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Ecological Aspects of the Upper Continental Slope of the Gulf of Mexico

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ECOLOGICAL ASPECTS OF THE UPPER CONTINENTAL SLOPE OF THE GULF OF MEXICO

by

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PART I. INTRODUCTION

1. THE NATURE OF THE STUDY

OBJECTIVES

As can be seen in a later section of this report, deep-water investigations of the biology of the Gulf of Mexico commenced over one hundred years ago. After this initial period of study, which was relatively short-lived, there was a major hiatus in time before deep-water biological studies were taken up again in the Gulf of Mexico. More importantly, however, is the fact that the early studies were concerned primarily with descriptions of the species found and thus little time was available for integrating the findings into even an overview of the assemblages of organisms found at any given depth. Perhaps the saddest fact of all is simply that during the long time span intervening between the early and more modern studies much of the taxonomical expertise died away. As a result, the taxonomy of many groups had to be re-discovered for one to achieve a position to begin to think about creating meaningful faunal assemblages. Needless to say, perhaps, the systematics of all of the deep-water organisms in the Gulf, e.g., the sponges, is far from satisfactorily worked out. In spite of this unfortunate situation, a first-cut attempt has been made to treat the entire issue of faunal assemblages or deep-water communities. This has been, then, the overriding objective of this study, viz., to describe the faunal assemblages of deep waters in the Gulf of Mexico. Obviously, one who is motivated to attempt such a study is likely to make some attempt to explain the existence of whatever communities he finds. Hence a second objective has been to attempt a very tentative analysis of causation in regard to community distribution. Finally, an attempt has been made to synthesize important facts and create a simple model of the functioning of that part of the ecosystem sustained on the upper slope.

SCOPE

From the beginning, the principal focus of this study never swerved from the bottom-dwelling organisms or benthos. But, as often happens when man tries to force a classificatory scheme upon the real world, some things bulge out and escape the mold, so to speak. Thus, there are fishes, cephalopods and other organisms that swim freely in the water and appear to belong to the pelagial, save for one thing, namely, they feed upon bottom organisms. Such fishes, in particular, have come to be called demersal fishes. But this escape from the bottom is a matter of degree, since there are some species of fishes that stray little if at all away from the bottom--these might well be called benthal species. The point of all of this is simply that although this study was principally conceived of as being a benthic study, some cognizance soon had to be taken of aspects of pelagic life, that is, the organisms that live in the water column above the bottom. This information has been used primarily in an attempt to provide an ecological synthesis in the last section of the study, since no one would wish to dispute the existence of some degree of matter and energy dependence of the benthos upon the pelagial.

It became apparent that if one were to be concerned at all with pelagic life, the nature of the water column itself must be described. Thus, the scope of the study was stretched to include physico-chemical matters. Since currents are important as facilitators of species distribution whereas temperature, salinity, and oxygen tension are factors that can limit distribution, some attention has been paid to these parameters in the report. All of these factors except currents are reasonably well known in the northern Gulf; however, only a few groups have tried to measure these parameters within a few centimeters of the bottom. The status of present knowledge of currents, especially those near the bottom, is deplorable. At the present time everyone has been forced to rework the same fragmentary data, in which, unfortunately, very few synoptic results are available.

The scope of the study has not been limited to the above. Three other factors are important to the distribution of individual species and thus to the formation of benthic animal communities. These are topography, sediments, and the biota itself. As a consequence, a major section on the physiography of the Gulf has been developed early in the report. Principal attention has been given to the region off Texas, but all northern areas are spoken of in this section. It is essential that one study parts of this chapter carefully, because here decisions are given as to where the continental slope begins (at 118 or so meters) and how the upper continental slope is defined in this report.

The discussion of sediments was not taken up in this section. Rather it was deferred until the section dealing with the benthic environment. Here new data have been integrated with those of others to provide a unique map of sediment distribution in the northern Gulf. These data particularly expand the mapping of the deeper aspects of the slope.

Finally, when coming to the faunal discussion, one can truly say that this is the first attempt to provide a conception of the nature of the communities of the continental slope of the Gulf of Mexico--at least, one based upon enough information to make the effort worthwhile. It is both fortunate and unfortunate that the decision was made to stop the analysis around 1000 meters depth. It is fortunate because it appears that there is a definitive break in faunal provinces in the range of 950 to 1000 meters. On the other hand, in order to discern this, it was necessary to study the distribution of organisms down to the abyssal plain (3850 m depth) in order to be sure that the 1000 m break represented more than a sampling artifact.

GEOGRAPHIC AND BATHYMETRIC LIMITS

Longitudinally the study has extended from the region offshore of Brownsville, Texas to the area of De Soto Canyon in the northeastern Gulf. The first boundary was established for practical reasons, being the southwestern limit of the United States on the Gulf of Mexico; the other boundary was established because the canyon establishes the boundary between clastic and carbonate sediments. A more esoteric study would have continued the western boundary down the Mexican coast to Campeche Canyon which, like De Soto Canyon, separates clastics from the great monolith of carbonates called Campeche Bank. Figure 1-1 is a map plotting the benthic stations within the study area delimited roughly between the 118 m and 1000 m depth contours, including a few deeper stations for comparative purposes. Table 1-1 lists station data for each station shown on the map.

Since the present study was motivated by practical considerations (largely to supply environmental data for future oil and gas leasing), it is appropriate that its lower bathymetric limit should have been set at no more than a depth of 1000 m, which intersects about the upper one-third of the continental slope's extension. It is the shallow bathymetric limit that is of special interest. A commonly accepted depth for the boundary between shelf and slope has been about 200 m; however, it appears that in the northern Gulf of Mexico the first shelf break occurs at about 118-120 m. This is the point where the bottom begins to dip gradually and then more precipitantly toward the Sigsbee Abyssal Plain. The abyssal plain is the flat surface of the mass of sediments that fill a great oceanic basin. Geophysicists advise that the basin of the Gulf of Mexico is among the deepest on earth; hence the sediments of the Sigsbee Abyssal Plain in the western Gulf of Mexico must be some nine or so kilometers thick. One place that a shelf-slope break of the usual type is not found is off the Mississippi River where the great Mississippi Fan begins which, of course, has been the source of some abyssal sediments, especially during Pleistocene.

BIOLOGICAL LIMITS

The present report deals almost exclusively with the macrofauna, that is, with organisms that are more than 1-2 mm in length. Recently a number of marine biologists have become interested in the smaller category of benthal

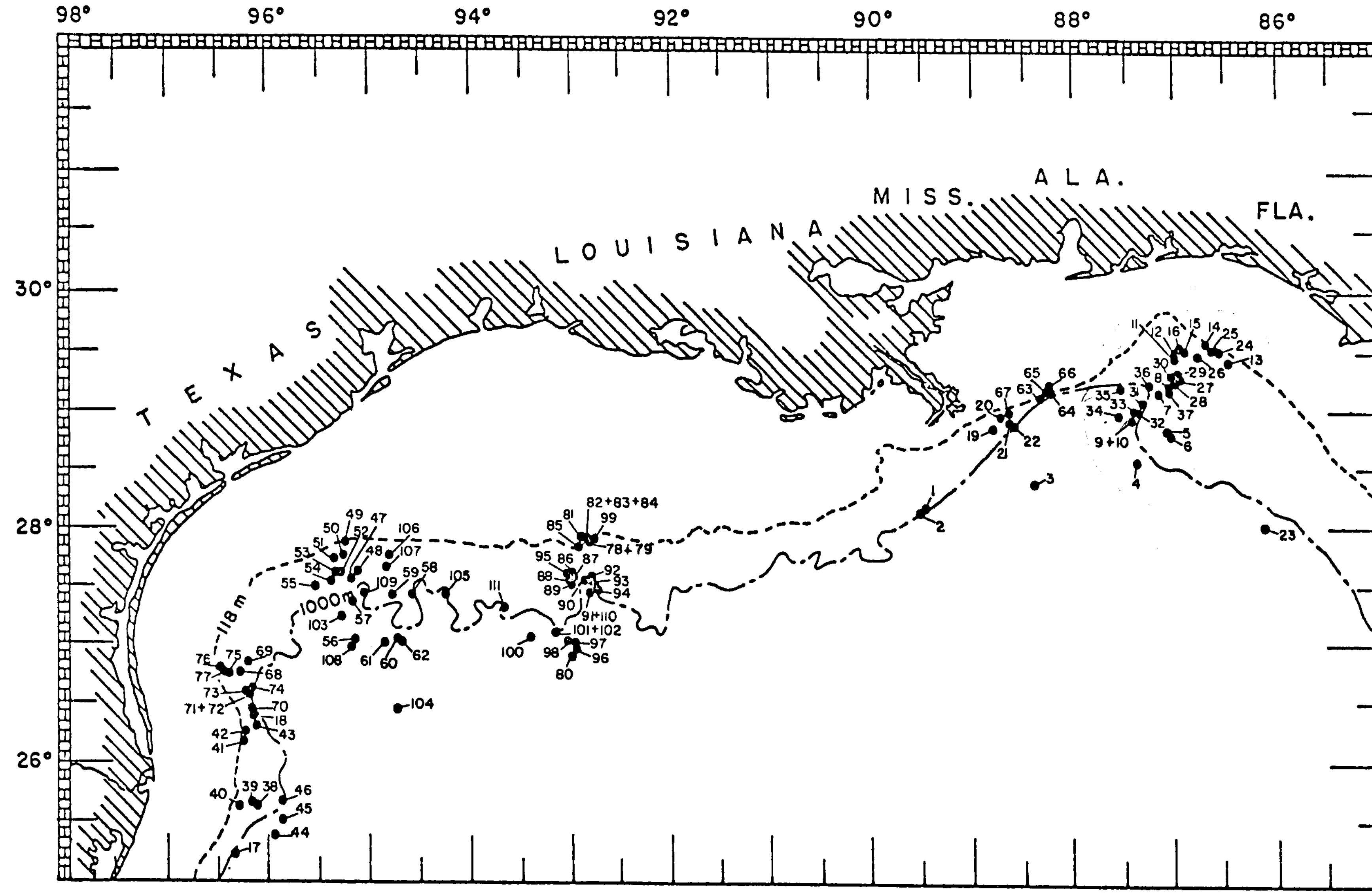

Fig. 1-1. Map of study area with benthic stations plotted between the 118 m and 1000 m contours. Station data for each station listed in Table 1-1.

Table 1-1. Station list for benthic stations analysed within the study area showing depth, position, date, and type of sampling gear.

	STATION	DEPTH (m)	POSITION N. LAT.	POSITION W. LONG.	DATE	GEAR
1.	675SK1A	1020	28°13'	89°27'	9 Jul 67	Skimmer
2.	675D1B	1020	28°12'	89°28.5'	9 Jul 67	Dredge
3.	675SK2H	1829	28°23'	88°22.5'	12 Jul 67	Skimmer
4.	675SK5D	1383-1524	28°32'	87°23'	15 Jul 67	Skimmer
5.	675SK6B	788	28°48'	87°03'	16 Jul 67	Skimmer
6.	675D6E	788	28°46.5'	87°02'	16 Jul 67	Dredge
7.	675SK7C	917- 787	29°10'	87°06'	17 Jul 67	Skimmer
8.	675D7E	752	29°13.4'	87°00'	17 Jul 67	Dredge
9.	675SK8B	1494	28°55'	87°24'	18 Jul 67	Skimmer
10.	675D8B	1494	28°55'	87°24'	23 Jul 67	Dredge
11.	675SK9A	752	29°27'	86°57'	19 Jul 67	Skimmer
12.	675D9E	640	29°29.5'	86°57'	19-20 Jul 67	Dredge
13.	675D11C	194	29°25'	86°21'	21 Jul 67	Dredge
14.	675D12A	193	29°36'	86°35.5'	21 Jul 67	Dredge
15.	675D13B	379	29°30.3'	86°52.4'	22 Jul 67	Dredge
16.	675SK13E	379	29°29.9'	86°53.7'	22 Jul 67	Skimmer
17.	683SK10B	988	25°09'	96°16'	24 Mar 68	Skimmer
18.	683D12C	732	26°22'	96°08'	24 Mar 68	Dredge
19.	687SK1A	864- 528	28°51'	88°47.5'	25 Jul 68	Skimmer
20.	687SK2A	408	28°56'	88°42'	26 Jul 68	Skimmer
21.	687SK2B	567- 622	28°53'	88°38'	26 Jul 68	Skimmer
22.	687SK2C	677- 714	28°51.5'	88°37'	26 Jul 68	Skimmer
23.	687SK7B	1097	28°00'	86°08.5'	1 Aug 68	Skimmer
24.	687D8A	194	29°31.7'	86°29.6'	3 Aug 68	Dredge
25.	687SK8C	203	29°33'	86°33.5'	3 Aug 68	Skimmer
26.	687SK9A	384	29°27.6'	86°45.5'	4 Aug 68	Skimmer
27.	687SK10A	565	29°15.5'	86°55'	4 Aug 68	Skimmer
28.	687SK11A	787	29°14'	87°00'	5 Aug 68	Skimmer
29.	687D12A	585	29°18.4'	86°56.4'	6 Aug 68	Dredge
30.	687SK12B	900	29°14'	86°59.7'	6 Aug 68	Skimmer
31.	687SK13A	1061	29°03'	87°15'	7 Aug 68	Skimmer
32.	687SK13B	1372-1426	28°59.5'	87°21.3'	7 Aug 68	Skimmer
33.	687SK13D	1463	28°59'	87°23.3'	7 Aug 68	Skimmer
34.	687SK14B	1829	28°56'	87°32.7'	8 Aug 68	Skimmer
35.	687SK15D	1097	29°10.3'	87°31.5'	9 Aug 68	Skimmer
36.	687SK15H	914	29°10.5'	87°16'	9 Aug 68	Skimmer
37.	687SK17B	900	29°09.5'	87°02'	11 Aug 68	Skimmer
38.	6813SK1	878	25°38'	96°07.3'	12 Nov 68	Skimmer
39.	6813D3	713	25°39'	96°11'	12 Nov 68	Dredge

Table 1-1 (continued)

	STATION	DEPTH (m)	POSITION N. LAT.	POSITION W. LONG.	DATE	GEAR
40.	6813SK4	512	25°38.4'	96°18.3'	12 Nov 68	Skimmer
41.	6813SK5	271	26°12.5'	96°19.8'	15 Nov 68	Skimmer
42.	6813SK7	274	26°17'	96°18'	15 Nov 68	Skimmer
43.	6813SK8	732	26°18'	96°08'	15 Nov 68	Skimmer
44.	6813SK11	1061-1372	25°23'	95°57'	17 Nov 68	Skimmer
45.	6813SK12A	1061-1317	25°31'	95°51'	17 Nov 68	Skimmer
46.	6813D14	969	25°39.5'	95°49.5'	17 Nov 68	2-M Dredge
47.	6813SK15	658- 860	27°34.5'	95°10.5'	18 Nov 68	Skimmer
48.	6813D16	713	27°37'	95°08'	19 Nov 68	2-M Dredge
49.	6813SK17	183	27°50'	95°12.5'	19 Nov 68	Skimmer
50.	6813D18	439	27°45'	95°16.2	19 Nov 68	2-M Dredge
51.	6813SK19	338- 384	27°44.9'	95°20.1'	19 Nov 68	Skimmer
52.	6813SK21	512- 640	27°38'	95°21.5'	19 Nov 68	Skimmer
53.	6813D22	476	27°38'	95°22.5'	20 Nov 68	2-M Dredge
54.	6813SK23	732	27°35'	95°23'	20 Nov 68	Skimmer
55.	6813SK24	878	27°29.5'	95°31'	20 Nov 68	Skimmer
56.	6813SK26	1372-1435	27°00.3'	95°08'	21 Nov 68	Skimmer
57.	6813SK27	1097-1170	27°17.5'	95°08.5'	21 Nov 68	Skimmer
58.	6911SK2	942	27°24.3'	94°32'	6 Aug 69	Skimmer
59.	6911SK4	1006	27°24.9'	94°44.5'	7 Aug 69	Skimmer
60.	6911SK7	1399	27°01.3'	94°43.5'	7 Aug 69	Skimmer
61.	6911D12	1463	27°00.6'	94°50.3'	10 Aug 69	2-M Dredge
62.	6911SK13	1463	27°01.6'	94°42'	10 Aug 69	Skimmer
63.	6913SK40	476	29°07'	88°18'	15 Oct 69	Skimmer
64.	6913SK41	311	29°11.5'	88°12.6'	15 Oct 69	Skimmer
65.	6913T42	183	29°14'	88°15'	15 Oct 69	20' Otter Trawl
66.	6913SK43	210	29°13.5'	88°16.5'	15 Oct 69	Skimmer
67.	6913T44	752	28°58'	88°28'	15 Oct 69	20' Otter Trawl
68.	717SK3	471	26°44.2'	96°14.8'	13 Jul 71	Skimmer
69.	717SK4	576	26°47.8'	96°12.5'	13 Jul 71	Skimmer
70.	717SK7	878- 869	26°26.7'	96°06'	14 Jul 71	Skimmer
71.	717T9	906	26°32'	96°07'	14 Jul 71	20-M Trawl
72.	717T10	937	26°32.9'	96°06.4'	14 Jul 71	20-M Trawl
73.	717T11	636	26°32.3'	96°13.3'	15 Jul 71	20-M Trawl
74.	717D16	939	26°34.7'	96°05'	15 Jul 71	Quant. Dredge
75.	717D17	204	26°43.1'	96°26.9'	15 Jul 71	Quant. Dredge
76.	717T18	229	26°46'	96°26'	16 Jul 71	20-M Trawl
77.	717SK20	229	26°42.2'	96°25.3'	16 Jul 71	Skimmer
78.	717SK23	210	27°54.7'	92°50.5'	20 Jul 71	Skimmer
79.	717D24	190	27°54.5'	92°50.7'	20 Jul 71	Quant. Dredge
80.	717T29	250	26°54.5'	92°57.2'	20 Jul 71	20-M Trawl

Table 1-1 (continued)

	STATION	DEPTH (m)	POSITION N. LAT.	W. LONG.	DATE	GEAR
81.	717T30	206	27°54.6'	92°50.5'	20 Jul 71	20-M Trawl
82.	717T31	182- 301	27°54.9'	92°49.3'	20 Jul 71	20-M Trawl
83.	717SK32	192	27°55.7'	92°48.5	20 Jul 71	Skimmer
84.	717T33	192	27°55.7'	92°48'	20 Jul 71	20-M Trawl
85.	717T34	192	27°52'	92°55'	20 Jul 71	20-M Trawl
86.	717SK35	502- 567	27°35.7'	92°59'	21 Jul 71	Skimmer
87.	717T38	511- 556	27°35.6'	92°58.6'	21 Jul 71	20-M Trawl
88.	717D40	546	27°35.2	92°58'	21 Jul 71	Quant. Dredge
89.	717SK41	732	27°34.8'	92°59.5'	21 Jul 71	Skimmer
90.	717SK42	936	27°30.4'	92°49.3'	22 Jul 71	Skimmer
91.	717T43	1006-1847	27°27.8'	92°46'	22 Jul 71	20-M Trawl
92.	717SK47	878	27°32.3'	92°47.8'	22 Jul 71	Skimmer
93.	717D48	890	27°32.6'	92°48.5'	22 Jul 71	Quant. Dredge
94.	717T49	937	27°26'	92°42'	23 Jul 71	20-M Trawl
95.	717T56	538	27°35.8'	93°01'	24 Jul 71	20-M Trawl
96.	717T57	1261-1234	26°55.8'	92°57.9'	24 Jul 71	20-M Trawl
97.	717D58	1198	26°59.1'	92°58.5'	24 Jul 71	Quant. Dredge
98.	717SK62	1198	27°00'	93°01.5'	25 Jul 71	Skimmer
99.	717SK65	237	27°57'	92°44.9'	25 Jul 71	Skimmer
100.	718SK3	1196	27°03'	93°23'	29 Jul 71	Skimmer
101.	718SK4	1364	27°08.6'	93°08.4'	29 Jul 71	Skimmer
102.	718SK5	1448	26°54'	92°54.5'	29 Jul 71	Skimmer
103.	7213T7	1207	27°13'	95°16'	8 Jul 72	20-M Trawl
104.	7213T32	1774	26°25'	94°47.5'	13 Jul 72	20-M Trawl
105.	7213T39	1061	27°26.4'	94°07.6'	14 Jul 72	20-M Trawl
106.	7213T45	412	27°46.7'	94°47.5'	16 Jul 72	20-M Trawl
107.	7213T49	640- 530	27°40'	94°49.8'	16 Jul 72	20-M Trawl
108.	7213T51	1399-1353	26°55.6'	95°10.5	17 Jul 72	20-M Trawl
109.	7213T53	1161	27°24.4'	94°56.5'	17 Jul 72	20-M Trawl
110.	7310T5	411- 462	27°29.8'	92°47.1'	20 Jun 73	20-M Otter Trawl
111.	7310T20	805-1134	27°15.3'	93°41.4'	23 Jun 73	20-M Otter Trawl

organisms, the meiofauna (62 microns up to 1-2 mm), but their inclusion would not contribute in a substantial manner to an understanding of the workings of the slope ecosystems. It is felt, however, that they may well be a significant food source for some macrofauna (see the section on key species), but a further study of the meiofauna at this time would not give more insights on this topic than is already at hand. Furthermore, sampling of the meiofauna requires employment of special techniques that have only recently been developed.

Limits have perforce been applied to the macrofauna itself, partly because of taxonomic problems involved and mostly because of the sheer numbers of species involved. Even if one excludes sponges, coelenterates, and crinoids, there are still over 500 species under consideration. This total can be reduced by dealing only with predominant species in some groups; even so the total dealt with in this study still remains above 400 species.

One might well ask how these limitations affect the achievements of the study. The immediate answer is very little, and here is why. It was and is intended to have an ecological emphasis, not a taxonomical one. Thus on the positive side it should be made clear that special attention has been paid to completeness of analysis of the demersal fishes. From an ecosystem point of view, this is particularly important, because these fishes must stand at the top of some trophic systems. This is the first study dealing with the deep sea Gulf of Mexico that has developed such a complete representation of the demersal fishes--a group totalling nearly 250 species.

Following this brief set of introductory remarks, the nature of the Gulf of Mexico will be discussed. After a glance at the results of other investigations in a general manner, the final part of the Introduction will then point out what is not known about the Gulf and what is thought should be done to rectify the situation.

2. PHYSIOGRAPHY OF THE GULF OF MEXICO

GEOLOGIC NATURE OF THE GULF

The Gulf of Mexico is a semi-enclosed sea with an approximate surface area of over 1,600,000 square kilometers and a maximum depth of about 3,840 meters (Fig. 2-1). Most of the oceanic input is from the Caribbean Sea via the Yucatan Strait (160 km wide and 1650-1900 meters deep) with outflow being primarily through the Florida Straits (less than 160 km wide and only around 800 meters deep). The facts that both of these connections with the parent Atlantic are confined to the southeastern sector and that runoff from approximately two-thirds of the United States and more than half of Mexico also empties into the basin contribute greatly to the characteristics of the Gulf in general and the western Gulf in particular. Those vastly different influences are used as a basis for dividing the Gulf into two major provinces: a carbonate province to the east and a terrigenous one to the west (Uchupi, 1967). These provinces are delineated by De Soto Canyon in the northeast quadrant and by Campeche Canyon off the Yucatan Peninsula in the southwestern region (Antoine and Bryant, 1968). Significant characteristics of this basin are the great width of the shelves, the steepness of the lower part of the continental slope (the scarps) and the flatness of the floor of the main basin with its exceptionally thick sequence of sediments. Hardin (1962) suggests that the influence of the river systems that delivered these sediments shifted to the east during the Tertiary so that the large sedimentation of Eocene came mainly from the Rio Grande, whereas the rivers of Texas delivered much of the mid-Tertiary load, and the Recent sediments were more clearly related to the Mississippi River drainage system.

STRUCTURAL SUBDIVISIONS

Further topographic division of the Gulf of Mexico follows Ewing et al. (1958) and Uchupi (1967), including the following physiographic provinces: the continental shelf (sub-divided into West Florida Shelf, Texas-Louisiana Shelf, East Mexico Shelf and Campeche Shelf), the continental slope

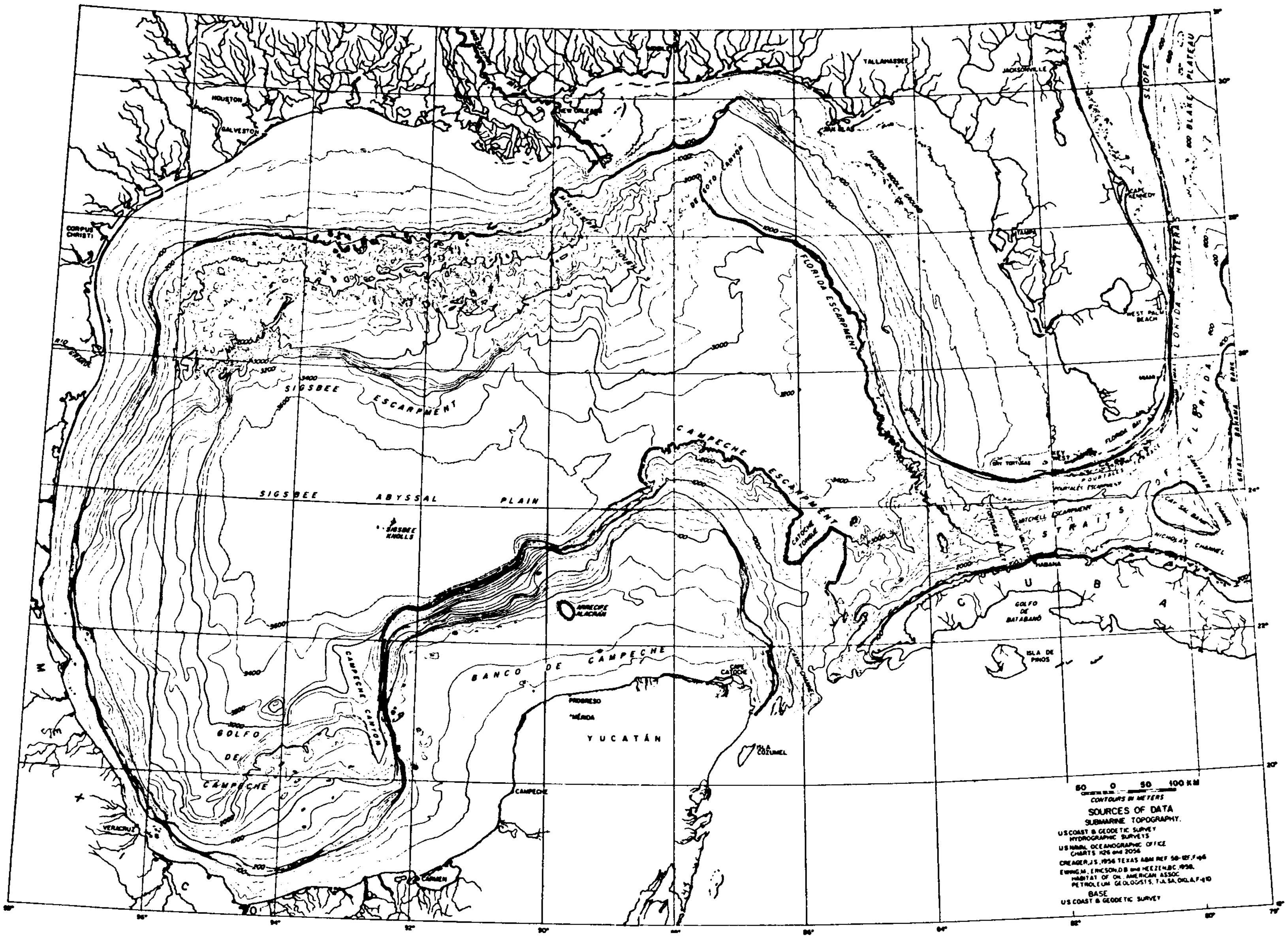

Fig. 2-1. General bathymetric chart of Gulf of Mexico (from Uchupi, 1967).

(including the Sigsbee, Florida and Campeche escarpments), the Mississippi Fan (Cone), the continental rise and the Sigsbee Abyssal Plain (floor of the main basin) (see Fig. 2-2).

Antoine (1972) divides the Gulf of Mexico into seven geologic provinces (Fig. 2-3) that he considers to be geologically distinct. Shallow seismic reflection methods were utilized to demonstrate unique characteristics of each province, then viewed from a background of other studies to outline the specific geologic areas - 1) Gulf of Mexico Basin, 2) Northeast Gulf of Mexico, 3) South Florida Continental Shelf and Slope, 4) Campeche Bank 5) Bay of Campeche, 6) Eastern Mexico Continental Shelf and Slope, and 7) Northern Gulf of Mexico. Insight into the origin and evolution of the Gulf led Antoine to describe the basin as geologically old and representing a subsided oceanic area that has been partially filled with sediments.

PROVINCES ENCOMPASSED BY PRESENT STUDY

NORTHEAST GULF OF MEXICO (PROVINCE 2)

This province is a transitional area between the clastic sedimentation of the continental shelf and slope of the northern Gulf of Mexico and the carbonaceous South Florida Platform. Its zonation extends from the broad northward indentation of the topographic contours east of the Mississippi Delta (De Soto Canyon) to the eastern side of Apalachee Bay.

Of the several structural features (e.g. Florida Escarpment and Ocala Uplift) only De Soto Canyon is of immediate importance to the present study. It is true, however, that the northern extension of the Florida Escarpment forms the canyon's eastern boundary. As Antoine et al. (1967) and Uchupi and Emery (1968) have suggested, a Lower Cretaceous reef trends from northern Mexico, across Texas, Louisiana and Mississippi and continues southeastward as a part of the west Florida Escarpment (see Fig. 2-4). It is distinctly possible that the break in this reef between Veracruz and Campeche may represent a connection with what is now the Pacific Ocean.

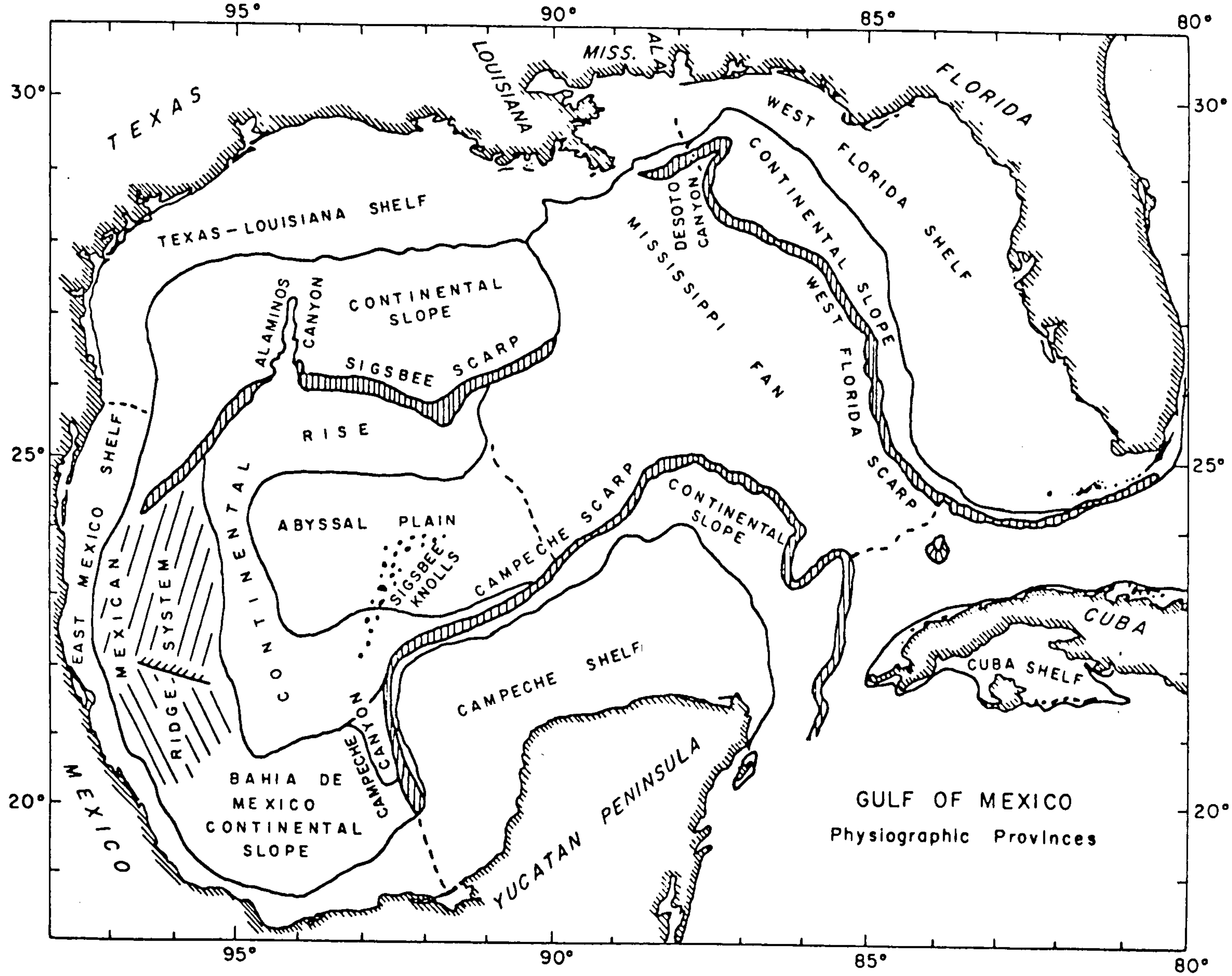

Fig. 2-2. Physiographic provinces in the Gulf of Mexico.

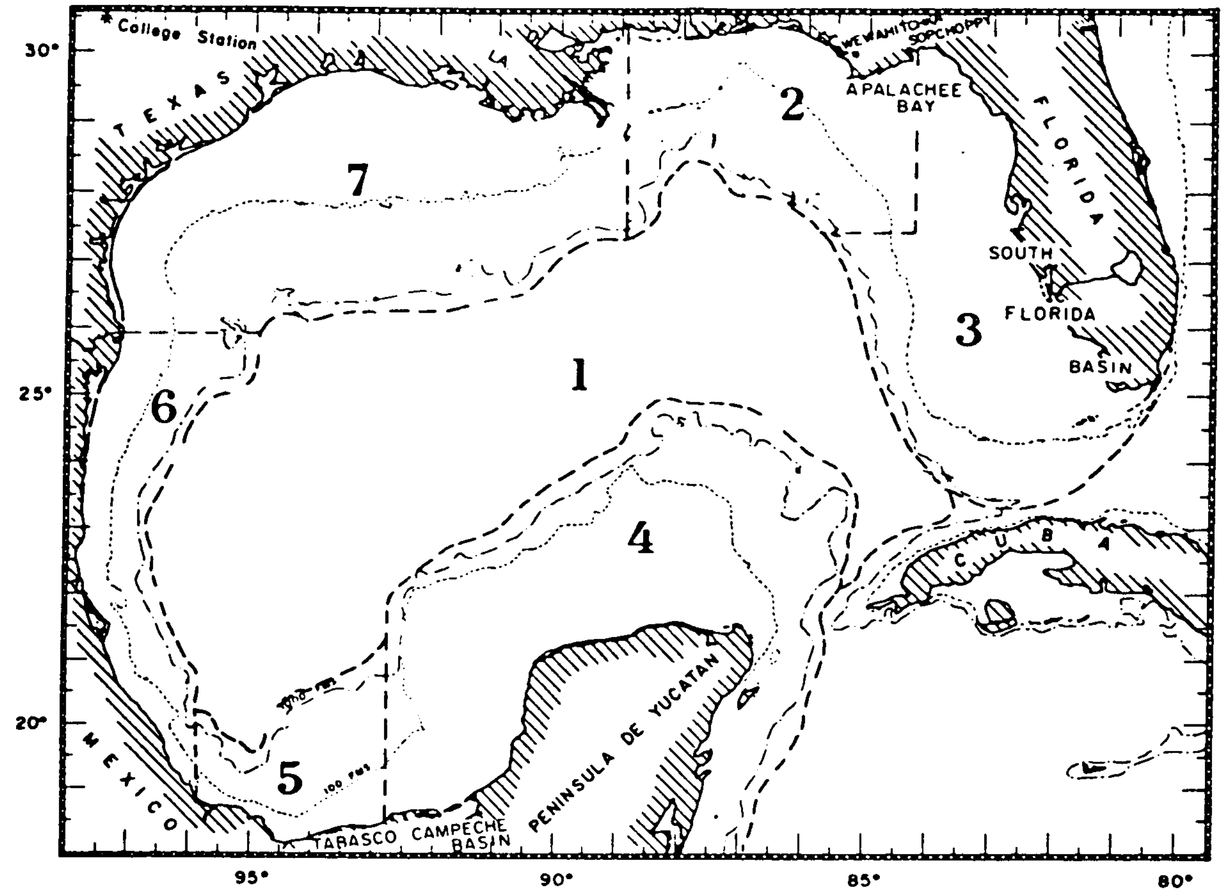

Fig. 2-3. Geologic provinces in the Gulf of Mexico (from Antoine, 1972).

1. Gulf of Mexico Basin
2. Northeastern Gulf of Mexico
3. South Florida Continental Shelf and Slope
4. Campeche Bank
5. Bay of Campeche
6. East Mexico Continental Shelf and Slope
7. Northern Gulf of Mexico

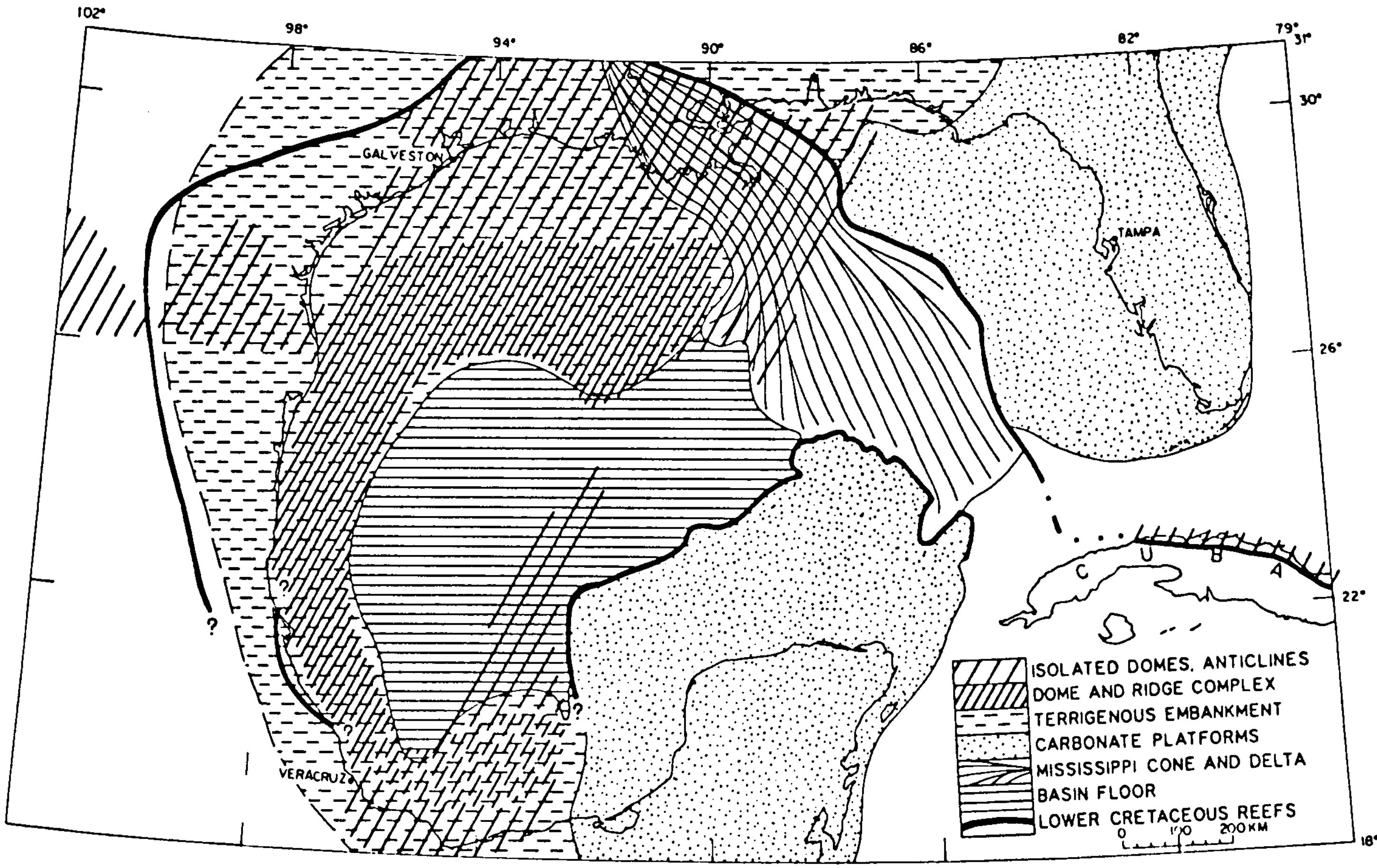

Fig. 2-4. Structural units of the Gulf of Mexico (from Uchupi and Emery, 1968).

Important evidence in support of the belief that a significant sedimentary boundary occurs near or at De Soto Canyon is provided by the fact that the salt dome provinces of the Gulf's northern rim, which extend from offshore Texas toward the east, end near the eastern side of the canyon. The absence of diapiric structures to the east is, in view of Ewing et al. (1968) and Antoine and Bryant (1969), accounted for either because the canyon marks a thinning and/or terminus of the salt deposits or because the more competent carbonate beds above the salt have not allowed the intrusion of salt stocks.

NORTHERN GULF OF MEXICO (PROVINCE 7)

The northwestern Gulf, at least from a structural point of view, is constituted of the continental shelf and slope of Texas, Louisiana, Mississippi, and Alabama. According to Ewing et al. (1968), it is bordered on the east by De Soto Canyon, on the south and southwest by the bottom of Sigsbee Scarp, and at the United States-Mexico border by the beginnings of the anticlinal folds that more or less parallel the shoreline. (These folds mark the northern extension of the Eastern Mexico Province, #6.)

The major structural element of the continental margin of the northwest Gulf of Mexico is the Gulf Coast Geosyncline. This extends southwestward from Alabama toward northeastern Mexico and contains upward of 20,000 m of sediment. The geosyncline is underlain by varying thicknesses of salt, probably of latest Triassic-Jurassic age (Jux, 1961). The offshore area of the northwest Gulf, which includes the major portion of the geosyncline, is characterized by diapiric structures from the coastline to the Sigsbee Scarp. On the continental shelf most of these features are covered by sediments, whereas on the slope they are evident in the topography and form Gealy's "hummocky" zone (Gealy, 1955). It is emphasized by Antoine (1972) that the widespread salt deposit provides a dynamic structural agent acting throughout the entire northern Gulf region.

TERRACE MORPHOLOGY

The origin of the continental terrace (shelf and slope) of the northwest Gulf of Mexico has been a topic for speculation since study of this basin began. Early investigators suggested that the Gulf basin resulted from massive Cretaceous or Pleistocene subsidence and faulting of continental type crust, resulting in the steep Florida, Campeche, and Sigsbee Escarpments (Suess, 1904; Schuchert, 1935; Dietz, 1952; Gealy, 1955; Greenman and LeBlanc, 1956). This line of thought led to the belief that the irregular nature of the bathymetry of the upper continental slope off Texas and Louisiana was caused by subaqueous erosion following subsidence (Dietz, 1952; Gealy, 1955). Pursuing another line of evidence, Shepard (1937) pointed out the existence of salt diapirs in the Mississippi Trough and Carsey (1950) speculated that the upper slope topography was a direct result of diapiric intrusion.

Ewing et al. (1960) and Antoine (1972) through geophysical studies of the Gulf Basin, have revealed the true oceanic nature of the crust under the deep Gulf, negating the fault postulate of Gulf origin. Continuous seismic profiling has also corroborated the existence and importance of salt diapirs in the formation of slope topography (Moore & Curray, 1963; Ewing & Antoine, 1966; Lehner, 1969). Ballard and Uchupi (1970), while acknowledging the importance of diapirs in producing the hummocky zone of the upper continental slope, point out that events related to Quaternary sea level fluctuations have left relict features, which also add to shelf and slope topography (see Fig. 2-5).

SLOPE MORPHOLOGY

The continental slope of the northern Gulf of Mexico represents the seaward part, or the growing margin, of the Gulf Coast geosyncline, where geologic processes that helped to shape the basin are active today (Lehner, 1969). Beds that are buried deeply in the Gulf basin are at shallow depths on broad salt swells and uplifts of the continental slope. Sparker records (Moore &

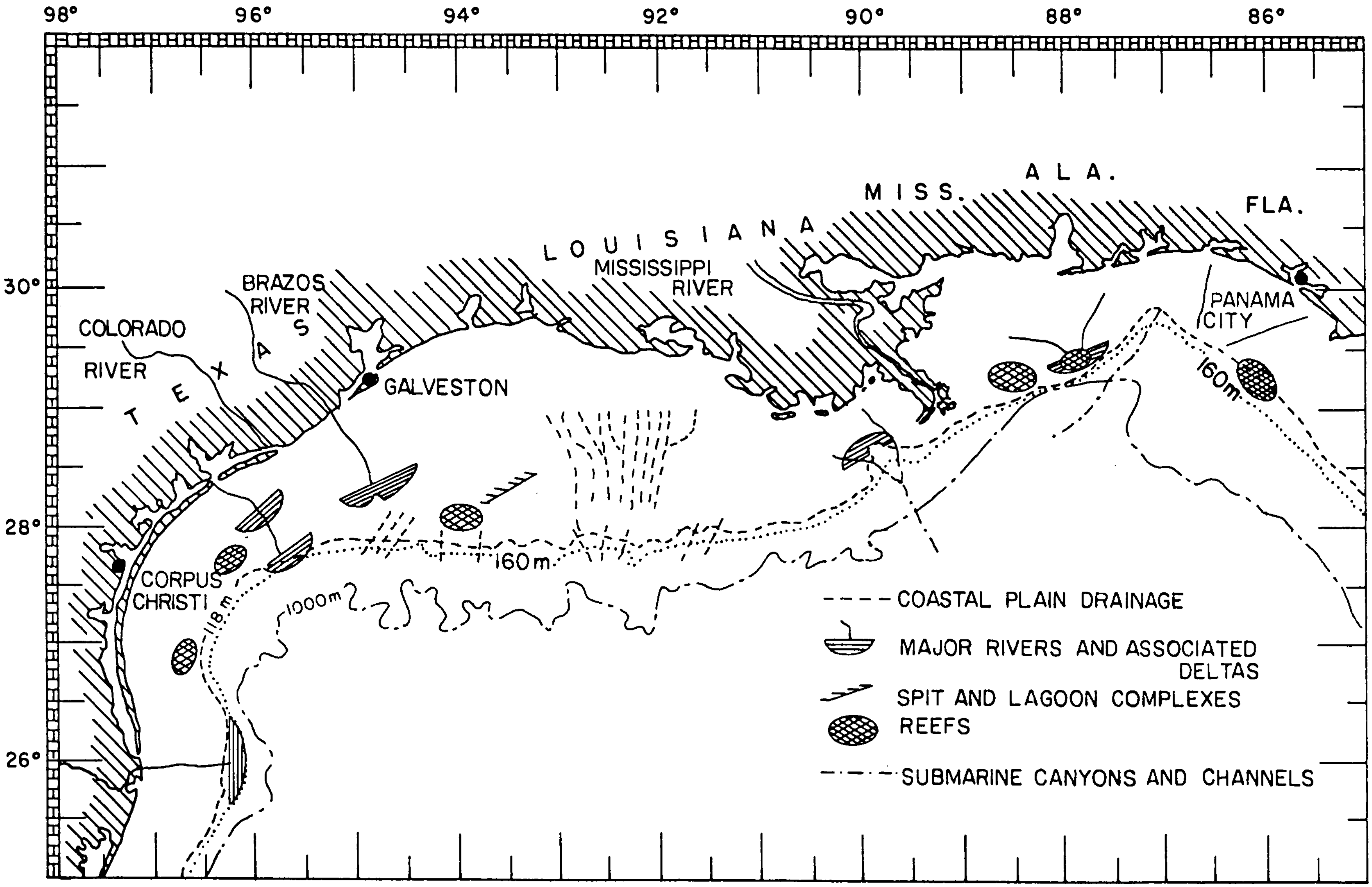

Fig. 2-5. Relict features related to Quaternary sea level fluctuation (after Ballard and Uchupi, 1970).

Curray, 1963; Ewing & Antoine, 1966; Lehner, 1969) show that salt pillows and swells with diameters of 28-37 km are typical structures on the upper slope forming seaknolls or seamounts with elevations of as much as 1524 m. The flat tops of the salt pillows on the lower slope reach a common elevation and tend to create a terracelike topography of broad sedimentary troughs. These synclinal basins are filled with slump deposits and turbidites, most of which are mud and clay, whose origin was related to the overloading of the shelf edge by prograding foreset beds (Fig. 2-6), giving rise to extensive submarine slides on the upper slope. The lower slope terrace breaks off abruptly along the Sigsbee Scarp, which has the appearance of being the south edge of a large salt mass. Toward the Mississippi Delta, the upper slope, lower slope, and Sigsbee Scarp merge into a relatively smooth incline known as the Mississippi Cone.

SLOPE TYPES AND CHARACTERISTICS

Continental slopes in the Gulf of Mexico are of three or possibly four distinct types which differ from the typical slopes of the Atlantic Ocean (Ewing et al., 1958). Their varied topography of high relief does not resemble the topography of the slopes of either the Atlantic or Pacific coasts of North America (Gealy, 1955). Off the wide limestone platforms of West Florida and Campeche, the slope is made of two segments - a gently sloping portion from the 128 m isobath to approximately 1829 m, and a precipitous lower scarp which drops to the abyssal plain. Off both these platforms the continental rise is lacking. A second type of continental slope is found off the Texas and Louisiana shelf. Here the slope is also made up of two segments - a wide upper hummocky zone with a gentle average seaward slope, and the steep lower scarp which abuts a well-developed continental rise (see Fig. 2-7). Steep-sided troughs, e.g. De Soto Canyon, cut the lower portion of this slope, tending to denote relative stability of the underlying sediments. Ewing et al. (1958) refer to the upper Mississippi Cone as representing a third type of continental slope. From the De Soto Canyon area to a point west of the Mississippi Delta, the continental slope is relatively smooth, fairly continuous, and lacks the twofold division of

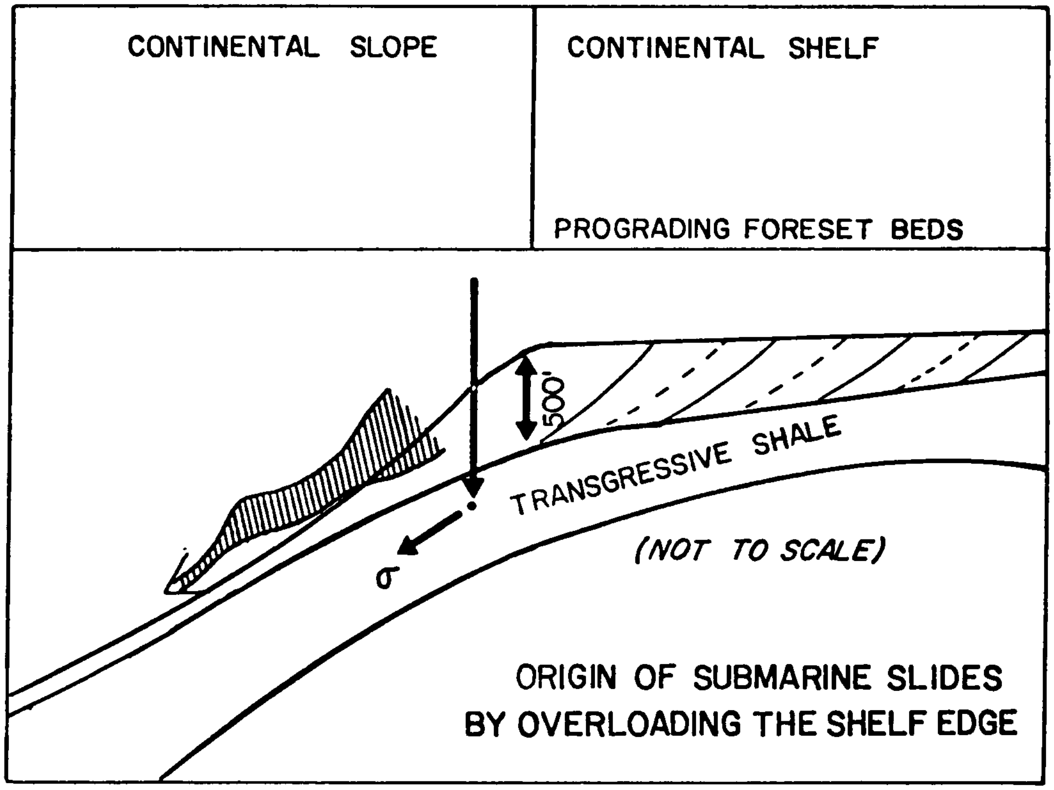

Fig. 2-6. Diagram showing simple model to explain origin of submarine slides. Foreset beds overload edge of continental shelf and begin to glide downhill, triggering mudflows and turbidites (after Lehner, 1969).

those just described. The Mississippi Cone laps across continental slope, continental rise, and joins with the abyssal plain, thereby masking all abrupt topographic discontinuities. Continental slopes of the latter two types are included in this study of the northern Gulf of Mexico. If the break in slope is assumed to be a line along which the gradient increases to at least 18 m per mile, the line is variable in depth according to Gealy (1955). Off the mouth of the Rio Grande south of 26°40'N and in the vicinity of the Mississippi Trough, it is at a depth of about 90 meters. Throughout most of the rest of the area, the line is near the 137 m contour although locally it can be deeper than 183 m. Ewing et al. (1958) consider the slope to begin at 128 m and terminate with the base of the Sigsbee Scarp (2925 m) while other investigators (Parker, 1960; Shepard, 1963) record the break in slope as being at a depth of 118 m (we accept this depth in our work). Between the 137 and 3100 m isobaths the slope is about 70 miles wide off the mouth of the Rio Grande, 135 miles wide at 92° W. Longitude, and 70 miles west of the Mississippi Trough. (These dimensions are reduced through restriction of this report to the upper continental slope, that region extending from the edge of the continental shelf (118 m) to near the 1000 m isobath). The average gradient of the slope ranges between 22 and 45 meters per mile with local steepenings exceeding 900 meters per mile in those areas of high relief.

TOPOGRAPHY OF NORTHERN GULF SLOPE

The slope is broken in many places by ridges, knobs, canyons, troughs, and basins. In the northeastern section of the Gulf of Mexico it is interrupted by De Soto Canyon, a trough which heads near the 440-m contour and terminates near the 950-m isobath, with a maximum relief ranging from 185 meters (Jordon, 1951) to 250 m (Harbison, 1968). Unlike most submarine canyons (see Shepard, 1963), De Soto Canyon has a comparatively gentle gradient, is S-shaped, and has a closed bathymetric low in its southern extremity. Harbison (1968) describes this topographic feature as being shaped by erosion, deposition, and structural highs associated with at least five domes. His seismic reflection data indicate that the canyon has not been formed as the direct result of major faulting but also from erosional and depositional processes.

Erosion of the east bank coupled with transgression of the west bank has shifted the canyon bottom to the east while a sediment dam across the southern end has created a small basin (43 m deep) north of the dam. Geophysical data of Antoine and Bryant (1968) from the De Soto Canyon also indicate that erosion has played an important part in its development. These authors suggest two mechanisms for formation of the canyon: 1) the loop current of the eastern Gulf of Mexico and associated circulation in the northeastern Gulf have sufficient velocity along the bottom during specific periods of time to effect a scouring action and/or keep sediments in suspension, and 2) erosion by turbidity flows during periods of low sea level stands associated with glacial stages. Their suggestion of circulation erosion is enhanced by Pequegnat's (1972) discovery of a swift bottom current (speed range from 6-19 cm/sec) in the eastern Gulf of Mexico at depths in excess of 3200 meters. Then too, the fact that De Soto Canyon extends over parts of two distinct geologic provinces (Antoine, 1972) adds credence to an hypothesis involving erosional rather than tectonic processes.

South of the Mississippi Delta, the continental slope lacks the two-fold division of the slope off Florida and Texas-Louisiana (Fig. 2-2). This continuous slope, the Mississippi Cone (Ewing et al. 1958) is believed to have been deposited by the Mississippi River during glacial times. To the west the cone grades into the continental rise, to the southwest into the Sigsbee Abyssal Plain, and to the southeast it fills the narrow trough between the Florida and Campeche Escarpments (Uchupi, 1967). Gradients of the cone range from 2° at its apex to less than 1° at its outer margin on the submarine Mississippi Fan with the greatest change in declivity at roughly 2745 m depth. The upper cone is described by Huang and Goodell (1970) as being indented by digitate leveed valleys and canyons cut by transverse ridges, whereas the lower section is characteristically smooth - a reflection of the underlying structure. The lower cone is composed of relatively flat-lying beds while, in contrast, the upper cone has many internal irregularities, probably caused by gravity sliding, folding, slumping and by diapirac salt intrusion. The cone's depocenter has continuously shifted basinward as the Mississippi Delta has prograded gulfward (Huang and Goodell, 1970). Distribution of Mississippi fluvial sediments in the Gulf occurs by both longshore and basinward processes. Near the apex of the cone are two canyons, De Soto (previously described) to the east and the Mississippi Trough to the west of the delta proper. The Mississippi Trough connects with a filled channel on the shelf that Carsey (1950) traced on the subaerial delta to Houma, Louisiana. On the seaward side the trough can be traced to a depth of 2200 m, where it terminates on a submarine fan. It is about 20 miles wide and 600 m deep where it cuts across the break in slope at the edge of the continental shelf (Gealy, 1955).

The continental slope off Texas and Louisiana consists of at least two segments, a relatively steep lower slope known as the Sigsbee Escarpment and an irregular upper segment identified by its hummocky topography (Uchupi, 1967) (see Fig. 2-7). Situated between these zones, Gealy (1955) had previously proposed a trough zone consisting of a relatively low relief surface cut by many steep-sided troughs that extend down slope, across the Sigsbee Escarpment and into the Sigsbee Deep. Alaminos Canyon (Bouma et al., 1972) and Ida Green Canyon (Watkins et al., 1975) would probably be considered as extreme components of the trough zone. Gealy (1955) concluded that some of the deep depressions shown on her profiles were definitely canyons which run down the slope whereas others were closed basins. Study of her profiles reveals a shift from the hummocky zone to a zone of troughs at a depth ranging from 475-550 meters.

The hummocky zone constitutes a major portion of the slope off the Texas-Louisiana shelf. Antoine (1972) associates the roughness and irregularity of the upper slope to underlying diapiric structures of Triassic-Jurassic salt and suggests that the Sigsbee Escarpment represents the present frontal edge of the salt migration. Other investigators, notably Shepard (1937), Carsey (1950), Moore and Curray (1963), Ewing & Antoine (1966), Wilhelm &

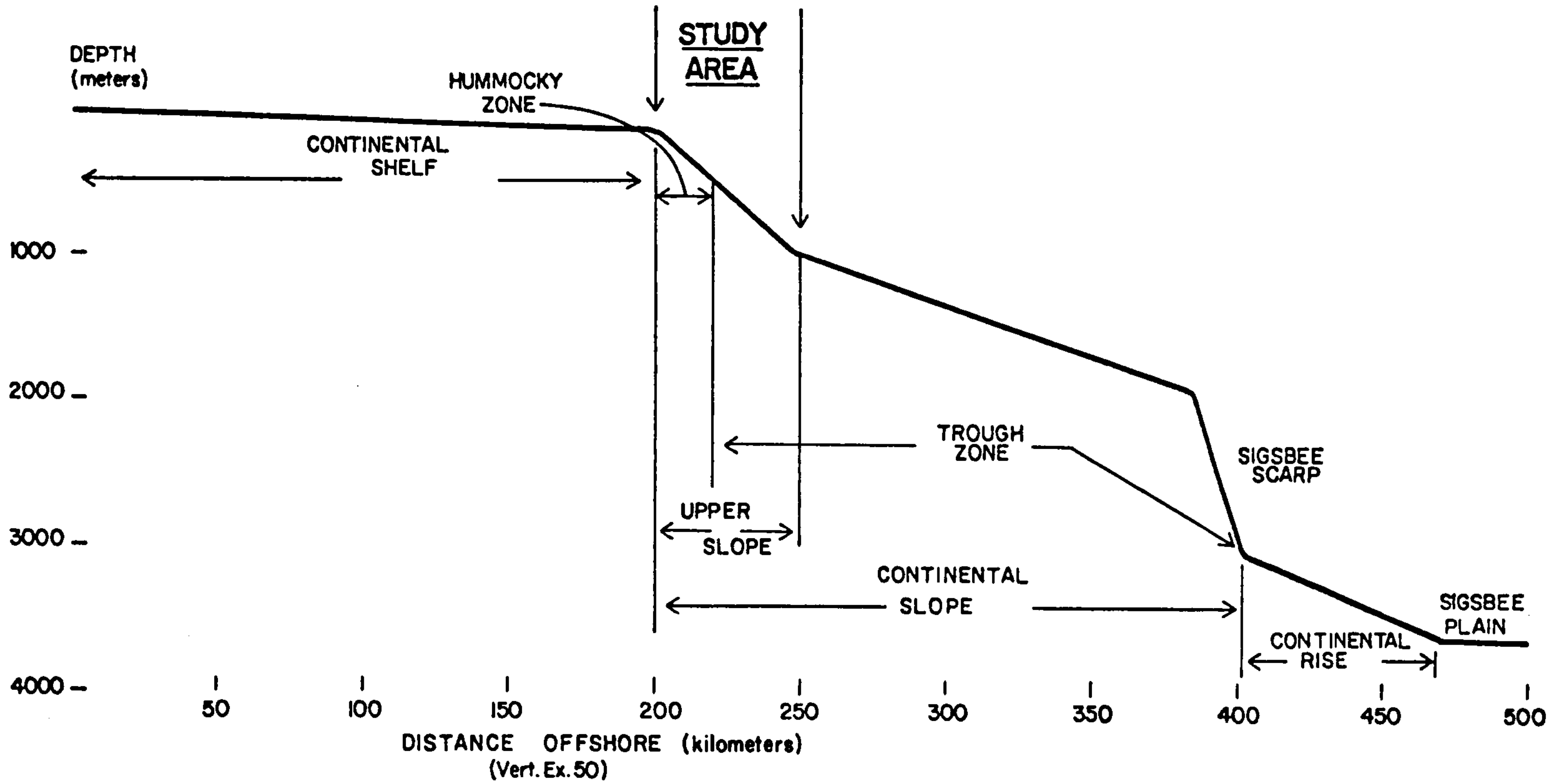

Fig. 2-7. Cross-section of the northern Gulf of Mexico, especially applicable to the Texas-Lousisana area (exclusive of the Mississippi Fan). Bottom profile along the 94° meridian; extracted from map by Uchupi (1967).

Ewing (1972), have also interpreted the hilly topography of seaknolls and seamounts as developing from growth of salt domes. Others (Gealy, 1955 and Ewing et al., 1958) considered submarine slides, turbidity currents, and submarine creep to be very important in shaping the slope topography. To be sure, gulf-floor relief was probably altered by erosion and deposition associated with lower stands of Pleistocene sea level (Watkins et al., 1975) and by the continuing process of submarine slumping but, as Ewing et al. (1958) suggest, the dominant source of sediments filling depressions on the upper slope enter the Gulf with Mississippi River flow.

Bryant et al. (1968) suggest that the folds of the western Gulf (Mexican ridge system) are a continuation of the east-west trending ridges and more complex structures on the Texas-Louisiana slope. Such a connection would imply a systematic development of salt structures in the northern and western Gulf of Mexico (Antoine, 1972). Antoine and Bryant (1969) note all stages of salt ridge development as being seen in the Gulf coastal province. An initial stage, characterized by simple folds (with only a few near shore being buried) and few diapiric structures, is located within the central portion of the eastern Mexican continental shelf and slope. These ridges trend toward the northeast where the sediment load generally increases along with an increase in number of diapirs, secondary growth features developing from mother ridges as successive troughs are buried. This transition zone continues to the area of the Texas-Louisiana continental slope where diapiric salt bodies dominate the topography, i.e. the hummocky zone, and the outline of the initial ridge system has been obliterated or greatly altered. This hypothesis follows that outlined by Jones et al. (1967) which associates deposition of clastic sediments with pre-existing salt deposits.

A feature peculiar to the shelf break in the northwest Gulf is a series of prominent banks or topographic highs rising abruptly from the generally smooth, sediment-covered bottom (Parker & Curray, 1956). Several investigators have offered explanations for their origin, dating from Shepard (1937) who suggested that these banks may be related to salt-dome structures.

Others have explained them on the basis of biohermal structures which have kept pace with changing sea-levels (Stetson, 1953; Mathews, 1963). One of the more interesting and intensively studied of the banks is the West Flower Garden, a possible element of a discontinuous arc of reefal structures occupying the Gulf's southern and western continental shelves (Bright & Pequegnat, 1974 and Edwards, 1971). It and the similar East Flower Garden Bank are capped by what are considered to be the northernmost thriving tropical shallow water coral reefs on the eastern coast of North America. In the near vicinity of these prominences there are many submerged topographic highs that extend 3.5 or more meters above the surrounding bottom and crest at depths less than 180 m (Fig. 2-8). The majority of these banks occur seaward of the 55-m isobath in two linear groupings. The first group forms a broad arc starting southeast of Brownsville and terminating near the Mississippi Delta. Its banks are widely spaced and occur within the 45-and 85-meter contours. The banks of the second group are closely packed and extend from 95° W Longitude to the Mississippi Delta between 90 and 365 meters. The latter group is only the northern half of a series of banks that continue out to the 1100 m line (see Carsey, 1950). Parker and Curray (1956) correlated the tops of deeper banks with terraces on those banks with shoaler tops and related them to erosion at various stands of sea-level.

3. PREVIOUS INVESTIGATIONS

GENERAL RESULTS OF EARLY CRUISES

The 16th, 17th, and 18th Century explorations in the Gulf of Mexico were confined primarily to geographical studies for purposes of charting and mapping and are summarized in detail by Galtsoff (1954). Some plotting of currents also occurred, especially during the 18th century, but only incidental biological observations were occasionally reported during that time by seafaring captains.

The first significant biological sampling of the benthic areas of the

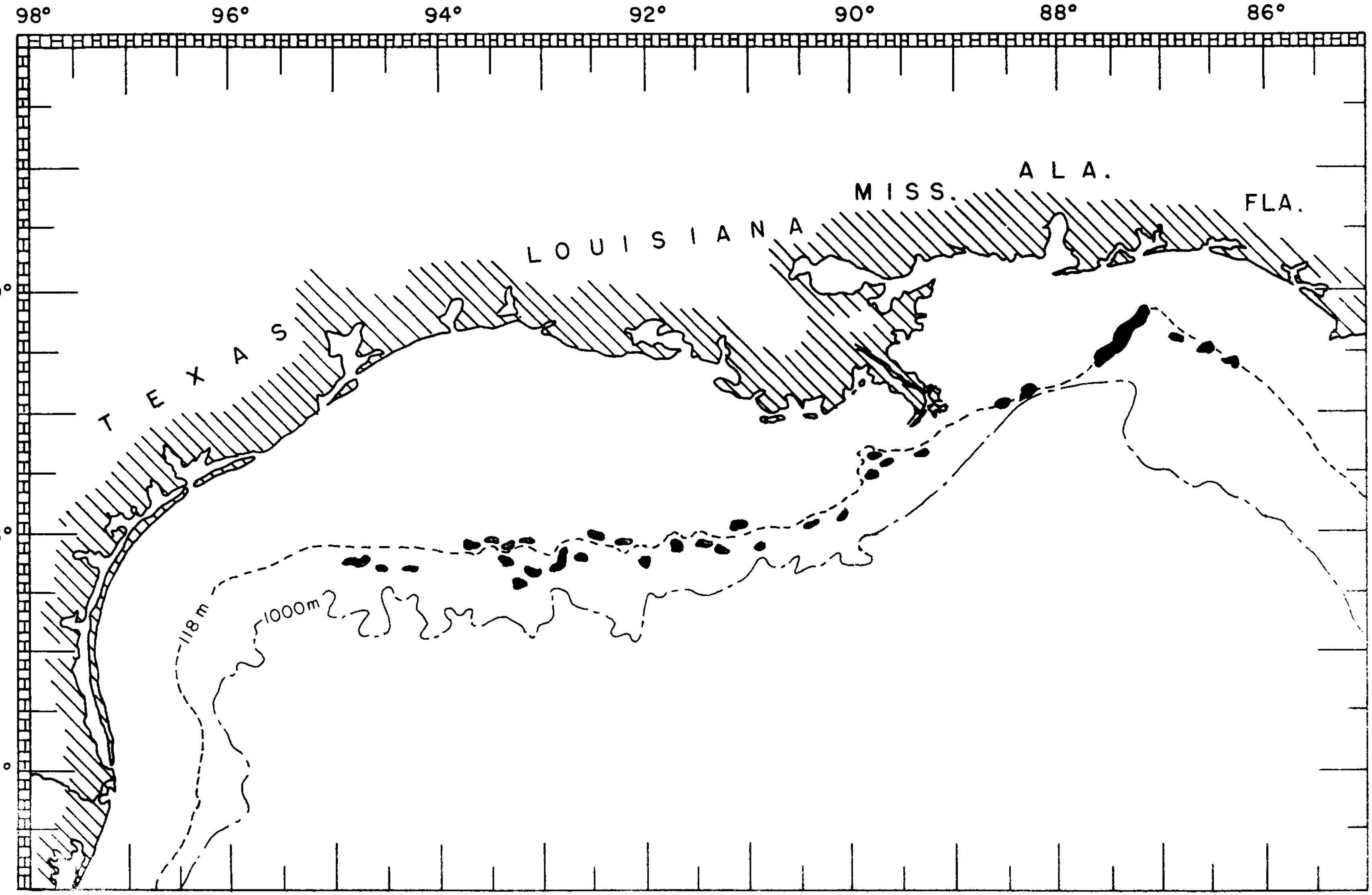

Fig. 2-8. Distribution of submarine banks in the northern Gulf of Mexico.

Gulf began with the three cruises of the U. S. Coast and Geodetic Steamer BLAKE from 1877 to 1880 (Agassiz, 1888). These expeditions resulted in the first extensive sampling of the bottom fauna extending to over 2000 fathoms (3658 meters). The biological collections of the BLAKE were studied and reported upon by Pourtales, 1870, 1880 (corals, crinoids, and Crustacea); A. Agassiz, 1863, 1869, 1878, and 1883 (echinoderms); Théel, 1886 (holothurians); Clarke, 1879 (hydroids); Ehlers, 1879 (annelids); Dall, 1880, 1886, 1889 (mollusks); A. Milne-Edwards, 1880 (brachyuran and anomuran Crustacea), 1881 (caridean shrimps), and 1883 (illustrations of decapod Crustacea); Smith, 1882 (decapod Crustacea); A. Milne-Edwards and Bouvier, 1894, 1897 (galatheid crabs) and 1909 (penaeid and stenopodian shrimps); and Bouvier, 1925 (macruran decapods).

Most of the publications dealing with the benthic organisms collected by the BLAKE are systematic in nature and can be found in the first 19 volumes of the Bulletin of the Harvard Museum of Comparative Zoology. In spite of the wealth of information and specimens gathered by the BLAKE, only three of the BLAKE stations were located in the western portion of the Gulf, i.e., west of 90° W. Longitude and very few successful stations at continental slope depths (Fig. 3-1).

The U. S. Fish Commission vessel, ALBATROSS, occupied dredging stations in a small area of the eastern Gulf and in the Yucatan Strait area in 1884 and 1885 during efforts to explore the fishery resources of the Gulf and Caribbean (Fig. 3-1).

Between 1898 and 1913 the U. S. Fish Commission vessel, FISH HAWK engaged in inshore, shallow-water fisheries investigations off the west coast of Florida, Alabama, Mississippi, Louisiana, and Texas (Matagorda and Lavaca Bays), but never extended as far as the outer shelf or slope areas. Likewise the U. S. Bureau of Fisheries vessel, GRAMPUS, studied shrimp and fishery grounds over the continental shelf from Key West to Aransas Pass in 1917 (U. S. Bureau of Fisheries, 1919).

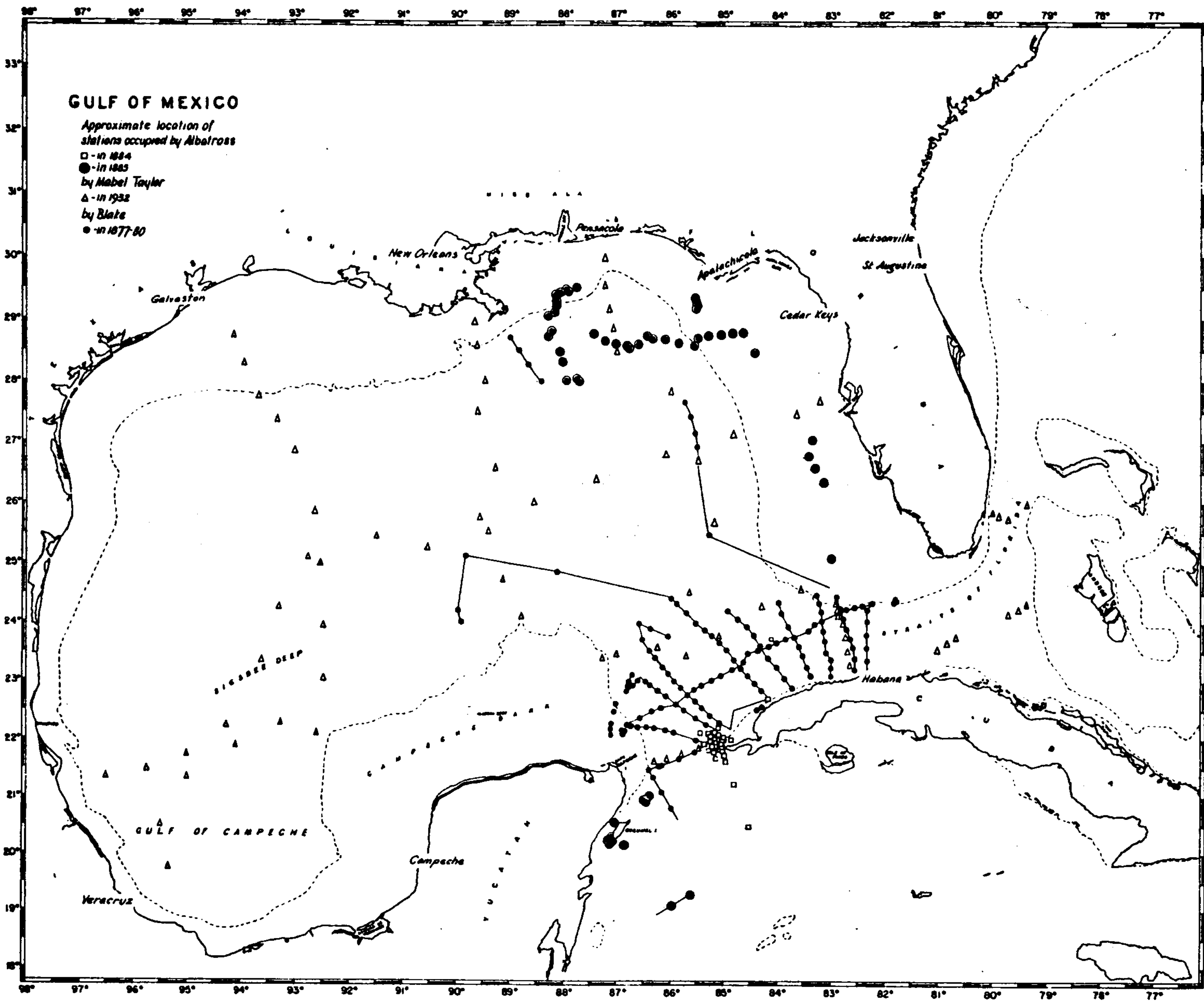

Fig. 3-1. Approximate location of stations occupied by early cruises in the Gulf of Mexico: the BLAKE, 1877-80, (black circles); the ALBATROSS, 1884, (open squares), 1885, (black double circles); and the MABEL TAYLOR (non-biological), 1932, (triangles) (after Galtsoff, 1954).

The 1932 Yale Oceanographic Expedition of the MABEL TAYLOR, sponsored by the Bingham Oceanographic Foundation, covered a relatively widespread area of the Gulf, especially the western Gulf for the first time, occupying a total of 87 stations, but was limited to hydrographic and chemical measurements such as temperature, salinity, and oxygen.

The ATLANTIS of the Woods Hole Oceanographic Institution undertook a series of hydrographic, geological, and paleontological studies in the Gulf in 1934, 1937, 1947, and 1951, part of which were in cooperation with the Bingham Oceanographic Foundation and the Geological Society of America. Biological samplings were made during the ATLANTIS' "Harvard-Havana Expedition" of 1938-39 in the vicinity of Cuba. Reports of decapod Crustacea from this expedition were reported on by Chace, 1939 (descriptions of new species of Decapoda and Stomatopoda), 1940 (brachyuran crabs) and 1942 (anomuran crabs).

