsewhere to more southerly winter feeding grounds, which are not well known. Probably depending on their stock of origin, some finbacks reach the Bay of Biscay, Portugal, the Mediterranean, the Azores, or possibly the Gulf of Mexico or the temperate U. S. Atlantic coast. However, some finbacks apparently winter on the Grand Banks of Newfoundland (Kellogg, 1929), while others reach Nantucket or Bermuda. Strandings have been recorded on the coast of North Carolina (Caldwell and Golley, 1965; Brimley, 1946) and as far south as Florida (Mitchell, 1974). On the whole, one can suspect that the migrations of fin whales are primarily determined by the abundance of the gregarious fishes (capelin, herring) which form the main food items in the North Atlantic, and that food abundance is governed to an important degree by temperature variations. Mitchell (1974) mentioned the possibility that winter dispersion of the population is not random, but that individuals return year after year to the breeding areas where they were conceived and born.

(3) Population density. As far back as records are available, the fin whale has always been one of the most common large whales in New England waters. According to Tomilin (1957) it is the dominant species of whalebone whale in the Northern Hemisphere. Although no quantitative records of past abundance are available, Clark (1887) called it the most common whale taken in Massachusetts Bay, and Norton (1930) called it the most common near Portland. Colonial and 19th century whaling concentrated on the right and humpback whales because they were easier to catch; however, a fishery for the finback was prosecuted on and off for many years in Massachusetts Bay (True, 1904), and sporadic hunting occurred from the Maine coast (Norton, 1930) despite the fact that Captain John Smith's group could not catch any in 1614. Allen (1916) recorded that the finback was not hunted during early New England whaling ventures. However, during the period from 1810 to 1896, finbacks were pursued with success by coastal whalers in small ships from Prospect Harbor, Tremont, and Winter Harbor, Maine; and from Gloucester, Provincetown, and Nantucket, Massachusetts. During 1885, five small steamers were engaged in this fishery in the Gulf of Maine, but no data are available on the catch (Allen, 1916).

Now, especially since the serious decline of right whale and humpback populations, the fin is by far the most abundant large whale in our area. Allen (1970) estimated that approximately 7,000 fin whales inhabit the area between Cape Cod and 57°N. During a cruise along the continental shelf from Cape Cod to northern Labrador, 57 percent of all cetaceans sighted were fin whales (Mitchell, 1972d). During a whalewatch from Mt. Desert Rock Lightstation in the Gulf of Maine, about 75 percent of the 350 cetaceans seen from July 7 through September 20, 1973, were probably fin whales (Katona, Kraus, and Savage, in preparation).

Data from strip census and tagging studies suggest that a total of about 7,200 fin whales inhabited the North Atlantic in 1967 (Mitchell, 1972d). Canadian whaling stations in Dildo and Williamsport, Newfoundland, and in Blandford, Nova Scotia (Schmitt, 1972) used to take up to 748 fin whales per year before whaling was stopped in December, 1972. Whereas stocks of fin whales used to be hunted at various places within the North Atlantic (Canada, Iceland, Greenland, Norway, Portugal, Straits of Gibraltar), little, if any, hunting occurs. According to MacKintosh (1965) overhunting in the Southern Hemisphere has diminished the population.

(4) Growth and longevity. Data summarized by Harrison (1969) on the Southern Hemisphere finbacks illustrate the course of growth in the northern subspecies, which is generally somewhat smaller. At birth, calves are 6.5 m long. After seven months of nursing, the length is about 12 meters, at which time weaning occurs. Sexual maturity is reached at an average of five years (3-8) and a length of 19 to 21 meters. However, Canadian finback males mature at 16.9 to 17.5 meters and females mature at about 17.6 to 18.4 meters (Mitchell, 1974). At sexual maturity, cetaceans are about 85 percent of their full size at physical maturity. The latter state is usually approached, rather than reached, as the growth process gradually slows and epiphyseal fusion of the vertebrae occurs. The maximum recorded length is 26 meters. Longevity appears to be 50 years, and fin whales normally live 40 years.

(5) Natural mortality. In life, the fin whale apparently has no serious enemies. Killer whales probably do not often harm this large, very fast whale (25 km/hr, possibly 40-50 km/hr in a sprint), although fin whales are known to flee an area inhabited by killers. However, at other times, the two species may be seen feeding together on herring (Tomilin, 1957).

(6) Reproduction characteristics. The peak of the breeding season in the North Atlantic appears to be January to March (Tomilin, 1957) or November to March (Harrison, 1969), at which time most fins are on their southern warm-water feeding grounds. Mating occurs at the surface, in a horizontal belly-to-belly position. Gestation is 11 to 12 months. Single births are the rule, but twins are occasionally seen. Calving occurs between December and April off the Canadian coast though calving grounds are not identified (Mitchell, 1974). Lactation continues for seven months. After weaning, young whales feed mainly on small planktonic crustaceans, such as

Calanus sp., a trend that may be related to the fact that their baleen fringe is much finer than that of adults (Tomilin, 1957). This may represent an economical way of partitioning resources between fin whales of different ages. The maternal instinct is highly developed in fin whales, but possibly less strong than in humpback whales. Females probably produce calves every other year.

(7) Food and feeding methods. Although young fin whales feed on small plankton, older whales feed on larger planktonic crustaceans such as euphausiids (Thysanoessa sp., Euphausia sp., Meganyctophanes norvegica), gregarious fishes (capelin, herring, mackerel, sardines, and in various areas sand lances, arctic cod, rockfish, arctic smelt, chum salmon, cod, walleye pollock, (and occasionally dogfish), some cephalopods, and small crustaceans (Calanus). The diet varies according to season and food abundance. Nemoto (1970) listed the "preferred" order of diet items as: euphausiids=large copepods=gregarious fish>small copepods>squids. All told, the fin whale is the most euryphagous of the large whales, a feature that may underlie its wide distribution in the world ocean.

When feeding on crustaceans, fin whales scatter; however, they assume a more gregarious concentration when feeding on fishes. When feeding on fishes, a fin whale usually swims on its side and turns round the body axis, belly up, so that the heavy lower jaw emerges from the water. This maneuver may help prevent fish from slipping out of the whale's mouth and may help close the mouth faster. Water is forced out of the mouth through the baleen with the tongue, and food is retained on the inner surface of the baleen. Mowat (1972) reported that a fin whale he observed swam clockwise in circles around schools of fish, herding them toward the center and catching them. Millais (1973) also described this behavior. Mowat (1972) hypothesized that the light-colored portions of the right side of the baleen and jaws helped to startle the fish and keep them within a tight school. Mitchell (1972b) suggested that this coloration is used for obliterative countershading to avoid startling fish. Either idea is more intriguing than Mackintosh and Wheeler's (1929) suggestion that the dark pigmentation of the left side of the jaws protects them from slightly greater exposure to light when the whale swims on its right side.

Schevill, Watkins, and Backus (1964) reported that fin whales are responsible for producing the somewhat ubiquitous high-intensity 20 Hz signals that had previously been detected in various waters. It is possible that the fin whale uses sounds to help locate food (Perkins, 1966; see also Beamish and Mitchell, 1973) or in orientation (Norris, 1969).

(8) Indications of environmental stress. None available except for evidence of depleted populations. The concentrations of Stronium-90

and Cesium-137 in 11 different tissues from seven fin whales taken near Blandford, Nova Scotia, in August, 1968, were all very low (Samuels, et al., 1970).

(9) Aesthetic and economic importance. After the demise of the blue whale, the fin whale became the most important species for the world whaling industry. In 1937, when the world take of this species reached its peak, 1,197 were killed in the North Atlantic. The North Atlantic generally yielded only three to ten percent of the Antarctic take of fin whales. In the years 1964-1971, respectively, the three eastern Canadian whaling stations killed 56, 141, 427, 748, 700, 510, 576, and 470 fin whales (Mitchell, 1968, 1972d; Allen, 1970). Earlier catch data are summarized in Allen (1970) and Mitchell (1972d, 1974). Recent Canadian whaling has apparently exceeded the sustainable yield of Canadian fin whales, which appears to be about 418 whales or less (Mitchell, 1972d).

The fin whale has always been moderately valuable to the industry. In the old Blue Whale Unit system, two fin whales were worth one blue whale. The whalebone is coarser than that of the right whales and was used in the fabrication of brushes, springs, soft furniture, and other items. The usual products (glycerin, lard, soap, margarine, thin leather, meat, oil, lubricants, cattle meal, fertilizer, liver oil, and pharmaceutical extracts, among others) were made from fin whales and continue to be produced in Japan and Russia. Substitutes for all products are available.

The fin whale is a relatively inconspicuous creature. It is only the second or third largest animal ever to have inhabited the earth. It is not unusually acrobatic; it is not known to be notably vocal; very little of its huge bulk is ever exposed to human view. On the other hand, underwater films and photographs by Jacques Costeau (Costeau and Diole, 1972) have revealed it to be a graceful, powerful creature possessing surprising beauty. Also of interest, a fin whale is the tragic hero of a recent book (Mowat, 1972) which has helped to focus popular attention on an examination of the relationship between humans and the great whales and has contributed a great deal to current sentiment for whale conservation.

FAMILY BALAENOPTERIDAE: MINKE WHALE, LITTLE PIKED WHALE, SHARP-HEADED FINNER, LESSER RORQUAL, PIGMY WHALE, BAY WHALE, Balaenoptera acutarostrata

This is the smallest species of the genus Balaenoptera. In common with the other three species of this genus present in the Northern Hemisphere and in the Gulf of Maine, it has baleen, a dorsal fin, and ventral grooves. However, its small size (usually 6-9 m, occasionally 10 m), yellowish-white whalebone, and characteristic transverse band of pure white across the flipper distinguish it from the blue, sei, and fin whales. Dorsally, the minke is dusky or black-gray with a bluish tinge.

It is lighter on the flanks, but usually lacks the ovate spots produced by epiphytic or parasitic organisms that flourish on other balaenopterines while they are in warm waters. Ventrally, the minke is porcelain white; however, the ventral grooves sometimes take on a rosy hue owing to the distension of blood vessels.

At sea, the minke can be recognized by its small size, the nearly simultaneous appearance of the blow and the dorsal fin, the sharply pointed head (from which the species derives its name), and the white patch on the flipper. It is the most acrobatic of the balaenopterine whales and and often breaches. Its jump is more graceful and arching than the humpback's. Finally, the minke has the habit of approaching ships. Additional information on this species may be found in Sergeant (1963), Tomilin (1957), Mitchell (1972a), and Scattergood (1949).

(1) Distribution and habitat preference. The minke is a widely distributed whale, found from the poles to the subtropics (in the Southern Hemisphere it is represented by *B. bonaerensis*, a very closely related form). In the western North Atlantic it occurs in Davis Strait, Baffin Bay, and Greenland down to 25°N. The frequency of occurrence in the Davis Strait can be described as rare in summer, and in Baffin Bay it is also rare. It is common in the Gulf of St. Lawrence, off Labrador. In New England waters it is most frequent in August, but rare in winter (Tomilin, 1957); Allen, 1916). According to Sergeant (1963) the northwest Atlantic population of minke whales summers along the coast between Cape Cod and Ungava Bay, Labrador, and winters offshore and south to Florida and Bermuda. Allen (1916) compiled 15 certain and nine possible records of occurrence of this species in New England, 16 of which were from the Gulf of Maine. Of the 15 certain historical records summarized by Scattergood (1949) for the occurrence of this whale along the Atlantic coast of North America, 13 were from the Gulf of Maine. Norton (1939) also found this to be a common whale in Maine waters. Sergeant (1961, 1963) described its presence in eastern Canadian waters and pointed out that almost all individuals recorded from the Gulf of Maine and farther south have been immature, whereas specimens from more northerly areas include many mature specimens. Although this whale is often found far from land, it still appears to stay nearer the shore than do the other rorquals, not counting the humpback (Tomilin, 1957). Sergeant (1963) mentioned that areas of cold, turbulent water may be especially attractive to this species and Allen (1916) noted that it tends to frequent bays, harbors, and shallow waters near shore during its search for herring.

(2) Migration characteristics. In some areas the minke performs regular migrations, but they are not well understood. There probably is a southern movement through or within the Gulf of Maine or outside of it during the winter and a return to these waters in spring. Sergeant (1961) concluded that the population migrates north past

Nova Scotia in May, reaching Newfoundland in June and northern Labrador in August, then starting south for winter. Sergeant (1963) judged that the earliest weaning females migrate north earlier than females which calve in August, then starting south for winter. Usually the minke swims alone, less often in couples, and rarely (only in food concentrations) in groups (Tomilin, 1957). When pursuing fish schools it may travel with larger rorquals.

(3) Population density. Historically, the minke has been a relatively abundant whale (Scattergood, 1949), no doubt in large part because it was, until recently, too small for large whaling operations to hunt. Now, with the successive decline of the populations of blue, fin, and sei whales, the hunting of minkes is taking place at an accelerated rate. In 1970, 3,616 minkes were taken by commercial whaling operations (Food and Agricultural Organization, 1971). The International Whaling Commission established a quota for this species for the first time in 1971. While it is not yet an endangered species, there is serious concern for some stocks of this species if hunting persists. Populations probably still number in the tens of thousands, at least, within the northwestern Atlantic Ocean. The population in the North Pacific is probably less than 46,000 (Mitchell, 1972), but no data are available for the Atlantic Ocean.

(4) Growth and longevity. The minke is about three m long at birth (Scattergood, 1949), and is physically mature at 7-8 m (Tomilin, 1957). The time required for maturation may be four years (Tomilin, 1957). In the northwest Atlantic, females reach sexual maturity at 7.3 m and males become mature at 6.7 to 7.0 m (Sergeant, 1963). Along with other balaenopterine whales, this species probably lives for decades (Mitchell, 1972), but no data on maximum lifetime are available.

(5) Natural mortality. In addition to the usual assemblage of parasites and disease expected for any wild mammal (Tomilin, 1957), the minke whale is probably subject to predation by killer whales (Orcinas orca), a common problem shared by all whales but perhaps more serious in minkes than in other balaenopterines due to its small size and slower swimming speed. In addition, this species (and especially juveniles) are quite prone to entanglement in fishing apparatus and subsequent drowning (Tomilin, 1957).

(6) Reproductive characteristics. Knowledge of the breeding habits is scanty, but in the northwest Atlantic, mating appears to be spread over several winter or early spring months (Sergeant, 1963; Scattergood, 1949). In the North Atlantic Ocean, the pairing season appears to be from January to May; females give birth every year (Christensen, 1972). Gestation occupies about 10 or 11 months. Calving appears to take place from December to February. A calf abandons its mother at two years of age and is ready to mate at four years, according to old data cited in Tomilin (1957). Much

more information is needed, and research in progress by Dr. Edward Mitchell of the Fisheries Research Board of Canada will help clarify our knowledge of the reproductive cycle of this species in the northwest Atlantic.

(7) Food and feeding. Although these processes are not yet well studied in this species, certain conclusions can be made. Of all the baleen whales, the minke shows the greatest dependence on fish as food (Tomilin, 1957), and its short baleen plates appear to be well-suited to catching them. In northern waters, herring (*Clupea* sp.) is eaten frequently, and capelin (*Mallotus* sp.) is also a common food. Other fish such as cod (*Gadus* sp.), pollock (*Pollachius* sp.), and whiting (*Merlangus* sp.) are eaten in European waters (Scattergood, 1949). In Newfoundland, capelin, cod " red bait " (copepods?), "shrimp" (euphausiids?), squid (*Illex illecebrosus*), salmon, and herring are eaten in that order of importance (Sergeant, 1963). The consumption of euphausiids ("krill"), crabs, shrimps, or planktonic crustaceans appears to be less common, at least in the Northern Hemisphere. Beamish and Mitchell (1973) presented evidence that the minke whale produces pulsed audio frequency sounds which could be used for echolocation of fish during feeding.

(8) Aesthetic and economic importance. Although certain local fisheries in Norway, Canada, and Iceland have hunted this species in the past, it has usually not been an economical whale to pursue and the commercial value has apparently not been great. It should be mentioned that the minke has been the subject of one of the most barbaric hunting operations in the world in fjords near Bergen, Norway, where individuals were trapped in bays and shot with arrows that had been dipped in the festering sores of a previously caught whale. After a period of time the animal died from blood poisoning and was captured. Up to 20 whales per year were taken this way until rifles were introduced in the 1940's (Scattergood, 1949).

Probably the most valuable qualities of this whale are aesthetic. Its extraordinary tendency to approach ships (Mitchell, 1974) and to perform graceful, acrobatic leaps may provide people of the sea, and its shores, with breathtaking experiences that will long be remembered. Weighed against this must be its eating of harvestable fish and the occasional damage to fishnets caused by entanglements of this whale during its pursuit of food. One must suspect that the size of herring stocks was probably much larger hundreds of years ago when minke whales were more abundant, leading to the conclusion that whales (and other marine mammals) are not primary or serious reasons for the apparent decline in fish stocks. The damage done to fishing gear is probably scattered and, in toto, rather small.

FAMILY BALAENOPTERIDAE: BLUE WHALE, SULPHUR BOTTOM, Balaenoptera musculus

The blue whale is the largest of all the whales and probably the biggest animal that has ever existed. The average length is 25 m, although the largest record is of a female measuring 31 m long. The weight reaches 150 tons. The color of this species is a mottled, pale blue-gray with black baleen plates and fringes. The body is long and streamlined with a relatively small dorsal fin set far back and with small flippers which are approximately 1/8 of the body length. The numerous ventral grooves are close together and extend from 55 to 58 percent of the body length. This is the only one of the rorqual whales which may consistently show flukes upon sounding (Rice, 1972; Allen, 1916). At sea, it may be identified by its extremely large size and by the long interval (two to three seconds) and long expanse of back that pass between the blow and the appearance of the small fin; and by the numerous patches of light skin which give the whale a mottled appearance.

(1) Distribution and habitat preference. The blue whale is found in the Atlantic, Pacific, and Indian Oceans, and is most abundant in biologically productive areas where there are large swarms of plankton and krill (Ruud, 1956). There is no exchange of populations between the Northern and Southern Hemispheres and those in the northern population (by approximately 1.5 meters at the same age) (Nishiwaki, 1972). In the Southern Hemisphere the blue whale spends its summer in the packed ice area around Antarctica, but there is some disagreement about where it breeds in the winter. While the IUCN Red Data Book (1972) and Pilson and Goldstein (1973), state that this species breeds in temperate waters, and Allen (1916) states that it avoids tropical seas, Nishiwaki (1972) claims that it winters in the warm waters near the equator. Perhaps Tomilin's (1957) suggestion that the wintering grounds of the blue whale in the Southern Hemisphere are in the areas of the subtropics away from navigation routes may account for some of the confusion and lack of information. The Northern population spends its summer in the cold waters of the Arctic seas, but little is know of its breeding grounds. Allen (1916) gives its southward limit as New Jersey. Within the study area, Pilson and Goldstein (1973) state that the blue whale is usually found north of the Gulf Stream.

The occurrence of the blue whale in New England waters is rare. Allen (1916) was only able to find occasional possible records of its presence and no positive record. It appears to prefer cool waters (Rice and Scheffer, 1968) and is usually found north of the Gulf Stream (Allen, 1916). It used to be common in summer in Newfoundland waters and in the Gulf of St. Lawrence, scattering about the Grand Banks in winter. Blue whales still congregate in the St. Lawrence River near the Saguenay River (Dr. E. Mitchell, personal communication). Occasional sightings of blue whales are made at the entrance of Passamaquoddy Bay in summer (Sergeant, 1961). The sightings of blues in the Bay of Fundy during the study of Neave and Wright (1965) are open to question owing to the difficulty of identifying blue whales at sea. The species is best categorized as nearly completely pelagic; however, all four of the relatively small (18-29 m long) blue whales studied by Cummings and Thompson (1971a) off the coast of Chile were in water less than 175 m deep, and one was observed so close to the beach of Guato Island that it was among breaking waves in water estimated to be only 7 m deep. According to McVay (1966), the blue whale is seldom seen except in these more remote southern seas.

(2) Migration characteristics. The blue whale travels singly or in pairs and does not seem to gather into large groups (Allen, 1916), except perhaps in the higher latitudes when they are concentrated in rather narrow belts in the polar seas (Ruud, 1956). It is believed that the whales disperse as they leave the polar regions (Ruud, 1956). In the Southern Hemisphere, this species migrates towards the equator in the fall and remains in this area, where it breeds, until spring. In the spring it moves south to the region around Antarctica. The blue whale population in the Northern Hemisphere spends the winter breeding in the temperate waters north of the equator. Then it migrates to the Arctic Sea in the spring and stays there until the end of summer, when it begins moving south again. The migrations are not well documented.

(3) Population density. In the past years the blue whale population has been greatly decimated because of extensive hunting. Over 350,000 blue whales were killed during modern whaling prior to 1956 (Ruud, 1956). Most hunting was done in the decade of the 1930's. In 1930-31 alone, 28,235 blue whales were killed in the Antarctic (Pilson and Goldstein, 1973). The species has declined from an original worldwide population of about 200,000 in the 1900's before intensive pelagic whaling concentrated on it, to about 15,000 in the Southern Hemisphere, 1,500 in the North Pacific, and only a few hundred in the North Atlantic (Rice, 1972). Allen (1970) concluded that the initial stock size in the northwest Atlantic was slightly over 1,100 blue whales. Mitchell (1974) noted that the blue whale population in this area has not recovered from overexploitation as rapidly as has the humpback whale. The species is now fully protected worldwide by the member nations of the International Whaling Commission; however, some hunting may still go on off the South American coast. All stocks are seriously reduced in numbers, and even with full protection it will be on the order of 50 years before the blue whale is once again abundant. During the 1960's and early 1970's, many authors expressed the fear that the blue whale might become extinct. Now that some stocks appear to be increasing slowly, there is reason to hope that that possibility has been averted.

(4) Growth and longevity. The life expectancy of this species is perhaps 90 years and rarely over 100 (Nishiwaki, 1972). At birth the calf is about 7.5 m long and weighs 2,500 kg. It gains about 90 kg per day and reaches 15-17 m and 22,700 kg by age seven months, when it is weaned (Ruud, Johsgard, and Ottestad, 1950).