RECENT CRUISES AND FINDINGS

The Bureau of Commercial Fisheries, Fish and Wildlife Service, Exploratory Fishing and Gear Research Base at Pascagoula, Mississippi (now the National Marine Fisheries Service, Southeast Fisheries Center) began dredging and trawling work in the Gulf of Mexico with the OREGON, SILVER BAY, COMBAT and PELICAN in the 1950's. Their operations included numerous continental shelf and shallow slope stations in the Northeast Gulf, but only a few stations in the western Gulf, and very little from the deep areas of any part of the Gulf. Some of these collections of fishes and invertebrates were presented, primarily as lists, by Springer & Bullis (1956) and Bullis and Thompson (1965). The investigations of potential fish and invertebrate fishery resources by the OREGON are discussed in detail in Section 8 of this report on Fishery Potential.

Hedgpeth's (1953) review of the zoogeography of the northwestern Gulf of Mexico with reference to the invertebrate fauna and Hildebrand's (1954) study of the fauna of the brown shrimp grounds in the western Gulf of Mexico were limited to shallow water over the continental shelf, and do not cover the outer shelf or continental slope areas relevant to the present study.

In a study of fauna and bathymetry of banks on the continental shelf in the northwest Gulf of Mexico, Parker and Curray (1956) report on the fauna on banks between depths of 44 and 57 meters including the Flower Garden Banks (arising from bottom depths of up to 130 meters). They point out the similarity of this fauna to intertidal fauna of the West Indies and Caribbean.

In the early 1960s comprehensive studies and collections of benthic, midwater, and planktonic specimens were begun by Texas A&M University on the R/V ALAMINOS under the direction of W. E. Pequegnat. These collections were made from the outer shelf, continental slope, and abyss in all areas of the Gulf of Mexico. This marked the first such extensive collecting in these areas of the Gulf for the purpose of ecological studies of the entire water column. Theses, dissertations, and publications emanating from these collections include reassessments of populations of benthic and pelagic organisms, systematic and taxonomic studies of specific groups, new distribution records, and descriptions of new species (Pequegnat and Chace, 1970; Pequegnat & Pequegnat, 1971; Pequegnat et al., 1971; and Downey, 1973, Asteroidea primarily taken from the OREGON and the ALAMINOS).

The University of Miami deep-sea biological investigations, which were directed by G.L. Voss after the mid-1960s, dealt with the development, behavior, ecology, geographical distribution, and systematics of numerous invertebrates and many fishes. Most of these collections, however, were made in the Straits of Florida and especially in the Caribbean Sea; hence they do not cover the northern Gulf of Mexico's outer shelf or continental slope areas. Nevertheless, their studies on systematics and geographical distribution, published primarily in numerous papers in the Bulletin of Marine Science over the past ten years, have added greatly to knowledge of the entire western Atlantic deep-sea fauna, and have indirectly contributed to similar studies in the Gulf of Mexico.

The Florida Board of Conservation's Hourglass Cruises included benthic trawling as well as pelagic sampling on a monthly basis between 1965-67, but were limited to the continental shelf area off the west coast of Florida, (Joyce & Williams, 1969) and therefore do not apply to the study area of this report.

Florida State University and the State University System Institute of Oceanography of Florida (SUSIO) have largely confined their studies to the eastern Gulf and to relatively shallow (inshore) areas of the continental shelf (SUSIO, 1972 ; Smith, 1974).

Rowe and Menzel (1971) in a study of quantitative benthic samples and measurements of deep-sea biomass based upon 13 anchor dredge stations from the southern and eastern Gulf in depths of 200-3780 meters (only 5 of which were shallower than 2000 meters), remark upon the depauperate nature of the deep benthic fauna of the Gulf compared to other ocean basins. They showed that infaunal biomass decreased logarithmically with depth suggesting "considerable energy loss in the passage of food along a complex food ladder in the water column". No specific faunal components were given in this study.

Other recent biological studies of the outer shelf and/or slope regions of the Gulf include detailed studies of the biota of the West Flower Garden Bank in the northwestern Gulf (Bright and Pequegnat, 1974) in which benthic organisms inhabiting the bank down to 450 feet (137 meters) were found to be stratified into distinct biotic zones, which were described and correlated with substratum type, light penetration, and depth. The biotic uniqueness of this reef, the most northerly occurring living coral reef in the western

Atlantic except for Bermuda, was demonstrated in these studies as were the Caribbean affinities of its fauna and the need to preserve this unusual feature of the Gulf.

Reconnaissance studies of other northwest Gulf continental shelf banks are presently under study by Bright and colleagues at Texas A&M University (Bright et al., 1974; Abbott & Bright, 1975; and Abbott, Leutermann, and Bright, 1975).

R. M. Darnell of Texas A&M University (personal communication) is in process of preparing, in conjunction with R. E. Defenbaugh, a photographic atlas of continental shelf invertebrates to be followed by a similar atlas of fishes based upon collections made on the continental shelf off Louisiana and Texas.

4. WHAT WE NEED TO KNOW

GAPS IN PHYSICO-CHEMICAL DATA

CHEMICAL

It is believed that the distribution of certain metals in the sediments may be exerting some influence over the distribution of some infaunal species. Although a substantial amount of work has been done on the levels of metals associated with sediments and organisms, much of it is not critical enough to be of great value to benthic ecologists. For instance, in regard to metals in sediments, the available information often does not indicate the valence involved nor whether the metal is in pore water or adsorbed on sediment particles. Much to the point is the fact that trivalent antimony in compound form is not very toxic, whereas pentavalent can well be. It is doubtful that adsorbed metals have much if any effect on interstitial organisms. The metal chemist may use boiling nitric acid to remove metals from sediments, but this is not a capability of either kind or degree possessed by organisms living in this milieu. Much of the earlier data on metals associated more directly with organisms is of very little ecological value because a distinction was not made between metal that was adnate to the outer body or that which was bound in one or another of the metabolic pools of the organism under investigation. Thus, when a test organism is digested in KOH or nitric acid for metal analysis, this does not specify the importance of the metal to the metabolic processes of the animal. A fish, for example, may carry much of its metal burden in the mucoid layer on and among the scales. This can be of importance to the animal that eats the fish, but it is not of much metabolic concern to the fish itself.

Secondly, it is important to know much more about the levels of dissolved oxygen in the first meter of water above the bottom, and this should be correlated with Eh values in the adjacent sediments. These values alone will give us important insights into just how important the slope ecosystem is in the total bioeconomy of the Gulf system.

PHYSICAL

Currents

Perhaps it goes without saying that much more needs to be known about the currents that flow along and down the continental slope. Of particular interest are currents generated by major temperature drops in the slope waters. From biological evidence it is believed that there may be reversals of water flow on the upper slope induced by strong offshore winds and followed by rapid drops in temperature. If such currents do exist, they serve as a mode of transport for nutrients.

Obviously of principal concern are currents that flow across the bottom. Nevertheless, much more attention needs to be given as well to surface currents, including the effects of diel rhythms and of seasonal rhythms. The point to be emphasized here is not that current studies are needed, but rather the genuine need of imaginative studies. Particularly needed is the development of relatively inexpensive ways of obtaining synoptic

synoptic data--and not simply quasi-or semi-synoptic data. Such methods are available and should be used (Richardson et al., 1972).

Slumping and Turbidity Flows

Considerable interest is now developing in the stability of the sediment layer on the upper slope. As is well known, the technology is now available to implant oil production platforms in water at least 1050 feet (320 m) deep (Shell Oil Company, Gulf of Mexico). Drilling from floating platforms will soon be carried out in water 534 m deep. Both of these depths are well down on the slope and are in areas where slumping can easily occur. What the effect of the installation of platforms or even the drilling process will have on the rate of slumping is not known, but one piece of information might well aid us in arriving at a reasonable level of predictability. The bathymetric distribution of certain key bivalves is now known with considerable precision. By noting the position of sizeable accumulations of "dead" valves at unlikely great depths, one can not only calculate the size of the slump but also its acceleration. Such evidence can be developed both by bottom sampling and by bottom photography and video work. In this way one can gain insights into the history of slumping in particular areas, noting particularly the frequency distribution of slumps and correlating this information with topography. This is one area of research that needs to be pursued in the near term.

HOLES IN BIOLOGICAL DATA

QUANTITATIVE POPULATION DATA

Now that the taxonomy of important animal groups on the slope has been worked out, sampling in a prescribed manner that will give quantitative data needs to be undertaken. In actuality these would only require a few days of ship time and could be handled very effectively by a small number of well-trained personnel. Such data would permit the development of the first mathematical model of the slope ecosystem when coupled with biomass data and inputs from the pelagial.

QUANTITATIVE BIOMASS DATA

The need for such data is evident and would be tied in with the above sampling. Again this is critical to development of a meaningful model. Transformations of standing crop data into meaningful production data can be undertaken.

FOOD INTAKE DATA -- CRITICAL SPECIES

The food habits of continental slope fishes and major invertebrates are only poorly known. Part of the reason is the way that sampling has been carried out and the manner in which specimens have been handled after being surfaced.

SUGGESTED RESEARCH PROJECT

THE USE OF PALAEOTAXODONT VALVES AS MEASURES OF SLUMPING PROBABILITY

Although this suggestion was mentioned in an earlier section, it is deemed important enough to bear repeating. The rapid slippage and resultant sediment slides on the continental slope are coming closer each day to being practical rather than academic or esoteric problems. Obviously "slumps", as these sediment slides are called, could cause major disasters involving collapse of platforms and resultant spills of petroleum into the marine environment. There is no solution to the problem of making a slope less likely to suffer slumps, but it is believed that by a combination of biological know-how and deep-sea photographic expertise one can come up with a way of predicting the likelihood of slumps at particular places. This would be done by analysis of the degree and number of displacement of bivalve shells in a given region. In areas found to be very prone to slumping, engineering studies of sediment stability should be required before drilling or permits are issued.

PART II. OCEANOGRAPHY OF THE NORTHERN GULF OF MEXICO

5. THE PELAGIC ENVIRONMENT

PHYSICO-CHEMICAL ASPECTS OF THE WATER COLUMN

WATER MASSES

The principal inflow of water into the Gulf of Mexico is from the Caribbean Sea through the Yucatan Strait whose sill depth is estimated to be between 1650-1900 meters. Under normal circumstances this sill determines the greatest depth from which Caribbean water is allowed to enter the Gulf. Most of the outflowing water passes through the Florida Straits into the North Atlantic. This latter passage has a sill depth of some 800 meters.

The waters entering the Gulf through the Yucatan Strait are a mixture of South Atlantic water (transported northwestward by the Guiana and Equatorial current systems) with North Atlantic water (from the west Sargasso Sea). The ratio of South Atlantic to North Atlantic water has been estimated to be between 1:4 and 1:2 (Harding and Nowlin, 1966).

The Gulf may be classified as tropical in the south and warm temperate in the north; the Tropic of Cancer, 23°27'N, passes through the western Gulf about 150 miles south of Brownsville, Texas, and through the eastern Gulf between Florida and Cuba. Characteristic open Gulf surface temperatures are 28-30°C in the summer and 20-25°C in the winter. Over the central Gulf basin, surface salinities are generally in the range of 36.0-36.3 ppt.

Five water masses are recognized in the Gulf. These water masses are vertically layered as follows: (1) Surface Mixed Layer, (2) Subtropical Underwater, (3) Oxygen Minimum Layer, (4) Subantarctic Intermediate Water, and (5) Gulf Basin Water. Each of these water masses can be distinguished in the Gulf by distinct values, gradients, or relative maxima or minima in specific parameters. In Fig. 5-1 are plotted temperature, salinity, and

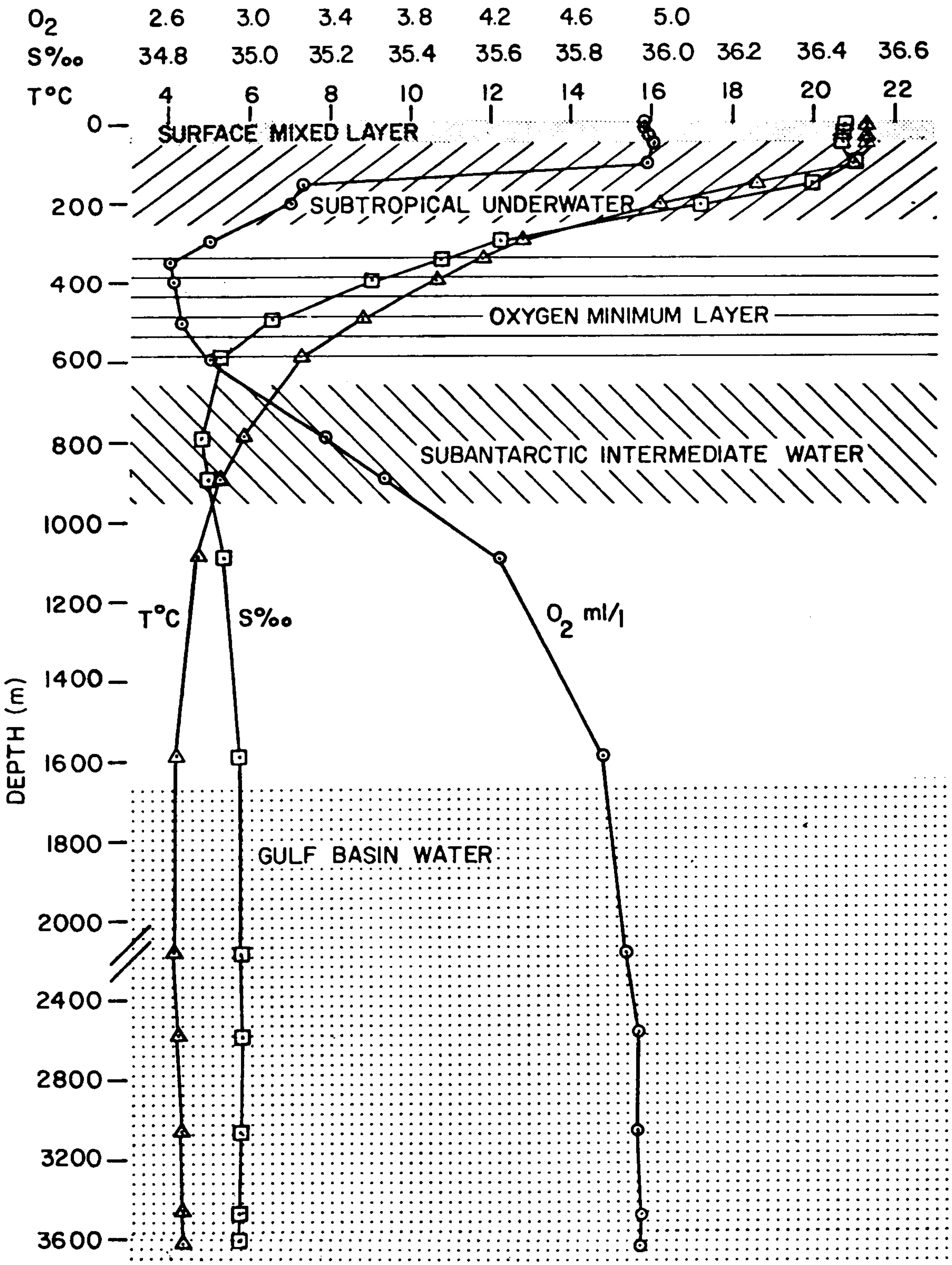

Fig. 5-1. Physical characteristics and water mass designations from a west-central Gulf hydrographic station (25°09'N, 94°11'W; 15 March 1968). Deepest sample taken 4 m above the bottom.

oxygen as functions of depth for a March hydrographic station taken in the west-central Gulf; also approximate water mass depth ranges are shown for the five water masses. The distinguishing characteristics given below for each water mass were taken from various sources - Harding and Nowlin, 1966; Nowlin, 1971, 1972; Wüst, 1964.

1. Surface Mixed Layer (SML) - generally characterized as the upper isothermal layer with temperature depending on the heat budget and by a salinity distribution depending on evaporation minus precipitation, run-off, and the horizontal advection of currents. The thickness of the SML may vary from a fraction of a meter to over 125 meters, depending on location, time of the year, and local influences. Depth of SML, shown in Fig. 5-1, is approximately 75 meters.

2. Subtropical Underwater (SU) - characterized by an intermediate maximum of salinity in depths between 50-200 meters. This water mass is present throughout the Caribbean, but its salinity maximum becomes eroded in the Gulf outside the Loop Current. The region of Campeche Bank appears to be a focal point for this modification in the Gulf. Fig. 5-2a gives horizontal distribution of the salinity maximum in the core of the SU; Fig. 5-2b gives the depth distribution of the core of the SU. The source of the SU in the Caribbean and Gulf is probably from the tropical North Atlantic at 20°- 25° N, 30° - 50° W.

3. Oxygen Minimum Layer (OML) - characterized by minimum oxygen values within depths of approximately 300-600 meters. The OML is not associated with salinity or temperature extremes. The Gulf OML is clearly continuous with that of the Caribbean. In the eastern Gulf a secondary OML is present throughout the water bounded by the Loop Current, but is almost completely suppressed in the western Gulf. Fig. 5-3 shows representative dissolved oxygen curves for various sections of the Gulf.

4. Subantarctic Intermediate Water (SIW) - characterized in the Gulf by a salinity minimum of 34.86-34.89 ppt. at depths between 550-900 meters. This water mass has its origin at the Antarctic Convergence where cold, low salinity water sinks and spreads to the north. This core of minimum salinity enters the Caribbean with salinities of slightly less than 34.7 ppt.

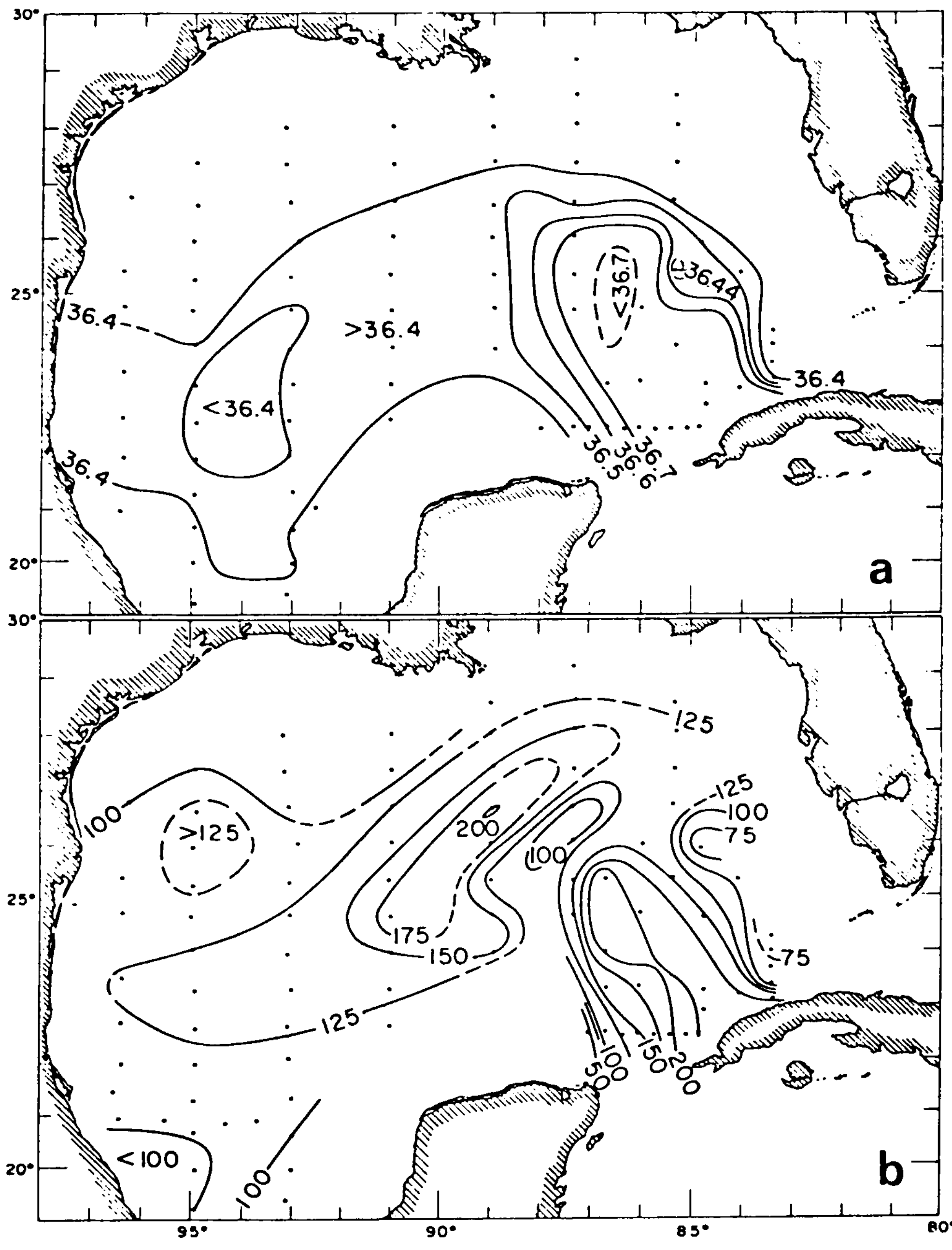

Fig. 5-2. Core of salinity maximum of the Subtropical Underwater: (a) core salinity at 0.1 ppt intervals, (b) core depth in 25 m intervals (from Nowlin, 1972).

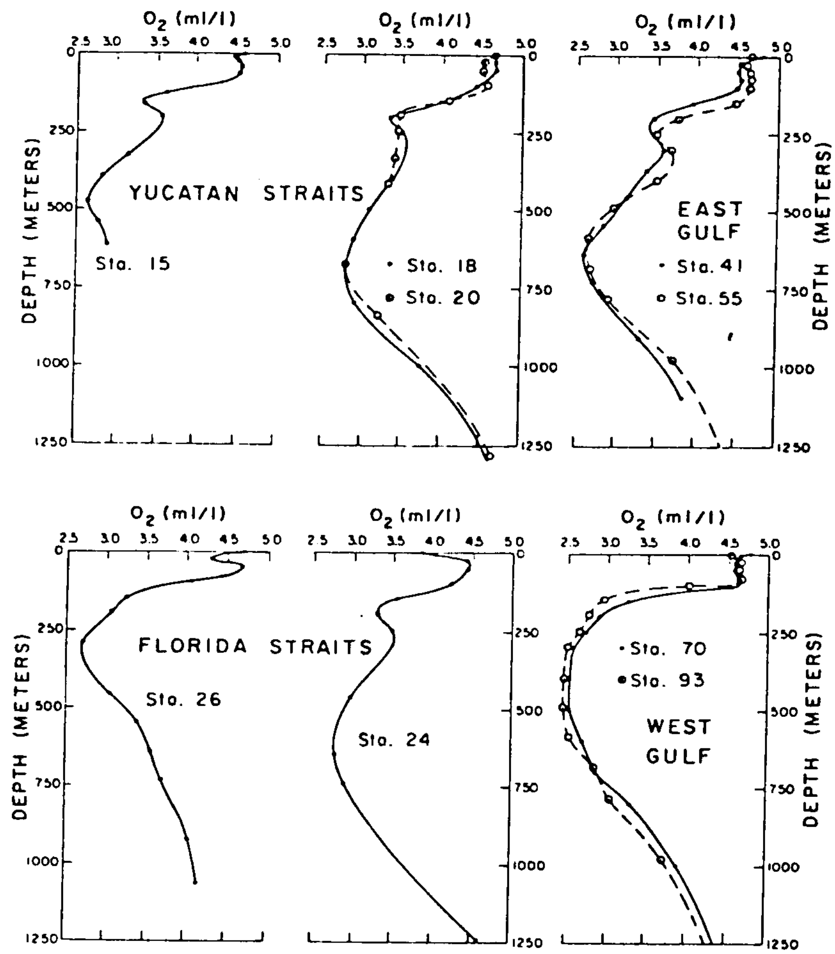

Fig. 5-3. Dissolved oxygen concentration versus depth for various sections of the Gulf (from Nowlin, 1972; Station numbers refer to Hidalgo Cruise 62-H-3).

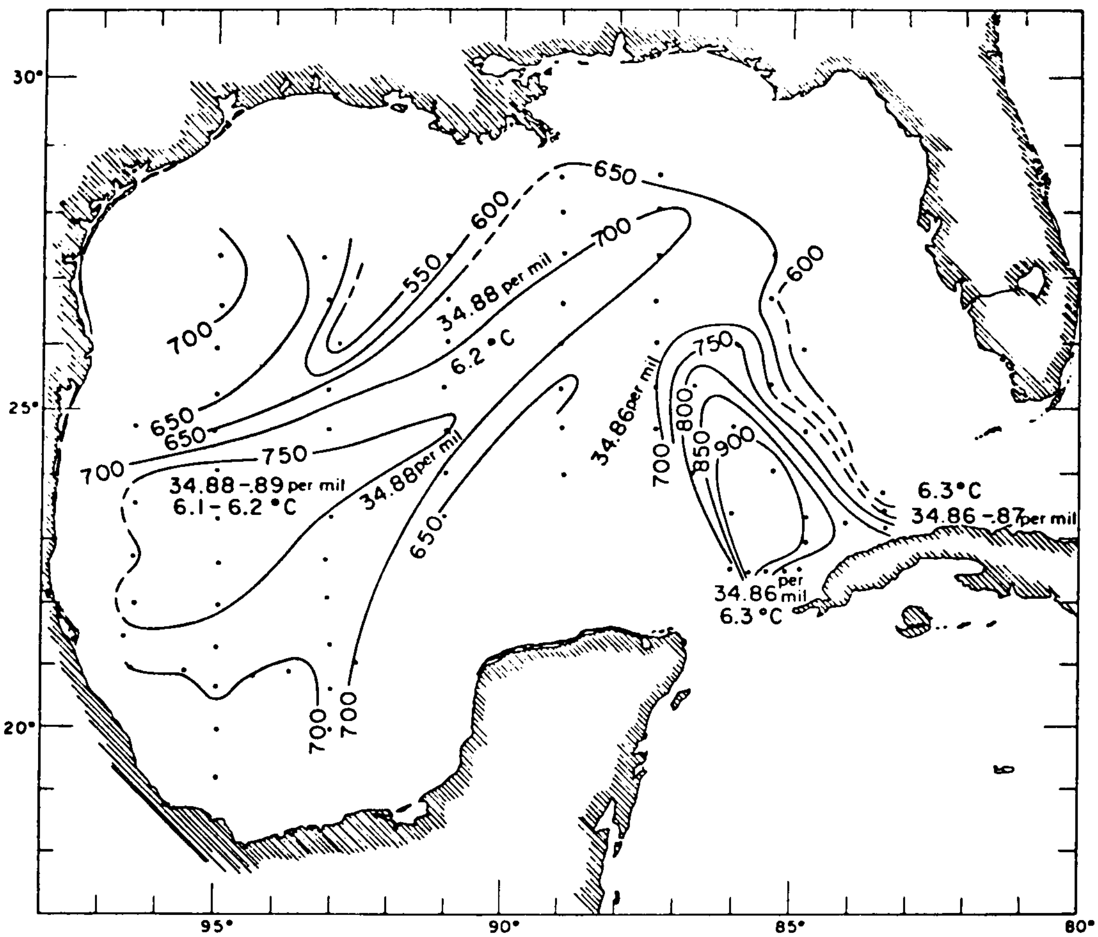

Fig. 5-4. Depth of core layer of the Subantarctic Intermediate Water (in 50 m intervals). Selected values of salinity and temperature at core depth are shown (from Nowlin, 1972).

but mixing that accompanies horizontal spreading raises the salinity to approximately 34.8 ppt. by the time it reaches the Yucatan Strait and is further raised to 34.88-34.89 ppt. in the western Gulf. Calculations show the percentage composition of Subantarctic water in the core to be less than 5% at the Yucatan Strait and only some 1-2% in the western Gulf. A suggestion has been made to label this portion of the Gulf water mass "Remnant of the Subantarctic Intermediate Water". The Gulf depth distribution of the SIW core layer is given in Fig. 5-4.

5. Gulf Basin Water (GBW) - defined as those waters below 1650-1900 meters (estimate of Yucatan sill depth). At approximately 2000 meters the mean temperature and salinity are 4.23°C and 34.97 ppt. respectively. Below 2000 meters in situ temperature increases approximately 0.1°C per 1000 meters (adiabatic warming) and salinity increases approximately 0.002 ppt. per 1000 meters. The stability of the GBW is reported to be near neutral (slightly positive) as calculated from the present state-of-the-art parameter determinations. Relationships of potential temperature versus salinity on both sides of the Yucatan sill are quite similar and thus are consistent with the idea of present day displacement of GBW by Caribbean waters.

PHYSICAL AND CHEMICAL PARAMETERS

Data Base

For the purposes of this report, the shelf-slope area of the present study has been divided into four regions and hereinafter will be referred to as Areas A, B, C, and D. These areas which are shown on Fig. 5-5 are helpful when discussing non-synoptic data. The data base for this section of the report is mostly that of unpublished works. For the upper part of the water column (above 250 m) the studies of Harrington, Etter and Cochrane, and Drennan are heavily drawn upon. Harrington's unpublished manuscript was written from data collected monthly on quasi-synoptic cruises by the National Marine Fisheries Service, Galveston, Texas, during January 1963 to December 1965. The data he reported were temperatures and salinities

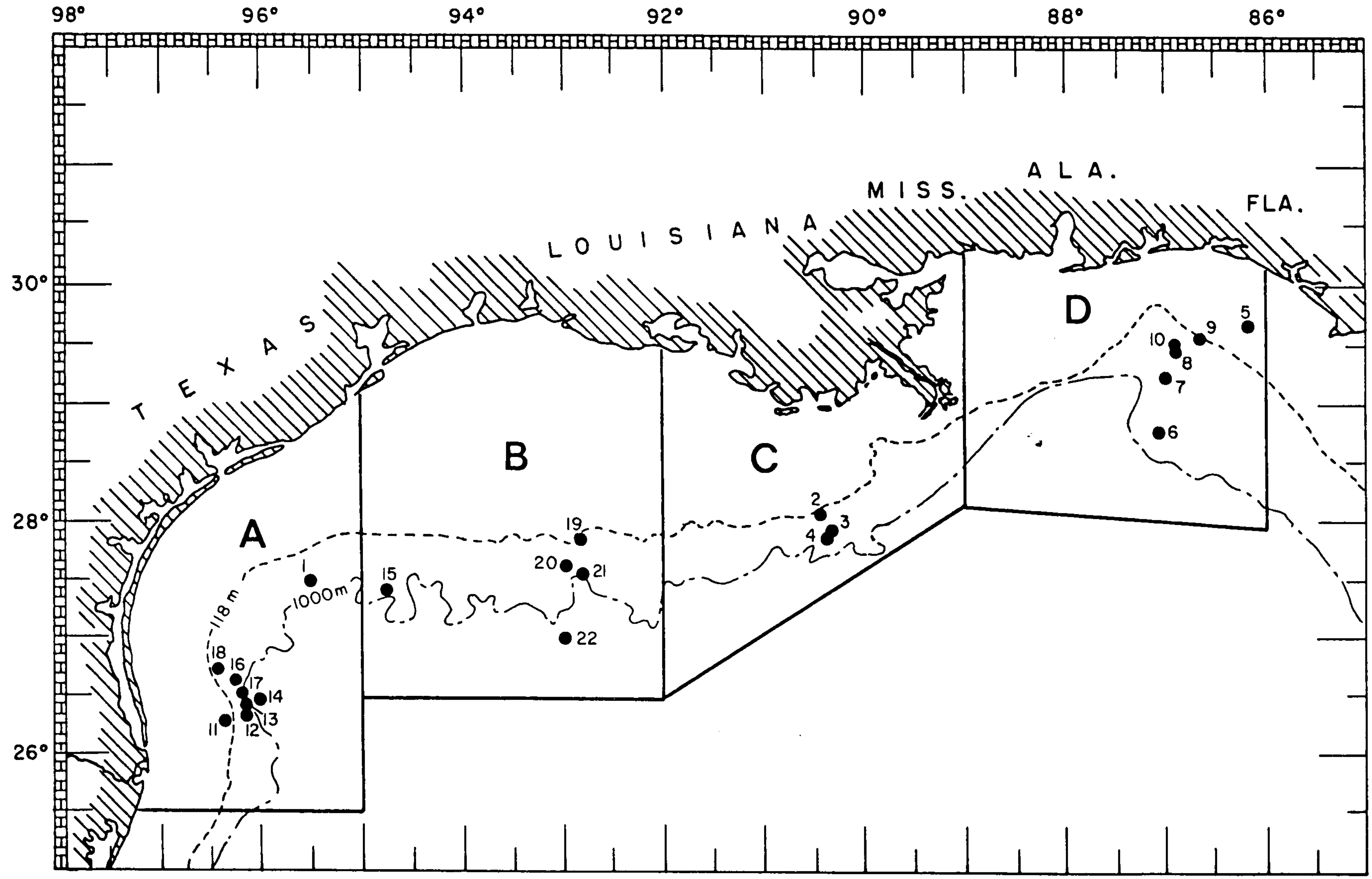

Fig. 5-5. Northern Gulf of Mexico showing areas A, B, C, and D referred to in text. Dots are locations of hydrographic stations given in Table 5-1.

Table 5-1. Location of Hydrographic Stations. Map number corresponds to those on Figure 5-5.

Map No.	Station	Date	Bottom Depth	Depth of Bottom Bottle	N Latitude	W Longitude
1	653H1	3/65	846	813	27°31'	95°30'
2	665H6	4/66	352	340	28°01'	90°26'
3	665H6C5	4/66	801	785	27°52.5'	90°22'
4	669H9C17	7/66	600	575	27°55'	90°20'
5	675H3F	7/67	47	40	29°40'	86°08.5'
6	675H6FG	7/67	751	750.5	28°47.3'	87°02.8'
7	675H7FG	7/67	868	867.5	29°15.5'	86°59'
8	675H9B	7/67	751	676	29°27'	86°51.1'
9	675H12C	7/67	191	190	29°35.5'	86°36'
10	675H13C	7/67	378	350	29°30'	86°52.5'
11	683H11B	3/68	90	85	26°18'	96°22'
12	683H12A	3/68	725	719	26°21'	96°08.5'
13	683H14A	3/68	949	945	26°25'	96°03.8'
14	683H15B	3/68	1090	1086	26°28.8'	95°59'
15	6911H6	8/69	940	937	27°25'	94°45.6'
16	717H5	7/71	585	582	26°38'	96°15.1'
17	717H8	7/71	960	957	26°31.2'	96°05.5'
18	717H21	7/71	229	227	26°43.5'	96°25.5'
19	717H25	7/71	190	187	27°54.6	92°49.5'
20	717H36	7/71	566	563	27°36.5'	92°58.4'
21	717H44	7/71	927	924	27°30.4'	92°49.3'
22	717H59	7/71	1196	1193	26°59.1'	92°58.5'

for the shelf portion of the herein designated areas A, B, and C. Etter and Cochrane's manuscript deals only with temperature structure in areas A, B, and C. They analyzed data from 1428 bathythermograph traces collected over a period of approximately 20 years. They sought over-all trends, thus extremes were suppressed. Drennan's progress report (1968) was compiled from data obtained as part of a joint survey by Gulf Coast Research Laboratory and Texas A&M University. His data include the temperature and salinity distributions as found in the waters over the shelf and slope of Area D during 1964 and 1965.

All the above investigators' works were in the shallower waters (above 300 m) of the present study area. The deeper waters have received less attention, especially concerning very near bottom parameters. To help fill this gap, data are presented for the first time in print from 22 hydrographic stations which were taken in the study area from 1965-1971. The main criterion for choosing these particular hydrographic stations was the close proximity to the bottom from which the water samples were taken; in many cases samples were collected within 1-3 m of the bottom. The locations of these hydrographic stations are given in Table 5-1 and are shown in Fig. 5-5.

Temperature

The temperature of the surface water over the northern continental shelf undergoes substantially greater fluctuations and ranges than those over the slope. Throughout the year, variations in shelf surface temperature closely follow those of coastal air temperature; however, farther offshore, in the vicinity of the slope, surface temperature corresponds with air temperature in the spring and summer, but deviates somewhat in the fall and winter (Harrington). This seasonal relationship between surface temperature and air temperature for the inshore and offshore continental shelf for Areas A, B, and C is shown in Fig. 5-6. Distributions of winter and summer isotherms for Areas A, B, and C are given in Fig. 5-7 and for Area D in Fig. 5-8. Note that surface isotherms in the winter almost parallel the

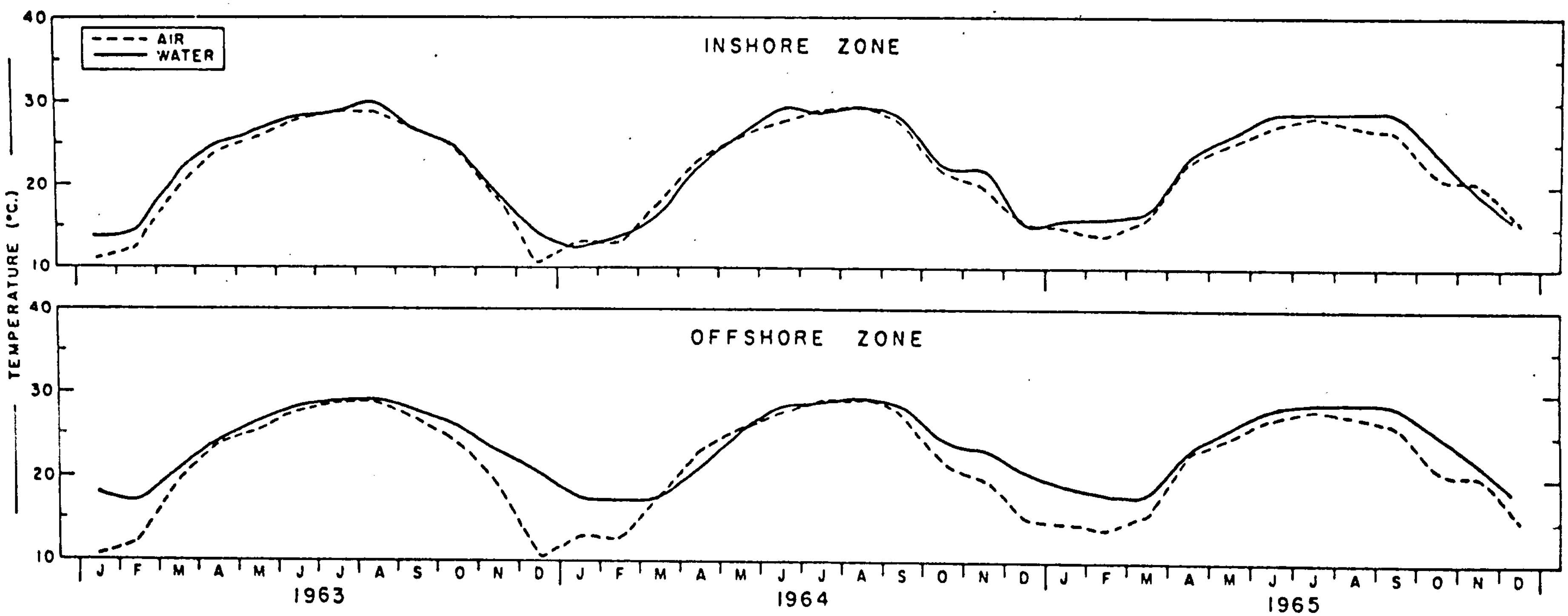

Fig. 5-6. Seasonal trends in average temperatures of inshore and offshore surface waters with coastal air (from Harrington, manuscript).

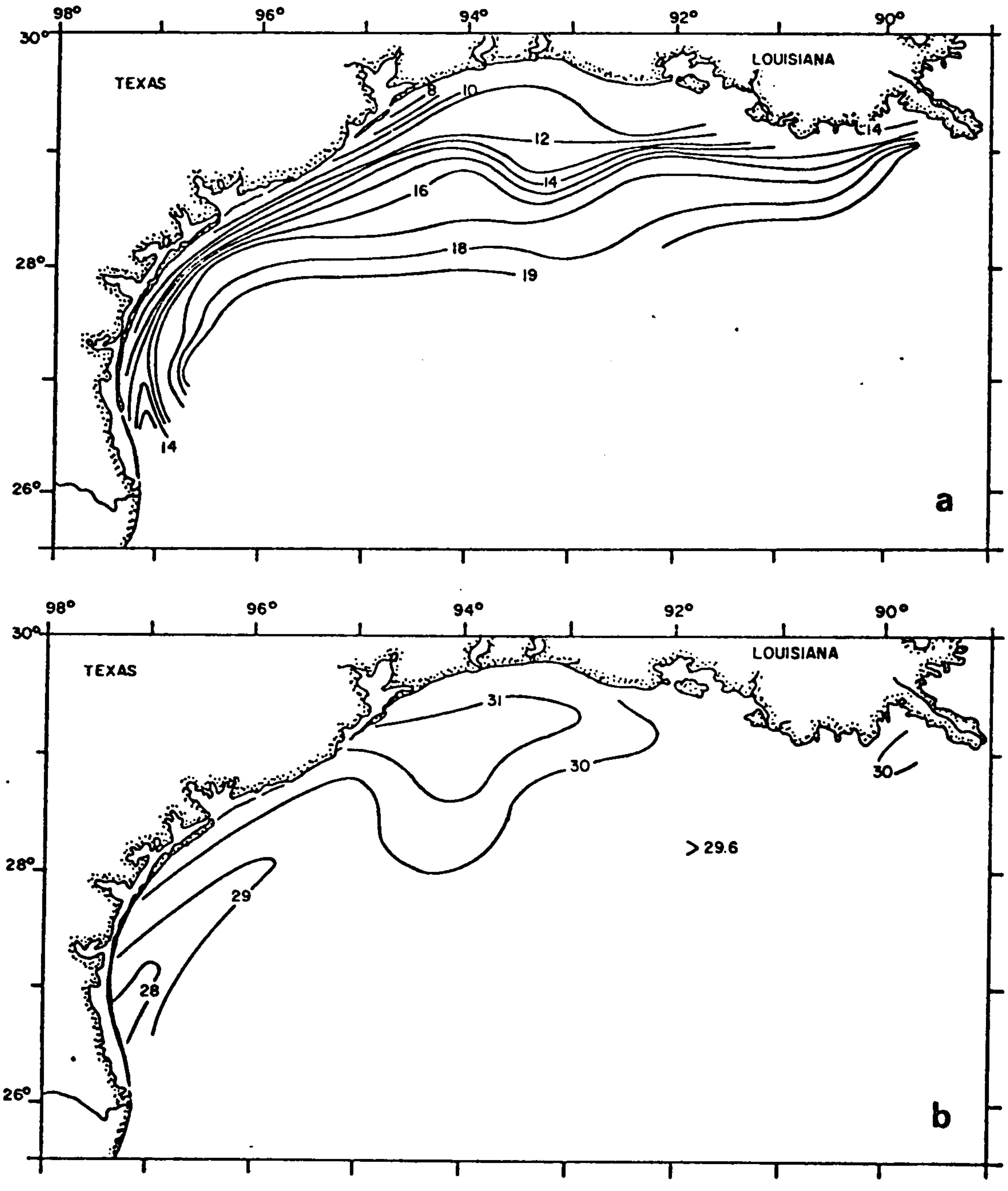

Fig. 5-7. Surface isotherms for winter (a, January, 1964) and summer (b, August, 1963) for Areas A, B, and C (from Harrington, manuscript).

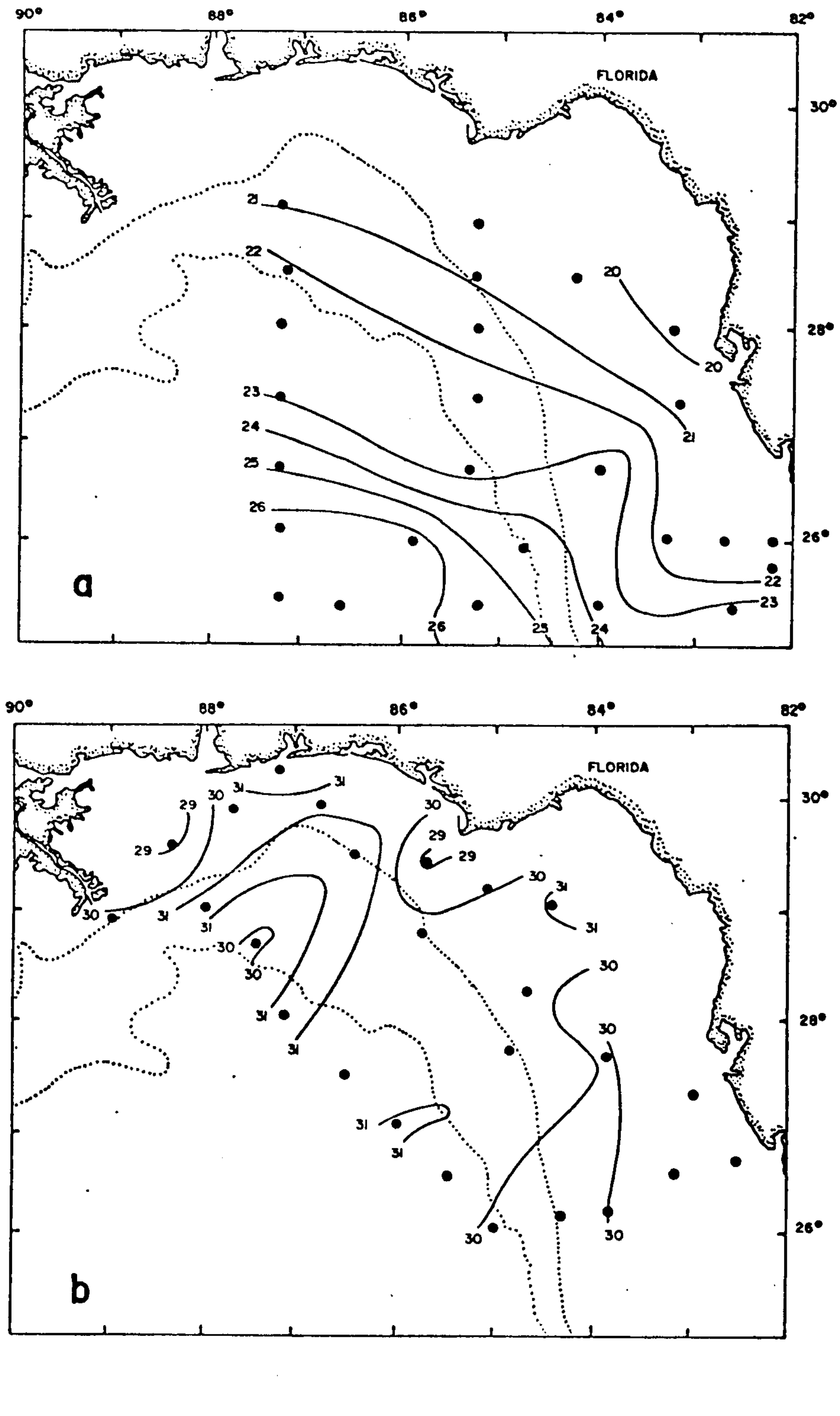

Fig. 5-8. Distribution of surface isotherms for winter (a, February, 1963) and summer (b, August, 1957) for Area D (from Ichiye et al., 1973).

coastline with a general trend of increasing temperature in a direction away from the coast. In the summer, surface temperatures are very nearly uniform throughout the study area, ranging from 29-31°C.

Annual average isotherm variations within the slope water column to a depth of 250 m are shown in Figs. 5-9, 5-10, and 5-11 for Areas A, B, and C respectively. These graphs depict the average temperature at selected depths for each month of the year. The graphs have depth as the ordinate and the months of the year as the abscissa. While all isotherms exhibit some irregularity, the most pronounced effects are confined to the upper 120 m. One feature, consistant throughout all three graphs, is that the 18°C isotherm remains relatively horizontal and this may serve as an indication of the depth to which seasonal fluctuations are perceptible (Etter and Cochrane). For Area D, the annual range of bottom temperatures down to 300 m is shown in Fig. 5-12. These latter graphs were constructed from data collected during 1964 through 1965 and presented by Drennan (1968). Data for Fig. 5-12a were taken to the east on a transect normal to shore at Pensacola, Florida; whereas, data for Fig. 5-12b were taken on a transect normal to shore just east of the Mississippi River. These mean annual bottom temperatures for Area D correlate reasonably well with winter and summer bottom temperatures presented by Etter and Cochrane for Areas A, B, and C shown in Fig. 5-13.

As mentioned before, the surface layer undergoes the greatest annual variation in temperature structure. At a depth of approximately 150 m the difference in annual temperature extremes for the bottom are some ± 3°C. Still deeper, at approximately 300 m, the annual extremes decrease to ± 2°C. Bottom temperatures below 300 m for Areas A, B, C, and D are shown in Fig. 5-14. Each of these latter figures was derived for its given area from composites of hydrographic stations taken at different bottom depths within that area (actual locations of hydrographic stations are shown on Fig. 5-5). These temperature-versus-depth figures were derived irrespective of time of year. As clearly is seen from the above designated figures, the difference in temperature extremes is approximately ± 1.5°C at 500 m, ± 1°C at 750 m, and ± 0.5°C at 900 m. It is also noteworthy that no abrupt temperature

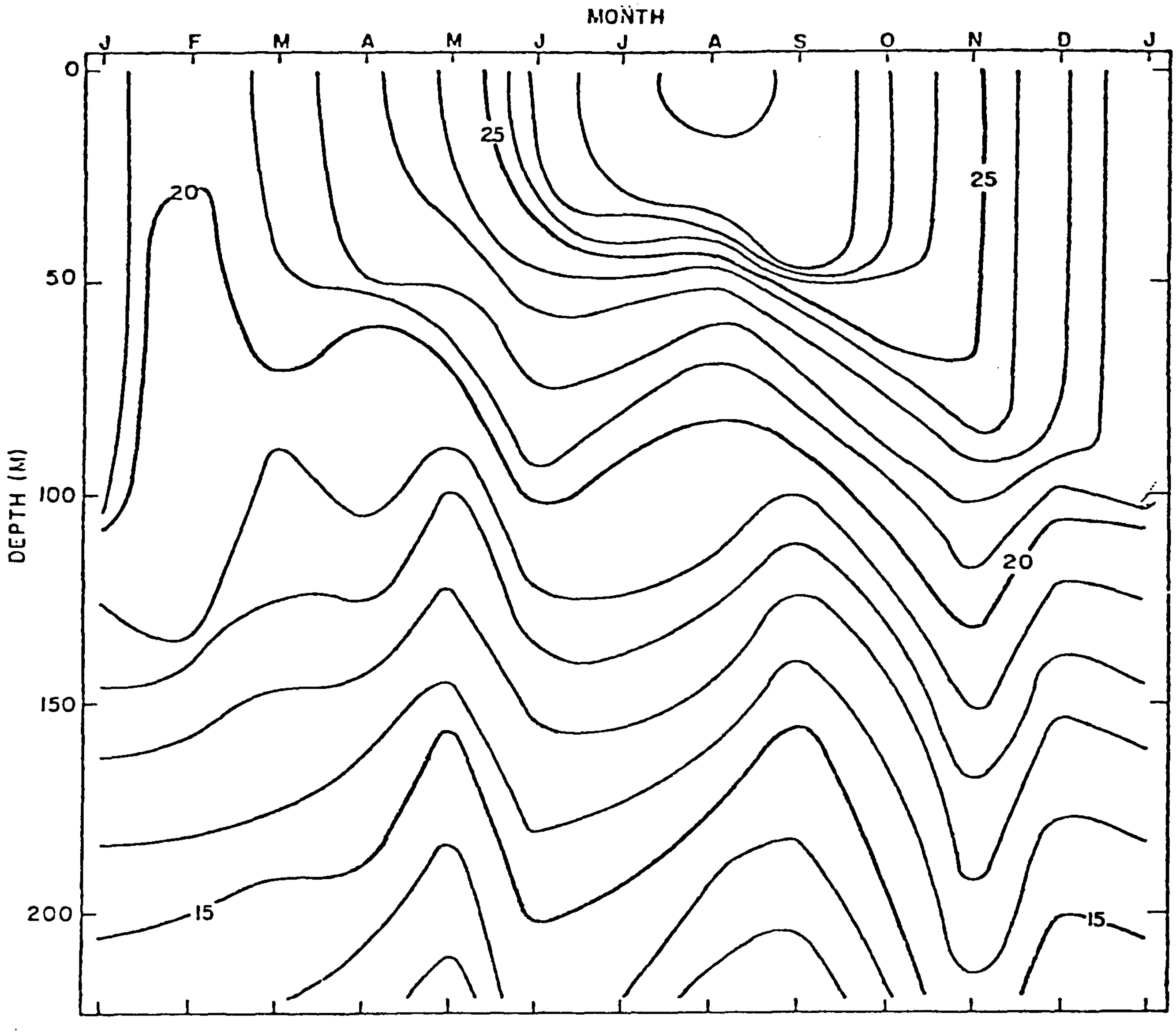

Fig. 5-9. Annual variation of temperature with depth for Area A (from Etter & Cochrane, manuscript).

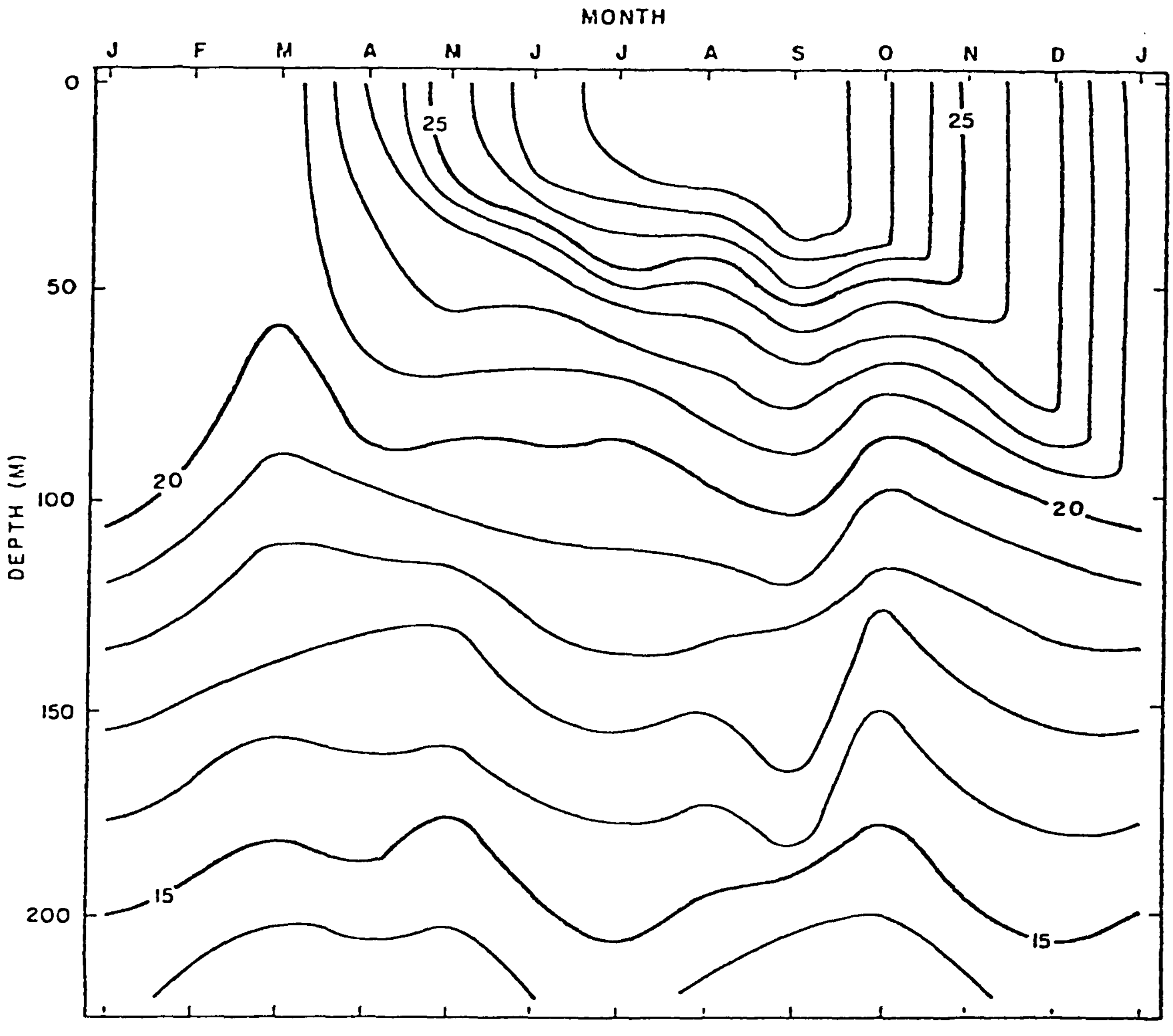

Fig. 5-10. Annual variation of temperature with depth for Area B (from Etter & Cochrane, manuscript).

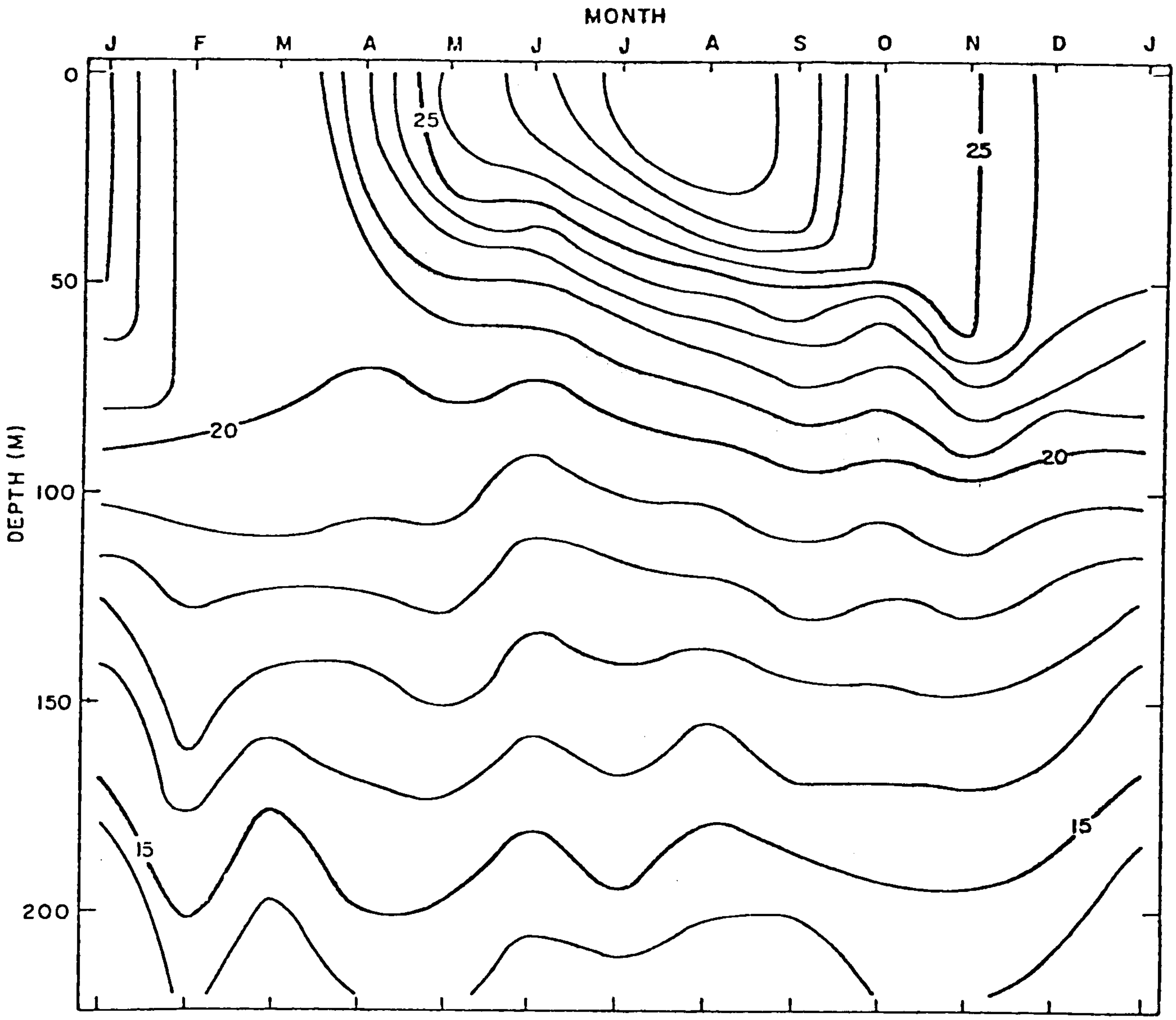

Fig. 5-11. Annual variation of temperature with depth for Area C (from Etter & Cochrane, manuscript).

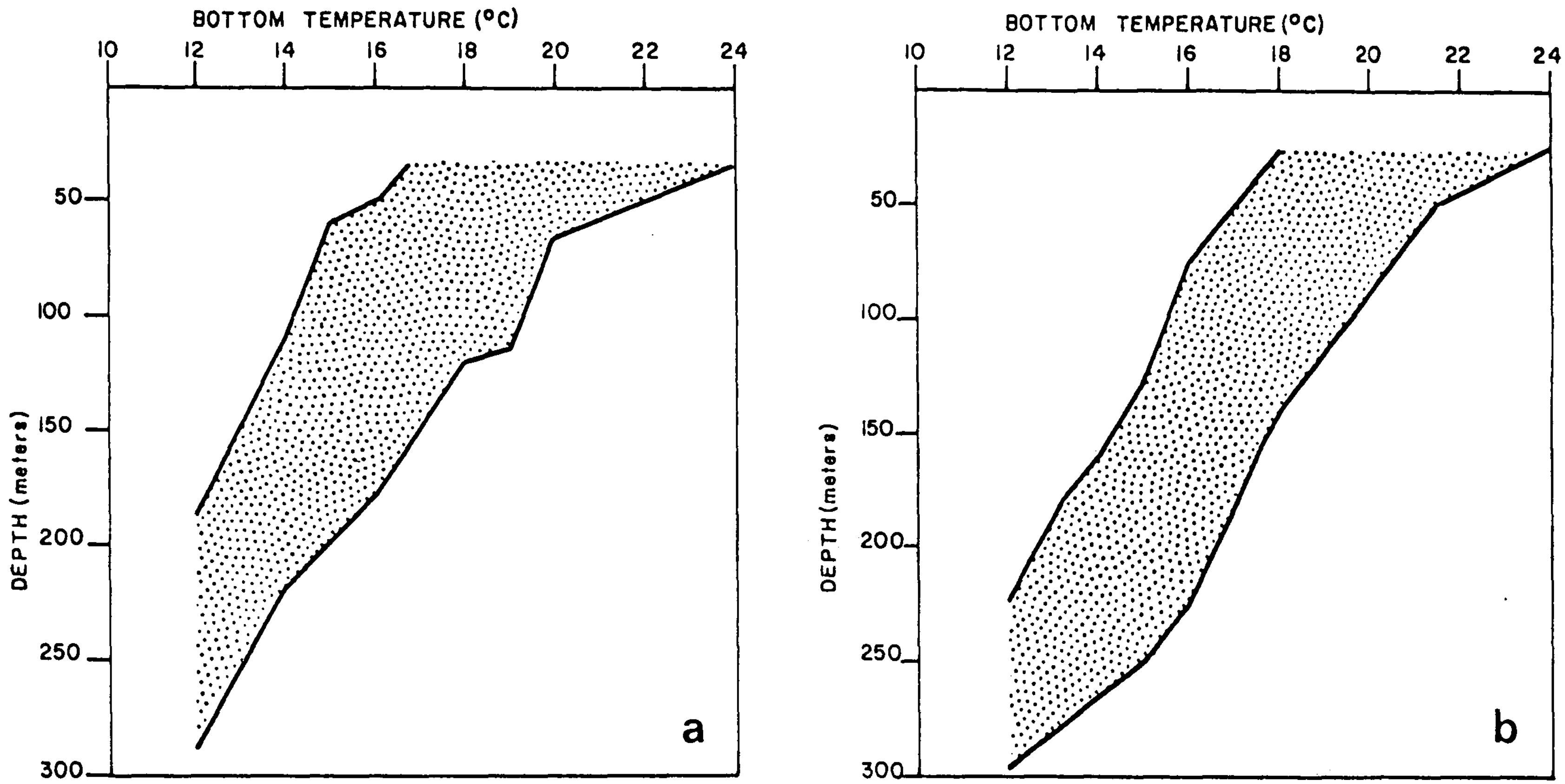

Fig. 5-12. Annual variation in bottom temperature with depth for Area D along Longitude 87 (a), and along Longitude 89 (b) (adapted from data of Drennan, 1968).

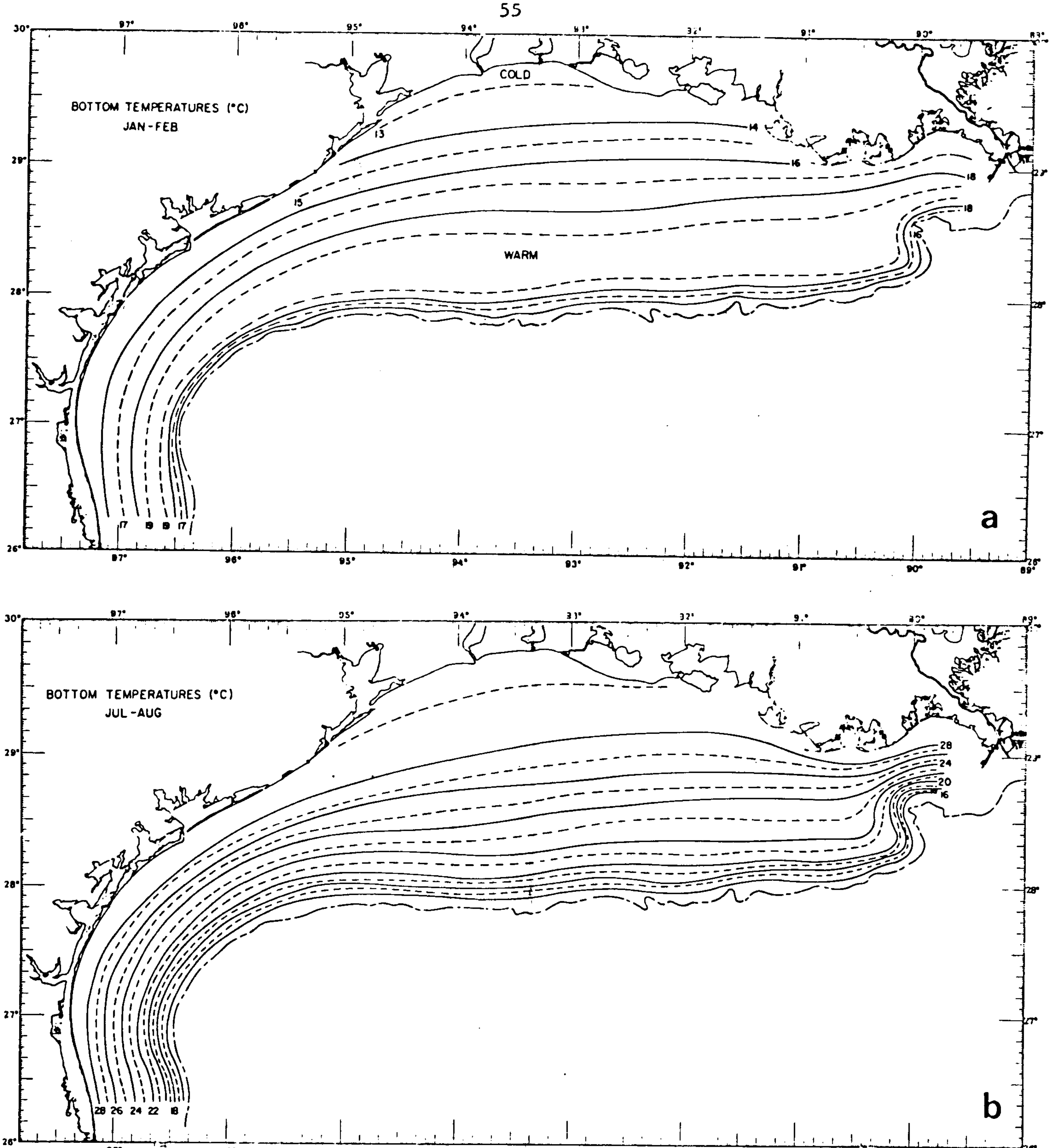

Fig. 5-13. Mean bottom temperatures for winter (a) and summer (b) along Areas A, B, C (from Etter & Cochrane, manuscript).

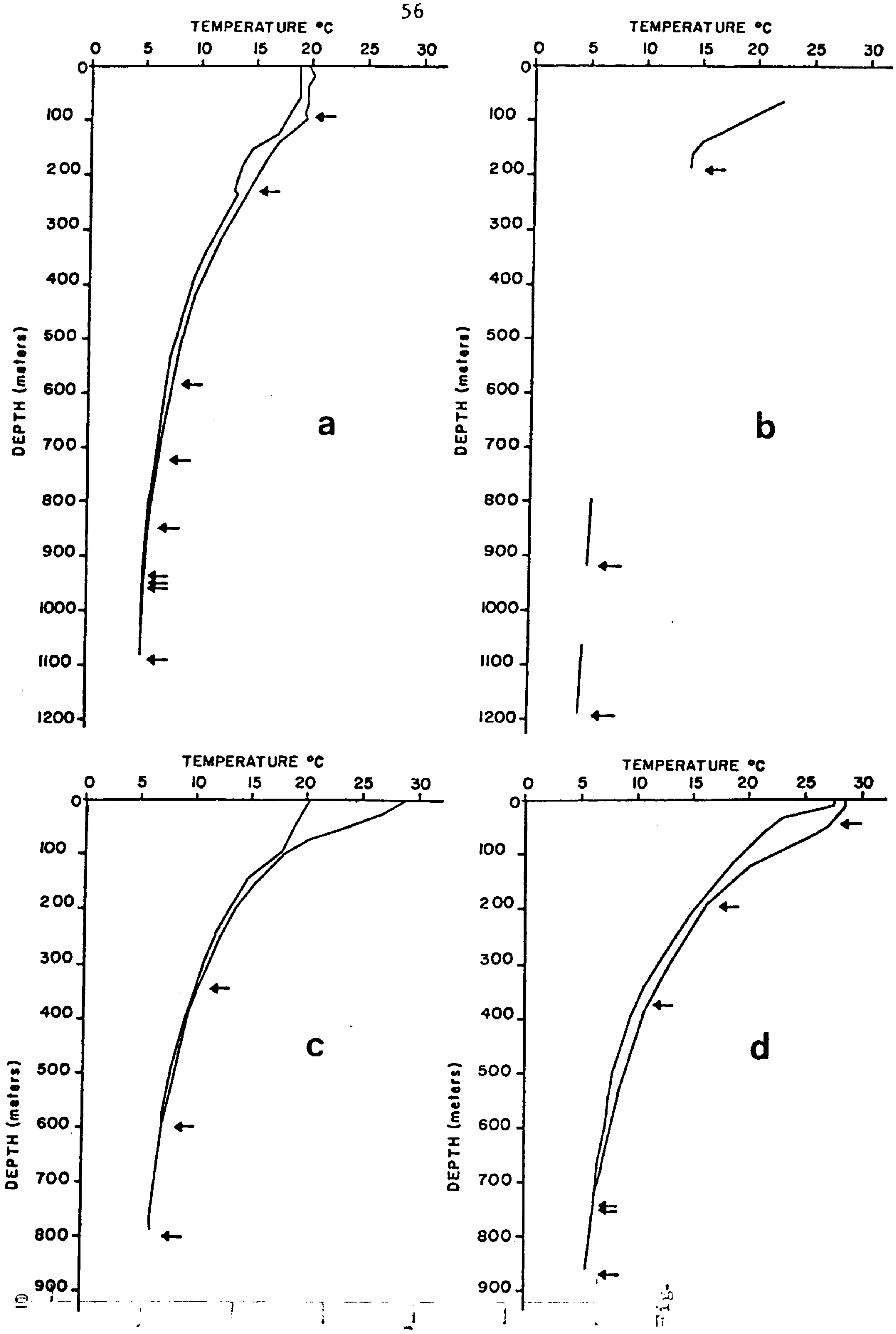

Fig. 5-14. Temperature-depth structure plotted from hydrographic stations taken in Areas A (a), B (b), C (c), and D (d). Arrows denote depths of near bottom samples.

change was noted in waters just above the bottom; thus, it is safe to assume that below 300 m the values given in Fig. 5-14 very closely approximate actual on-bottom temperatures.

Salinity

Over the central Gulf basin the salinity of the surface waters is generally within the range of 36.0-36.4 ppt.(Fig. 5-15); salinities as high as 36.6 ppt. have been observed off the western Yucatan Peninsula (Nowlin and McLellan, 1967). The salinity of the near shore surface water is greatly influenced by local runoff and river discharge, evaporation, and possibly upwelling. There is a marked seasonality in the discharge of fresh water by the Mississippi and Atchafalaya Rivers. High discharge occurs in the spring (March-April) while low discharge is in the fall (September-November). Drennan (1968) reported Mississippi River discharges in the range of 23,000 m^3/sec and 5,000 m^3/sec during spring and fall respectively for the years 1963-1965. Atchafalaya River discharge is approximately one-half that of the Mississippi River. Spring discharge from these and other close-by rivers gives rise to a band of low salinity water over the northern Gulf shelf and slope. Throughout much of the year most of the water flows westward over the Louisiana and Texas shelf (see section on Currents). Seasonal influence of runoff on surface salinities in Areas A, B, and C are shown in Fig. 5-16, whereas its influence on Area D is shown in Fig. 5-17. River-influenced, low salinity water has been detected as far south as 26°N; however, its influence on bottom salinities is approximately limited to the upper 50 m (Abbott and Bright, 1975). Northern Gulf bottom salinities for the upper 250 m are shown in x-section in Figs. 5-18 and 5-19. These x-sections are from the coast seaward along West Longitude lines of 95°,93°,91°,89°, and 87°. For bottom salinities down to 1000 m, Fig. 5-20 is given for Areas A, B, C, and D. These figures are composites of salinity data taken within the respective areas from hydrographic stations shown in Fig. 5-5.

As was seen with temperature, salinity also has its greatest variation in the upper layers. This is quite evident in Area D (Fig. 5-20d) where near

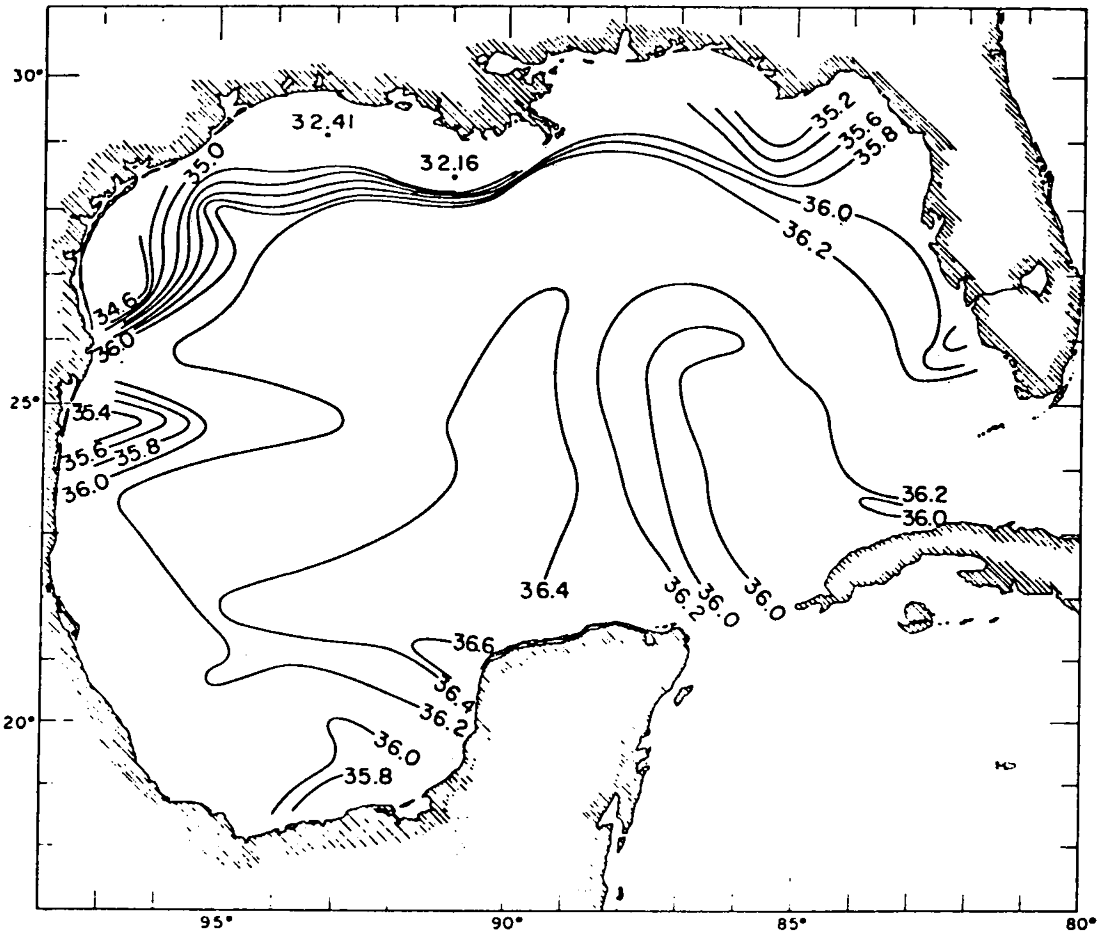

Fig. 5-15. Gulf of Mexico surface salinities for March, 1962 (from Nowlin & McLellan, 1967).

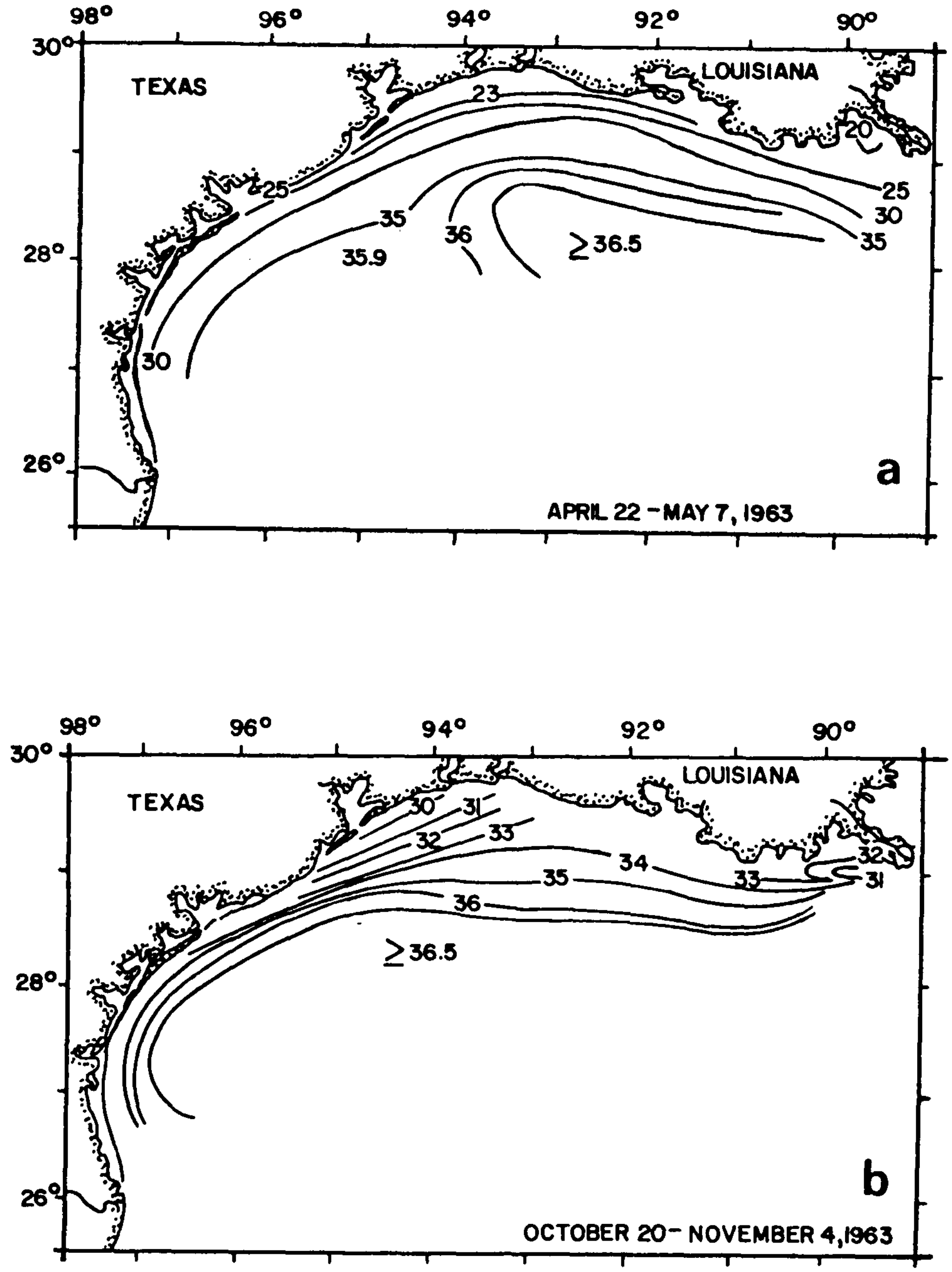

Fig. 5-16. Surface salinities for Areas A, B, and C during Spring (a) and Fall (b) (from Harrington, manuscript).

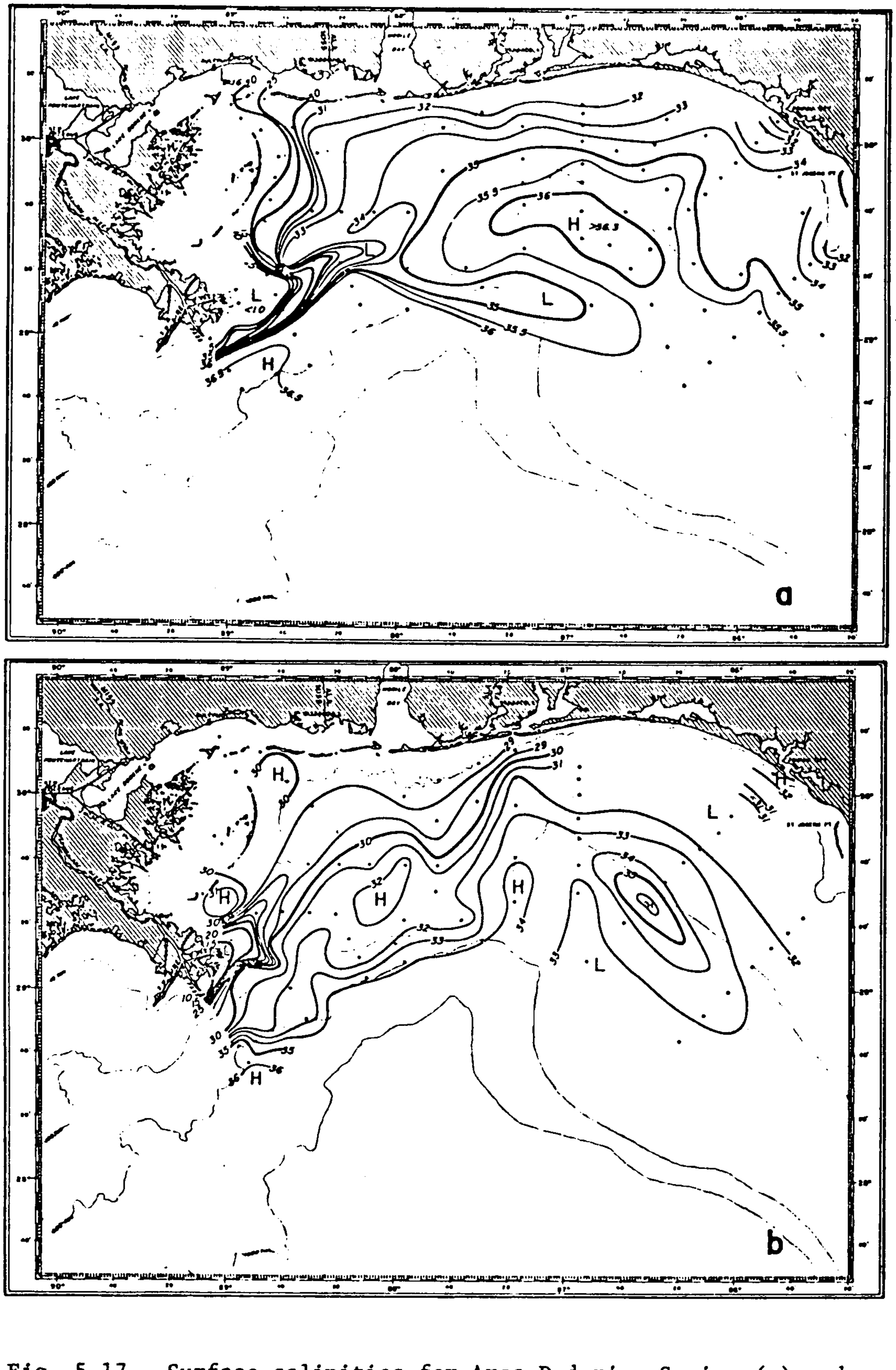

Fig. 5-17. Surface salinities for Area D during Spring (a) and Fall (b) (from Drennan, 1968).

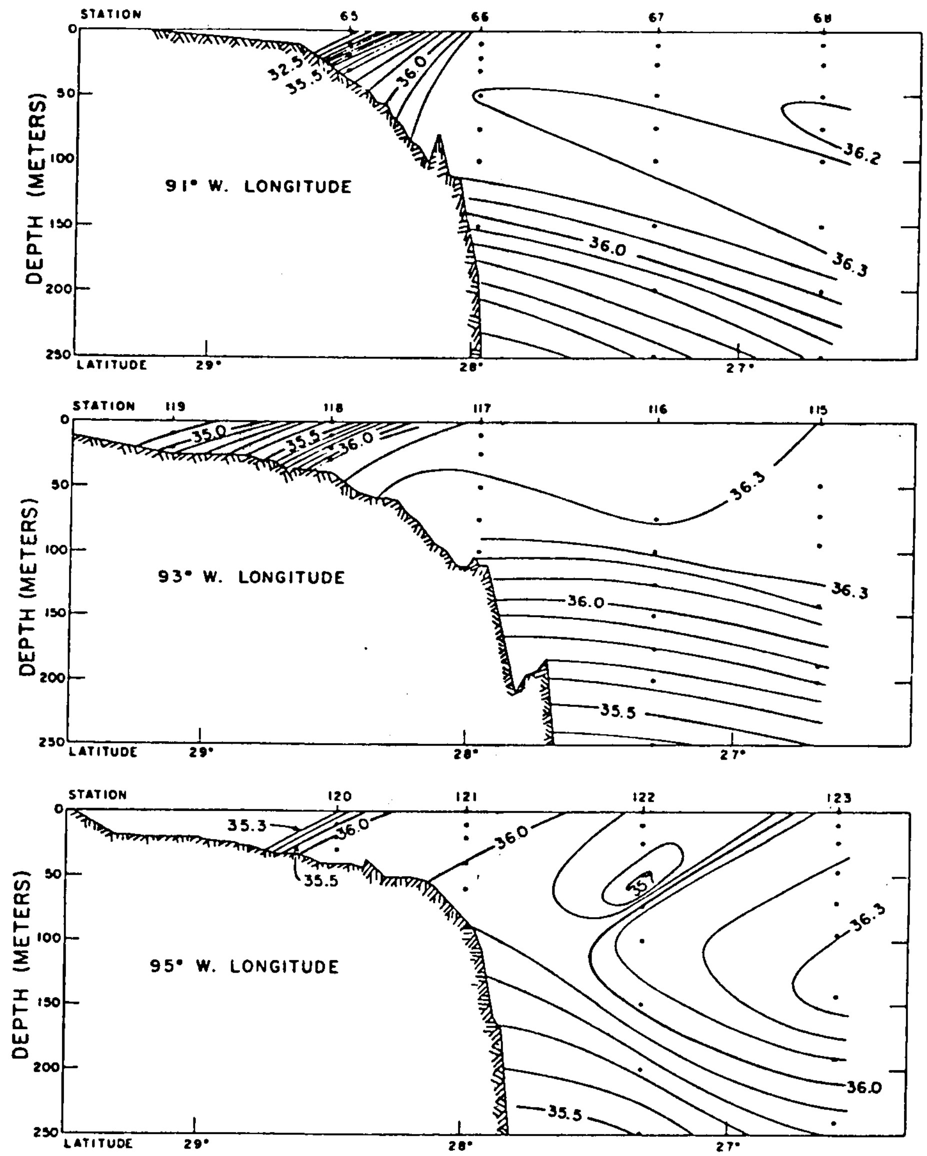

Fig. 5-18. Vertical sections of salinity (ppt) over the shelf and upper slope of Areas A, B, and C for March, 1962 (from Nowlin & McLellan, 1967).

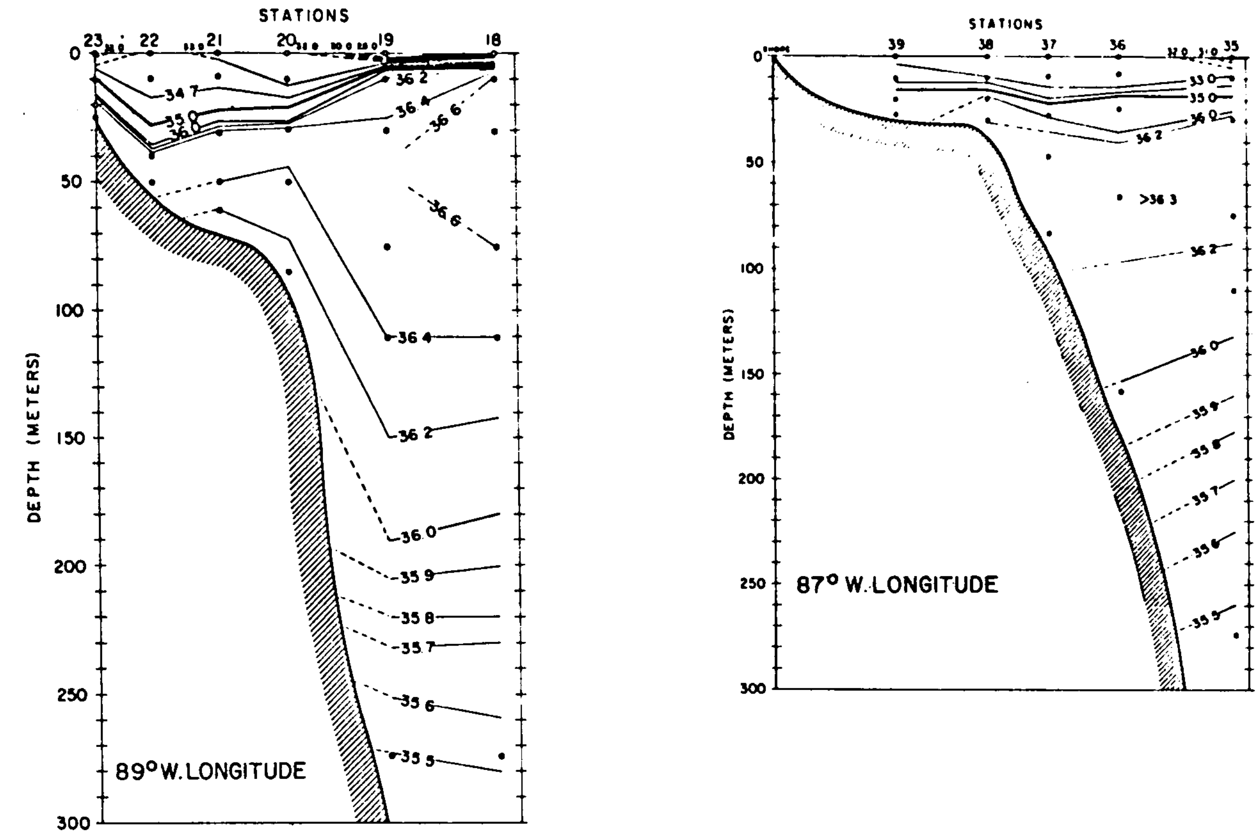

Fig. 5-19. Vertical sections of salinity (ppt) over the shelf and upper slope of Area D for July, 1965 (from Drennan, 1968).

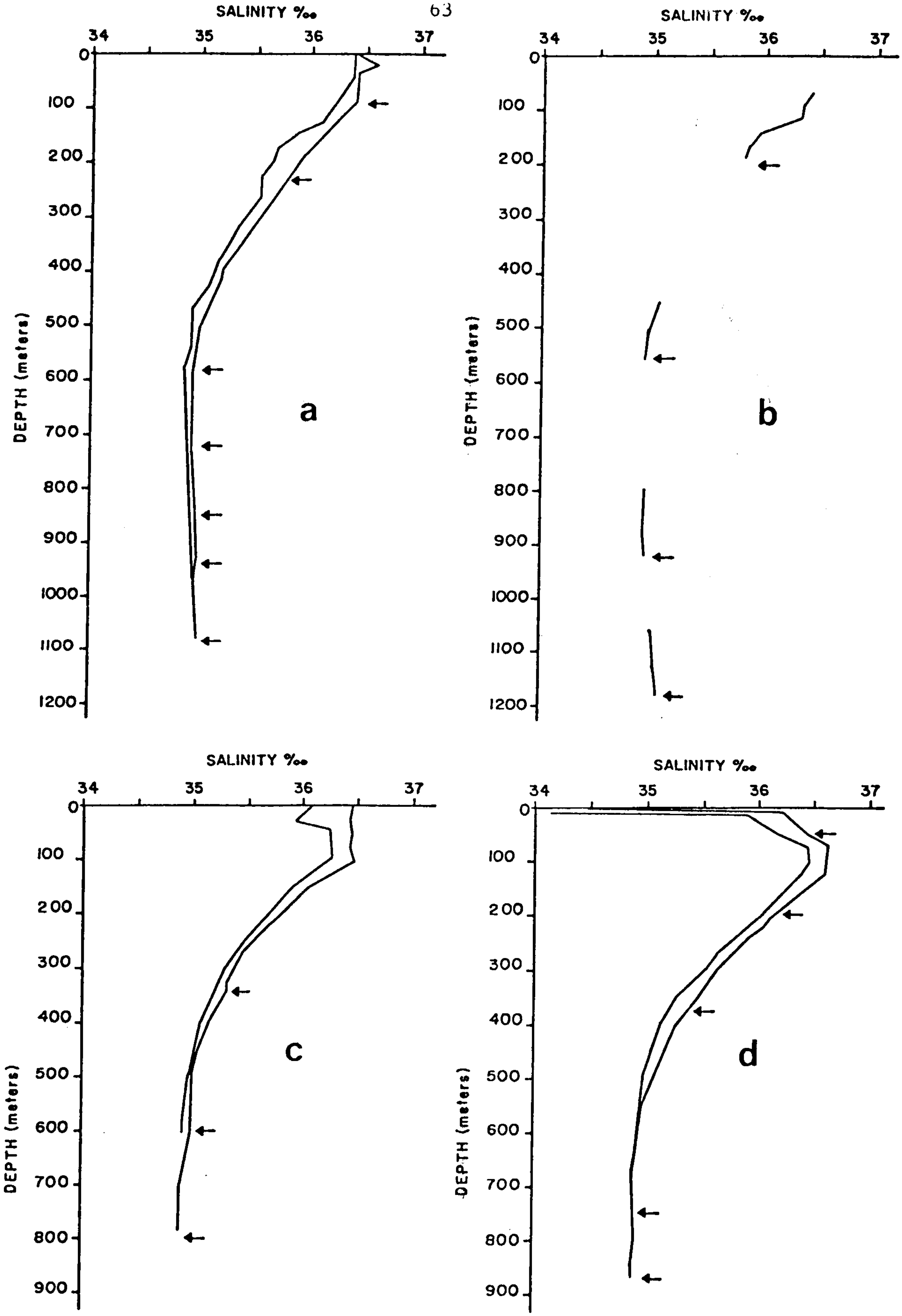

Fig. 5-20. Salinity-depth structure plotted from hydrographic stations taken in Areas A (a), B (b), C (c), D (d). Arrows denote sampling depths near bottom.

surface salinities were below 34 ppt. Also in Area D the influence of the Subtropical Underwater reveals its presence, having a salinity maximum of approximately 36.6 ppt. at a depth of 100 m. This feature becomes muted or non-existent over the slope of the northwestern Gulf where salinity maxima at 100 m do not reach 36.5 ppt. At 350 m the study area's bottom salinities become less variable, being some 35.1 ppt.±.01 ppt. At 750 m salinities have decreased to approximately 34.92 ppt.±.05 ppt. Below about 750 m bottom salinities increase slightly and at a depth of 1000 m salinities are 34.95 ppt.±.03 ppt. Gulf Basin Water, found below 1650-1900 m, has salinities of 34.97 ppt.±.01 ppt.

Dissolved Oxygen

Dissolved oxygen can only be added to the sea in the upper layers by absorption of air and by photosynthesis. It can be lost from the system through exchange with the atmosphere, through consumption by respiration of plants and animals, or through oxidation of substances largely confined to surface and bottom layers; thus it is not a conservative property.

In the Surface Mixed Layer, dissolved oxygen concentration is fairly uniform and tends to be at saturation values. If the upper part of the water column is relatively stable (little mixing), a subsurface maximum in dissolved oxygen concentration is frequently present somewhere in the first 50 m as a result of oxygen production by photosynthesis. Below the photosynthetic zone, oxidation and respiration tend to reduce the dissolved oxygen content. This process contributes to the formation of the oxygen minimum layer. The degree to which this core of low dissolved oxygen is depleted depends mainly on (1) its original dissolved oxygen content at formation, (2) the amount of oxidizable matter within the layer, and (3) its residence time. The Gulf's oxygen minimum layer is derived primarily from the outside and enters the Gulf via the Yucatan Strait (Wüst, 1964). This entering layer, with a dissolved oxygen content of approximately 2.6 ml/l, spreads northward and becomes contiguous with the sediment along the slope (Fig. 5-21).

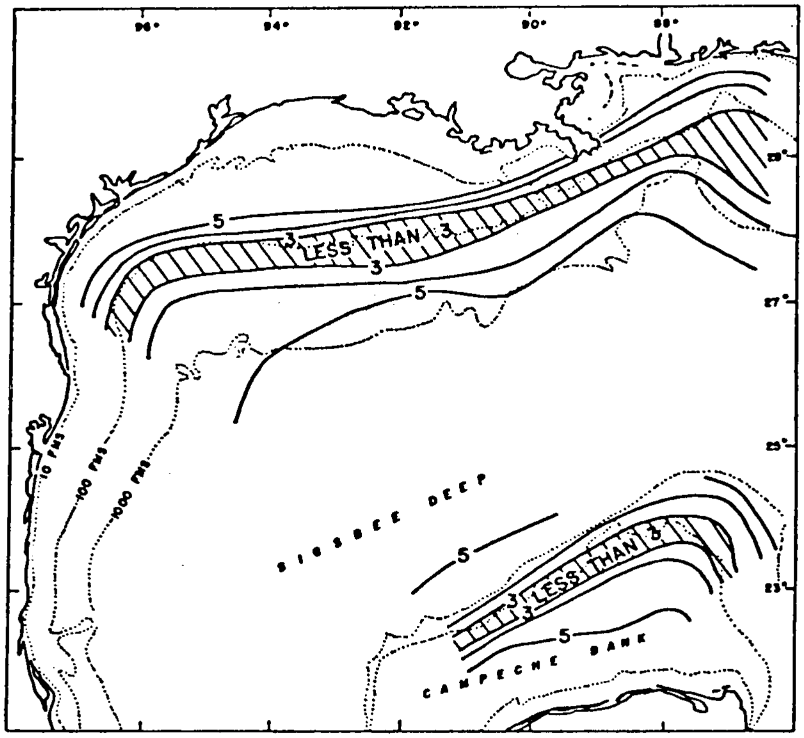

Fig. 5-21. Dissolved oxygen content (ml/l) of waters contiguous with the bottom. (from Richards, 1957)

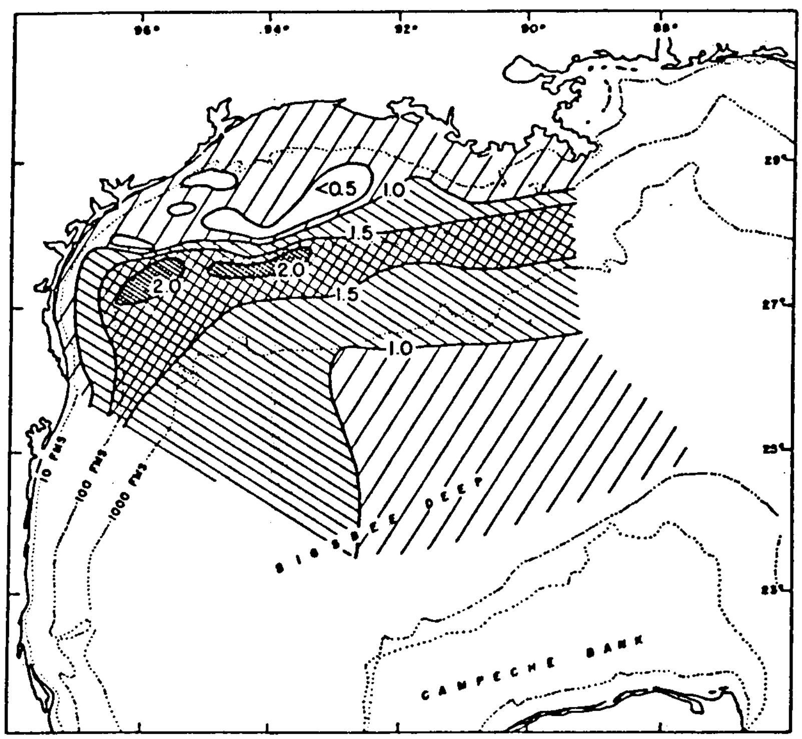

Fig. 5-22. Organic content of sediments of Northwestern Gulf of Mexico. Numbers represent per cent of organic matter, estimated as 1.8 times the carbon content (from Richards, 1957).

Dissolved oxygen data for areas A, B, C, and D are presented in Fig. 5-23. If oxygen minimum layers are defined as having a dissolved oxygen content of less than 3 ml/l, noteworthy differences are apparent between Area D and Areas A, B, and C. In Area D the oxygen minimum layer occurs in depths of 250-650 m whereas in Areas A, B, and C the oxygen minimum layer has thickened and is thus present at depths of 150-750 m. Additionally, the extreme minimum is slightly higher in Area D than in Areas A, B, and C, being approximately 2.7 and 2.5 ml/l, respectively. The thickening, coupled with lower value, suggest a much longer residence time and/or a high level of oxidizable material at this depth within the region west of Area D.

A correlation between organic content of the sediments and dissolved oxygen content of the water impinging on the sediments has been strongly suggested by Richards (1957). The premise for the correlation is that relatively low dissolved oxygen content is favorable for the preservation of organic substances. Thus, where the oxygen minimum layer impinges on the bottom, there should be a zone of relatively high organic content in the surface sediments because this zone would have the lowest oxidation diffusion gradient (Richards, 1957). This correlation has been demonstrated for the Gulf and can be seen upon comparison of Fig. 5-21 with Fig. 5-22.

Temperature-Salinity Relationships

The temperature-salinity diagram, which was introduced by Helland-Hansen (1916, fide Pickard, 1963), has proved to be an extremely valuable tool in oceanography for a number of reasons: (1) regions of uniform water masses are characterized by a narrow envelope of data points on a T-S curve; (2) incorrect data can be detected since they will fall outside the normal T-S curve envelope for that particular region; (3) after a normal T-S curve is established for a particular region only one parameter need be measured-the other may be taken from the normal T-S curve; (4) the origin of water masses and (5) amount of mixing that has taken place can be determined from the T-S curve by the "core method" developed by Wüst

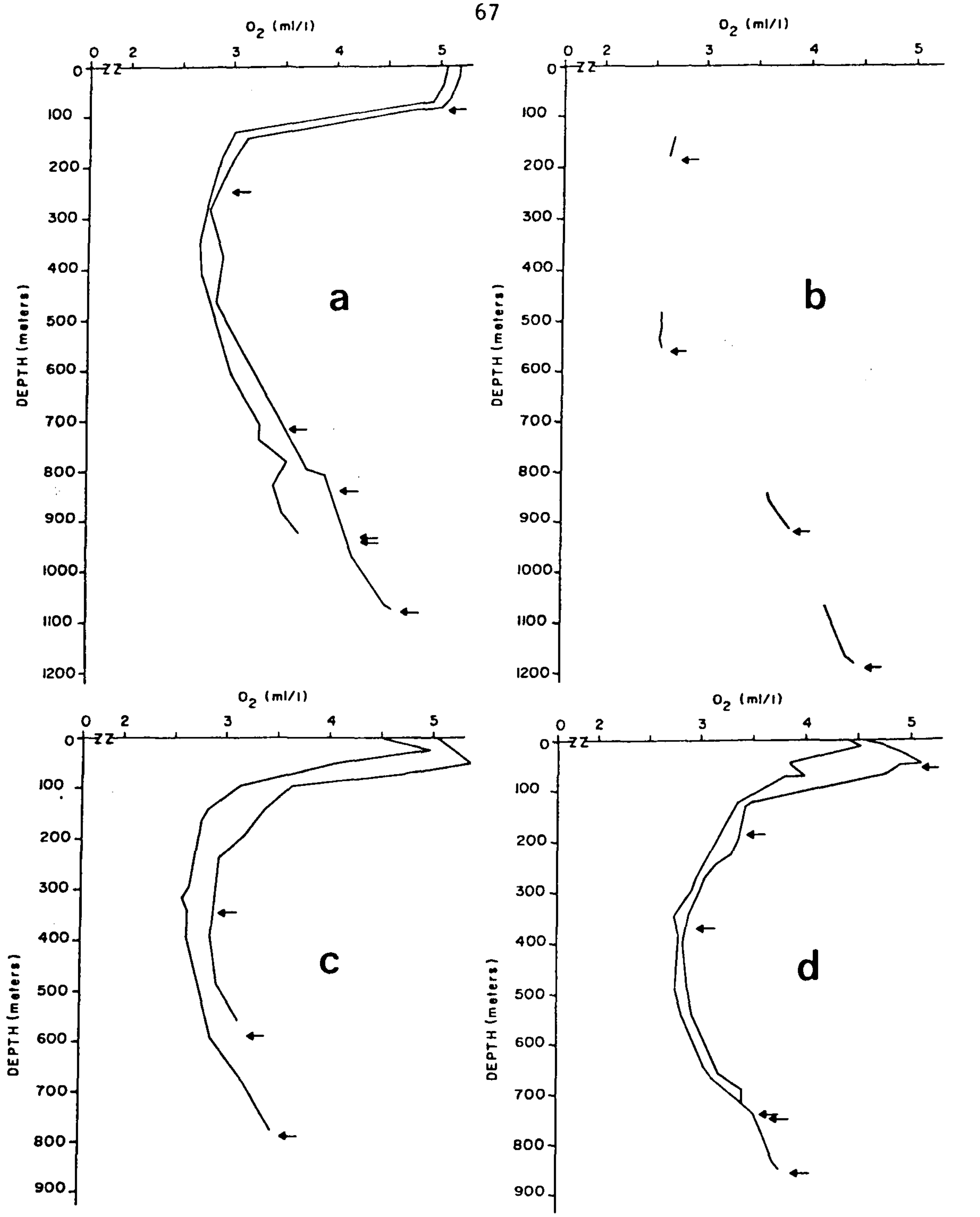

Fig. 5-23. Oxygen-depth structure plotted from hydrographic stations taken in all four areas (A,B,C,D). Arrows denote depths of near bottom samples.

(1935, fide Sverdrup et al., 1942). It was through the use of the core method that the Gulf water masses were determined and described and remnant percentages of original composition were determined.

For the Gulf of Mexico, Nowlin and McLellan (1967) have shown that when many separate paired observations of temperature and salinity are plotted, they fall within a specific "envelope" on the T-S diagram. The width of the "envelope" is at least the precision of temperature and salinity measurements, but is usually wider due to secondary variations of the water masses.

The T-S "envelopes" for Areas A, B, C, and D are presented in Fig. 5-24. That portion of the T-S "envelope" below about 17°C in these latter figures closely corresponds to the one given by Nowlin and McLellan (1967) even though their data were taken well above the bottom. As seen from the arrows (denoting near bottom samples) on figures presented herein, no abrupt changes were found in thermosteric anomaly just above the bottom. As described earlier in the sections on Temperature and Salinity vs. Depth, it is the upper part of the water column (temperature above 17°C) which is affected by seasonal changes and geographical influences.

Since the data were not taken seasonally or synoptically it is not possible to determine regions of possible upwelling or downwelling nor seasonal changes in thermosteric anomaly. The data do indicate, however, that the water column is stable below the seasonally affected water mass.

In a recently reported study (Nowlin and Parker, 1974) two quasi-synoptic surveys were carried out over an area of the northwestern Gulf's continental shelf. One survey was conducted before a cold-air outbreak and the second survey (2 weeks later) was conducted at the same location after the cold-air outbreak. Their study of the change in T-S relationships before and after the outbreak indicates the strong possibility that water types found beneath the Subtropical Underwater core may be formed from the cooling and thus downwelling of shelf water due to these periodic fast-moving cold fronts. Considering the benthos, this downwelling would have a direct effect to a depth of approximately 200 m.

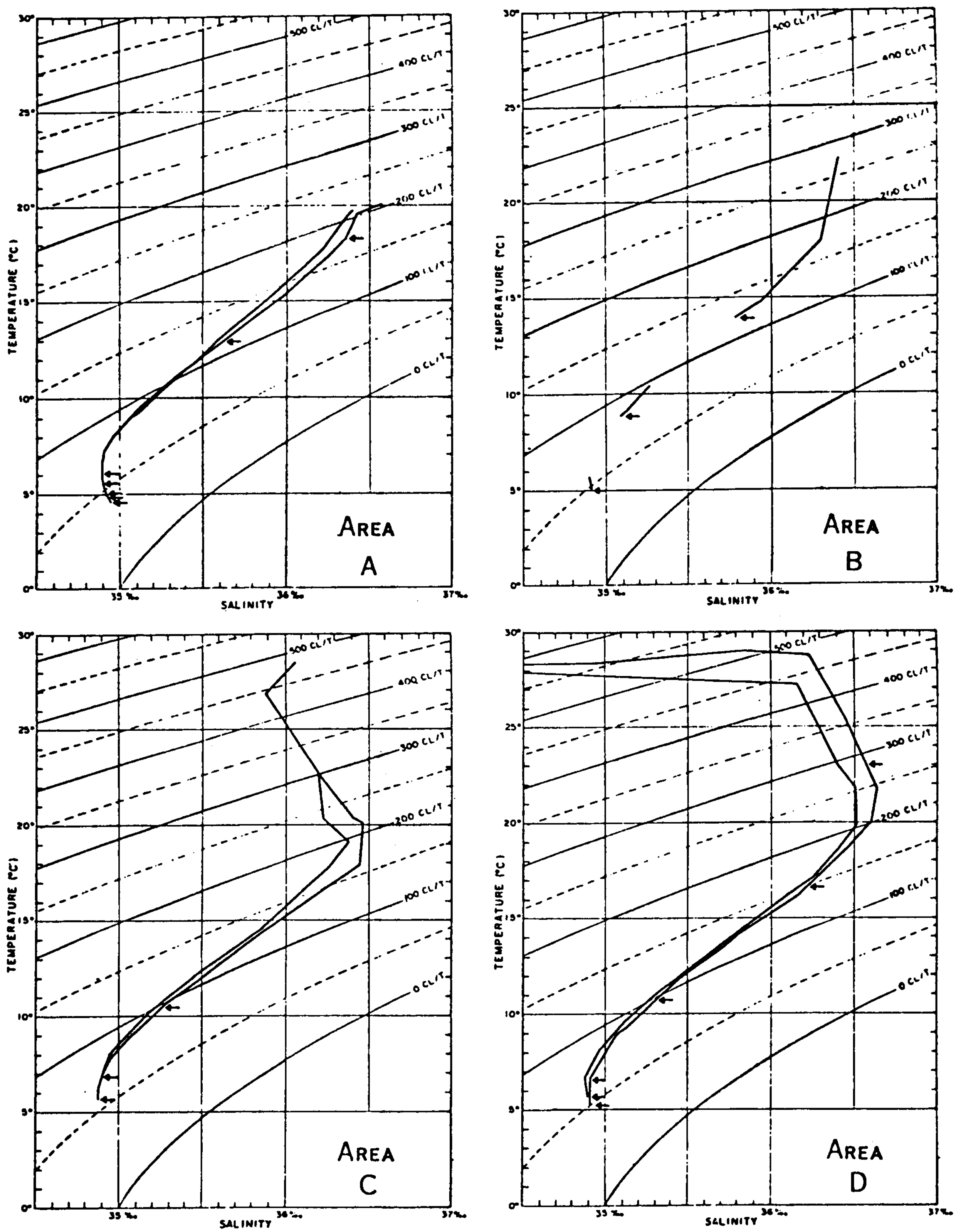

Fig. 5-24. Temperature-Salinity "envelopes" plotted for Areas A,B, C, and D. Arrows denote near bottom samples. Isopleths of thermosteric anomaly are in centiliters per metric ton.

CIRCULATION IN THE NORTHERN GULF

GENERAL SURFACE CURRENT PATTERNS

Several attempts have been made from time to time to describe the general circulation of surface waters in the Gulf of Mexico. Notable among the more recent of these are syntheses by Nowlin (1971 and 1972), by Leipper (1970), and by Ichiye (1962). These macroscale studies appear to be reasonably successful in giving us a conception of the Gulf's major circulation patterns. At the other extreme of the scale there is available an even larger number of microscale or quasi-regional studies of currents and circulation that have been carried out by means of various sorts of drifters (drift battles, drift cards, etc.). A partial listing of these would include Drennan (1968), Gaul and Boykin (1964), Cochrane (1969), Kimsey and Temple (1963 and 1964), Nowlin and Hubertz (1972), Sweet (1974) and a number of others largely in the form of unpublished technical reports, project reports, and simple data reports. These have been worked over many times and are still under consideration. What is lacking most of all is the mesoscale picture of what is going on at any given area relative to the sources of impacts upon it and to the areas that it will affect. In short, when one picks an area where he wishes to carry out a biological, chemical, engineering or geological study, he is likely to find a lack of information on circulation patterns at the site.

Giving first consideration to the large scale picture of Gulf circulation, the basis is usually dynamic computations (e.g., Whitaker, 1971). From these one becomes aware that the flow in the eastern Gulf is dominated, especially in late spring and summer by the Loop Current; water enters through Yucatan Strait as the Yucatan Current and flows in a clockwise loop which extends well north into the Gulf (varying considerably from year to year) and exits principally via Florida Straits. In late summer or fall large rings of circulating water (an eddy) may separate from the Loop and generally move westward taking perhaps several months or a year before complete decay occurs. Presumably some rings may go eastward. It is strongly believed that the flow of surface water in the western Gulf is somewhat less dynamic and is thought to be more predictable than that of the eastern Gulf (Nowlin, 1972). Essentially there are three sizable gyres from north to south in the western Gulf. Only the central and northern ones are of concern to this study. In winter a large clockwise (anti-cyclonic) cell is centered over the west-central Gulf. Obviously its southern limb will be flowing westward and its northern limb will flow northeastward where it veers into and reinforces the southern limb of a counterclockwise cell. As it continues to move, it comes to be flanked by a southwestward current flowing along the outer Texas-Louisiana shelf (see Figs. 5-25 and 5-26).

SURFACE CURRENT PATTERNS IN THE NORTHERN GULF

The flow of surface water over the outer continental shelf and upper continental slope varies seasonally and with longitude in the span from Brownsville to De Soto Canyon. From January to March in a typical year one can expect the gross movement of surface water to be generally westward (west-southwestward) from over De Soto Canyon to Corpus Christi (see Figs. 5-25 and 5-26). This situation permits the conclusion that some pelagic larvae of benthos (e.g. barnacle cyprids) and some larval fishes could be carried across the Delta, which is normally a physical barrier to benthic organisms. As mentioned in a different context earlier, in the region off Brownsville there is a counterclockwise gyre (cyclonic flow) the eastern arc of which is moving northeastward (see Environmental-Acoustic Atlas of the Caribbean Sea and Gulf of Mexico, Vol. II, 1972). Later, in the period from April to June, a dichotomy occurs at the Mississippi Delta; the east limb of the split moves northeastward from the Delta across De Soto Canyon and is entrained by an anticyclonic gyre (clockwise) just west of Cape San Blas, Florida. West of the Delta the prevailing flow is, as before, to the west except for the Brownsville gyre which, by this time, has begun to move northeastward parallel to the arc of the Texas coast. In the year's third quarter (July-September) the dichotomy of current patterns on each side of the Delta continues but the Cape San Blas gyre has migrated westward to lie over the De Soto Canyon. Meanwhile, the Brownsville anticyclone has positioned itself off Galveston, Texas , allowing waters moving northward from as far

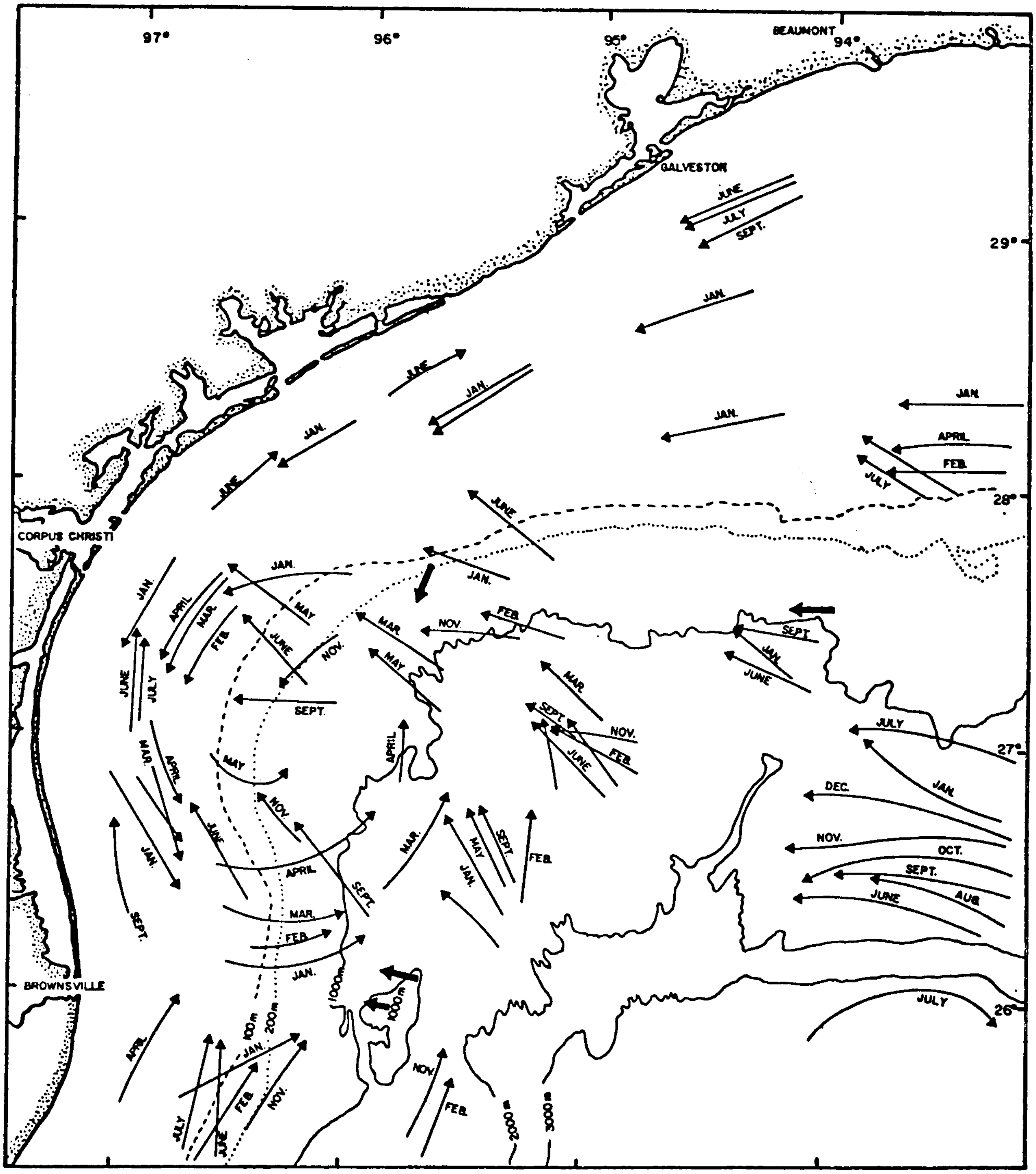

Fig. 5-25. Possible patterns of flow of surface waters in the western part of the northern Gulf shown by fine arrows on a monthly basis. Note the counter-clockwise gyre northeast of Brownsville. Heavy arrows show submarine flow.

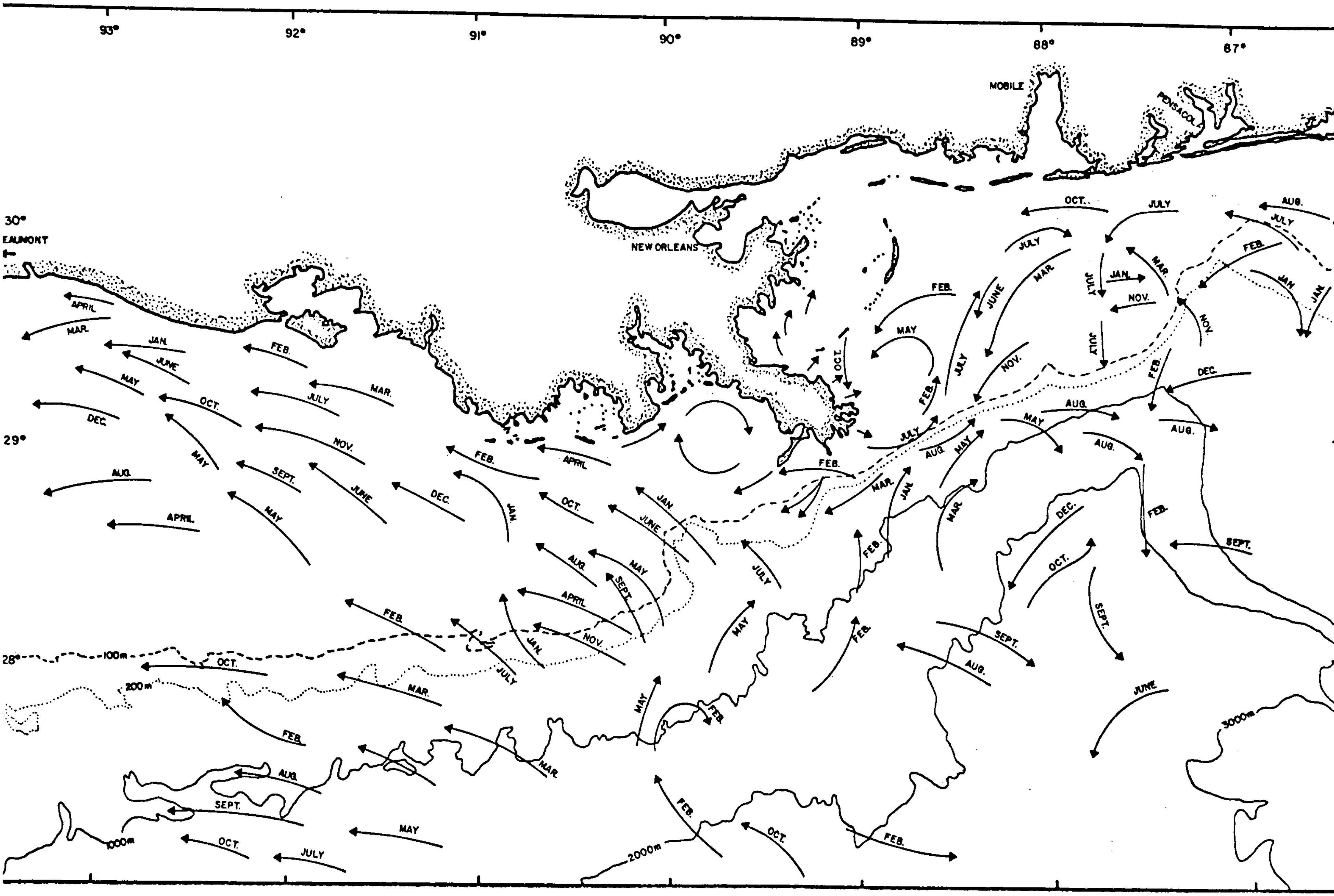

Fig. 5-26. Possible directions of flow of surface waters in the northern Gulf of Mexico by month. Derived from many sources.

south as the Gulf of Campeche to join the gyre off Galveston, Texas. This situation, then, constitutes a reversal of flow off the Texas coast from predominantly southwestward to northeastward. This reverse flow is, however, only a short-lived one. Thus, by August the northward flow shows signs of weakening. So far as is known now, water movements in the fourth quarter of the year (Oct. thru Dec.) are much as they were in the first with the possible exception that the Brownsville and Cape San Blas gyres do not achieve their typical development and strongest circulation until January.

SPEEDS OF SURFACE CURRENTS IN THE NORTHERN GULF

In general one can say that these major currents flow at rates ranging between 0.5 and 1.1 kts. There appears to be very little seasonal difference, although if any difference is to be noted they may be somewhat less swift during the latter half of the year.

BIOLOGICAL IMPORTANCE OF SURFACE CURRENT PATTERNS

The above outlined pattern of the flow of surface currents has some of the following influences:

1. Modulation of the salinity and temperature of the outer shelf and over-the-slope waters. These waters can be traced back to limbs of the North Equatorial Current that flows westward from the Atlantic Ocean into the Caribbean Sea, both north and south of the Antilles. The Guiana Current, which flows along the coast of South America, joins with parts of the North Equatorial Current to form the principal westward flow through the Caribbean. This current becomes the Yucatan Current as it enters the Gulf of Mexico where it branches into three major flows: (a) the East Gulf Loop (noted previously) which, after flowing out through the Florida Straits combines with the Antilles Current off Grand Bahama Island to form the Gulf Stream (obviously the Loop entrains adjacent waters, including some from the western Gulf); (b) the Central Gulf Current (Moore, 1973), which flows northward from off the Yucatan Peninsula toward the Mississippi River Delta and then

turns westward along the coast to Galveston or Brownsville (depending on season, as noted previously); and (c) the West Gulf Current that flows over and around the Yucatan Shelf in a westerly direction until it is forced to move northward by the curvature of the Mexican shelf (Brucks, 1971). It is important to note that probabilities are high that the West Gulf Current maintains its integrity into the northwestern Gulf.

2. The above flow, then, can be the source of pelagic larvae, phytoplankters, and zooplankters sustaining interrelationships of parts of the northern Gulf slope faunae with the Caribbean.

3. The flow off Mexico that continues to points off Texas can be especially important to the recruitment of epifaunal species, including demersal fishes, living on hard banks and the upper slope (including west Flower Garden Bank) off Texas and Louisiana.

4. The converging of waters coming from Mexico and from Louisiana in the westward-flowing limb of the Brownsville gyre transports water rapidly offshore, carrying living and nonliving organic materials, parts of which can be deposited on the continental slope. Also, it may transport meroplankters of shelf benthonic species into unsuitable far-offshore habitats, resulting in death and sinking. In this context it should be noted that upwelling is occurring in the Brownsville gyre - a fact that has some implications for the sustaining of benthonic life on the upper slope. Also some downwelling can be expected along the periphery of this gyre.

5. The surface patterns of flow also influence the westward and eastward distribution of the Mississippi-Atchafalaya drainage waters with their contained dissolved, particulate and vegetational burdens. This movement of water and materials undoubtedly plays the key role in sustaining the great penaeid fishery on the northern shelf and probably plays an equally important role in the maintenance of the upper slope fauna.

SUBSURFACE CURRENT PATTERNS

When it comes to discussing subsurface currents, including bottom currents, in the northern Gulf one must content himself with even more meager data than exists for the surface currents. Fortunately, however, there is just enough information, some of which is indirect being derived from failure of dredges and trawls to reach bottom, to contruct a reasonably coherent conception of flows and shears. Moreover, there appears to be a sufficient positive correlation between the depth limits of these currents and faunal zones on the continental slope as to make further study of the situation very promising of worthwhile results. Since these currents would determine in a substantial way where petroleum from a submarine wellhead spill would go (e.g., an off Texas submarine spill could end up on the shrimping grounds off Louisiana), they may well prove to be of major interest to the Bureau of Land Management.

Moore (1973) has demonstrated that currents ranging in speed from 0.1 to 0.6 kts. move along or obliquely across the upper continental slope of the northwestern and northern Gulf of Mexico. His data support a tentative conclusion that an east-northeasterly flowing current exist between depths of 120 (shelf break) and perhaps as much as 650-700 m on the slope. But the valuable aspect of this finding is that the core of the current, with speeds in excess of 0.5 kts. (over 26 cm/sec) courses around and deeper than the 200 meter isobath. This is where a major faunal break on the slope has been proposed. Beginning somewhere around 450 m depth (where another faunal break is sited) there is a shear where the current flows to the south-southwestward. Moore's data showing a deepening of these currents on a northeast-southwest trending line, but until additional data are obtained the significance of this cannot be evaluated. A series of 30-hour stations need to be established along the slope from the Delta to Brownsville at which vertical profiles of water movement are determined from depths of 100-150 m to the bottom.

The full significance of these currents to benthic life in this region cannot be fully assessed at the present time. Point sources of data are hardly a sufficient basis for constitution of circulation patterns. Nevertheless, knowledge of their existence is very important in that it signifies that this will be a fruitful area for future research. Moreover, it points to the possibility that if, indeed a shear exists at the depths indicated above, then one can conclude that upper slope organisms are living in waters of possibly very different histories and organic (i.e., biologic) burdens.

Even with the meager data available, it can be hypothesized that the flow at intermediate depths is sufficient to bring a southwest Gulf (offshore Mexico) influence to the outermost shelf (hard banks) and uppermost slope, whereas the deeper aspects may well show greater affinities with the central and eastern Gulf.

It is important to note that Moore (1973) believes that these over-the-slope currents are not regulated by tidal movements. Moore (1970) has also demonstrated that submarine currents of velocities ranging from 0.1 to 0.6 kts. are able to move medium to coarse sands (0.7 to 4.0 mm).

THE BIOLOGICAL COMPONENT

PHYTOPLANKTON

Species Distribution

Phytoplankton sampling in the northern Gulf of Mexico has been sparse, intermittent, and mostly unquantitative. The eastern region, especially south of Tampa Bay, has received far better coverage (Curl, 1959; Davis, 1950; Dragovich, 1963; King, 1950; Saunders and Glenn, 1969; Steidinger and Williams, 1970; Steidinger et al., 1967). Much of the information on the species found in the present study area comes from the reports of Balech (1967), Saunders and Fryxell (1972), and Steidinger (1972b). These studies pertain only to presence of species in given areas. Thus, it is difficult to recognize seasonal fluctuations or geographic shifts in phytoplankton abundance or species succession.

Since phytoplankers are at the mercy of water movement, their distributions vary with space and time. Thus, considerable overlap of species distributions would be expected between continental slope waters and the adjacent oceanic and neritic regions. Temporal variation in the composition of phytoplankton populations was evident after shipboard analyses of net samples collected from various stations during successive summer cruises in the northern Gulf of Mexico (El-Sayed and Turner, in press). During the 1973 cruise, diatoms (Ceratulina pelagica, Rhizosolenia alata, and Thalassionema nitzschoides) were the most abundant phytoplankters collected; dinoflagellates were rare in all of the samples. During the 1972 cruise, diatoms were conspicuous only in Louisiana coastal waters, whereas Trichodesmium sp. (blue-green alga) and various dinoflagellate species of the genus Ceratium predominated at other stations.

Undoubtedly, there are more phytoplankton species present over the continental slope region than have been recorded. However, it is possible to generalize on the geographic distributions of some diatom, dinoflagellate, cyanophyte (blue-green algae), and coccolithophorid species. In the following discussion, several species are listed as being "abundant", "frequently recorded", or "widespread". It should be noted that these designations reflect a bias of the samples being discussed since these samples are not actually comparable, because of different station locations, seasons, and sampling techniques.

Diatoms

Conger et al. (1972) listed 939 diatom species which have been reported from the Gulf of Mexico. Of all the species in their list, Rhizosolenia alata is the one most frequently recorded from Gulf waters throughout the year (Balech, 1967; Saunders and Fryxell, 1972). This species is also cited as the most important diatom in Apalachee Bay and in the northeastern Gulf of Mexico (Curl, 1959). Ceratulina pelagica is present in most estuarine waters of the Gulf but is occasionally found in continental shelf waters. Asterionella japonica and Skeletonema costatum occur over the entire continental shelf, but occasionally are found in oceanic regions (Steidinger, 1973). Although abundant in the northern and northeastern Gulf of Mexico, Biddulphia chinensis is replaced by B. regia in coastal waters south of

Cedar Key, Florida. Other diatom species found throughout the Gulf of Mexico in most months include: Guinardia flaccida, Chaetoceros compressum, C. peruvianum, Hemiaulus membranaceus, H. hauckii, and Rhizosolenia stolterfothii (Saunders and Fryxell, 1972).

Over 200 phytoplankton species were recorded from an extensive seasonal survey in neritic waters of the eastern Mississippi Delta region immediately north of the continental slope (Thomas and Simmons, 1960). Two diatom assemblages were noted: a river population consisting of Cyclotella comta, C. meneghiniana, Melosira distans, M. granulata, Navicula gracilis, and N. rhynococephala; and a Gulf population comprised of Asterionella japonica, Chaetoceros affinis, C. decipiens, C. diversus, Nitzschia seriata, Skeletonema costatum, Thalassionema nitzschoides, and Thalassiothrix frauenfeldii. Elements of both populations were found in areas of convergence between the river and oceanic waters. Chaetoceros, Melosira, and Rhizosolenia have also been reported to be the predominant diatom genera in the same region during a later study (Khromov, 1965).

Fifty miles west of the Southwest Pass of the Mississippi River, Skeletonema costatum was the most abundant phytoplankton species (Fucik, 1974). Other predominant diatoms included Cyclotella sp., Melosira sp., Nitzschia pungens, N. subfraudulenta, and Rhizosolenia fragilissima. In both the studies of Thomas and Simmons (1960) and Fucik (1974), a Melosira-Cyclotella complex was indicative of river waters while a Asterionella-Chaetoceros-Nitzschia-Skeletonema-Thalassionema-Thalassiothrix association was indicative of Gulf water.

The geographic ranges of the predominant species recorded from net samples by Balech (1967) were plotted by Saunders and Fryxell (1972). Species they plotted in the region of the present study area include: Biddulphia chinensis, B. regia, Ceratulina pelagica, Chaetoceros coarchtatum, C. compressum, Guinardia flaccida, Hemiaulus membranaceus, H. sinensis, Rhizosolenia alata, R. stolterfothii, and Thalassionema nitzschoides.

In oceanic waters south of the northern Gulf continental slope between 26°26'N - 26°52'N and 93°38'W - 93°55'W, 29 diatom species were recorded in October 1974 (TerEco, 1974). The most abundant diatom species included Bacteriastrum delicatulum, Chaetoceros affinis, C. atlanticum, Navicula sp., Nitzschia seriata, Rhixosolenia calcar avis, R. hebetata, R. styliformis, and Synedra sp.

Dinoflagellates

Steidinger (1972a) listed 405 dinoflagellate species which have been recorded for the Gulf of Mexico. In addition she found that Ceratium furca, C. fusus, C. massiliense, and C. trichoceros are widespread species in both coastal and oceanic waters, while Ceratium teres, Ceratocorys horrida, and Pyrocystis pseudonoctiluca are generally present in oceanic waters (Steidinger, 1972b).

The geographic ranges of the predominant dinoflagellate species recorded from net samples by Balech (1967) were plotted by Steidinger (1972b). All of the predominant species were found in the present study area. They include: Blepharocysta splendormaris, Ceratium furca, C. fusus, C. massiliense, C. teres, C. trichoceros, C. tripos, Ceratocorys horrida, Dinophysis caudata, Diplopelta asymmetrica, Gonyaulax polygramma, Heteraulacus polyedricus, Peridinium brochii, Pyrocystis pseudonoctiluca, and Pyrophacus horologium.

Other Phytoplankters

The cyanophyte, Trichodesmium sp. (=Oscillatoria, probably T. erythraeum) has been reported to be the most abundant phytoplankter during certain periods at various locations throughout the Gulf of Mexico (Ivanov, 1966; TerEco, 1974; Fucik, 1974; El-Sayed and Turner, in press).

Thirty-two coccolithophorid species were collected in qualitative samples from the Gulf of Mexico (Gaarder and Hasle, 1971), of which Coccolithus huxleyi and Gephyrocapsa oceanica were the most frequently recorded. In addition, quantitative samples revealed that C. huxleyi may become the most numerous phytoplankton species in offshore waters of the Gulf of Mexico in late autumn (Hulburt and Corwin, 1972).

Phytoplankton Standing Crop Distributions

Abundance of Phytoplankton Cells

Mean phytoplankton cell numbers in oceanic regions of the Gulf of Mexico approximate 10^2 cells/liter (Fukase, 1967, Steidinger, 1973). Similar results were found in oceanic waters immediately south of the northern Gulf slope where cell numbers ranged from 1.30 - 4.88 x 10^2 cells/liter (excluding Oscillatoria sp.) with Oscillatoria sp. values of 0.35 - 48.8 x 10^2 cells/liter (TerEco, 1974). At stations close to the 200 m contour along the continental shelf break in the northern Gulf of Mexico, phytoplankton cell numbers of 0.15 - 1.27 x 10^3 cells/liter were found while values of 3.9 x 10^4 cells/liter were recorded near the mouth of the Mississippi River (Hulburt and Corwin, 1972). In continental shelf waters near the Mississippi Delta, values ranging from 0.237 to 3.056 x 10^6 cells/liter and as high as 6.0-9.0 x 10^6 cells/liter were recorded by Thomas and Simmons (1960) and Fucik (1974), respectively.

Chlorophyll-a and Total Plankton: Geographical Distribution

Numerous phytoplankton standing crop values (measured as chlorophyll-a concentration) have been collected over a period of nine years, covering virtually the entire Gulf of Mexico (El-Sayed, 1972). Averages in the Gulf of Mexico for chlorophyll-a concentrations at the surface and integrated to the bottom of the euphotic zone are 0.20 mg/m^3 and 12.42 mg/m^2, respectively (El-Sayed, 1972). Additional measurements obtained during four summer and autumn cruises revealed similar surface and integrated averages of 0.23 mg/m^3 and 11.50 mg/m^2 (El-Sayed and Turner, in press).

Chlorophyll-a averages from intermittent sampling without respect to season for 2° squares of latitude and longitude for the areas which cover the northern Gulf continental slope are presented in Figure 5-27. When compared with the whole Gulf, northern Gulf averages were low to moderate with surface and integrated values ranging from 0.009 - 0.20 mg/m^3 and 5.40 - 15.35 mg/m^2, respectively, with highest values east of the Mississippi Delta (El-Sayed, 1972). A possible reason for surface values in the present study area being generally lower than the average for the Gulf of Mexico as a whole, is that the Gulf average includes data from the productive areas of upwelling near the Yucatan peninsula.

The low standing crop of the continental slope and oceanic regions is apparent upon comparison with Fucik's (1974) data from the adjacent continental shelf region. He reported annual mean surface and integrated chlorophyll-a values of 1.69 mg/m^3 and 23.55 mg/m^2, respectively.

Soviet investigations in the Gulf of Mexico of total plankton biomass (measured as mg/m^3 wet weight) reveal geographical patterns similar to those of chlorophyll-a with the most productive regions being found along the northeastern continental shelf between the Mississippi Delta and the northwestern coast of Florida (Khromov, 1965). Plankton biomass in the open Gulf was low, with values of 100-150 mg/m^3, compared to 200-1000 mg/m^3 in the region near the Mississippi Delta (Khromov, 1965, Bodganov et al., 1968). Upwelling in the northern Gulf along the bottom of the continental slope and over the outer edge of the continental shelf was suggested as the reason for the high productivity (Bogdanov et al., 1968).

Chlorophyll-a : Vertical Distribution

Typical profiles of vertical chlorophyll-a distributions in the Gulf of Mexico reveal low values near the surface with maximum concentrations at depths of 50-110 m, which in many cases, coincide with the bottom of the euphotic zone (El-Sayed, 1972; El-Sayed and Turner, in press), pycnoclines (Hobson and Lorenzen, 1972), or nitrate nutriclines (El-Sayed and Turner,

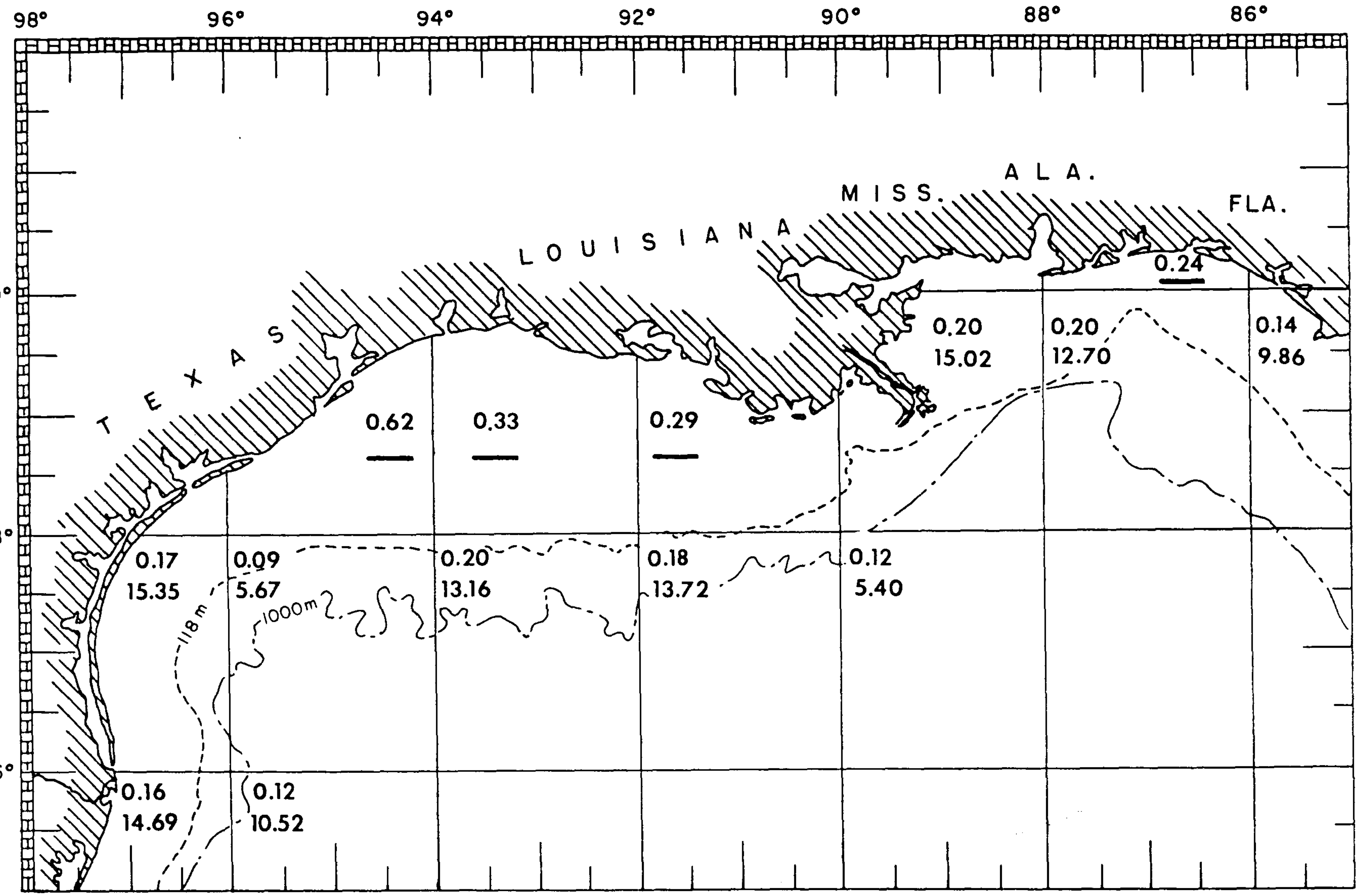

Fig. 5-27. Surface and integrated chlorophyll-a averages for 2° squares of latitude and longitude in the regions of the study area. Upper values are for the surface (mg chl-a/m^3) and lower values are integrated to the bottom of the euphotic zone (mg chl-a/m^2) (redrawn from El-Sayed, 1972).

in press). This pattern appears to be a regular feature in other oceanic areas (Anderson, 1969; Goering et al., 1970; Venrick et al., 1973). The subsurface chlorophyll-a maximum may be due to an increase in the chlorophyll-a content of shade-adapted phytoplankton cells (Steele, 1964), increased supply of nutrients (diffusing from deeper layers into nutrient-poor surface waters) to the phytoplankton of the chlorophyll-a maximum layer (Anderson, 1969), accumulation of sinking cells at pycnoclines, or a combination of these factors.

Primary Production

Geographic Distribution

Primary production averages for 2° squares of latitude and longitude for the area over the northern Gulf continental slope were low (Fig. 5-28) with surface and integrated values ranging from 0.08-0.26 $mgC/m^3/hr$ and 2.02-4.00 $mgC/m^2/hr$, respectively. Maximum values over the continental slope were off Panama City, Florida, with surface and integrated averages of 0.43 $mgC/m^3/hr$ and 5.0 $mgC/m^2/hr$, respectively (El-Sayed, 1972).

A comparison of oceanic values with Fucik's (1974) data from the adjacent continental shelf waters reveals the low primary production values of the continental slope and oceanic waters. His annual mean surface and integrated primary production values for Louisiana coastal waters were 26.53 $mgC/m^3/hr$ and 98.56 $mgC/m^2/hr$, respectively.

Vertical Distribution

In a pattern similar to the vertical chlorophyll-a distributions previously discussed, maximum primary production values in the Gulf of Mexico occur at depths of 20-60 m (El-Sayed, 1972; El-Sayed and Turner, in press). A probable explanation for the reduced primary production near the surface is photoinhibition where intense sunlight may bleach photosynthetic pigments.

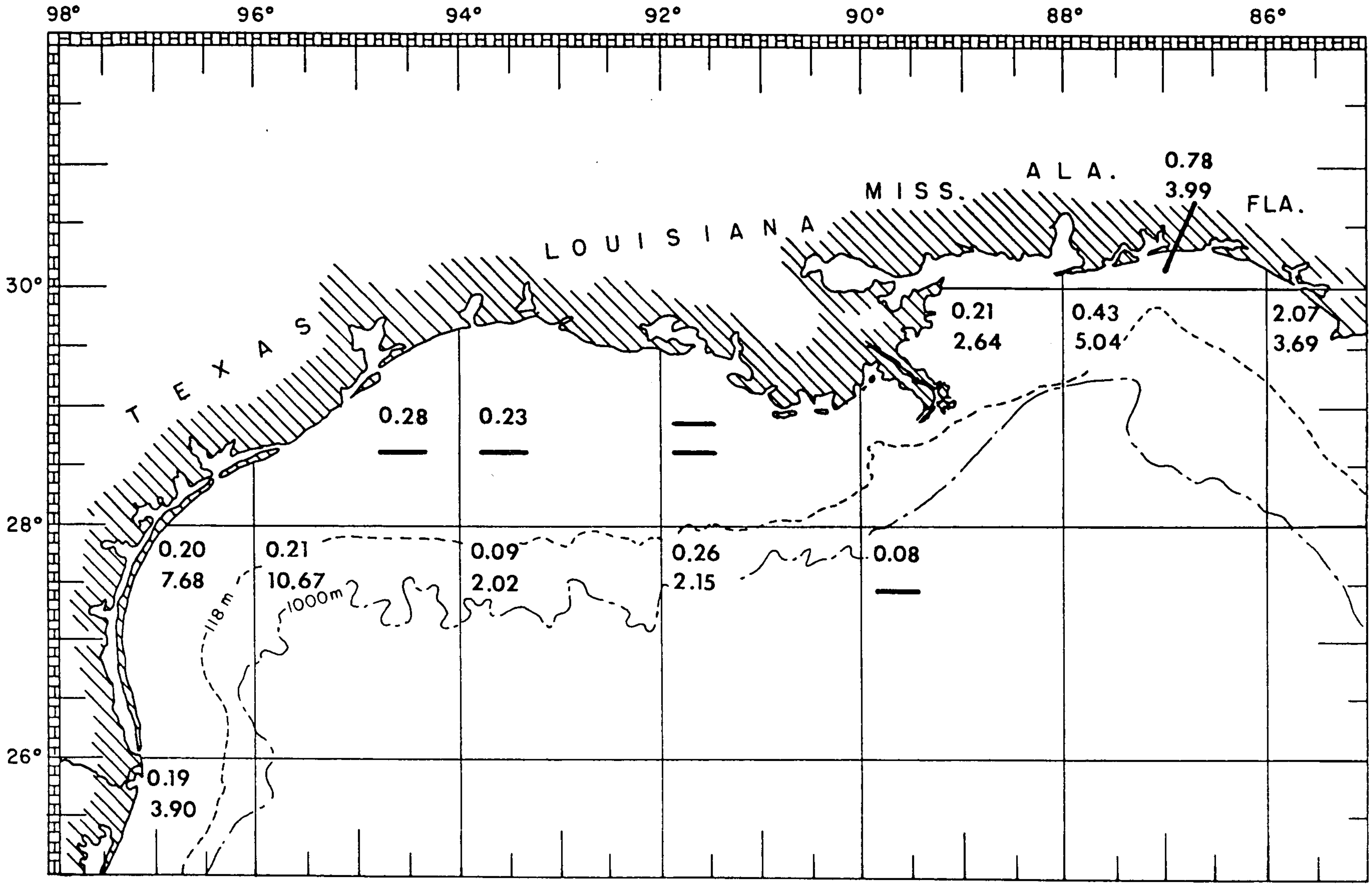

Fig. 5-28. Surface and integrated primary production averages for 2° squares of latitude and longitude in the regions of the study area. Upper values are for the surface (mgC/m^3/hr) and lower values are integrated to the bottom of the euphotic zone (mgC/m^2/hr) (redrawn from El-Sayed, 1972).

Seasonal Cycles

Phytoplankton Species Distributions and Numbers

The only available data for the northern Gulf of Mexico come from the studies of Thomas and Simmons (1960) and Fucik (1974), east and west of the Mississippi Delta, respectively. In both studies, phytoplankton numbers were highest in spring and lowest in fall in inshore waters, but Thomas and Simmons (1960) found no significant differences at their most seaward stations. In addition, Fucik found that diatoms comprised 72-90% of the cell numbers while dinoflagellates accounted for only 10-28% of the phytoplankters present.

Seasonal Cycles of Standing Crop and Primary Production

Maximum surface chlorophyll-a values for the Gulf of Mexico as a whole were found in winter, with decreases in the spring followed by gradual increases during summer and fall. The mean integrated chlorophyll-a values for summer and winter were identical, and only slightly higher than those for spring and autumn (El-Sayed, 1972).

Seasonal primary production patterns for the Gulf of Mexico as a whole, generally parallel those of chlorophyll-a with maximum values in winter (El-Sayed, 1972). The amplitude of seasonal changes in primary production and chlorophyll-a concentrations in the oceanic regions of the Gulf is small (El-Sayed, 1972).

Seasonal differences are much more apparent in inshore waters along the northern Gulf of Mexico. In waters near the Mississippi Delta, there were increases in primary production in spring, coinciding with increased river discharge (Thomas and Simmons, 1960; Fucik, 1974). Primary production values during the spring of 1973 were six times higher than those of the previous fall due to the spring flood of the Mississippi River. The flood drove low-salinity, high-nutrient river water out into the Gulf, forming a low density layer where high levels of nutrients were maintained near the surface by stratification (Fucik, 1974). The influence of the Mississippi River flood may be reflected in high chlorophyll-a and nutrient levels extending 30-40 miles seaward into the Gulf and 80 miles west of the river mouth (Riley, 1937). By contrast, total plankton biomass east of the Mississippi Delta decreased to 130 mg/m^3 from mean values of 200-1000 mg/m^3 during a period of reduced river discharge (Bogdanov et al., 1968).

Summary

Phytoplankton species distributions in the Gulf of Mexico are still not well known. Although some qualitative net sampling has been carried out, there have been no comprehensive, seasonal, quantitative studies for the slope and oceanic regions comparable to those in Florida estuaries, over the Florida shelf, and in the Mississippi Delta region.

Major unanswered questions concerning phytoplankton species distributions persist. For example, the nannoplankton (phytoplankton which are so small that they pass through conventional phytoplankton nets) were found to account for averages of 83-84% of the chlorophyll-a and 84-89% of the primary production in the Gulf of Mexico (Fay, 1974; El-Sayed and Turner, in press). There has been no attempt to identify the species comprising the nannoplankton which are probably the most important primary producers in the slope and oceanic waters of the Gulf of Mexico.

Primary production and chlorophyll-a patterns in the Gulf of Mexico are more thoroughly understood than are phytoplankton species distributions. Except for the regions near the Mississippi Delta and the Yucatan Peninsula the production of the Gulf is low, and overall primary production averages for the Gulf of Mexico are similar to those reported for other tropical and subtropical areas (Steeman Nielsen, 1954; Menzel and Ryther, 1960; Beers et al., 1968; Owen and Zeitzschel, 1970).

Although there are more data on the seasonal distributions of primary production and chlorophyll-a concentration than for phytoplankton species, these data for oceanic regions were collected in widely scattered areas during different years (El-Sayed, 1972). The only concerted seasonal studies of primary production were performed in the Mississippi Delta region (Thomas and Simmons, 1960; Fucik, 1974). It appears, however, that seasonal variations in phytoplankton production and standing crop are small in the oceanic waters of the Gulf of Mexico. Seasonal fluctuations in these parameters are more apparent on the northern Gulf continental shelf but these are largely a function of the increased nutrient load supplied by the seasonal flooding of the Mississippi River.

ZOOPLANKTON

Distribution of Predominant Species

Practically every major animal phylum makes some contribution to the zooplankton. Although most zooplankters remain planktonic throughout their existence, a large array of animals occurs in the plankton during only part of their lives. Those organisms which spend only part of their lives as plankton are known as meroplankton in contrast to the holoplankton which remain in the plankton throughout their life cycle. Meroplankton includes the larvae of benthonic invertebrates (viz., trochophores and veligers of mollusks, nauplii of barnacles, various larval stages of crabs and shrimps, larvae of echinoderms, and etc.) as well as eggs and larval stages of many fish species. Included in the holoplankton are siphonophores, ctenophores, pteropods, euphausiids, and most copepods and chaetognaths. Of course, members of most other larger animal groups are also represented in the holoplankton but do not conform to generalities.