(5) Reproduction characteristics. Estimates of the time of sexual maturing for the blue whale vary from four to five years (male) and five to six years (female) (Harrison, 1969) to ten years (Rice, 1972). The pregnancy lasts from 10 to 11 months, and in the Southern Hemisphere birth takes place in temperate seas during July and August. The lactating mother and calf then travel together for approximately 12 months. After weaning the female can be impregnated again for the following winter (Nishiwaki, 1972). The average female will give birth every two or three years. In the Northern Hemisphere this species also breeds in temperate waters in the winter months. Twins occur in 0.7 percent of births (Harrison, 1969).

(6) Food and feeding methods. Most of the feeding is done in the summer in the regions near the Antarctic and the Arctic, where the blue whale is able to find swarms of planktonic food. Food may be echolocated (Beamish and Mitchell, 1971). The blue whale eats by taking in huge amounts of water where the food is swarming and then discharging the water through the baleen plates, using the large, flabby tongue. The food becomes caught on the inside of the rough fringes of the short, tough baleen plates. In the Antarctic the major diet items of this species are Euphausia crystallorophias, Euphausia superba, Thysanoessa macrura, and Thysanoessa viana. In the Arctic, euphausiids make up the main part of the diet (Nemoto, 1970). The blue whale has possibly the shortest food chain of all the baleen whales. It consists of phytoplankton>herbivorous euphausiids>blue whale (Mackintosh, 1965). Furthermore, of all the balaenopterine whales, blues are the most stenophagous, rarely eating anything besides euphausiids (Rice, 1972; Beamish and Mitchell, 1971). Beamish and Mitchell (1971) recorded narrow band sound pulses of frequencies between 21 and 31 khz in the presence of a blue whale and suggested that the sounds could be used for echolocating euphausiids. However, Cummings and Thompson (1971a) recorded only low frequency moans of frequencies 14-222 Hz which they felt would not be suitable for echolocating planktonic crustaceans. Instead, they suggested that those sounds could be used for long distance communication. They also noted that the moans were the most powerful sustained utterances known from whales or any other living source.

(7) Indications of environmental stress. Other than evidence of severely depleted population size due to hunting, no data are available. According to Mitchell (1974), only with continued full protection can blue whale stocks be restored. Only a few hundred now exist in the northwest Atlantic (Mitchell, 1974).

(8) Aesthetic and economic importance. In the modern history of whaling the blue whale has been the most valuable to the whaling industry, since one whale alone yielded 20 tons of oil, plus tons of meat and byproducts. Between 1900 and 1950, approximately 25 million tons of blue whales were taken in the Antarctic. However, because of the present scarcity, this species is now of little economic importance and since 1967 has had complete worldwide protection (Rice, 1968). The fact that this whale is the largest animal ever to have inhabited this planet must certainly confer upon it a unique aesthetic and biological value.

FAMILY BALAENOPTERIDAE: SEI WHALE, POLLOCK WHALE, RUDOLPH'S RORQUAL, Balaenoptera borealis

The body plan of the sei whale is similar to that of the other whales in the genus Balaenoptera, but its coloration may be somewhat more variable between individuals. The back of the sei whale is a dark gray with a bluish tinge. The flanks are lighter, often with small, bright spots, and the belly is a light gray with a patch of white. The inner surface of the flippers and the undersides of the flukes are gray, and the baleen plates are black with fringes of fine, white bristles. The flippers are smaller, relative to the body, than in other rorquals. The dorsal fin, however, is relatively large. It is triangular in shape and curved backwards. The largest sei whales recorded in the International Whaling Statistics are an 18.5 m male and a 20 m female. More recently, the largest caught are 15 to 16 m in length (Nishiwaki, 1972). The sei whales in the Northern Hemisphere are about two m shorter than those in the Southern Hemisphere (Tomilin, 1957).

(1) Distribution and habitat preference. According to Kellogg (1929), sei whales have a "roving disposition and occur sporadically in large numbers from time to time at widely scattered localities." This is a cosmopolitan species; however, in neither hemisphere does it seem to frequent as high latitudes as do other rorquals. It is rarely seen in the packed ice regions (Nishiwaki, 1972; Tomilin, 1957), seeming to prefer warmer waters than blue whales or fin whales. (Marcuzzi and Pilleri, 1971). It spends its winter in temperate seas, but it also is seen in small numbers in tropical areas where it is more abundant than are other rorquals. Within the North Atlantic, the sei whale seems to be commonest in waters on Northern Europe (Allen, 1916). This species does not frequent the coasts and is rarely seen in New England waters, perhaps because it bypasses the region during its migration (Pilson and Goldstein, 1973). According to Pilson and Goldstein (1973), the sei is distributed from Labrador waters and Newfoundland south to Florida and Venezuela. However, it may actually be more numerous than the records show, as it can easily be mistaken for a fin whale. In fact, experienced whale scientists are often very skeptical that this species can be positively identified at sea.

The records of Neave and Wright's (1968) study are certainly suspect. However, Beamish and Mitchell's (1971) sightings of two on the south edge of Sable Bank in late May, 1969, are reliable. The only stranding and only possible sighting known to Allen (1916) for this species in New England, occurred on the south shore of Cape Cod. Sightings in eastern Canada (Sergeant, 1961) have also been reported to frequent waters southeast of Cape Sable, Nova Scotia.

(2) Migration characteristics. The migration cycle of the sei whale is probably generally similar to that of other rorquals, but it is not well known. For example, neither the geographic limits, migration, nor ranges of the sei whale population that were fished at Blandford. Nova Scotia, are known (Mitchell, 1972c). The sei whale appears in temperate and subtropical waters. However, according to Tomilin (1957), the movements of this species may differ from those of other rorquals in several respects. First, the sei appears later in the high latitudes than do other species. For example, its peak appearance in Antarctica is in February and March as opposed to January and February for the larger baleen whales (Mackintosh, 1965). Second, it has lower tolerance for cold and makes less distant migrations in the summer. Third, it concentrates in the regions of warm currents in the temperate and temperately cold belt. Fourth, the migrations of the sei whale are much less regular than those of other rorquals and migration paths may undergo large, sudden fluctuations in regions affected by warmer currents. According to Mitchell (1972a) sei whales tend to travel in groups of about ten; but Tomilin (1957) records that they occur mostly alone or in pairs, except when food is abundant, at which times groups of 50 or more may congregate. Although they may graze in company with right whales(Neomoto, 1970), there is apparently a mutual exclusiveness between the distribution of sei whales and of the other rorquals. This is probably explained by the different prey size requirement as described below (Tomilin, 1957).

(3) Population density. In 1971 estimated population of the sei whale in the North Pacific was 46,000 (Mitchell, 1972a). Gullard (1974) estimates that sei whale populations are perhaps the same magnitude as the fin whale: 7,000 animals between Cape Cod and 57^{O}N.

(4) Growth and longevity. No sei whales have been found older than 70 years (Nishiwaki, 1972), suggesting that the life span might be shorter than that of either the blue whale or the fin whale. Newborn sei whales are 4.3 to 5.3 m long and they grow at the rate of about 2 cm per day. According to Nishiwaki (1972), sexual maturity is attained at lengths of 12 m for males and 12.8-13.5 m for females, and physical maturity is attained at 10 to 11 years of age. However, at the Blandford, Nova Scotia, whaling station, where an average of 114 sei whales were taken from 1968-1970, most mature

females were at least 15.1 m long.

(5) Natural mortality. According to Tomilin (1957), the sei whale is one of the fastest whales and is probably not bothered by killer whales. However, no data are available on the relative swimming speeds of the two species.

(6) Reproduction characteristics. Sei whales become sexually mature by at least 18 months of age, and begin to mate in the second year of life (Tomilin, 1957). Gestation lasts for 10 to 12 months (Mackintosh, 1965), and lactation for approximately five months. Females generally give birth every two years with a six to seven month interval between lactation and conception (Tomilin, 1957). Sexual activity continues the year round; however, the peak mating periods are January and February in the Northern Hemisphere, and July and August in the Southern Hemisphere.

(7) Food and feeding methods. The sei whale has the typical rorqual baleen: short, tough plates with rough fringes. However, both plates and fringes are more delicate than those of the blue whale or the fin whale, allowing the capture of smaller food species. In the Southern Hemisphere the sei feeds on various plankton, including carnivorous amphipods (Parathemisto gaudichaudi), herbivorous copepods (Drepanopus pectinatus, etc.), and also zooplankton, including the decapod Munida gregaria (Lobster krill). All of these are found in the Antarctic and subtropical convergences, and this is the reason that the sei does not move into higher latitudes (Nemoto, 1970). In the North Pacific, the sei feeds on copepods (Calanus plumchris). The diet of the sei, in order of importance, is made up of: copepods>amphipods>euphausiids>swarming fish>squid. Its "food chain" is: small phytoplankton→protozoa, larvae of zooplankton, small copepods→carnivorous amphipods→sei whale (Neomoto, 1970). In the North Atlantic the sei whale is very closely associated with the crustacean Calanus finmarchicus (Allen, 1916; Tomilin, (1957).

The sei uses two methods of feeding. The first, which is used for food that is swarming, is to swallow large amounts of water and then to use the tongue to discharge it through the baleen plates where the food becomes stuck on the inner surfaces. The second method, which is used when food is more sparse, is to swim along the surface with an open mouth. This method could subject the animal to stress from any surface pollution of the ocean, including oil, plastic wastes, or pollutants accumulated in the surface monolayer (MacIntyre, 1974). When skimming for crustaceans, the sei whale may swim slowly at a depth of 1 m, covering a distance of 15 to 20 m at a time, and rolling gently from side to side so that the left and right margins of its upper lip alternately touch the surface. After seven minutes of such swimming, the whale rolls on its side (Tomilin, 1957). The respiratory rate of sei whales is much more even and constant than that of other rorquals, according to Mitchell (1972a), because it does not dive deeply and stays near the surface.

The sei whale is less well adapted to feeding on fish than are fins or humpbacks and uses a different method on the unusual occasions when it does so. It does not make sudden half turns around the body axis, but instead pursues fish at the surface with its dorsal fin exposed. Although fish such as capelin, walleye pollock, Arctic cod, sand lances, anchovies and sardines are taken in various locations, copepods - and especially Calanus species - remain the overwhelmingly important diet item. Tomilin (1957) suggested that this whale probably evolved in the North Atlantic, since it is here that the structure of its baleen is best adapted to the small size of the local food.

(8) Indications of environmental stress. Although the sei whale is not listed in the IUCN Red Data Book (1972), it is listed on the U. S. Department of the Interior's Endangered Species List of 1971, as are all the baleen whales except the minke, owing to the serious decline in population numbers from overhunting. As blue and fin whales became rarer, attention turned to sei whales, whose catches increased dramatically, starting in the middle 1950's (Mitchell, 1972a; Mackintosh, 1965). McVay (1966) lists the sei as one of the eight that have been important as a commercial species during recent years. Canada's three whaling stations began catching sei whales in 1966. In 1968, 104 were caught. Canada stopped all East Coast whaling in December, 1972. Although our Gulf of Maine population is now apparently safe from hunting, the sei whale is under heavy pressure in other areas of the world. For 1971 alone, the estimated catch was approximately 9,366 animals worldwide (Committee Merchant Marine and Fisheries, 1974).

(9) Aesthetic and economic importance. In 1938, the sei whale was rarely hunted because of its small size, but as other species declined the sei has grown in economic importance. The sei is now among the eight species commercially most important in the world (Pilson and Goldstein, 1973). An average of 114 sei whales were taken at Blandford Land Station, Nova Scotia, each year from 1968-1972.

FAMILY BALAENOPTERIDAE: HUMPBACK WHALE, Megaptera novaengliae

The humpback whale has a short, fat body with long flippers that are approximately ¼ the length of its body. The color is dark, with some unpigmented skin on the ventral side which extent varies among individuals. Coloration in this species is quite variable (Tomilin, 1957). The North Atlantic population is distinguished by the huge, pure white flippers, which are a striking field mark and help in the identification of this whale at sea. The edges of the tail and flippers are irregular and the head, snout, and flippers are covered with knoblike swellings each of which contains a sensory hair. The dorsal fin is small and set fairly far back. The ventral grooves, which extend back to the navel, are widely spaced, with only 12 to 36 grooves, as compared with the Balaenopterine whales, which all have more than 40 grooves. The largest humpback recorded was a 19 m female although at present the average seems to be closer to 15 m (Nishiwaki, 1972). The species is also characterized by its acrobatic behavior. This includes frequent breaching (leaping completely out of the water) followed by rolling over onto the back, rolling on the water surface, and turning somersaults under and above water. The humpback usually shows its flukes before sounding, and their irregular trailing margins make a good field mark. This species is known to follow or play alongside ships for long periods (Tomilin, 1957).

(1) Distribution and habitat preference. The range of the humpback is very large, comprising almost all of the oceans between the Arctic and Antarctic. The range in both hemispheres is from the poles to the tropics (Tomilin, 1957). There are six separate populations within the Southern Hemisphere, but there is little exchange across the equator (Mackintosh, 1965). Similarly, there are probably a number of separate stocks within the Atlantic Ocean, but their identity and relationships are not yet well know. Within the Gulf of Maine the species is well known from strandings and, especially, from live sightings at sea (Allen, 1916; Norton, 1930). Most of the records are of schools seen about Nantucket Shoals, on the Georges Banks or off Provincetown and the outer parts of Massachusetts Bay (Allen, 1916). Allen (1916) included records of sightings of large schools of humpbacks near Cape Elizabeth, Maine (June, 1841); in the Bay of Fundy near Grand Manan Island (July-early August, 1859); and of over a hundred humpback individuals or pairs seen during a cruise from the Isles of Shoals to Nova Scotia (September 4-6, 1903). Norton (1930) included one observation of a herd of about 100 humpbacks inside of Stratton's Island near Portland, Maine. Humpbacks have been recorded as far south as Florida (Pilson and Goldstein, 1973).

Tomilin (1957) characterized this species as living close to land, although it can be found in the deep ocean. Tomilin (1957) furthermore, suggested that the long flippers may help these whales to free themselves if they become beached in shallow water, and that individuals may be helped out of such situations by other whales. Voice communication is apparently used (compare Mowat, 1972). Schevill and Backus (1960) observed a daily patrol by a humpback of a fixed area near Portland, Maine, over a ten-day period, sometimes only one or two miles from land.

(2) Migration characteristics. In general, the humpback migrates along well-defined routes, generally close to the coast (Tomilin, 1957); however, the tracing of movements of specific stocks or herds in the northwest Atlantic is not yet possible due to lack of information. In both hemispheres this species arrives in the polar regions in the summer to feed and begins returning to the tropics in the early fall. It reaches its tropical breeding grounds in mid-winter and remains there until early spring (Kellogg, 1929). Northward and southward migrations each take about two months. Five and one-half months are thus spent on the feeding grounds and a little over one month on the breeding grounds (Wolman, 1972). Humpbacks usually travel in pods of two to five individuals, and the average rate is less than four knots (Wolman, 1972). Apparently, males and barren females leave the wintering grounds (near Bermuda and the Greater Antilles) first and are later followed by the lactating females and newborn calves.

From Massachusetts to Maine, humpbacks first appear in April and May (Kellogg, 1929) and large herds seen about 200 miles offshore in April probably indicate that many humpbacks travel over the banks rather than entering the Gulf of Maine. Later migrants remain offshore of New England instead of going north to Newfoundland, Greenland, or Iceland (Tomilin, 1957). The southward migration may be more gradual, and may also take place largely offshore. According to Kellogg (1929), humpbacks have been observed off the New England Coast as late as October, with one December record for Massachusetts.

(3) Population density. Before exploitation by hunting, the humpback whale population probably numbered from 40,000 to 50,000 in the Southern Hemisphere and somewhat less in the Northern Hemisphere (Wolman, 1972). Sources generally agree that the present world population is under 10,000. The IUCN Red Data Book (1972) gives the total population as 7,000 to 8,000 while Wolman's figure is 5,000 (Wolman, 1972). Since 1966, this species has enjoyed worldwide protection, and in the North Atlantic since 1955. Within the northwestern Atlantic Ocean, Allen (1970) estimated the population to be 1,500 on the basis of cumulative catch data, but a large scale strip census survey from shipboard, which covered over six million square nautical miles, yielded only 96 sightings during spring and summer, 1966-1968, leading to a population estimate of 1,259 (Mitchell, 1973b). The interrelationships among stocks from the Caribbean, Bermuda, the eastern U. S., the Nova Scotian shelf, and the Grand Banks are not yet clear.

(4) Growth and longevity. According to Tomilin (1957), individuals live at least to 20 to 22 years, judging by old harpoons found in their bodies; but they probably can live much longer.

(5) Reproduction characteristics. Sexual maturity of the North Pacific humpback is attained at the age of two years and physical maturity at the age of 10 years (Tomilin, 1957). Females are polyestrous and may ovulate five times per year. The gestation period is 11 to 12 months and lactation lasts 11 months. Females generally bear a calf every two or three years, and only rarely two years in succession. Birth appears to be in mid to late winter in the northwest Atlantic, where newborn calves have been sighted off Puerto Rico in February, 1969, and one suckling calf has been seen on the Grand Banks on 8 March, 1961, (Mitchell, 1974). In the Southern Hemisphere breeding peaks in August (Mackintosh, 1965) in areas very close to the equator (Tomilin, 1957). In the Northern Hemisphere, the peak is between October and December in latitude 10°N to 20°N (Nishiwaki, 1972). A newborn humpback measures 4.5 to 5 m in length. Its rate of growth is somewhere between 17 cm and 45 cm per month. The incidence of twins is about 0.5 percent (Tomilin, 1957). Maternal instinct is exceptionally strong in humpbacks, and females will not abandon calves even in extreme danger. Weaning occurs when calves are 8 to 9 m long. Growth decelerates after weaning. Calves stay with their mothers at least for a year, and perhaps longer. It now appears that the main calving area for perhaps half of the northwest Atlantic population of humpbacks is in the Navidad Bank-Silver Bank area off the Dominican Republic, where up to 700 whales have been seen.

(6) Food and feeding methods. The ash black baleen plates of the humpback are short and tough with rough baleen fringes. The main foods are euphausiids and gregarious fish, both of which can form swarms. The humpback eats by taking in large mouthfuls of water and food, then discharging the water through the baleen plates, where the food becomes caught, by using the tongue as a plunger (Nemoto, 1970). In the North Atlantic, humpbacks are known to eat the euphausiids Thysanoessa inermis and Meganyctiphanes norvegica, herring, capelin, and rarely, cephalopods and pteropod molluscs. Euphausiids appear to be more important to the diet than fish in this area. Southwell (1904) described a humpback whale that was found dead near Scotland, apparently after eating too many cormorants, which had perhaps been swallowed accidently.

(7) Aesthetic and economic value. The humpback was one of the most important species to commercial whalers. It was easy to catch, because of its slow movement, coastal habitat, and lack of fear of humans. A small fishery for humpback whales used to be carried on near Seguin Island, Portland, Maine (Norton, 1930) and Clark (1887) noted that whalers out of Wellfleet, Massachusetts, used to sail to the Mt. Desert Island region for humpback whaling. From 1810-1860, humpbacks were the main object of the Maine shore whaling stations at Prospect Harbor, Tremont, and Winter Harbor (Allen, 1916).

Additional humpback whaling along the coast of Cape Cod also occurred during the 18th and 19th centuries. Between 1909 and 1947, 11.4 percent of 902,000 whales killed in the world were humpbacks (Tomilin, 1957). As a result of extreme overfishing, many populations of the species have been decimated and since 1966 the species has had complete protection, so that it is now of no direct economic importance. Populations of humpback whales are growing very slowly, if at all, and even under full protection many will take as long as 50 years to recover maximum sustainable yield levels (Allen, 1973; Wolman, 1972).

Vocalization ability is remarkable, consisting of a wide range of tones and an extensive vocabulary. The "songs", which are the subject of scientific studies (Payne and McVay, 1971), are available on several popular recordings (Capitol Records, 1971; Hovaness, 1970). There is no evidence that humpbacks sing while in New England waters, and all recordings of complex sounds have been made around the presumed breeding area near Bermuda or in the Caribbean. Dr. Howard Winn of the University of Rhode Island is trying to detect dialects in the vocalizations of humpbacks to make an estimate of the population size in the West Indies (Anonymous, 1971). The songs of the humpback whale have probably kindled public interest in whale conservation more than any other discovery with the possible exception of Lilly's (1961, 1967) early work on Tursiops.

Finally, the acrobatic nature of this whale (Millais, 1973), its striking coloration and morphology, and its habit of playing around or following ships earned it the nickname of "veselyi kit"-- "the merry whale"-- among Russian whalers (Tomilin, 1957). One can hope that this interesting and inspirational species will recover from the human depredations and will once again enliven our waters with its abundant presence. The possibility for making the Navidad Bank-Silver Bank area a humpback whale reserve has occasionally been mentioned.

(8) Indications of environmental stress. Samples taken by Mitchell (1973b) are being analyzed for pesticide and heavy metal residues, but no data are yet available.

FAMILY BALAENIDAE: RIGHT WHALE, NORTH ATLANTIC RIGHT WHALE, Eubalaena glacialis glacialis

This species is easily recognized by its thick, stout body, arched jaw, the absence of a dorsal fin, and by the large, light-colored, wart-like calluses or "bonnets" which adorn the anterior of the upper jaw and various other positions around the blowhole, eye, and lower jaw. Individual whales have somewhat distinctive patterns of bonnet arrangement. The baleen plates are olive black, and the body is a deep ebony black.

The maximum recorded length for an Atlantic right whale is 16.5 m.

It is called the "right whale" because it was traditionally the right whale to hunt, owing to its large yield of oil and whalebone, slow swimming speed, and tendency to float when killed. In the Atlantic Ocean, this species was hunted for at least 1,000 years, and it plus the humpback (Megaptera novaeangliae) were the two whales most commonly hunted by earliest colonial whalers in America. However, by 1750, right whaling had already been nearly abandoned at Cape Cod due to the lack of whales (Allen, 1916).

Nishiwaki (1972) and Tomilin (1957) provide additional general information on this species, and Allen (1916) includes a wealth of biological and historical data on the right whale in New England waters.

(1) Distribution and habitat preference. The right whale is found in temperate waters of the North Atlantic Ocean and once was distributed from the Gulf of St. Lawrence to Florida (Clark, 1887; True, 1904; Allen, 1916; Tomilin, 1957); however, it is absent in the tropics, and it avoids the ice of latitudes higher than about 70°N. Following centuries of depredation by hunting, the right whale population was nearly reduced to extinction by the late 1800's (Committee on Merchant Marine and Fisheries, 1974). This whale was protected in 1937 by international agreement; however, it still remains an endangered and fully protected species (IUCN, 1972). The population now appears to be recovering and can once again be seen in New England waters, although it will be many years before this whale regains its former abundance here (Allen, 1916). Between 1620 and 1913, Allen (1916) recorded over 50 instances of sighting or capture of right whales in New England waters, 22 of them from the Gulf of Maine. Most records were made between February and May, and less frequently between June and September. Waters and Rivard (1962) reported an increase in numbers in Massachusetts, and in Cape Cod Bay a herd of 30 to 50 individuals can sometimes be seen. In addition to summarizing sightings south of Cape Cod, Pilson and Goldstein (1973) listed sightings of a school off Cape Cod in 1953, an individual at Cape Cod Canal in June, 1957, and a school in Cape Cod Bay in May, 1959 and May, 1961. Watkins and Schevill (1972) recorded the sounds from members of a herd of 20 right whales in Cape Cod Bay in May, 1970.

Whereas Allen (1916) listed no sightings from along the Maine coast and considered it rare in this area (perhaps owing to lower productivity in the northern portion of the Gulf of Maine), Norton (1930) listed one stranding in summer, 1919, in Sheepscot Bay. Recently, Arnold and Gaskin (1972) sighted at least five E. glacialis in the Bay of Fundy in late August, 1971. The photograph of a right whale which appeared in the Calais, Maine, Advertiser for September 2, 1971 could be one of that group. Neave and

Wright (1968) included the record of a herd of 15 right whales in the Bay of Fundy during August, 1968, and although that report was criticized by Schevill (1968) with good reason, the additional comments of Neave and Wright (1969) lend support to the record. Residents of Eastport and Lubec, Maine, claim that right whales often appear near the West Quoddy Head Lightstation during August and may engage in mating activity. However, the whales were not seen in 1973. Most recently, one E. glacialis was observed for three hours from Mt. Desert Rock Lightstation, July 12, 1973 (Katona, et al., in preparation).

(2) Migration characteristics. Although Allen (1916) noted that this whale migrates individually, in pairs, or in very small groups of three to five individuals, the recent sightings of herds indicate that larger groupings can be expected more commonly as the species becomes more numerous. Allen's (1916) observations indicate that the northward migration began to pass through Massachusetts waters in January, became stronger in February and March, and peaked in April. Southbound right whales appeared to pass that coast in November. E. glacialis appears to migrate through the Gulf of Maine in early spring on its way to feeding grounds around the Grand Banks, Newfoundland, the mouth of Davis Strait, Iceland, the Faero Islands, and the Hebrides. However, as Allen (1916) pointed out, most right whales probably bypass the Gulf of Maine. In late summer and autumn, they return to warmer temperate waters, probably including Florida, Bermuda, the coasts of Georgia and the Carolinas (Caldwell and Golley, 1965), and possibly Massachusetts Bay (Allen, 1916).

(3) Population density. This whale is still exceedingly rare everywhere in its range although it has been protected for 50 years. The northwest Atlantic stock was hunted as early as 1631, and, by 1750, the right whale fishery off the United States had collapsed (Allen, 1908) owing to the drastic decline of the stock. Mitchell (1974) summarized evidence that the population may possibly be recovering slowly both in the southern and northern limits of its range, (Florida to Canada); however, the population still appears to be only in the tens of individuals in the region off eastern Canada during summer. The total population inhabiting the waters of eastern North America and eastern Canada has been estimated variously as less than several hundred and perhaps less than 100 (IUCN, 1972).

(4) Growth and longevity. Newborn calves measure 4.5 to 6 m in length. There are practically no data on growth rate (Tomilin, 1957). Sexual maturity is attained in three to five years (Nishiwaki, 1972).

(5) Natural mortality. Attacks by killer whales may occur (Allen, 1916),

but are poorly documented (Tomilin, 1957).

(6) Reproduction characteristics. Like other baleen whales, the right whale female calves once every two years after a gestation period of about one year. Mating occurs in May to July, and birth from January to March. Pregnant females tend to remain apart from the rest of the stock (Tomilin, 1957). Calving probably occurs in still waters near shore (Tomilin, 1957; Payne, Curtsinger, and Nicklin, 1972). The exact location of calving grounds is not known. Lactating females have very well developed maternal instincts and apparently refuse to abandon sucklings even after death (Tomilin, 1957).

(7) Food and feeding methods. The baleen of this whale is very finely fringed, allowing it to strain small plankton animals from the water, and its diet correspondingly consists of copepods, especially Calanus finmarchicus (3-6 mm) and,less commonly, euphausiids such as Thysanoessa inermis (16 mm). Occasionally pteropod molluscs are taken. The right whale sometimes grazes in company with the sei whale. It is important to note that the method of feeding is quite different from the "gulping" strategy of most balaenopterine whales. The right whale is a "skimmer", cruising along the surface with its mouth open and continuously filtering out food (Nemoto, 1970). This suggests that the right whale is probably much more vulnerable to any pollution of the ocean surface than are whales which feed underwater. Pollution of the ocean surface with oil could possibly affect this whale in a serious way, although no data are currently available. Similarly, the accumulation of pollutants in the organic surface microlayer of the ocean (MacIntyre, 1974) could affect this whale more than other species.

(8) Indications of environmental stress. Other than the drastically reduced populations of this species, owing to overhunting, no data are available. According to McVay (1966), the right whale is now protected worldwide.

(9) Aesthetic and economic importance. Prior to the adoption of steam-powered whaling vessels and the invention of the explosive harpoon, this whale was a mainstay of the whaling industry. After intensive hunting by many nations (starting in the 9th century), the North Atlantic population was decimated by the 18th century, and whalers turned to its Arctic relative, the Greenland right whale (Balaena mysticetus). Very few have been killed in the last 80 years, because few were left alive. In the old days these whales yielded up to 18 tons of oil and up to 600 kg of whalebone each. The species probably will not be commercially important in the near future, and its return to abundance will have to be encouraged for non-monetary reasons. Among these might be its occasionally acrobatic nature, its unique morphology, the possibility that it

might produce complex sounds and communicate vocally, and for related scientific and aesthetic reasons.

FAMILY PHYSETERIDAE: SPERM WHALE, SPERMACETI, CACHALOT, Physeter catodon

The sperm whale is the largest of all the toothed whales (Order Odontoceti). Males may reach a length of 18.3 m, although a 15.2 m length is more common. The females are significantly smaller than the males (as is the case in most Odontocetes) and average under 11.3 m. The head is massive and makes up from 1/4 to 1/3 of the body length. Most of the volume of the head is made up of the barrel-shaped spermaceti organ, called the case, which contains the spermaceti. The spermaceti is the sperm whale "oil". Although it is a clear liquid when heated (or refined), it has a white paraffin-like consistency when cooled.

There are 50 teeth on the long, narrow, lower jaw, 25 on each side. The upper jaw contains cavities into which the teeth fit, however, it sometimes contains several rudimentary teeth which do not show outside the gums. The whale does not possess a dorsal fin, but instead has a somewhat rectangular hump or dorsal prominence set near the back of the body. Females appear to have a "callus" on the hump which adult males lack (Kasuya and Ohsumi, 1966). The flippers are relatively short and round. One of the unique characteristics of the sperm whale is that the blowhole, which is single as in all the Odontocete whales, is offset toward the left side of the head. The color of the adult body is generally slate gray above with a paler shade of gray on the abdomen. A young sperm whale is light colored, but grows darker as it matures and then becomes faded and light again when it grows old. The skin around the mouth is particularly pale and is almost white. In all sperm whales, the skin has a wrinkled corrugated appearance that is distinctive.

(1) Distribution and niche preference. The sperm whale lives in all oceans of the world, and its range extends from the equator to both the North and South Poles. However, the distribution of males and females is quite different. While females tend to remain between the latitudes 45°N and 45°S, and to perform abbreviated migrations (Tomilin, 1957), males annuallv migrate from tropical waters to the polar regions (Rice, 1971). The females, including those that are pregnant or lactating, along with juveniles of both sexes, tend to congregate in groups called "nursery schools", which may number from ten to several hundred whales, and average 25 individuals. After weaning, some young whales may form "juvenile schools" containing ten whales or less. During the breeding season, eligible males (males may start breeding at age 25) apparently vie with each other to join a nursery school and to breed with the mature females. Such a group is then called a "harem" when it includes a bull. Old "socially mature" males form small "bull schools" or live alone. Harem bulls probably leave the

nursery school at the end of the breeding season and live alone or in a "bull school" until the next season (Ohsumi, 1971; Rice, 1971). The behavioral repertoire of the species is quite varied (Gambell, 1968; Gaskin, 1964; Ashley, 1944) and requires further study.

While Nishiwaki (1967) states that no sperm whale marked in one hemisphere has been sighted in the other, Mackintosh (1965) claims that the world population is not segregated in northern and southern stocks. Instead, he suggests that the population is segregated into Atlantic, Pacific, and Indian Ocean stocks with some mingling at the southern ends of the continents. Bennet (1840) claimed that sperm whales are fond of areas where there are powerful currents or where currents flow in opposite directions.

The sperm whale is seen only rarely in New England waters. It is generally an oceanic whale, found in deep water; however, it is not uncommon in coastal waters in some areas. The bulk of the population generally is located south of our waters. Although males do migrate to high latitudes, they probably migrate along the continental slope, and they may follow the Gulf Stream or stay outside of the Gulf of Maine for other reasons. Only a few records of the sperm whale are available since its first description here in 1608 by Josselyn (1674), including Norton's (1930) listing of three seen in 1918 south of Monhegan Island. In October, 1968, a live female sperm whale stranded at Seawall on Mt. Desert Island and died. During the summer of 1973, one enterprising mariner chased a sperm in the region of Provincetown in an attempt to kill it for its teeth (Malcolm Jones, personal communication).

Evidently, the Micmac Indians of the Passamaquoddy Bay region had a name for the sperm whale (Ded-men-ak-part = "head cut off squarely or sharply") and Piers (1923) suggested that the species may have been somewhat more common along the Nova Scotia coast in past times.

(2) Migration characteristics. The migration pattern of the sperm whale is unique among all the cetaceans. Much of the population, including all the females and juveniles, as well as the males involved in mating appear to remain within temperate waters all year round (Rice, 1971). Short migrations are made in the spring, northward in the Northern Hemisphere and southward in the Southern (Tomilin, 1957). Unlike other cetaceans, mating is done in spring and early summer, and this prevents the mating males from moving to colder waters during the warm periods, as usually occurs in the other large cetaceans. According to Marcuzzi and Pilleri (1971), migrations depend on temperature, abundance of cephalopods, and the presence or absence of harem schools or solitary males. In addition, Pilson and Goldstein (1973), state that migrations are bounded by latitudes 40°N and 40°S.

The males not involved in mating also migrate in the spring, but their migrations are far more extensive, and they spend their summers in the polar regions. According to Mitchell (1974) bull sperm whales migrate along the continental slope and pods have been seen feeding on the slope as far north as Cape Chidley, Labrador. They return to lower latitudes in the fall (Tomilin, 1957). Little is known of the migration routes. The extent to which the non-breeding males become separated from the rest of the population is still not clear.

(3) Population density. The total population of all ages in the northwest Atlantic is estimated to be about 22,000. Evidently, far fewer sperm whales inhabit our seas than live in the North Pacific (70,000 males; 184,000 females) or southern oceans (128,000 males; 295,000 females) (Dent, 1973). The sperm whale has been only lightly exploited in the North Atlantic since the mid-19th century and complete cessation of whaling would probably permit a slow return to pre-whaling population size (Allen, 1973). Few published records exist for the sperm whale in the Gulf of Maine, probably because it stays farther out to sea during migrations.

(4) Growth and longevity. Calves are about 4.0 m long at birth. Females mature sexually at about 8 to 11 years of age and at a length of 11.0 to 11.5 m. Males reach sexual maturity at 10.0 to 11.9 m (Ohsumi, 1971; Dent, 1973) and at 19 to 25 years of age. At 25 years, males are "socially mature." Males continue growing until they are 15.5 to 16.8 m long. Both sexes can live to be 70 years old (Ohsumi, 1966).

(5) Reproduction characteristics. Many aspects of reproduction are still unclear in this species, and there is some disagreement on statistics among authors. The sperm whale is polygamous, and during the mating season, harems are formed, composed of from ten to several hundred females and juveniles and from one to several breeding males. The female comes into heat in the spring or early summer. Judging from the scars and tooth marks found on mature males, battles over females may occur commonly (Ohsumi, 1971) and Hopkins (1922) witnessed and described a serious battle between two males which left one with severe injuries. One bull may service 14 sexually mature females on the average (Ohsumi, 1971). Gestation lasts 16 months in the Southern Hemisphere; however, it may be shorter by four months in the Northern Hemisphere (Rice, 1971; Tomilin, 1957). Estimates of the length of the lactation period vary from six months (Tomilin, 1957) to 13 months (Ommanndy, 1971; Nishiwaki, 1972) to two years (Rice, 1971). The relationship between cows and calves is very close, and mothers will not desert a wounded calf. Calves are weaned at about 6.7 m length.

Females go through a period of sexual inactivity after calving, but there is some disagreement about the average interval between calves. Estimates include every two years (Tomilin, 1957), every three years (Ommanney, 1971) and every four to five years (Rice, 1971).

(6) Food and feeding. The main food of this species is squid, particularly the larger species (Rice, 1971). The mouth of the sperm whale seems to be particularly adapted for seizing slippery cephalopods, but the sharp teeth are apparently not used for chewing. Many authors believe that the sperm whale must battle with some of the larger squid, which may reach 18 m in length. This is suggested by the scars left by the suckers of squid around the mouth and body of many sperm whales (Tomilin, 1957). In order to catch the squid, sperms must dive to tremendous depths. They are probably the deepest diving whales. Drowned sperms have been found entangled in submarine cables 3,720 feet deep (Rice, 1971). Sperm whales can remain underwater for at least an hour.

Sperm whales may feed most frequently at night (Gaskin, 1967). At any rate, there is no sunlight at the depths where the sperm whale usually hunts squid, and it relies strongly on a well-developed echolocation system. The whale emits clicks at a rate of six per second and the encased spermaceti may somehow act to focus these pulses (Rice, 1971). Additional information on the sperm whale's sonic capabilities is given by Backus and Schevill (1966). Gaskin (1967) contends that the sperm whale could not possibly support its huge food requirements by hunting individual squids, even if it does have the ability to locate them. He hypothesized that the whales may take advantage of the luminescent secretions of some squids in the following manner. The whale could echolocate a squid, catch it, and allow some of the luminescent material to remain between its teeth. The whale could then hang motionless in the water with its mouth open and let the light lure other squids to it. This energy-saving mechanism would be analogous to the use of luminescent lures by some fish, for example, the deep sea angler fish. Heezen and Hollister (1971) presented additional evidence that sperm whales may also plow furrows in the bottom with their lower jaws in search of food, which would explain the propensity of this species to become entangled in cables lying on the sea floor. One must conclude that much more information is needed on the feeding methods of this species. For example, one would like to learn the importance of Murphy's (1924) finding of seal vibrissae in the stomach of a sperm whale.

When the sperm whale dives deeply it experiences a significant drop in water temperature from the relatively mild surface temperatures. This fact may help to explain the narrow geographical distribution of females and juveniles, which remain within temperate or tropical waters. Sperm whale calves do not possess the thick blubber of the adults, and may require relatively warmer habitats. The deeper warmed layer of tropical waters may allow them to dive to greater depths when they begin to seek their own food, then to return to the surface to warm up. Additional reasons for this geographical pattern are available in Tomilin (1957).

Heezen (1957) summarizes 14 instances, between 1877-1951, of sperm whale entanglements in deep sea cables, concluding that entanglements occur as whales swim along the sea floor with their jaws plowing sediment in search of food in depths as great as 1,200 m. Possibly sperm whales attack tangled masses of cables, mistaking it for food. Most cable entanglements occur in about 914.5 m, perhaps due to the natural occurrence of food at this depth or because slack cable is laid in deep sloping areas by cable ship masters, since exact depth is more difficult to determine on steep slopes. A similar entanglement occured between Lisbon and Maloga at a depth of 2,200 m (Nishiwaki, 1972).

(7) Economic and aesthetic value. In the 18th and 19th centuries, spermaceti was a crucial part of the New England and world economies. This waxy substance was the main lubricant and liquid fuel in use at that time. Ambergris, which is a hard, dark, lumpy substance found in the intestine of this whale, and probably forms as a concretion around undigested squid beaks, was used as a stabilizer for the scent of perfumes. It has always been rare and valuable, and in 1962 its price was $100 per kg (Nishiwaki, 1972). A synthetic substitute is now available. Scrimshaw is the name given to the art of carving on sperm whale teeth. The art was practiced extensively by American whalemen during their long voyages.

The New England sperm whale hunting industry began in 1712 when the first sperm whale was caught - by accident. For the next 150 years, the industry prospered and Yankee whalers ranged the seas of the world in the hunt for sperm. American interests dominated the industry. Whaling expeditions lasted as long as five years and reached every part of the globe. The hunt was pursued from open boats and was exciting and dangerous. Unlike the more passive rorquals, sperm whales were often aggressive, especially when wounded. Whale boats were often overturned and loss of life was not uncommon. On some occasions, whole whaling ships were sunk, the most famous examples being the sinking of the Essex in 1820 after ramming by a sperm whale and the sinking of the Ann Alexander off Peru in 1851 (Nayman, 1973). The world's best know whaling story, Melville's Moby Dick centers on a sperm whale and is an excellent historical description of the whaling industry of the mid-1800's when the American industry was at its peak. At the time, there were over 700 American whaling vessels, and over 100,000 barrels of sperm oil were brought in annually. This amount of oil represented a kill of only 500 to 700 whales, which apparently did not affect the stocks of sperm whales. New Bedford, Massachusetts was the center of the industry, whose rise and fall has been chronicled by Allen (1973)in a recent best seller.

According to Pilsen and Goldstein (1973), profitable whaling grounds existed at what was known as the Charleston ground (29^o to 32^oN latitude and 74^o to 77^oW longitude) and at the Hatteras ground which extended along the edge of the Gulf Stream. During the late 1700's and early 1800's, hunting was frequently concentrated on the southern ground (from Philadelphia to Cape Hatteras) which was bounded by the U. S. East Coast and 60^oW longitude (Anonymous, 1968). Aircraft oceanographic observations which began in 1966 established that whales are still fairly numerous in this region near the western edge of the Gulf Stream (Anonymous, 1968).

In 1859, the industry suffered a sharp decline and eventual death when petroleum, which proved to be a superior fuel and lubricant, and which was easier to obtain than sperm oil, was discovered.

In the 1870's, the modern harpoon was perfected by the Norwegians. Its use, in combination with the use of steam whaleships, would soon make possible the capture of the large, swift, rorqual whales. This began a new, more effective phase in the whaling industry. At first, the sperm whale was largely ignored, because its waxy oil was not as popular as the oil from baleen whales. Prior to World War II, the annual sperm whale catch rarely totalled more than two or three thousand animals. However, as rorqual whale populations decreased owing to overhunting, sperm whales were once again subjected to increased hunting pressure. The annual catch began to rise and reached 25,921 in 1967 (Rice, 1973), though McVay (1964) reported the peak catch was 29,000 in 1964. In 1971, 22,781 sperms were killed worldwide, 558 in the Atlantic Ocean (Dent, 1973). The sperm whale is currently the most important species of the world whaling industry. The only limitation is on the minimum size of sperm cow (38 feet in length) that can be killed (McVay, 1964).

It is difficult to speculate on what effect this harvest has on the sperm whale stocks. Owing to the polygamous social structure of this species, many male sperm whales can be killed without reducing reproductive potential. However, if we have learned anything at all from the vast over-exploitation of the other whales, it is that we can no longer afford to be complacent about the ocean's resources. The continuation of sperm whaling must also be weighed against the fact that the meat of these whales is not eaten, even in Japan or Russia. The products obtained from its body are used entirely for industrial products of many kinds, including crayons, photographic film, oils, waxes, and lubricants. Synthetic or vegetable substitutes are readily available for all these products.

FAMILY PHYSETERIDAE: PYGMY SPERM WHALE, LESSER CACHALOT, Kogia breviceps

The maximum length of the pygmy sperm whale is 4 m, and males are larger than females. The general form resembles a dolphin (Tomilin, 1957) and the skull is as wide as it is long (Nishiwaki, 1972). The dorsal fin is quite low and somewhat to the rear of the middle of the body. The dorsal body is a dark gray and the ventral surface is light gray to white. The flippers and tail flukes are slate gray, and the flippers are rounded and large (1/6 body length).

(1) Distribution and habitat preference. This species is widely distributed in warm waters of the Indian, Atlantic, and Pacific Oceans. However, as it is rarely seen, nothing is known of the size of the world population (Nishiwaki, 1972). One individual was stranded in Nahant, Massachusetts, in 1910 (Waters and Rivard, 1902), and a decayed specimen washed up at Sable Island in January, 1969 (Sergeant, Mansfield, and Beck, 1970). Piers (1923) reported a female found dead under the ice in the outer part of Halifax Harbor, Nova Scotia, on January 17, 1920. Caldwell and Golley (1965) reports K. breviceps as far south as North Carolina.

(2) Migration characteristics. Gunter, Hubbs, and Beal (1955) as well as Caldwell and Golley (1965) indicate that the stranding records for the species suggest a northward migration in summer with a return to warmer waters in the fall for breeding. The pygmy sperm whale has only been seen singly or in pairs.