In neritic waters of the Gulf of Mexico (i.e., extending seaward to a depth of about 200 m) the meroplankton reach their greatest abundance and often exceed the holoplankton. In the oceanic zone (seaward of the neritic zone) holoplanktonic species predominate. The present study area, delineated previously, is essentially a zone of transition between the neritic and oceanic zones.

As will be shown in Section 8 on Fishery Potential, the only adult shrimp of commercial importance occurring in the present study area is the royal red shrimp, Hymenopenaeus robustus. The waters of this study area, however, do contain small numbers of the meroplanktonic shrimp larvae of various commercially important species. Temple (1965) reported on 385 plankton tows taken on the northwestern Gulf continental shelf. The total catch of planktonic penaeid larvae was 27,800; of this total, the larvae of commercially important shrimp (Penaeus spp.) made up 20% of the catch with non-commercial forms, namely Trachypenaeus spp. (47%), Sicyonia spp. (24%), Solenocera spp. (7%), and Parapenaeus spp. (2%) making up the remainder. Figure 5-29 shows the yearly distribution of Penaeus spp. larvae in the northwestern Gulf.

By and large the most abundant holoplanktonic zooplankton groups of the present study area are copepods, chaetognaths, euphausiids and pteropods. These four groups are discussed separately below.

Copepods

Copepods are very small crustaceans, most ranging from less than one millimeter to several millimeters in length. Marine copepods exist in enormous numbers; they may be the most abundant metazoans on the earth. It is their enormous numbers that delegates their importance in the marine food web. As was shown by Fleminger (1957,1959), certain copepod species or groups of species are excellent water mass indicators. Fleminger (1957) established the value of the pontellid copepods as indicators of Gulf waters. Labidocera acutifrons and Pontella spiniceps are tropical-oceanic, L. aestiva and P. meadi are temperate-neritic, and L. scotti is tropical-neritic. Fleminger (1959) also studied the geographic distribution of calanoid copepods from Gulf waters based on approximately 500 samples. The majority of the Gulf species are tropical forms inhabiting equatorial waters around the world. Some neritic species with temperate North Atlantic affinities vary in their adaptation to tropical conditions such as Centropages hamatus, Acartia tonsa, Pseudodiaptomus coronatus, and Labidocera aestiva. These species are

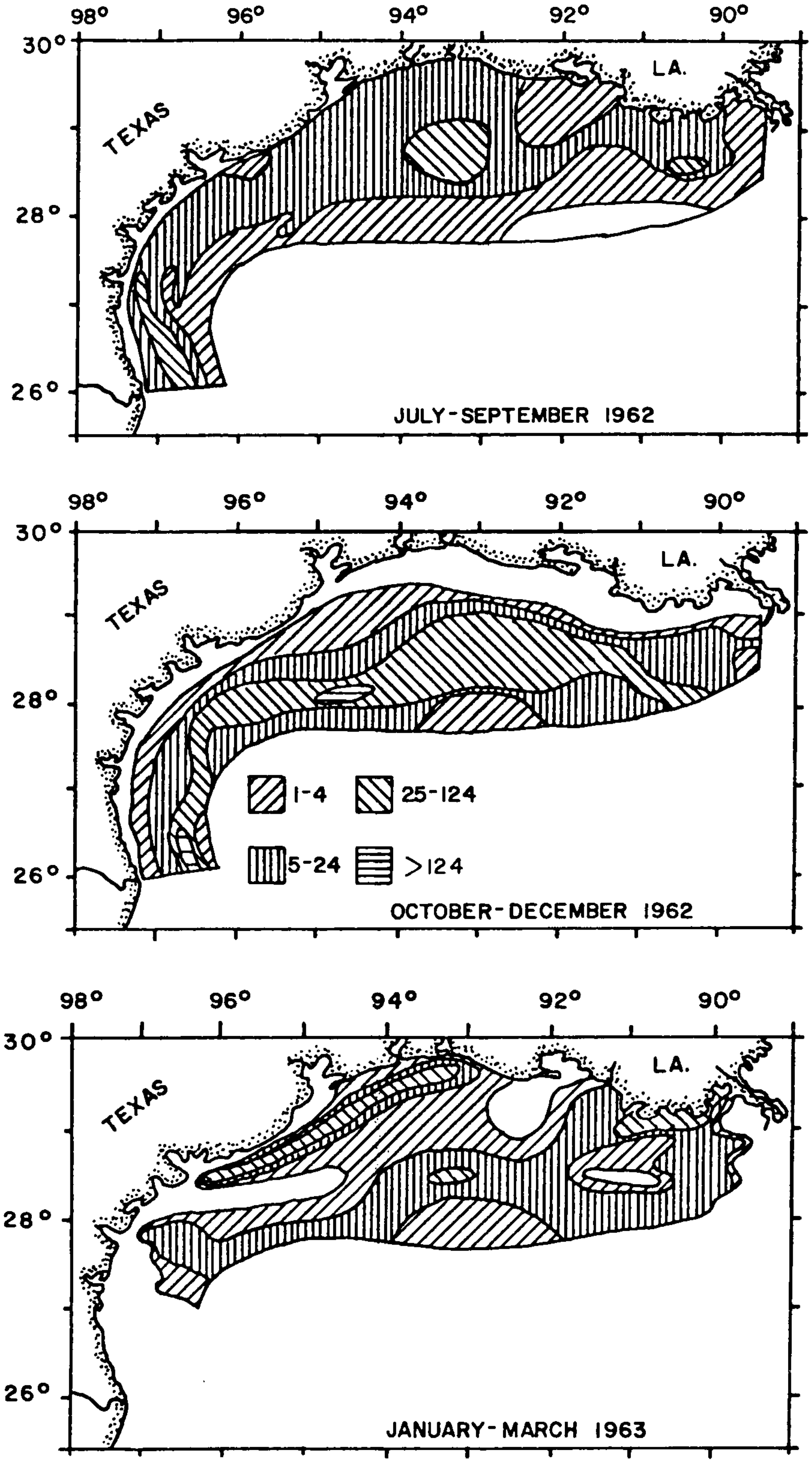

Fig. 5-29. Distributions of numbers of planktonic-stage Penaeus spp. per standard plankton tow in the northwestern Gulf during the period July 1962 to March 1963 (after Temple, 1965).

numerous in coastal and estuarine waters with winter minima of 10°C and summer maxima temperatures of 28°C. When the lowest temperature in winter is 8°C, they diminish in quantity.

In relation to onshore-offshore gradients Fleminger (1959) found 5 modes of spatial distribution of copepod species, in successive bands parallel to the shoreline with overlapping boundaries:

1. Estuarine facies - in estuaries, lagoons, and contiguous coastal waters: *Acartia tonsa* and *Paracalanus crassirostris*.
2. Coastal-Neritic facies - inshore to midcontinental shelf waters: *Centropages furcatus* and *Temora tubinata*.
3. Neritic-Shelf facies - roughly between the 20 m and 200 m isobaths: *Eucalanus pileatus* and *Paracalanus parvus*.
4. Shelf-Oceanic facies - the outermost shelf and slope: *Clausocalanus furcatus* and *Undinula vulgaris*.
5. Oceanic facies - oceanic waters: *Centropages violaceus* and *Pontellina plumata*.

Park (1970) reported on the calanoid copepods collected with a modified Nansen net used during R/V CHAIN Cruise 60 in the Gulf and Caribbean. His study was principally systematic but a check list of species and their vertical distribution within the oceanic Gulf were gleaned from his data and are presented in Table 5-2. Park's (1970) Gulf samples were chiefly taken from below 200 m which probably accounts for the large number of species listed as bathypelagic.

Chaetognaths

The phylum Chaetognatha is a group of exclusively marine invertebrates. With the exception of the benthonic genus *Spadella*, all chaetognaths are holoplanktonic. These organisms are voracious carnivores, feeding heavily on crustaceans and larval fishes. This, coupled with their being among the most common plankters, classifies them as being very important in the marine food web.

Table 5-2. Vertical zonation of calanoid copepods in the Gulf of Mexico as reported by Park (1970).

Epipelagic

Calocalanus pavoninus
C. styliremis
Paracalanus parvus
Clausocalanus furcatus
C. paululus
Heterohabdus spinifera
Ctenocalanus vanus
Euaetideus acutus
E. giesbrechti
Scolecithricella vittata
Lucicutia paraclausi
L. favicornis

Mesopelagic

Spinocalanus parabyssalis
S. brevicaudatus
S. oligospinosus
Chiridius gracilis
Chirundina streetsii
Gaetanus minor
G. pileatus
Scaphocalanus subcurtus
S. amplius
S. brevirostris
S. magnus
Scrolecithricella abyssalis
S. dentata
Scolecithrix brady
Temoropia mayumbaensis
Lucicutia clausi
Heterohabdus papilliger
H. vipera
H. medianus
Haloptilus paralongicirrus
Pseudodaugaptilus longiremis

Bathypelagic

Eucalanus attenuatus
E. elongatus
Rhincalanus cornutus
Farrania frigidus
Microcalanus pygmaeus
Mimocalanus crassus
M. cultrifer
M. nudus
Monacilla tenera
Spinocalanus abyssalis
S. spinosus
S. pteronus
S. usitatus
S. horridus
S. magnus
Teneriforma naso
Chiridiella bispinosa
C. poppei
Undinella brevipes
Metridia brevicauda
M. curticauda
Lucicutia curta
L. ovalis
Heterorhabdus abyssalis
Euchirella pulchra
E. splendens
Undeuchaeta major
U. plumosa
Xanthocalanus paululus
Racovitzanus porrecta
Scaphocalanus curtus
S. echinatus
S. major
S. longifurca
S. acuminatus
Scolecithricella emarginata
S. maritima
S. ovata
S. valens
S. pseudoarcuata
S. lobophora
Scollocalanus helenae
S. persecans
Euaugaptilus nodifrons
E. palumboi
Haloptilus longicirrus
Bathypontia minor
B. similus

Studies by Pierce (1951, 1954, 1962), Adelmann (1967) and Every (1968) have delineated the Gulf's chaetognath fauna. Pierce's (1951, 1962) and Adelmann's (1967) studies were confined to the neritic Gulf while Every's (1968) study concentrated on the oceanic waters of the Gulf. No obvious east-west geographical affinities have been found. However, definite neritic-oceanic distributions are present. In Table 5-3 the common chaetognatha found in the Gulf are listed along with their neritic or oceanic affinities. Sagitta enflata, a cosmopolitan species has been reported to be the most abundant chaetognath species in neritic as well as oceanic waters. The remaining species listed in Table 5-3 should be considered expatriates when found outside their designated zones. Of course, since the present study area is essentially at the neritic-oceanic boundary it is safe to assume that all species listed in Table 5-3 will be found to a greater or lesser degree in the present study area.

Table 5-3. List of common neritic and oceanic chaetognaths reported from the Gulf of Mexico.

Species	Designation
Sagitta enflata	Cosmopolitan
Sagitta hexaptera	Oceanic
Sagitta serratodentata	Oceanic
Sagitta bipunctata	Oceanic
Sagitta decipiens	Oceanic
Sagitta helenae	Neritic
Sagitta hispida	Neritic
Sagitta tenuis	Neritic
Krohnitta pacifica	Neritic
Pterosagitta draco	Oceanic

The majority of Every's (1968) samples were taken with open nets thus specific vertical distribution data were not obtained. However, upon examination of data from his opening-closing nets combined with data of depth of tow vs species collected from open nets, certain distributional trends appear. From these data Table 5-4 was derived denoting those chaetognaths found in the Gulf and designating their probable vertical distributions as epipelagic, mesopelagic, or bathypelagic.

Table 5-4. Vertical distribution of Gulf chaetognaths (from Every, 1968).

Epipelagic	
Pterosagitta draco	Sagitta hispida
Sagitta enflata	Sagitta bipunctata
Sagitta hexaptera	Sagitta serratodentata
Sagitta helenae	Sagitta tenuis
	Krohnitta pacifica
Mesopelagic	
Krohnitta subtilis	Sagitta minima
Sagitta decipiens	Sagitta lyra
Bathypelagic	
Eukrohnia fowleri	Sagitta macrocephala
Eukrohnia hamata	

Euphausiacea

The euphausiacean fauna of the Gulf is typical of that of the tropical western Atlantic (James, 1971). Investigations by James (1970) and Schroeder (1971) showed that 33 species occur in the Gulf. These latter investigators' samples were concentrated mainly in oceanic waters, but several of their stations were taken in or very near the present study area. Dividing the northern Gulf into east and west sectors by 90°W longitude, Schroeder (1971) listed the species by abundance for the northwest and northeast Gulf. Table 5-5 gives the 10 most abundant species found by Schroeder (1971) in each of the areas. Distributional data presented by James (1971) documents the presence of Schroeder's most abundant species in the present study area. Cognizance of sampling technique limitations and lack of seasonal data prompted James (1970, 1971) and Schroeder (1971) not to speculate on euphausiacean geographical affinities which may exist for the Gulf of Mexico.

Table 5-5. The ten most abundant euphausiids, arranged in decreasing order of abundance, found in the northwest and northeast Gulf (from Schroeder, 1971).

Northwest	Northeast
Stylocheiron schumii	Nematoscelis microps-atlantica
Euphausia tenera	Stylocheiron carinatum
Stylocheiron carinatum	Euphausia tenera
Euphausia mutica	Stylocheiron abbreviatum
Euphausia americana	Stylocheiron schumii
Stylocheiron affine	Euphausia americana
Stylocheiron abbreviatum	Euphausia pseudogibba
Nematoscelis microps-atlantica	Stylocheiron longicorne
Stylocheiron longicorne	Euphausia hemigibba
Euphausia hemigibba	Stylocheiron affine

James (1971) generalized the vertical distribution of Gulf euphausiids as (1) Epipelagic - adults common above 100 m, (2) Mesopelagic - adults from 100-700 m, (3) Bathypelagic - adults below 700 m. Species belonging to these categories are given in Table 5-6.

Table 5-6. Vertical distribution of Gulf euphausiaceans. Asterisk (*) denotes those species reported by Schroeder (1971) as diurnal vertical migrators.

Epipelagic

Euphausia americana*	Nematoscelis microps
E. brevis*	Stylocheiron abbreviatum
E. gibboides*	S. affine
E. hemigibba*	S. carinatum
E. mutica*	S. suhmii
E. pseudogibba*	Thysanopoda monacantha
E. tenera*	T. subequalis*
Nematoscelis atlantica	T. tricuspidata*

Mesopelagic

Nematobranchion boopis	Stylocheiron maximum
N. flexipes	S. robustum
N. sexspinosum	Thysanopoda cristata
Nematoscelis tenella	T. obtusifrons
Stylocheiron elongatum	T. orientalis
S. longicorne	T. pectinata

Bathypelagic

Bentheuphausia amblyops	Thysanopoda egregia
Thysanopoda cornuta	

Pteropod Mollusks

Pteropods, which are holoplanktonic mollusks, are important contributors to the plankton of oceanic waters, but are of little importance to the inshore or coastal plankton. As emphasized by Bjornberg (1971) an abundance of pteropod species usually indicates offshore waters. Their direct importance to man as indicator organisms may soon be more fully exploited. Austin (1971) has shown that water masses of the eastern Gulf can be recognized and differentiated by occurrence of certain pteropods. He concluded that biological characteristics of water permit a finer definition of water masses than do physical or chemical parameters. In particular, Austin found that the velocity core of the Loop Current and regions of upwelling could be recognized by the presence of particular species of pteropods and foraminiferans.

The inshore area of the Gulf is depauperate in pteropod species. A comprehensive study of the plankton of St. Andrew Bay, Florida was reported by Hopkins (1966) who found only one species of pteropod, Creseis acicula, which is also very abundant in offshore waters.

On the northern Gulf shelf, the most abundant pteropod species reported by Snyder (1975) were juveniles of Limacina inflata, L. trachiformis, Creseis acicula acicula, and C. virgula conica. From samples taken at the Flower Gardens (27°54'N, 93°50.5'W) during March 1973 and March 1974, she reported pteropod abundances of 1003 - 3017/1000 m^3 and 9598 - 10,070/1000 m^3, respectively for the two years. She believed the fluctuations in abundance to be typical of pteropod populations in shallow water. For her few stations on the slope, abundances were up to 12,000 - 14,000/1000 m^3. In Gulf oceanic waters she reported the average concentration of pteropods to range between 10,000 - 20,000/1000 m^3.

Of the pteropod species reported by Snyder (1975), from the slope and oceanic waters of the Gulf, Limacina inflata was the most common species occurring in 90% of the samples, and frequently was the most abundant. She reported abundance for L. inflata up to 12,400/1000 m^3 for samples taken in the central Gulf. Listed below are pteropod species which occurred in at least 80% of Snyder's samples from Gulf slope and oceanic waters.

Limacina inflata	Styliola subula
Creseis acicula acicula	Hyalocylis striata
C. virgula conica	Diacria quadridentata
	Cavolina inflexa

The vertical distributions of pteropods are somewhat obscured by their diurnal vertical migrations, but considering only daytime collections, Snyder separated the Gulf species into the following two groups:

Group I 0-100 m	Group II >100 m
Limacina trochiformis	*Limacina inflata*
Creseis acicula acicula	*L. lesueurii*
C. virgula virgula	*L. bulimoides*
C. virgula conica	*Hyalocylis striata*
Cavolina inflexa	*Styliola subula*
Diacria quadridentata	*Clio pyramidata*
Peraclis reticulata	*C. cuspidata*
	Peraclis bispinosa
	Cavolina uncinata

Standing Crop

The principal standing crop research within the study area has come from U. S. Fish & Wildlife Service and Soviet-Cuba expeditions. Arnold (1958) reported on the plankton volumes of about 350 samples collected Gulf-wide by the Fish & Wildlife Service. He divided the Gulf into eight subareas; four subareas which relate to the present study area are shown in Fig. 5-30. Table 5-7 gives the average seasonal plankton volumes for each subarea in three bottom depth ranges.

Khromov (1965) and Bogdanov et al. (1969) reported on the distribution of plankton standing crop collected in conjunction with the Soviet-Cuban expeditions of 1962-1966. These Soviet researchers' data cannot be directly compared with Arnold's (1958) since different field and laboratory techniques were used. However, as will be shown later, the overall picture is about the same. Figures 5-31 and 5-32 give the food plankton (net plankton less the detritus) standing crop as reported by Khromov (1965).

From the studies mentioned above two trends become clear. First, the western half of the study area has a lower plankton standing crop than does the eastern half, and second, the standing crop in the upper layers generally decreases with increasing distances from shore or increasing depth.

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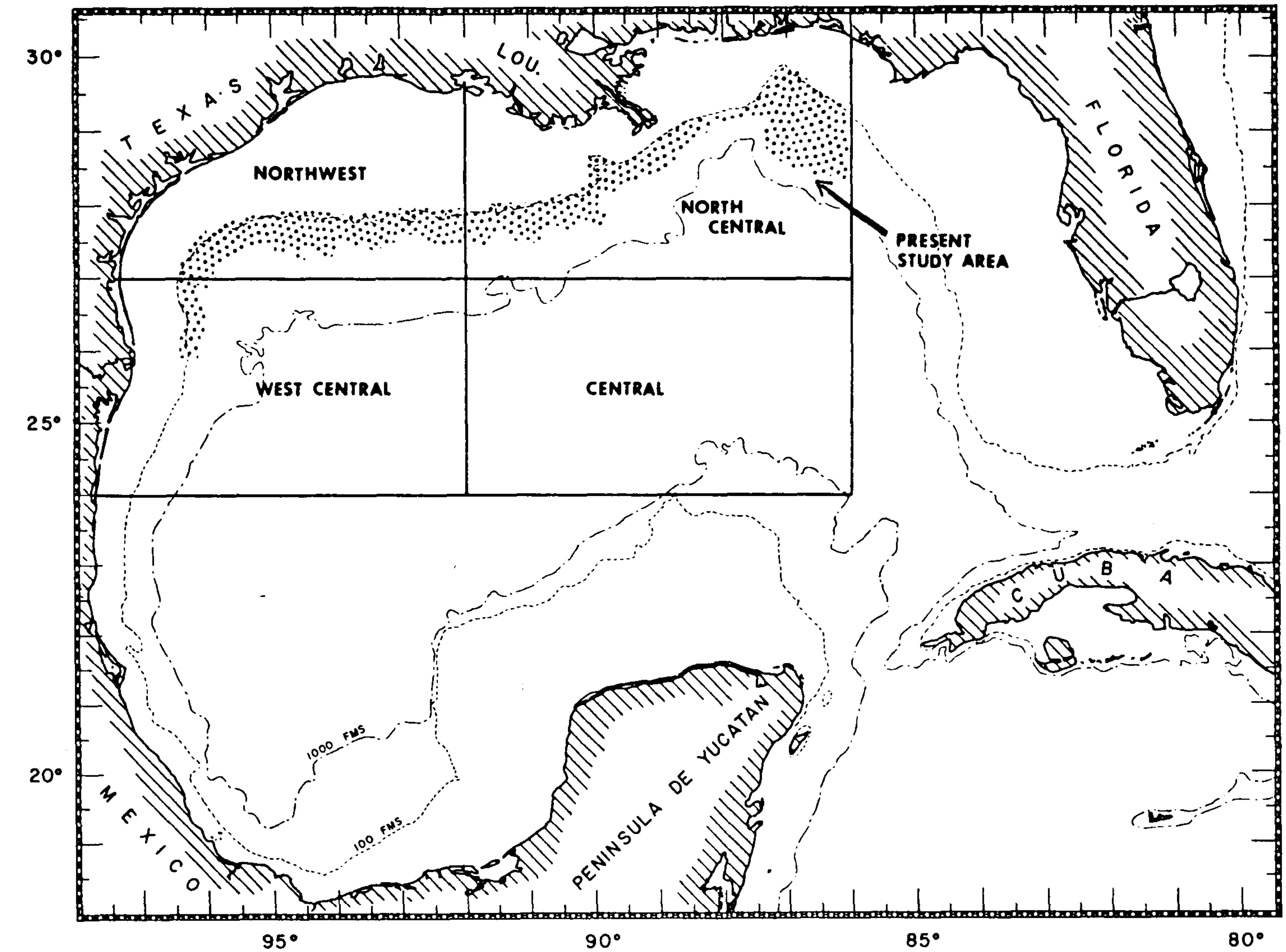

Fig. 5-30. Arnold's (1958) subareas which relate to the present study.

Table 5-7. Gulf of Mexico seasonal plankton standing crop (ml/m^3) for three bottom depth ranges. Area designations equate to those on Fig. 5-30. The number of samples is given in parentheses ( ) (from Arnold, 1958).

Area	0-100 fms			100-1000 fms			over 1000 fms		
	winter	spring	fall	winter	spring	fall	winter	spring	fall
NW	.055	.104		.009					
	(10)	(14)		(2)					
NC	.094	.142	.152	.113	.061	.074	.091	.054	.096
	(6)	(17)	(3)	(4)	(11)	(1)	(2)	(4)	(6)
WC		.065			.029			.008	
		(5)			(4)			(1)	
C							.038	.050	.063
							(9)	(8)	(1)

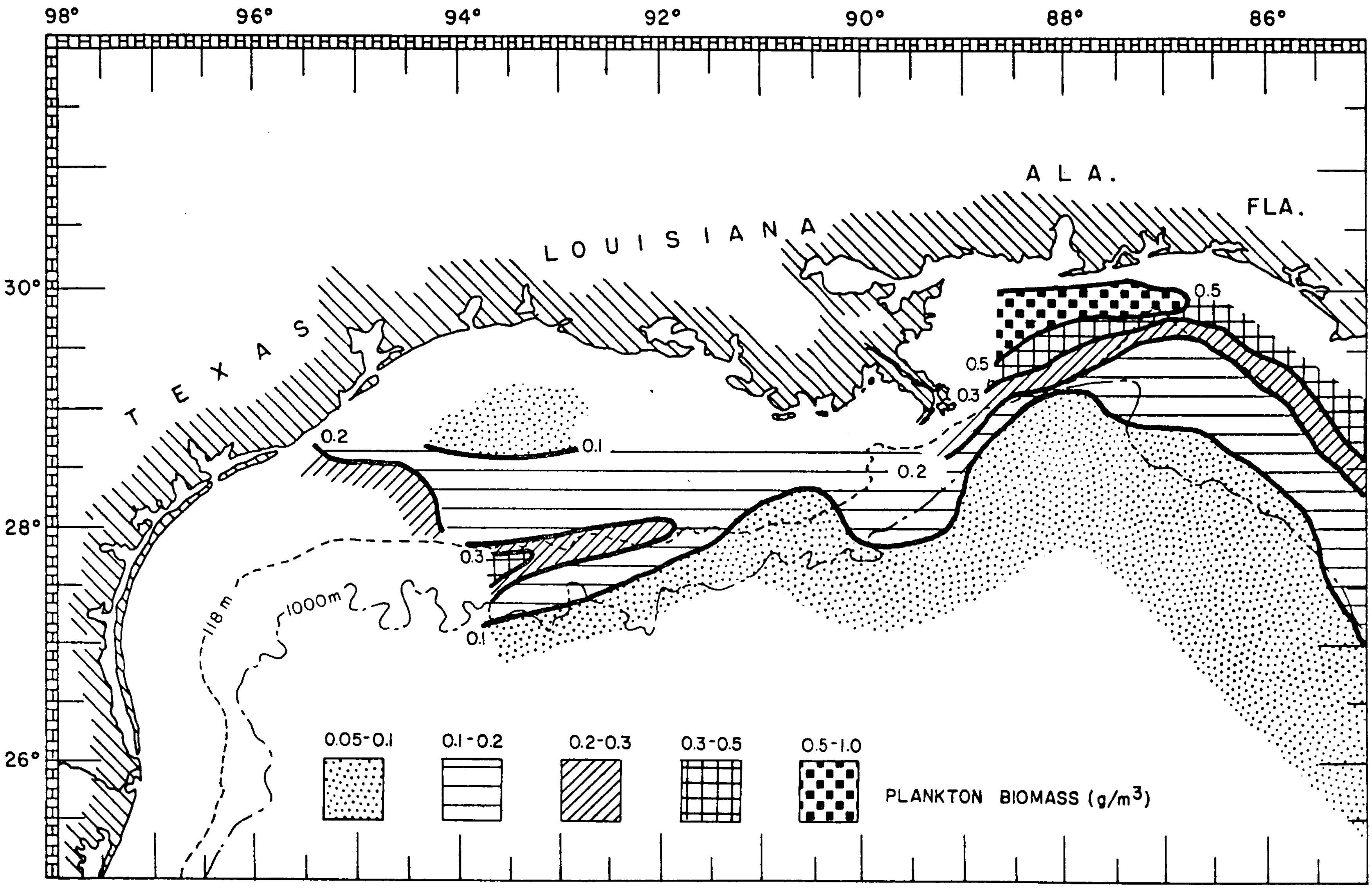

Fig. 5-31. Distribution of food plankton along the northern coast of the Gulf of Mexico during February-March 1964. (after Khromov, 1965).

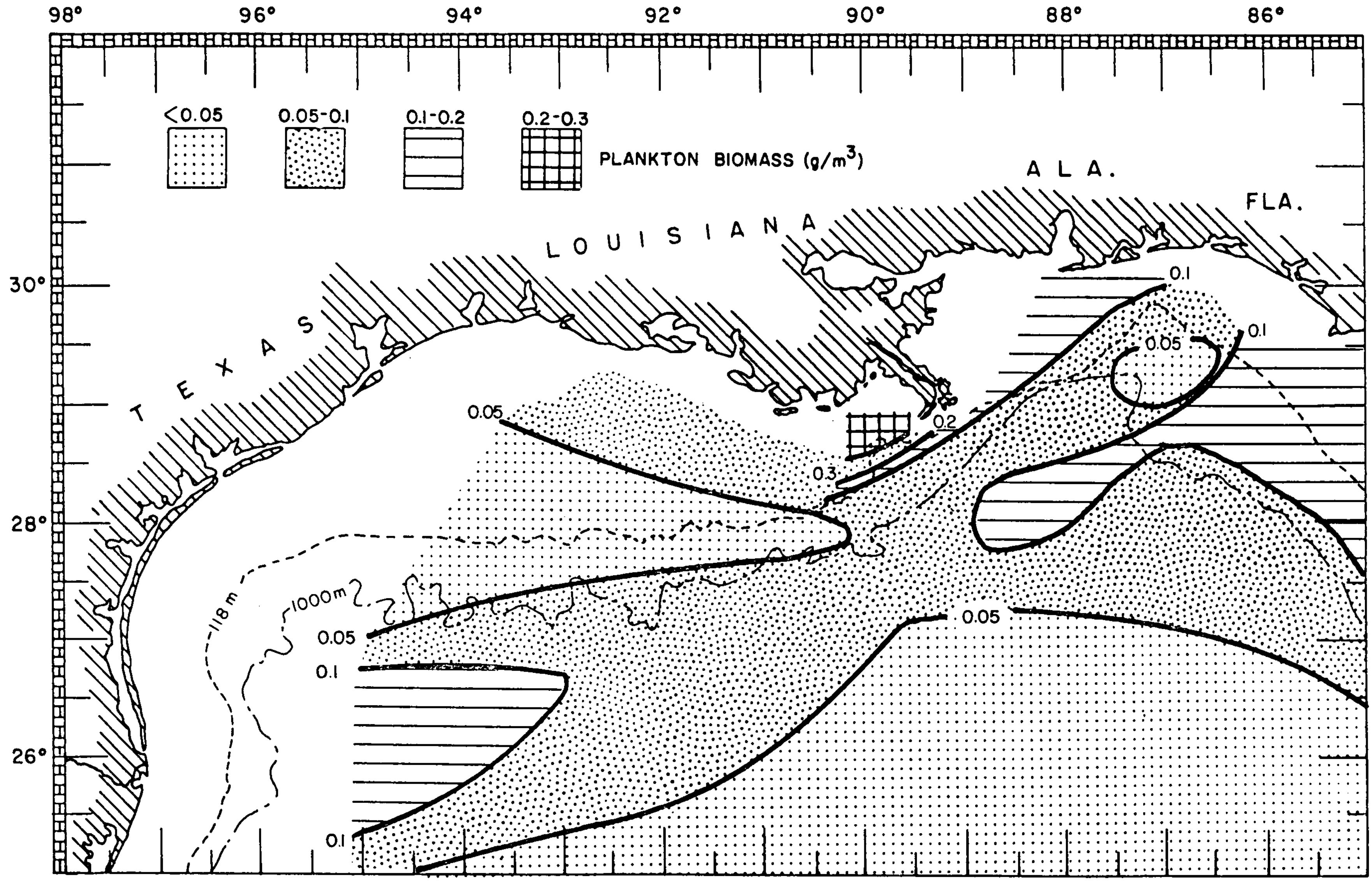

Fig. 5-32. Distribution of food plankton in the northern Gulf of Mexico during August-October 1964 (after Khromov, 1965).

Vertical Movements

Many zooplankters live by day at greater depths than during the night; that is, they carry out an upward and downward movement during the 24 hours. In general the organisms tend to rise toward the surface at sunset and descend to deeper water at sunrise. The amount of vertical movement varies from species to species, season to season, and also according to the developmental stage and sex.

A strong correlation between the vertical distribution of migrants and the vertical distribution of a given light intensity (isolume) has been shown by several investigators, e.g., Moore, 1950; Hardy, 1965; Clarke and Backus, 1956; Owre, 1960; Banse, 1964; Bright et al., 1972. In the Gulf of Mexico, plankton sampling conducted before, during, and after a mid-day solar eclipse revealed migrants to be at a significantly shallower depth during the eclipse (Bright et al., 1972). Many planktonic animals swim faster in light than in complete darkness, thus during the night animals move slower and thereby tend to sink. At dawn the preferred isolume will be above the animals and they swim upwards to it; then as light increases the organisms descend following their optimum isolume (Friedrick, 1969). However, according to Moore (1950) and Owre (1960) the depth taken by some planktonic migrants during the day appears to be determined by temperature.

The speed at which these animals move is considerable when one takes into account their size. In the laboratory barnacle nauplii covered 16m/hr, copepods (Centropages sp.) moved 82m/hr, and euphausiids and pelagic polychaetes have been recorded up to 200m/hr (Friedrick, 1969 ; Hardy and Bainbridge, 1954). Ascent of the deep scattering layer as measured by fathometer tracings, has been shown to have a speed of approximately 300m/hr (Dietz, 1948). Undoubtedly, the deep scattering layer contains bathypelagic fish (Families Gonostomatidae, Sternaptychidae, and Myctophidae), squids, siphonophores, and larger crustaceans. Bé (1966) reported the above groups of organisms can migrate at a rate of 300-900m/hr.

NEKTON

Nekton includes marine mammals, most fishes and cephalopod mollusks, and certain crustaceans which, because of their powerful swimming abilities, are able to move independently of water currents. These species are often able to escape most nets and other collecting gear, hence knowledge of the geographic and vertical distribution patterns of nektonic species is often incomplete. Nekton of the surface waters is of less immediate concern in the ecology of the deep slope, and some of the surface nektonic species are covered in the discussion of the fishery potential of the continental slope area. Therefore, the present section deals with the nekton of the midwater (=aphotic) zone of the Gulf. The predominant components of this fauna are cephalopods, shrimps, and fishes.

Cephalopods - Lipka (1975) reported 66 species of pelagic cephalopods from the Gulf. Most species were represented by very few adult specimens, and collections of abundant adults occurred at only a few locations. On the basis of such limited data Lipka was unable to establish any clearcut faunal distributional patterns within the open Gulf.

Cephalopods of the neritic zone include *Doryteuthis plei*, *Loligo pealei*, and *Lolliguncula brevis*. *L. brevis* is ubiquitous in nearshore regions where it generally inhabits estuaries and bays with salinities as low as 17 ppt. *D. plei* and *L. pealei* tend to be found in more saline waters of the shelf.

The majority of Lipka's pelagic cephalopod samples were collected during descent or ascent of bottom dredges and trawls. Thus, precise bathymetric distributional limits were impossible to determine. However, Lipka determined the probable vertical distributions of certain species based upon morphological indicators described by Voss (1967). The probable bathymetric distribution patterns of the pelagic cephalopods of the Gulf of Mexico are given in Table 5-8 (compiled from Lipka, 1975).

Table 5-8. Vertical distribution of Gulf cephalopods (compiled from Lipka, 1975).

Epipelagic (0-200 m)

Onykia carriboea
Onychoteuthis banksi
Ommastrephes pteropus
Ommastrephes bartramii
Thysanoteuthis rhombus
Liocranchia reinhardti
Leachia cyclura
Cranchia scabra
Heteroteuthis hawaiiensis
Tremoctopus violaceous
Argonauta argo

Mesopelagic (200-700 m)

Enoploteuthis leptura
Enoploteuthis anapsis
Abralia veranyi
Abralia grimpei
Pyroteuthis margaritifera
Pterygioteuthis giardi
Pterygioteuthis gemmata
Lycoteuthis diadema
Oregoniateuthis springeri
Selenoteuthis scintillans
Histioteuthis corona corona
Histioteuthis dofleini

Bathypelagic (700-2000 m)

Chiroteuthis lacertosa
Bathyteuthis abyssicola
Mastigoteuthis glaucopsis
Mastigoteuthis grimaldi
Joubiniteuthis portieri
Cycloteuthis sirventi
Japetella diaphana
Eledonella pygamaea
Grimalditeuthis bomplandii
Sandalops ecthambus
Corynomma speculator
Egea inermis
Phasmatopsis oceanica
Bathothauma lyromma
Helicocranchia pfefferi
Helicocranchia papillata
Megalocranchia megalops
Vampyroteuthis infernalis

Crustacea - Decapod and mysidacean shrimps are conspicuous components of the mid-water fauna. L. Pequegnat (1972) noted that of the 23 species of penaeid shrimps known to occur from depths below 200 m, only six are pelagic, and only two of these (Gennadas valens and Bentheogennema intermedia) can be considered "common". Of the 63 species of caridean shrimps occurring below 200 m, 22 species are pelagic, and only three of these (Acanthephyra purpurea, Acanthephyra stylorostrata, and Systellaspis debilis) may be called "common". Ten species of deep-sea mysidacean shrimps are known from the open Gulf, and only three of these (Gnathophausia ingens, Eucopia australis, and Eucopia sculpticauda) are considered "common".

L. Pequegnat (based upon unpublished research still in progress) has provided information concerning approximate depth ranges, areas of occurrence, and relative abundance of the meso-and bathypelagic species of penaeid, caridean, and mysidacean shrimps of the Gulf of Mexico (Table 5-9).

Table 5-9. Meso-and bathypelagic shrimps and their distribution and relative abundance in the Gulf of Mexico listed in order of relative abundance within each group.

MESOPELAGIC (200-700 m)

	Relative Abundance	Area of Gulf in Order of Abundance
PENAEIDAE		
*Gennadas valens (Smith, 1884)	Abundant	NE,NW,SE,SW
*Bentheogennema intermedia Bate, 1888	Common	SW,NE,NW,SE
*Gennadas capensis Calman, 1925	Sparse	SE,NE,NW,SW
Gennadas scutatus Bouvier, 1906	Sparse	SE, NE
*Gennadas bouvieri Kemp, 1909	Sparse	SE,NE,SW
Gennadas talismani Bouvier, 1906	Rare	NE,SE
CARIDEA		
*Acanthephyra purpurea A. Milne-Edwards, 1881	Common	SW,NW,NE,SE
*Systellaspis debilis (A. Milne-Edwards, 1881)	Common	SW,NW,NE,SE
*Oplophorus gracilirostris A. Milne-Edwards, 1881	Sparse	SW,SE,NE,NW
*Oplophorus spinicauda A. Milne-Edwards, 1881	Sparse	SW,SE,NE,NW
*Parapandalus richardi (Courtière, 1905)	Sparse	SW,SE,NE
Psathyrocaris infirma Alcock & Anderson, 1894	Rare	SW
MYSIDACEA		
*Gnathophausia ingens (Dohrn, 1870)	Common	NE,SE,NW,SW
*Gnathophausia zoea Willemoes-Suhm, 1875	Common	SE,SW,NE,NW

Table 5-9 (cont'd)

BATHYPELAGIC (700-2000 m)

	Relative Abundance	Area of Gulf in Order of Abundance
CARIDEA		
Acanthephyra stylorostrata (Bate, 1888)	Common	SW,NE,NW
*Acanthephyra acanthitelsonis Bate, 1888	Sparse	NE,SW,NW
*Acanthephyra curtirostris Wood-Mason, 1891	Sparse	SW,NE,NW,SE
*Acanthephyra acutifrons Bate, 1888	Sparse	SW,NE,NW,SE
*Notostromus gibbosus A. Milne-Edwards, 1881	Sparse	NE,NW,SW,SE
*Acanthephyra brevirostris Smith, 1885	Sparse	NW,SW,NE
Oplophorus spinosus (Brulle, 1835)	Rare	SW,NE
Ephyrina benedicti Smith, 1885	Rare	SW,NW
Meningodora mollis Smith, 1882	Rare	SW,NE
*Parapasiphai cristata Smith, 1884	Rare	SW,NE
*Ephyrina hoskynii Wood-Mason, 1891	Rare	SW,NE
Acanthephyra pelagica (Risso, 1816)	Rare	SW
Notostomus longirostris Bate, 1888	Rare	SW
Hymenodora sp.	Rare	SW
Hymenodora glacialis (Buchholtz, 1874)	Rare	SW
Parapasiphae sulcatifrons Smith, 1884	Rare	NW
MYSIDACEA		
*Eucopia sculpticauda Faxon, 1893	Common	SE,SW,NE,NW
*Eucopia australis Dana, 1852	Sparse	NE,SE
*Gnathophausia gracilis Willemoes-Suhm, 1873	Rare	NE,SE
Gnathophausia gigas Willemoes-Suhm, 1873	Rare	SW

* Known to occur over the continental slope in the northern Gulf of Mexico study area.

Fishes - The fish groups which predominate in the mid-water areas of the Gulf of Mexico include the hatchetfishes (Sternoptychidae), lanternfishes (Myctophidae), lightfishes (Gonostomatidae), viperfishes (Chauliodontidae), and scaleless dragonfishes (Melanostomiatidae). Very little is known of the distribution of any of these groups in the northern Gulf of Mexico except the hatchetfishes. Baird (1971) noted the general world-wide depth distribution patterns for the following three sternoptychid genera:

Argyropelecus - high seas, pelagic; upper 600 m

Polyipnus - close to shore

Sternoptyx - high seas, pelagic; 500-1500 m

Bright and Pequegnat (1969) reported that of the 10 species of hatchetfishes known from the Gulf of Mexico, 8 are distributed Gulf-wide and are probably residents, and 2 species (Argyropelecus amabalis and Polyipnus laternatus) appear to be transients which are transported into and out of the eastern Gulf by the Loop Current. Within the Gulf hatchetfishes occur chiefly between the depths of 250 and 1500 m. They are apparently not associated with the sound-scattering layers above 200 m in the Gulf (which are apparently caused by invertebrates rather than by fishes). The data of Bright and Pequegnat suggest ascent at night and descent during the day for Argyropelecus aculeatus and most other members of the family. However, the reverse migration is suggested for Sternoptyx diaphana and possibly Argyropelecus hemigymnus, both of which tend to inhabit the deeper layers. Information concerning species of hatchetfishes taken with opening-closing midwater trawls at three depth levels in the Gulf of Mexico is given in Table 5-10.

In order to obtain information on the other groups of midwater fishes not previously reported upon in the literature, we are able to compile data on those midwater fishes fortuitously collected during descent and ascent of the benthic trawls and dredges within the depth limits of this study. Generally the fishes collected were small, since the larger, more mobile forms could more easily avoid capture. Also, mesopelagic and bathypelagic fishes, as a whole, tend to be smaller than epipelagic or benthonic representatives. The most commonly collected species (Table 5-11) are from families Sternoptychidae (hatchetfish), Chauliodontidae (viperfishes), Gonostomatidae (lightfishes) and Myctophidae (lanternfishes).

Most of the midwater pelagic fishes collected are well adapted to deep-sea pelagic life. Besides luminescent organs along the body which

Table 5-10. Numbers of hatchetfish caught per hour using opening-closing device (from Bright and Pequegnat, 1969).

Depth range (meters)		0-175	175-500	500-900
Hours	D	4.8	3.0	0.8
trawling time	N	1.9	4.4	2.4
Argyropelecus	D	-	-	-
affinis	N	-	0.2	-
Argyropelecus	D	-	-	1.2
gigas	N	-	-	-
Argyropelecus	D	-	1.0	-
hemigymnus	N	-	1.1	-
Argyropelecus	D	-	3.3	2.4
aculeatus	N	0.5	1.8	-
Argyropelecus	D	-	-	-
olfersi	N	-	0.5	-
Argyropelecus lynchus	D	-	-	-
lynchus	N	1.0	1.8	-
Sternoptyx	D	-	2.0	8.4
diaphana	N	-	0.2	6.8
Polyipnus	D	-	0.3	-
asteroides	N	-	0.2	-
All	D	-	5.7	12.0
species	N	1.6	6.0	6.8

D-Day
N-Night

are possessed by many of these fishes, some have luminescent organs on their barbels which may act as lures for attracting prey. Since food is relatively scarce in the mesopelagic and bathypelagic zones, the principle of large predator-small prey breaks down. A good example of this is Chauliodus sloanei which can engulf prey larger than it is by the means of opening its mouth and extending its stomach. Various other degrees of specialization are encompassed among the pelagic fishes collected during this investigation. Table 5-12 lists the Gulf pelagic fish species, along with their respective families, collected within the depth limits of this study.

Table 5-11. Most commonly collected pelagic fishes in descending rank of occurrence.

Species	Family
Sternoptyx diaphana	Sternoptychidae
Chauliodus sloanei	Chauliodontidae
Gonostoma elongatum	Gonostomatidae
Yarella blackfordi	Gonostomatidae
Cyclothone sp.	Gonostomatidae
Neoscopelus macrolepidotus	Myctophidae

Table 5-12. Alphabetized list of Gulf pelagic fish collected within the depth limits of the study area.

SPECIES	FAMILY	COMMON NAMES
Antennarius radiosus Garman, 1896	ANTENNARIIDAE	Frogfishes
Apogon sp.	APOGONIDAE	Cardinalfishes
Argyropelecus gigas Norman, 1930	STERNOPTYCHIDAE	Hatchetfishes
Argyropelecus lynchus Garman, 1899	STERNOPTYCHIDAE	Hatchetfishes
Argyropelecus sp.	STERNOPTYCHIDAE	Hatchetfishes
Aristostomias grimaldii Zugmayer, 1913	MALACOSTEIDAE	
Avocettina infans (Gunther, 1878)	NEMICHTHYIDAE	Snipe eels
Balistes capriscus Gmelin, 1788	BALISTIDAE	Triggerfishes
Bathophilus pawneei Parr, 1927	MELANOSTOMIATIDAE	Scaleless dragonfishes
Bathyclupea argentea Goode & Bean, 1895	BATHYCLUPEIDAE	
Bregmaceros atlanticus Goode & Bean, 1886	BREGMACEROTIDAE	Codlets
Bregmaceros cayorum Nichols, 1952	BREGMACEROTIDAE	Codlets
Chauliodus sloanei Bloch & Schneider, 1801	CHAULIODONTIDAE	Viperfishes
Chloroscombrus chrysurus (Linnaeus, 1766)	CARANGIDAE	Jacks & Pompanos
Cyclothone sp.	GONOSTOMATIDAE	Lightfishes
Diaphus metopoclampus Cocco, 1829	MYCTOPHIDAE	Lanternfishes
Diplophos taenia Gunther, 1878	GONOSTOMATIDAE	Lightfishes
Epigonus occidentalis Goode & Bean, 1895	APOGONIDAE	Cardinalfishes
Epigonus pandionis (Goode & Bean, 1881)	APOGONIDAE	Cardinalfishes
Epinnula magistralis Poey, 1851	GEMPYLIDAE	Snake mackerals
Equetus acuminatus (Bloch & Schneider, 1801)	SCIAENIDAE	Drums
Evermannella sp.	EVERMANNELLIDAE	
Gonostoma elongatum Gunther, 1878	GONOSTOMATIDAE	Lightfishes
Hygophum macrochir (Gunther, 1864)	MYCTOPHIDAE	Lanternfishes
Lagocephalus laevigatus (L., 1766)	TETRAODONTIDAE	Puffers
Macdonaldia sp.	NOTACANTHIDAE	Spiny eels
Macrorhamphosus scolopax (Linnaeus, 1758)	CENTRISCIDAE	Snipefishes
Malacosteus niger Ayres, 1848	MALACOSTEIDAE	
Melamphaes beanii Gunther, 1887	MELAMPHAEIDAE	
Melamphaes sp.	MELAMPHAEIDAE	
Melanostomias biseratus Regan & Trewavas, 1930	MELANOSTOMIATIDAE	Scaleless dragonfishes
Mullus auratus Jordan & Gilbert, 1882	MULLIDAE	Goatfishes
Neoscopelus macrolepidotus Johnson, 1863	MYCTOPHIDAE	Lanternfishes
Notacanthus analis Gill, 1883	NOTACANTHIDAE	Spiny eels
Oxyodon sp.	APOGONIDAE	Cardinalfishes
Peprilus burti Fowler	STROMATEIDAE	Butterflyfishes
Photostomias sp.	MALACOSTEIDAE	
Polymixia lowei Gunther, 1859	POLYMIXIIDAE	Beardfishes
Selar crumenophthalmus (Bloch, 1793)	CARANGIDAE	Jacks & Pompanos
Sphoeroides parvus Shipp & Yerger	TETRAODONTIDAE	Puffers
Sphoeroides splengeri (Bloch, 1782)	TETRAODONTIDAE	Puffers
Stenotomus caprinus Bean, 1882	SPARIDAE	Porgies
Sternoptyx diaphana Hermann, 1781	STERNOPTYCHIDAE	Hatchetfishes
Stomias ferox Reinhardt, 1842	STOMIATIDAE	
Stomias sp.	STOMIATIDAE	
Synagrops bella (Goode & Bean, 1895)	APOGONIDAE	Cardinalfishes

(continued on next page)

Table 5-12 (Continued)

SPECIES	FAMILY	COMMON NAMES
Synagrops spinosa Schultz	APOGONIDAE	Cardinalfishes
Trachurus lathami Nichols	CARANGIDAE	Jacks & Pompanos
Trichiurus lepturus L., 1758	TRICHIURIDAE	Cutlassfishes (Atlantic)
Upeneus parvus Poey, 1851	MULLIDAE	Goatfishes
Yarella blackfordi Goode & Bean, 1895	GONOSTOMATIDAE	Lightfishes

NEUSTON

Neuston designates the fauna that lives on, in, or just below the surface film of water bodies. When first applied, the term referred to organisms inhabiting the surface of sluggish bodies of water such as fresh water ponds and pools (Zaitsev, 1970). Despite its easy accessibility, the study of marine neuston is relatively new due to extant doubt concerning the possibility of its existence on a turbulent ocean; therefore, knowledge of the qualitative composition of the neuston is somewhat rudimentary.

Although data characterizing conditions in the top microhorizon (Zaitsev, 1970) or top microlayer (MacIntyre, 1974) of the ocean surface are still incomplete, there can be no doubt of its being a unique biotope. The surface layer of aquatic bodies differs from the underlying waters in a number of ways, notably, the inflow and accumulation of dead organic matter, the biological activity of the foam and the presence of ultraviolet and infrared rays from solar radiation. Among the abiotic factors which strongly influence the surface biotope are temperature, wave action, currents and man's pollutants (e.g. - pelagic tar, plastic, DDT and PCB's). MacIntyre (1974), in discussing the top millimeter of the ocean, states that this microlayer concentrates heavy metals such as lead, mercury, copper, etc. and also retains slow-degrading chlorinated hydrocarbons such as DDT and PCB's. Therefore marine neustonts must be adapted to, or at least capable of adjusting to, fluctuating degrees of environmental stress in their ecological niche.

Investigations into the fauna of the surface layer is still in a preliminary stage with it being possible to give no more than a description of some of the animals found there. Most of the early literature refers to the larger, more visible elements of this population on the generic level (Physalia, Velella, Janthina) and generally groups the remainder of the neustonts into categories such as fish larvae, copepods, chaetognaths, pelagic mollusks and crustacean larvae (David, 1965). Their relative abundance was noted by such terms as predominant, common, several, and occasional. More recently, Russians have been active in the study of neuston with their work being centered predominantly in the Black Sea and the Sea of Azov with additional studies in the Caspian Sea, the Antarctic and the Gulf of Mexico (Zaitsev, 1970). Hempel and others have done extensive work in the North Sea, the Norwegian Sea and the subtropical northeast Atlantic (Hempel and Weikert, 1972). Neuston studies in the western Gulf of Mexico began in the summer of 1972 with samples being collected by means of a 30 ft neuston net (mesh aperature-1 mm) affixed to a tubular aluminum frame measuring 1 x 2 meters (Jeffrey et al., 1974). Through construction designs and bridle adjustment, the net consistently sampled its entire width to a depth of 0.5 meters.

Some descriptive terms and a classification of the surface fauna was proposed by Zaitsev (1964) and expanded in his book Marine Neustonology (1970). Major divisions and subdivisions of these metazoans are given as follows.

- Pleuston
- Neuston
  - Epineuston
  - Hyponeuston
    - Euneuston
    - Faculative neuston
    - Pseudoneuston

The pleuston are those animals living in the air-water interface, partially in air and partially in water, possessing some type of gas flotation device and mainly distributed by the direct action of the wind. The remainder of the surface hydrobionts is considered as neuston and subdivided into epi-neuston (animals living above the interface on the water surface) and hyponeuston (animals living in the surface layer but below the interface). Minor subdivisions of the hyponeuston relate to such factors as permanency at the surface, larval forms whose adult stage inhabit a different environment, and diurnal migrators. In this report these divisions are treated collectively as neuston and differentiated only from the flotsam or flotage.

Principal Living Components

The neuston biotope is not clearly separated from the rest of the water column nor is the neuston itself strictly separated from the plankton. Under certain conditions (e.g. - during dim light, in turbid waters, and at night) the neuston community becomes less distinct or even almost identical to the plankton community of the adjacent strata. In boreal waters, the ecological difference between the uppermost layer and deeper strata is less pronounced than in lower latitudes (Hempel and Weikert, 1972). However, it has been shown that a number of marine species have their maximum concentrations in a layer extending from the surface to a depth of around 15 cm. These neustonts are often collected from such widely separated regions as the Sea of Azov, the Indian Ocean and the Gulf of Mexico (Zaitsev, 1970). Table 5-13 is a listing of genera that are commonly collected from the world oceans during neuston tows, both day and night samples included. Approximately 65% of those organisms listed are known to inhabit Gulf of Mexico waters but not all of that percentage have been recorded in neuston samples.

Early neuston samples from the northwestern Gulf were taken in order to ascertain the abundance of pelagic tar within a semi-enclosed sea that has extensive offshore oil production and tanker traffic (Jeffrey et al., 1974). During removal of the tar lumps for laboratory analysis, these investigators classified the neustonts to major taxa and enumerated the organisms on the basis of relative abundance. Results of this cursory study are shown in Table 5-14 for stations #1 - 9 which are near the limits of the present study area. Station locations can be found on Fig. 5-33.

A more detailed study of neuston samples was conducted by TerEco Corporation

Table 5-13. Common genera collected from world oceans in neuston samples.

Siphonophora

Physalia, *Porpita*, *Velella*

Chaetognatha

Krohnitta, *Pterosagitta*, *Sagitta*

Polychaeta

Nereis, *Nephthis*, *Phyllodoce*, *Platynereis*, *Tomopterus*

Gastropod Mollusca

Atlanta, *Cavolinia*, *Creseis*, *Glaucus*, *Hydrobia*, *Janthina*, *Styliola*

Crustacea

Amphipoda

Caprella, *Corophium*, *Gammarus*, *Nototropis*

Copepoda

Anomalocera, *Calanus*, *Candacea*, *Copilia*, *Eucalanus*, *Euchaeta*, *Labidocera*, *Parathemisto*, *Pontella*, *Pontellopsis*

Cumacea

Bodotria, *Cumella*, *Cumopsis*, *Pterocuma*

Decapoda

Crangon, *Latreutes*, *Leander*, *Lucifer*, *Palaemon*, *Parapeneus*, *Planes*, *Portunus*, *Sergestes*

Euphausiacea

Euphausia, *Nyctiphanes*, *Stylocheiron*, *Thysanoessa*

Isopoda

Eurydice, *Idotea*, *Sphaeroma*

Mysidacea

Gastrosaccus, *Mysis*, *Pseudoparamysis*, *Siriella*

Insecta

Halobates

Pisces

Balistidae, Blenniidae, Carangidae, Eugraulidae, Exocoetidae, Gonostomatidae, Mugilidae, Mullidae, Myctophidae, Sternoptychidae

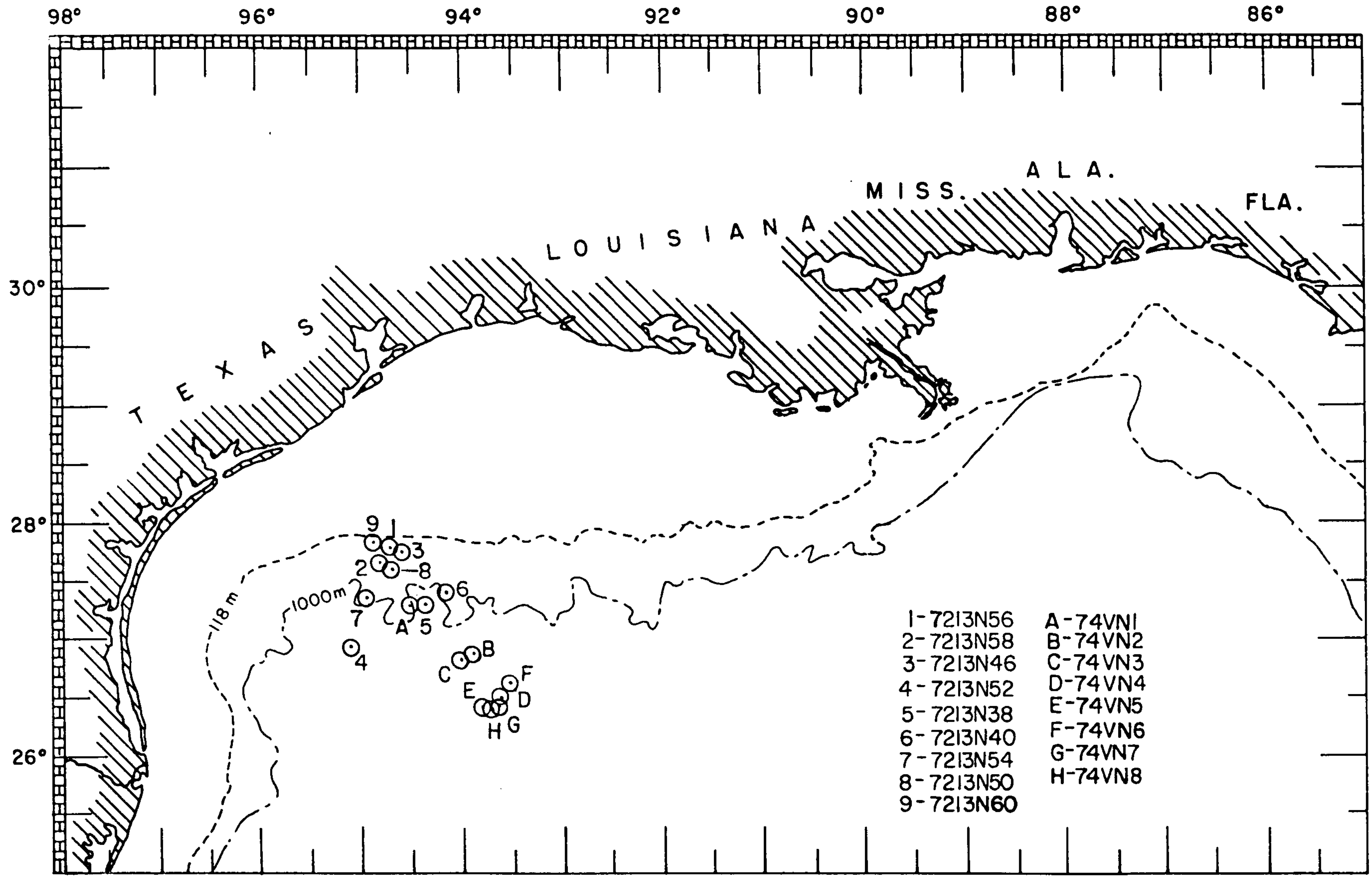

Fig. 5-33. Locations of neuston stations.

Table 5-14. Relative abundance of neustonts from samples taken for pelagic tar study.

Specimen	Station 1	2	3	4	5	6	7	8	9
Cnidaria									
Hydroid (parts)	x	x	x	x			x	x	x
Medusa					x	xxx			
Siphonophore (parts)						x	x		
Porpita sp.					x		x		
Chaetognatha	x		x				x		x
Polychaeta	x	x	x			x	x		
Gastropod Mollusca									
Prosobranchia	x			x	x	x	x		
Atlanta sp.							x		
Opisthobranchia									
Pteropods			x		x		x	x	
Crustacea									
Amphipoda			x				x	x	x
Copepoda	x	x	x	xx	x		xx	x	x
Decapoda (larvae)	x	x	x	xx	x	x	xxx	xxx	xxx
Brachyuran	x							x	
Natantian shrimp				x					
Sergestid shrimp									
Lucifer sp.	x		x	x	x	xx	x		
Euphausiacea						x	x		
Isopoda			x	x		x	x		
Mysidacea		x		x			xx		xx
Stomatopoda	x			x			xx	x	x
Echinodermata (larvae)									
Insecta			x	x	x	x	x	x	x
Chordata									
Thalliacea						x			
Pisces									
Eggs						x	xx		
Juvenile	x			x		x	x	xx	x
Adult	x	xx	x	x	x	xx	xxx	xxx	xx
Sargassum	xx	x	x	x	x	x	x	x	x
Actinaria			x		x	x	x		x
Serpulidae	x	x	x						x

x = present
xx = abundant
xxx = very abundant

during the fall of 1974 in conjunction with incineration activities over oceanic waters of the Gulf. Even though several of the stations are just seaward of the upper continental slope, their data are deemed worthy since that study constitutes one believed to offer complete enumeration of organisms collected during neuston tows. These stations are designated as A through H in Fig. 5-33, and the specimens are enumerated in Table 5-15.

An indication of seasonality in the neuston fauna has been noted by investigators during various cruises in the Gulf. During a winter expedition (late January - early February), large numbers of the cnidarians Velella and Physalia along with species of the pelagic gastropod Janthina were not only captured by the neuston net but also observed floating in all directions around the ship. Then too, three species of the barnacle genus Lepas were found attached to floating Sargassum weed and pelagic tar lumps. The specimen tables show no occurrence of those three groups; but, these collections were obtained during late summer and early fall months (August-October).

Abiotic Substances

Floating tar in the open ocean has been observed for at least twenty years, but no concentrations were determined until Horn et al. (1970) made a survey of pelagic tar in the Mediterranean. They found concentrations ranging up to 540 mg/m^2 with a mean concentration of 20 mg/m^2 using a water displacement method for determining the tar concentration, a rapid but only semiquantitative technique. Using a wet weight method, Morris (1971) reported considerably lower quantities of floating tar in the northwestern Atlantic, i.e., a range of 0.1 to 9.7 mg/m^2 with a mean of 2.2 mg/m^2. Heyerdahl and his associates on expeditions across the Atlantic observed heavy oil residue pollution, but no concentrations were determined (Butler, 1975). Morris and Butler (1973) made biweekly tows approximately 20 miles southeast of Bermuda in the Sargasso Sea in 1971 and 1972 and reported tar concentrations ranging from 0.1 to 40 mg/m^2 with an arithmetic mean of 9.4 mg/m^2. More recently Sherman et al. (1974) of the National Marine Fisheries Service made a semiquantitative estimate of pelagic tars in an area extending from Cape Cod to

Table 5-15. Enumeration of organisms collected in neuston net tows from northwest Gulf of Mexico.

Specimen	A	B	C	D	E	F	G	H
Cnidaria								
Medusa							1	
Siphonophore (parts)	xx	xx	xx	xx	xx	xx	xx	xx
Porpita sp.		1			14			3
Chaetognatha	17	3	1	4	68	42	21	51
Polychaeta				1		6		
Mollusca								
Gastropoda								
Prosobranchia	5	11	1	7	1	2	2	
Heteropods	24					247		1
Opisthobrachia								
Pteropods	59	30	5	5	33	456	15	41
Cephalopoda								
Argonauta sp.							1	
Larvae						3		
Arthropoda								
Crustacea								
Amphipoda	4					83	128	176
Copepoda								
Pontella sp.	153	106	45	61	148	83	112	39
Candacea sp.	1	1						
Copilia sp.	1						1	2
Decapoda								
Brachyuran (larvae)	1	20	2	7	2	9	55	110
Natantian shrimp	4	6		1	4	7	109	38
Caridean shrimp								
Latreutes fucorum	2	56	2	13		2	60	4
Leander tenuicornis	1							
Palaemonid (larvae)				1		165	4	1
Other Caridea (larvae)	33		1			19		
Sergestid shrimp								
Lucifer sp.	12		2	1	251	107	23	31
Palinuridae								
Larvae							1	1
Juvenile								1
Euphausiacea	2					2	88	129
Isopoda	1				3		1	
Mysidacea					12		179	69
Siriella thompsonii						579		
Stomatopoda (larvae)	1					17	14	12
Insecta								
Halobates sp.	62	26	7	8	7	20	7	18
Terrestrial forms	59	3	3	5	5	1	3	8
Echinodermata (larvae)						3		2
Chordata								
Pisces								
Antennariidae (Sargassum fish)								
Histro sp.		1				1		
Balistidae (Trigger fish)	5	5	4	7	4	3	1	
Coryphanidae (Dolphin)								
Coryphana sp.							2	
Exocetidae (Flying fish)			1	1				
Cypselurus sp.							3	
Parexocoetus sp.								1
Gonostomatidae (Viper fish)								1
Mugilidae (Mullet)								
Mugil sp.		1						
Myctophidae (Lantern fish)	3						1	16
Gonichthys sp.	2					5	8	18
Hygophym sp.							1	
Myctophum sp.							5	
Pleuronectiformes (Flatfish)						8		
Sternoptychidae (Hatchet fish)								
Sternoptyx diaphana								1
Others (juvenile)	11	3	11	2	2			
Sargassum	x	x		x		x		
Actinara	24	10		3				

x = present
xx = abundant

the Caribbean. Essentially, these investigators found that coastal areas had lower concentrations than offshore areas and that an area north of the Antilles and Bahamas had the highest concentrations of the areas studied (summer - 3.9 mg/m^2; winter - 4.8 mg/m^2). The data of Jeffrey et al. (1974), derived from a quantitative chemical extraction method, indicate that the Gulf of Mexico and Caribbean Sea are less polluted with pelagic tars (1.20 and 0.772 mg/m^2, respectively) than the Mediterranean and Sargasso Seas (see Table 5-16).

Table 5-16. Comparison of pelagic tar concentrations in the Gulf of Mexico with those of other marine areas (after Jeffrey, et al., 1974).

REGION	NO. SAMPLES	RANGE (mg/m^2)	MEAN TAR CONCENTRATIONS (mg/m^2)
Gulf of Mexico	84	0.0-10.0	1.20
Caribbean Sea	32	0.0- 4.7	0.773
Northwest Pacific	15	0.3-14.0	3.8
Northeast Pacific	18	0.0- 2.9	0.4
Northwest Atlantic Marginal Sea	8	0.0- 2.4	0.9
Gulf Stream	16	0.1- 9.7	2.2
Sargasso Sea	34	0.1-40.0	9.4
Mediterranean	41	0.0-54.0	20.0

Concern about the amount of tar and its residence time in the world's oceans prompted a calculation of the total amount of pelagic tar in the Gulf of Mexico and Caribbean, utilizing data from Jeffrey et al. (1974) and TerEco (1973). (Since in all probability some of the pelagic tar is swept into the Gulf of Mexico through the Yucatan Straits from the Caribbean, this sea is also being considered.) It is realized that these calculations are only estimates, and it is suspected that the amount varies with time but the findings show 1920 metric tons for the Gulf of Mexico and 2040 metric tons for the Caribbean. These amounts were obtained by using 1.60 x $10^{12}m^2$ area and 1.20 mg/m^2 mean tar concentration for the Gulf and 2.64 x $10^{12}m^2$ area and 0.773 mg tar/m^2 for the Caribbean. Morris and Butler (1973) have made similar estimates for the northwest Atlantic (20,000 metric tons), Sargasso Sea (66,000 metric tons) and Mediterranean (50,000 metric tons). It seems possible that their average concentrations are 35-45% too high, because they included organisms and debris in the weight of samples used for the calculations. Such a possibility seems likely when one notes the percent of debris remaining on the filters during laboratory analysis by the chemical extraction method (see Table 5-17).

Table 5-17. Pelagic tar concentrations over the continental slope of the northwest Gulf of Mexico on the basis of dry benzene-soluble material.

STATION		DRY WT. (g)	EXTRACTED WT. (g)	DEBRIS (%)	TAR (mg/m^2)
7213N38	(5)	6.173	4.030	35	0.40
7213N40	(6)	4.517	3.450	24	0.31
7213N46	(3)	0.466	0.030	36	0.03
7213N50	(8)	6.478	5.300	18	0.44
7213N52	(4)	0.838	0.190	77	0.02
7213N54	(7)	4.694	3.670	36	0.99
7213N56	(1)	5.748	4.010	30	0.23
7213N58	(2)	10.530	5.240	50	0.13
7213N60	(9)	3.851	2.200	43	0.59

Many of the tars in the Gulf of Mexico may have been in the environment for a period of several months, because some were covered with living organisms. One also finds that pelagic tar distribution is very heterogeneous as evidenced by the results of Morris and Butler (1973) and the findings of Jeffry et al. (1974) at one station near the center of the Gulf where 9 samples were taken in a 24 hour period. At this station the range of tar concentration was from 0.004 to 9.20 mg/m^2 (Mean-2.42 mg/m^2) even though the neuston tows were positioned and timed as identically as possible. Therefore, in order to correctly assess the amount of pelagic tar in the Gulf of Mexico, it will be necessary to have many data points at different times in a given area. One can only speculate as to the origin of these tars but it appears as if waste disposal in offshore waters and/or tanker flushings over the outer shelf and slope could account for a large percentage (Jeffrey et al., 1974).

6. THE BENTHIC ENVIRONMENT

SEDIMENTOLOGY

The Recent and near-Recent sediments of the Gulf of Mexico have been extensively studied by Stetson (1953), Greenman and LeBlanc (1956), Ewing et al. (1958), Shepard et al. (1960) and other investigators. As a result of these studies Phleger (1967) implies that the distribution of surface sediments in this region is better known than for any comparable marine area in the world. This is essentially true for the embayments, nearshore waters, and shallow shelf waters of the Gulf. In reality, however, the geology of the offshore area of Texas and Louisiana is perhaps better known at the subsurface level than at the surface due to the enormous amount of work with precision echo sounding and in refraction seismic, gravity, and magnetic surveying by such investigators as Antoine, Ewing, Bryant, Uchupi, Moore and Lehner (see citations in Section 2, Physiography of the Gulf of Mexico). Appelbaum (1972) found that comprehensive sedimentological studies in the northwestern Gulf had been restricted to the continental shelf and abyssal plain, with limited study on the upper continental slope.

One of the deeper-water studies was that of Curray's investigation of Holocene sediments of the northwest Gulf as a part of American Petroleum Institute Project 51 (Curray, 1960). While utilizing samples from depths shallower than 190 meters, he compiled most of what was known of the surficial sediments and history of Holocene deposition. Bouma (1972) has updated the subject of sediment distribution in the Gulf; however, his data was obtained from average content within the upper 7 m of the sediment column. He describes the sediments from the outer shelf and deeper environments as primarily clay with variable amounts of silt (i.e., pelite - a combination of all size fractions in the clay and silt range). To show variation in sediment types, a clayey pelite is defined as a pelite containing 75% or more clay and a silty pelite as one with 25% or more silt. In Fig. 6-1, the 75% clay isopleth indicates clayey and silty pelites while the numbers represent average clay percentage for the various stations.

The thick clay covering much of the central Texas shelf and upper continental slope are probably a result of reworking and deposition of river sediments from the large rivers in the past. Curray (1960) attributes most of the sheet sands and shell deposits on the shelf to reworking of shorelines formed during the various glacial interstadials. Verification of these old shorelines was found by Parker (1960) when he identified estuarine and freshwater shells at depths of 20, 60, 80 and 120 meters. Phleger (1960) concurred that relict shallow water sediments were deposited on the present outer shelf during lowered sea level of the last glacial stage. The macrofauna and microfauna are a mixed assemblage consisting of relict shallow water forms and outer continental shelf species which are living there at the present time (Curray, 1960; Phleger 1960).

During the period of lowest sea-level stand, sediments from all rivers were carried directly across the exposed continental shelf. Currents and longshore drift carried Rio Grande material northward and Mississippi material westward along the edge of the shelf. Colorado, Brazos and Trinity River sediments were deposited in a somewhat neutral zone between these two tongues. When sea level started to rise, drift of sediment from all rivers except the Rio Grande began to fluctuate (west to east to west) and finally stabilized during the last part of the transgression

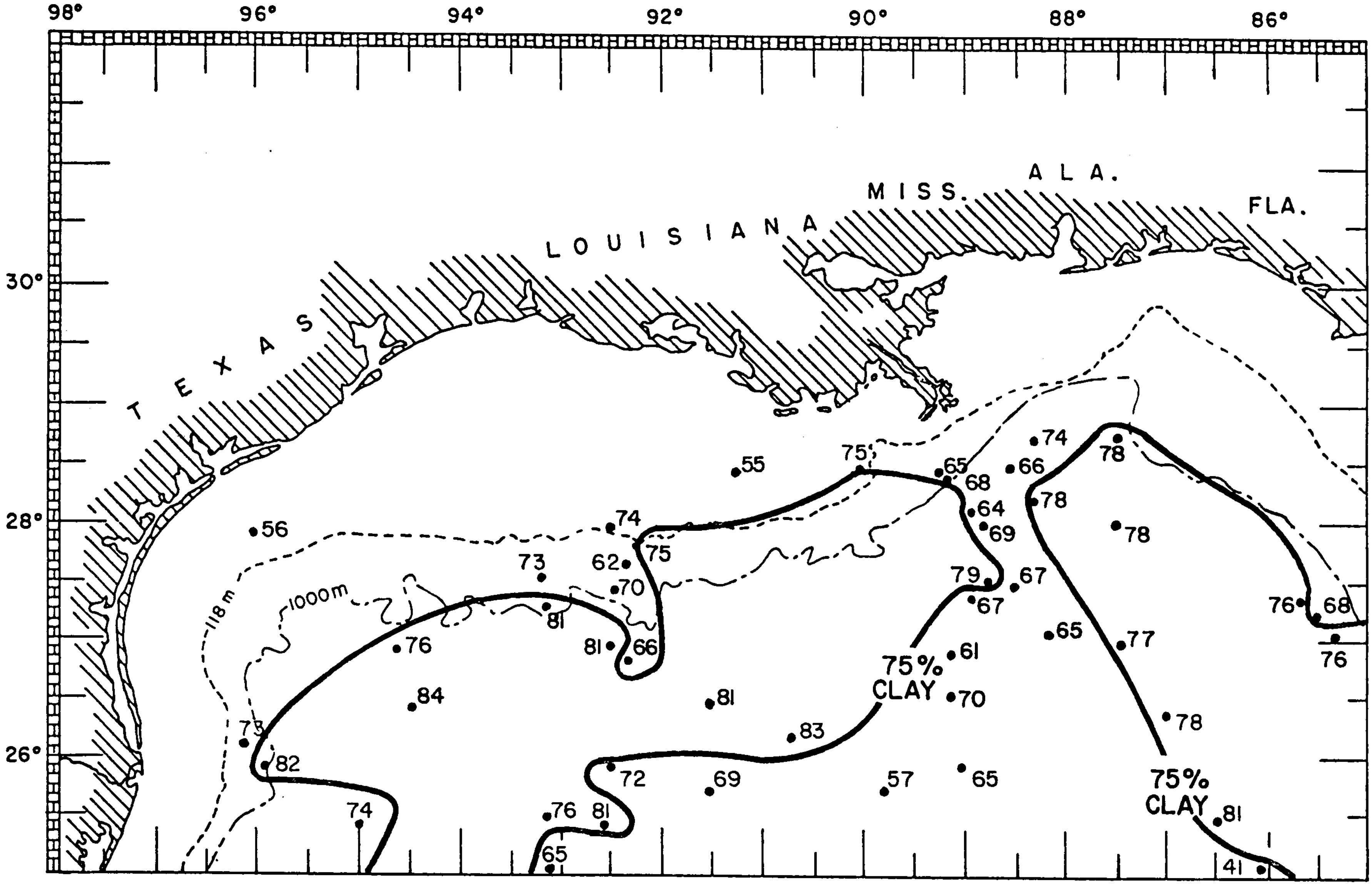

Fig. 6-1. Clay content map of northern Gulf of Mexico (from Bouma, 1972).

to that of present conditions. Such an occurrence would certainly cause a mixing of sediments in the western Gulf.

There is essentially no deposition of detrital sediment from the continent in the relict areas at the present time. This can be shown on the basis of foraminifera ratios (Phleger, 1960) and by the presence of shallow water sediments at the surface. The fact that detrital sediments are being deposited on the inner continental shelf can be substantiated by the nature of the material, the presence of pure, indigenous faunas and foraminifera population ratios. This suggests that sediment being supplied to the Gulf does not reach the outer shelf (i.e.-all sediment may be deposited on the inner shelf), or if it does, it is being deposited seaward from there. Off the Mississippi Delta, material coarser than fine silt is transported in small amounts across the entire width of the shelf but the sites of active deposition are almost impossible to distinguish. While investigating the dispersion of fine-grained sediments Curray (1960) found the clays to be displaced seaward of the silts and their dispersion pattern to be independent of the sand distribution. Phleger (1967) speculates that detrital sediments from the land are being deposited at the present time on the continental slope and in the basin (see Fig. 6-2) but has no certainty of such activity or the mechanics and amount of this supply. In general, it is felt that the major source of sediment for the western Gulf is Mississippi River discharge, which Drennan (1968) found to have an approximate average between 5000m^3/sec (late fall) and 23,000m^3/sec in the spring. The sedimentary products of weathering are also supplied by the Rio Grande and many medium and small streams in conjunction with some material being contributed by marine erosion of the coastal zone. During transport to and within the basin the materials are mixed and sorted by a variety of agents before final deposition.