(3) Food and feeding habits. Nishiwaki (1972) and Handley (1966) report that this species feeds on squid, crabs, and shrimp.

(4) Aesthetic and economic importance. Since specimens have only been stranded at the very fringes of the Gulf of Maine, with only one record on the shores of the Gulf itself, this species is of value merely as a scientific curiosity in this region.

FAMILY DELPHINIDAE: BOTTLENOSED DOLPHIN, Tursiops truncatus

The bottlenosed dolphin is distributed along all coasts in the regions of warm water in both hemispheres (Tomilin, 1957). It does not reach New England frequently, though it is quite common along the southern portion of the eastern coast of North America. The bottlenose is a migratory species off the coast of North Carolina (Moore, 1953) and was once the subject of a fishery off Cape Hatteras (where 500 to 1,500 animals were taken annually (Committee on Merchant Marine and Fisheries, 1974). Usually it is seen within 12 miles of the coast (Gunter, 1942) which means that the bottlenosed dolphin will be found near slope waters primarily off North Carolina where the slope is closer to the coast. T. truncatus should not be considered an important species of the slope waters.

FAMILY DELPHINIDAE: WHITE-BEAKED DOLPHIN, SQUID HOUND, Lagenorhynchus albirostris

This species is similar in shape to the white-sided dolphin, but is somewhat larger, and it may reach 3 m in length. The dorsal body is black, including the flippers, the flanks are dusky and the ventral surface is white. Specimens from the Gulf of Maine area probably do not have a noticeably white beak.

(1) Distribution and habitat preference. This form ranges from France northward and westward past Greenland to Canada, and from the Davis Strait to the coast of Massachusetts (Tomilin, 1957). The first reported sighting in New England waters (Waters and Rivard, 1962) refers to an individual seen April 27, 1901, thirty miles north of Cape Cod, and another was washed ashore at Orleans, Massachusetts, April 29, 1901. Watkins and Schevill (1972) saw some L. albirostris in Cape Cod Bay during May, 1970. Gilpin described two white-beaked dolphins (called L. leucopleurus) which were shot at Digby Gut in August, 1975, during the Micmac Indian porpoise fishery in the Bay of Fundy. One specimen measured 1.78 m long and the other was longer. This species apparently prefers colder waters than L. acutus (Sergeant and Fisher, 1957) and could possibly be considered a stray in the Gulf of Maine region.

(2) Migration characteristics. The migrations are poorly known. The species apparently travels in schools of more than 1,500 individuals in some areas (Nishiwaki, 1972). In the Davis Strait, this species appears in spring and summer together with harbor porpoises (Phocoena phocoena) after the rorqual whales, belugas and narwhals have already appeared and migrated north (Tomilin, 1957).

(3) Reproductive characteristics. It is assumed that most calves are born in mid-summer (Tomilin, 1957).

(4) Food and feeding characteristics. The dolphin's food consists of squid, octopus, cod, herring, capelin, and small crustacea (Nishiwaki, 1972).

(5) Economic importance. White-beaked dolphins are taken commercially along Norwegian shores, where they are known as squid hounds. There they occur in spring and fall (at least March to May and October to November) in small herds of six to eight which apparently do not associate with other species.

FAMILY DELPHINIDAE: WHITE-SIDED DOLPHIN, Lagenorhynchus acutus

Male white-sided dolphins are between 2.3 and 2.75 m long and females range from 2 to 2.4 m in length (Tomilin, 1957). The dorsal body is mostly black, and the ventral side is white or yellowish gray with a sharp boundary between the shades. A wide white band runs along the body on both sides below the dorsal fin and onto the caudal peduncle. A black line runs from either the eye or the mouth to the all-black flipper, and another from the caudal peduncle to the black dorsal portion. However, there is a great deal of individual variation in color pattern, and there may be a variety of different white portions on the black dorsal area. The flippers are short and the dorsal fin is high.

(1) Distribution and habitat preference. This species is commonly found in coastal waters south of Greenland, off Norway, near the Shetland and Orkney Islands off Great Britain, and off Cape Cod, Massachusetts. It has never been seen in tropical waters (Nishiwaki, 1972). The species visits inshore waters of Newfoundland in summer (July to October) often in the company of pilot whales, and there is a record of some white-sided dolphins being driven ashore with pilot whales (Sergeant and Fisher, 1957).

The species is seen more frequently in New England waters than is the white-beaked dolphin (L. albirostris), perhaps because it likes the warmer waters of the area. Nevertheless, there are not many published records of sightings, probably because it does not approach shore as closely as does the harbor porpoise and because most people do not report sightings of small cetaceans, even if they are able to identify them. Norton (1930) traced the history of one museum specimen which was supposedly taken from Casco Bay, Maine. Beamish and Mitchell (1974) saw four specimens on May 22, 1969, near the Sable Island Bank, Nova Scotia. Fifteen individuals beached themselves in Wellfleet, Massachusetts, on May 11, 1973 (McGrath and Thomas, 1973; Mead, 1973).

(2) Migration characteristics. The species is quite gregarious and has been seen in schools of one to 1,000 or 1,500 individuals (Tomilin, 1957). Little is known of its migrations. Sergeant and Fisher (1957) reported that it usually forms medium-sized herds of 40 to 50 individuals.

(3) Population density. No accurate estimate of population has been made; estimates range from 30,000 to 50,000.

(4) Reproduction characteristics. Birth of calves is thought to take place either in midsummer (Tomilin, 1957) or in spring and summer (Nishiwaki, 1972). Gestation lasts about ten months (Tomilin, 1957). Little or nothing is known about the longevity of the species. Of the 12 dolphins which stranded at Cape Cod on

May 11, 1973 which were examined (Mead, 1973), nine were females, eight of which were pregnant or near term. The ninth female may have had a calf a year before and was still lactating. One other female with a yearling lived for a short time at the Sealand Aquarium in Brewster, Massachusetts.

(5) Food and feeding methods. The species feeds on pelagic fish, benthopelagic fish, and crustaceans. Eight dolphins beached at Wellfleet and Orleans, Massachusetts in May, 1973 had been feeding on herring, striped bass, and bait fish when beached.

(6) Natural mortality. Predation by killer whales or sharks is probably an important source of mortality. Carcasses of the dolphins which stranded at Cape Cod were found to have heavy parasitic infestation in the inner ear and nasal passages which may have impaired their sonar ability so that they could not find their way to deep water (Mead, 1971).

(7) Aesthetic and economic importance. The white-sided dolphin is of little economic importance and is only taken in Norway in the summer when it enters the fjords in pursuit of herring (Tomilin, 1957).

FAMILY DELPHINIDAE: COMMON DOLPHIN, SADDLEBACK DOLPHIN, Delphinus delphis

This species reaches a length of about 2.5 m with males slightly larger than females. The color of the highly streamlined body is distinctive although there is some variation among individuals. The entire dorsal surface is black, the ventral surface, except for the caudal peduncle and flukes, is white. The complex and variable color pattern on the flanks is basically composed of an anterior and a posterior field of light gray, separated by a downward projection of the black dorsal coloration in the region below the dorsal fin. These gray fields include washes of ochre, intrusions of lighter shades, and narrow, dark bands, whose arrangements probably differ among the different geographical races. The head possesses a long, markedly defined beak. The fairly high dorsal fin is triangular and sharply pointed with a slight backward curve. The sides of the body may bear parallel scratch marks, perhaps inflicted by other dolphins (Sergeant, 1958). Tomilin (1957) includes information on intraspecific fighting and other behavior.

(1) Distribution and habitat preference. The common dolphin is a pelagic and widely distributed species, found in tropical and warm temperate ocean waters (Sergeant, 1958). It is known to range from the Atlantic seaboard of the United States northward to Labrador (Marcuzzi and Pilleri, 1971). According to Kellogg (1940), it follows the Gulf Stream as far as Finmark, Norway. It is also found in the Indian Ocean and the North and South Pacific. It does not, however, move into the cold waters (Nishiwaki, 1972),

and since it is a deep water pelagic species it is rarely seen alive close to shore (Tomilin, 1957).

Pilson and Goldstein (1973) state that it has been reported as far south as Florida and the Gulf of Mexico. Golley (1966) reported the species has been seen off South Carolina.

Delphinus delphis sometimes ascends rivers, and a school of 30 to 40 was observed in the Hudson River (Moore, 1953). In 1956, two individuals were seen 75-175 miles up the Hudson. Although sighting reports of this species are relatively numerous from the region south of Cape Cod, there are not many published records for the Gulf of Maine.

Eleven animals were stranded in South Wellfleet, Massachusetts in February, 1949 (Waters and Rivard, 1962). An individual stranded at Falmouth, Maine,on March 13, 1974,and autopsied at the New England Aquarium was originally identified as Delphinis delphis, but may actually be Stenella ceruleoalba (S. Katona, unpublished information).

(2) Migration characteristics. The common dolphin's migrations have not been studied except in the Black Sea, where it seems that the large herds follow the movements of the sardines and herring, which comprise the main part of their diet (Tomilin, 1957). However, an individual shot in Newfoundland while associating with a school of pilot whales (Globicephala melaena) had been feeding on squid (Sergeant, 1968).

Although most Massachusetts records involve winter encounters, they are believed to be most common in these waters during the summer months (Waters and Rivard, 1962). They are also numerous off the east coast of Nova Scotia in late summer (Sergeant and Fisher, 1957). This may indicate a seasonal migration pattern.

(3) Population density. The number of Delphinus delphis found in the Atlantic Ocean and all adjoining seas is estimated at more than 30,000 (Nishiwaki, 1972). Far greater numbers are found in other areas such as the Black Sea, the Mediterranean Sea, and along the coast of Anatolia, where populations number in the hundreds of thousands or millions (Tomilin, 1957).

(4) Growth and longevity. Sexual maturity in this species is reached at three years. Individuals are assumed to live 25 to 30 years.

(5) Reproductive characteristics. The peak mating season in the Black Sea is from August to October, and the peak breeding season is from June to August with a nine-month gestation period. In California, birth occurs in December through March and the gestation

period is reported to be 11 months (Harrison, et al., 1969). Mating may take place mainly in mid- to late summer. There is a period of nine months after every three pregnancies when the female remains infertile. The lactation period is four months, and females are thought to mate and calve annually (Tomilin, 1957; Harrison, et al., 1969). Additional data including descriptions of copulation, birth, and lactation are included in Tomilin (1957).

(6) Food and feeding methods. Common dolphins typically feed on pelagic fish which they catch in the upper layers of water far from shore. Their very sharp teeth are extremely numerous (160-260) and well adapted to seize and hold slippery prey. Although Tomilin (1957) lists crustaceans and molluscs as accidental dietary items, the most important foods are a variety of fishes, including mackerel, anchovy, pipefish, mullet, flying fish and others, depending on season and location. Cephalopods may at times be secondary food items. Data cited in Tomilin (1957) indicate that a common dolphin can eat between 5 and 10 kg of fish per day. Food is found by echolocation (Tomilin, 1957).

(7) Aesthetic and economic importance. In some areas, common dolphins consume large amounts of commercially valuable fish. For example, in the Black Sea they consume about four times as much (Tomilin, 1957). On the other hand, Mediterranean fishermen follow dolphins and find them helpful in herding anchovies or sardines to the surface where they can be netted. The importance of the species in our region has not been evaluated.

FAMILY DELPHINIDAEL: RISSO'S DOLPHIN, GRAY GRAMPUS, WHITE-HEADED DOLPHIN, *Grampus griseus*

Full grown Risso's dolphins are 4.0 to 4.2 m long. The head and front part of the body are quite round and fat, but the posterior body, from anus to flukes, is slender. The dorsal fin, which is high and narrow, is sharply pointed and curved backward. There are no teeth in the upper jaw and only two to seven pairs of teeth in the lower jaw (average three or four). The color is generally gray, with dark gray on the back, light gray on the flanks, and white on the belly. The dorsal suraces of Risso's dolphin become covered with white scars and scratches inflicted by squid or possibly by members of their own species during fights (Nishiwaki, 1972; Tomilin, 1957).

(1) Distribution and habitat preference. The Risso's dolphin is widely distributed in the warm waters of the world. However, since it is seen only rarely, its exact distribution and migration pattern is unknown (Tomilin, 1957). It keeps to the open seas and approaches the coasts only rarely. There is only one uncertain record of a stranding on the New England shore. Paul (1968) states that along

the East Coast of the United States, G. griseus exists from Massachusetts to New Jersey. Risso's dolphins often travel alone or in pairs (Tomilin, 1957), although they may also be seen in small groups (Nishiwaki, 1972). Schevill (1954) reported sighting three individuals 200 miles east of Cape Cod in 1950, and 60 individuals 70 nautical miles south of Block Island (latitude 40° 00'N, Longitude 71° 31'W) August, 1952. The animals were grouped in threes and fours, and were quite frolicsome, often breaching clear. Sometimes one waved the posterior third of the body in the air. They were shy of the ship but approached a dory. They appeared to be in vocal communication with each other. Schevill (1954) noted that field marks for the species include the high slender dorsal fin, reminiscent of that of Orcinus orca, the pale gleam of the back in front of the fin, a rather blunt snout, slender tail with lunate flukes, and characteristic scratch marks on the back.

(2) Food habits. Cephalopods are the main, if not the exclusive, diet of this species (Tomilin, 1957).

(3) Reproduction. Almost nothing is known of the breeding biology of the species, although there is apparently one documented record of successful interbreeding between Grampus griseus and Tursiops truncata (Tomilin, 1957).

(4) Aesthetic and economic importance. There is no fishery for Risso's dolphin. One Risso's dolphin named Pelorus Jack, became famous in New Zealand for its habit of accompanying ships across Cook Strait between Wellington and Nelson, New Zealand, from 1888 to 1912. The dolphin was protected by an Order in Council. It disappeared before the outbreak of World War I (Tomilin, 1957; Nayman, 1973).

FAMILY DELPHINIDAE: PILOT WHALE, BLACKFISH, CAAING (=CALLING WHALE, POTHEAD, Globicephala melaena

The pilot whale reaches 6.5 m in length and, as in almost all other toothed whales, males are larger than females. The color of the body is black and is more deeply pigmented above than below. A narrow, mid-ventral streak of light color widens into an anchor-shaped spot at the base of the flippers and on the throat. Viewed from the side, there is no constriction between the head and body, and the flippers, which are pointed, long (1/5 body length), and appear to be attached at the neck. The dorsal fin is high, strongly recurved, very wide at the base, and is set slightly behind the midpoint of the body. The forehead is high and bulbous. The shape of this bulge (also called the "melon") can be changed by the individual whale, to focus pulses of sound for echolocation (Norris, 1968; Matthews, 1968).

(1) Distribution and habitat preference. Despite the fact that it is

apparently much more common north of the Canadian Maritime Provinces (Mercer, 1974), the pilot whale is still one of the most commonly seen species of whale in New England waters. Norton (1930) listed it as common in waters near Portland, Maine. This species is common throughout the North Atlantic, reaching from the Mediterranean Sea and Madeira to New Jersey, and from southwest and southeast Greenland to northwestern Norway. Mercer (1967) reports having sighted four pilot whales at 38° 44'N, 73° 04'W, on April 2, 1967. Mercer also cites Schevill as having reported three sightings from on board Woods Hole Oceanographic Institution vessels at 39° 42' - 41° 00'N, 70° 25' - 70° 53'W between December and March. It is found most frequently between Iceland and Scotland, near the Faroes, Shetland, and Orkneys, as well as in the region of Newfoundland (Tomilin, 1957). Strandings reported for Virginia, North Carolina, and Florida (McGrath and Thomas, 1973) could possibly refer to G. macrorhyncha (Mercer, 1974). Although it generally favors the pelagic regions, this species can come quite close to shore in its search for food (Tomilin, 1957). In a list of whale strandings kept by the British Museum since 1911, there are many more instances of pilot whales coming ashore than any other species (Ommanney, 1971). The species is quite gregarious, often traveling in herds numbering in the hundreds. There is one record of a herd of 1,975 which beached in 1895, near Wellfleet, Massachusetts, and another record of a herd of 3,000 stranded on Cape Cod in 1974 (Pilson and Goldstein, 1973). This tendency to strand en masse is one of the most interesting features of the pilot whale. There are numerous reports of large herds becoming stranded on beaches and eventually dying. The pilot whale seems to have a strong tendency to follow the leader of the herd and once the leader becomes stranded, the rest follow. This herding tendency has been exploited in the past by the hunters of the northern British islands, who used to drive several individuals from a herd ashore and then wait for the rest to follow. Ommanney (1971) explained this on the basis of inherent limitations in the whales' echolocation systems. Pilot whales, like many other whales, use echolocation to find food, maintain communication and perhaps to navigate. Experiments carried out on the bottlenosed dolphin (Tursiops truncatus) have shown that the beam of sound pulses emitted by that species never falls below the horizontal. A majority of pilot whale strandings have occurred on long sloping beaches of sand or mud, which must present two problems to a whale approaching the shore. First, mud and sand never give as clear an echo as do more solid substances. Second, when the whale is very close to shore, its upwardly directed beam will receive no echo at all because of the gentle slope (Ommanney, 1971). The strongly developed schooling instinct impels the other animals to follow and stay with injured or stranded fellows.

(2) Migration characteristics. The pilot whale spends its winter in

the warmer waters of the North Atlantic, offshore of the continental shelf, and in the early summer moves northward. According to Brown (1961), G. melaena are found in deep water across the North Atlantic throughout the year. The direction and extent of northward migration is determined by the abundance of squid, which is the main food of this species (Sergeant and Fisher, 1957). The times of arrival of the squid in northern waters seem to be determined mainly by the temperature of the water, the preferred range being from 5 to 15°C. It is, therefore, difficult to give the summer range of the pilot whale, since it varies greatly with the fluctuations in squid distribution. For example, in the summer of 1954, pilot whales reached as far north as White Bay, Newfoundland, where the squid were also abundant that summer. In other years, when squid were scarce in the area, pilot whales failed to reach Newfoundland inshore waters at all (Sergeant and Fisher, 1957). Pilot whales do not commonly penetrate into the coastal waters in the southern Canadian Maritime Provinces (Sergeant and Fisher, 1957). Although it is so commonly sighted in Maine waters, the species is still outside of its main range when in our area. South of New York, G. melaena is replaced by the subtropical G. machrorhyncha, but the species interactions in that area require much more study.

(3) Population density. No data have yet been obtained.

(4) Growth and longevity. The maximum age has been estimated at 25 years (Tomilin, 1957). Newly born calves average about 1.8 m. By age one year, females are 2.3 m long and males 2.4 m. The largest individuals finally weigh up to three tons.

(5) Reproduction characteristics. The age of sexual maturity has been estimated for females as six years, and for males as 13 years. Females seem to breed between the ages of six and 18 years, and in that time produce five to six young, usually as single calves. The periods of gestation and lactation each last about a year. Although newborn calves are found in all seasons, the peak of the mating period is June and July, and the peak of breeding period is in July and August. The sex ratio in herds seems usually to be equal; nevertheless, the pilot whale is a polygamous animal and bachelor males may sometimes form separate herds (Tomilin, 1957).

(6) Food and feeding methods. The main diet of the pilot whale consists of cephalopods and gregarious fishes. The wide rostrum with sharp teeth in its forward portion allows this species to catch both fish and slippery invertebrates. Judging by the marks left by the suckers of squids on the lips and head of pilot whales, the squids consumed may reach 1 m in length (Tomilin, 1957). The pilot whale sometimes dives to the bottom for food and its stomach may contain stones and sand (Tomilin, 1957). Squid species on which

it feeds include Ilex illecebrosus, Ommatostrephos sagittatus and Todarodes sagittatus. In Newfoundland waters, I. illecebrosus (short-finned squid) is usually the only food eaten and an average sized pilot whale (4 m long, 830 kg) will eat about 34-41 kg (4.1 to 4.0 percent of its body weight) per day (Mercer, 1974).

(7) Aesthetic and economic importance. A fishery for pilot whales was developed in 1947, in Trinity Bay, Newfoundland, where a few thousand were taken every summer (Sergeant and Fisher, 1957). This species has also been important to the people of the Faroes, Orkney and Shetland Islands. For hundreds of years it has been hunted there for its oil, which provides these islands with winter fuel, and for its meat (Ommanney, 1971; Tomilin, 1957). However, in recent years the number taken in the North Atlantic has decreased considerably, from 6,412 in 1955 (Sergeant and Fisher, 1957) to 738 in 1970 (Pilson and Goldstein, 1973), leading to the speculation that overfishing during 1951-1961 severely depleted the G. melaena population around Newfoundland. During that period, over 47,000 pilot whales were killed there, over 30,000 between 1953 and 1957.

Owing to its propensity to strand in great numbers, the pilot whale is more intimately known to many people than are other cetaceans. There are frequent reports of people who have worked to rescue stranded whales. For example, clamdiggers worked to rescue a stranded pilot whale in Milbridge, Maine, on March 28, 1973. After covering it with seaweed to keep it moist, they went to get the warden. Before they could return, local youths killed the animal. Often these animals swim back to the beach after being towed off.

Pilot whales of the genus Globicephala have been maintained by various marine aquaria since about 1949 (Kritzler, 1949; Brown, 1962). The animals respond to training and provide an opportunity for many people to see a live whale for the first time.

FAMILY ZIPHIIDAE: DENSE-BEAKED WHALE, BLAINVILLE'S BEAKED WHALE, Mesoplodon densirostris

This species averages about 4.6 m in length. The body is dark with a small dorsal fin set far back. The flukes have no median notch. The body is generally covered with white scars, possibly formed from wounds suffered during intraspecific fights. As this species is known solely by stranded specimens, there is little information on its life cycle or migrations.

(1) Distribution and habitat preference. M. densirostris is found in all oceans having tropical and warm temperate waters (Rice and Scheffer, 1968) True (1910) reported a female stranded at Annisquam, Massachusetts, in August, 1898, and that is the only record

of this species in the Gulf of Maine. Originally, Allen (1906) described that specimen as M. bidens. One individual stranded at Peggy's Cove, Nova Scotia (Sergeant and Fisher, 1957). However, since the species appears to be mainly pelagic in warm waters (Ulmer, 1941; Moore, 1958), individuals found in the Gulf of Maine are probably strays from the main population and might be unhealthy, drifting animals. Strandings have been reported off South Carolina (Golley, 1966), Texas (Gunter, 1955) and Florida (Caldwell and Caldwell, 1971).

One possible reason for the lack of sightings of M. densirostris is that its breath is apparently directed forward over the snout instead of straight up into the air, as in most other cetaceans which have been observed (Anonymous, 1973). If this is true, it may be nearly impossible to see these whales at sea, unless the observer is very close.

(2) Aesthetic and economic importance. None, although any new records or information would be of great scientific interest.

FAMILY ZIPHIIDAE: TRUE'S BEAKED WHALE, Mesoplodon mirus

This whale is about 5.2 m in length, with a slender body compressed laterally. The forehead is low and the dorsal fin is situated behind the middle of the body. The flippers are small and the flukes lack a median notch. The whale is black above and on flippers and flukes. The underside is yellowish purple flecked with black, though the coloration varies.

(1) Distribution and habitat preference. Mesoplodon mirus is primarily a North Atlantic species (Moore and Wood, 1957). It has been found in the Gulf of Maine on one occasion in which a male was stranded on Wells Beach, Maine, as reported by Raven (1937). Its distribution is inferred from the records of strandings, which have occurred from Florida to Nova Scotia and on the British Isles. Little is known of its migrations and life cycle.

(2) Food and feeding methods. Stomach contents of beached specimens indicate the whale's food to be squid and sometimes fish.

(3) Reproductive characteristics. A newborn calf measuring 2.2 m was found with a mother of 5.2 m in March (Brimley, 1943).

FAMILY ZIPHIIDAE: NORTHERN BOTTLENOSED WHALE, Hyperoodon ampullatus

Full-grown females of the species reach 7.3 m and males reach 9.1 m. The dorsal surface is usually described as a dark, charcoal gray and the ventral surface is a pale gray. However, observers who have been fortunate enough to see the animal at sea usually describe the color as brown. Winn, et al., (1970) noted that smaller animals were a uniform chocolate brown, while larger ones had varying amounts of cream or yellow blotchiness. The ventral portions were cream-colored. The largest individual possessed a cream-colored, bulbous head and the smaller individuals possessed distinctly brown or tan heads. The short flippers are darker than the body. The forehead is high and bulging, particularly in males, and becomes larger as the animal grows older. The rostrum is in a "bottlenose" shape, which prompted its common name.

(1) Distribution and habitat preference. The range of this species is limited to the North Atlantic (Tomilin, 1957). Northern bottlenose whales have beached in North Dennis, Massachusetts (True, 1910), and in 1906 at Wells Beach, Maine (Norton, 1930). Rice and Scheffer (1968) give the southern limit of its range as Rhode Island. The species penetrates quite far north and frequently is seen among the floating ice. It is a pelagic species but occasionally is seen close to shore including off the New England coast (Tomilin, 1957). Mitchell (1974) reported that concentrations occur mainly in early summer months near Sable Island and along the edge of the continental shelf around Newfoundland and along Labrador. Winn, et al., (1970) encountered small groups of two, five, and four animals off the Nova Scotia coast near the 200-m line at 43° 50°N, 58° 56'W on August 24 and 25, 1969, in water of 17°C surface temperature. A 21-foot immature male H. ampullatus was found beached on the shores of Cobequid Bay, Nova Scotia on October 9, 1969 (Case and Densmore, 1970). Informal reports suggest that bottlenose whales approach stopped vessels very closely or are attracted to non-motorized vessels (Winn, et al., (1970).

(2) Migration characteristics. In the spring, the whales migrate to the Arctic where they spend the summer. The return migration begins in September and continues into the winter. Gray (1882) reported that females and juveniles migrated closer to shore than did males. Little is known of their wintering grounds. The species forms herds of up to ten individuals. Bottlenosed whales generally keep together in small schools, and if one is harpooned, the others usually do not leave it, but move more or less close to it until it has been killed (Jonsgard, 1969). Southwell (1884) reported that the species was playful and that individuals reacted to sounds in the water.

(3) Reproductive characteristics. Very little is know of the reproduction of the bottlenosed whale. It appears that most calves are born from March through June and the lactation period may last five to seven months (Tomilin, 1957).

(4) Food and feeding methods. The chief diet of the bottlenosed whale consists of cephalopod mollusks and occasional fishes (Tomilin, 1957). Supposedly, this whale can dive for longer (two hours) than any other cetacean, but no recent evidence confirms Gray's (1882)

old report.

(5) Economic importance. In the late 19th century after Greenland right whales had become scarce, bottlenosed whales were hunted extensively until the development of the rorqual fisheries. They were hunted for the oil in their blubber, and also for the spermaceti in their foreheads (Southwell, 1882 ; Nishiwaki, 1972). They have been hunted in recent times by the Norwegians, Danes, and occasionally the Canadians within the northwest Atlantic. A total of 2,014 were killed by those three countries from 1966-1970.

CONSERVATION EFFORTS

Conservation efforts to date have slowed the decline of some whales, but several species are still in danger of extinction (right, bowhead, fin, sei, blue, gray, humpback, and sperm). Overhunting of the great whales escalated in the late 1920's with the development of floating factories and pelagic whaling fleets (Committee on Merchant Marine and Fisheries, 1974). The efficiency of these units created a glut of whale products and led to a collapse of the market in 1931 (McHugh, 1974). At that time, Norway and Britain agreed to limit their catch in order to stabilize the whaling industry. But Japan and Germany soon became the whaling countries, defeating the conservation efforts of Norway and Britain (Committee on Merchant Marine and Fisheries, 1974).

From the late 1920's through the sixties, the whaling industry systematically drove one species after another into commercial extinction (Committee on Merchant Marine and Fisheries, 1974). As one species became too scarce to exploit commercially, the hunt shifted to the next economically exploitable species, until the right, bowhead, blue, and humpback whale populations became dangerously low. At present the sei, sperm, fin, and minke whales are harvested commercially.

As early as 1929, efforts were made to establish a regulatory agency to slow the decline of diminishing whale stocks. By 1935, the International Convention for the Regulation of Whaling had come into force, protecting the right and gray whales, prohibiting the taking of female whales accompanied by calves, and the killing of calves. In 1937, an agreement protecting the gray whale was reached although this did not apply to Japan or the U. S. S. R. (Committee on Merchant Marine and Fisheries, 1974). The International Convention for the Regulation of Whaling, held in 1946, established the International Whaling Commission which is empowered to protect overexploited whales, set minimum size limits below which various species cannot be taken, set maximum annual catch quotas for the Antarctic fishery, and designate areas closed to hunting (McVay, 1966). However, overhunting continued, despite efforts by the IWC (McHugh, 1974). By December 1970, the U. S. Secretary of the Interior had placed all eight species of great whales on the Endangered Species List and as a result of this action (Endangered Species Conservation Act, effective June, 1970), all importation of products of these whales ended and any remaining whaling licenses were cancelled (Committee on Merchant Marine and Fisheries, 1974). In 1972, the IWC took action reducing the quotas on fin, sei, and sperm whales. Conservative quotas were established for minkes and an international observer scheme was implemented to ensure that quotas and regulations were upheld (McHugh, 1974). Finally, the IWC abolished the old blue whale unit for setting quotas in the Antarctic in favor of a quota based on species. This method was based on the premise that one blue whale was equal to two and one-half humpbacks, six sei, and two fin whales (McHugh, 1974). At present, Russia and Japan take about 80% of the world's whales and continue to consistently object to most conservation measures proposed by the IWC in an attempt to maintain stocks of great whales at sustained yield levels (Committee on Merchant Marine and Fisheries, 1974). The Marine Mammal Protection Act of 1972, passed by Congress, prohibits U. S. citizens from "taking, harassing, or importing any marine mammals or its byproducts into the U. S. except when authorized to do so by special permit." The bowhead, right, gray, blue, and humpback whales are completely protected except for some hunting by aboriginal inhabitants of the U. S. (i.e. Eskimos, Indians, and Aleuts of the North Pacific and Arctic) (Committee on Merchant Marine and Fisheries, 1974).

DATA GAPS

The diversified group of animals that comprise the nekton, with the possible exception of a few species that are important as commercial or sportfish, have received relatively little scientific attention, particularly as they relate to the slope water. Many of these species are relatively remote, highly mobile and of little direct importance to the economy of the northeastern United States. Because of this, there has been less incentive to investigate these groups then their nearshore counterparts.

Of these groups, the epipelagic fishes have probably received the greatest scientific effort because of their importance to the fishery industries. Growth, migrations, population size indices and other biological characteristics of the tunas and billfishes are being studied currently through tagging programs and sampling of the sport catch. The squid have also received attention recently because they have emerged as an important commercial fishery. For both of these groups more information is needed for adequate resource management.

The mesopelagic fishes, turtles, and whales in the study area require more research effort if their role in the slope water is to be fully understood. In particular, little is known of the life histories or migration routes of the deep water species of whales and turtles. As Winn (1975) states, a comprehensive study of several years duration should be initiated immediately to define geographic distributions of species, patchiness of distribution, migration routes, population levels of cetaceans. Specifically, Winn believes that it is very important in view of future oil and gas development activities in the Baltimore Canyon and Georges Bank areas that these studies relate the potential environmental impacts of such activities to the life histories of cetaceans.

REFERENCES

Allen, E. S. 1973. Children of the light. The rise and fall of New Bedford whaling and the death of the Arctic fleet. Little, Brown and Co., Boston. 302 p.

Allen, G. M. 1906. Sowerby's whale on the American coast. Amer. Natur., 30: 357-370.

__________. 1916. The whalebone whales of New England. Mem. Boston Soc. Natur. Hist., 8(2): 107-322.

__________. 1939 True's beaked whale in Nova Scotia. J. Mammalogy, 20: 259-260.

Allen, J. A. 1880. The fauna of eastern Massachusetts: forms brought in and expelled by civilization. In: J. Winser (ed.), The memorial history of Boston, including Suffolk County, Massachusetts, 1630-1880 (4 v.). v. 1. The early and colonial periods. Boston, J. R. Osgood and Co., 1880.

__________. 1908. The North Atlantic right whale and its near allies. Bull. Amer. Mus. Natur. Hist., 24: 277-329.

Allen, K. R. 1970. A note on the baleen whale stocks of the northwest Atlantic. Int. Whaling Comm. 20th Rept. Annex I, p. 112-113.

__________. 1971. A preliminary assessment of fin whale stocks off the Canadian Atlantic coast. Int. Whaling Comm. 21st Rept. Annex H, p. 64-66.

__________. 1973. Current status and effect of a moratorium on the major whale stocks. Int. Whaling Comm. 23rd Rept. Annex G. 5 p.

Anonymous. 1968. Western part of Gulf Stream lures whales. Ocean Ind., 3(7): 88-89.

__________.1971. The call of the humpback whale. Maritimes, Univ. Rhode Island Grad. School of Oceanography, 15(3): 10-12.

__________. 1972. White whale sighting in Cape Cod Canal. Yankee Magazine, August 1972: 138.

__________. 1973. Network flashes news of beached whales on Atlantic Coast. Smithsonian Res. Rept. Summer 1973: 4-5.

Arnold, P. W. 1972. Predation on harbor porpoise by a white shark. J. Fish. Res. Bd. Canada, 29: 1213-1214.

Arnold, P. W. and D. E. Gaskin. 1972. Sight records of right whales (Eubalaena glacialis) and finback whales (Balaenoptera physalus) from the lower Bay of Fundy. J. Fish. Res. Bd. Canada, 29: 1477-1478.

Ashley, C. W. 1944. Yankee whaler. Augustus M. Kelley, Publ. Clifton, N. J.

Backus, R. H. and W. E. Schevill. 1961. The stranding of a Curier's beaked whale (Ziphius cavirostris) in Rhode Island, U.S.A. Norsk Hvalfangsttidende, 5: 189-193 (1961).

__________. 1966. Physeterclicks, In: K. S. Norris (ed.) Whales, dolphins and porpoises. Univ. Calif. Press. Berkeley and Los Angeles, p. 510-518.

Baldridge, A. 1972. Killer whales attack and eat a grey whale. J. Mammalogy, 53(4): 898-900.

Beamish, P. and E. Mitchell. 1971. Ultrasonic sounds recorded in the presence of a blue whale Balaenoptera musculus. Deep Sea Res., 18: 803-809.

__________. 1973. Short pulse length audio frequency sounds recorded in the presence of a minke whale (Balaenoptera acutorostrata). Deep Sea Res. and Oceanogr. Abst., 20(4): 375-386.

Bennett, F. D. 1840. Narrative of a whaling voyage around the globe, from the year 1833 to 1836. 2 v. London.

Brimley, H. H. 1943. A second specimen of True's beaked whale, Mesoplodon mirus True, from North Carolina. J. Mammalogy, 24(2): 199-203.

Brimley, C. S. 1946. The mammals of North Carolina. Installment no. 18, Carolina Tips, Carolina Supply Co., 9: 6-7.

Brodie, P. F. 1971. A reconsideration of aspects of growth, reproduction, and behavior of the white whale (Delphinapterus leucas) with reference to the Cumberland Sound, Baffin Island, Population. J. Fish. Res. Bd. Canada, 28: 1309-1318.

Brown, C. E. 1913. Pocket list of the mammals of eastern Massachusetts, with special reference to Essex County. Peabody Acad. Sci., Salem, Mass. 53 p.

Brown, D. H. 1962. Further observations on the pilot whale in captivity, Zoologica 47(1): 59-64.

Brown, S. G. 1961. Observations on pilot whales in the North Atlantic: Norwegian Whaling Gaz., 50(6): 225-254.

Brown, S. G., S. J. Jones and A. Boyd. 1971. Sightings of cetacea during two trans-Atlantic yacht races. J. du Cons., 34(1): 106-120.

Burgess, K. 1968. The behavior and training of a killer whale (Orcinus orca) at San Diego Sea World. Int. Zoo Yearbook, 8: 202-205.

Caldwell, D. K. and F. B. Golley. 1965. Marine mammals from the coast of Georgia to Cape Hatteras. J. Elisha Mitchell Sci. Soc., 81: 24-32.

Caldwell, D. K. and M. C. Caldwell. 1971. Sounds produced by two rare cetaceans stranded in Florida. Cetology, 4: 6 p.

Caldwell, D. K. and M. Caldwell. 1974. Is it true that dolphins are more intelligent than men and more talkative than women? Underwater Natur. Bull. Amer. Littoral Soc., 8(2): 14-24.

Capital Records. 1970. Songs of the humpback whale.

Case, G. R. and H. Densmore. 1970. Report of a beached bottlenosed whale on the shores of Cobequid Bay, Nova Scotia. Underwater Natur. Bull. Amer. Littoral Soc., 6(3): 18-20.

Christensen, I. 1972. Minke whale investigations in the area Spitsbergen-Barents Sea in May-June 1972 (in Norwegean, English Abstract). Saertrykk au Fiskets Gang., 48: 961-965.

Clark, A. C. 1957. The deep range. (1st ed.) New York, Harcourt, Brace. 238 p.

Committee on Merchant Marine and Fisheries. 1974. Marine mammal protection oversight: hearings before the subcommittee on fisheries and wildlife, conservation and the environment. U.S. Govt. Print. Office, Ser. no. 93-24, 93rd Congress.

Cousteau, J. Y. and P. Diole. 1972. The whale: mighty monarch of the sea. Doubleday and Co., Inc., Garden City, N.Y.

Cummings, W. C. and P. O. Thompson. 1971a. Underwater sounds from the blue whale. Balaenoptera musculus. J. Acoust. Soc. Amer., 50(4): 1193-1198.

__________. 1971b. Gray whales, Eschrichtius robustus, avoid the underwater sounds of killer whales, Orcinus orca Fish. Bull., 69: 525-530.

Dent, F. B. 1973. Current status of the stocks of marine mammals. Part 2 of Report of Secretary of Commerce, NOAA. Federal Register, 38(147), Part 3: 20564-20601, Wed., Aug. 1, 1973.

Fay, F. H. 1971. Arctic white whale-belukha. In: A. Seed (ed.) Toothed whales. Pacific Search Books, Seattle, Washington, p. 23-27.

Fish, J. F. and J. S. Vania. 1971. Killer whale, Orcinus orca, sounds repel white whales, Delphinapterus leucas. Fish. Bull., 69(3): 531-535.

Fisher, H. D. and D. E. Sergeant. 1954. A white whale in the Bay of Fundy. Can. Field. Natur., 68: 138-139.

Fisher, H. D. and R. J. Harrison. 1970. Reproduction in the common porpoise (Phocoena phocoena) of the North Atlantic. J. Zool., London 161: 471-486.

Food and Agricultural Organization. 1971. Catches and landings, 1970. Yearbook of fishery statistics. v. 30. Food and Agr. Organ. of the United Nations, Rome. 467 p.

Gambell, R. 1963. Aerial observations of sperm whale behavior based on observations, notes and comments by K. J. Pinkerton. Norsk Hvalfangst-Tid., 57(6): 126-138.

Gaskin, D. E. 1964. Recent observation in New Zealand waters on some aspects of behavior of the sperm whale (Physeter macrocephalus). Tuatara, 12(2): 106-114.

__________. 1967. Luminescence in a squid Morofeuthis sp. (probably Ingens Smith), and a possible feeding mechanism in the sperm whale Physeter catodon L. Tuatera, 15(2): 86-88.

Gaskin, D. E., M. Holdrinct, and R. Frank. 1971. Organochlorine pesticide residues in harbor porpoise from the Bay of Fundy region. Nature, 233: 499-500.

Gaskin, D. E., K. Ishida and R. Frank. 1972. Mercury in harbour porpoises (Phocoena phocoena) from the Bay of Fundy region. J. Fish. Res. Bd. Canada, 29: 1644-1646.

Gaskin, D. E., P. W. Arnold and B. A. Blair. 1974. Phocoena phocoena. Amer. Soc. of Mammalogists, Mammalian Species, 42: 1-8, 4 fig.

Gilpin, J. B. 1875. On the smaller cetaceans inhabiting the Bay of Fundy and shores of Nova Scotia: Proc. N.S. Inst. Sci., 4: 21-24.

Golley, F. B. 1966. South Carolina mammals. The Charleston Mus., S. C. 181 p.

Goode, G. B. 1884. The fisheries and fishery industries of the United States. Sec. I. Natural history of useful aquatic animals, with an atlas of 277 plates. Washington, 1884.

———. 1887. The fisheries and fishery industries of the United States. Sec. II. A geographical review of the fisheries industries and fishing communities for the year 1880. Washington, 1887.

Goode, G. B. and Associates. 1887. The fisheries and fishery industries of the United States. Sec. V., v.1,2, atlas of 255 pl. Washington, Govt. Printing Office 1887. U. S. Commer. Fish & Fisheries.

Gray, D. 1882. Notes on the characters and habits of the bottlenose whale (Hyperoodon nostratus). Proc. Zool. Soc. London, 50: 726-731.

Gullard, J. A. 1974. Distribution and abundance of whales in relation basic productivity. In: W. E. Schevill (ed.), The whale problem: a status report. Harvard Univ. Press.

Gunter, G. 1942. Contributions to the natural history of the bottlenose dolphin. Tursiops truncatus (Montague), on the Texas coast, with particular reference to food habits. J. Mammalogy, 23(3): 267-276.

———. 1955. Blainville's beaked whale, Mesoplodon dinsirostris, on the Texas coast. J. Mammal., 36: 573-574.

Gunter, G., C. L. Hubbs and M. A. Beal. 1955. Records of Rogia breviceps from Texas with remarks on movement and distribution. J. Mammal., 36: 263-270.

Hachey, H. B., F. Hermann and W. B. Bailey. 1954. The waters of the ICNAF Convention Area. Int. Comm. Northwest Atl. Fish. Annu. Proc., 4 (1953-1954): 67-102.

Hancock, D. 1965. Killer whales kill and eat a minke whale. J. Mammalogy, 46: 341-342.

Handley, C. O. 1966. A synopsis of the genus Rogia (Pigmy sperm whales). In: K. S. Norris (ed.), Whales, dolphins, and porpoises. Univ. of California Press, Berkeley and Los Angeles. XVI & 789 p.

Harrison, R. J. 1969. Reproduction and reproductive organs. In: H. T. Anderson(ed.), The biology of marine mammals, Academic Press, N. Y. p. 253-348.

Harrison, R. J., R. C. Boice and R. L. Brownell, Jr. 1969. Reproduction in wild and captive dolphins. Nature, London,222: 1143-1147.

Heezen, B. C. 1957. Whales entangled in deep sea cables. Deep Sea Res., 4: 105-115.

Hershkovitz, P. 1966. Catalogue of living whales. U.S. Nat. Mus. Bull. 246, Smithsonian Inst., Washington, D.C. 259 p.

Hoese, H. D. 1971. Dolphin feeding out of water is in salt marsh. J. Mammal.,52: 222-223.

Hopkins, W. J. 1922. She blows and sparm at that. Riverside Bookshelf Series. Houghton Mifflin Co., Boston. 120 p.

Horne, P. 1973. Inside II. Epic Recording No. EK 31600.

Hovaness, A. 1970. And god created great whales, played by A. Kostelanitz and Orchestra. Columbia Stereo Recording M30390.

International Union for the Conservation of Nature and Natural Resources. (IUCN). 1972. Red data book, I: Mammalia. IUCN, Morges, Switzerland.

Jenkins, J. T. 1921. A history of the whale fisheries form the Basque fisheries of the tenth century to the hunting of the finner whale at the present date. Witherby, London.

Jonsgard, A. 1968. A note on the attacking behavior of the killer whale (Orcinus orca). Norsk Hvalfangst-Tideude 1968, 4: 84-85.

Jonsgard, A. and P. B. Lyshoel. 1970. A contribution to the knowledge of the biology of the killer whale (Orcinus orca L.). Nytt Magasin for Zoologi,18: 41-48.