Appelbaum (1972) concluded that the Brazos, Colorado and Mississippi Rivers were the main suppliers of sand size sediment to his study area on the upper continental slope. This area extends from the shelf

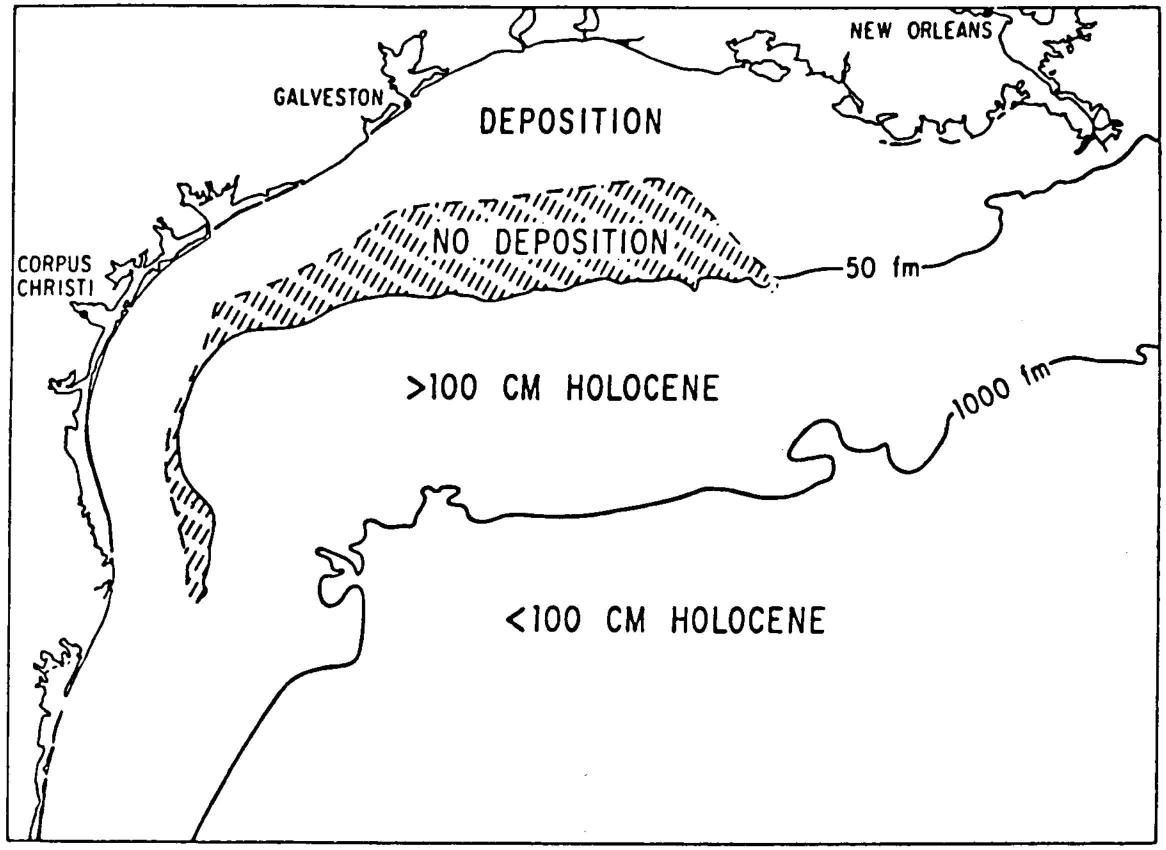

Fig. 6-2. Generalized relative sedimentation rates in offshore Gulf of Mexico (from Phleger, 1967).

break to a depth of nearly 500 fathoms (915 meters), and is bounded on the east and west by 94° and 94°30'W longitude, and on the north and south by 28° and 27°30' N latitude. His evidence for a mixing of varied sources stemmed from heavy mineral grain counts when compared to previous patterns of northern Gulf assemblages (van Andel and Poole, 1960) with corroboration being afforded through clay mineral analyses.

Deposition of the last major volume of clastic sediment on the Mississippi Cone is inferred by Wilhelm and Ewing (1972) to have taken place during early Holocene time. Later deposits from the Mississippi and other rivers were laid down on the continental shelves with a minimum reaching the abyssal plain by turbidity currents. All evidence suggests that the processes of sediment transport include pelagic differential settling, low-flow-regime bottom currents and internal waves. Upper sediments of the eastern Mississippi Cone consist of fine sand, silt, and silty clay layers overlain by a 20-50 cm layer of foraminiferal clay with most sediments being mineralogically homogeneous (Huang and Goodell, 1970). These investigators believe the sedimentation rate averages approximately 30 cm/1000 yrs but depends primarily on rates of detrital influx and on fluctuations in sea level.

Heavy Mineral Studies

Work on the heavy minerals of the northwest Gulf began with Bullard's examination of the heavy mineral suites of Texas river and beach sands in order to determine their source areas (Bullard, 1942). He concluded that each of the principal Texas rivers carries a distinct heavy mineral suite dependent upon the nature of the source rock of the various drainage basins. Goldstein (1942) divided the northern Gulf of Mexico into four distinct sedimentary provinces on the basis of heavy mineral suites. These divisions are the East Gulf province, the Mississippi province, the Western province and the Rio Grande province. In the northwest Gulf, the Mississippi and Western provinces are differentiated by a lower percentage of pyroxene and a higher percentage of leucoxene in the Western province. The Rio Grande province is distinguished from the Western by a higher percentage of pyroxene and the presence of basaltic hornblende.

van Andel (1960) pointed out that with the exception of the Colorado River sedimentary suite, the sediments of rivers emptying into the northwest Gulf are orthoquartzitic and are derived mainly from the Cretaceous and Tertiary margins of the Gulf Coast basin. He found modification of the sand in the basin only slight except for the removal of pyroxenes from Rio Grande and Mississippi sands exposed during the Pleistocene. van Andel and Poole (1960) examined the heavy minerals shoreward of the 110-meter contour in order to determine sand sources. In addition to Goldstein's provinces, these authors added a Texas coast province characterized by abundant tourmaline with zircon and some epidote. They attributed the Western province assemblage to mixing during the early Holocene transgression.

Clay Mineral Studies

As pointed out by van Andel and Poole (1960), the distribution patterns for different size fractions of sediment are not necessarily the same. Modern clay mineral examination of the western Gulf began with Grim and Johns (1954) who worked with samples from Texas coastal waters. They identified montmorillonite, chlorite, illite and kaolinite and suggested alteration of clay minerals in response to changing chemical environments as accountable for the variation in mineral quantities. Samples from the Sigsbee Deep were examined by Murray and Harrison (1956) and were found to contain approximately twice as much montmorillonite as chlorite and illite.

Johns and Grim (1958) discovered that the bulk of the material being deposited by the Mississippi River is montmorillonitic in nature and undergoes no diagenesis upon introduction into the Gulf. Its original source, the Missouri River system, differs from the Ohio River system in that material from the latter alters to chlorite and illite. Pinsak & Murray (1960) reported on regional clay mineral patterns in the Gulf, giving concentration areas and possible sources for montmorillonite, illite, kaolinite and chlorite. McAllister (1964) worked on the clay minerals of the west Mississippi Delta whereas Harlan (1966) investigated those of the Sigsbee Deep. Scafe and Kunze (1970) determined that the complex of conditions during and since the Pleistocene had little effect on the relative abundance of clay minerals in their core samples from the western Gulf.

Sediment Character and Distribution

Analyses of the sediment from core stations in the general slope region (see Fig. 6-3) yielded data concerning grain size and percentage composition for the upper 5-7 cm of core section. These determinations were obtained by means of wet sieve and settling velocity procedures. Sand was considered to be any material greater than 0.062 mm in size, regardless of being terrestrial or biogenous (i.e. foraminifera tests, mollusk shells or coral debris) in origin. Later microscopic examination revealed the presence of carbonate sand and almost complete absence of quartz sand in the coarse fraction obtained from the core samples. Only the material cored from station 675C10 yielded any quartz sand (very fine in size); however, approximately 99% of its sand-sized material was biogenically related, mainly coral debris. No authigenic grains, that is, deposited on the sea floor as a result of chemical reactions (e.g. glauconite), were noted in any of the samples. Table 6-1 shows the actual data obtained.

As one will note, sixteen core stations were occupied within or near the limits of the present study area. These cores were taken during biological cruises, that is, in conjunction with other sampling activities such as trawling, dredging, hydrocasts and bottom photography. Those samples revealed almost equal distribution of the finer sediments - 38% of the cores were predominantly clay and 38% were predominantly silt. Sand, silt and clay undifferentiated accounted for 18% of the samples. These findings are consistent and agree with van Andel and Curray (1960) who described the recent facies of the continental slope as homogeneous clays and silty clays, some having a high percentage of planktonic foraminifera.

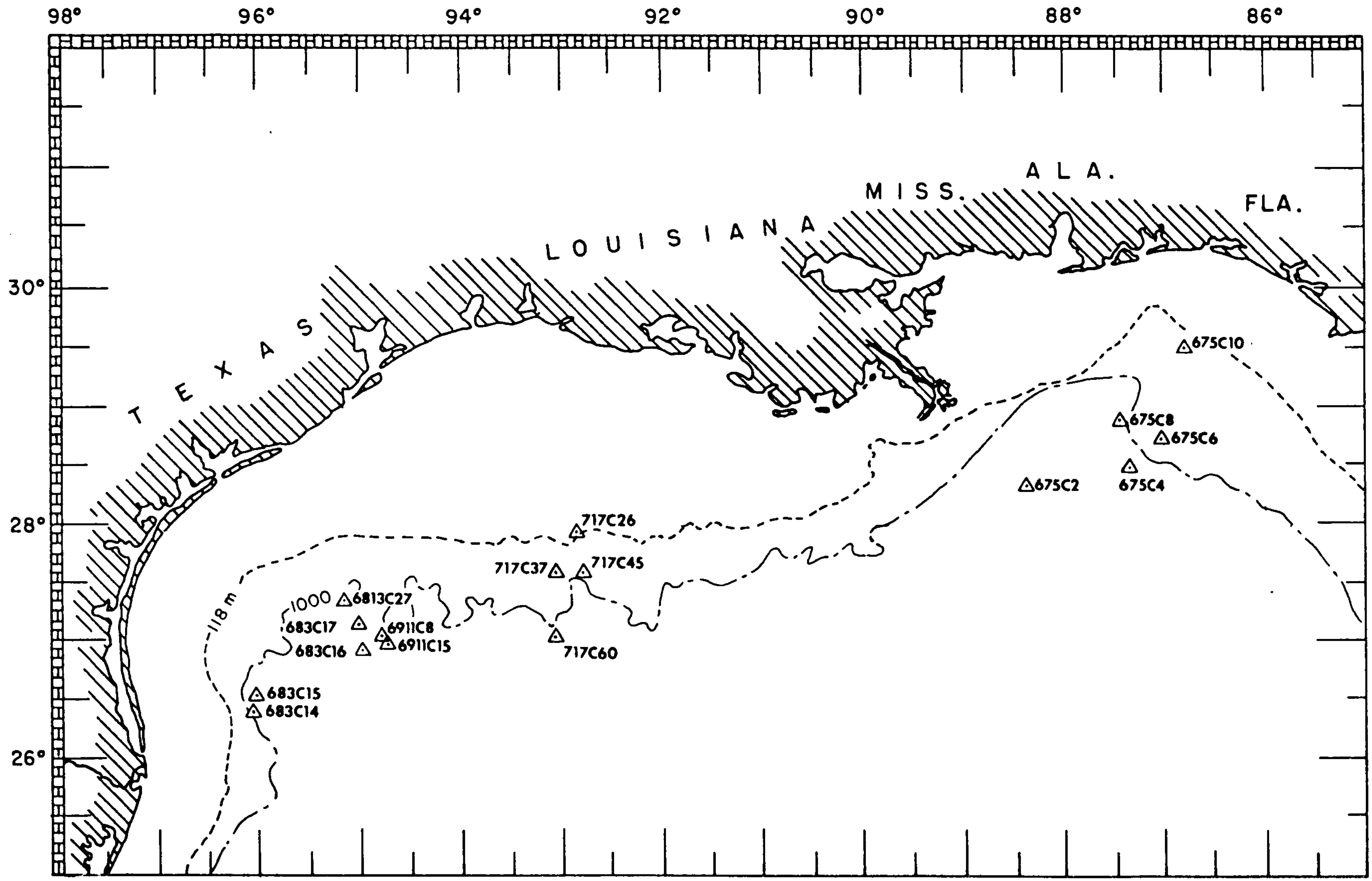

Fig. 6-3. Locations of core stations for sediment analysis.

Table 6-1. Sediment data from laboratory analysis of core samples.

Station	Percentage Composition Clay	Silt	Sand	Median Grain Size	Sediment Designation
675C2	46	15	39	7.4ϕ	Sandy Clay
675C4	7	92	1	8.3ϕ	Clayey Silt
675C6	56	29	15	9.2ϕ	Sandy Silty Clay
675C8	1	96	3	8.3ϕ	Silt
675C10	6	32	62	3.2ϕ	Silty Sand
683C14	62	38	0	9.5ϕ	Silty Clay
683C15	1	88	11	7.1ϕ	Sandy Silt
683C16	7	88	5	5.8ϕ	Sandy Clayey Silt
683C17	85	12	3	11.0ϕ	Silty Clay
6813C27	57	38	5	9.2ϕ	Silty Clay
6911C8	41	55	4	8.9ϕ	Clayey Silt
6911C15	61	34	5	9.4ϕ	Sandy Silty Clay
717C26	43	52	5	8.7ϕ	Sandy Clayey Silt
717C37	61	32	7	9.7ϕ	Sandy Silty Clay
717C45	73	23	4	9.7ϕ	Silty Clay
717C60	23	61	16	7.5ϕ	Sandy Clayey Silt

A map of sediment distribution in the northern Gulf was constructed by Grady (1970) for the National Marine Fisheries Service. In general, his chart shows sediment types from the shoreline to depths ranging between 100 and 1000 meters for that area north of the 24th parallel. It is notable that several of the above core stations are located within the limits of his map and that comparisions reveal almost total agreement with his general sediment type for that locale. With this in mind and using Grady's work as a base, a map of predominant sediment types has been constructed by means of interpolation from his control area seaward to the cited core stations. This compilation is designated as Fig. 6-4. One should be aware that some extrapolation of data was required between 89° and 92° W longitudes; however, literature related to the Mississippi Cone (Huang and Goodell, 1970; Wilhelm and Ewing, 1972) indicate the predominant sediment of that area to be foraminiferal clay.

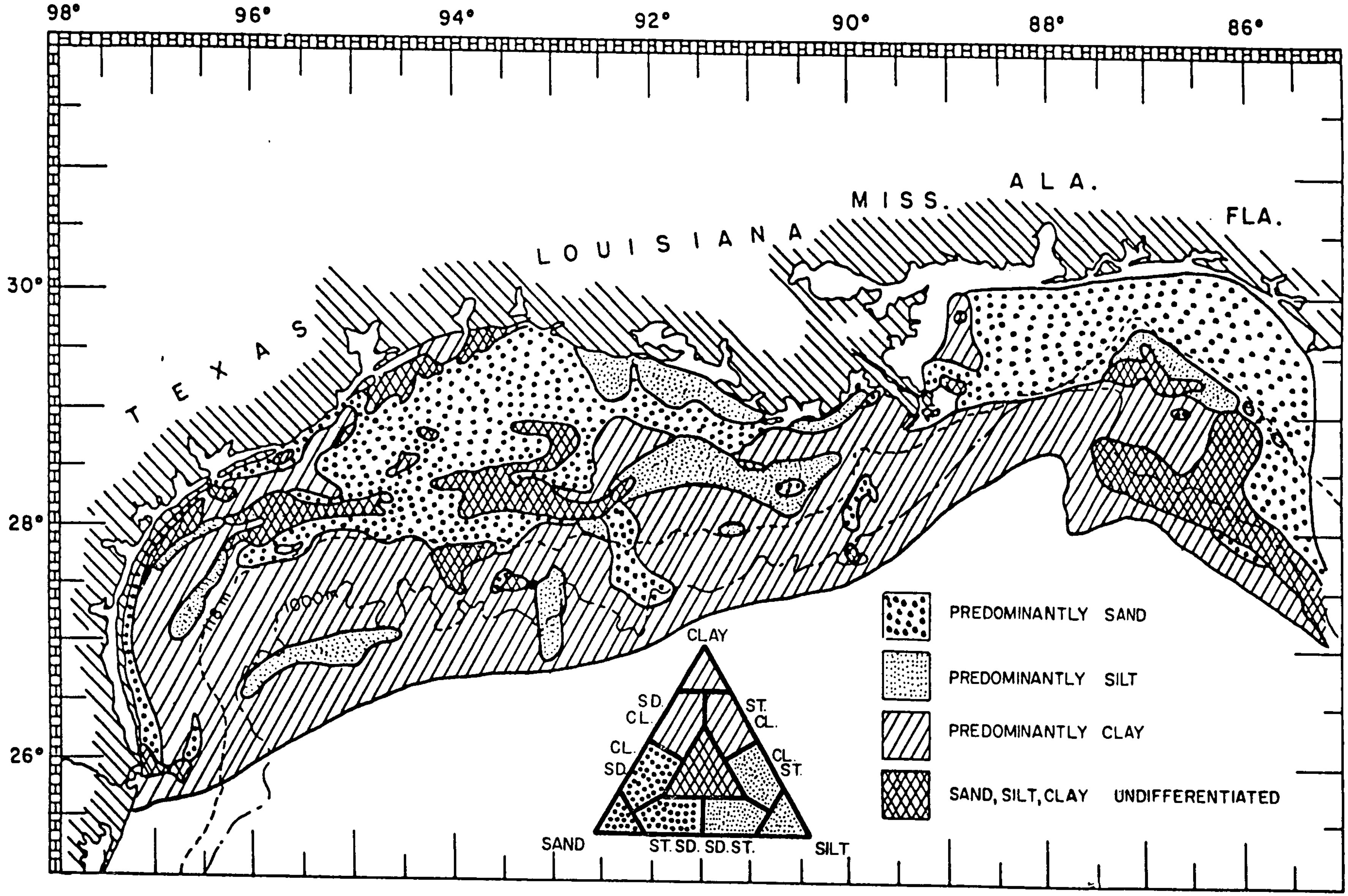

Fig. 6-4. Distribution of sediment types in the northern Gulf of Mexico (based in part on Grady, 1970 and unpublished data).

THE ZOOBENTHOS

The aggregate of animals living on (and in) the bottom and those substantially dependent upon bottom organisms as food constitute the zoobenthos (in the photic zone there may be a well-developed phytobenthos). The composition and structure of the substratum is the key to the fundamental nature of the benthic faunal assemblages found in a local area of the marine environment. Hard bottoms support groupings of organisms that are almost wholly categorized as epifaunal species; those species on the other hand that inhabit soft bottoms and live within the unconsolidated sediments are called infaunal species. These broad definitions leave decisions as to how the following kinds of organisms should be fitted into these major categories:

1) Species, generally quite mobile, that live on the surface of soft bottoms (often called level bottoms) and do not burrow into them (so far as is known), e.g., the Giant Red Crab, *Geryon quinquedens*, are relegated to the epifauna (soft-bottom type).
2) Species that are quite mobile and move over soft bottoms but that burrow in largely for refuge and possibly for protection of newly hatched individuals and emerge to feed on the sediment surface, e.g., the caridean *Glyphocrangon nobilis* and possibly the giant isopod *Bathynomus giganteus*, even though they burrow into the sediments, should be treated as epifaunal species.
3) Species that burrow into hard substrata, siltstone for example, and remain there for life, e.g., the Date Mussel, *Lithophaga plumula*, are considered to be epifaunal species - since this habit is essentially a special extension of the sessile life that is so typical of hard substrata.

Demersal fishes might seem to present a special problem, but it seems best to let them remain in this category. Some prefer to set apart those species that have a very intimate physical relationship with the bottom, even burrowing into sediments, as benthic fishes. In any case if one should assign these demersal fishes to one or another of the above categories, it is apparent that they bear greater functional relationships with the epifauna than with the infauna.

This leaves, then as infaunal those species that are intimately bound with the soft bottom substratum, usually burrowing into it, having limited mobility, if any, as adults, except perhaps within burrows, and that feed wholly within the sediments by either drawing water into their burrows or moving through the sediments. Typical infaunal species dealt with here are most (but not all) of the bivalve mollusks, some holothurians, some echinoids, some polychaete annelids, etc. Excellent examples, although not under consideration in this report, are much of the meiofauna, e.g., tiny nematodes, megaciliates, and tardigrades, inter alia.

The numbers of species of organisms living on hard substrata have been estimated by Thorson (1957) to far exceed those living on level bottoms. This is probably true in deep water, and it certainly applies if the macrofauna only is considered. One wonders, however, just how the comparison would change if the meiofaunal component were included.

In the depth range of this report (118-1000 m) major areas of hard bottoms are scarce, and those hard banks of the northern Gulf that fall into the depth category are only poorly known. Secondary hard bottoms (Remane, 1940) such as mollusk shells and small rocks are about the only developments that are observed. These serve as the substratum for small brachiopods (e.g. Pelagodiscus atlanticus), such bivalves as Bentharca, some barnacles (Verruca and Scalpellum), a few ecotoprocts, and an occasional gorgonian, horny coral (Chrysogorgia).

The composition of the infauna will vary considerably depending upon the different types of bottom, such as mixtures of sand, silt, and clay or simply mud. On the upper continental slope the materials of soft bottoms are largely terrigenous in origin and consist of clay (mud) with a large amount of decomposing organic material. In places these muddy layers are extremely flocculent and have only a poorly defined boundary separating them from the overlying, sometimes cloudy water. These areas are probably largely free of currents. On the other hand there are slope areas where such flocculent layers are absent and the sediments seem much more consolidated, at least in photographs. This fact plus the larger median grain size of the sediment indicates that currents may be found here, at least periodically (see treatment of currents in Section 5).

THE EPIFAUNA

Distribution of Soft Bottom Epifauna

One can find here lists of all species upon which this report is based; they are arranged by some major taxonomic grouping. These lists contain specific information on the numbers of individuals collected and their rank ordering. The latter was obtained simply by determining where a given species was predominant by numbers and then multiplying this frequency by five. The product of this frequency of occurrence and the total number of individuals taken produced the rank order. In addition, the depth range and an estimate of the isobath within plus or minus 50 m at which each species attains its maximum populations is given.

The second list contains the predominant species presented in order of importance as derived from the first table. Here are also presented their depth range and isobath of presumed maximum population development.

A graph is then presented which portrays the number of species of each taxonomic group found in one or another sample at each of the isobaths studied.

Finally the geographic distributions of the species involved are shown within the horizontal and vertical limits of this study.

Systematic listings of all of the benthic or demersal invertebrates and fishes identified from samplings within the study area are presented in Appendix B.

Echinodermata

Asteroidea (Starfish). Twenty-six species of starfishes are found within the depth and geographic limits of this study, i.e., on the upper continental slope of the northern Gulf of Mexico (see Table 6-2A). This does not include some of those species that are more abundant on the continental shelf and move onto the slope in more limited numbers. These are discussed in the following section on Benthic Faunal Assemblages. The 10 dominant asteroids are presented in Table 6-2B. Here it is seen that all achieve peak populations at different depths. This could mean that their feeding habits are quite similar and that they achieve more effective habitat utilization by proper spacing of major populations. Histograms showing numbers of species collected at each isobath are presented in Fig. 6-5.

As can be seen on the distributional maps (Figs. 6-6 and 6-7), there are some important differences in the asteroid fauna of the upper continental slope between the east and west Gulf. For example, specifically 14 species (designated by asterick in Figs. 6-6 and 6-7) are found in the northwestern Gulf that are not found in the depth range in the northeastern Gulf. Only one species was found in the northeastern Gulf but not in the northwestern area of the slope. This may be another indication that the upper slope region of the northwestern Gulf is a very productive region (see Thorson, 1957).

Echinoidea (Sea Urchins and Sand Dollars). Some 19 species of echinoids are found on the upper continental slope within the depth limits of this study (Table 6-3 and Fig. 6-8). As yet it is uncertain as to the significance of the fact that neither Phormosoma placenta nor

Table 6-2. (A) Starfish found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Asteroidea on the upper continental slope of the Gulf of Mexico arranged by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A x B	Depth Range (m)	Depth of Maximum Population (m)
Astropecten nitidus	39	5	195	150-200	150
Luidia barbadensis	1	0	-	150 only	150
Cheiraster echinulatus	30	0	-	150-200	150
Rosaster alexandri	13	0	-	150-200	150
Coronaster briareus	1	0	-	150 only	150
Anthenoides piercei	23	5	115	150-200	150
Luidia elegans	41	0	-	200 only	200
Luidia barimae	2	0	-	200 only	200
Tethyaster grandis	30	0	-	100-250	250
Astropecten americanus	93	15	1395	250-1050	250
Persephonaster echinulatus	24	5	120	500-950	500
Plinthaster dentatus	20	5	100	500-1000	550
Pseudarchaster n. sp.	3	0	-	600-1450	600
Pteraster militaroides	1	0	-	600 only	600
Midgardia xandaros	15	0	-	500-1100	600
Cheiraster enoplus	18	0	-	550-700	600
Ceramaster sp.	5	5	25	600-650	650
Doraster constellatus	38	10	380	400-1050	700
Cheiraster mirabilis	16	5	80	650-950	750
Brisingella verticellata	4	0	-	750 only	750
Psilaster cassiope	8	0	-	600-750	600
Nymphaster arenatus	180	30	5400	400-2100	900
Goniopecten demonstrans	19	10	190	600-1450	950
Psilaster patagiatus	1	0	-	950 only	950
Plutonaster intermedius	163	20	3260	750-1450	1400
Zoroaster fulgens	20	0	-	650-2250	2250

B. Dominant asteroids presented in rank order.

	SPECIES	Depth of Peak Pop. (m)		SPECIES	Depth of Peak Pop. (m)
1.	Nymphaster arenatus	900	6.	Goniopecten demonstrans	950
2.	Plutonaster intermedius	1400	7.	Persephonaster echinulatus	500
3.	Astropecten americanus	200	8.	Anthenoides piercei	150
4.	Doraster constellatus	700	9.	Plinthaster dentatus	550
5.	Astropecten nitidus	150	10.	Cheiraster mirabilis	750

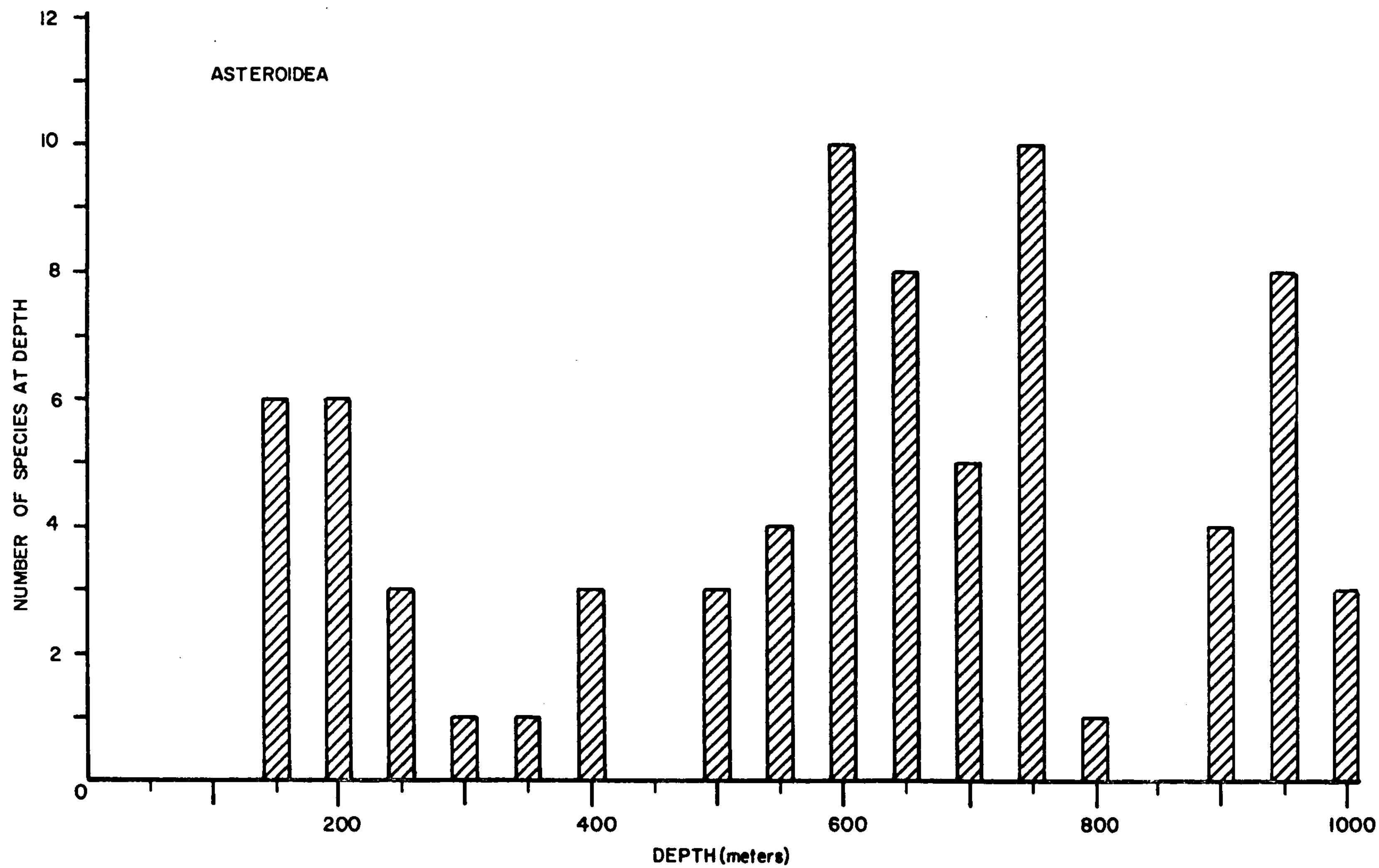

Fig. 6-5. Histograms showing the total numbers of starfish species collected at the given depths. This graph should be compared with the relevant sections on faunal assemblages. Note particularly here the substantial numbers found at increasing depths.

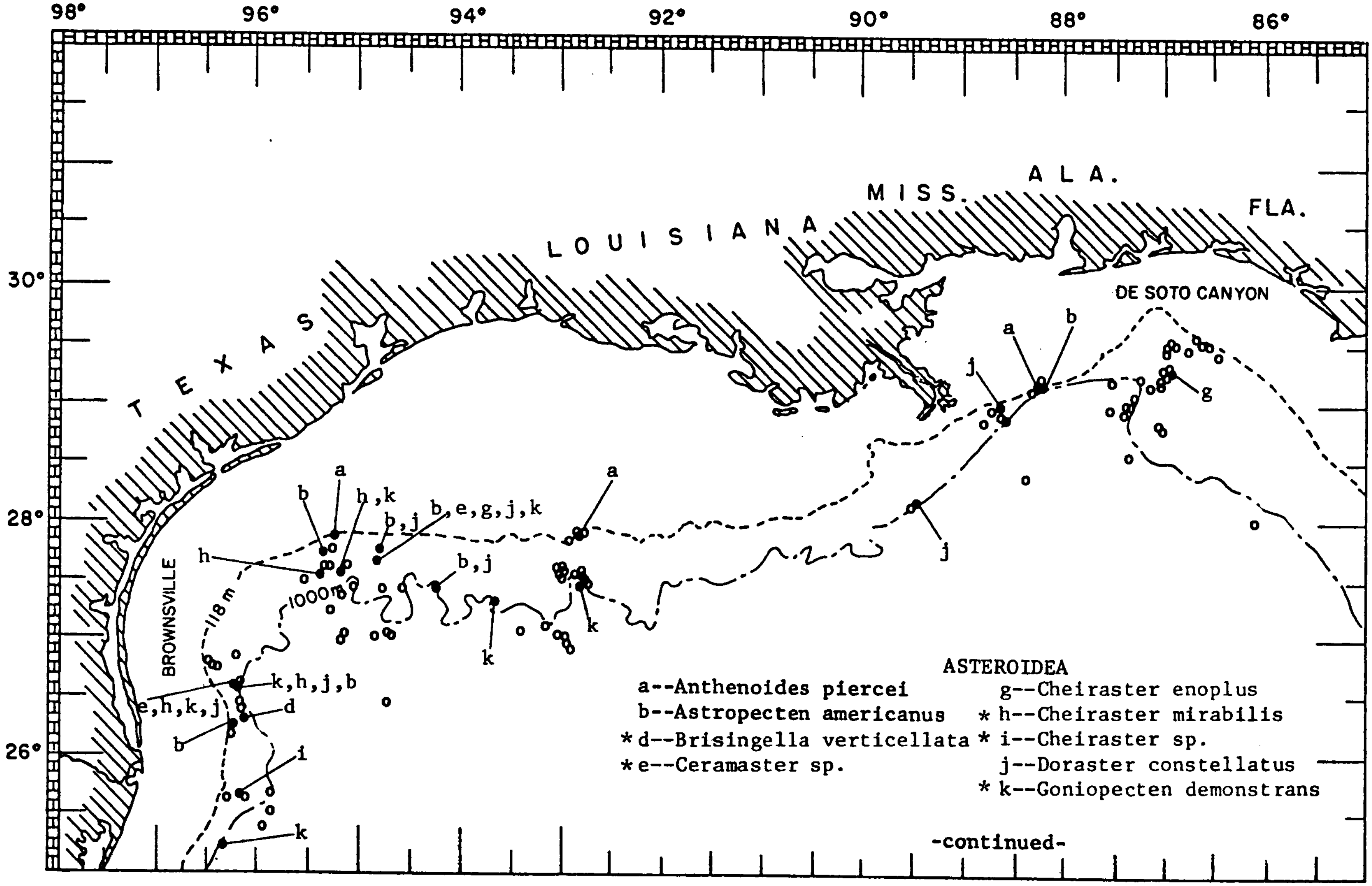

Fig. 6-6. Distribution of starfishes among the 111 stations of the upper continental slope study area. (continued on Fig. 6-7.)

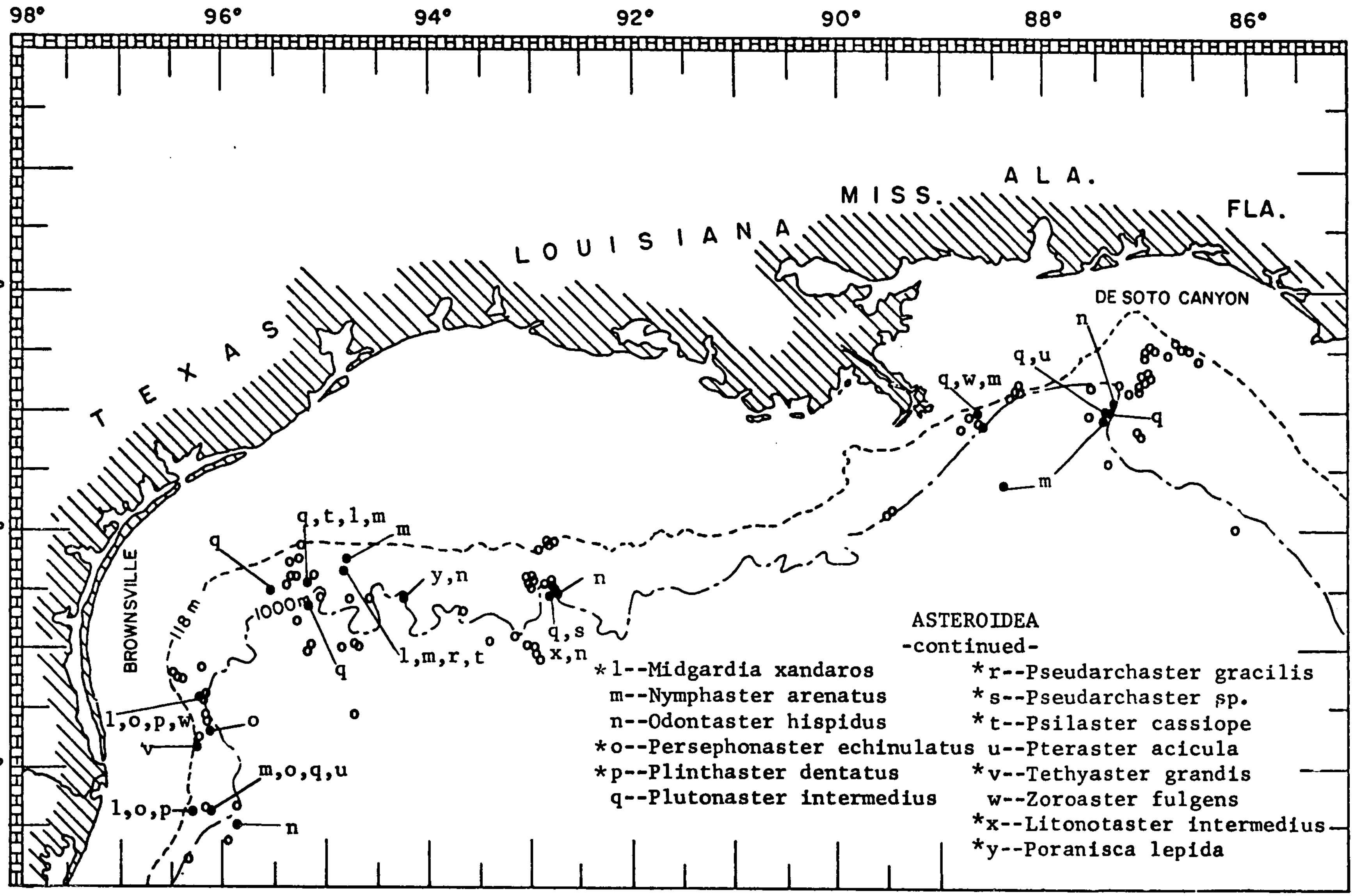

Fig. 6-7. Continuation of distribution of starfishes among the 111 stations of the upper continental slope study area.

Table 6-3. (A) Sea urchins found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of deep water Echinoidea of the Gulf of Mexico upper continental slope area arranged by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x 5)	C. Product A x B	Depth Range (m)	Depth of Maximum Population (m)
Stylocidaris affinis	54	5	270	150-400	150
Stylocidaris sp.	5	0	-	150 only	150
Genocidaris maculata	3	0	-	150 only	150
Conolampas sigsbei	1	0	-	150 only	150
Lytechinus euerces	1	0	-	150 only	150
Brissopsis atlantica	5,144	10	51,440	100-300	200
Brissopsis alta	2,393	5	11,965	150-500	200
Brissopsis elongata	1,044	0	-	200 only	200
Hypselaster limicolus	233	5	1,165	200-300	300
Echinolampas depressa	4	0	-	300-500	300
Agassizia excentrica	2	0	-	400 only	400
Podocidaris sculpta	1	0	-	400 only	400
Palaeobrissus hilgardi	1	0	-	400 only	400
Araeosoma fenestratum	1	0	-	400 only	400
Phormosoma placenta	2,016	65	131,040	450-2150	700
Hemiaster expergitus	1	0	-	850 only	850
Hypselaster brachypetalus	12	0	-	900 only	900
Plesiodiadema antillarum	11,070	25	276,750	850-1350	950
Brissopsis sp.	529	5	2,645	750-2100	1200
Echinocyamus grandiporus	6	0	-	2100 only	2100
Hygrosoma petersii	12	0	-	2100-2150	2150
Aceste bellidifera	1	0	-	3550 only	3550

B. Dominant sea urchins presented in rank order.

SPECIES	Depth of Peak Population (m)
1. Plesiodiadema antillarum	950
2. Phormosoma placenta	700
3. Brissopsis atlantica	200
4. Brissopsis alta	200
5. Brissopsis sp.	1200
6. Hypselaster limicolus	300

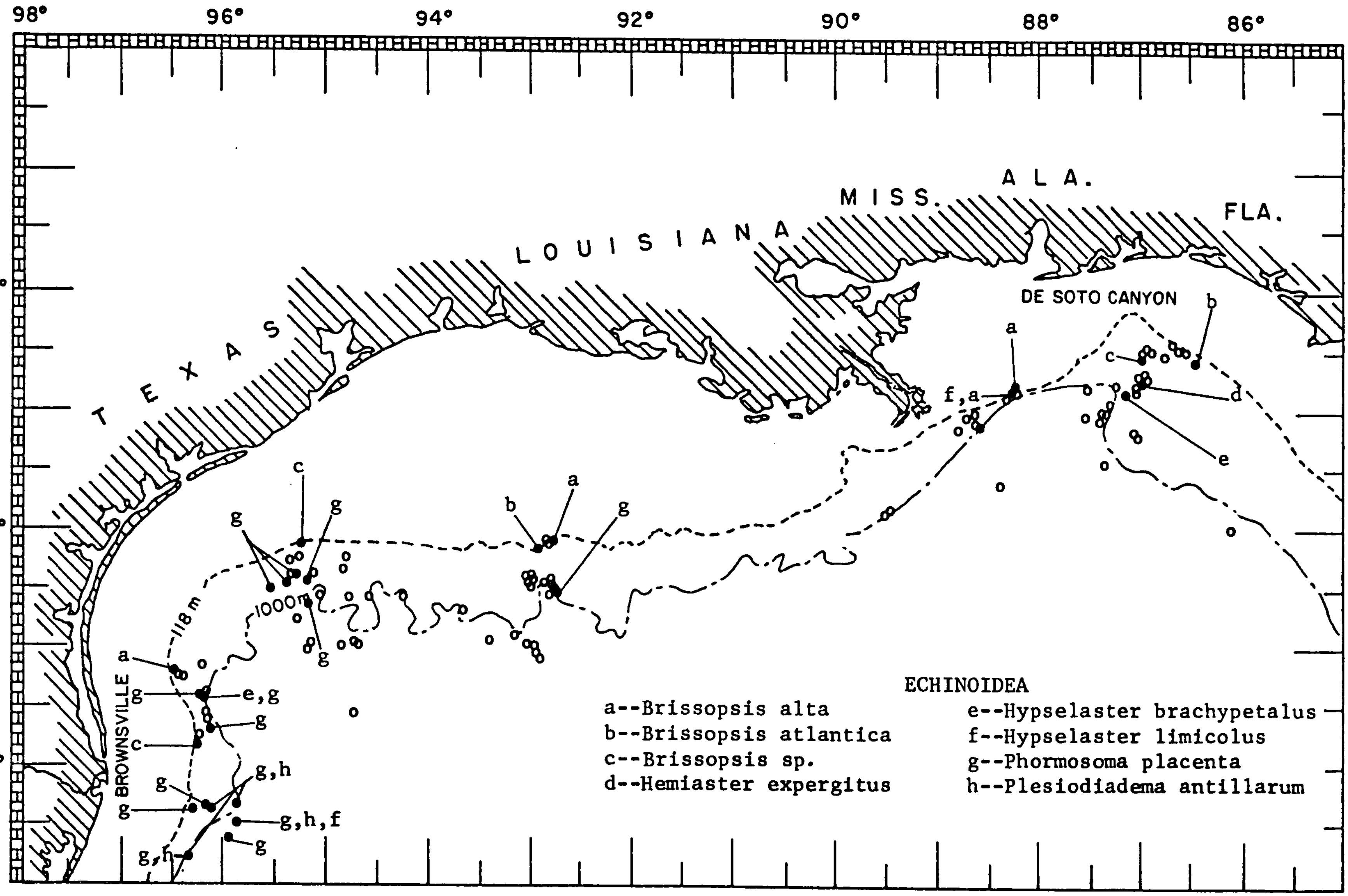

Fig. 6-8. Distribution of sea urchins and sand dollars among the 111 stations of the upper continental slope study area.

Plesiodiadema antillarum was found in the sampling depth in the De Soto Canyon region.

In Fig. 6-9 it appears that the echinoids present essentially two centers of importance on the upper continental slope: the shallow center between 100-500 m, dominated by species of the genus Brissopsis and the deep group between 750-1000 m (and deeper) dominated by Phormosoma and Plesiodiadema. Phormosoma placenta overlaps in vertical distribution two other species of interest: on the shallow end it is found with Plesiodiadema and it shares the deep end of its range with Hygrosoma petersii. Apparently the food of Phormosoma is derived principally from sediments, whereas both Plesiodiadema and Hygrosoma appear to attack decaying vegetation (Booker, 1971).

Holothuroidea (Sea Cucumbers). Some 15 species of sea cucumbers occur in the designated depth limits of the upper continental slope of the northern Gulf of Mexico (see Table 6.4). One notes in Fig. 6-10, however, that holothurians do not appear on the slope until somewhere between 450 and 500 m. It is also important to note that some species of sea cucumbers are found on the inner shelf. Furthermore, Molpadia cubana also occurs in shallow water on the Texas shelf but it is not found on the adjacent slope until around 500 m. It is highly unlikely that one has missed collecting it in this bathymetric hiatus. The explanation may lie in the nature of the currents and distribution of food materials.

According to the distribution maps (Fig. 6-11 and 6-12) there is a real east-west separation in the distribution of a few species. It appears now that Bathyplotes natans, Benthodytes sanguinolenta, and Molpadia barbouri are found in the west only, whereas Euphronides kerhervei and Ypsilothuria talismani are in the east only. It is interesting to note also that the record of Protankyra sluiteri is not only the first for the Gulf of Mexico but indeed it has been reported previously only from the East Indies.

Ophiuroidea (Serpent Stars). The identification of the ophiuroids of the upper continental slope has not progressed to the point where

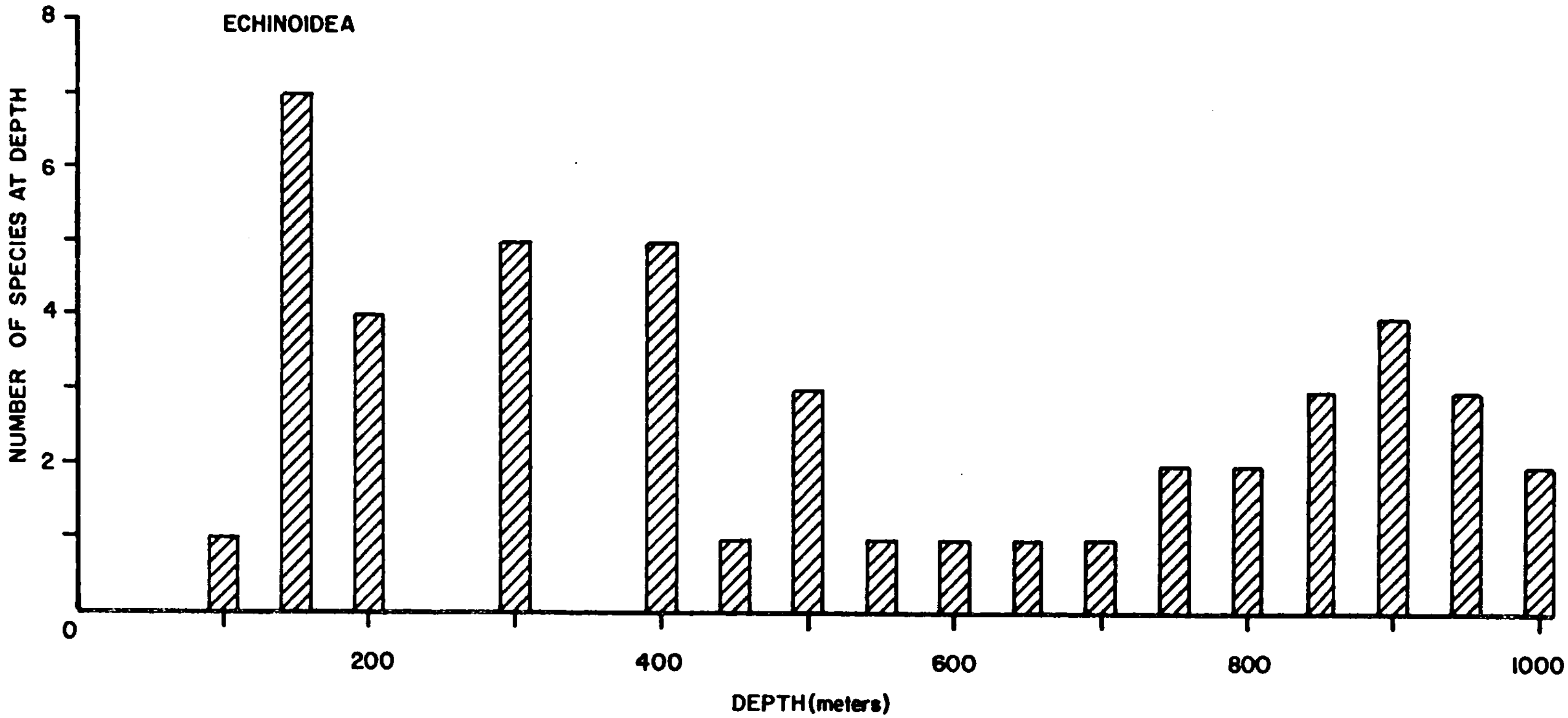

Fig. 6-9. Histograms showing the number of species of sea urchins found at the various isobaths within the sampling area on the upper continental slope.

Table 6-4. (A) Sea cucumbers found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of deep water Holothuroidea of the Gulf of Mexico upper continental slope listed by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x 5)	C. Product A x B	Depth Range (m)	Depth of Maximum Population (m)
Molpadia musculus	379	15	5,685	500-1300	950
Mesothuria lactea	571	45	25,695	500-1750	950
Hedingia albicans	18	0	-	500-750	750
Molpadia oolitica	8	0	-	500-750	750
Molpadia cubana	7	0	-	550-750	750
Ypsilothuria talismani	35	0	-	600-700	600
Bathyplotes natans	11	0	-	600-1000	750
Paracaudina sp.	4	5	20	650 only	650
Molpadia barbouri	303	0	-	700-1150	950
Benthodytes sanguinolenta	26	5	130	700-1450	1000
Echinocucumis hispida	65	15	975	800-1500	1000
Euphronides kerhervei	6	0	-	800 only	800
Protankyra sluiteri	1	0	-	850 only	850
Molpadia sp.	16	0	-	900-950	900
Deima blakei	33	10	330	1000-3450	1850

B. Dominant sea cucumbers presented in rank order.

SPECIES	Depth of Peak Population (m)
1. *Mesothuria lactea*	950
2. *Molpadia musculus*	950
3. *Echinocucumis hispida*	1000
4. *Deima blakei*	1850
5. *Benthodytes sanguinolenta*	1000

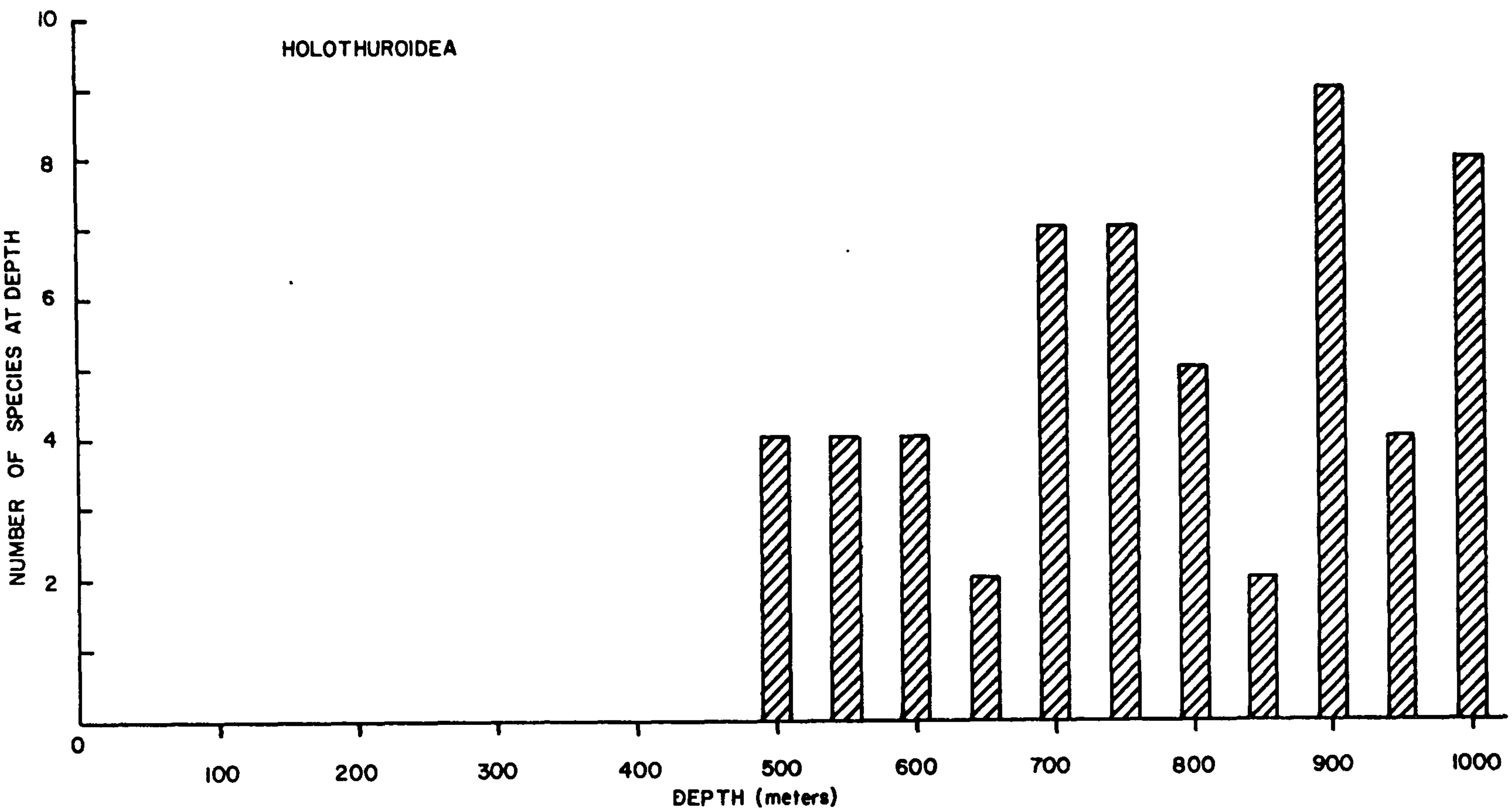

Fig. 6-10. Histograms showing the numbers of species of sea cucumbers occurring at the various sampling isobaths on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m depth. Note that they appear to be absent from about the shelf break to 450-500 meters. They are known to exist on the shelf, however.

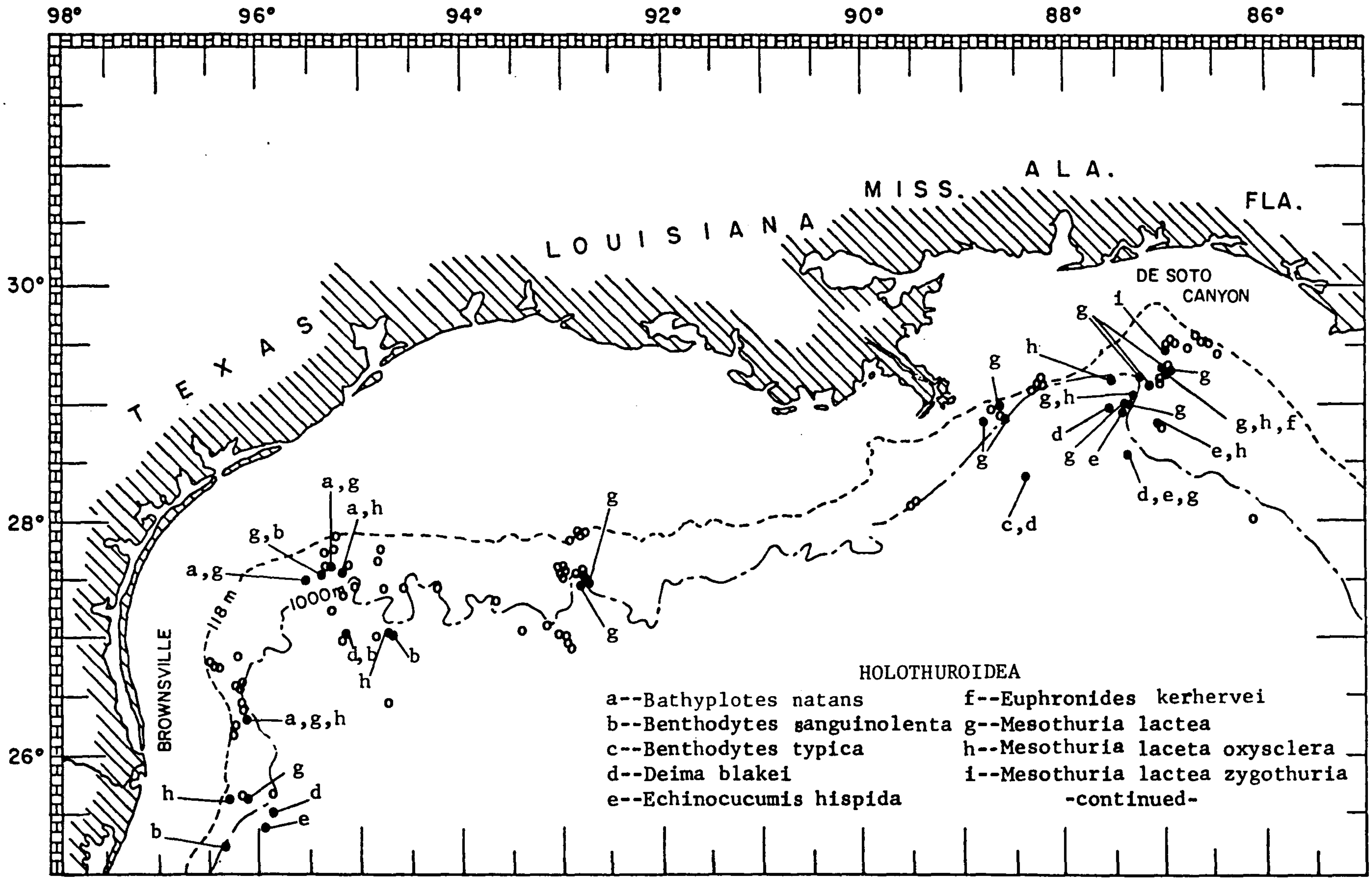

Fig. 6-11. Distribution of some sea cucumbers among the 111 stations of the study area. Although found at one of the 111 stations, Benthodytes typica is outside the depth range of the upper slope.

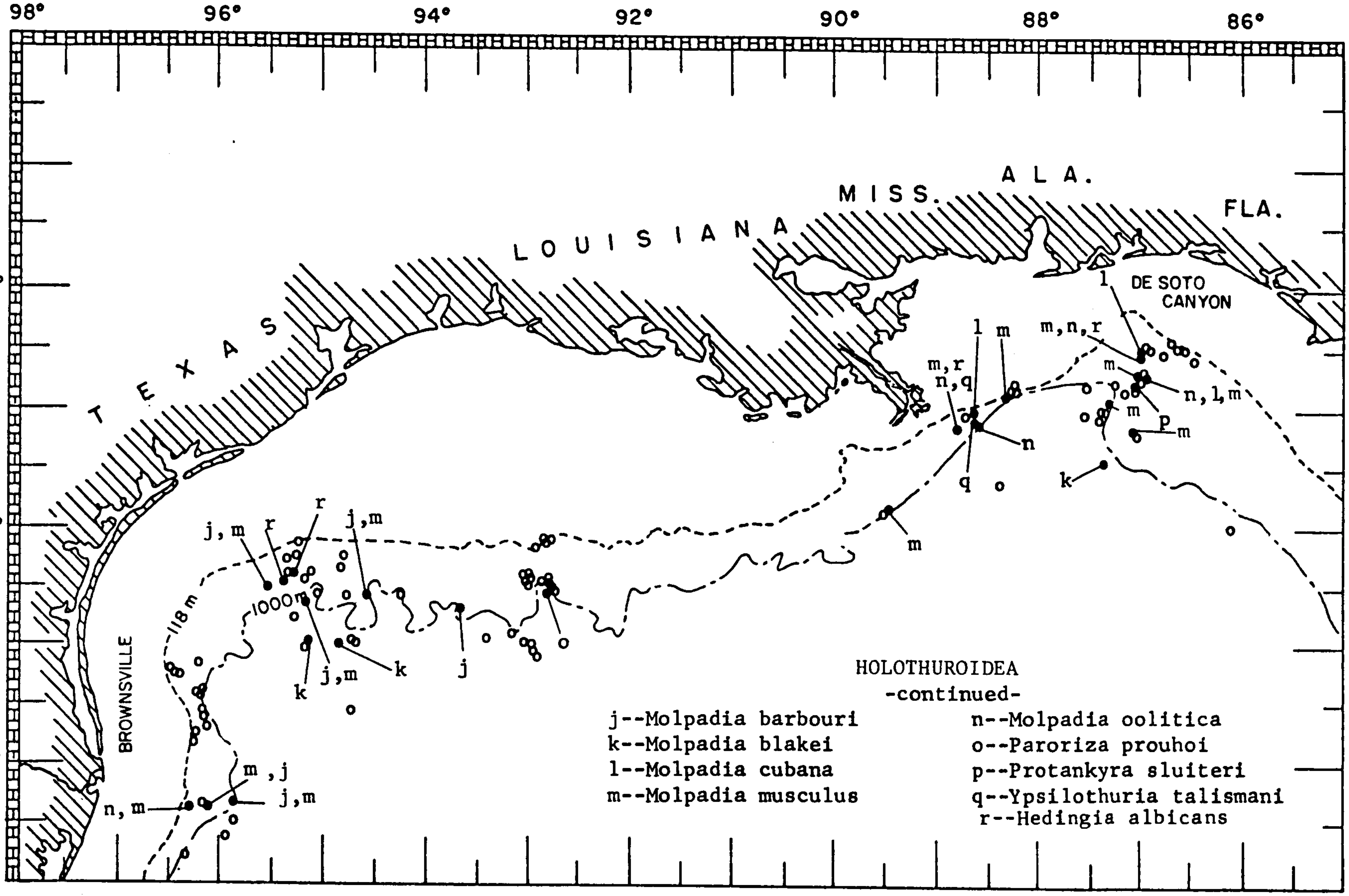

Fig. 6-12. Continuation of the distribution of sea cucumbers among the 111 stations of the study area.

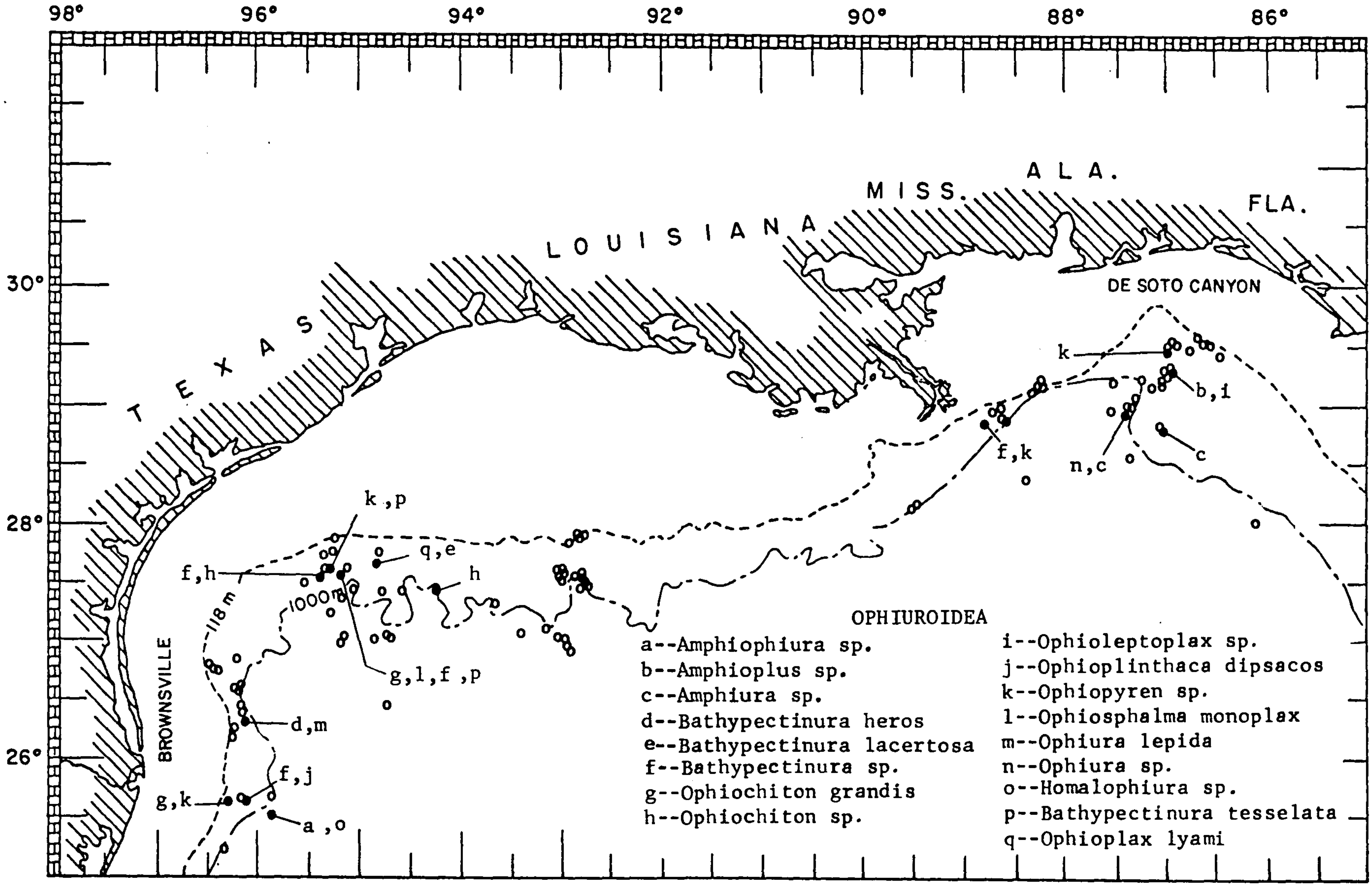

Fig. 6-13. Distribution of the serpent and brittle stars of the continental slope in the study area. Unfortunately, much remains to be done with the specific identifications of these organisms.

generalizations can be drawn from their distribution. It appears from Fig. 6-13 that at least six species occur at more than one station on the upper slope.

Crustacea

Isopoda. The only isopod crustacean discussed in this report is the giant cirolanid Bathynomus giganteus. This is by far the largest isopod found anywhere in the world. Bathynomus attains an overall length of over 30 cm.

It occurs both inside and outside of the depth limits of this report; it also occurs both in the eastern and western parts of the Gulf (see Fig. 6-14). Its bathymetric range in the Gulf runs from 400 to 2150 m with a peak of population around the 1200 m isobath. This form, then, is confined to the continental slope throughout its life-cycle; being a peracaridan, it does not have pelagic larvae.

Natantia: Penaeidea. Fourteen species of penaeid shrimps occur on the upper continental slope of the northern Gulf (see Table 6-5). Up to now Aristaeomorpha foliacea has only been taken on the western continental slope (see Figs. 6-15 and 6-16).

By all measures Penaeopsis megalops is the dominant penaeid of the shallower part of the upper slope and Benthesicymus bartletti fills the role on the lower part. Their ranges barely overlap between 700 and 750 m. Note that the shrimps of commerce (Penaeus and Sicyonia) do not reach the depths of the slope proper.

Natantia: Caridea. Twenty-four species of caridean shrimps occur on the upper continental slope of the northern Gulf of Mexico (see Table 6.6). The overwhelming dominant is Nematocarcinus rotundus, which peaks out population wise at 1050 m, followed by Glyphocrangon nobilis, which is a poor

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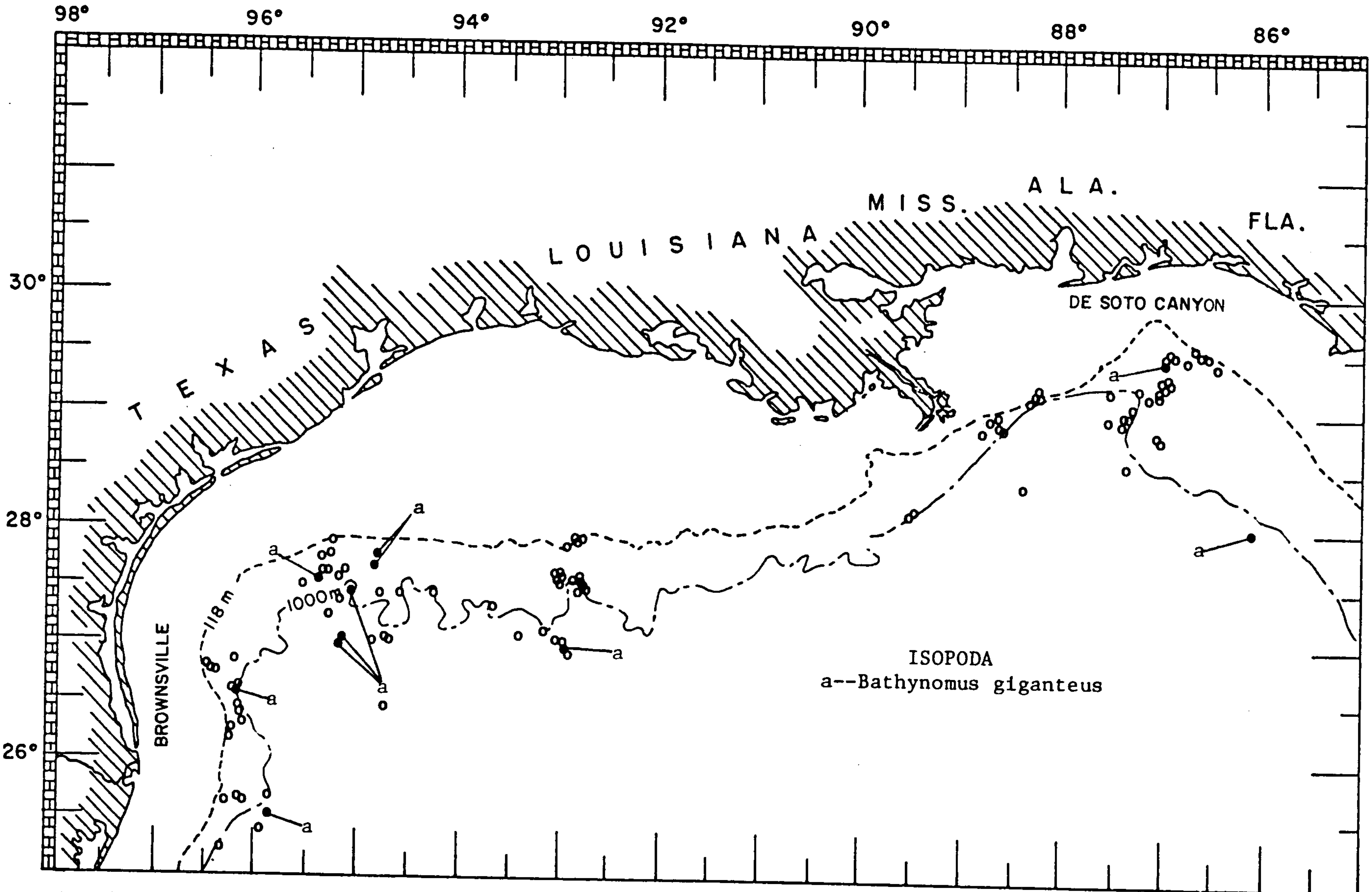

Fig. 6-14. Distribution of Bathynomus giganteus on the upper continental slope of the northern Gulf of Mexico.

Table 6-5. (A) Penaeid shrimps found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of deep water Penaeidea on the upper continental slope of the Gulf of Mexico arranged by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Hymenopenaeus tropicalis	2	0	-	150 only	150
Solenocera vioscai	111	5	555	Shelf-750	200
Parapenaeus longirostris	586	5	2930	Shelf-300	250
Solenocera necopina	14	0	-	200-250	250
Penaeopsis megalops	2634	25	65,850	200-750	250
Hymenopenaeus robustus	188	10	1880	250-750	500
Aristaeomorpha foliacea	23	5	115	500-650	550
Hymenopenaeus debilis	280	5	1400	300-1050	600
Aristeus antillensis	6	0	-	500-750	700
Plesiopenaeus edwardsianus	48	5	240	400-1450	950
Benthesicymus bartletti	660	85	56,100	700-2250	1050
Funchalia taaningi	2	0	-	1000-1100	1050
Hymenopenaeus aphoticus	37	15	555	1000-3250	1400
Hepomadus tener	11	20	220	1000-3850	2350

B. Dominant penaeid shrimps presented in rank order.

SPECIES	Depth of Peak Pop. (m)	SPECIES	Depth of Peak Pop. (m)
1. Penaeopsis megalops	250	6. Solenocera vioscai	200
2. Benthesicymus bartletti	1050	7. Hymenopenaeus aphoticus	1400
3. Parapenaeus longirostris	250	8. Plesiopenaeus edwardsianus	950
4. Hymenopenaeus robustus	500	9. Hepomadus tener	2350
5. Hymenopenaeus debilis	600	10. Aristaeomorpha foliacea	550

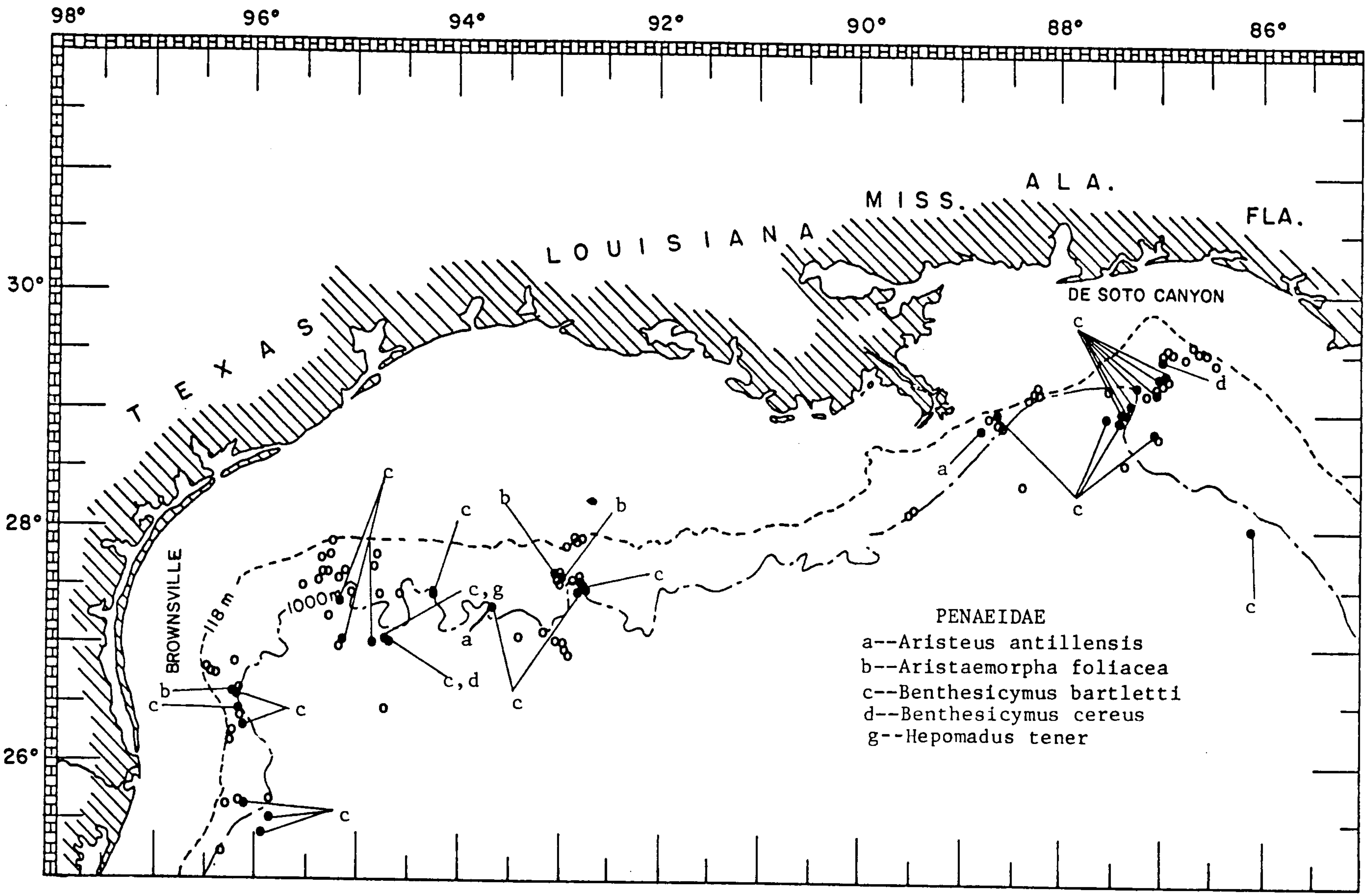

Fig. 6-15. Distribution of penaeid shrimps among the 111 stations of the study area. (Continued on Fig. 6-16).