Josselyn, J. 1674. An account of two voyages to New England. London, Printed for Giles Widdows at the Green Dragon Inst. Pauls Churchyard. 279 & 3 p.

Kasuya, T. and S. Ohsumi. 1966. A secondary sexual character of the sperm whale. Sci. Rept. Whales Res. Inst., Tokyo 20: 89-94.

Katona, S. K., S. Kraus and S. Savage. (in preparation). Cetaceans observed from Mt. Desert Rock Lightstation, Gulf of Maine. Manuscript, in preparation.

Kellogg, R. 1929. What is known of the migrations of some of the whalebone whales. Smithsonian Rept. for 1928, Publ. 2981: 467-494.

________. 1940. Whales, giants of the sea. Nat. Geogr., 77: 35-90.

Kritzler, H. 1949. The pilot whale at Marineland. Natur. Hist., 58: 302-308, 331-332.

Lear, W. H. and O. Christensen. 1974. Bycatches of harbor porpoise (Phocoena phocoena) in salmon drift nets at West Greenland in 1972. Int. Whaling Comm., Sub-Committee on Small Cetacea of the Scientific Committee, Montreal, Apr. 1-12, 1974.

Levenson, C. 1972. Estimation of whale numbers in the North Atlantic. NAVOCEANO Tech. Note 7700-5-72: 1-23.

Lilly, J. C. 1961. Man and dolphin. Doubleday and Co., Inc., Garden City, N. Y. 312 p.

__________. 1967. The mind of the dolphin. Doubleday and Co., Inc., Garden City, N. Y. 310 p.

MacIntyre, F. 1974. The top millimeter of the ocean. Sci. Amer., 230 (5): 62-74.

Mackintosh, N. A. 1965. The stocks of whales. Fishing News (Books) Ltd., London. 232 p.

Mairs, D. F. and L. W. Scattergood. 1958. Recent Maine records of the bottlenose dolphin and the beluga. Maine Field Natur., 14: 78-80.

__________. 1959. Three Maine cetacean records. Maine Field Natur., 15(4): 111-113.

Marcuzzi G. and G. Pilleri. 1971. On the zoogeography of cetacea. In: G. Pilleri (ed.), Investigations on cetacea, III: 101-170.

Matthews, L. H. 1968. The whale. Simon and Schuster, N. Y. 287 p.

McGrath, R. A. and J. P. Thomas. 1973. Requiem for a heavyweight: a call to action. Underwater Natur. Bull. Amer. Littoral Soc., 8(2): 4-13.

McHugh, J. L. 1974. The role and history of the International Whaling Commission. In: W. E. Schevill (ed.), The whale problem: a status report. Harvard Univ. Press.

McVay, S. 1966. The last of the great whales. Sci. Amer., 215(2): 13-21.

Mead, J. 1973. Cape Cod dolphin stranding. Smithsonian Institution, Center for Short-lived Phenomena, Cambridge, Mass. Event 61-73. Event Notification Reports 1630, 1640, 1641.

Mercer, M. C. 1967. Wintering of pilot whales, Globicephala melaena, in Newfoundland inshore waters. J. Fish. Res. Bd. Can., 24(11): 2481-2484.

__________. 1974. The interaction between the northern pilot whale (Globicephala melaena) and the short-finned squid (Illex illecebrosus) at Newfoundland with particular reference to stock assessments and production estimates. Sub-committee on Small Cetacea, Scientific Committee of the International Whaling Commission, Montreal April 1-12, 1974.

Millais, J. G. 1973. From Placentia Bay to Spitzbergen: a naturalist aboard a North Atlantic whaler, Nature Canada, 2(4): 4-8.

Mitchell, E. 1968. North Atlantic whale research. Ann. Rev. Fish. Counc. Canada, 1968: 45, 47-48.

__________. 1970. Request for information on tagged whales in the North Atlantic. J. Mammalogy, 51: 378-379.

__________. 1972a. Balaenopterine or finner whales. In: A. Seed (ed.) Baleen whales in eastern North Pacific and Arctic waters. Pacific Search Books, Seattle, Washington, p. 24-30.

__________. 1972 b. Whale pigmentation and feeding behavior. Amer. Zool., 12(4): 60.

__________. 1972c. Memorandum on northwest Atlantic sei whales. Int. Whaling Comm., 22nd Rept., Annex M, p. 119-120.

__________. 1972d. Assessment of northwest Atlantic fin whale stocks. Rept. Int. Comm. Whal., 22nd Report, Annex L, p. 111-118.

__________. 1973a. The status of the world's whales. Nature Canada, 2: 9-25.

__________. 1973b. Draft report on humpback whales taken under special scientific permit by eastern Canadian land stations, 1969-1971. Int. Whaling Comm., 23rd Report, Annex M, p. 138-154.

__________. 1974. Present status of northwest Atlantic fin and other whale stocks. *In*: W.E. Schevill (ed.), The whale problem. Harvard Univ. Press, p. 108-169.

Moore, J. C. 1953. Distribution of marine mammals in Florida waters. Amer. Midl. Nat., 49: 117-158.

__________. 1958. A beaked whale from the Bahama Islands and comments on the distribution of *Mesopolodon densirostris*. *Novitates* (Am. Mus. Natur. Hist.), 1897: 1-12.

__________. 1966. Diagnoses and distributions of beaked whales of the genus *Mesoplodon* known from North American waters. *In*: K. S. Norris (ed.) Whales, dolphins and porpoises. Univ. Calif. Press, Berkeley and Los Angeles, p. 32-61.

__________. 1968. Relationships among the living genera of beaked whales. Fieldiana: Zoology, 53(4): 228.

Moore, J. C. and F. G. Wood, Jr. 1957. Differences between the beaked whales *Mesoplodon mirus* and *Mesoplodon gervaisi*. Novitates (Amer. Mus. Natur. Hist.), 1831: 1-25.

Mowat, F. 1972. A whale for the killing. Atlantic/Little Brown. Boston, Mass. 239 p.

Murphy, R. C. 1924. Seal as sperm whale food. J. Mammalogy, 5: 132.

Nayman, J. 1973. Whales, dolphins and man. Hamlyn Pub., N. Y.

Neave, D. J. and B. S. Wright. 1968. Seasonal migrations of the harbor porpoise (*Phocoena phocoena*) and other cetacea in the Bay of Fundy. J. Mammalogy, 49: 254-264.

__________. 1969. Observations of *Phocoena phocoena* in the Bay of Fundy. J. Mammalogy, 50: 653-654.

Nemoto, T. 1970. Feeding patterns of baleen whales in the ocean. *In*: G.H. Steele (ed.), Marine food chains. Univ. of Calif. Press, Berkeley, p. 241-252.

Nishiwaki, M. 1972. General biology. *In*: S. H. Ridgway, (ed.) Mammals of the sea, C. C. Thomas Publ., Springfield, Ill., p. 3-214.

Norris, K. S. 1969. The echolocation of marine mammals. In: H. T. Andersen, (ed.), The biology of marine mammals, Academic Press, N. Y., p. 391-423.

Norton, A. H. 1930. The mammals of Portland, Maine and vicinity. Proc. Portland Soc. Natur. Hist., 4(1): 1-150.

Ommanney, F. D. 1971. Lost Leviathon. Dodd, Mead and Co., N. Y. 280 p.

Ohsumi, S. 1966. Sexual segregation of the sperm whale in the North Pacific. Sci. Rept. Whales Res. Inst., Tokyo, 20: 1-16.

O'Riordan. 1974. Commercial whale fishing in Ireland. Int. Whaling Comm., Sub-committee on Small Cetacea of the Scientific Committee, Montreal, Apr. 1-12,1974.

Paul, J. R. 1968. Risso's dolphin, Grampus griseus, in the Gulf of Mexico. J. Mammal., 49: 746-748.

Payne, R. and S. McVay. 1971. Songs of humpback whales. Science, 173 (3997): 585-597.

Payne, R., W. R. Curtsinger and C. R. Nichlin, Jr. 1972. Swimming with right whales. Nat. Geogr., 142(4): 576-586.

Perkins, P. J. 1966. Communication sounds of finback whales. Norsk Hvalfangsttid., 55(10): 199-200.

Piers, H. 1923. Accidental occurrence of the pygmy sperm whale (Kogia breviceps) on the coast of Nova Scotia: an extension of its known range. Proc. and Trans. Nova Scotian Inst. Sci., 15: 95-114, Halifax.

Pilleri, G. 1971. (ed). Investigations on cetacea. Univ. of Berne, Switzerland, p. 101-170.

Pilson, M. E. Q. and E. Goldstein. 1973. Marine mammals. Part 7 of Coastal and Offshore Environmental Inventory, Cape Hatteras to Nantucket Shoals, Marine Publ. Ser. no. 2, Univ. Rhode Island, Kingston, R. I. 48 p.

Raven, H. C. 1937. Notes on the taxonomy and osteology of two species of Mesoplodon (M. evrodaeus Gervais, M. mirus True). Novitates (Amer. Mus. Natur. Hist.), 903: 1-30.

Rice, D. W. 1971. Sounders of the deep-sperm whales. In: A. Seed, (ed.), Toothed whales in eastern North Pacific waters. Pacific Search Books, Seattle, Washington, p. 17-20.

__________. 1972. Blue whale. *In*: A. Seed (ed.), Baleen whales in eastern North Pacific and Arctic waters. Pacific Search Books, Seattle, Washington, p. 31-37.

Rice, D. W. and V. B. Scheffer. 1968. A list of marine mammals of the world. U.S. Fish and Wildlife Services, Spec. Sci. Rep., Fisheries., 579: 1-16.

Robertson, D. 1973. Survive the savage sea. Praeger Publ., N.Y. 269 p.

Ruud, J. 1956. The blue whale. Sci. Amer., 195(6): 46-50. .

Ruud, J., A. Johnsgard and P. Ottestad. 1950. Age studies on blue whales. Hvalradets skrifter, 23: 28-31, 37-39.

Samuels, E. R., M. Cawthorn, B. H. Laver and B. E. Baker. 1970. Strontium-90 and Cesium-127 levels in tissues of fin whale (*Balaenoptera physalus*) and harp seal (*Pagophilus greenlandicus*). Can. J. Zool., 48: 267-269.

Scattergood, L. W. 1949. Notes on the little piked whale. Murrelet, 30: 3-17, Jan-April, 1949.

Scheffer, V. 1971. Fat choppers-Killer whales. *In*: A. Seed (ed.). Toothed whales. Pacific Search Books, Seattle, Washington, p. 12-15.

Schevill, W. E. 1954. Sight records of the gray grampus, *Grampus griseus* (Cuvier). J. Mammal., 35: 123-124.

__________. 1968. Sight records of *Phocoena phocoena* and of other cetaceans in general. J. Mammal., 49: 794-496.

Schevill, W. E. and R. H. Backus. 1960. Daily patrol of a *Megaptera*. J. Mammal., 41(2): 279-281.

Schevill, W. E. and W. A. Watkins. 1966. Sound structure and directionality in *Orcinus* (Killer Whale). Zoologica, 51: 71-76.

__________. 1972. Intense low-frequency sounds from an Antarctic minke whale, *Balaenoptera acutirostrata*. Breviora, no. 388. Museum of Comparative Zoology, Harvard Univ., Cambridge, Mass. 8 p.

Schevill, W. E., W. A. Watkins and R. H. Backus. 1964. The 20-cycle signals and *Balaenoptera* (fin whales). *In*: W. N. Ravoiga (ed.), Marine bio-acoustics. Pergamon Press, N.Y., p. 147-152.

Schevill, W. E., W. A. Watkins and C. Ray. 1969. Click structure in the porpoise *Phocoena phocoena*. J. Mammal., 50: 721-728.

Schmitt, F. P. 1972. Where great whales come sailing. Oceans 5(6): 38-43.

Sergeant, D. E. 1958. Dolphins in Newfoundland waters. Canadian Field Natur., 72: 156-159.

__________. 1961. Whales and dolphins of the Canadian east coast. Fish. Res. Bd. of Canada. Arctic Unit Circ. 7, 111 + 26 p.

__________. 1962. The biology of the pilot or pothead whale Globicephala melaena (Traill) in Newfoundland waters. Bull. Fish. Res. Bd. Canada, 132: i-vii 1-84, 1962.

__________. 1963. Minke whales, Balaenoptera acutorostrata Lacepede of the western North Atlantic. J. Fish. Res. Bd. Canada, 20: 1489-1504.

__________. 1966. Populations of large whale species in the western North Atlantic with special reference to the fin whale. Arctic Biol. Station, Fish. Res. Bd. Can., Circ. 9.

__________. 1968. Whales. In: C.S. Beal (ed.). Science, history and Hudson Bay. Queen's Printers, Ottawa, I: 388-396.

__________. 1969. Feeding rates of cetacea. Fisk. Div. Skr. Ser. Hav. Unders., 15: 246-258.

__________. 1973. Biology of white whales (Delphinapterac leucas) in western Hudson Bay. J. Fish. Res. Bd. Canada, 30: 1065-1090.

Sergeant, D. E. and P. F. Brodie. 1969a. Body size in white whales (Delphiapterus leucas) J. Fish. Res. Bd. Canada, 26: 2561-2580.

__________. 1969b. Tagging white whales in the Canadian Arctic. J. Fish. Res. Bd. Canada, 26(8): 2201-2205.

Sergeant, D. E., D. K. Caldwell and M. C. Caldwell. 1973. Age, growth, and maturity of bottlenosed dolphin (Tursiops truncatus) from northeast Florida. J. Fish. Res. Bd. Canada, 30: 1009-1011.

Sergeant, D. E. and H. D. Fisher. 1957. The smaller ceta ea of eastern Canadian waters. J. Fish. Res. Bd. Canada, 14: 83-115.

Sergeant, D. E., A. W. Mansfield and B. Beck. 1970. Inshore records of cetacea for eastern Canada, 1949-1968. J. Fish. Res. Bd. Can., 27: 1903-1915.

Smith, G. J. D. and D. E. Gaskin. 1974. The diet of harbor porpoises (Phocoena phocoena L.) in coastal waters of Eastern Canada, with special reference to the Bay of Fundy. Canadian J. Zool., 52(6): 777-782.

Southwell, T. 1882. The bottlenose whale fishery in the North Atlantic Ocean. Rept. U. S. Comm. Fish and Fisheries for 1882, p. 221-227.

__________. 1904. On the whale fishery from Scotland, with some account of the changes in that industry and of the species hunted. Edinburgh, Ann. Scot. Natur. Hist., 1904: 77-89.

Tomilin, A. G. 1957. Mammals of the U.S.S.R. and adjacent countries, v. 9, Cetacea. In Russian. Trans. Israel Program for Scientific Translations Jerusalem, 1967. Distributed by Clearinghouse, Springfield, Va., 22151.

Townsend, C. W. 1929. The white whale at Ipswich, Massachusetts. J. Mammalogy, 10: 171.

True, F. W. 1904a. The whalebone whales of the western North Atlantic compared with those occuring in European waters, with some observations of those occurring in the North Pacific. Smithsonian Contributions to Knowledge, 33: 1-332, pl. 1-50, text-fig. 1-97.

__________. 1904b. Notes on a killer whale (Genus Orcinus) from the Coast of Maine. Proc. U. S. Nat. Mus., 27: 227-231, 2 pls.

__________. 1910. An account of the beaked whales of the family Ziphiidae in the collection of the United States National Museum, with remarks on some specimens on other American museums. Bull. U. S. Nat. Mus., 73: 1-89(42 pls.).

Ulmer, F. A., Jr. 1941. Mesoplodon mirus in New Jersey, with additional notes on the New Jersey M. densirostris, and a list and key to the ziphoid whales of the Atlantic Coast of North America. Proc. Acad. Nat. Sci. Philadelphia, 43: 107-122.

Waters, J. H. and C. J. J. Rivard. 1962. Terrestrial and marine mammals of Massachusetts and other New England states. Standard Modern Printing Co., Brockton, Mass., 151 p.

Webb, B. F. 1973. Dolphin sightings, Tasman Bay to Cook Strait, New Zealand, September 1968-June 1969. N. Z. J. Mar. Fresh. Res., 7(4): 399-405.

Winn, H.E. 1975. Cetaceans of Atlantic Coast: distribution, movements, and populations. In: Marine environmental implications of offshore oil and gas development in the Baltimore Canyon region of the Mid-Atlantic Coast. Proc. Est. Res. Fed. Outer Continental Shelf Conf. and Workshop, Dec. 2,3,4, 1974. Spon. by Bur. Land Manage.

Winn, H.E., P.J. Perkins, and K. Winn. 1970. Sounds and behavior of the bottlenosed whale. Proc. 7th. Annu. Conf. on Biol. Sonar and Diving Mammals. Stanford Research Inst., Menlo Park, Ca., p. 53-59.

Wolman, A.A. 1972. Humpback whale. In: A. Seed (ed.), Baleen whales. Pacific Search Books, Seattle, Washington, p. 38-42.

Wray, P. 1974. The whalebook. Endangered Species Productions, Boston, Mass.

Young, A. 1846. Chronicles of the first planters of the colony of Massachusetts Bay from 1623 to 1636. Boston, C.C. Little and James Brown.

CHAPTER 7.0

BIOLOGICAL OCEANOGRAPHY

7.5 OFFSHORE BIRDS

SALLY ROONEY

Preceding page blank

CHAPTER 7.5 TABLE OF CONTENTS

Page

Chapter 7.5 Birds of the Atlantic Continental Slope from Cape Cod to Cape Hatteras

7.5 BIRDS OF THE ATLANTIC CONTINENTAL SLOPE FROM CAPE COD TO CAPE HATTERAS

7.5.1 INTRODUCTION

The records of occurrence and relative abundance of oceanic birds in the western North Atlantic have been discussed in the literature: Rich, 1929; Wynne-Edwards, 1935; Moore, 1951; Cross, 1954; Buckley, 1973; Drury, 1973. Wynne-Edwards (1935) contributed a major paper on the subject and thoroughly searched the literature. Moore (1951) compiled data from various trips of the Woods Hole Oceanographic Institution vessel, Atlantis, and graphically represented each species in terms of average numbers seen per day.

This chapter deals specifically with those pelagic species found on the continental slope from Cape Cod to Cape Hatteras. There is a general problem in placing the species present in the area into either the ecological "offshore" or "pelagic" habitats (Wynne-Edwards, 1935). Some of the species mentioned occur in both areas. Other problems are the vastness of the open ocean and the dearth of records. The Great Shearwater (Puffinus gravis) for example, is widely dispersed over the North Atlantic as a biological "winterer", as is Wilson's Petrel (Oceanites oceanicus). According to the literature (Bent, 1922) and the above cited references, these two species are considered to occur more frequently and in greater numbers than either the Sooty Shearwater (P. griseus) or Leach's Petrel (Oceanodroma leucorhoa). Lockley's systematic banding of the Manx Shearwater (P. puffinus) on Skokholm Island remains as one of the few times sea bird migrations and movements have been accurately studied (Dorst, 1962). Certainly, more records and banding studies are needed to further extend knowledge of the birds of the study area.

The list of species occurring in the study area (Table 7-50 and 7-52) was compiled from the state bird books (Cape Cod, Massachusetts: Hill, 1965; New York: Bull, 1964; New Jersey: Stone, 1937; Maryland: Stewart and Robbins, 1958; North Carolina: Pearson, Brimley and Brimley, 1959). Some state bird books were not available, information was taken from Heppner and Gould, 1973. Three field guides were also used: Alexander, 1938; Peterson, 1947; Robbins, Bruun, and Zim, 1966. The journal American Birds proved to be invaluable in updating previous studies, i.e., Buckley, 1973.

The species accounts sections (Table 7-54) were done from various authors: Bent, 1921, 1922; Matthiessen and Stout, 1967; Palmer, 1962.

7.5.2 STATUS REPORTS

Since most of the birds in the area are visitants, rather than breeders, and densities are difficult to determine, an accurate picture of the population trends of the species in the study area is unrealistic. Apparently, two species have decreased since the early 1900's, and two have increased.

Drury (1973) cites the steady decline of Leach's Petrel in the New England area since 1900. This species is considered uncommon to rare south of New England (Stone, 1937; Stewart and Robbins, 1958). Drury (1973) states that serious detrimental effects to the breeding populations occur when sheep are introduced to islands where this petrel breeds. Another factor in the decline of this species is the rapid expansion of the larger Larus gulls, which are major predators on the breeding grounds of the petrel. Zeldin (1971) summarizes the negative effects of oil spills on seabirds in general. He gives no specific data for Leach's Petrel, but it is likely that some foods ingested by the petrels in their wide peregrinations may have been contaminated by oil. All seabirds are adversely affected by oil (Giles and Livingston, 1960).

Hill (1965) states that the Black-legged Kittiwake (Rissa tridactyla) may be decreasing in numbers, coincident with the decline of the fishing industry in the Cape Cod area.

Hill (1965) believes the Sooty Shearwater (Puffinus griseus) and the Gannet (Movus bassanus) are on the increase in the Cape Cod area. In both cases, Hill contributes the population increase to the cessation of persecution by fishermen. The Gannet is now strictly protected on its Canadian breeding grounds. At the time Fisher and Vevers (1949) studied breeding colonies, history and population of the Gannet, the species was increasing in numbers. They found no reasons why the increases should not continue. However, a recent television program on the Canadian Broadcasting Company ("Earthwatch", October 29, 1975) stated that Gannets had decreased in numbers on Bonaventure Island. Damage to the ecosystem by pollution was the suspected cause, but the matter needs more investigation.

7.5.3 GEOGRAPHIC FEATURES INFLUENCING BIRDS

The Gulf Stream is the major ocean current in the study area. Its pathway into the western North Atlantic carries with it warmer waters and food supply for pelagic birds in the area. Wilson's Petrel is definitely concentrated in the Gulf Stream during migration through the study area in the spring and fall (Moore, 1951). The Stream is a principal supplier of food to pelagic species following its course.

The migration and local abundance of seabirds is largely governed by the prevailing winds and the food supply. Pelagic species do not struggle against gale winds while over the ocean, but may become exhausted trying to regain open water after being blown overland.

Dorst (1962) cites Leach's Petrel, Black-legged Kittiwake, and Dovekie as examples. Wilson's Petrel and the Great Shearwater have almost identical migration routes which are governed by the prevailing winds (Dorst, 1962).

7.5.4 BIRDS OF THE AREA

Most of the birds in the study area are strictly pelagic in habitat, although at various seasons and under certain ecological conditions, all of them have been seen from shore or over land on numerous occasions (Dorst, 1962).

Most pelagic species belong to the Order Procellariiformes or "tubenoses" which includes the Fulmar, Shearwaters and Petrels. The Gannet (Pelecaniformes) is not apt to occur in most of the study area, being primarily littoral. Because many Gannets winter off the coasts of Virginia and North Carolina (and further south), they have been included in the Species Accounts. The Order Charadriiformes includes the remaining species, with two members of the family Phalaropidae: Red and Northern Phalaropes (Phalaropus fulicarius and Lobipes lobatus), respectively; three members of the Stercorariidae: the jaegers; one pelagic gull (Laridae), the Black-legged Kittiwake; and four members of the auk family (Alcidae). The latter are primarily littoral (except Dovekie), but undoubtedly occur in the study area at different times in varying numbers.

7.5.5 SPECIES IDENTIFICATION

One point should be made regarding field identification of the species found in the study area. Both Wynne-Edwards (1935) and Moore (1951) mention that there were discrepancies in the proper field separation of the Great Shearwater (P. gravis) and Cory's Shearwater (P. diomeda). Wilson's and Leach's Petrel may be misidentified by the inexperienced observer (Hill, 1965) and the Red and Northern Phalaropes are sometimes very difficult to distinguish in winter plumage over the ocean (Hill, 1965).

7.5.6 MAN/BIRD RELATIONS

OIL

Oil is undoubtedly one of the worst enemies of seabirds. Oil pollution fouls the feathers, robbing the birds of insulation, and poisons the bird when it preens and ingests the toxic oil (Zeldin, 1971). Much has been written on this topic. The reader is referred to the references at the end of this chapter. Virtually all seabirds are affected by oil pollution (Giles and Livingston, 1960).

CHEMICAL PESTICIDES AND RESIDUES

In general, birds most affected are the more littoral species, i.e., pelicans and cormorants (Stickel, 1963). However, Stokes (1968) cites positive decline in egg productivity of the Cahow (Pterodroma cahow), a petrel closely related to those found in the study area.

7.5.7 SUMMARY

The occurrence of pelagic birds in the study area, and their numbers, are dependent upon several factors: primarily, available food, the location of the Gulf Stream, and prevailing winds.

Studies are needed to determine more exactly the status of species at various seasons of the year in the study area.

Table 7-50. List of all birds occurring in the area (scientific names are from Checklist of North American Birds, A.O.U., (1957), in taxonomic order.

*	denotes accidental occurrence
**	denotes casual occurrence
***	denotes common occurrence
****	denotes key species

*	Diomedea chlororhynchos	Yellow-nosed Albatross
**	Fulmarus glacialis	Fulmar
****	Puffinus diomeda	Cory's Shearwater
****	P. gravis	Great Shearwater
****	P. griseus	Sooty Shearwater
**	P. puffinus	Manx Shearwater
**	P. lherminieri	Audubon's Shearwater
*	Pterodroma hasitata	Black-capped Petrel
*	Pterodroma arminjoniana	South Trinidad Petrel
*	Pelagodroma marina	White-faced Petrel
**	Oceanodroma leucorhoa	Leach's Petrel
****	Oceanites oceanicus	Wilson's Petrel
*	Phaethon aethereus	Red-billed Tropic bird
**	Phaethon lepturus	White-tailed tropic bird
****	Movus bassanus	Gannet
****	Phalaropus fulicarius	Red Phalarope
***	Lobipes lobatus	Northern Phalarope
***	Stercorarius pomarinus	Pomarine Jaeger
***	S. parasiticus	Parasitic Jaeger
***	S. longicaudus	Long-tailed Jaeger
**	Catharacta skua	Skua
****	Rissa tridactyla	Black-legged Kittiwake
***	Alca torda	Razorbill
**	Uria aalge	Common Murre
***	U. lomvia	Thick-billed Murre
***	Plautus alle	Dovekie
***	Cepphus grylle	Black Guillemot
**	Fratercula arctica	Common Puffin

Table 7-51. List of abbreviations used in Table 7-52.

Acc. = accidental
Cas. = casual
a = abundant
c = common
fc = fairly common
r = rare
o = occasional
r = regular
i = irregular
u = uncommon
* = largest numbers

Sp = Spring
S = Summer
F = Fall
W = Winter
V = Visitant
Mg = Migrant
HYPO = Hypothetical

Months of the Year

1 = January
2 = February
3 = March
4 = April
5 = May
6 = June
7 = July
8 = August
9 = September
10 = October
11 = November
12 = December

In Reference to Months

e = early
m = middle
l = late

Relative Abundance Numbers = August numbers likely to be seen in one day or locality

I = 1 - 100
II = 100 - 500
III = 500 - 1000
IV = 1000 - 5000
V = 5000+

Table 7-52 Distribution and Status of Birds in the Study Area

	Cape Cod Massachusetts		Rhode Island		Long Island, New York and New Jersey		Maryland		Delaware	Virginia		North Carolina	
	Status	Dates	Status	Dates	Status	Dates	Status	Dates	Status	Status	Dates	Status	Dates
Fulmar	Acc; I	9-5	Acc.	-----	Acc; I	10-1	no recs.	-----	no recs.	no recs.	-----		-----
*Cory's Shearwater	SV; I	5-10 *m7-m9	SV; I	8-10	c/a 1S& FV:I-III	7-m11 *18-110	fc/c SV I	16-m9	no recs.	Acc.	-----	uSV& FV: I	7-8
*Greater Shearwater	r/a SV; I	5-10 *8-9	rS&FV	6-e10	r/c SV I-II	15-e10	r/u SV I	m5-e6	no recs.	Acc.	8	u/o SV. &FV: I	6-8; 12
*Sooty Shearwater	u/c SV; I	[illegible]-e9	u SV	15-e9	c/a SV I-II	15-m9 *15-e6	r Sp V I	5-e6	no recs.	u/r Sp V I	5-6	r/a S+FV	5-6; 9
Audubon's Shearwater	Acc. (1 rec)	(1 7)	Acc. 3 recs.	-----	Acc. 5 recs.	(8)	Acc. (1 rec.)	(8)	no recs.	Acc. Cas.	8,9, 10	u SV	7-8
Leach's Petrel	r SV & FMg; I	5-10 *9-10	Acc.; 3 recs.	-----	Cas. S&FV	e5-e11	rS+FV I	6-10 *6-8	Acc.	r SV:I	7-8	r S&FV I	7-9
*Wilson's Petrel	c/a Mg I-III	6-e9	SV	6-m9	c/a SV I-V	15-18	r/fc SV I-III	m5-e9	Acc	o/fc SV I-II	6-8	r/c S&FV	5-9
*Gannet	c/a Mg I-II	m9-111 13-m5	o Sp & FV	13-e6 9-e12	c/a Mg o in W	13-m5 1 10-e12	u/fc Mg rWV;I-II	9-5 *11&4	Acc.	u/c WV& Mg;I-III	*3 *11	a WV,r SV; c Mg	8;11-12; 4-5
Northern Phalarope	c/a Mg I-II	5; 8-m10 *9	Sp& FMg	5; 8-10	R FMg, CasSpMG I	7-9					LITTORAL		
*Red Phalarope	c/a Mg I-IV	m4-m5 m8-m11	u S&FM	e4-5 17-11	cS&FMg; I-IV	13-14 9-e11	r Mg I	e4-15 8-9	Acc.	rFMg uWV I	9-e10	u/r Sp Mg&WV	3-5; 2
Pomarine Jaeger	Cas/rMg &SV; I	15-m6 8-9	r FM	8-10	u/rg Mg I	e5-m11	o FM;I	9-e10	no recs.	r FM; I	9-11	u Mg	9-10 (1);5
Parasitic Jaeger	u/fcMg rSV I	15; 18-m9	u Mg	m5-e6 17-m10	rg Mg I	e5-m11	r Mg;I	m5; 9-[illegible]	Acc.	uMg; rWV I	5; 8-9	rSpMg&WV; uSVFMg	9-10
Long-tailed Jaeger	CasSpMg r FMg	15; m8-m9	Acc.	-----	Cas Mg	15-e6 e8-e9	HYPO; 1 rec	5/1/05	no recs.	-----	-----	Acc.	-----
*Black-legged Kittiwake	cWV; r FV I-II	9-4 *11-12	r WV	11-e4	u/c WV I-III	11-2					LITTORAL		
Razor-billed Auk	u/r WV; I	111-4 *11	u WV	m11-e4	r/i WV I	112-e3					LITTORAL		
Common Murre	r/iWV I	m11-e4	r WV	11-14	Cas; I	------	no recs.	-----	no recs.	no recs.	-----	no recs.	-----
Thick-billed Murre	r WV I	m11-e4	r WV	m11-e4	r/i WV; I	12-2	Cas.	-----	no recs.	no recs.	11-1	oWV	12-2
Dovekie	uWV; a o I-IV	e11-e4	u WV	e11-13	r/rg WV I	m11-e3	rMg&WV I	e11-m3	no recs.	r WV; I	11-2	u/r WV	11-2

* = Species Accounts

Table 7-53. List of abbreviations used in Table 7-54.

a = abundant
acc = accidental
avg = average
Chesa = Chesapeake Bay
Ext = extreme
F = fall
fc = fairly common
freq = frequent, frequently
gen = generally
imm = immature
impt = important
indiv = individual, individuals
infr = infrequent
i = irregular
L.I. = Long Island
Max = maximum
Mg = migrant, migrates, migration
#'s = numbers
o = occasional
r = rare
R = resident
reg = regular, regularly
rel = relatively
S = summer
Sp = spring
uc = uncommon
W = winter
Yr = year(s)
V = visitant

Table 7-54. Species accounts.

Species:	*Puffinus diomeda*	Cory's Shearwater
Literature:	Bent, 1922 Buckley, 1973 Bull, 1964	Heppner and Gould, 1973 Hill, 1965 Palmer, 1962
Status:	Summer visitant to study area; common to abundant; replaces Great Shearwater in warmer waters of study area; the last Shearwater to arrive and last to leave. S., and F., Mg. V.	
Distribution:	Very pelagic; offshore, over Gulf Stream and farther east in more southerly portion of the study area.	
Habitat:	Over oceanic waters where currents and upwellings occur.	
Breeding:	Does not breed in study area.	
Effects from Man:	Oil spills on open water; in past, persecution by fishermen.	
Food:	Not much data (Palmer); fish row and cephalopods. Some plant material, fishes and crustaceans. Follows whales and predaceous fishes to clean scraps which come to surface. Feeds on herring (*Clupea*) and oily substances.	

Table 7-54. (cont.)

Species:

Puffinus gravis Great Shearwater

Literature:

Bent, 1922
Bull, 1964
Heppner and Gould, 1973
Hill, 1965
Palmer, 1962
Wass, 1974

Status:

Rare to abundant, depending on good fishing years. More abundant in northern waters of study area (replaces Cory's Shearwater in the more northerly portions of the study area). Post-breeding "winterer". S., F., Mg., V.

Distribution:

Pelagic entire area. Arrives on New England fishing grounds around May.

Habitat:

Oceanic; most abundant offshore over currents (Gulf Stream) and upwellings.

Breeding:

Does not breed in the study area.

Effects from Man:

In past, persecuted by fishermen; used for bait. Oil spills may be a present hazard.

Food:

Mainly squids and fish; also sand launces (*Ammodytes*) and capelin (*Mallotus villosus*). May feed on cetacean feces.

Table 7-54 (cont.)

Species:

Puffinus griseus Sooty Shearwater

Literature:

Bent, 1922
Buckley, 1973
Bull, 1964
Heppner and Gould, 1973
Hill, 1965
Palmer, 1962
Wass, 1974

Status:

Rare to abundant, depending on good fishing years. Not usually in as large numbers as preceding species. Post-breeding "winterer". First shearwater to arrive and first to depart. Sp., F., Mg., V.

Distribution:

Pelagic, entire study area. Moves up along west Atlantic in April and May. Most common in study area in Sp.

Habitat:

Oceanic; most abundant in good fishing years, and under certain ecological conditions. Follows currents and upwellings.

Breeding:

Does not breed in study area.

Effects from Man:

Oiling may be a factor. Formerly caught with hook and line by fishermen - used for bait.

Food:

Mainly squids; small fish, e.g., capelin and sand launces; also crustaceans.

Table 7-54. (Cont)

Species:

Oceanites oceanicus Wilson's Petrel

Literature:

Bent, 1922
Bull, 1964
Heppner and Gould, 1973
Hill, 1965
Palmer, 1962
Wynne-Edwards, 1935

Status:

Rare to abundant throughout study area. April-October (sometimes later); post-breeding "winterer"; Sp., S., F., Mg., V.

Distribution:

Pelagic, chiefly along Gulf Stream; most common in study area during summer months.

Habitat:

Oceanic; most abundant in good fishing years. Follows currents (Gulf Stream) and upwellings.

Breeding:

Does not breed in study area.

Effects from Man:

Oil possible; fishermen did not persecute this species because of superstition that it brings bad luck.

Food:

Little specific information for Atlantic - probably mainly plankton and offal from boats; have found remains of squids and otoliths of small fishes.

Table 7-54. (cont.)

Species:

Movus bassanus Gannet

Literature:

Bent, 1922	Heppner and Gould, 1973
Forbush and May, 1939	Hill, 1965
Bull, 1964	Palmer, 1962
	Stewart and Robbins, 1958

Status:

Sp., F., Mg., V.

Distribution:

Ranges in summer, rarely to Mass. In winter from coast of Va., rarely from Mass. to Fla. Migration: N. England peak in early Nov.; mid-April to early May. N. J. and L. I. - late Nov.; April Sp., F., Mg., V.

Habitat:

Littoral and pelagic; uncommon beyond outer limits of continental shelf.

Breeding:

Does not breed in the study area.

Effects from Man:

Killed by fishermen for use as catfish bait (Bent). Numbers reduced, coming back under protection (Hill). Young birds eaten by humans (Bent).

Food:

School fishes, i.e., herring, squids, possibly other mollusks and crustacea (Heppner and Gould).

Table 7-54 (cont.)

Species:	Phalaropus fulicarius	Red (Grey) Phalarope
Literature:	Bent, 1927 Matthiessen and Stout, 1967 Hill, 1965	Heppner and Gould, 1973 Wass, 1974
Status:	Rare to abundant in study area. S., F., Mg., in area. Also W.V. in Virginia and North Carolina.	
Distribution:	The most pelagic of the Phalaropidae; winters in rich waters of all oceans (except Antarctic).	
Habitat:	Oceanic, far offshore, over currents and upwellings.	
Breeding:	Does not breed in study area.	
Effects from Man:	Hunted by Eskimos on breeding grounds; oil may be a factor at sea.	
Food:	Plankton; mainly crustaceans, some jellyfishes; known to feed in wake of whales and on whale parasites.	

Table 7-54 (cont.)

Species:

Rissa tridactyla — Black-legged Kittiwake

Literature:

Bent, 1921
Drury, 1973
Heppner and Gould, 1973
Hill, 1965
Stokes, 1968

Status:

Uncommon to common winter visitant; rare fall visitant northern portions of study area. F., W. V.

Distribution:

Primarily pelagic, becoming more littoral in the southern portions of the study area.

Habitat:

The most oceanic of the gulls; becoming more littoral in Maryland, Virginia and North Carolina.

Breeding:

Does not breed in study area.

Effects from Man:

May have declined due to decrease in fishing industry. Oil on high seas possible factor; no longer persecuted by fishermen - in past were shot in large numbers.

Food:

This gull unique in that it can swim under water in pursuit of fish; eats capelin and sand launces; fish offal from boats.

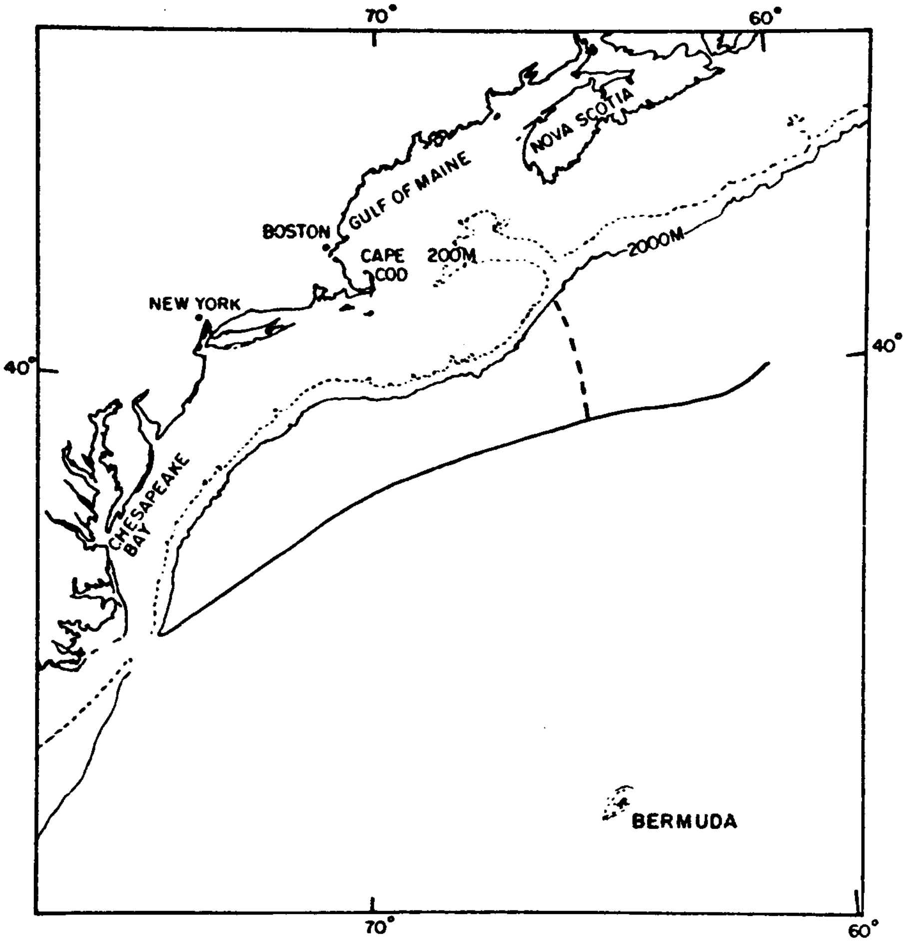
Table 7-54 (cont.)

The following birds are listed as occurring commonly in the area in Table 7-50, but are not in sufficient numbers to warrant "key species" status.

Species:	Stercorarius pomarinus	Pomarine Jaeger
	Stercorarius parasiticus	Parasitic Jaeger
	Stercorarius longicaudus	Long-tailed Jaeger
	Lobibes lobatus	Northern Phalarope
	Alca torda	Razorbill
	Uria lomvia	Common Murre
	Plautus alle	Dovekie
	Cepphus grylle	Black Guillemot
Literature:	Bent, 1921	Bull, 1964
	Drury, 1973	Hill, 1965
	Heppner and Gould, 1973	Stokes, 1968

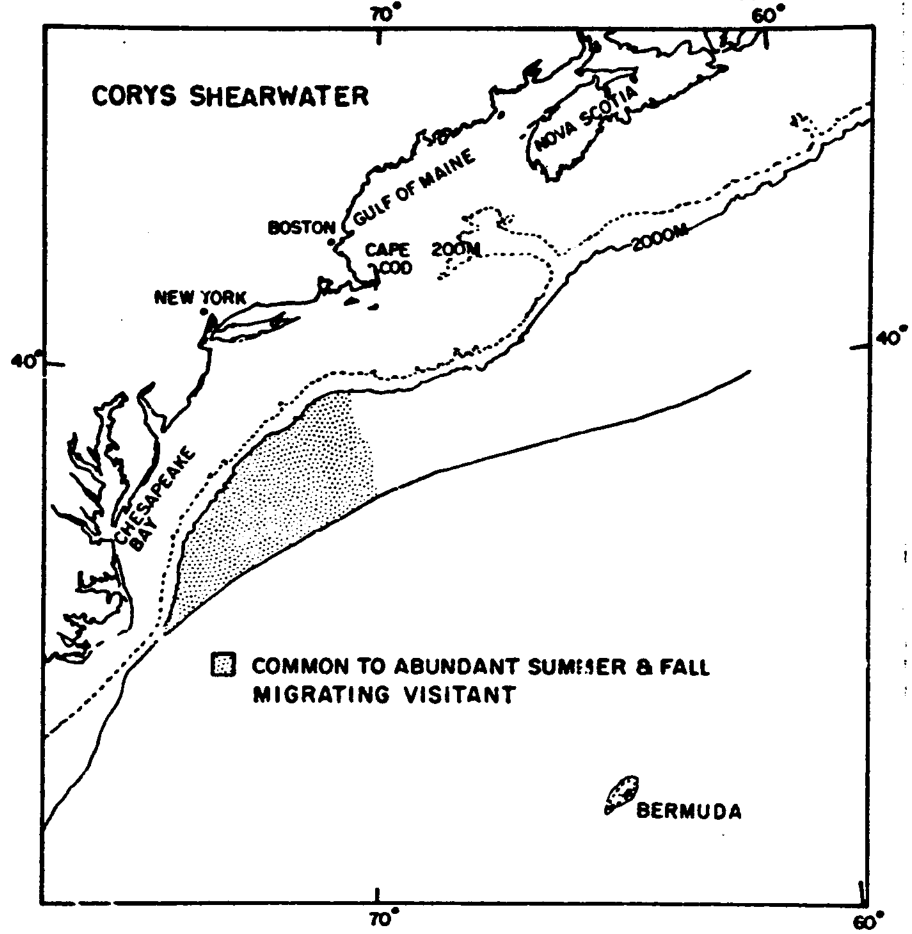
The three jaegers, Stercorarius pomarinus, S. parasiticus, and S. longicaudus occur rarely to frequently in the area. Being predators, these birds occur in relatively smaller numbers than other non-predator species, especially S. longicaudus, and for this reason have not been considered key species within the scope of this chapter (Bent, 1921; Bull, 1964; Hill, 1965; Heppner and Gould, 1973; Stokes, 1968).