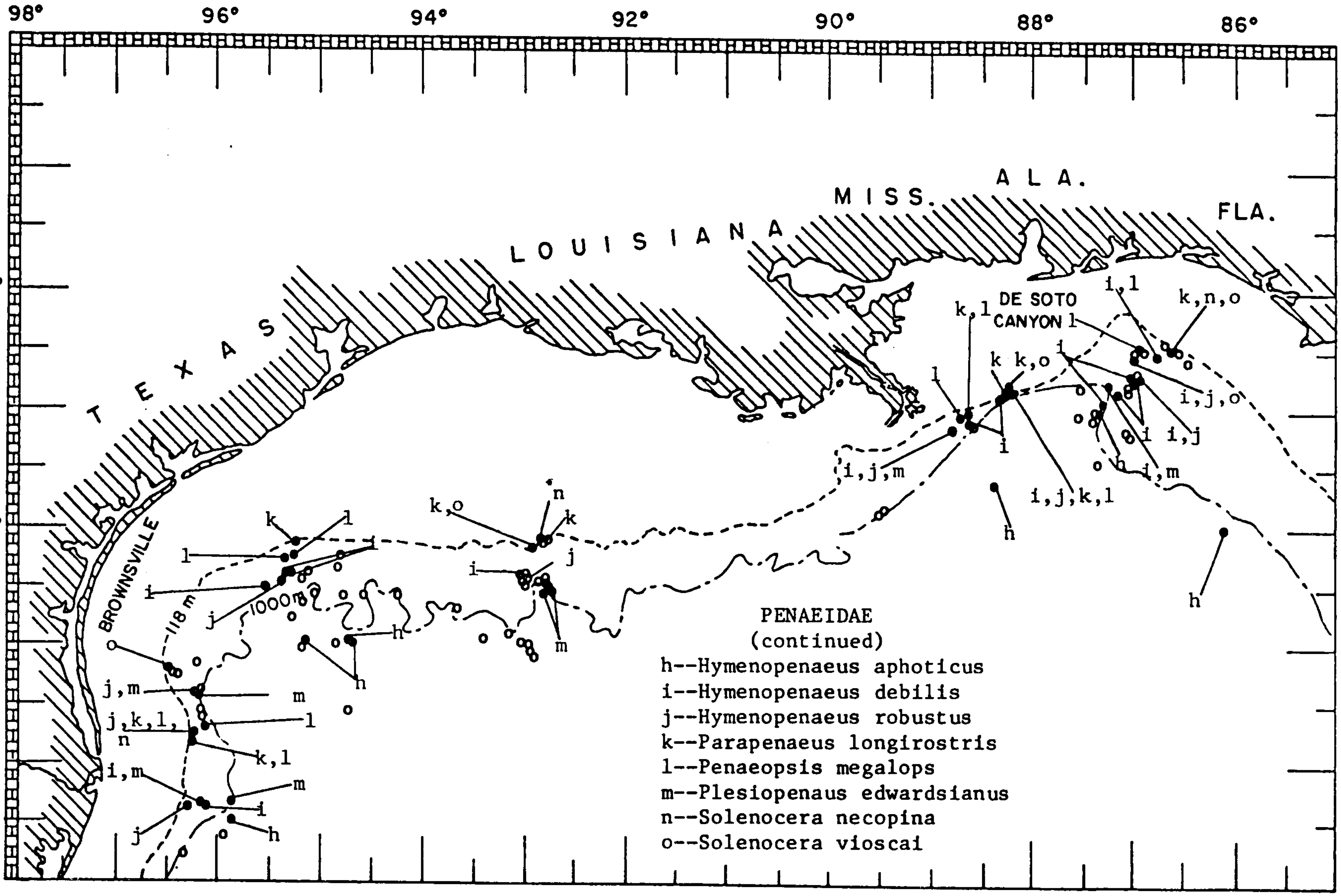

Fig. 6-16. Continuation of distribution of penaeid shrimps among the 111 stations of the study area.

Table 6-6. (A) Caridean shrimps found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Caridea on the upper continental slope of the Gulf of Mexico arranged by depth of maximum occurrence.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Plesionika tenuipes	75	5	375	250-500	250
Stystellaspis affinis	1413	5	7065	250-750	300
Pontocaris caribbaeus	31	0	-	300 only	300
Parapandalus willisi	252	10	2520	250-450	400
Plesionika edwardsii	10	0	-	400 only	400
Sabinea tridentata	3	0	-	400 only	400
Heterocarpus ensifer	178	5	890	450 only	450
Plesionika martia	4	0	-	500 only	500
Glyphocrangon longleyi	71	10	710	500-650	550
Pasiphaea merriami	673	5	3365	300-800	600
Plesionika holthuisi	255	59	1275	500-900	600
Plesionika acanthonotus	43	0	-	550-750	600
Pontophilus gracilis	72	0	-	450-1400	700
Plesionika polyacanthomerus	30	0	-	500-900	700
Glyphocrangon alispina	427	10	4270	650-1050	750
Parapandalus richardi	1	0	-	850 only	850
Acanthephyra armata	15	0	-	700-950	950
Psalidopus barbouri	3	0	-	650-950	950
Nematocarcinus cursor	1	0	-	950 only	950
Glyphocrangon aculeata	468	5	2340	800-1750	1000
Nematocarcinus rotundus	1746	65	113,490	300-1850	1050
Glyphocrangon nobilis	945	15	14,175	700-2100	1050
Heterocarpus oryx	234	0	-	700-1750	1100
Acanthephyra eximia	20	0	-	900-1750	1400

B. Dominant carideans presented in rank order.

	SPECIES	Depth of Peak Pop. (m)		SPECIES	Depth of Peak Pop. (m)
1.	*Nematocarcinus rotundus*	1050	6.	*Parapandalus willisi*	400
2.	*Glyphocrangon nobilis*	1050	7.	*Glyphocrangon aculeata*	1000
3.	*Stystellaspis affinis*	300	8.	*Plesionika holthuisi*	600
4.	*Glyphocrangon alispina*	750	9.	*Heterocarpus ensifer*	450
5.	*Pasiphaea merriami*	600	10.	*Glyphocrangon longleyi*	550

second, reaching peak population at the same depth. This probably indicates that these two species have very different feeding habits. In fact, Glyphocrangon nobilis is now known to burrow (Pequegnat et al., 1972), whereas it is highly unlikely that Nematocarcinus has that ability.

In Fig. 6-17 one sees that the carideans far exceed the penaeids in species diversity between 500 and 1000 m depth and, as a matter of fact, the trend is accentuated on the lower continental slope. There is some east-west differentiation among carideans; on the distribution maps (Figs. 6-18, 6-19, 6-20, 6-21) it may be observed that Psalidopus barbouri, Glyphocrangon longleyi, and Acanthephyra acutifrons occur on the western but not the eastern upper slope.

Macrura. The macrurous decapod crustaceans belonging to families Polychelidae and Nephropidae are not well known, even among marine biologists. This applies particularly to the polychelids as adults. The only common name applied to any member of the group was given only recently by personnel at the National Marine Fisheries Service Laboratory in Pascagoula, Mississippi. The name flatback lobsterette was applied principally to the species Stereomastis sculpta sculpta. Their habits as adults are almost entirely unknown, although it is known that they have a deep-sea pelagic larva known as the eryonid. This lack of information is epitomized by the fact that the polychelids are the only large crustaceans that in all probability have never been photographed in their habitat. This in itself is quite remarkable in that Stereomastis, in particular, is among the most abundant (see Table 6-7) of all crustaceans in the collection, and is sufficiently easy to capture by trawl that it has been given serious consideration as a candidate for economic exploitation. See Fig. 6-22 for the distribution of polychelids over the northern Gulf of Mexico continental slope area.

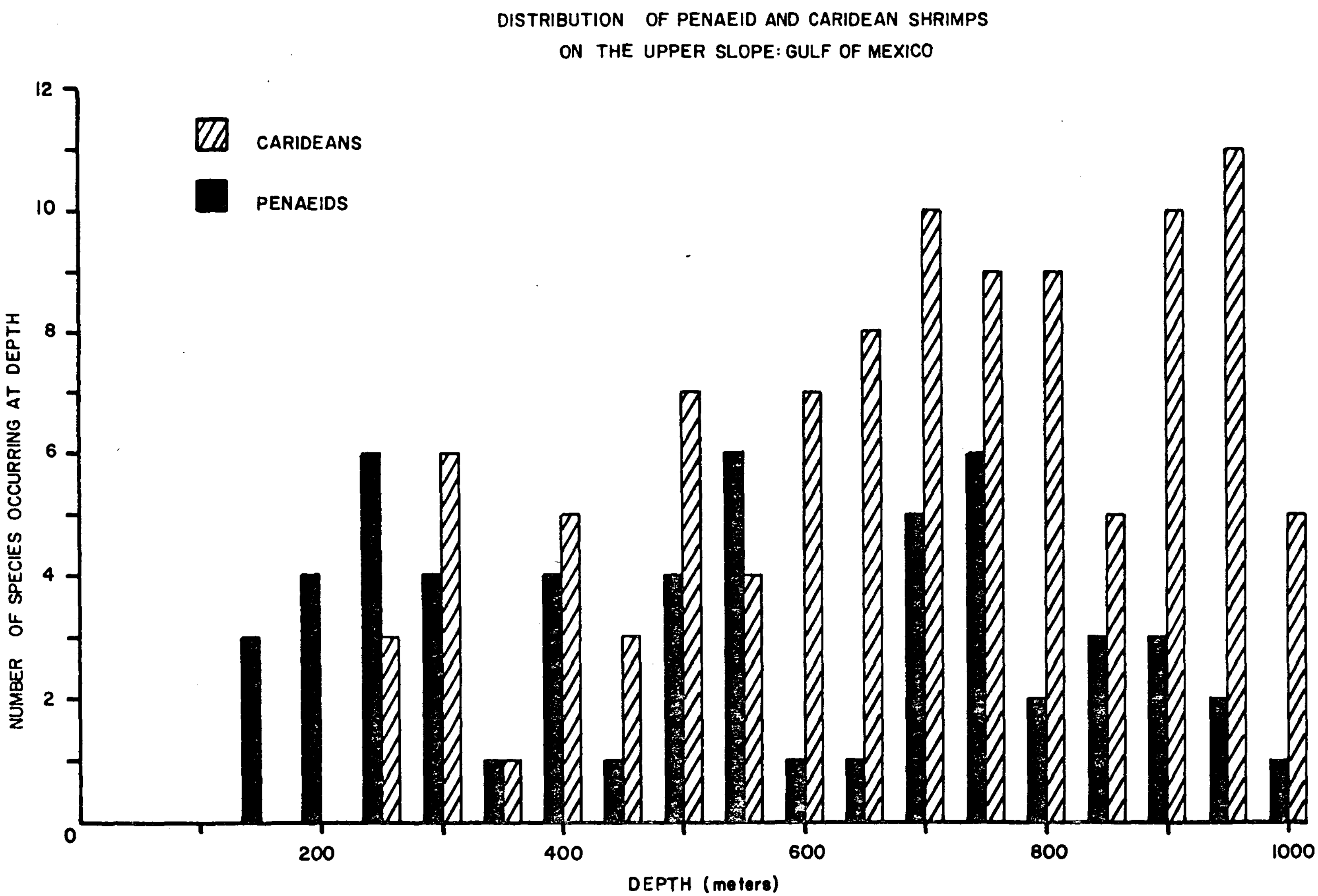

Fig. 6-17. Histograms showing the numbers of species of penaeid and caridean shrimps among the isobaths of the study area. Note penaeids predominate in shallower water, whereas carideans take over in deeper reaches of the slope.

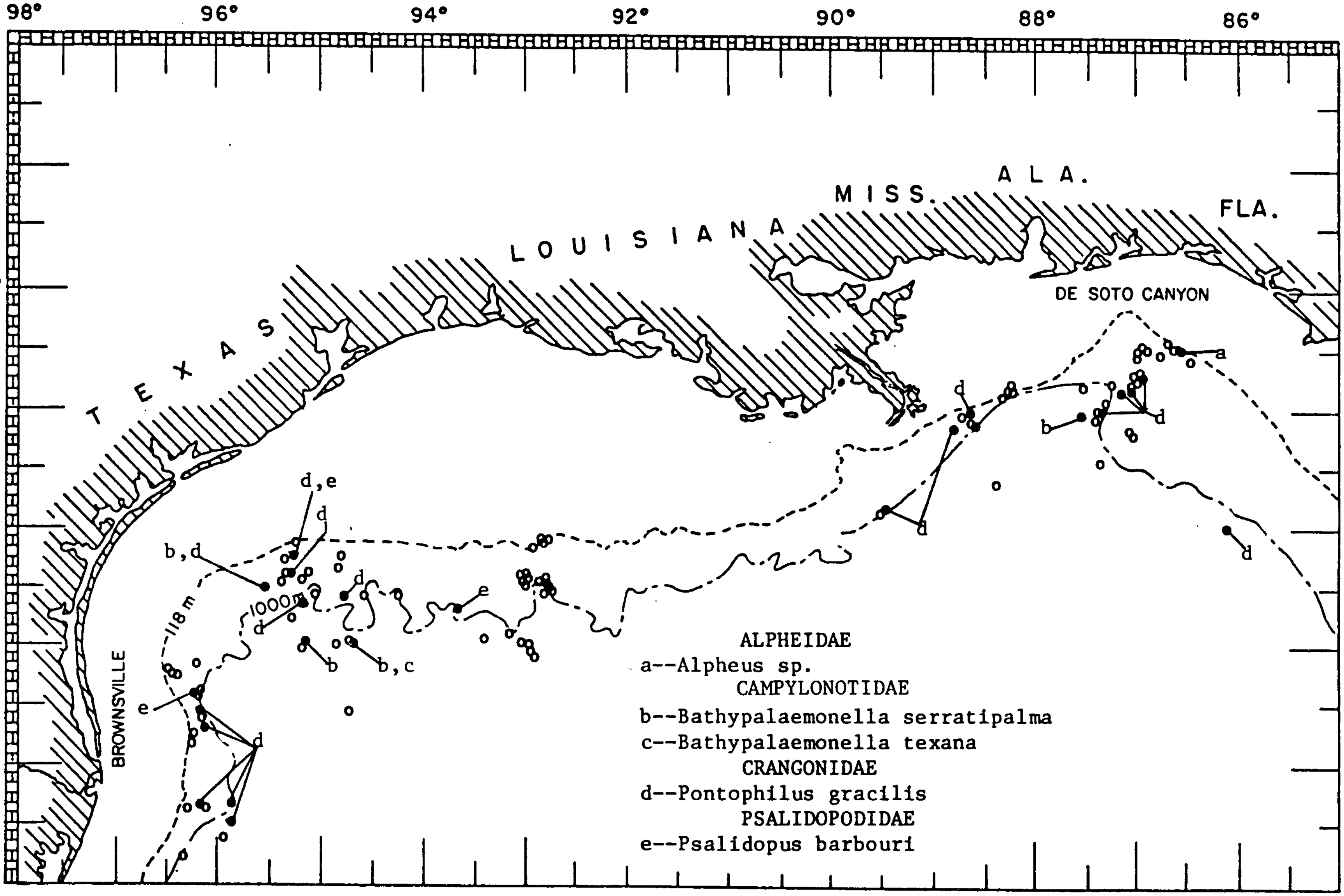

Fig. 6-18. Distribution of caridean shrimps among the 111 stations of the study area. (Continued on Figs. 6-19, 6-20, and 6-21).

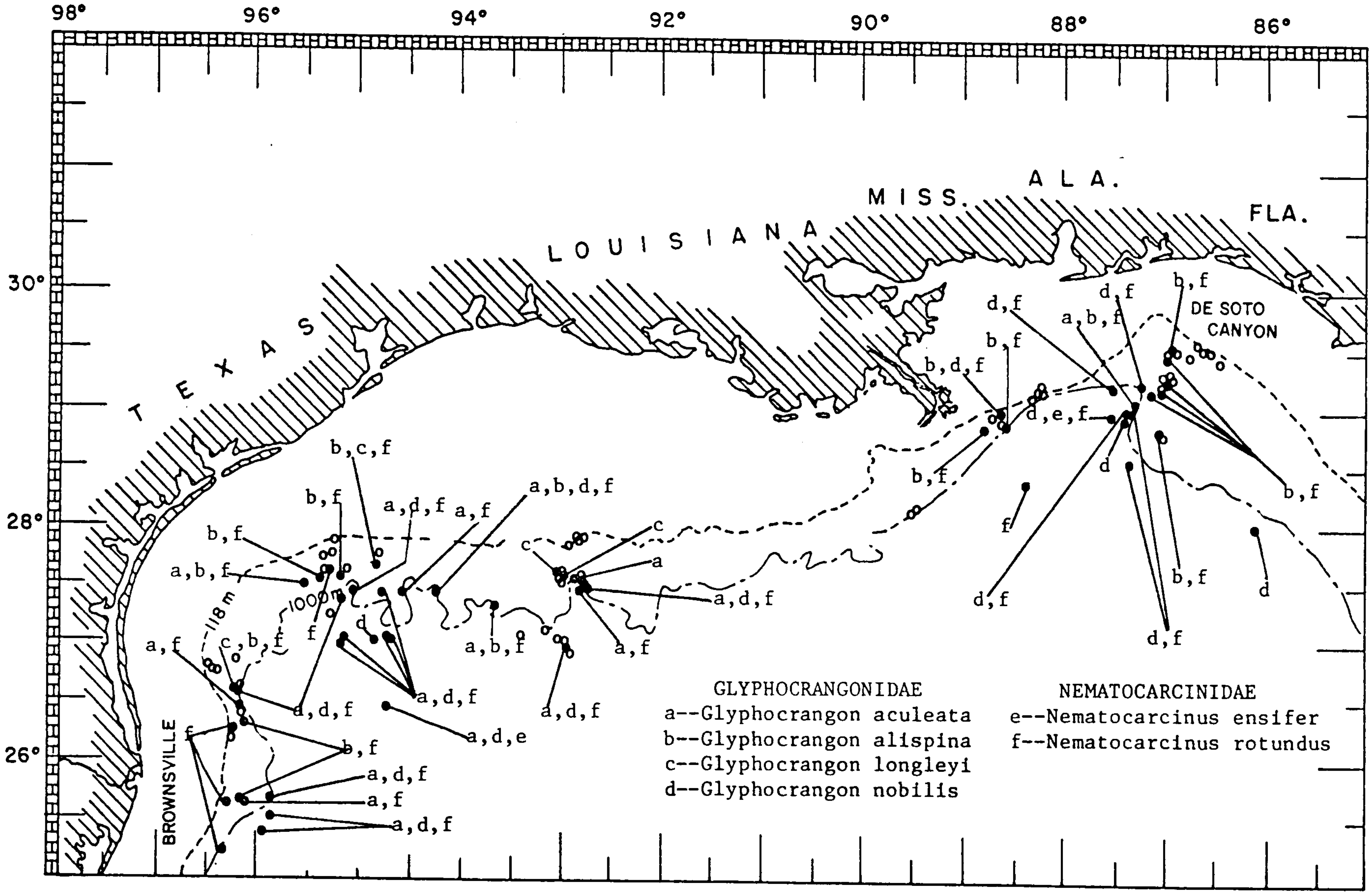

Fig. 6-19. Continuation of distribution of caridean shrimps among the 111 stations of the study area. (Continued on Figs. 6-20 and 6-21).

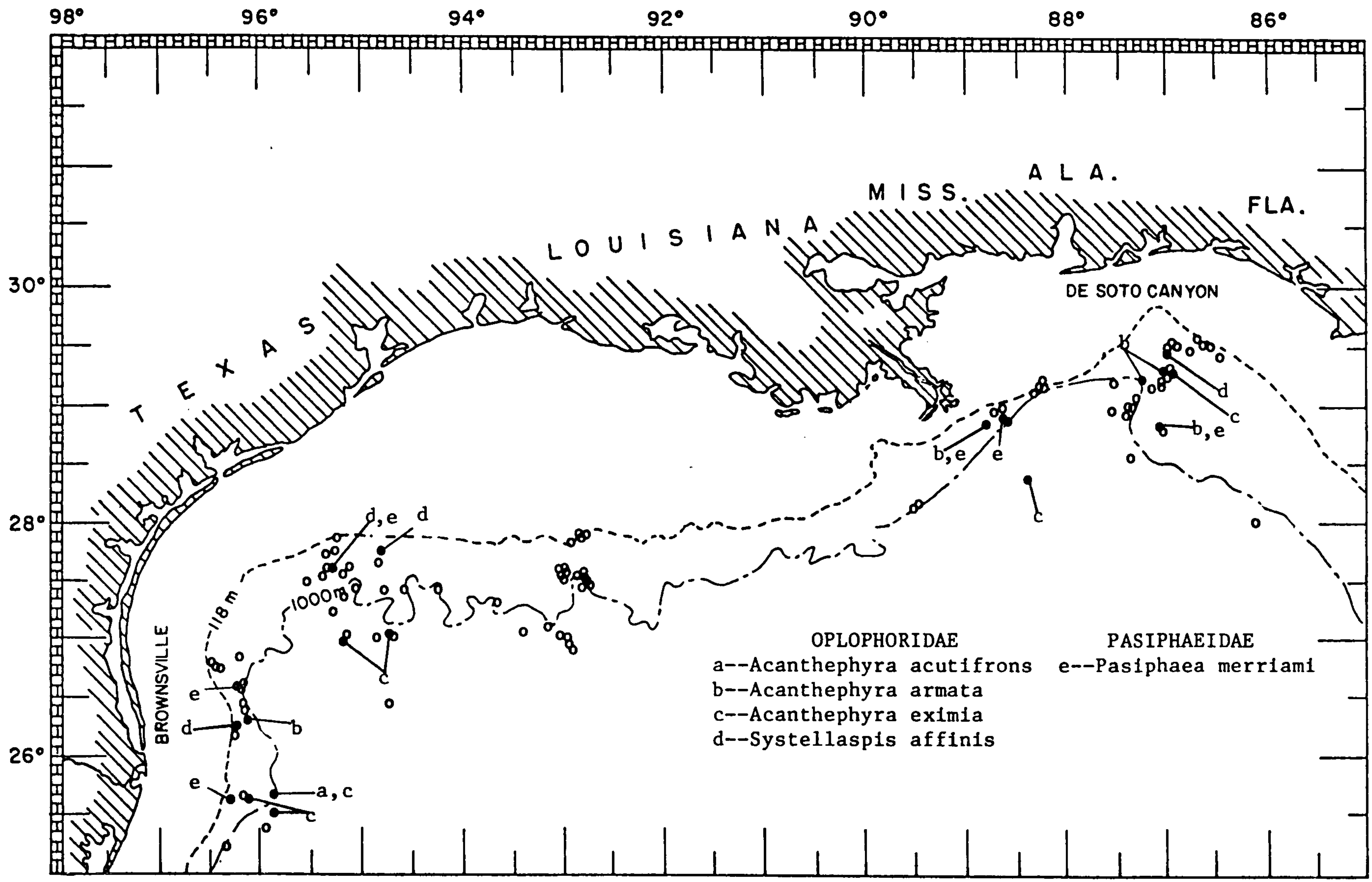

Fig. 6-20. Continuation of the distribution of caridean shrimps among the 111 stations of the study area. (Continued on Fig. 6-21).

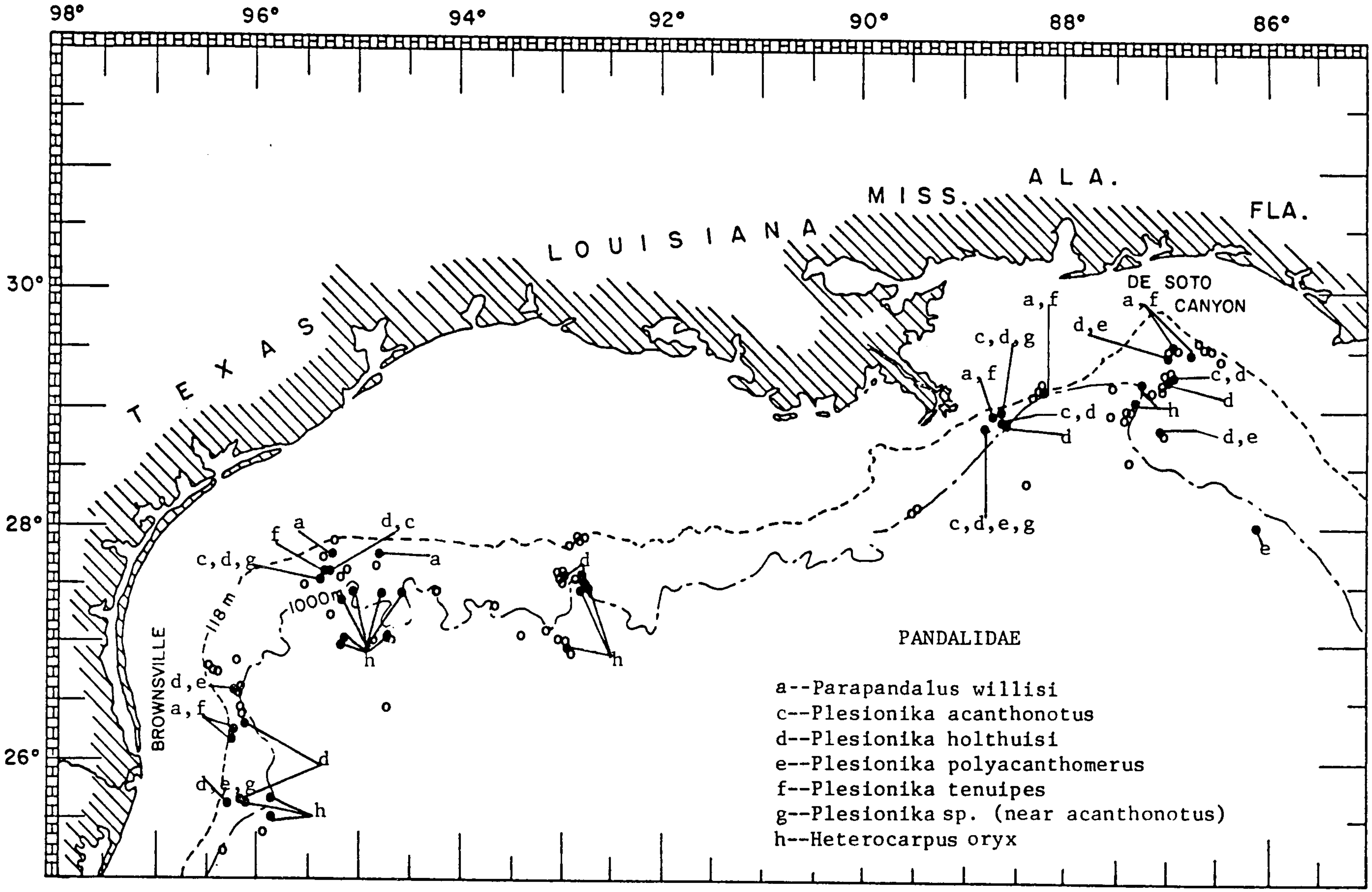

Fig. 6-21. Continuation of distribution of caridean shrimps among the 111 stations of the study area.

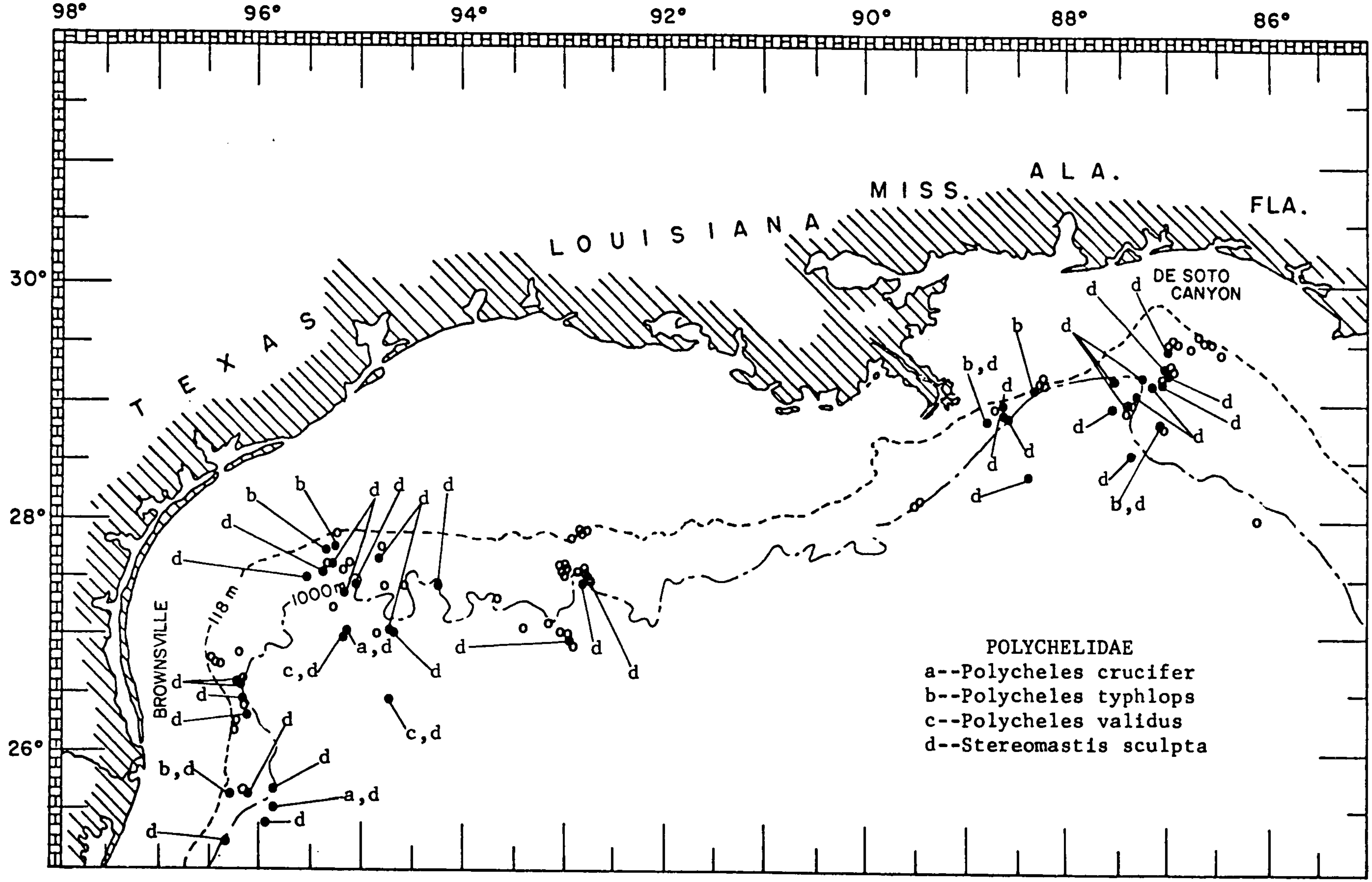

Fig. 6-22. Distribution of macruran decapods ("flat-backed lobsterettes") among the 111 stations of the study area.

Table 6-7. (A) Polychelid and nephropid crustaceans found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m.
(B) Dominant species in rank order.

A. Inventory of Polychelidae and Nephropidae on the upper continental slope-Gulf of Mexico arranged by depth of maximum population.

SPECIES	A. Total Individuals at all stations	B. Sum of stations where species is dominant (x5)	C. Product A X B	Depth Range (m)	Depth of Maximum Population (m)
Polychelidae					
Polycheles typhlops	98	15	1470	350-800	500
Stereomastis s. sculpta	1481	110	162,910	500-2750	900
Polycheles crucifer	4	0	-	1000-1400	1200
Nephropidae					
Nephropsis aculeata	101	25	2525	350-1350	500
Nephropsis rosea	16	5	80	500-750	700
Acanthacaris caeca	5	0	-	500-950	500

B. Dominants of Polychelidae and Nephropidae presented in rank order.

1. Stereomastis s. sculpta
2. Polycheles typhlops

1. Nephropsis aculeata
2. Nephropsis rosea

The nephropids or deep-sea lobsters, on the other hand, are nowhere as abundantly represented in this collection (see Table 6-7) but even so at least two species have been photographed in their habitat. The fact that one can obtain Stereomastis very easily with a trawl and yet cannot obtain photographs of it with a bottom camera suggests that it moves very rapidly and is capable of "diving" into the surface layer of unconsolidated sediments when disturbed.

The distribution of some of the nephropids in the Gulf displays an interesting pattern (Fig. 6-23). So far as present data indicate three species, viz., Acanthacaris caeca, Nephropsis agassizii and N. rosea, which are common in the Caribbean off Mexico and Honduras, appear to be found primarily on the continental slope of the western Gulf of Mexico. This may be related entirely to habitat preference and the lack of suitable places to the east,

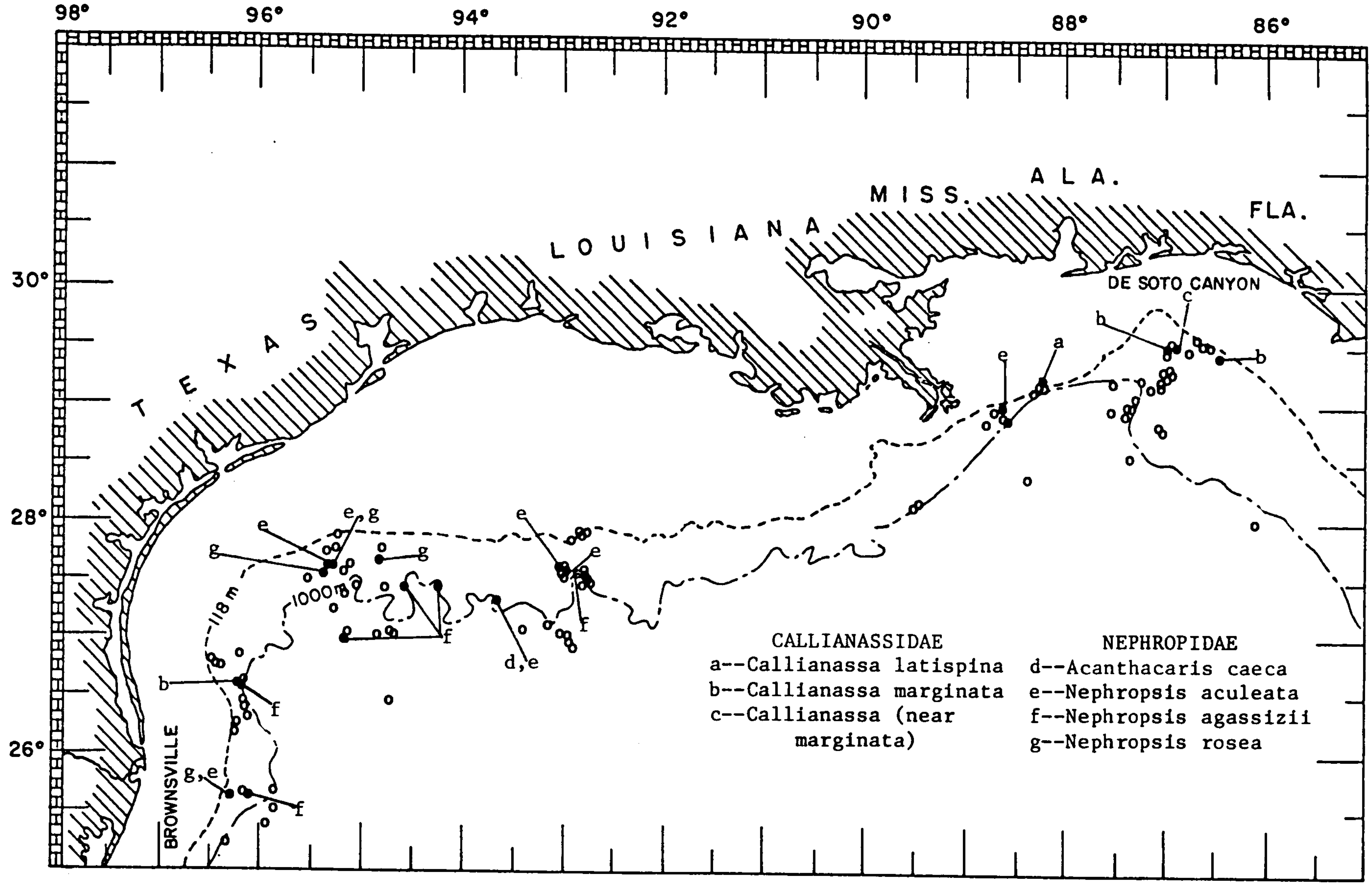

Fig. 6-23. Distribution of macruran decapods ("lobsters") among the 111 stations of the study area.

but possibly it may result from the fact that only those larvae in the west-flowing branches of the Yucatan Current have any opportunity to reach suitable habitat and thus provide recruitment for the northern Gulf populations. This phenomenon is not restricted to nephropids, being applicable to some galatheids and fishes as well.

Anomura. The Anomura are represented on the upper continental slope by (in order of importance) (1) the Galatheidae of the genera Munida and Munidopsis; (2) the Paguridae or hermit crabs especially by the genus Parapagurus; (3) the Lithodidae with the crablike Lithodes agassizii; (4) the Chirostylidae, which are represented on the slope only by Uroptychus nitidus which lives only in the gorgonian horny coral Chrysogorgia; and finally (5) the Porcellanidae which has the species Porcellana sigsbeiana on the upper slope.

The vertical distribution of galatheids will be presented in considerable detail (see Table 6-8). In this table and on Fig. 6-24 it is very evident that species in the genus Munida are found on the shallowest part of the slope, whereas those in the genus Munidopsis appear deeper and attain their greatest development well down on the upper slope. In fact species of Munidopsis are found on the abyssal plain but the deepest species of Munida occurs between 1100 and 1350 m on the slope.

The distributions of the remainder of the anomurans are found in Fig. 6-24 and on the distribution maps (Figs. 6-25, 6-26, 6-27, and 6-28).

Brachyura. A great deal is told about the distribution and nature of the brachyuran crabs when one notes that 43 of the 44 species of deep-water crabs in the Gulf of Mexico occur in the faunal assemblages of the upper continental slope (see Table 6-9). Moreover, the 44th species, Homologenus rostratus, is represented in the collection by a single specimen taken at a depth of 1350 m. Incidentally, it is one of two known to exist in the world. Brachyurans are reasonably common on the shelf, as might be expected. They are, by and large, a relatively shallow group that clearly reach peak

Table 6-8. (A) Galatheids found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Galatheidae on the upper continental slope of the Gulf of Mexico arranged by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Populatic (m)
Munida irrasa	4	5	20	150-200	150
Munida forceps	37	10	370	100-350	200
Munida flinti	5	0	-	200 only	200
Munida sculpta	1	0	-	200 only	200
Munida longipes	209	25	5225	150-500	400
Munida valida	115	25	2875	450-950	650
Munidopsis tridentata	4	0	-	400-800	450
Munidopsis polita	4	0	-	400-750	500
Munidopsis robusta	22	0	-	400-1100	500
Munidopsis serratifrons	1	0	-	550 only	550
Munidopsis erinaceus	11	0	-	500-750	600
Munidopsis longimanus	21	10	210	400-1150	750
Munidopsis subspinoculata	1	0	-	800 only	800
Munidopsis alaminos	13	5	65	500-800	800
Munidopsis sigsbei	190	40	7600	750-1450	950
Munidopsis spinosa	6	0	-	800-1050	950
Munidopsis abbreviata	8	0	-	900-1150	1100
Munidopsis spinoculata	5	0	-	950-1350	1350
Munidopsis simplex	26	20	520	1000-1850	1350

B. Dominant galatheids presented in rank order.

SPECIES	Depth of Peak Pop. (m)	SPECIES	Depth c Peak Pop. (n
1. Munida longipes	400	1. Munidopsis sigsbei	950
2. Munida valida	650	2. Munidopsis simplex	1350
3. Munida forceps	200	3. Munidopsis longimanus	750

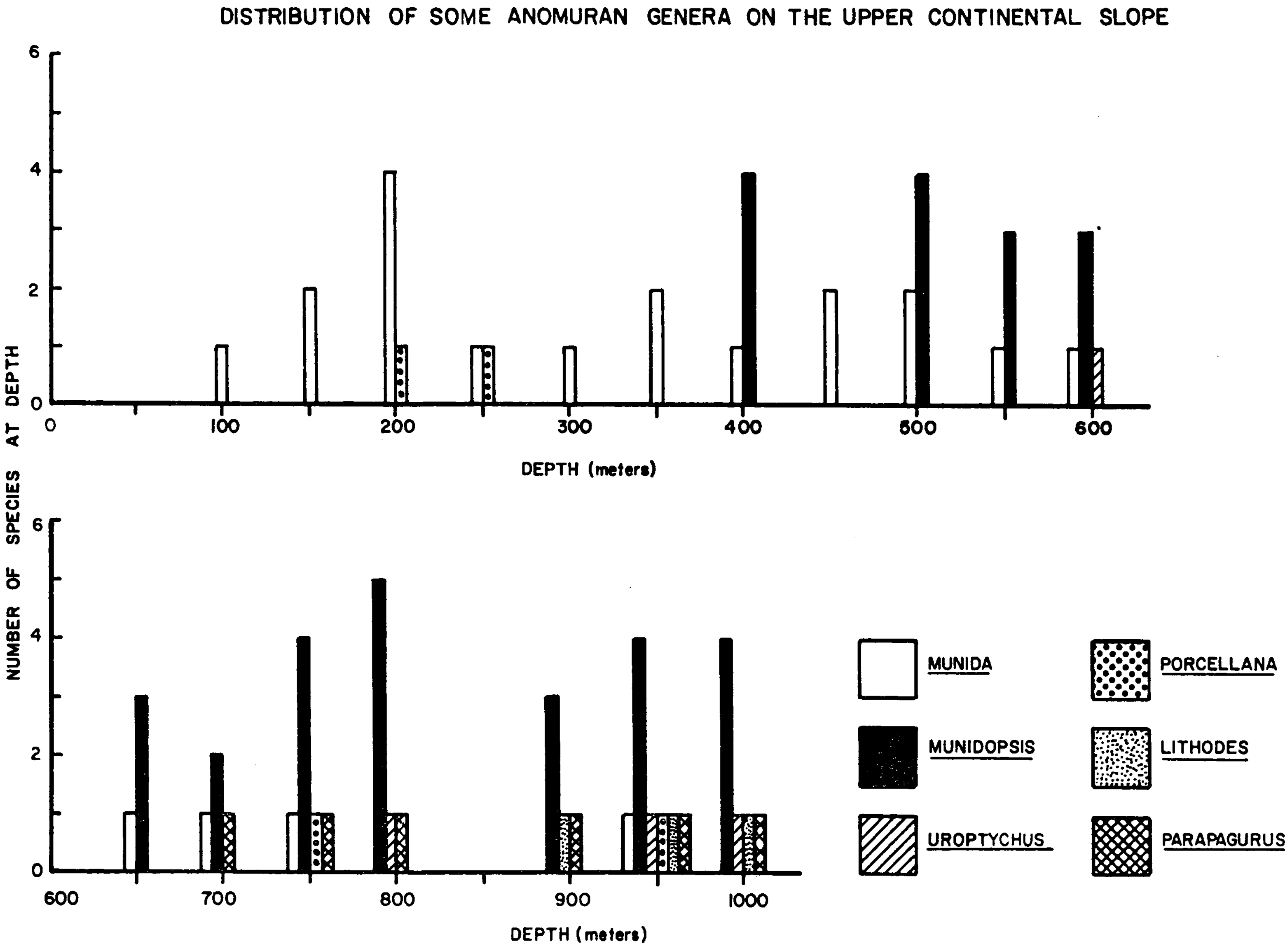

Fig. 6-24. Histograms showing the numbers of anomuran species among the isobaths of the study area.

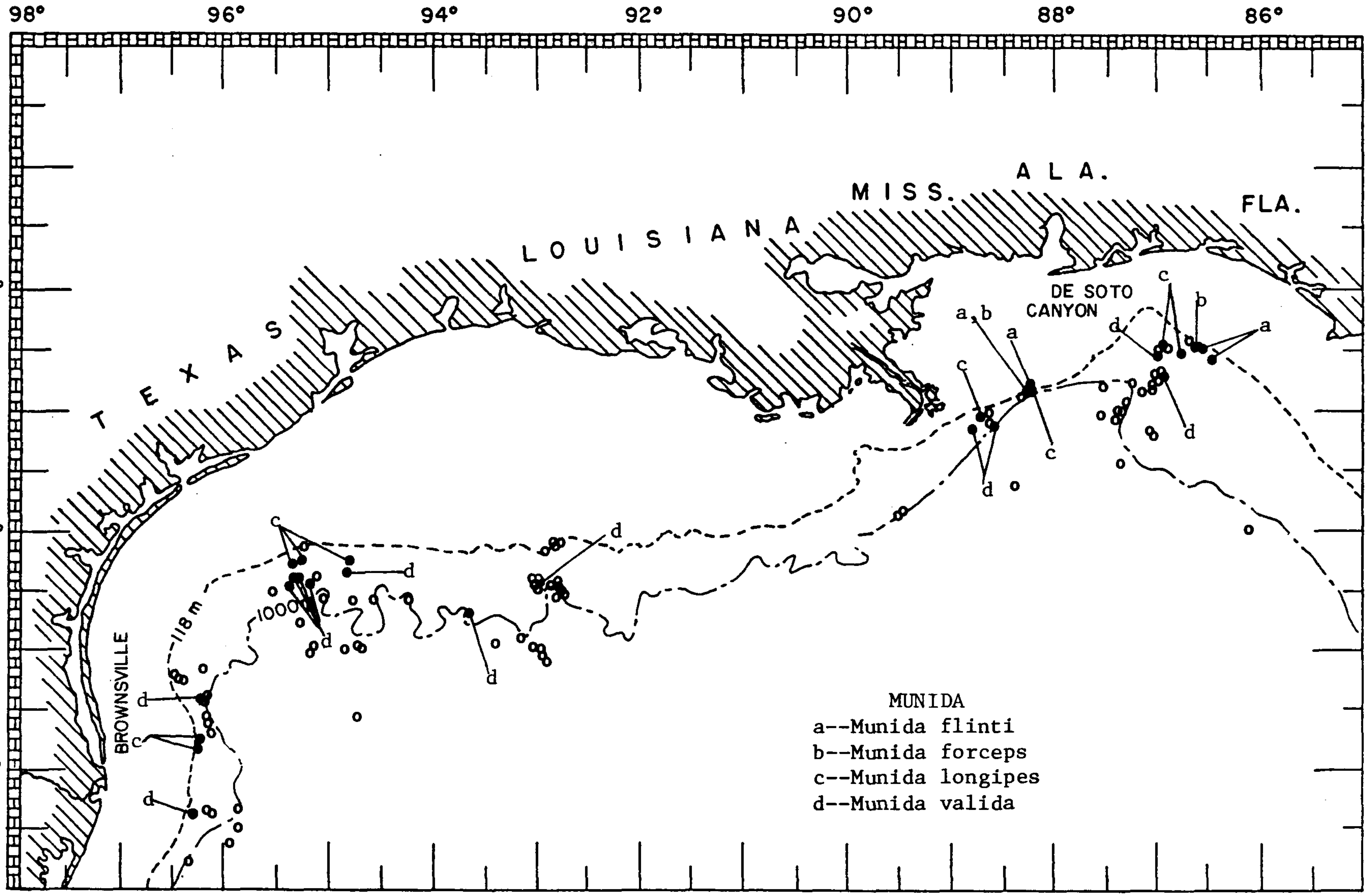

Fig. 6-25. Distribution of galatheid anomuran crabs among the 111 stations of the study area. (Continued on Fig. 6-26).

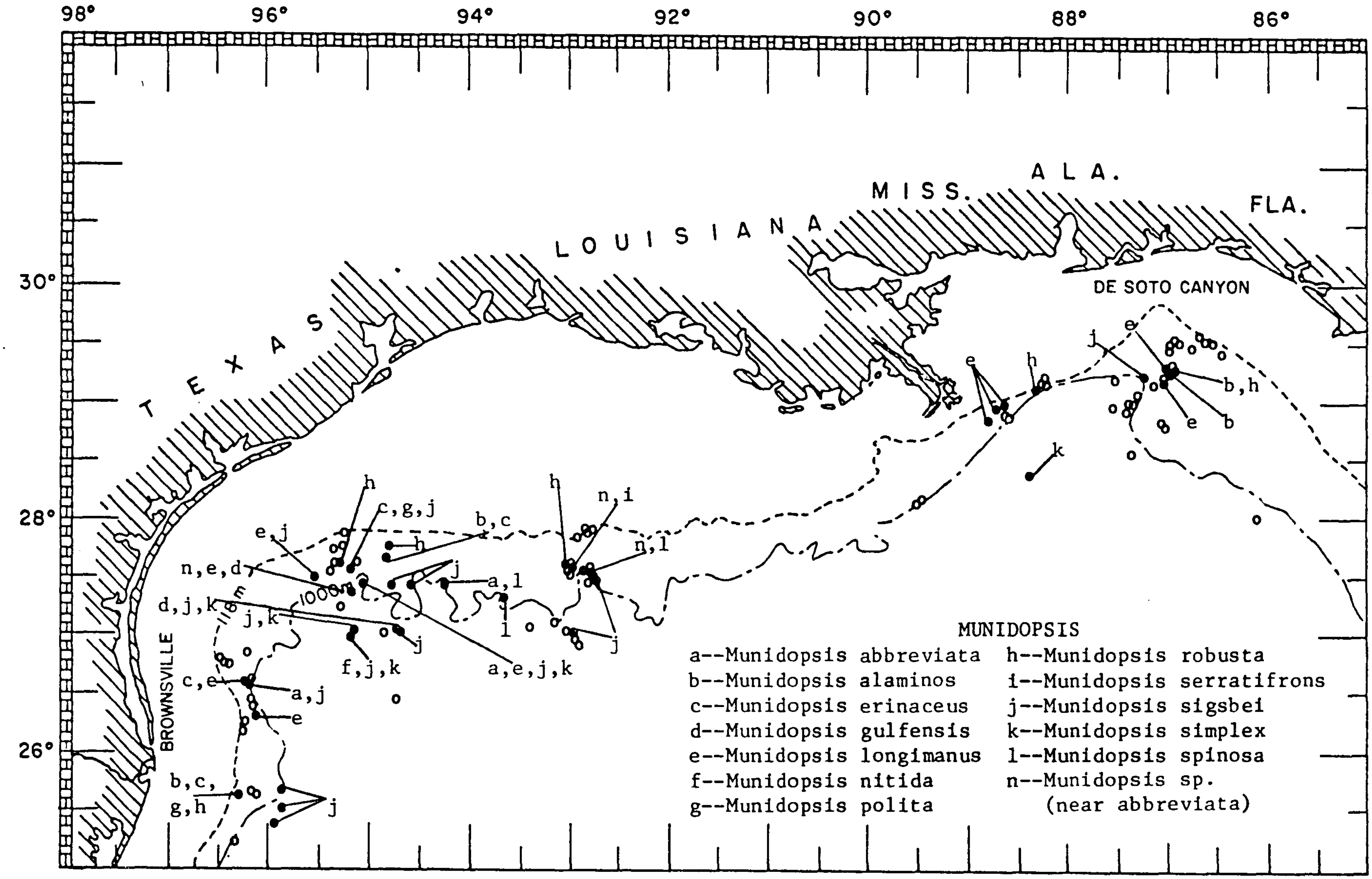

Fig. 6-26. Continuation of distribution of galatheid anomuran crabs among the 111 stations of the study area.

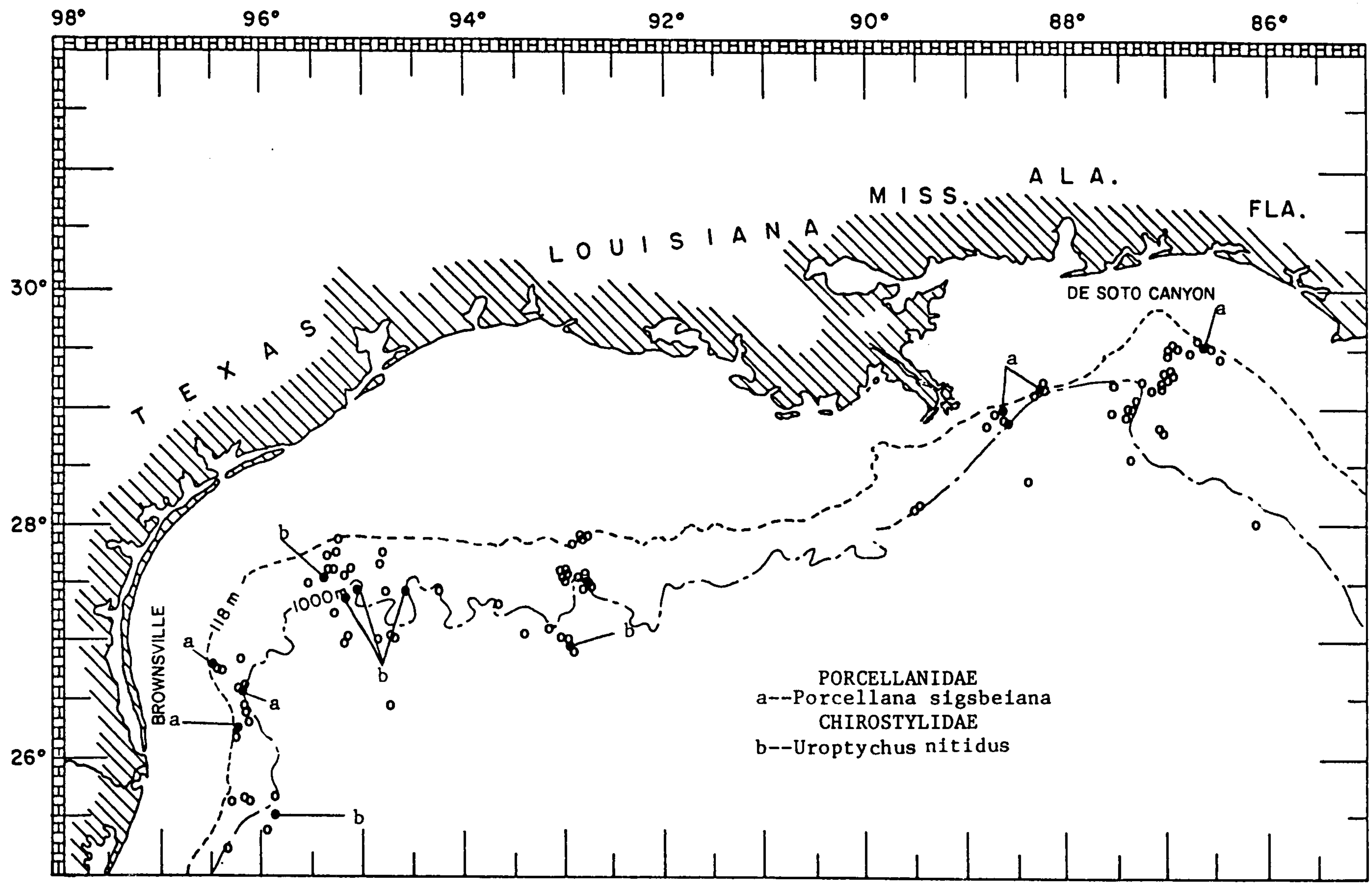

Fig. 6-27. Distribution of galatheoidean anomuran crabs of the families Porcellanidae and Chirostylidae among the 111 stations of the study area.

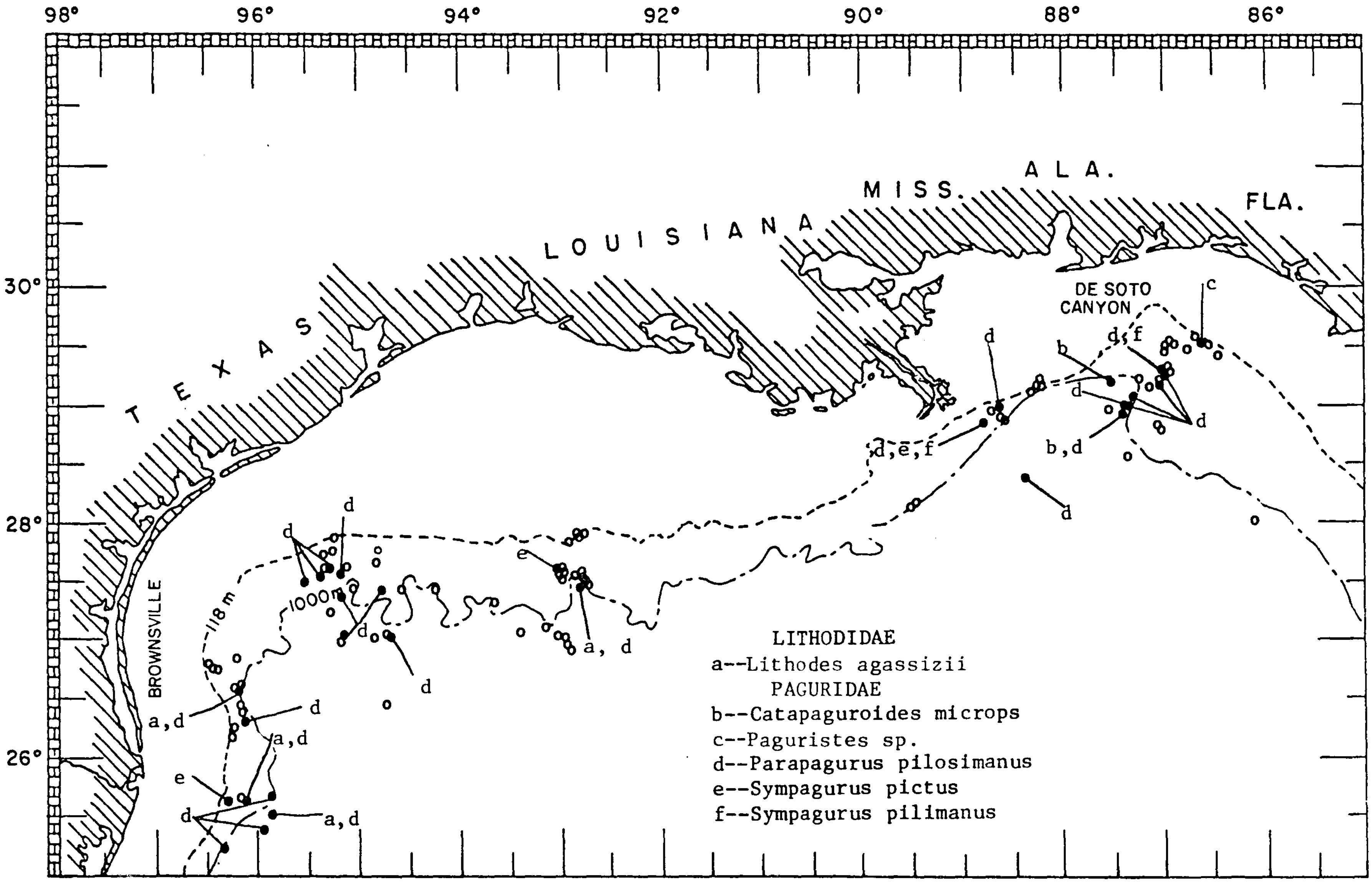

Fig. 6-28. Distribution of paguroidean anomuran crabs (hermit crabs, etc.) among the 111 stations of the study area.

Table 6-9. (A) Brachyuran crabs found on the upper continental slope of the northern Gulf of Mexico between 100 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Brachyura on the upper continental slope of the Gulf of Mexico listed by depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Calappa sulcata	2	0	-	Shelf-120	<100
Portunus spinicarpus	37	5	185	Shelf-200	100
Portunus sayi	1	0	-	Shelf-120	<100
Goneplax barbata	1	0	-	100 only	<100
Podochela sidneyi	2	0	-	Shelf-200	150
Anasimus latus	4	0	-	Shelf-200	150
Iliacantha subglobossa	10	0	-	100-600	150
Pyromaia cuspidata	3	0	-	Shelf-200	150
Stenocionops spinimana	5	0	-	150-200	150
Parthenope agona	9	0	-	150-400	150
Osachila tuberosa	8	0	-	Shelf-200	150
Parthenope pourtalesii	2	0	-	150 only	150
Raninoides louisianensis	59	0	-	Shelf-200	200
Acanthocarpus alexandri	251	10	2510	120-400	200
Chasmocarcinus cylindricus	27	0	-	100-200	200
Calappa angusta	6	0	-	150-200	200
Palicus sicus	7	0	-	150-400	200
Pyromaia arachna	52	0	-	150-700	200
Palicus obesus	25	0	-	150-200	200
Thalassoplax angusta	106	0	-	200-750	200
Eucratodes agassizii	16	0	-	200 only	200
Cyclodorippe antennaria	3	0	-	200 only	200
Palicus dentatus	1	0	-	200 only	200
Solenolambrus typicus	1	0	-	200 only	200
Ethusa micropthalma	145	0	-	150-750	200
Euphrosynoplax clausa	15	0	-	200-250	200
Myropsis quinquespinosa	127	0	-	200-300	200
Collodes leptocheles	31	0	-	200-400	200
Tetraxanthus rathbunae	7	0	-	200 only	200
Stenocionops spinosissima	4	0	-	250 only	250
Palicus gracilis	22	0	-	250-600	250
Dicranodromia ovata	1	0	-	400 only	400
Bathyplax typhla	368	30	11,040	450-950	500
Rochinia crassa	16	0	-	400-750	550
Ranilia constricta	2	0	-	600 only	600
Trichopeltarion nobile	25	0	-	500-750	700
Rochinia umbonata	3	0	-	900-950	900
Geryon quinquedens	54	60	3240	400-2050	950
Cymonomus sp.	1	0	-	950 only	950
Homolodromia paradoxa	3	0	-	950-1250	1050
Ethusina abyssicola	11	15	165	900-3850	3250

Table 6-9. (cont'd)

B. Dominant brachyurans in rank order.

SPECIES	Depth of Peak Pop. (m)
1. Bathyplax typhla	500
2. Geryon quinquedens	950
3. Acanthocarpus alexandri	200
4. Portunus spinicarpus	100
5. Ethusina abyssicola	3250

abundance on the upper slope. This seems to support the concept that this is a rather productive part of the Gulf, especially since one of the more abundant crabs centering around a depth of 950 m is also the largest known species, viz., Geryon quinquedens.

Distributions of the brachyuran crabs in the upper continental slope study area are shown in Figs. 6-29, 6-30, 6-31, and 6-32.

Demersal Fishes

Our records indicate that 249 species of bottom fishes are found in the deep aspects of the Gulf of Mexico. A list of these species is found in Appendix A. It is somewhat surprising to learn that 128 of the 249 species are found at one or more of the 111 stations covered by this report. But, as might be expected, a substantial number of the 128 belong to only two families, viz., the Macrouridae (Rattails) and Ophidiidae (Brotulids). If one takes the six or so predominant fishes at each isobath from 100 to 1000 m depth one obtains a list of the 53 most common species on the upper slope. These are presented together with their depth ranges in Table 6-10. The assertion that the macrourids dominate among fishes of the upper slope is documented by the fact that 8 of the 20 species of dominant fishes belong to the Macrouridae and only 2 to the Ophidiidae (see Table 6-11).

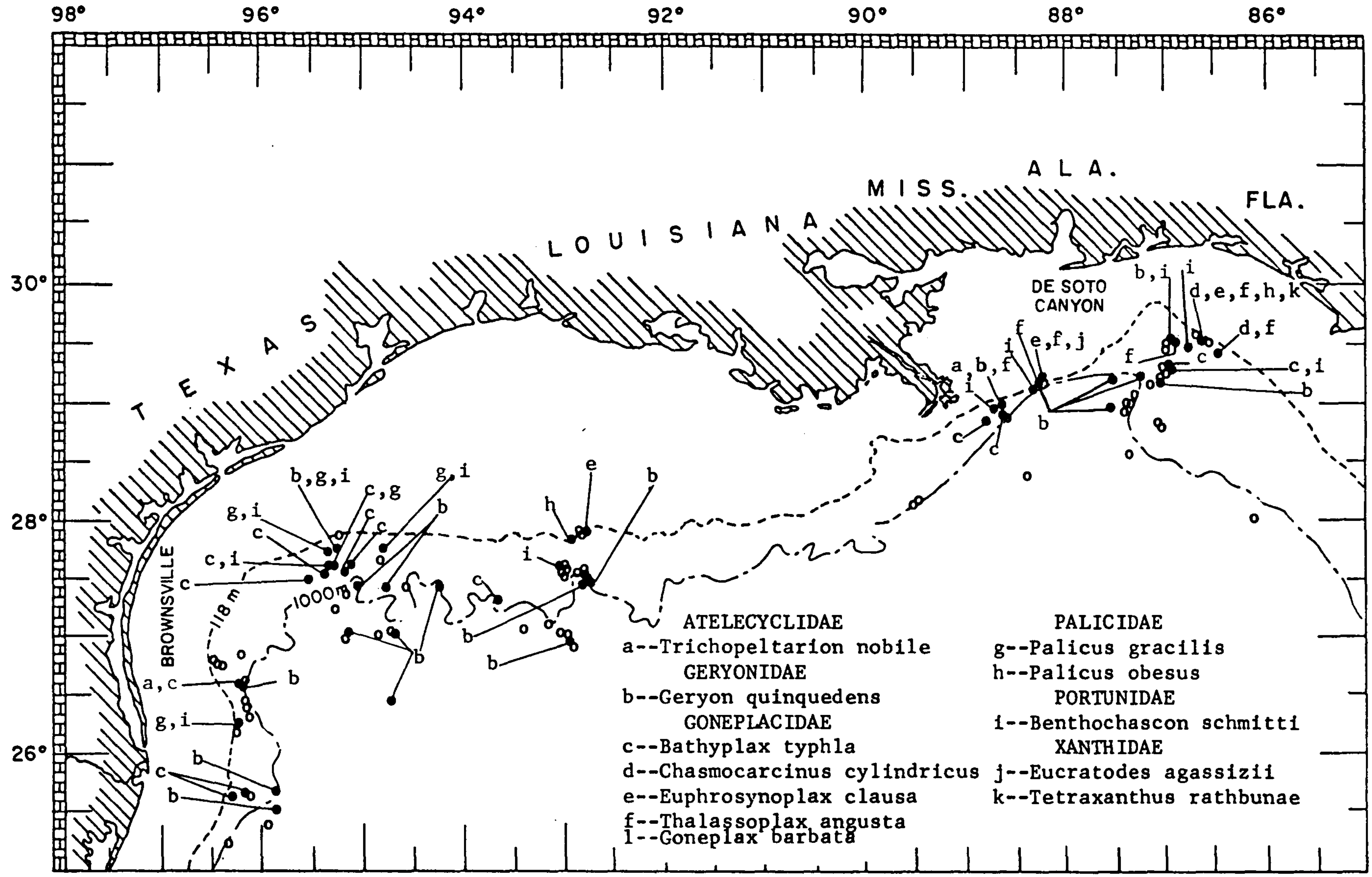

Fig. 6-29. Distribution of brachyuran crabs (Brachyrhyncha) among the 111 stations of the study area.

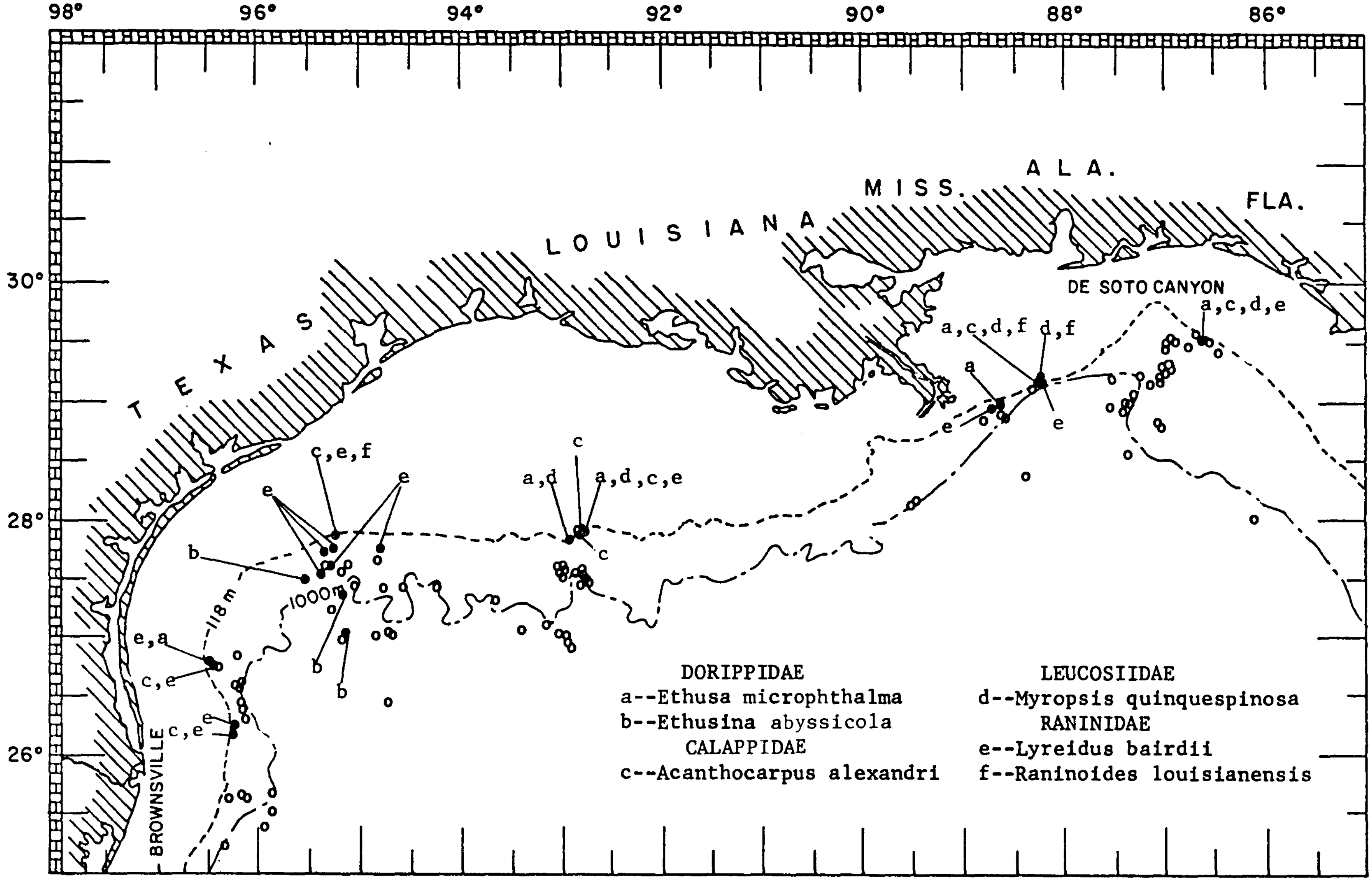

Fig. 6-30. Distribution of brachyuran crabs (Oxystomia) among the 111 stations of the study area.

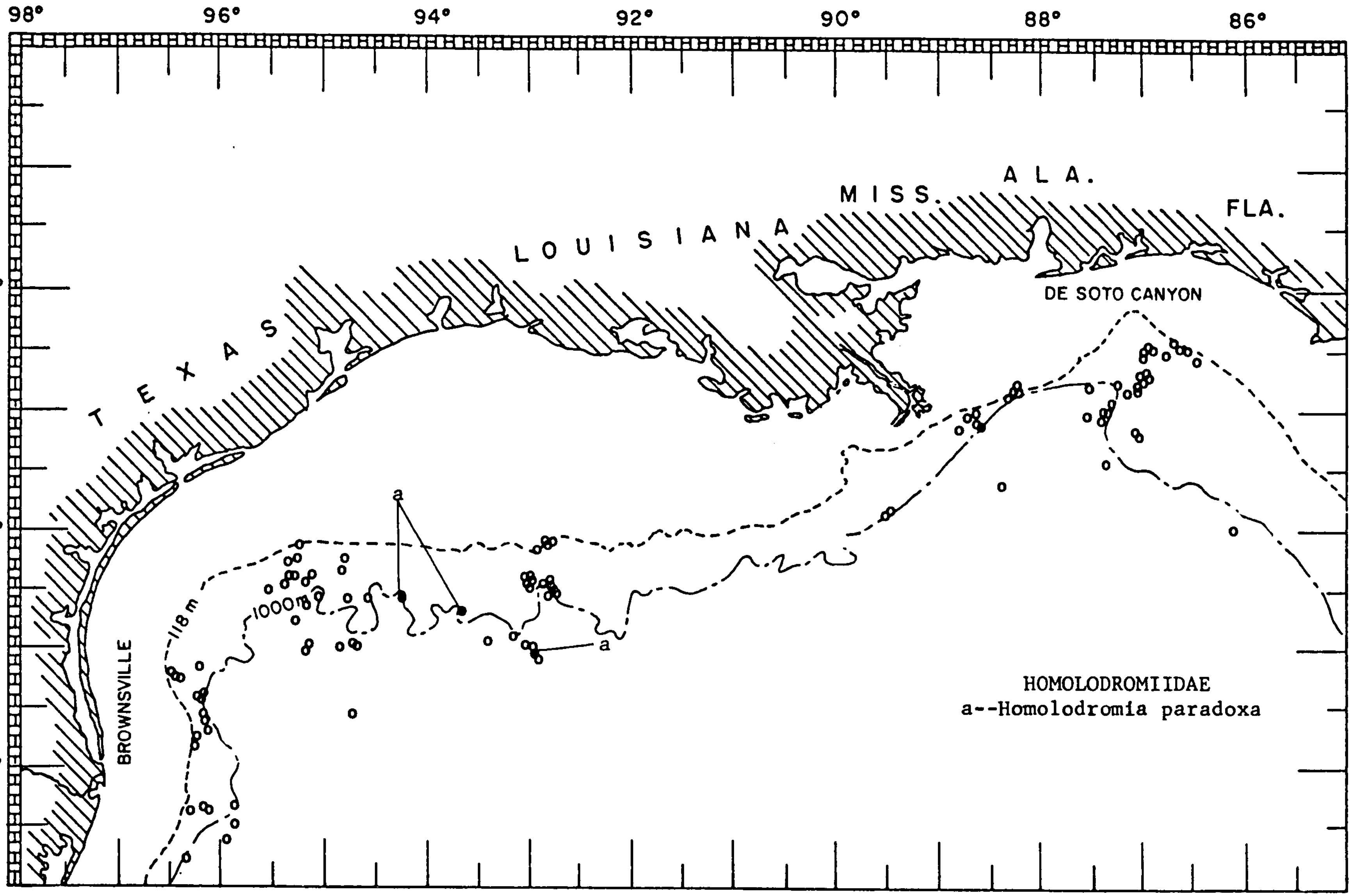

Fig. 6-31. Distribution of Homolodromia paradoxa (brachyuran crab - Dromiacea) among the 111 stations of the study area.

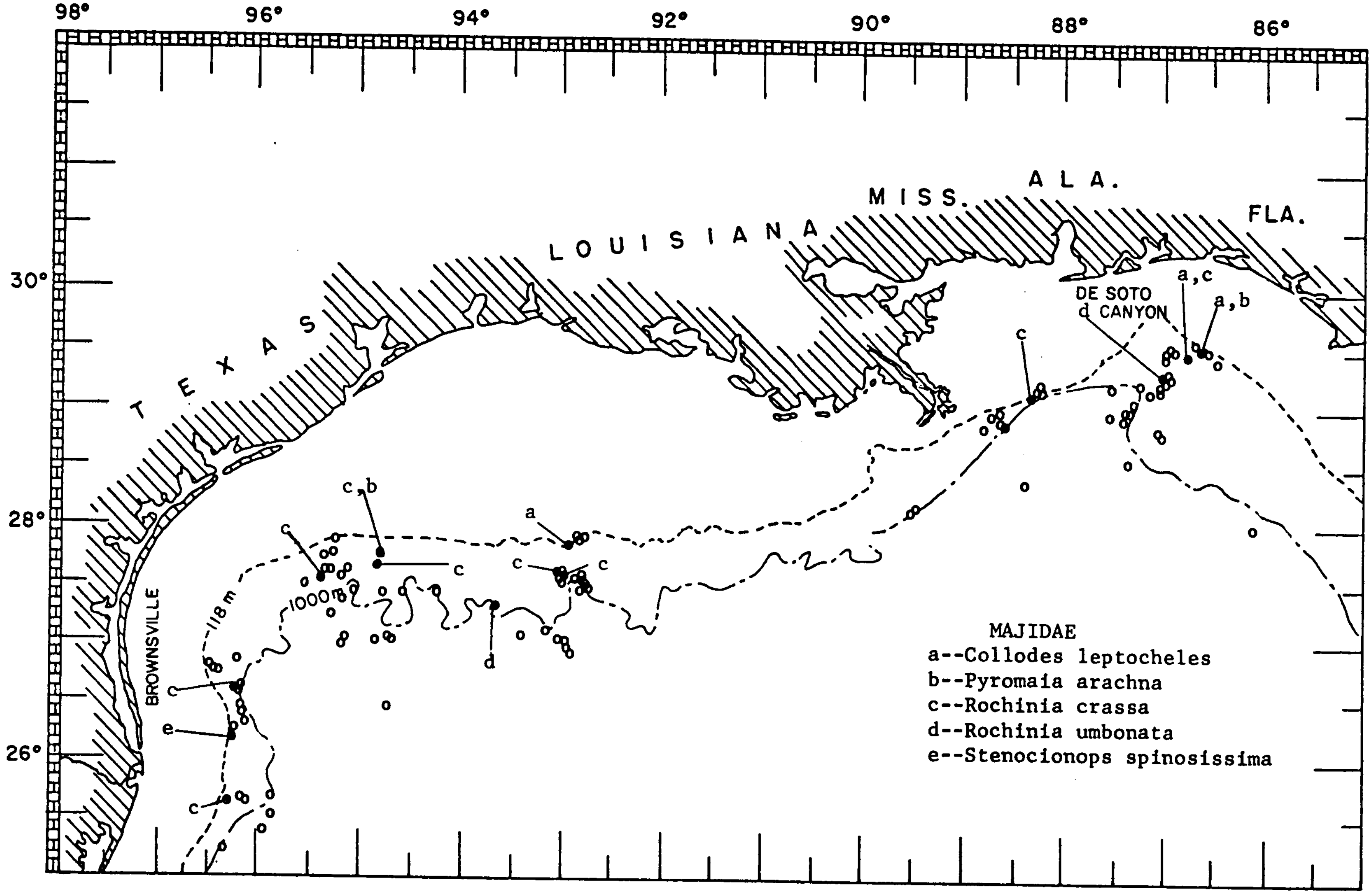

Fig. 6-32. Distribution of spider crabs (Oxyrhyncha) among the 111 stations of the study area.

Table 6-10. Inventory of deep water demersal fishes of the Gulf of Mexico continental slope area.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x 5)	C. Product A x B	Depth Range (m)	Depth of Peak Population (m)
Serranus atrobranchus	9	0	-	(100 only)	< 100
Synodus foetens	7	0	-	(100 only)	< 100
Haliuetichthys aculeatus	31	5	155	(100-150)	100
Caulolatilus sp.	16	0	-	(100-200)	100
Saurida brasiliense	15	0	-	(100-200)	100
Pristipomoides aquilonaris	151	0	-	(100-250)	200
Pontinus longispinus	119	5	595	(100-250)	200
Monolene sp.	8	0	-	(100-250)	150
Trichopsetta ventralis	26	0	-	(100-250)	200
Parasudis truculentis	64	0	-	(100-250)	250
Coelorhynchus caribbaeus	78	5	390	(100-350)	250
Bembrops gobioides	134	5	670	(100-550)	450
Bembrops anatirostris	113	0	-	(100-550)	200
Urophycis cirratus	86	0	-	(100-550)	450
Malacocephalus occidentalis	65	0	-	(100-600)	250
Poecilopsetta beanii	339	5	1695	(100-750)	250
Steindachneria argentea	71	0	-	(150-250)	250
Ancylopsetta dilecta	39	5	195	(150-250)	150
Dibranchus atlanticus	238	5	1190	(150-1250)	500
Hymenocephalus cavernosus	183	5	915	(250-600)	550
Symphurus piger	5	0	-	(400-500)	400
Chlorophthalmus agassizii	17	0	-	(400-550)	550
Coelorhynchus carminatus	75	5	375	(400-650)	550
Peristedion greyae	50	0	-	(400-700)	550
Chaunax pictus	18	0	-	(400-800)	800
Scytalichthys sp.	44	0	-	(450 only)	450
Bathygadus macrops	50	5	250	(500-950)	700
Nezumia hildebrandi	248	5	1240	(500-1450)	1050
Bythites sp.	9	0	-	(550-650)	650
Ventrifossa atlantica	7	0	-	(550-700)	600
Symphurus marginatus	7	0	-	(550-750)	750
Etmopterus spinax	16	0	-	(550-800)	550
Bathygadus vaillanti	126	10	1260	(550-1100)	900
Halosaurus guntheri	32	0	-	(550-1100)	900

(continued on next page)

Table 6-10 (Continued)

	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x 5)	C. Product A x B	Depth Range (m)	Depth of Peak Population (m)
Gadomus longifilis	497	10	4970	(550-1450)	1050
Venefica procera	27	0	-	(550-2150)	1100
Diplacanthopoma brachysoma	11	0	-	(600-800)	700
Etmopterus pusillus	7	0	-	(650 only)	650
Synaphobranchus oregoni	227	10	2270	(650-1450)	1100
Cariburus zaniophorus	44	0	-	(650-1450)	950
Promyllantor schmitti	3	0	-	(700-750)	700
Dicrolene intronigra	336	25	8400	(700-2150)	1050
Trachonurus sulcatus	11	0	-	(750-1200)	1100
Cariburus mexicanus	42	10	420	(800-1500)	1450
Aldrovandia affinis	62	5	310	(800-1950)	1400
Monomitopus agassizi	188	0	-	(700-1450)	1050
Ilyophis brunneus	73	0	-	(900-1150)	1050
Squalogadus intermedius	32	0	-	(950-1100)	1050
Bathypterois quadrifilis	42	0	-	(950-1400)	1100
Grenurus grenadae	18	0	-	(950-1450)	1100
Stephanoberyx monae	82	10	820	(950-1500)	1100
Conocara mcdonaldi	30	0	-	(950-1850)	1400
Aldrovandia gracilis	105	5	525	(950-2500)	2100

Table 6-11. A rank ordering of the twenty most abundant demersal fish species on the upper continental slope of the northern Gulf of Mexico with depth of population peak and family affiliation.

	Species	Depth of Peak Population (m)	Family
1.	*Dicrolene intronigra*	1050	Ophidiidae
2.	*Gadomus longifilis*	1050	Macrouridae
3.	*Synaphobranchus oregoni*	1100	Synaphobranchidae
4.	*Poecilopsetta beanii*	250	Pleuronectidae
5.	*Bathygadus vaillanti*	900	Macrouridae
6.	*Nezumia hildebrandi*	1050	Macrouridae
7.	*Dibranchus atlanticus*	500	Ogcocephalidae
8.	*Hymenocephalus cavernosus*	550	Macrouridae
9.	*Stephanoberyx monae*	1100	Stephanoberycidae
10.	*Bembrops gobioides*	450	Percophididae
11.	*Pontinus longispinus*	200	Scorpaenidae
12.	*Aldrovandia gracilis*	2100	Halosauridae
13.	*Cariburus mexicanus*	1450	Macrouridae
14.	*Coelorhynchus caribbaeus*	250	Macrouridae
15.	*Coelorhynchus carminatus*	550	Macrouridae
16.	*Aldrovandia affinis*	1400	Halosauridae
17.	*Bathygadus macrops*	700	Macrouridae
18.	*Ancylopsetta dilecta*	150	Bothidae
19.	*Haliuetichthys aculeatus*	100	Ogcocephalidae
20.	*Monomitopus agassizi*	1050	Ophidiidae

While calculating the depth at which each species appeared to reach peak abundance, it was surprising to find the average depth was well down the slope (800 m). Furthermore, it was noted that six of the 20 species reached maximum populations between 1000 and 1100 m depth. These observations seem to indicate that the continental slope is a very productive area, and that those species that occur in large numbers at the same isobath very likely have quite different feeding habits. While plotting the depth of these peak abundances of the 20 dominant species, as below, one can pick out about three groupings or assemblages on the upper slope:

100 m - 1 species	450 m - 1 species	Depth hiatus	Depth hiatus
150 m - 1 "	500 m - 1 "	900 m - 1 species	1400 m - 1 species
200 m - 1 "	550 m - 2 "	Depth hiatus	1450 m - 1 "
250 m - 2 "	Depth hiatus	1050 m - 4 species	Depth hiatus
Depth hiatus	700 m - 1 species	1100 m - 2 "	2100 m - 1 species

These groupings are also evident among the histograms shown in Fig. 6-33.

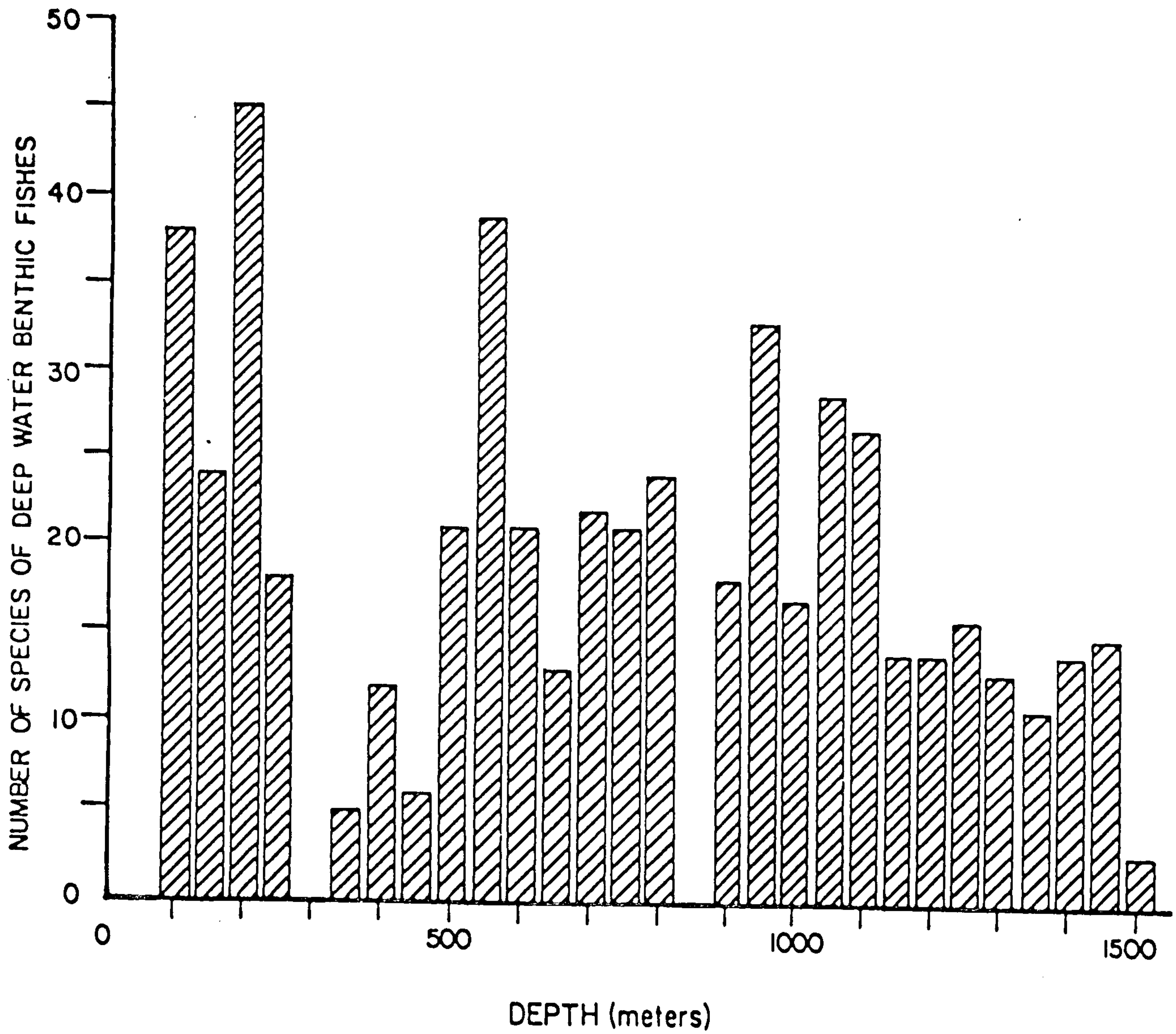

Fig. 6-33. Histograms showing the numbers of species of demersal fishes taken at given isobaths on the continental slope.

The geographic distributions of the species of demersal fishes taken among the 111 stations are shown in Fig. 6-34 through 6-56, which are presented alphabetically by families.

Mollusca

Cephalopod Mollusks. The principal benthonic cephalopods occurring within the limits of this study are the sepiolids Semirossia tenera, S. equalis, Rossia bullisi, and Neorossia sp. and the octopods Opisthoteuthis agassizi, Pteroctopus tetracirrhus, and Benthoctopus januari. For geographic distribution of these species, see Lipka (1975). Depth limits of the above species are shown below:

Sepiolidae	Depth Range (m)
Semirossia tenera	160-900
Semirossia equalis	180-900
Rossia bullisi	360-560
Neorossia sp.	920-1375
Octopoda	
Pteroctopus tetracirrhus	450-565
Benthoctopus januari	450-1830
Opisthoteuthis agassizi	1098 only

Gastropod Mollusks. Some twenty-five species of gastropods were detected within the depth limits of the upper continental slope (see Table 6-12). This region appears to be the principal area inhabited by these organisms, that is to say only one species was found that attains a maximum population below 1050 meters depth. The average depth of development of maximum population turns out to be 590 m. This may be somewhat too deep in that it includes a few species, such as Antillophos candei and Polystira albida, that are found on the continental shelf where they may reach higher population levels than found on the slope. In any event the center of gastropod developments on the entire slope lies somewhere between 500 and 600 m depth.

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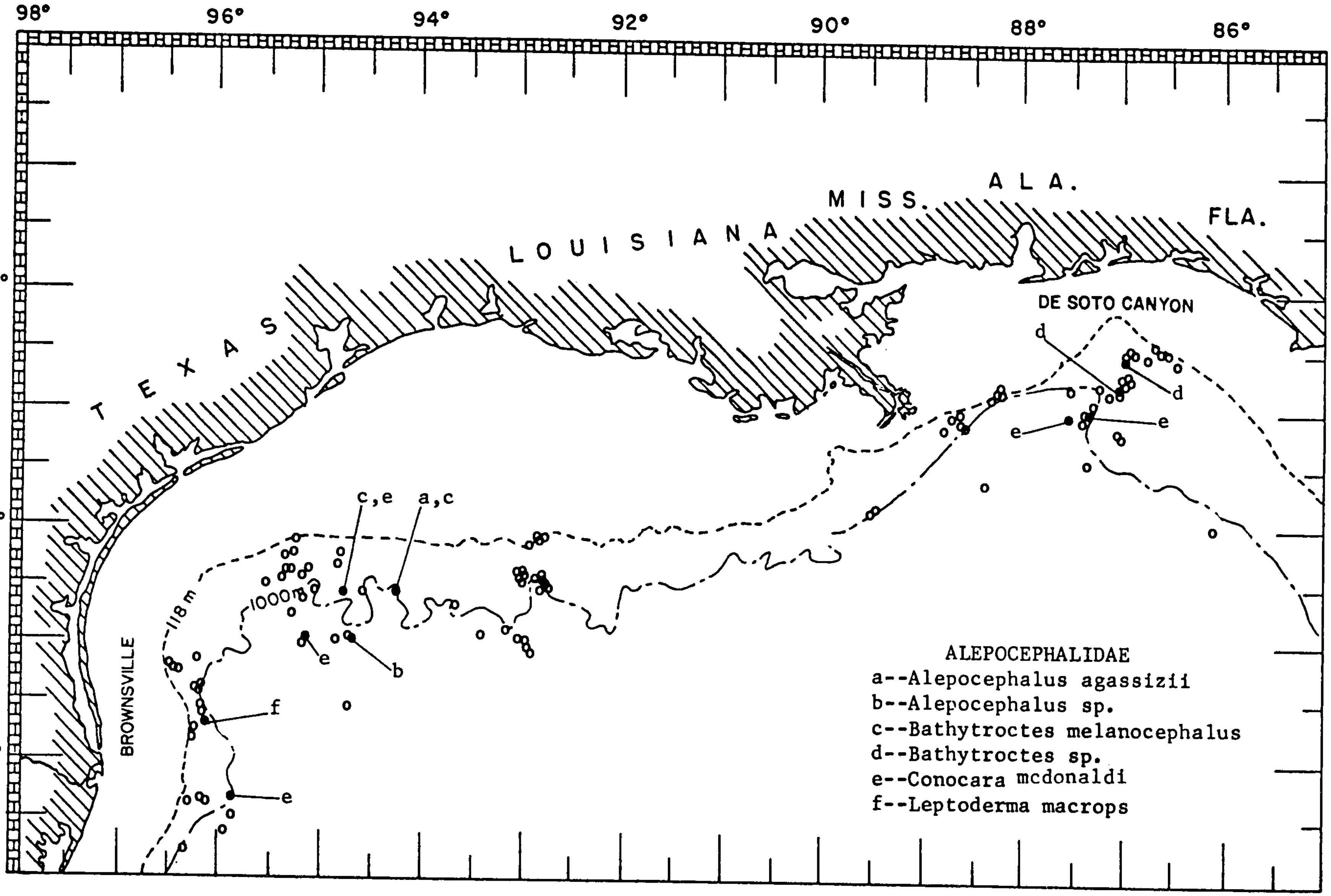

Fig. 6-34. Distribution of alephocephalid fishes among the 111 stations of the continental slope study area.

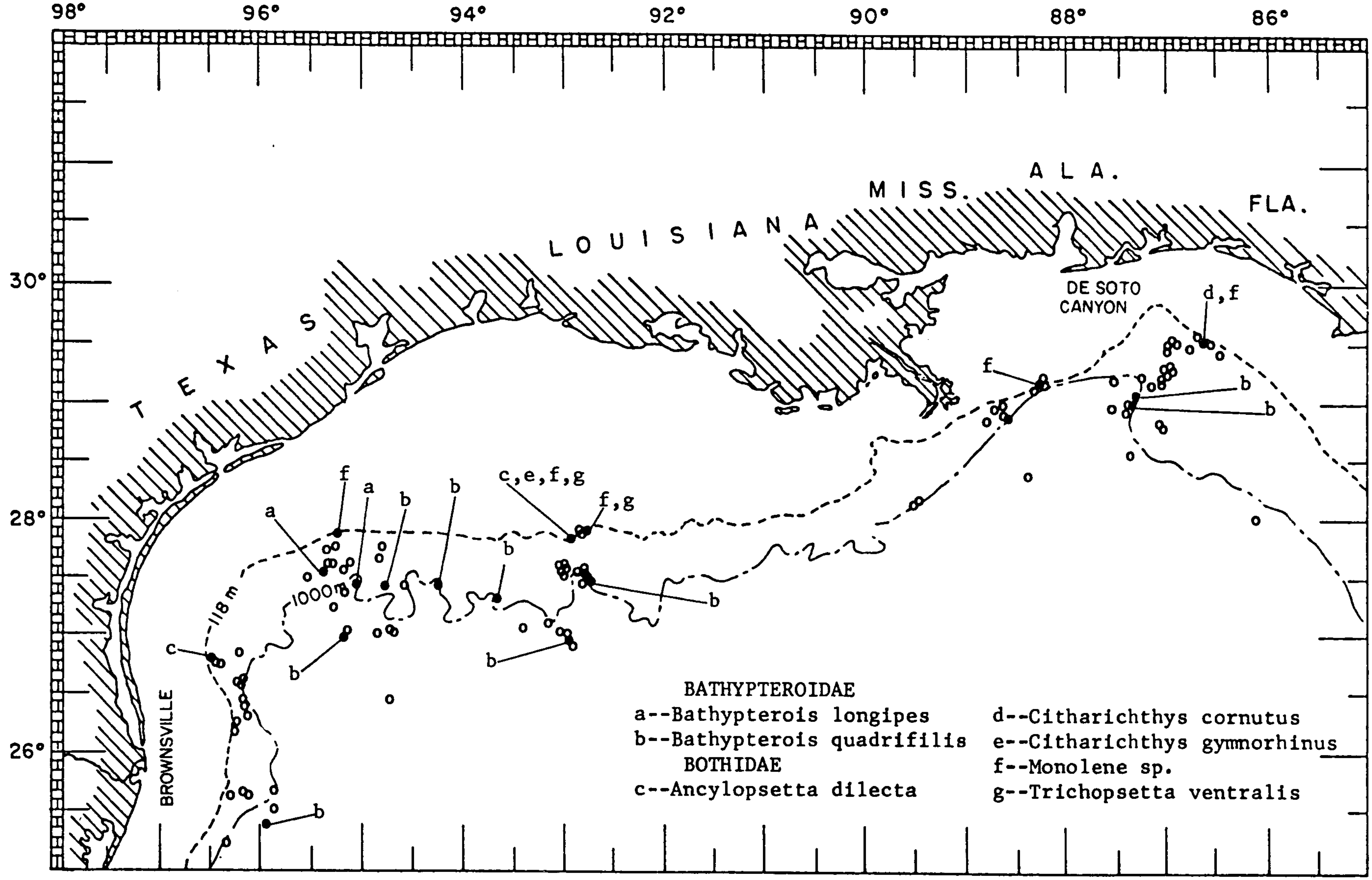

Fig. 6-35. Distribution of bathypteroids and lefteye flounders (Bothidae) among the 111 stations of the continental slope study area.

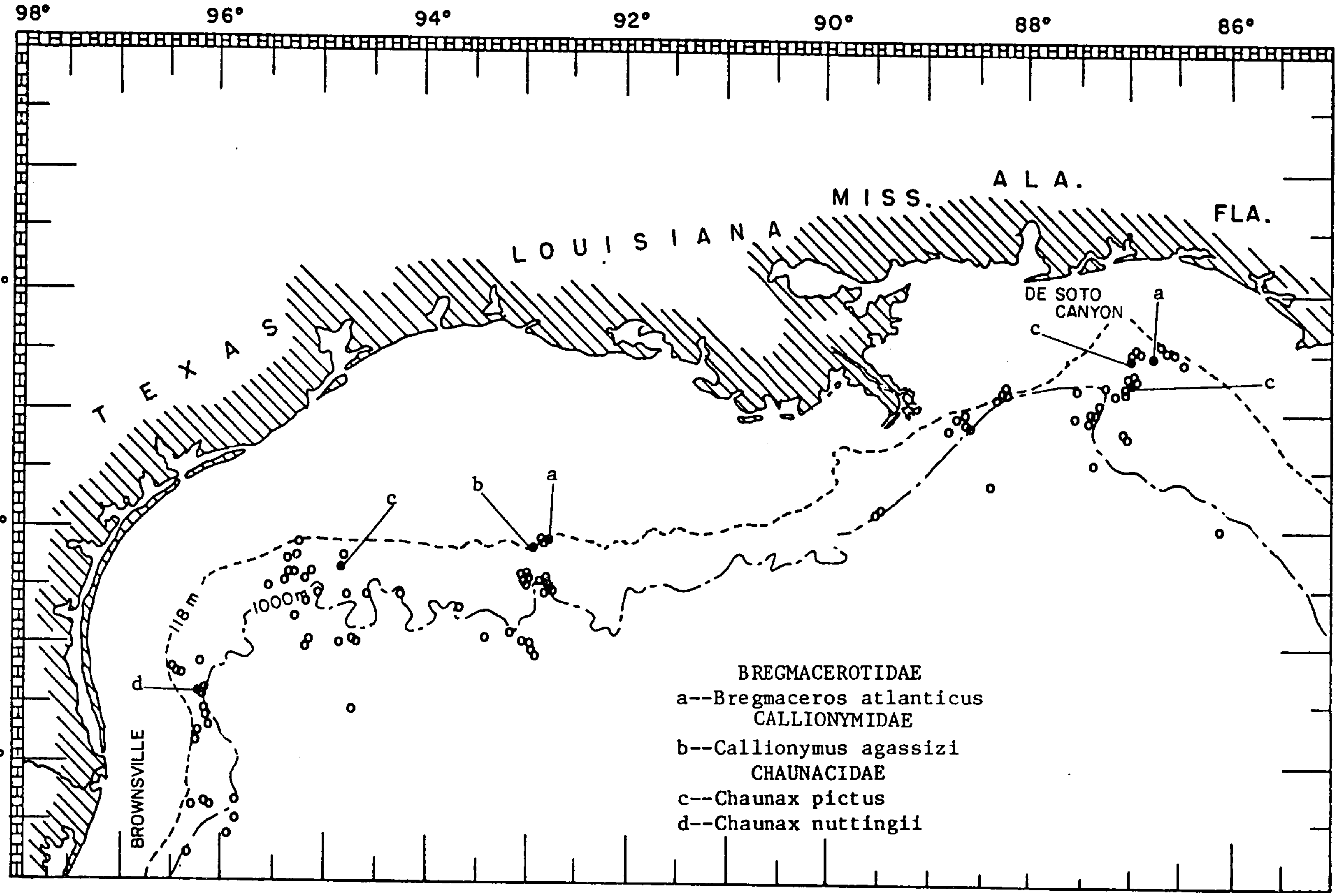

Fig. 6-36. Distribution of codlets (Bregmacerotidae), dragonets (Callionymidae), and anglerfishes (Chaunacidae) among the 111 stations of the continental slope study area.

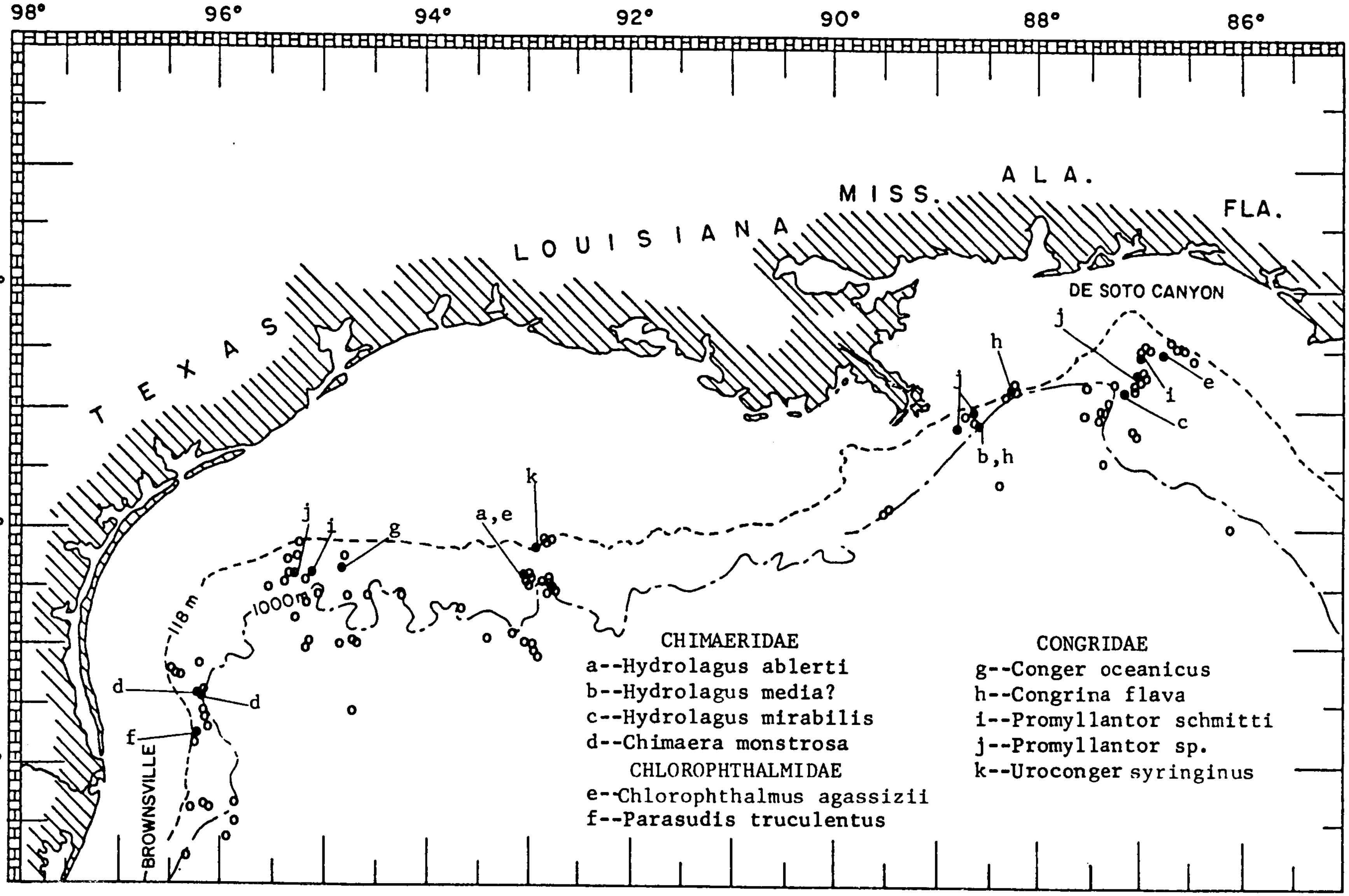

Fig. 6-37. Distribution of elephant fishes (Chimaeridae), greeneyes (Chlorophthalmidae), and conger eels (Congridae) among the 111 stations of the continental slope study area.

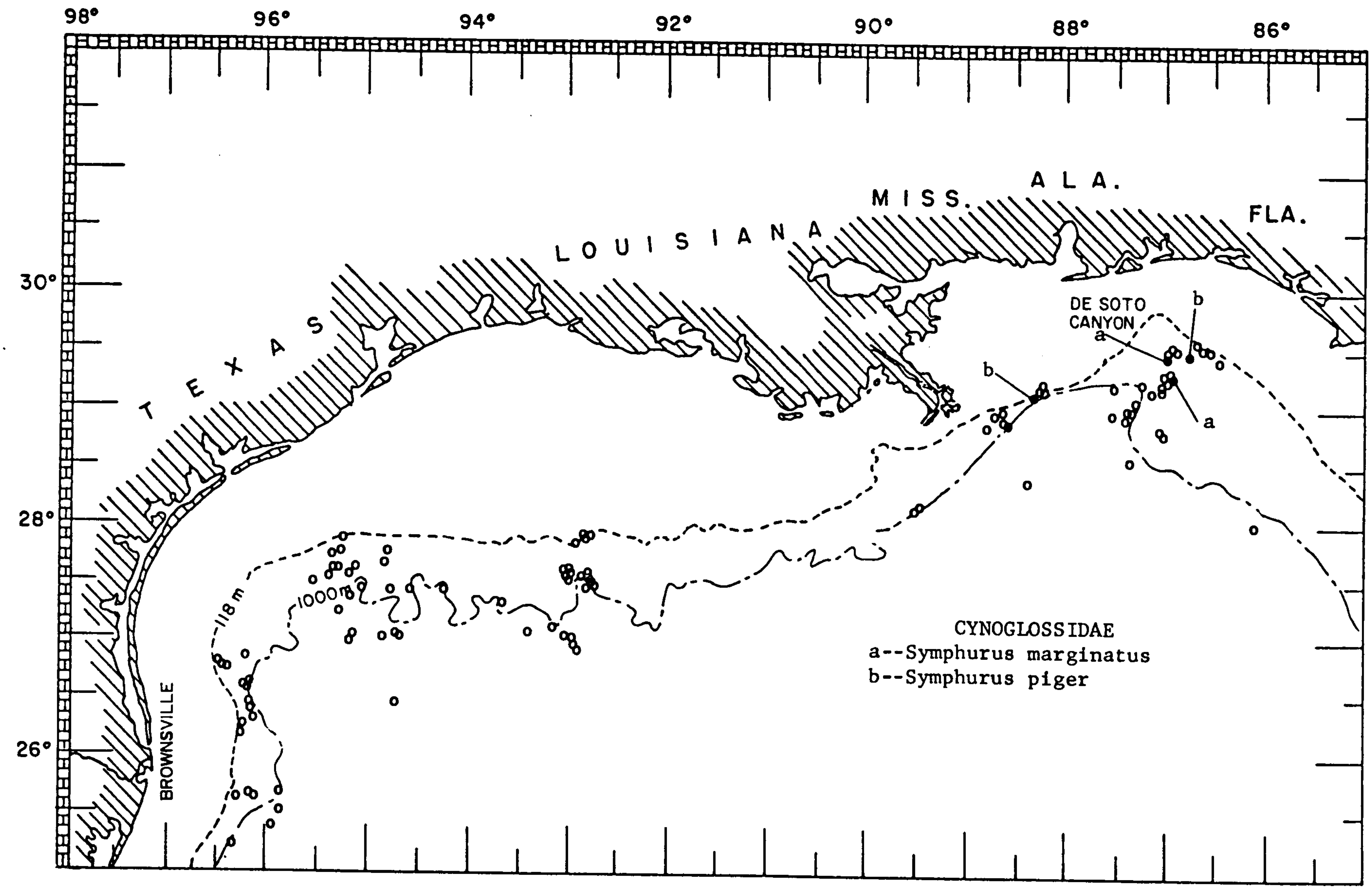

Fig. 6-38. Distribution of tonguefishes (Cynoglossidae) among the 111 stations of the continental slope study area.

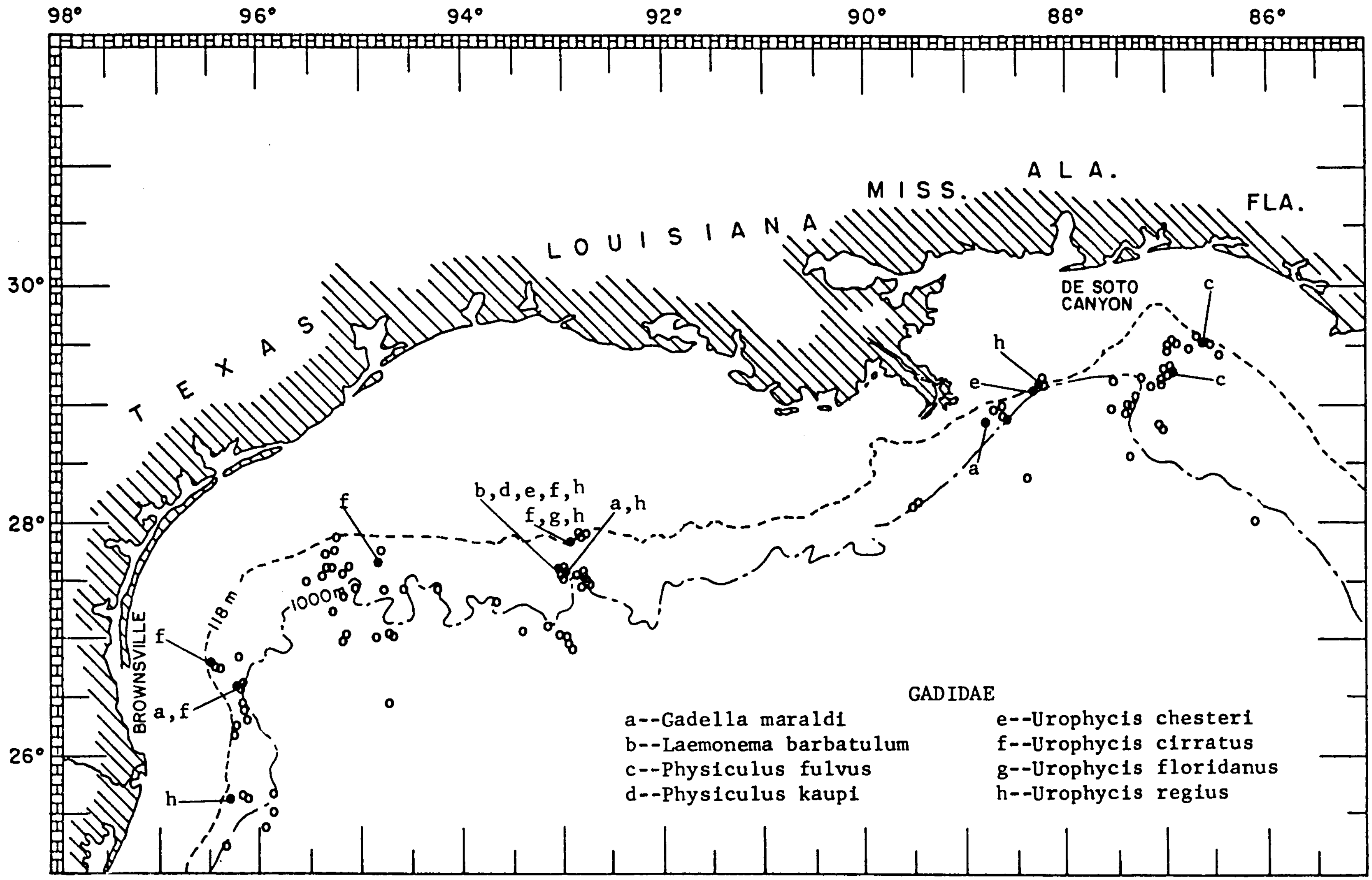

Fig. 6-39. Distribution of codfishes (Gadidae) among the 111 stations of the continental slope study area.

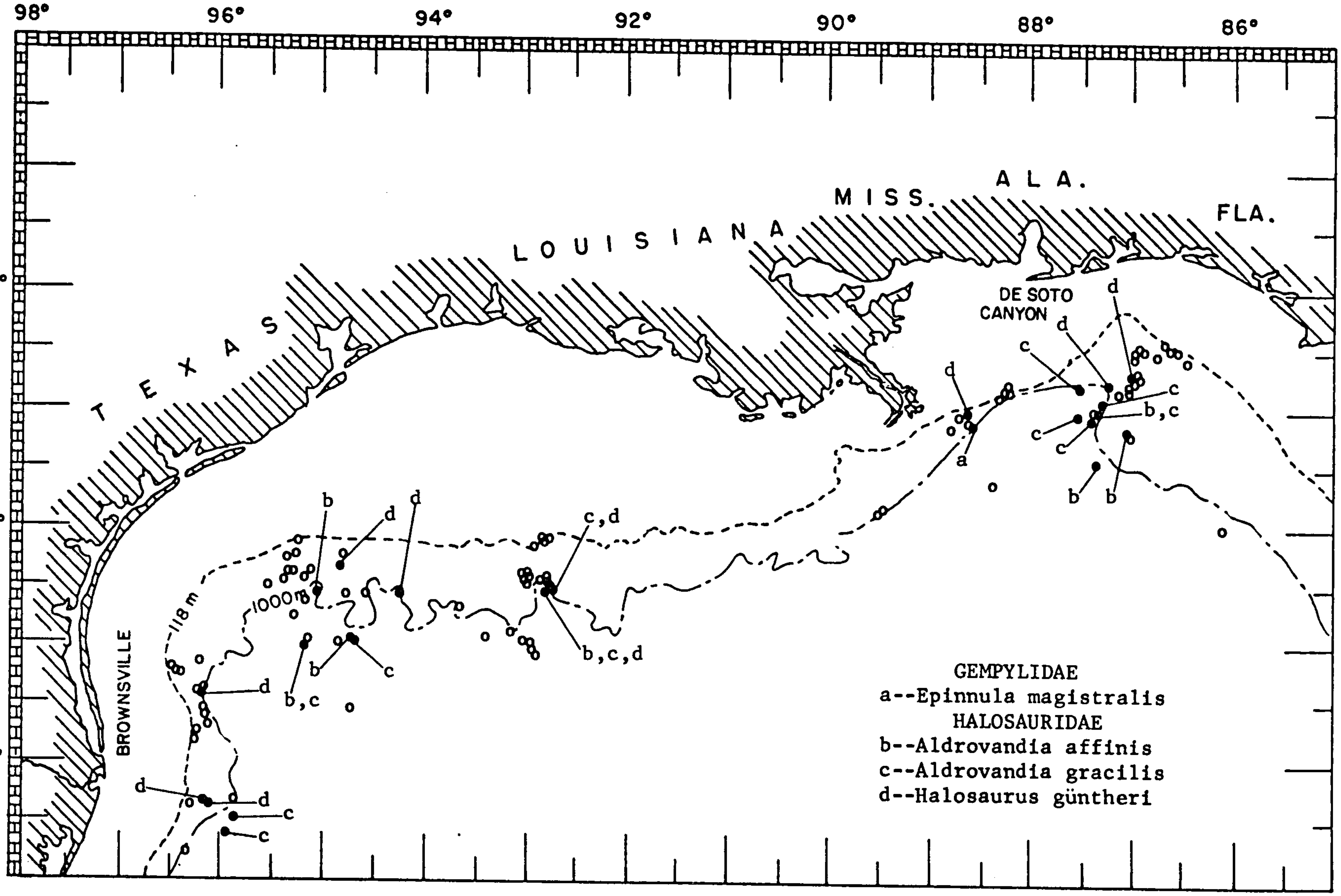

Fig. 6-40. Distribution of snake mackerels (Gemphlidae) and halosaurid fishes (Halosauridae) among the 111 stations of the continental slope study area.

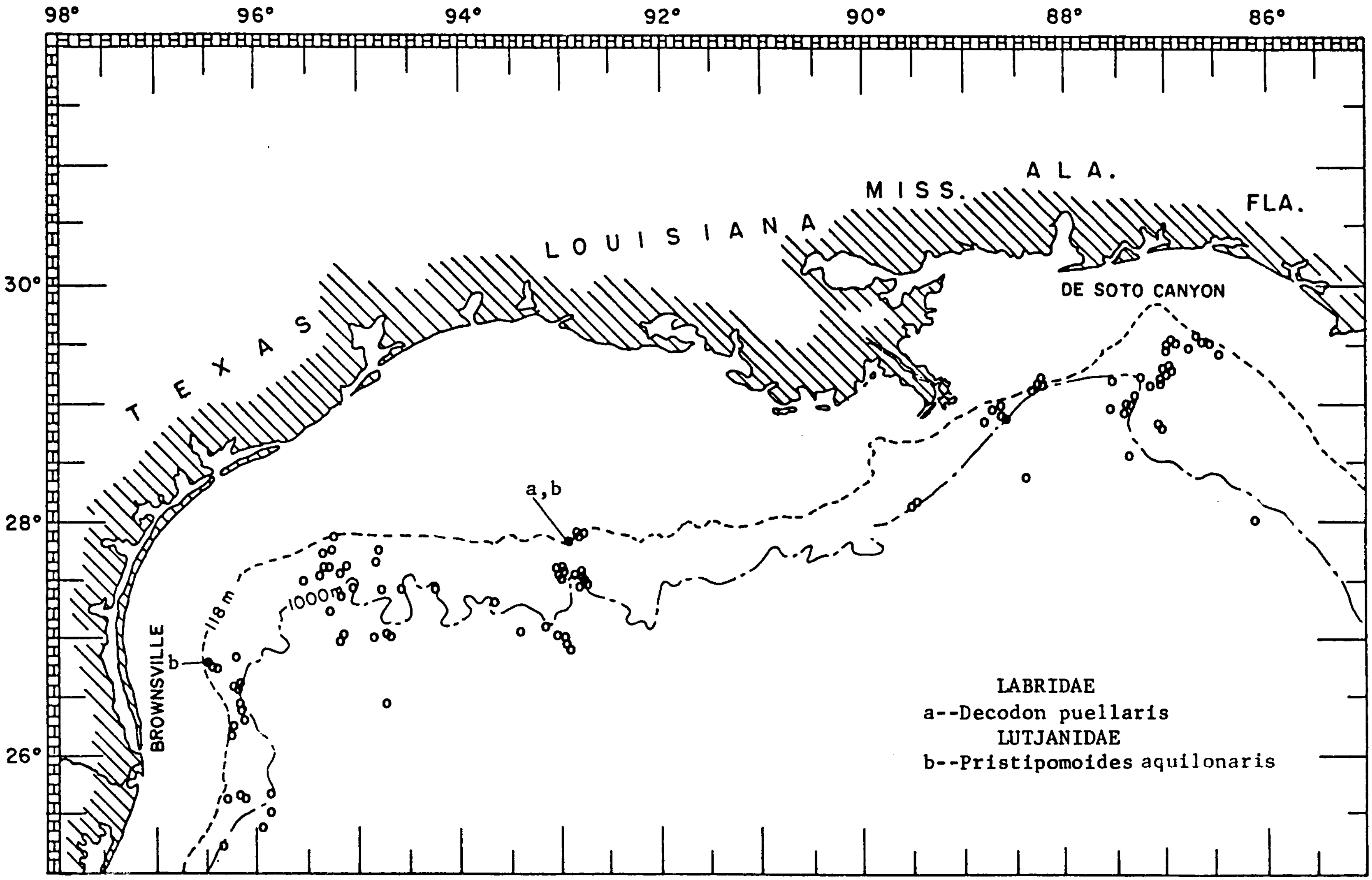

Fig. 6-41. Distribution of wrasses (Labridae) and snappers (Lutjanidae) among the 111 stations of the continental slope study area.

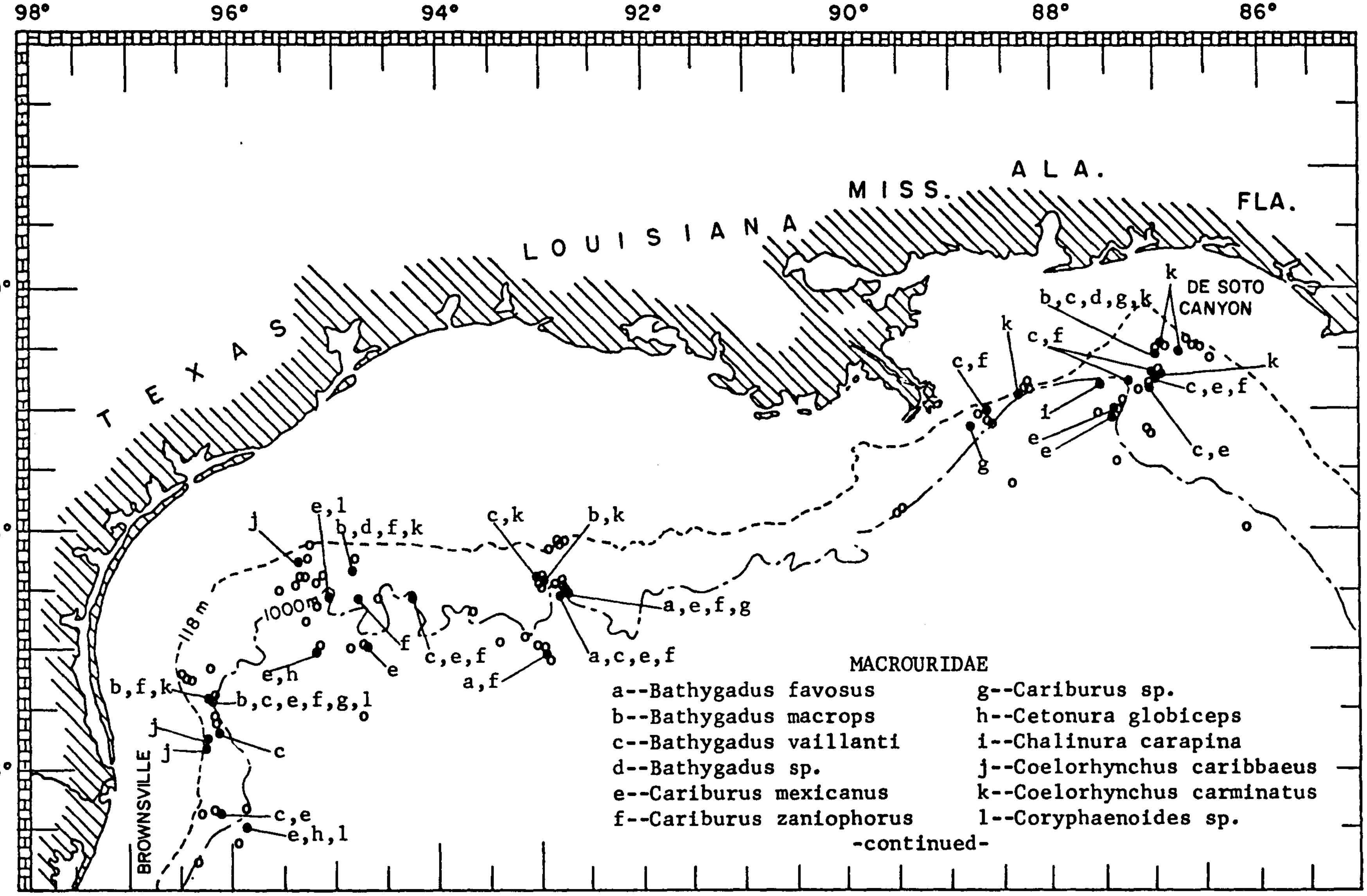

Fig. 6-42. Distribution of grenadier fishes (Macrouridae) among the 111 stations of the continental slope study area. (Continuation on Fig. 6-43).

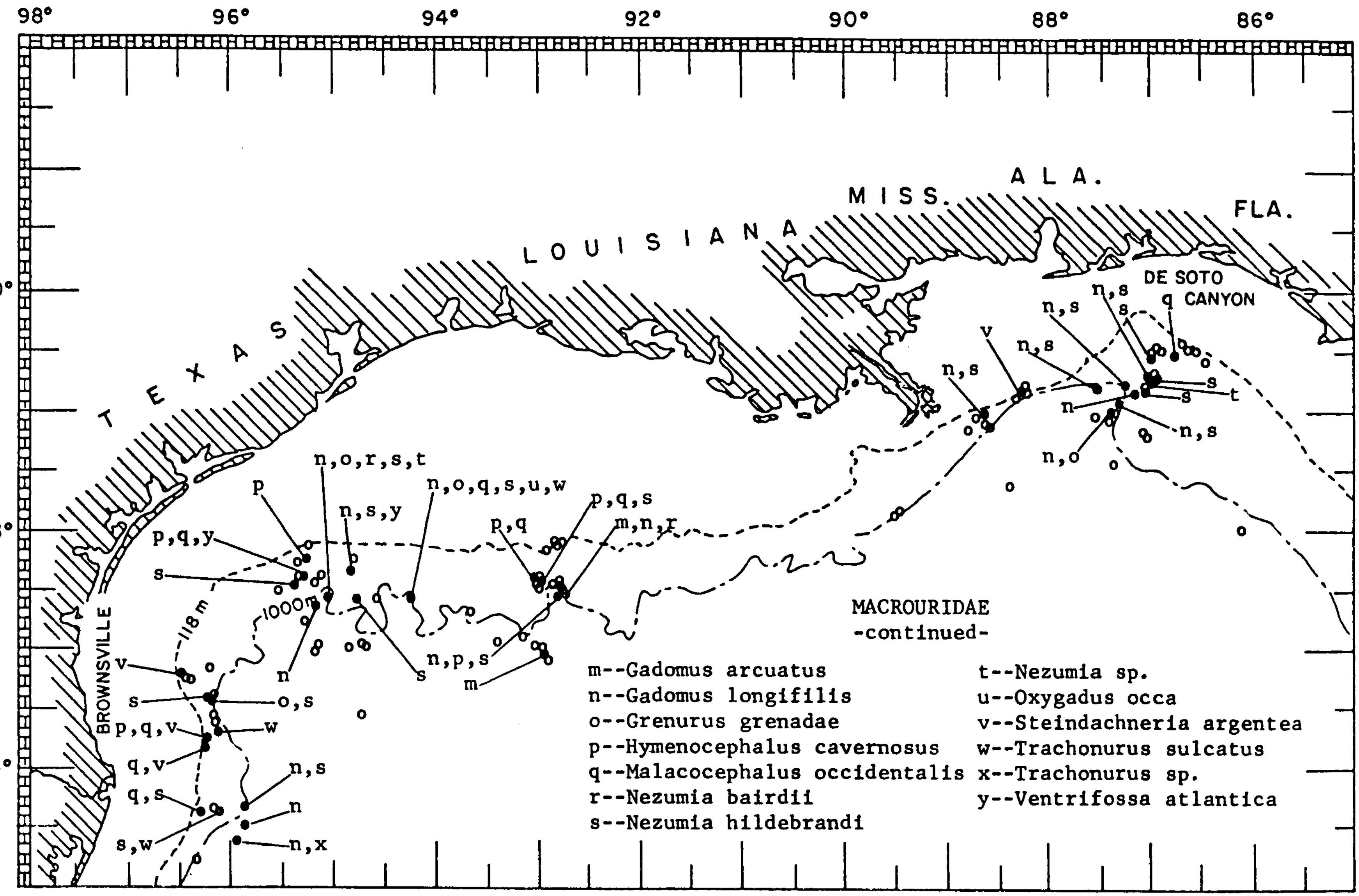

Fig. 6-43. Continuation of distribution of grenadier fishes (Macrouridae) among the 111 stations of the continental slope study area.

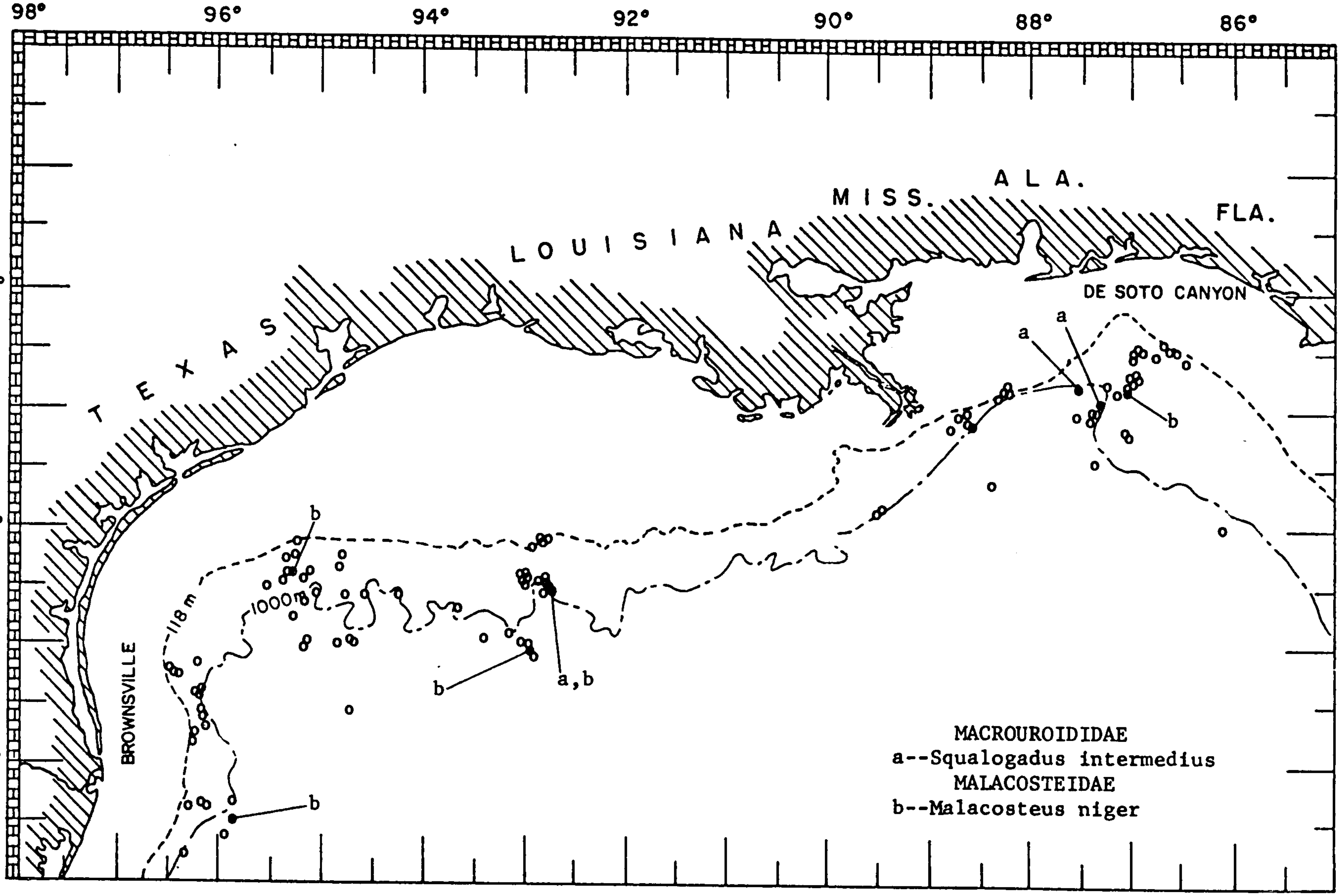

Fig. 6-44. Distribution of macrouroid fishes and malacosteid fishes among the 111 stations of the continental slope study area.

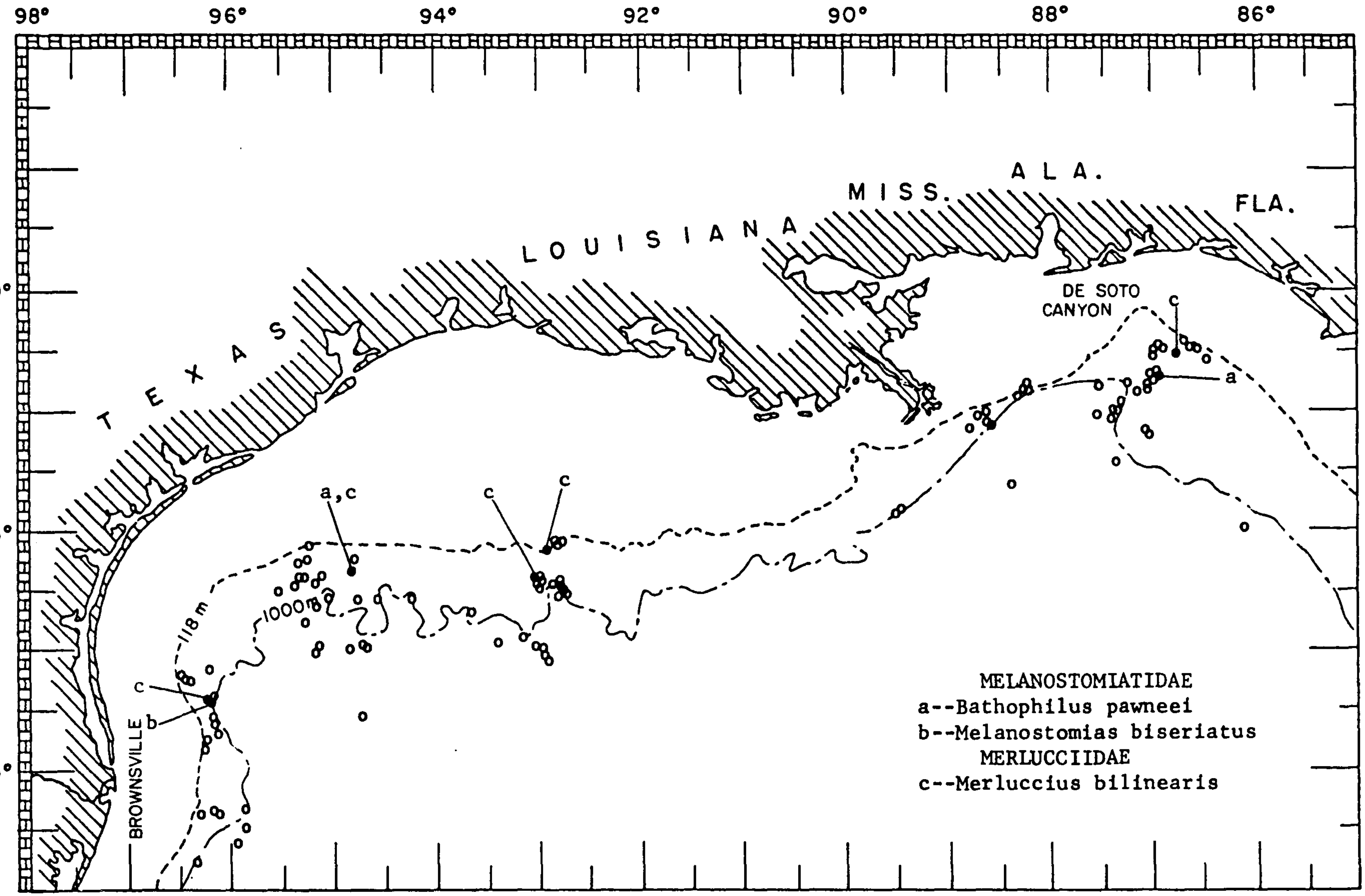

Fig. 6-45. Distribution of scaleless dragonfishes (Melanostomiatidae) and silver hakes (Merluccidae) among the 111 stations of the continental slope study area.

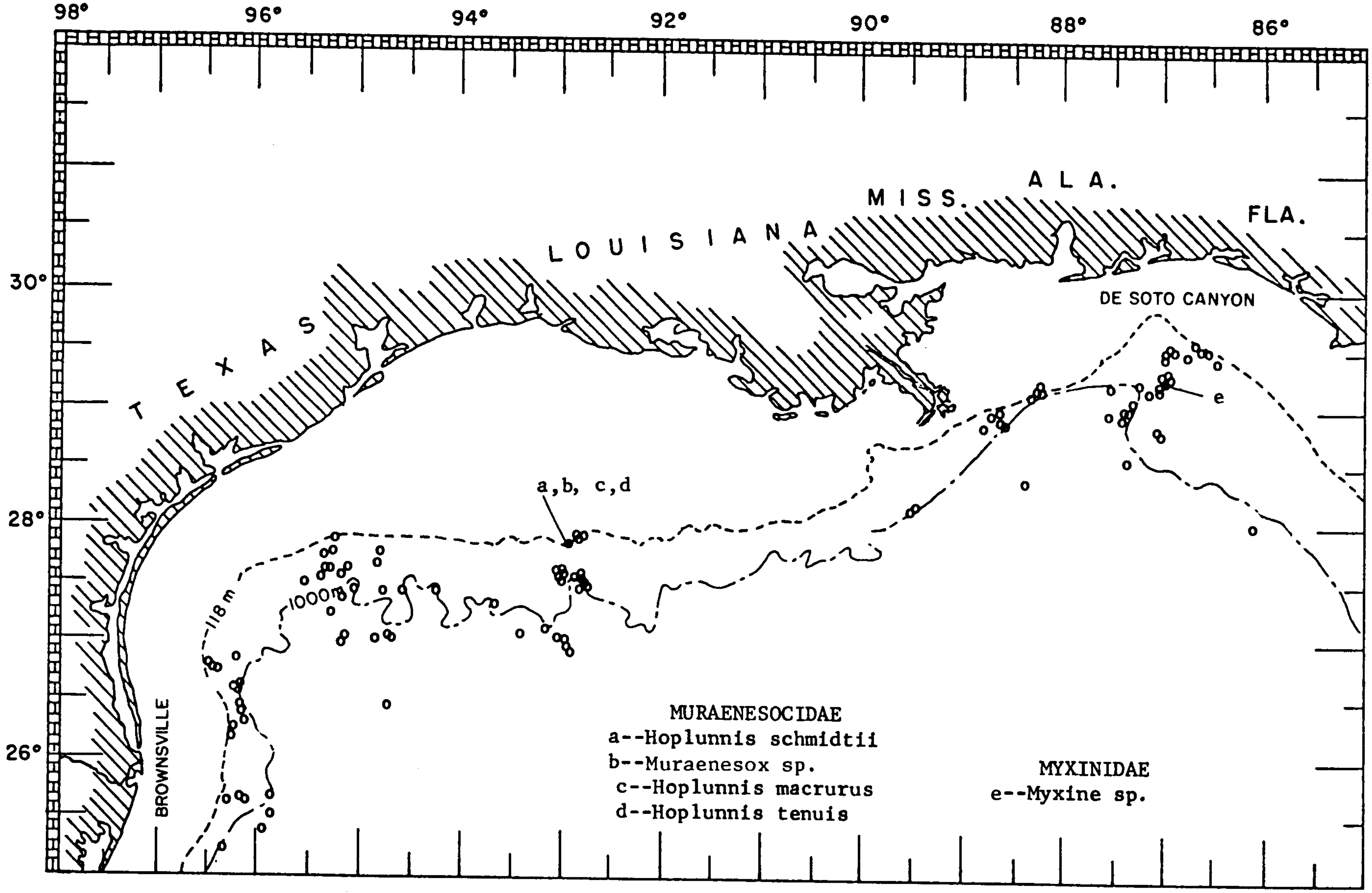

Fig. 6-46. Distribution of pike congers (Muraenesocidae) and hagfishes (Myxinidae) among the 111 stations of the continental slope study area.

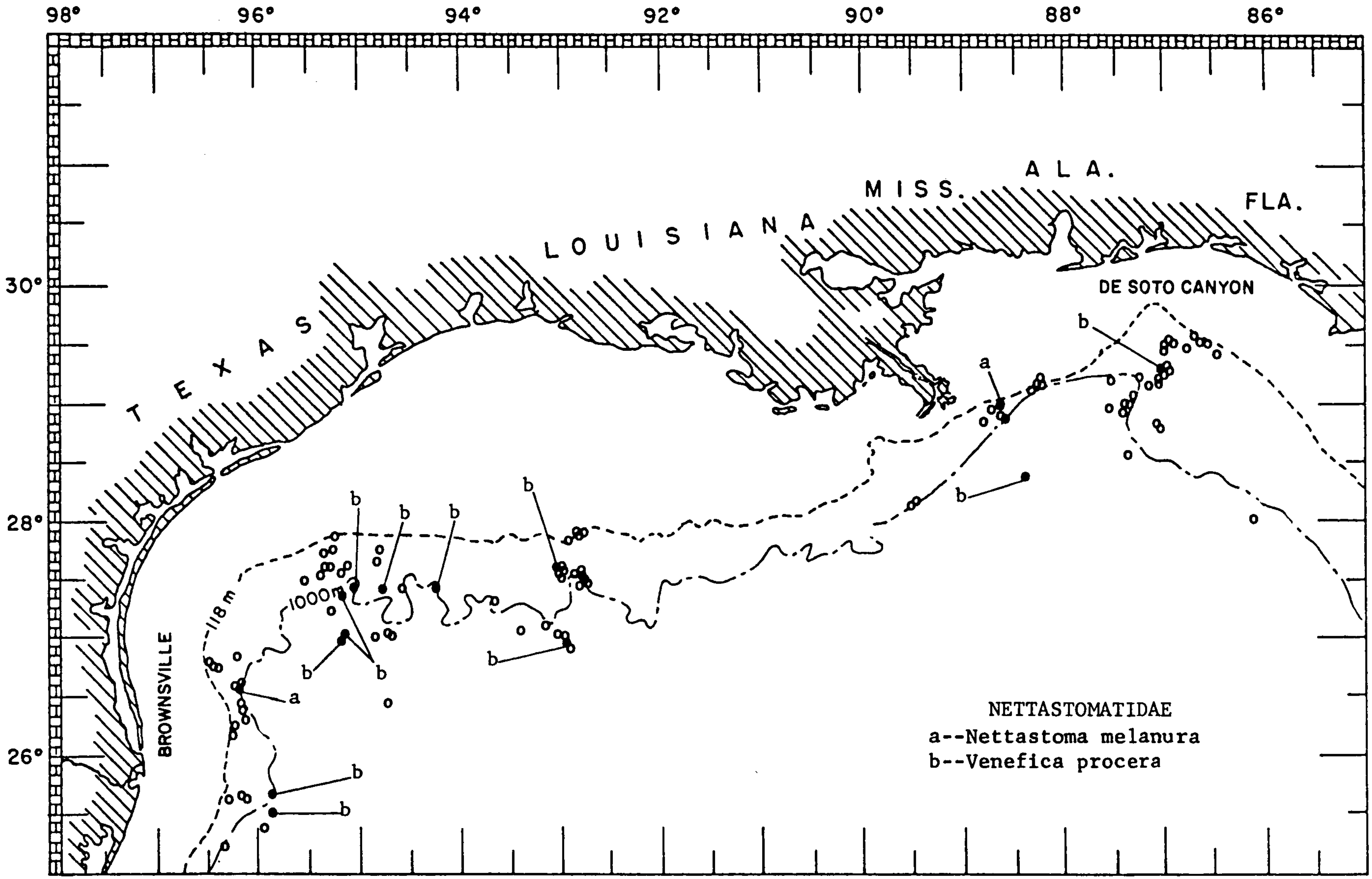

Fig. 6-47. Distribution of sorcerer eels (Nettastomatidae) among the 111 stations of the continental slope study area.

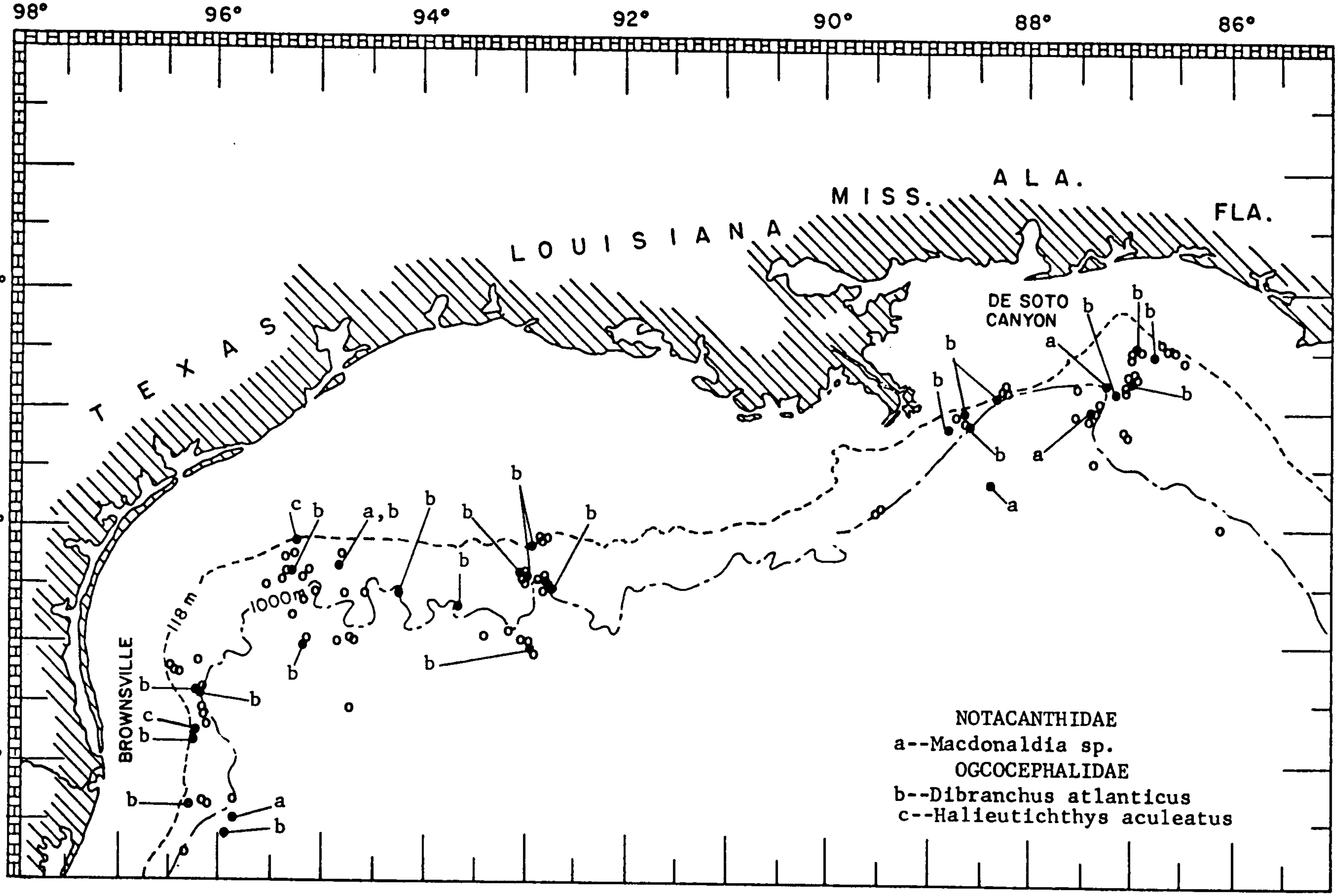

Fig. 6-48. Distribution of spiny eels (Notacanthidae) and batfishes (Ogcocephalidae) among the 111 stations of the continental slope study area.

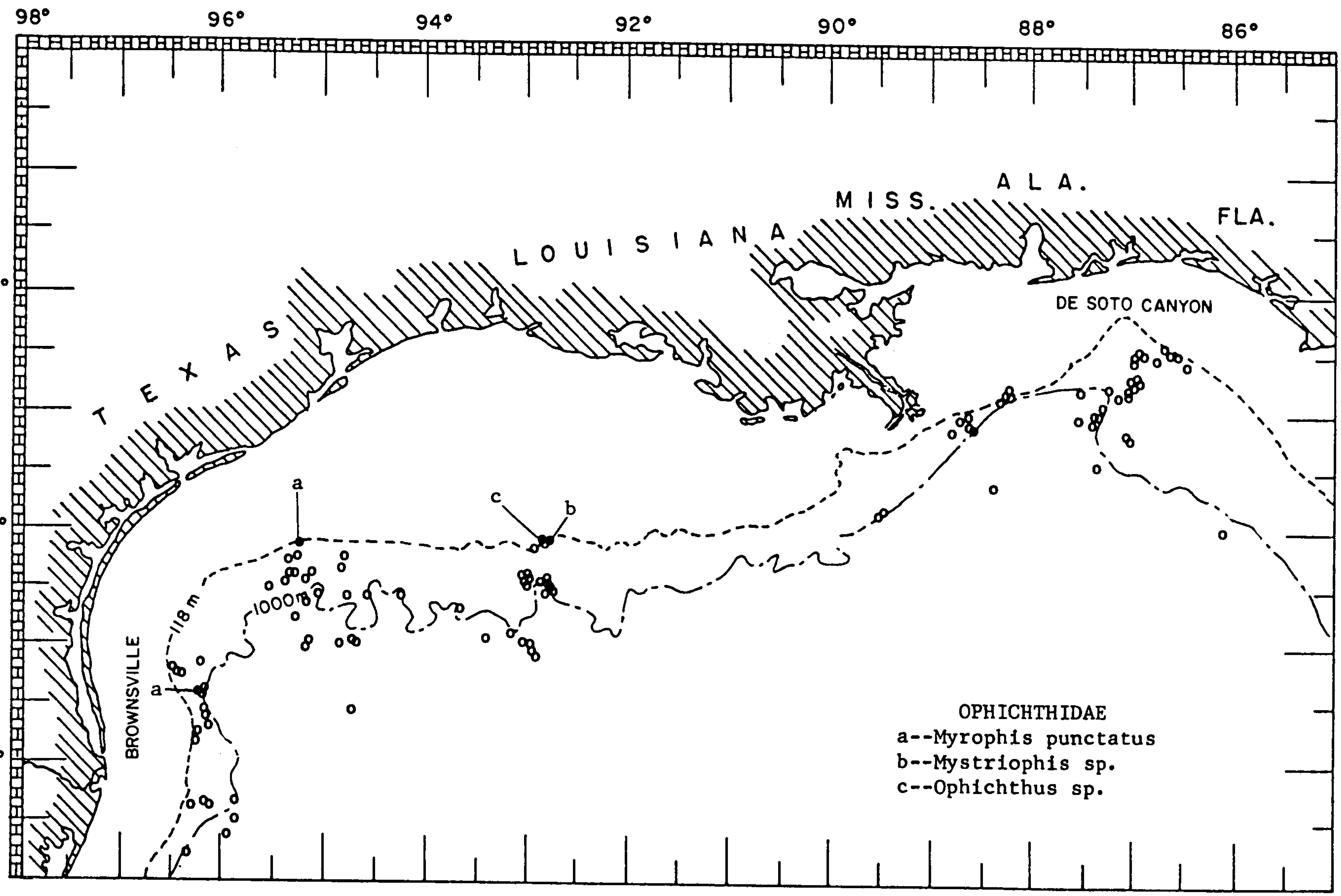

Fig. 6-49. Distribution of snake eels (Ophichthidae) among the 111 stations of the continental slope study area.

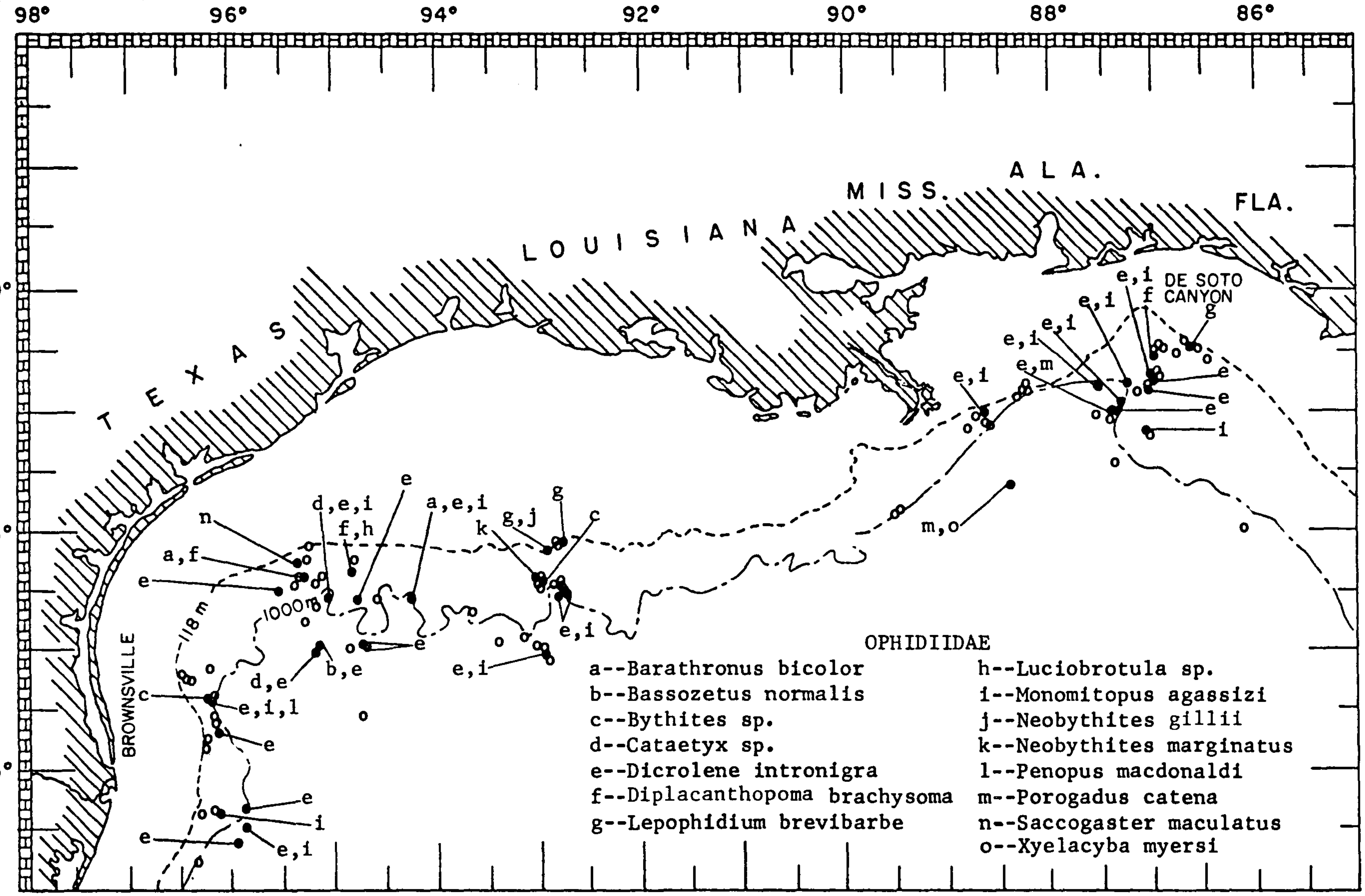

Fig. 6-50. Distribution of cusk-eels and brotulas (Ophidiidae) among the 111 stations of the continental slope study area.