Lobibes lobatus (Northern Phalarope), Alca torda (Razorbill), Uria lomvia (Thick-billed Murre), and Cepphus grylle (Black Guillemot), all occur in the study area during migration and in the winter, but their major numbers demonstrate a more littoral than pelagic distribution within the limits of the area (Bent, 1921; Drury, 1973; Heppner and Gould, 1973).



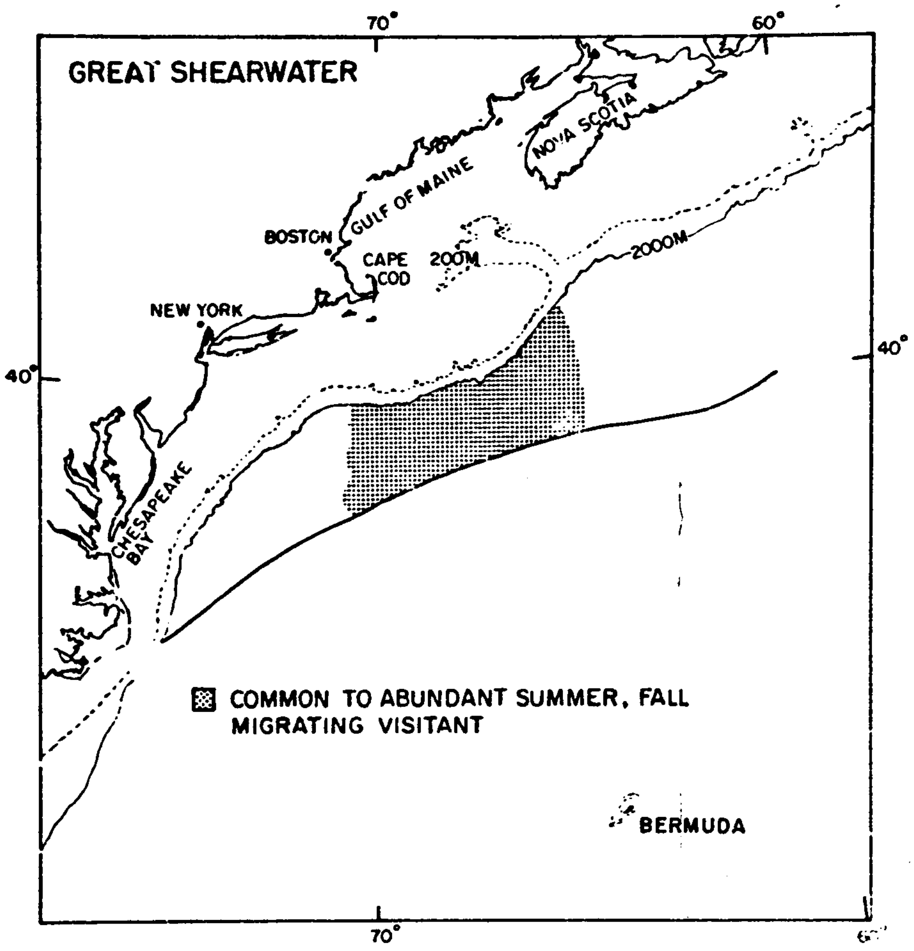
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-64	Limits of the Study Area Covered in Chapter



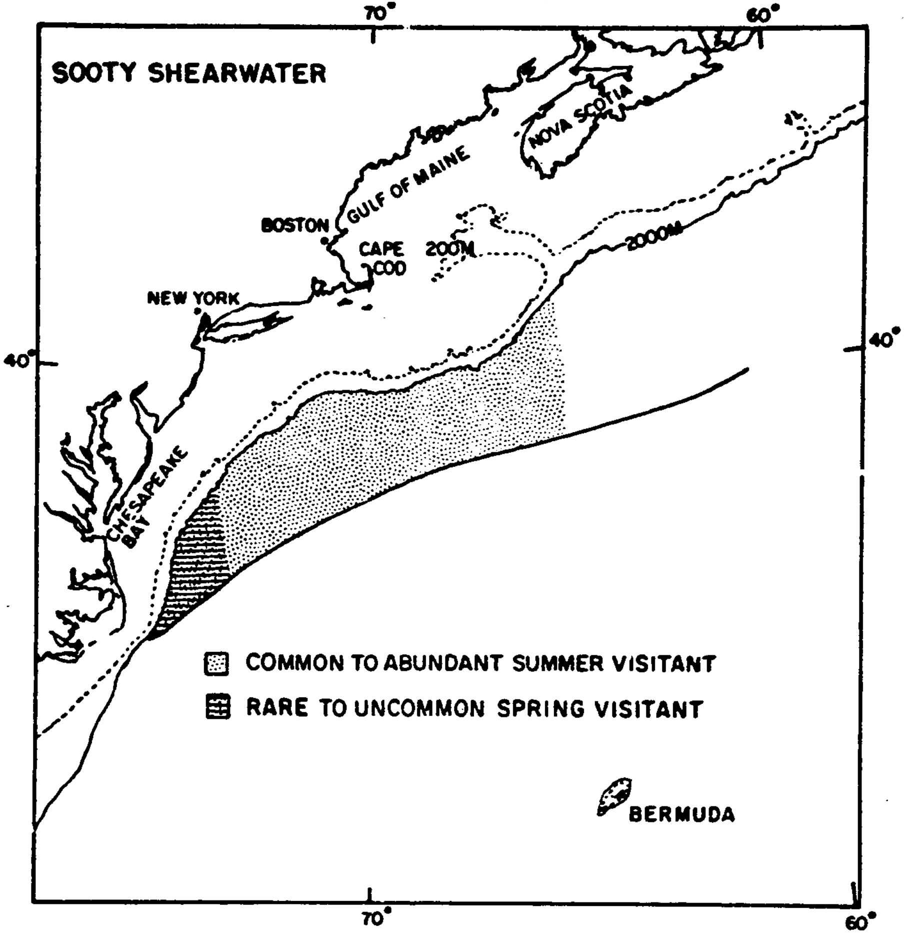
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-65	Distribution of Corys Shearwater in the Study Area



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-66 Distribution of Great Shearwater in the Study Area

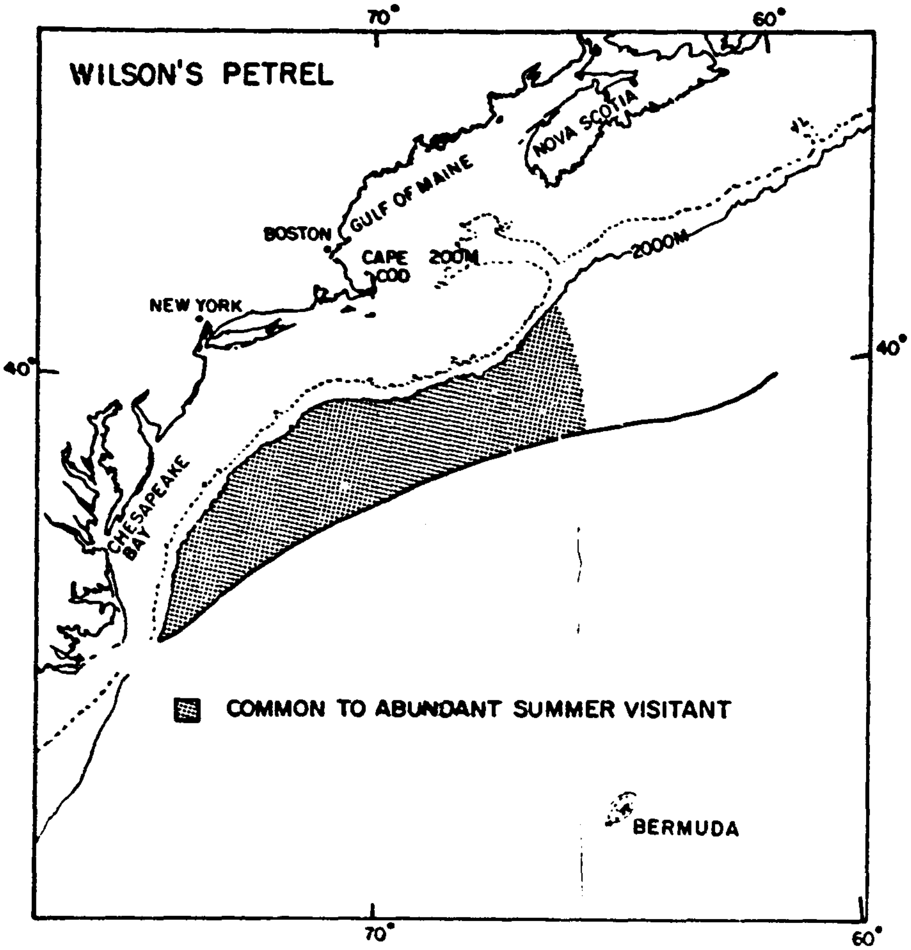


▨ COMMON TO ABUNDANT SUMMER VISITANT

▤ RARE TO UNCOMMON SPRING VISITANT

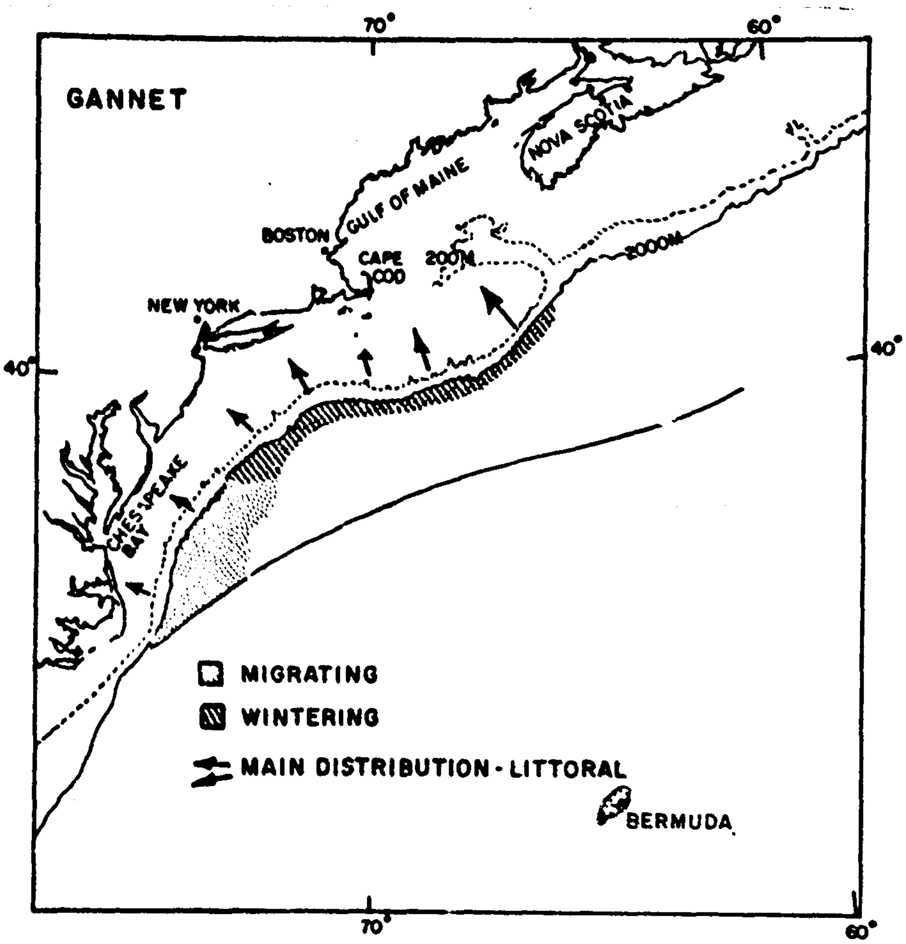
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-57	Distribution of Sooty Shearwater in the Study Area



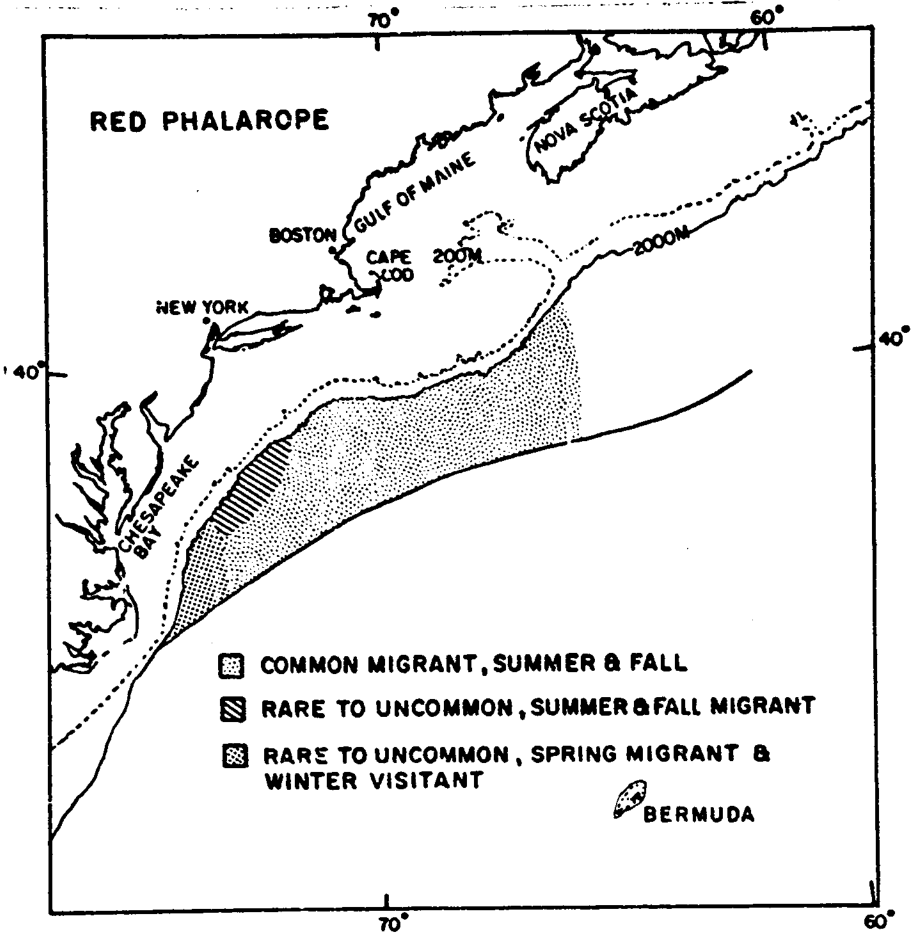
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM FIGURE 7-68 Distribution of Wilson's Petrel in the Study Area



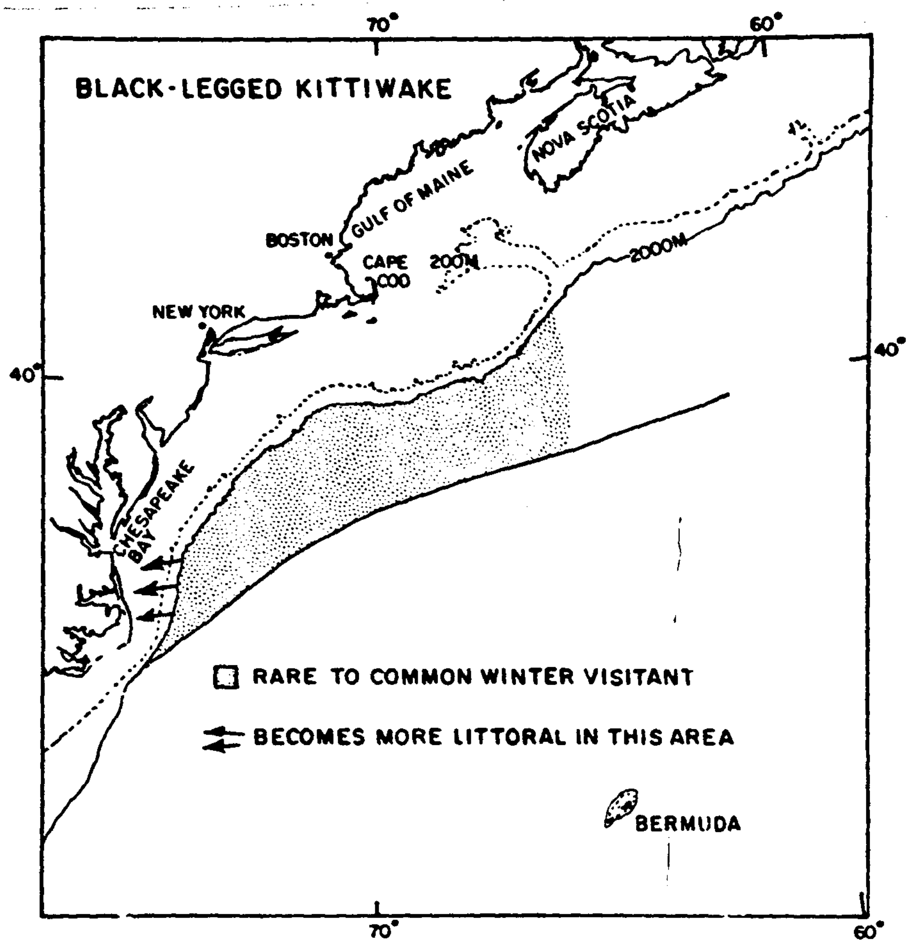
ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-69	Distribution (*relative) of the Gannet in the Study Area. *more littoral than pelagic, but does occur in study area.



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-70	Distribution of Red Phalarope in the Study Area



ENVIRONMENTAL INVENTORY OF THE NORTH ATLANTIC CONTINENTAL SLOPE

TRIGOM	FIGURE 7-71	Distribution of Black-legged Kittiwake in the Study Area

7.5.8 REFERENCES

Alexander, W.B. 1938. Birds of the ocean. G.P. Putnam's Sons, New York. 306 p.

American Ornithologists' Union. 1957. Checklist of North American birds. 5th. edition. Amer. Ornithol. Union, Baltimore. 691 p.

_________. 1973. Thirty-second supplement to A.O.U. checklist of North American birds. Committee on Clarification and Nomenclature. Auk, 90: 411-419.

Bent, A.C. 1921. Life histories of North American gulls and terns. Dover Publications, New York. 335 p.

_________. 1922. Life histories of North American petrels and pelicans and their allies. Dover Publications, New York. 335 p.

_________. 1927. Life histories of North American shore birds. Part I. Dover Publications, New York. 420 p.

Buckley, P.A. 1973. A massive spring movement including three species new to North Carolina, at Cape Hatteras National Seashore. Amer. Birds, 27: 8-10.

Bull, J.L. 1964. Birds of the New York area. Harper and Row, New York, 540 p.

Dorst, J. 1962. The migrations of birds. Houghton Mifflin Co., Boston. 476 p.

Drury, W.H. 1973. Population changes in New England seabirds (Pt. 1). Bird-banding, 44(4): 267-313.

Fisher, J. and H.G. Vevers. 1949. The breeding distribution history and population of the North American Gannet (<u>Sula bassana</u>).J. Animal Ecol., 13: 49-62.

Forbush, E.H. and J.B. May. 1939. Natural history of American birds. Bramhall House. 554 p.

Giles, L.A.,Jr. and J. Livingston. 1960. Oil pollution of the seas. Trans. N. Amer. Wildl. and Natur. Resour. Conf., 26: 297-302.

Gross, A.O. 1954. Changes of certain seabird populations along the New England coast of North America. Acts, 11th Congr. Int. Ornithol.: 446-449.

Heppner, F.H. and L. L. Gould. 1973. Birds of the Atlantic seaboard from Cape Hatteras to Cape Cod. Mar. Publ. Ser. No. 2, Univ. of R.I., Kingston: 8-1 to 8-138.

Hill, N.P. 1965. Birds of Cape Cod, Massachusetts. William Morrow and Co. 364 p.

Matthiessen, P. and G.P. Stout. 1967. The shorebirds of North America. The Viking Press, New York. 270 p.

Moore, H.B. 1951. The seasonal distribution of oceanic birds in western North Atlantic. Bull. Mar. Sci. Gulf Caribb., 1(1): 1-14.

Palmer, R.S. 1962. Handbook of North American birds. I: Loons through flamingos. New Haven and London, Yale Univ. Press. 567 p.

Pearson, T.G., C.S. Brimley, and H.H. Brimley. 1959. Birds of North Carolina. Rev. ed., N.C. Dep. of Agr.

Peterson, R.T. 1947. A field guide to the birds (east of the Rockies). Boston, Houghton Mifflin Co. 230 p.

Rich, W. 1929. Random notes on the birds on the offshore fishing ground of the Gulf of Maine. Me. Natur., 9(1): 3-24.

Robbins, C.S., B. Bruun, and H.S. Zim. 1966. Birds of North America. New York, Golden Press. 340 p.

Stewart, R.E. and C.S. Robbins. 1958. Birds of Maryland and the District of Columbia. U.S. Govt. Print. Office, Washington, D.C. 401 p.

Stickel, L.F. 1968. rganochlorine pesticides in the environment. Spec. Sci. Rep. Wildlife, 119: 1-32.

Stokes, T. 1968. Birds of the Atlantic. Country Life Books, Hamlyn Publishing Group, Ltd., Hamlyn House, Feltham, Middlesex, Eng. 156 p.

Stone, W. 1937. Bird studies at Old Cape May. Dover Publications, Inc., New York. 941 p., 2 v.

Wass, M.L. 1974. Birds of the coastal zone. In: A socio-economic and environmental baseline summary for the South Atlantic region between Cape Hatteras and Cape Canaveral, Florida. III: Chemical and biological oceanography. Va. Inst. Mar. Sci., Gloucester Pt., Va., p. 521-703.

Wynne-Edwards, V.C. 1935. On the habits and distribution of birds on the North Atlantic. Proc. Boston Soc. Natur. Hist., 40: 233-246.

Zeldin, M. 1971. Audubon black paper number i: oil pollution. Audubon, 73: 99-120.