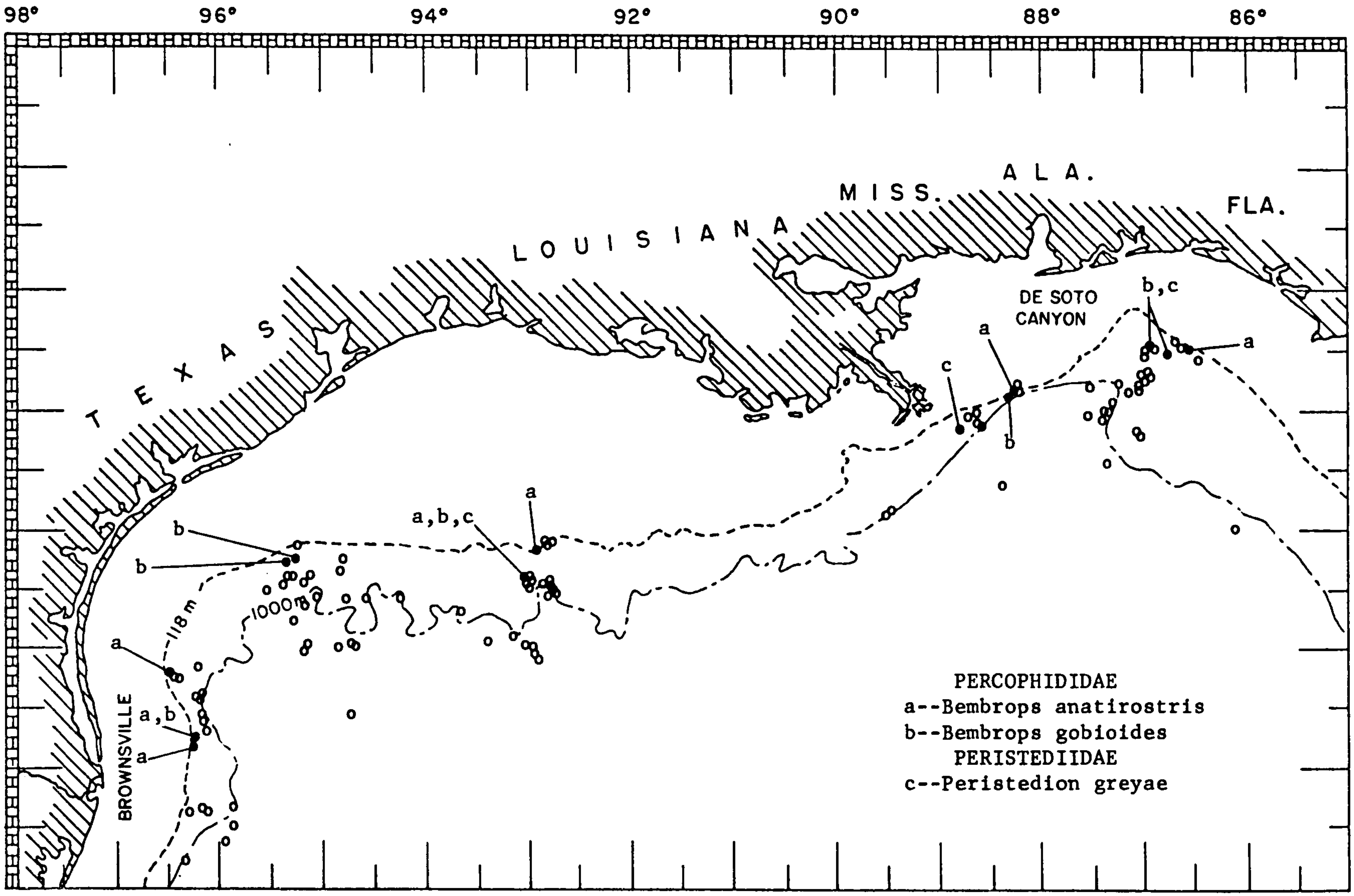

Fig. 6-51. Distribution of flathead fishes (Percophididae) and deep-water gurnards (Peristediidae) among the 111 stations of the continental slope study area.

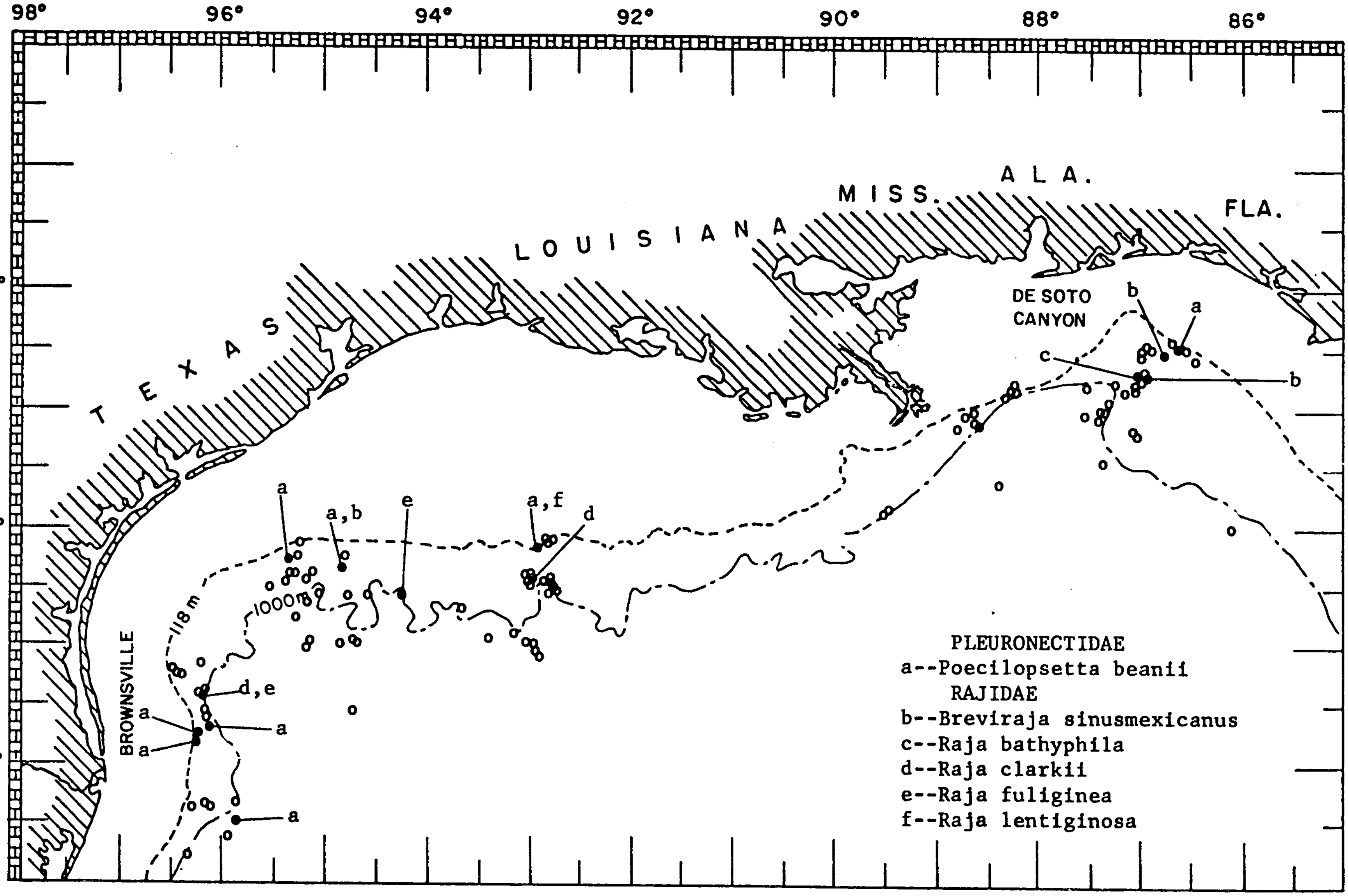

Fig. 6-52. Distribution of righteye flounders (Pleuronectidae) and skates (Rajidae) among the 111 stations of the continental slope study area.

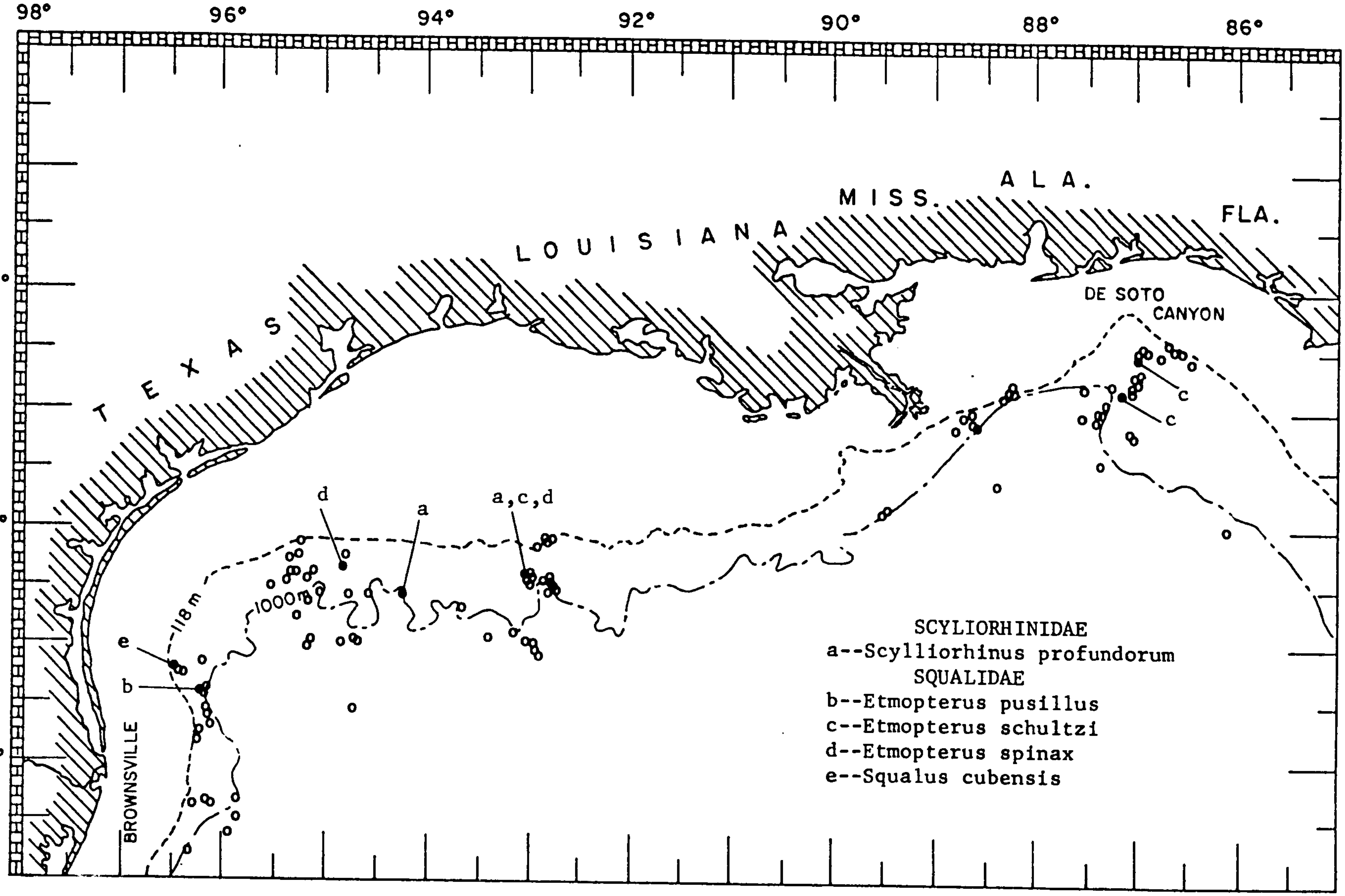

Fig. 6-53. Distribution of cat sharks (Scyliorhinidae) and dogfish sharks (Squalidae) among the 111 stations of the continental slope study area.

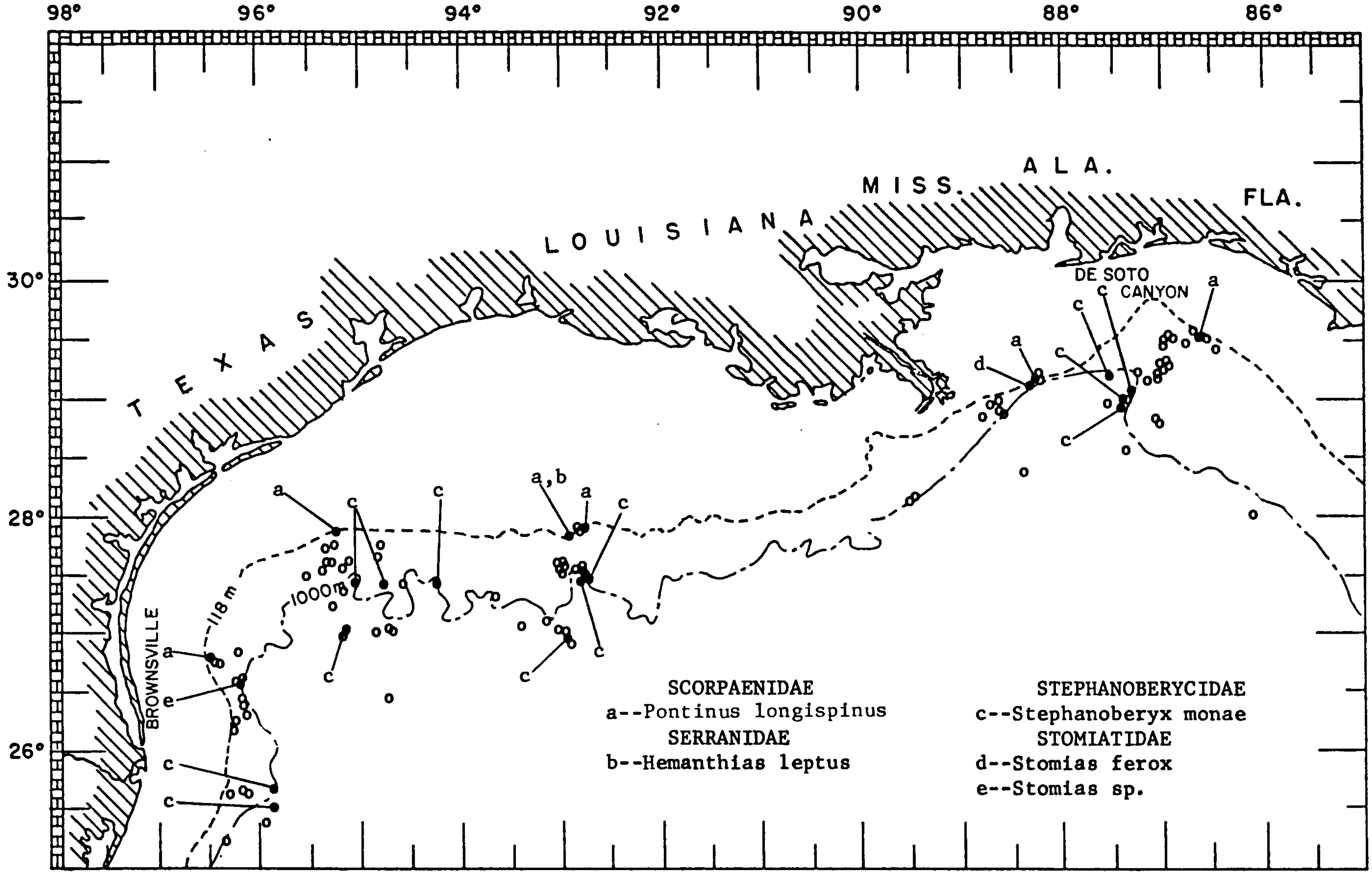

Fig. 6-54. Distribution of scorpionfishes (Scorpaenidae), sea basses (Serranidae), stephanoberycid fishes, and stomiatid fishes among the 111 stations of the continental slope study area.

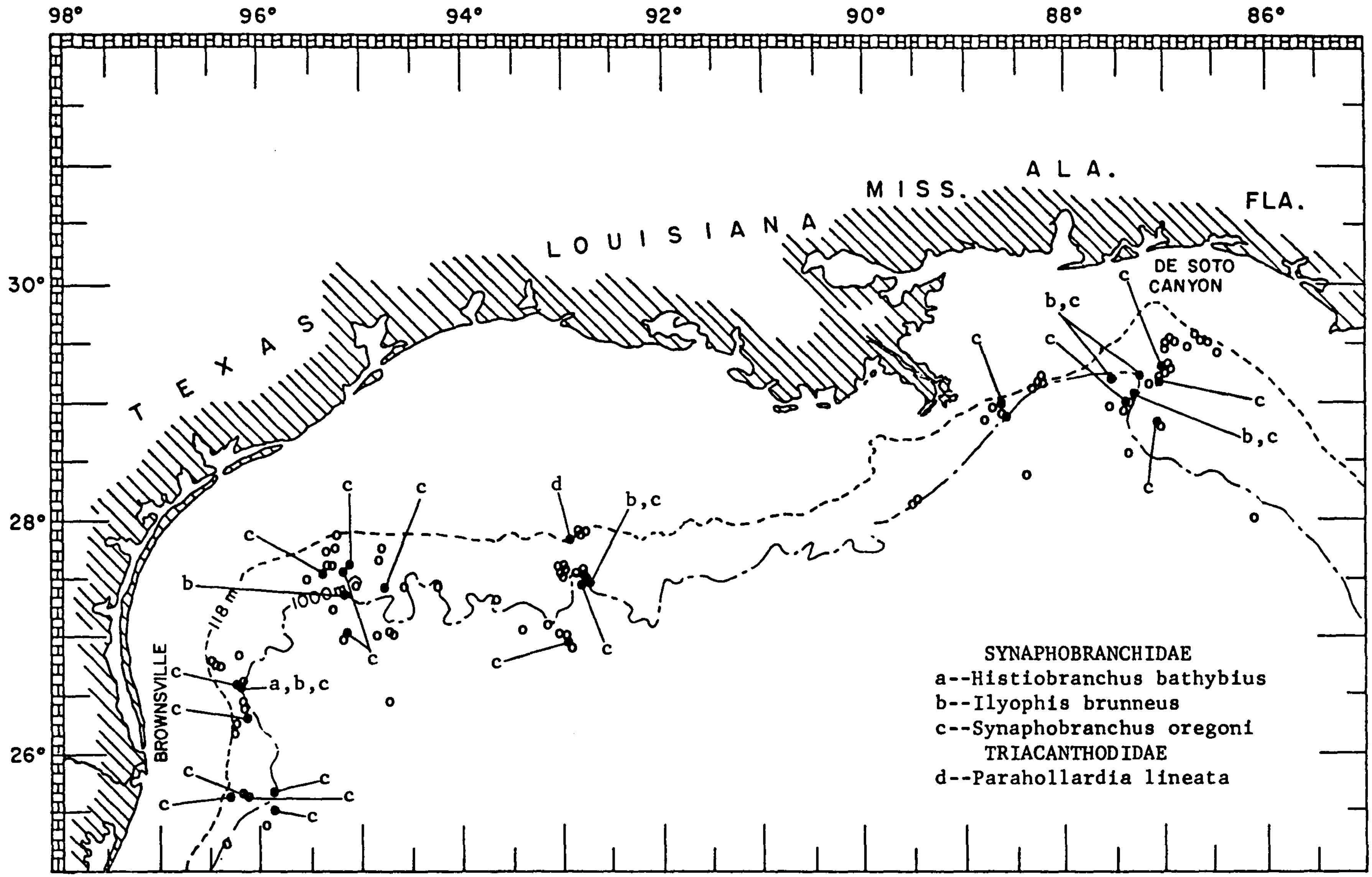

Fig. 6-55. Distribution of ooze eels (Synaphobranchidae) and spikefishes (Triacanthodidae) among the 111 stations of the continental slope study area.

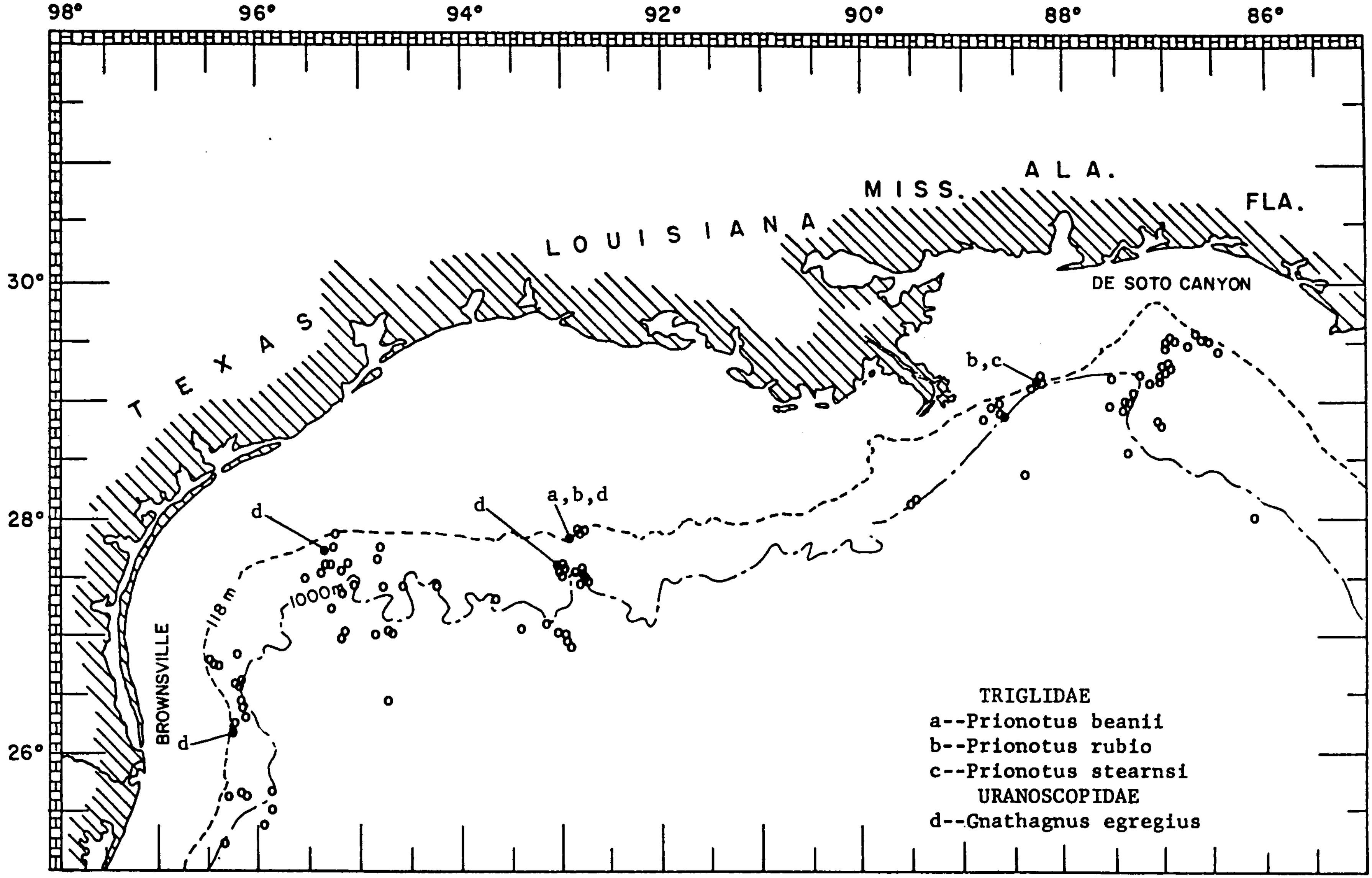

Fig. 6-56. Distribution of searobins (Triglidae) and stargazer eels (Uranoscopidae) among the 111 stations of the continental slope study area.

Table 6-12. (A) Gastropod mollusks found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Gastropoda on the upper continental slope - Gulf of Mexico.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Antillophos candei	20	5	100	Shelf-400	100
Polystira albida	74	0	-	Shelf-300	200
Sconsia striata	10	0	-	Shelf-250	200
Conus mazei	25	0	-	200-650	200
Murex beauii	118	5	590	150-200	200
Scaphella dubia	13	0	-	200 only	200
Polystira tellea	45	0	-	200 only	200
Phalium granulatum	3	0	-	200 only	200
Hindsiclava alesidota	2	0	-	200 only	200
Gemmula periscelida	56	10	560	250-650	250
Scaphander watsoni	14	0	-	400-500	500
Scaphella gouldiana	1	0	-	600 only	600
Gaza superba	200	20	4000	500-700	600
Oocorys bartschi	37	10	370	300-900	650
Leucosyrinx subgrundifera	7	0	-	700-800	700
Leucosyrinx cf. sigsbei	2	0	-	700-3230	700
Bulla cf. abyssicola	2	0	-	750 only	750
Colus sp.	10	0	-	750 only	750
Scaphander clavus	148	10	1480	600-900	800
Leucosyrinx tenoceras	164	5	820	1050 only	1050
Pleurotomella cf. chariessa	16	0	-	1050 only	1050
Pleurotomella cf. agassizii	48	5	240	700-1500	1050
Volutomitra cf. bairdii	49	10	490	700-2750	1050
Mangelia exsculpta	4	0	-	900-1100	1100
Leucosyrinx verrilli	23	0	-	700-1500	1450

B. Dominant gastropods presented in rank order.

SPECIES	Depth of Peak Pop. (m)	SPECIES	Depth of Peak Pop. (m)
1. Gaza superba	600	5. Gemmula periscelida	250
2. Scaphander clavus	800	6. Volutomitra cf. bairdii	1050
3. Leucosyrinx tenoceras	1050	7. Oocorys bartschi	650
4. Murex beauii	200	8. Pleurotomella cf. agassizii	1050

THE INFAUNA

Bivalve Mollusks

Thirty-three described and undescribed species of bivalve mollusks were collected in the northern Gulf from the shelf to the Sigsbee Abyssal Plain (James, 1972). Nineteen of these occur on the slope within the depth limits of the present study, whereas 14 are found only at greater depths (i.e. below 1000 m) down to the abyssal plain at 3750 m (see Table 6-13). While the shallow group contains both suspension feeders and deposit feeders, the latter 14 species are paleotaxodonts, which are exclusively deposit feeders. These provide an important source of food for some deep-sea asteroids (see page 242 and thus constitute an important link in a food web characteristic of the deep sea. One may speculate that the explanation of the observation that gastropods are not as abundantly represented on the lower slope as the above bivalves is probably related to the fact that the majority are carnivores and scavengers that must depend upon relatively higher levels of secondary production than appear to occur in the Gulf's deeper waters.

Interestingly the first and second most abundant bivalves on the slope, viz., Propeamussium cf. dalli and Tindaria amabilis overlap in vertical distribution between 1000 and 1500 m. Furthermore, they have been taken repeatedly at the same collecting station, indicating a significant difference in feeding. James (1972) reports that the intestine of Tindaria amabilis regularly contain forams free of debris, indicating a high degree of feeding selectivity.

Scaphopod Mollusks

Eleven species of scaphopod mollusks (tooth shells) have been detected upon the continental slope of the northern Gulf of Mexico. The extreme vertical range of at least two of these species, viz., Dentalium laqueatum and Dentalium circumcinctum suggests that the group should receive further study. According to Table 6-14 these species ranged from the shelf to the abyssal plain (D. laqueatum) and from 350 to 2550 m on the lower slope (D. circumcinctum). There is a strong possibility that the deeper individuals (which may actually have been dead at time of capture) were displaced by slumping.

Table 6-13. (A) Bivalve mollusks found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Bivalvia on the upper continental slope - Gulf of Mexico.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Nuculana acuta	48	10	480	150-250	200
Aequipecten glyptus	24	0	-	150-200	200
Yoldia solenoides	8	0	-	200-400	200
Microcardium peramabile	21	0	-	200 only	200
Anadara cf. baughmani	1	0	-	200 only	200
Astarte cf. nana	10	5	50	300 only	300
Nucula sp. A	3	0	-	350 only	350
Nuculana hebes	3	0	-	350 only	350
Amygdalum politum	44	20	880	400-750	400
Nuculana platessa	2	0	-	400 only	400
Abra longicallis americanus	62	10	620	400-2150	700
Brevinucula verrillii	108	15	1620	950-3500	950
Yoldiella pachia	1	0	-	1000 only	1000
Yoldiella quadrangularis	38	0	-	1000-1150	1050
Nucula pernambucensis	8	0	-	1000-1500	1150
Tindariopsis agathida	11	5	55	1000-1850	1150
Tindaria amabilis	107	30	3210	1000-1500	1400
Propeamussium cf. dalli	1378	35	48,230	550-1500	1450
Neilonella sp. A	2	0	-	1000-2450	1750

B. Dominant bivalve species presented in rank order.

SPECIES	Depth of Peak Pop. (m)	SPECIES	Depth of Peak Pop. (m)
1. Propeamussium cf. dalli	1450	5. Abra longicallis americanus	700
2. Tindaria amabilis	1400	6. Nuculana acuta	200
3. Brevinucula verrillii	950	7. Tindariopsis agathida	1150
4. Amygdalum politum	400	8. Astarte cf. nana	300

Table 6-14. (A) Scaphopod mollusks found on the upper continental slope of the northern Gulf of Mexico between 150 and 1000 m. (B) Dominant species in rank order.

A. Inventory of Scaphopoda on the upper continental slope of the Gulf of Mexico listed in order of depth of maximum population.

SPECIES	A. Total Individuals at all Stations	B. Sum of Stations Where Species is Dominant (x5)	C. Product A × B	Depth Range (m)	Depth of Maximum Population (m)
Dentalium ceratum	5	0	-	100-200	100
Dentalium stenoschizum	5	0	-	150-200	200
Pulsellum pressum	201	0	-	350-1400	950
Dentalium circumcinctum	308	20	6160	350-2550	950
Cadulus sp.	365	5	1825	200-1150	950
Dentalium perlongum	752	60	45,120	750-3300	950
Dentalium callithrix	775	20	15,500	950-2650	950
Entalina platamodes	9	5	45	950-1150	950
Dentalium obscurum	4	0	-	750-1350	1050
Dentalium laqueatum	35	20	700	Shelf-3700	1400
Dentalium carduum	1	0	-	1750 only	1750
Dentalium ensiculus	32	5	160	1000-3200	3200
Dentalium meridionale	312	20	6240	1350-3350	3250

B. Dominant tooth shells presented in rank order.

SPECIES	Depth of Peak Pop. (m)	SPECIES	Depth of Peak Pop. (m)
1. Dentalium perlongum	950	5. Cadulus sp.	950
2. Dentalium callithrix	950	6. Dentalium laqueatum	1400
3. Dentalium meridionale	3250	7. Dentalium ensiculus	3200
4. Dentalium circumcinctum	950		

BENTHIC FAUNAL ASSEMBLAGES OF THE UPPER CONTINENTAL SLOPE

DEFINITIONS

The concept of benthic animal communities seems to have been formulated first in the late 19th century by Karl Möbius as an outgrowth of his observations of oyster reefs. Presumably he intended the word "biocoenosis" to apply to those groupings of animals that were near equilibrium with the totality of their environment. If true, this implies an integration of species actions, involving interdependencies, that marine ecologists tend to assume do occur even though they may not be able to demonstrate their nature. The difficulty of obtaining these critical data is recognized in the definition of a community presented by Mills (1969) as follows: "--- a group of organisms occurring in a particular environment, presumably interacting with each other and with the environment, and separable by means of ecological survey from other groups." This definition is quite acceptable to many ecologists, but others find Krebs' (1972) operational definition better fits the state of our knowledge of marine benthic communities, especially those in deep water, when he says that a community may be thought of as "any assemblage of populations of living organisms in a prescribed area or habitat." This is similar to Fager's (1963) wholly operational definition: "a community is any group of species which are often found living together." No matter which definition seems preferable, one should be willing to agree that in a community one is dealing with (1) populations of organisms that together make up (2) assemblages of co-incidental species that (3) exhibit sufficient degrees of recurrence in prescribed areas as to (4) repudiate the notion that they are simply randomly assembled collections of species.

The acceptability of the above definitions is heightened by the fact that none of them puts any limit on the size of communities nor does any one require that attempts be made to include every species that lives in the habitat. This is especially important to marine benthic studies where species diversity can be high and the availability of species-level taxonomic expertise may be low. Moreover, the shift from pelagic to benthic environments, the large range of size and mobility of the constituent species, and changes in substratum type demand that several sampling techniques be employed if any reasonable approximation of a "complete" representation of the constituents of a marine community is to be achieved. For these reasons, the discussion and description of communities in the following pages is limited to large benthic organisms that can be captured by means of dredges and/or trawls. Even here sampling problems in deep water could easily dissuade one from attempting to discuss deep-benthic communities except for one thing, viz., that after gaining a backlog of experience one cannot but be impressed by the observation that when the catch of a trawl or dredge from a particular isobath or habitat is laid out on the deck it is similar to but not identical with recurrent groups of species taken previously by the same gear. This is not new. Petersen (1918) was motivated to write about "recurrent organized systems of organisms" that were revealed in his grab samples. At that time he was impressed by similarities among samples, as expressed in terms of species presence and abundance. Acceptance of this concept of recurrent groups has been advanced by Fager and others, but in so doing neither he nor others have necessarily felt constrained to accept more tenuous portions of the concept of "parallel communities", which was championed in recent years by the late Gunnar Thorson.

In the present study of the faunal assemblages residing on the continental slope of the northern Gulf between depths of 118 and 1000 m, one is concerned with benthic organisms ranging in size from small (1 cm or so) palaeotaxodont bivalves to fishes of considerable size. Even though the meiofauna are excluded by design and whereas the largest and most mobile invertebrates and vertebrates may be missed by sampling shortcomings, it is felt that the essential nature of the outer shelf and upper slope assemblages is being presented for the first time. Then too, only those species that seem to predominate by frequency of occurrence and population size are included in the assemblages. Even with these limitations, which are not everywhere adhered to, the assemblages described hereinafter have a total of over 400 species. It is fortunate that most but not all of these (some are undescribed) have been identified to the species level so that comparisons with other areas and other habitats are feasible.

Probably one should not attempt here to take a firm position as to whether or not the communities on the shelf and slope are more nearly discrete functioning units easily separable one from the other or whether they form a continuum of assemblages wherein the components are responding to complex and usually poorly understood environmental gradients. Nevertheless, the idea of a continuum is attractive if one remains aware of the fact that some of the component species have rather definite depth limits along a given vertical transect. When many species tend to attain a lower or upper depth limit on the same isobath (or near to it), their clusters within the continuum tend to be impressive. But when, on the other hand, groups of species have wide bathymetric ranges starting and stopping depthwise without obvious reason, one may focus more on the continuum than on the smaller and more discrete clusters. Clearly then there are groups within groups, as will be demonstrated on both the shelf and the slope. So far as can be told, however, there is no hierarchical arrangement, the "within" groups simply being made up of species that for one reason or other have smaller ranges of distribution than others. The truly interesting point is related to the limiting factors rather than to whether or not they form discrete functioning units.

The approach to describing the faunal assemblages will be to list under the proper assemblage name those species that are essentially limited to the bathymetric limits stipulated for the assemblage as a whole. Then, however, in Appendix A, one will find a complete listing of all of the species found on the isobaths falling across the assemblage's vertical limits. These lists also contain in rank order under each taxon given those organisms that are considered to be Key Species on the isobath and thus within the assemblage.

Following the material on faunal assemblages will come a brief discussion of species diversity indices (the Shannon-Wiener function) as they apply, not to pooling of data for isobaths, but to individual stations. These then will be compared with the depth of appearance of species on the vertical axis (called starts) as one samples across the outer shelf and progressively deeper down the slope (see Fig. 6-57).

Data from individual stations will be used also to construct a similarity dendrogram that will show how the results of sampling are interrelated and reflected against the isobaths (see Fig. 6-58).

At this point one should look more closely at the nature of and interrelationships among some of the key species in three sections:

(1) Physical Characteristics of Some Key Species
(2) Food Habits of Selected Key Species
(3) Food Chains Involving Some Key Species

Finally in this section on Benthic Faunal Assemblages, some consideration shall be given to a few of the factors that probably control the nature of the assemblages.

SPECIES COMPOSITION OF THE FAUNAL ASSEMBLAGES

As stated earlier, the main objective of the present study deals with faunal assemblages of the upper continental slope but some attention must be given to their relationships with the continental shelf if for no other reason than to gain perspective on the importance of similarities and differences. Unfortunately, only a small proportion of samples readily available are representative of the shelf, but they are sufficient to give comprehension of relationships. For additional information on the species composition of the assemblages on isobaths in the zones, see Appendix A.

Shelf Assemblages

This region appears to afford ecological niches for three major groupings of organisms, some of which change habitats while completing their life-cycles or when responding to very evident seasonal changes of temperature.

Outward from the estuarine, lagoonal, and intertidal environments there is an Inner Shelf Assemblage, an Outer Shelf Assemblage, and a Shelf-Slope Transitional Assemblage that may range from the inner part of the continental shelf down the slope for some distance.

Inner Shelf Assemblage
(From the Intertidal to 50-70 m depth)

The average depth of the distribution of the constituent species appears to be about 25 m.

Demersal Fishes

1.	Micropogon undulatus	Atlantic croaker
2.	Galeichthys felis	Sea catfish
3.	Cynoscion arenarius	Sand seatrout
4.	Leiostomus zanthurus	Spot
5.	Menticirchus americanus	Southern kingfish
6.	Syacium gunteri	Shoal flounder

Crustaceans

1.	Penaeus duorarum	Shrimp, white
2.	Penaeus setiferus	Shrimp, pink
3.	Hepatus epheliticus	Crab
4.	Scyllarus chacei	Shovelnose lobster
5.	Squilla empusa	Mantis shrimp

Asteroids

1.	Luidia clathrata	starfish
2.	Astropecten duplicatus	starfish

Echinoids

1.	Arbacia punctulata	Sea urchin
2.	Mellita quinquesperforata	Sand dollar

Gastropod

1.	Polinices duplicatus	Moon snail

Cephalopods

1.	Lolliguncula brevis	Squid
2.	Octopus joubini	Octopus

All of the fishes of this assemblage (except the flounder) and of course the penaeid shrimps are definitely associated with the estuaries of the northern Gulf. There are definite differences in the relative abundance of these fishes on the east-west axis (Moore et al., 1970). The greater abundance of fishes off Louisiana is probably related to the Mississippi flow. Furthermore, many of these fishes move into deeper waters offshore in winter and then return to the inner shelf area in summer. This is clearly a response to some effects of temperature.

Outer Shelf Assemblage
(From 50-70 m to 118 m or so)

The average depth of the centers of the populations of the constituent species appears to be around 75 m.

Demersal Fishes

1. Stenotomus caprinus — Longspine porgy
2. Prionotus paralatus — Mexican searobin
3. Many other fishes exist here, but these are restricted here (Moore et al., 1970).

These fishes are never associated as such with the estuaries, and they tend to have less seasonality in their abundance.

Crustaceans

1. Leiolambrus nitidus — Crab
2. Portunus spinimanus — Swimming crab
3. Penaeus aztecus — Shrimp, brown
4. Porcellana sayana — Porcellanid crab (anomuran)
5. Stenocionops furcata coelata — Spider crab
6. Solenocera atlantidis — Shrimp (penaeid)
7. Sicyonia brevirostris — Rock shrimp

Asteroids

1. Astropecten cingulatus — Starfish

Shelf-Slope Transition Assemblage
(Species that range from near 118 m to depths around 200 m)

The average depth of the constituent species appears to be about 135 m. The fishes are caught in commercial quantities on the shelf but they also range down on the slope. These species are not associated with the estuaries.

Demersal Fishes

1.	Halieutichthys aculeatus	Batfish
2.	Pristipomoides aquilonaris	Wenchman
3.	Serranus atrobranchus	Blackear bass
4.	Synodus foetens	Lizardfish
5.	Caulolatilus sp.	Tilefish
6.	Centropristis philadelphicus	Rock sea bass
7.	Prionotus rubio	Blackfin searobin
8.	Cyclopsetta chittendeni	Mexican flounder
9.	Myrophis punctatus	Speckled worm eel
10.	Urophycis floridanus	Codling

Crustaceans

1.	Raninoides louisianensis	Crab
2.	Podochela sidneyi	Crab
3.	Parapenaeus longirostris	Penaeid shrimp
4.	Solenocera vioscai	Penaeid shrimp
5.	Porcellana sigsbeiana	Porcellanid crab
6.	Portunus spinicarpus	Swimming crab
7.	Anasimus latus	Crab
8.	Squilla chydaea	Mantis shrimp
9.	Dardanus insignis	Hermit crab
10.	Myropsis quinquespinosa	Crab
11.	Munida forceps	Galatheid crab
12.	Munida irrasa	Galatheid crab

Asteroids

1.	Anthenoides piercei	Starfish
2.	Tethyaster grandis	Starfish

Echinoidea

1.	Brissopsis atlantica	Heart urchin

Gastropods

1. Sconsia striata
2. Polystira albida
3. Antillophos candei

Cephalopods

1.	Semirossia equalis	Cuttlefish
2.	Semirossia tenera	Cuttlefish

True Slope Assemblages

Shallow Zone
(175-450 m)

Demersal Fishes

1.	Ancylopsetta dilecta	Three-eye flounder
2.	Steindachneria argentea	Luminous hake
3.	Lepophidium brevibarbe	Cusk-eel
4.	Coelorhynchus caribbaeus	Caribbean hollowsnout
5.	Synodus poeyi	Offshore lizardfish
6.	Citharichthys cornutus	Horned whiff
7.	Syacium papillosum	Dusky flounder
8.	Saccogaster maculatus	No common name
9.	Callionymus agassizi	Spotfin dragonet
10.	Hoplunnis macrurus	Largetail pike conger
11.	Hemanthias leptus	Longtail bass
12.	Citharichthys gymnorhinus	Baresnout sanddab
13.	Gonioplectrus hispanus	Spanish flag
14.	Bellator militaris	Horned searobin
15.	Hoplunnis schmidtii	Schmidt's pike conger

The above fishes attain their maximal populations within the Shallow Zone of the slope, and most of them are found only within the depth limits established above. This zone is also rich in brachyuran crabs.

Crustaceans

1.	Acanthacarpus alexandri	Crab
2.	Chasmocarcinus cylindricus	Crab
3.	Calappa angusta	Crab
4.	Stenocionops spinimana	Crab
5.	Collodes leptochela	Crab
6.	Palicus dentatus	Crab
7.	Palicus sicus	Crab
8.	Palicus obesus	Crab
9.	Euphrosynoplax clausa	Crab
10.	Dicranodromia ovata	Crab
11.	Myropsis quinquespinosa	Crab
12.	Parthenope agona	Crab
13.	Parapandalus willisi	Caridean shrimp
14.	Munida longipes	Galatheid crab

Asteroids

1. *Astropecten nitidus*
2. *Cheiraster echinulatus*
3. *Rosaster alexandri*

Echinoids

1. *Brissopsis alta*
2. *Stylocidaris affinis*
3. *Hypselaster limicolus*
4. *Brissopsis elongata*
5. *Agassizia excentrica*
6. *Araeosoma fenestratum*
7. *Palaeobrissus hilgardi*
8. *Podocidaris sculpta*

Ophiuroids

1. *Amphilimna olivacea*
2. *Amphiura semiermis*

Bivalves

1. *Astarte nana*
2. *Yoldia solenoides*

Cephalopods

1. *Rossia bullisi*

Intermediate Zone
(450-750 m)

Demersal Fishes

1.	*Symphurus marginatus*	Tonguefish
2.	*Coelorhynchus carminatus*	Macrourid
3.	*Peristedion greyae*	Gurnard
4.	*Chlorophthalmus agassizii*	Shortnose greeneye
5.	*Ventrifossa atlantica*	No common name
6.	*Chaunax pictus*	No common name
7.	*Diplacanthopoma brachysoma*	No common name
8.	*Etmopterus spinax*	Shark
9.	*Breviraja sinusmexicanus*	Ray
10.	*Symphurus piger*	Tonguefish
11.	*Conger oceanicus*	Conger eel
12.	*Trachyscorpia cristulata*	Atlantic thornyhead

Demersal Fishes (cont'd)

13.	Urophycis tenuis	White hake
14.	Promyllantor schmitti	No common name
15.	Benthodesmus atlanticus	No common name
16.	Urophycis chesteri	Hake
17.	Etmopterus schultzi	Shark

Crustaceans

1.	Rochinia crassa	Spider crab
2.	Trichopeltarion nobile	Crab
3.	Aristeus antillensis	Penaeid shrimp
4.	Aristaeomorpha foliacea	Penaeid shrimp
5.	Munidopsis longimanus	Galatheid crab
6.	Munidopsis polita	Galatheid crab
7.	Munidopsis alaminos	Galatheid crab
8.	Munidopsis erinaceus	Galatheid crab
9.	Munidopsis serratifrons	Galatheid crab
10.	Sympagurus pictus	Hermit crab

Asteroid

1. Cheiraster enoplus

Ophiuroids

1. Bathypectinura tesselata
2. Ophiochiton grandis

Holothuroids

1. Hedingia albicans
2. Molpadia oolitica
3. Molpadia cubana
4. Ypsilothuria talismani

Bivalves

1. Amygdalum politum
2. Nuculana platessa

Gastropods

1. Scaphander watsoni
2. Gaza superba

Middle Zone
(800-1050 m)

Demersal Fishes

1.	Gadomus arcuatus	No common name
2.	Hydrolagus mirabilis	Ratfish
3.	Bathytroctes sp.	No common name
4.	Leptoderma macrops	No common name
5.	Bathypterois longipes	No common name
6.	Raja bathyphila	Skate
7.	Bathypterois viridensis	No common name
8.	Penopus macdonaldi	No common name
9.	Histiobranchus bathybius	Eel

Crustaceans

1.	Rochinia umbonata	Spider crab
2.	Acanthephyra armata	Caridean shrimp
3.	Parapandalus richardi	Caridean shrimp
4.	Munidopsis subspinoculata	Galatheid crab
5.	Munidopsis tridentata	Galatheid crab

Asteroid

1. Psilaster patagiatus

Ophiuroid

1. Ophioplinthaca dipsacos

Echinoid

1. Hypselaster brachypetalus

Holothuroidea

1. Euphronides kerhervei
2. Protankyra sleuteri

In Fig. 6-57 one can see the relative numbers of genera and species that make their appearance at given isobaths. One can also see that there are five peaks and that those at 200 and 500 m depth appear to be the more important. These probably form the basis for at least four zones on the continental slope between 118 and 1000 meters, but further sampling will be required around 450 and 1050 m to be sure.

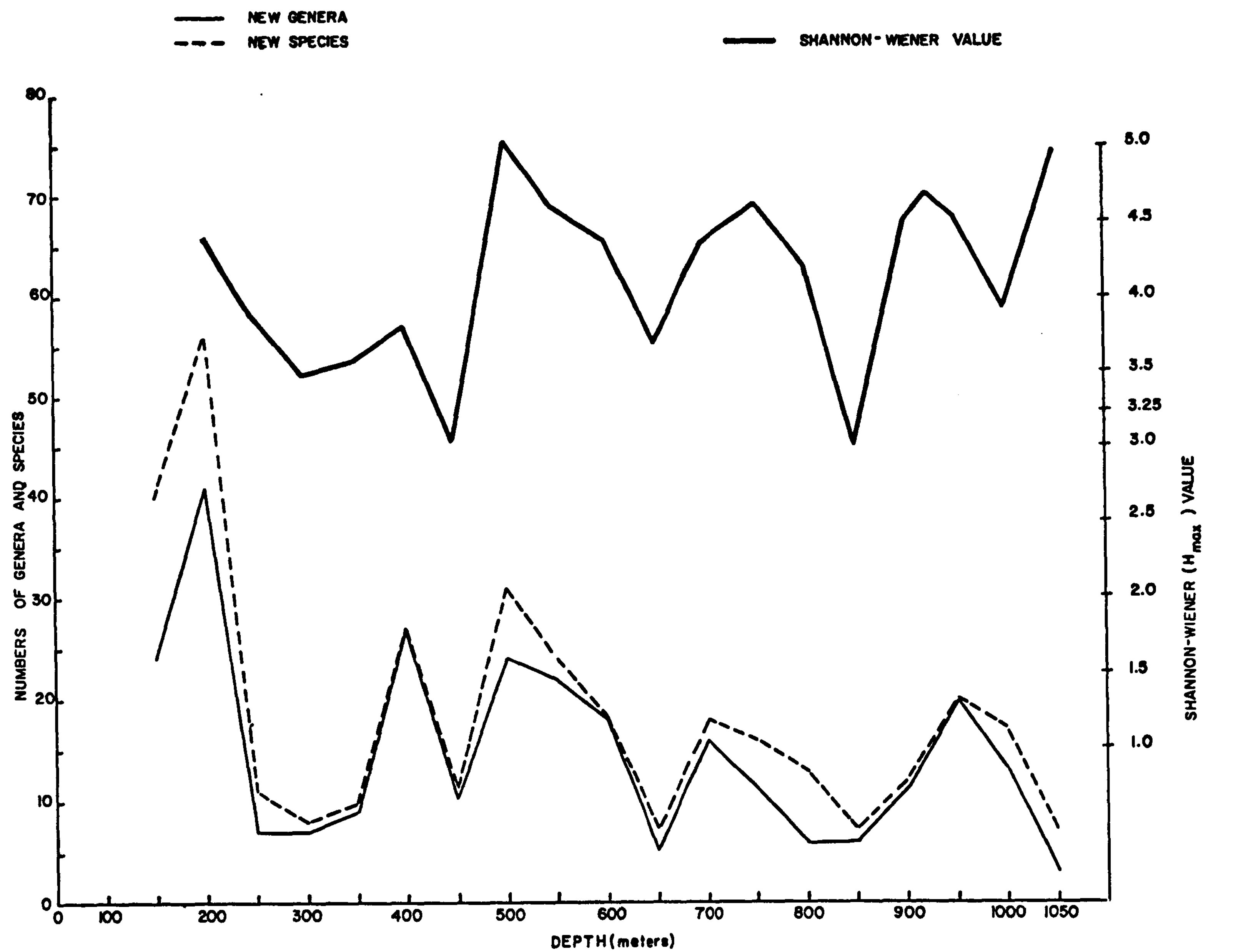

Fig. 6-57. Comparison of Shannon-Wiener maximal diversity values (H_{max}, upper curve of solid line) with genus starts (lower curve with solid line) and species starts (dashed line) appearing at isobaths of the Upper Continental Slope.

SPECIES DIVERSITY

Station Diversity Calculations

One important parameter of animal communities is species richness or diversity. Since all communities do not contain the same number of species, the species diversity index becomes a rather important tool for making comparisons between such groups. The simplest method to gain this information would seem to be to count the number of species and then to make whatever comparisons with other stations or habitats that appear to be worthwhile. Unfortunately this simple approach has two important shortcomings that are amplified by application to deep-water studies. The first of these relates to the fact that it is often very difficult to obtain samples of benthonic animals in deep water that are sufficiently representative of the species in a community to be reliable. In other words species counts are dependent upon sample size, and sample size in turn is often dependent upon the type or types of sampling gear employed. Moreover, the same piece of benthic sampling gear can be expected to vary in efficiency when it is employed in very different substrata. A second shortcoming of direct species counts is that the number of individuals is not necessarily related to the number of species. That is to say, the quality of equitability is not included in the estimate of species diversity by simple counts. Equitability measures the distribution of individuals among species, and thus species diversity, in contradistinction to dominance diversity, is greater when individuals trend toward being evenly distributed among the species.

Use has been made in the present study of the Shannon-Wiener function to calculate species diversity indices for individual collecting stations. This function is somewhat dependent upon sample size, but it is affected primarily by the number of species and by equitability. Thus, when two stations are compared the one with the larger number of species will have a larger index but just how much larger will depend upon the evenness or unevenness of distribution of individuals. Hence, maximal diversity for any given number of species is attained when each species is represented

Table 6-15. Shannon-Wiener diversity functions (H) and maximal indices (H_{max}) for the 111 slope stations. Some explanatory statements provided where appropriate under COMMENTS.

	STATION	DEPTH (m)	GEAR	H	H_{max}	COMMENTS
1.	675SK1A	1020	Sk	0.81	0.99	Short time on bottom
2.	675D1B	1020	D	--	--	No sample
3.	675SK2H	1829	Sk	3.52	3.70	Representative sample
4.	675SK5D	1450	Sk	2.85	3.70	No crabs, penaeids, echinoids or asteroids
5.	675SK6B	788	Sk	3.11	3.99	No crabs, echinoids or asteroids
6.	675D6E	788	D	--	--	No sample
7.	675SK7C	850	Sk	2.97	3.70	No crabs, echinoids or asteroids
8.	675D7E	752	D	2.49	2.58	No crustacea, asteroids or fish
9.	675SK8B	1494	Sk	3.67	3.90	No crabs or echinoids
10.	675D8B	1494	D	1.92	1.99	Poor sample for comparsion
11.	675SK9A	752	Sk	3.86	4.75	No crabs or asteroids
12.	675D9E	640	D	2.95	2.99	
13.	675D11C	194	D	3.28	3.58	
14.	675D12A	193	D	--	--	No specimens
15.	675D13B	379	D	2.94	2.99	
16.	675SK13E	379	Sk	2.81	3.58	No echinoderms or mollusks
17.	683SK10B	988	Sk	1.22	2.81	Skimmer turned over
18.	683D12C	732	D	0.99	0.99	Poor sample, shallow shells
19.	687SK1A	696	Sk	4.37	5.29	Lots of plant material
20.	687SK2A	408	Sk	2.47	3.17	Far less plant material
21.	687SK2B	595	Sk	2.43	2.99	Very little vegetation
22.	687SK2C	696	Sk	2.55	3.46	Many groups not represented
23.	687SK7B	1097	Sk	2.42	2.58	Many groups not represented
24.	687D8A	194	D	0.99	1.99	Sample spilled
25.	687SK8C	203	Sk	4.02	4.64	Many crabs
26.	687SK9A	384	Sk	2.17	4.32	Disproportionate numbers of crabs and shrimps
27.	687SK10A	565	Sk	3.62	4.95	Disproportionate numbers of carideans, bivalves and holothuroids
28.	687SK11A	787	Sk	3.08	4.46	Disproportionate in polychelids and holothuroids
29.	687D12A	585	D	2.23	2.32	Small sample
30.	687SK12B	900	Sk	3.40	4.58	Disproportionate in carideans, polychelids, holothuroids
31.	687SK13A	1061	Sk	3.71	4.58	Same as immediate above
32.	687SK13B	1400	Sk	3.46	3.99	OK sample
33.	687SK13D	1463	Sk	1.94	4.10	Disproportionate-carideans, polychelids
34.	687SK14B	1829	Sk	3.78	3.91	Small sample-good equitability
35.	687SK15D	1097	Sk	3.62	4.25	OK sample
36.	687SK15H	914	Sk	3.79	4.32	OK sample

Table 6-15(cont'd).

	STATION	DEPTH (m)	GEAR	H	H_{max}	COMMENTS
37.	687SK17B	900	Sk	2.51	4.52	Disproportionate-carideans, polychelids
38.	6813SK1	878	Sk	2.96	4.95	Disproportionate-carideans, echinoids
39.	6813D3	713	D	2.97	3.46	Same as above
40.	6813SK4	512	Sk	2.95	5.04	Good sample-high in carideans and crabs
41.	6813SK5	271	Sk	2.49	4.32	Good sample-high in crabs and penaeids
42.	6813SK7	274	Sk	3.02	4.52	Same as above
43.	6813SK8	732	Sk	3.25	4.52	Good sample-high in carideans, echinoids and ophiuroids
44.	6813SK11	1216	Sk	3.14	3.91	Good sample
45.	6813SK12A	1189	Sk	2.88	5.21	Excellent sample-high in carideans, echinoids, and ophiuroids.
46.	6813D14	969	2-M D	0.85	4.58	Excellent sample-high in echinoids
47.	6813SK15	759	Sk	3.42	4.46	High in ophiuroids
48.	6813D16	713	2-M D	1.58	1.58	Two species, 1 individual each
49.	6813SK17	183	Sk	3.01	3.32	Small sample
50.	6813D18	439	2-M D	3.20	3.46	Moderate sample
51.	6813SK19	361	Sk	3.01	3.58	Moderate sample
52.	6813SK21	576	Sk	3.37	4.99	Excellent sample-high in carideans and ophiuroids
53.	6813D22	476	2-M D	1.88	3.17	Small sample-high in crabs
54.	6813SK23	732	Sk	2.94	4.64	Excellent sample-high in crabs and echinoids
55.	6813SK24	878	Sk	2.22	4.25	Good sample-high in carideans and pagurids
56.	6813SK26	1400	Sk	3.28	4.86	Excellent sample-high in carideans, bivalves
57.	6813SK27	1134	Sk	2.99	4.39	Good sample-high carideans and polychelids
58.	6911SK2	942	Sk	2.39	3.17	Moderate sample
59.	6911SK4	1006	Sk	3.39	4.39	Moderate sample-high carideans
60.	6911SK7	1399	Sk	3.72	4.39	Good sample-high carideans
61.	6911D12	1463	2-M D	1.92	1.99	Small sample
62.	6911SK13	1463	Sk	3.30	4.25	Good sample-high carideans, <u>Munidopsis</u>, polychelids
63.	6913SK40	476	Sk	3.65	4.25	Moderate sample
64.	6913SK41	311	Sk	2.19	3.46	Small sample
65.	6913T42	183	20' O.T.	3.67	4.70	Excellent sample-high crabs, penaeids, echinoids
66.	6913SK43	210	Sk	2.81	3.70	Moderate sample
67.	6913T44	752	20' O.T.	3.84	5.43	Excellent sample-high carideans, holothurians, polychelids.

Table 6-15 (cont'd).

	STATION	DEPTH (m)	GEAR	H	H_{max}	COMMENTS
68.	717SK3	471	Sk	--	--	No sample
69.	717SK4	576	Sk	--	--	Small sample
70.	717SK7	874	Sk	2.25	2.32	Small sample
71.	717T9	906	20-M T	2.89	4.70	Moderate sample-high pagurids and holothuroids
72.	717T10	937	20-M T	3.68	4.95	Good sample-high in pagurids and fish
73.	717T11	636	20-M T	4.49	5.43	Excellent sample-high in carideans and echinoids
74.	717D16	939	Q.D.	--	--	No sample
75.	717D17	204	Q.D.	--	--	No sample
76.	717T18	229	20-M T	3.07	3.58	Moderate sample
77.	717SK20	229	Sk	--	--	Very small sample
78.	717SK23	210	Sk	--	--	Very small sample
79.	717D24	190	Q.D.	--	--	No sample
80.	717T29	250	20-M T	--	--	No sample
81.	717T30	206	20-M T	--	--	No sample
82.	717T31	240	20-M T	--	--	No sample
83.	717SK32	192	Sk	1.58	1.58	Very small sample
84.	717T33	192	20-M T	--	--	No sample
85.	717T34	192	20-M T	4.03	5.17	Good sample-high in crabs and fish
86.	717SK35	535	Sk	--	--	No sample
87.	717T38	534	20-M T	3.92	4.25	Good sample
88.	717D40	546	Q.D.	--	--	No sample
89.	717SK41	732	Sk	--	--	No sample
90.	717SK42	936	Sk	1.92	1.99	Small sample
91.	717T43	1427	20-M T	3.86	4.95	Good sample-high in carideans, pagurids, polychelids
92.	717SK47	878	Sk	--	--	No sample
93.	717D48	890	Q.D.	--	--	No sample
94.	717T49	937	20-M T	3.98	4.95	Excellent sample-high carideans, polychelids, fish
95.	717T56	538	20-M T	3.77	4.91	Good sample-high penaeids, nephropids, fish
96.	717T57	1247	20-M T	3.56	4.32	Good sample-high carideans, polychelids, galatheids
97.	717D58	1198	Q.D.	--	--	No sample
98.	717SK62	1198	Sk	--	--	No sample
99.	717SK65	237	Sk	3.55	3.70	Small sample
100.	718SK3	1196	Sk	--	--	No sample
101.	718SK4	1364	Sk	--	--	No sample
102.	718SK5	1448	Sk	--	--	No sample
103.	7213T7	1207	20-M T	--	--	No sample
104.	7213T32	1774	20-M T	2.64	3.17	Moderate sample
105.	7213T39	1061	20-M T	3.89	5.29	Excellent sample-high carideans, polychelids,fish

Table 6-15 (cont'd).

	STATION	DEPTH (m)	GEAR	H	H_{max}	COMMENTS
106.	7213T45	412	20-M T	2.35	3.70	Good sample-high carideans
107.	7213T49	589	20-M T	4.38	5.32	Excellent sample
108.	7213T51	1376	20-M T	2.69	4.52	Good sample-high carideans low fish
109.	7213T53	1161	20-M T	3.02	4.64	Good sample-high carideans, more fish
110.	7310T5	435	20-M O.T.	--	--	No sample
111.	7310T20	870	20-M O.T.	2.08	3.99	Good sample-high in carideans and crabs

Sk--Skimmer
D --Dredge
T --Trawl
Q.D.--Quant. Dredge
O.T.--Otter Trawl

in the sample by equal numbers of individuals. This situation is seldom achieved except, perhaps, when a small sample has only two species each of which has only a single individual.

From the Shannon-Wiener function, which is

$$H = -\sum_{i=1}^{S} (p_i)\ (\log_2 p_i)$$

Where H = index of species diversity

S = number of species in sample

p_i = proportion of total sample belonging to the i^{th} species,

one can calculate equitability. First, however, one must determine H_{max}, which is the maximal diversity obtainable where every species is presented by a single individual. Hence, $H_{max} = \log_2 S$ and the ratio H/H_{max} is defined as equitability.

The species diversity indices and H_{max} are shown in Table 6-15 (p. 223) for each of the 111 stations at which a sufficient sample was taken to make the calculation feasible. Where there is a substantial spread between H and H_{max}, comments have been added to help explain what accounted for the uneven distribution of individuals. The H_{max} values have been plotted on Fig. 6-57 alongside of starts of genera and species. The spread between H and H_{max} can be attributed to any one or more of several factors:

(1) Sampling gear is not appropriate for sampling the habitat.

(2) Sampling gear is not adequate for sampling most species equally effectively.

(3) One or more species tend to aggregate, congregate or travel in groups, whereas others occur singly or in small numbers at a given site.

The last point is the most interesting in the present study. It was noted upon studying those stations where the hiatus between H and H_{max} was large that a few species of a relatively small number of kinds of organisms accounted for the difference. Principal among these are:

1. Crustaceans, particularly
   (a) caridean and penaeid shrimps
   (b) brachyuran crabs, just a few species
   (c) only 1 species of polychelid lobster
   (d) only 2 species of galatheid crabs

2. Echinoderms
   (a) one or two species of asteroids
   (b) the same for echinoids, and

3. Fishes, particularly among the
   (a) Macrouridae and
   (b) Ophidiidae

Obviously, the species involved will vary with the depth of sampling, as the following examples will demonstrate:

Shallow water stations (200-400 m) will tend to have disproportionate numbers of

Parapenaeus longirostris	penaeid shrimp
Penaeopsis megalops	penaeid shrimp
Parapandalus willisi	caridean shrimp
Porcellana sigsbeiana	anomuran crabs
Munida longipes	anomuran crabs
Thalassoplax angusta	brachyurans
Lyreidus bairdii	brachyurans
Astropecten americanus	asteroid
Brissopsis alta	echinoid

Between depths of 500-1000 m, the principal species represented by many individuals will be

Plesionika holthuisi	caridean shrimp
Glyphocrangon alispina	caridean shrimp
Nematocarcinus rotundus	caridean shrimp
Bathyplax typhla	crab
Stereomastis s. sculpta	polychelid "lobsterette"
Cheiraster mirabilis	asteroid (starfish)
Phormosoma placenta	echinoid (sea urchin)
Mesothuria lactea	holothuroid (sea cucumber)
Bathygadus macrops	fish
Nezumia hildebrandi	fish
Hymenocephalus cavernosus	fish

Between depths of 1050 and 1450 m the principals will be

Benthesicymus bartletti	penaeid shrimp
Glyphocrangon aculeata	caridean shrimp (1100 m or so)

Glyphocrangon nobilis	caridean shrimp (1400 m or so)
Munidopsis sigsbei	galatheid crab
Stereomastis sculpta sculpta	polychelid "lobsterette"
Geryon quinquedens	brachyuran crab
Plesiodiadema antillarum	echinoid
Parapagurus pilosimanus	pagurid crab
Nezumia hildebrandi	fish
Dicrolene intronigra	fish
Monomitopus agassizii	fish

As can be seen by reference to the appropriate tables many of these species are dominants among their type.

Variations of Diversity Index with Depth

When the species diversity (H_{max}) of various stations on a given isobath are gathered together, they are found to be remarkably similar on the same isobath but they differ considerably among isobaths. If one averages all of the stations of a given isobath and plot these over the depth range of the study, the values rise and fall in a manner that resembles the peaks and valleys of the faunal zones on the upper continental slope (discussed in the preceding section). But more important is the fact that the species diversity indices at 500 m, 900 m, and 1050 m are rather high, equaling or exceeding those at shallower isobaths (see below, and Fig. 6-57).

ISOBATH (m)	H_{max}
200	4.24
250	3.88
300	3.46
350	3.58
400	3.83
500	5.04
550	4.60
600	4.42
700	4.38
750	4.59
800	4.23
850	3.01
900	4.50
950	4.47
1000	3.93
1050	4.94
1100	3.42

Isobath (m) (cont'd)	H_{max} (cont'd)
1150	4.52
1200	4.32
1400	4.47
1450	4.49
1500	3.90
1750	3.17
1850	3.81

Perhaps the principal value of species diversity indices in the context of the present study is to evaluate samples and to add another point of corroboration to the existence of faunal zones on the slope.

Dendrogram Showing Faunal Relationships

The diagram in Fig. 6-58 is based upon the data obtained from the 111 stations. Instead of pooling the results of sampling around each isobath, in constructing the dendrogram, station data have been used and then reflected on the isobath in order to make comparisons with the information on Shannon-Wiener functions and the divisions among faunal assemblages. The dendrogram seems to point to important faunal breaks between 200 and 250 m, between 500 and 550 m, and probably between 750 and 800 m.

This dendrogram is based upon the index of similarity I, which is calculated by using the value

$$\frac{2j}{2ab-(a+b)j}$$

where a and b are the respective number of species in two samples and j is the number of species common to both samples. Mountford (1962) derived the index, based on logarithmic-series distribution, and showed it to be less dependent on sample size than earlier ones. This method tends to classify stations into groups of similar stations on the basis of the fauna collected at each and makes use not only of the index of similarity between a pair of single stations, but also of an index of similarity between two groups of stations. The index between a station B and a group composed of A_1 and A_2 is defined as

$$I(A_1A_2;\ B) = \frac{I(A_1B) + I(A_2B)}{2}$$

where $I(A_1B)$ is the index of similarity between the pair of stations A_1 and B; and, in general, the index of similarity between a station B and a group composed of m stations is defined as

$$I(A_1,A_2\cdots A_m;\ B) = \frac{I(A_1B) + I(A_2B)\cdots+I(A_mB)}{m}$$

The index between a group composed of stations A_1 and A_2 and a second group composed of stations B_1 and B_2 is

$$I(A_1A_2;\ B_1B_2) = \frac{I(A_1B_1) + I(A_1B_2) + I(A_2B_1) + I(A_2B_2)}{4}$$

In general the index between groups A_1, A_2, $\cdots$ A_m and B_1, B_2, $\cdots$ B_m is defined as

$$\frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} I(A_iB_j)$$

Fig. 6 - 59 shows the indices of similarity for various stations near the designated isobaths. The highest index of similarity, between isobaths 300 m and 350 m, has been blocked off while the second highest between 600 m and 650 m, has been underscored. The following tabulation, in rank order, contains the indices of similarity between the various isobaths and/or groups of isobaths that provided the data for construction of the dendrogram (Fig. 6-58).

RANK	ISOBATHS	INDEX OF SIMILARITY
1	300 350	.1013
2	600 650	.0966

RANK	ISOBATHS	INDEX OF SIMILARITY
3	800 850	.0783
4	700 750	.0757
5	800-850 900	.0634
6	400 450	.0617
7	250 300-350	.0559
8	950 1000	.0494
9	550 600-650	.0394
10	400-450 500	.0381
11	550-600-650 700-750	.0312
12	800-850-900 950-1000	.0278
13	250-300-350 400-450-500	.0236
14	100 150	.0201

RANK	ISOBATHS	INDEX OF SIMILARITY
15	800/1000 1050	.0188
16	100/150 200	.0137
17	550/750 800/1050	.0120
18	250/500 550-1050	.0064
19	100-150-200 250/1050	.0030

The distribution of similarity index values appears to support the conclusion that there are four major faunal assemblages on the upper continental slope of the northern Gulf of Mexico between depths of 118 to 1000 m (see Fig. 6-58). Three of these are considered to be "true" slope assemblages, which is to say that not only are their depth limits confined to the slope but also most if not all of their constituent species occur only on the shelf. These findings are generally borne out by examination of the occurrences of the numerically dominant species, as discussed in a previous section of this report (Species Composition of the Faunal Assemblages). Some slight discrepancies in depth limits of the assemblage between that section and the dendrogram are considered to be insignificant, since depths were rounded to the nearest whole 50-meter increment. It seems likely from examination of the dendrogram that at least one additional true slope assemblage occurs at depths below 1050 m.

KEY SPECIES

Physical Characteristics of Key Species

This section is devoted to presenting a large number of measurements of

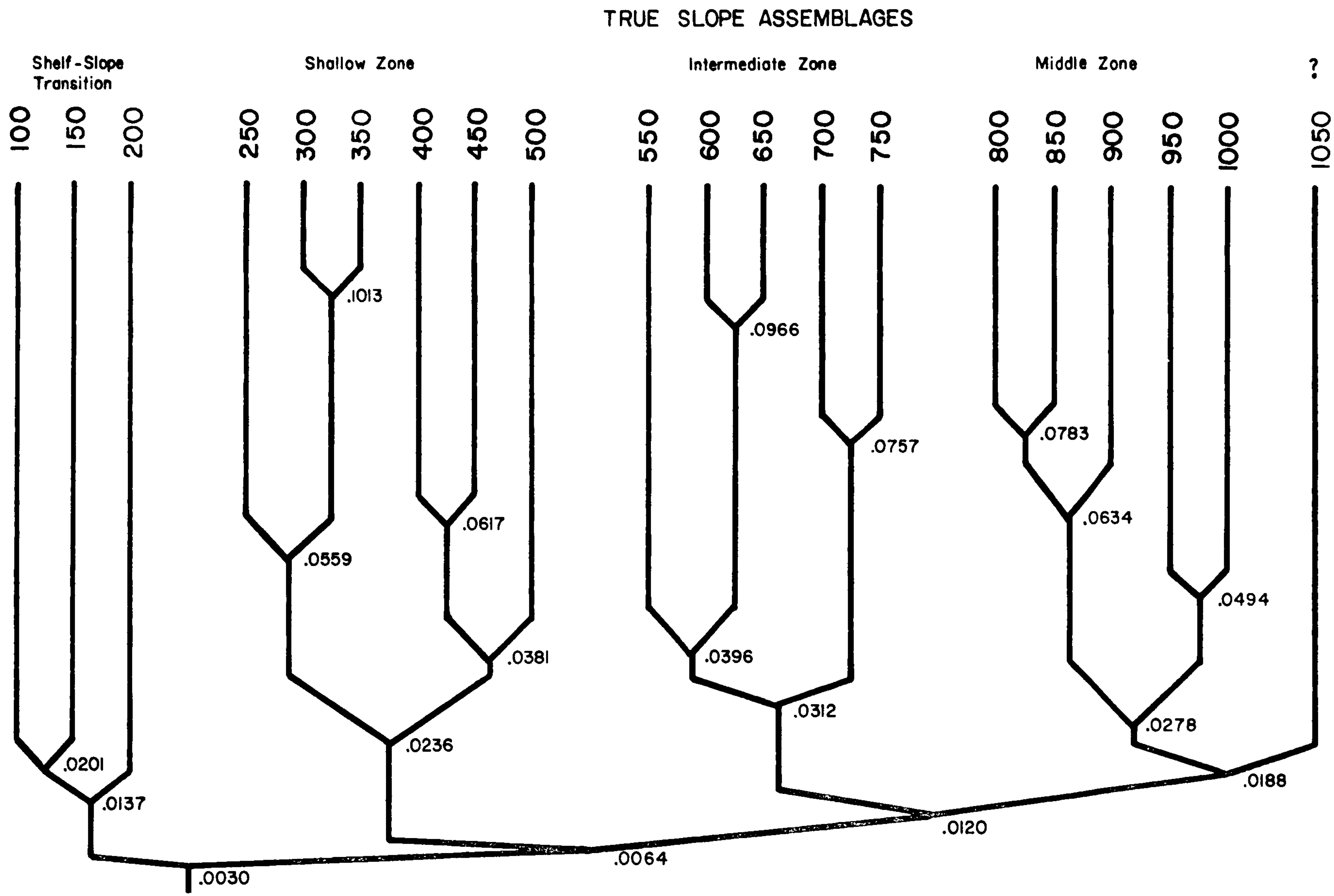

Fig. 6-58. Faunal similarity dendogram. Compiled from data on similarity of species collected from stations near the designated isobaths. (Upper numbers represent depth in meters while those numbers within the diagram are indices of similarity.)

	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050
100		.0165	.0108	.0075	.0064	.0046	.0028	.0027	.0019	.0016	.0011	.0010	.0009	.0008	.0005	.0005	.0005	.0004	.0003	.0003
150			.0201	.0129	.0096	.0074	.0046	.0035	.0025	.0021	.0014	.0013	.0011	.0009	.0008	.0007	.0007	.0005	.0004	.0004
200				.0181	.0186	.0092	.0053	.0041	.0029	.0022	.0016	.0016	.0012	.0010	.0007	.0006	.0005	.0004	.0003	.0003
250					.0719	.0398	.0191	.0142	.0090	.0064	.0047	.0039	.0027	.0023	.0013	.0011	.0010	.0008	.0006	.0006
300						.1013	.0352	.0231	.0139	.0093	.0069	.0057	.0041	.0035	.0024	.0019	.0018	.0013	.0011	.0011
350							.0488	.0310	.0179	.0111	.0080	.0068	.0049	.0043	.0032	.0025	.0024	.0018	.0016	.0016
400								.0617	.0266	.0144	.0105	.0090	.0066	.0055	.0041	.0034	.0033	.0026	.0023	.0021
450									.0495	.0227	.0152	.0130	.0094	.0079	.0058	.0049	.0048	.0039	.0032	.0028
500										.0454	.0272	.0227	.0153	.0121	.0072	.0061	.0060	.0043	.0032	.0029
550											.0437	.0355	.0210	.0151	.0079	.0074	.0067	.0047	.0036	.0033
600												.0966	.0377	.0224	.0127	.0104	.0093	.0061	.0046	.0045
650													.0630	.0319	.0168	.0137	.0122	.0078	.0057	.0049
700														.0757	.0295	.0228	.0191	.0114	.0079	.0068
750															.0378	.0289	.0226	.0131	.0092	.0080
800																.0783	.0510	.0238	.0155	.0127
850																	.0758	.0313	.0192	.0155
900																		.0514	.0254	.0201
950																			.0494	.0340
1000																				.0118
1050																				

Fig. 6-59. Indices of similarity between stations near the designated isobaths. (Numbers along ordinate and abscissa represent depth in meters for isobaths.)

those species that have been designated as key species primarily on the basis of frequency of appearance in samples and numbers taken per trawl. Others are shown for comparison.

Fishes

		Length (mm)			Width (mm)			Volume (ml)
		Max.	Min.	Ave.	Max.	Min.	Ave.	Ave.
1.	Dicrolene intronigra	337	144	200	25	7	13	24
2.	Gadomus longifilis	245	99	157	16	7	10	16
3.	Poecilopsetta beanii	139	121	125	7	6	6.3	36
4.	Bathygadus vaillanti	421	234	382	37	15	28	53
5.	Nezumia hildebrandi	281	135	205	28	7	15	27
6.	Dibranchus atlanticus	198	35	100	69	12	40	14
7.	Hymenocephalus cavernosus	147	73	124	13	7	11	15
8.	Stephanoberyx monae	118	53	91	14	5	11	19
9.	Bembrops gobioides	233	145	203	23	13	19	19
10.	Pontinus longispinus	193	83	153	32	11	23	37
11.	Aldrovandia gracilis	509	402	418	14	8	11	15
12.	Cariburus mexicanus	498	163	293	50	18	26	47
13.	Coelorhynchus carminatus	298	206	267	29	17	24	38
14.	Aldrovandia affinis	499	264	349	20	9	14	17
15.	Bathygadus macrops	407	126	261	34	8	20	32
16.	Ancylopsetta dilecta	-	-	138	-	-	7	52
17.	Monomitopus agassizi	189	127	165	14	8	12	24

Rayburn (1975) found that on the average each milliliter of fish volume was equal to 1 gram of ash-free dry weight (correlation = 0.95).

On this basis, the following distribution of demersal fish biomass was found on the upper continental slope:

Depth	Fish Biomass (mg ash-free organics/m^2)
192	16.15
538	12.12
636	5.68
920	1.15
1000	2.15

Invertebrates

Isopods	Overall Length			Width		
	Max.	Min.	Ave.	Max.	Min.	Ave.
1. Bathynomus giganteus	330	46	150	152	19	65

	Max.	Min.	Ave.
Penaeid shrimps	Carapace length (mm)		
1. Hymenopenaeus robustus	88	11	56
2. Penaeopsis megalops	52	15	33
3. Plesiopenaeus armatus	81	15	44
4. Benthesicymus bartletti	30	10	19
5. Parapenaeus longirostris	47	7	19
6. Hymenopenaeus debilis	21	10	15
Caridean shrimps			
1. Nematocarcinus rotundus	27	9	17
2. Glyphocrangon nobilis	20	5	14
3. Nematocarcinus ensifer	26	4	17
4. Systellaspis affinis	17	10	14
5. Glyphocrangon alispina	20	5	14
6. Pasiphaea merriami	36	10	22
7. Parapandalus willisi	15	8	10
8. Glyphocrangon aculeata	30	5	15
9. Plesionika holthuisi	18	6	11
10. Heterocarpus ensifer	10	9	9
11. Glyphocrangon longleyi	33	11	21
12. Plesionika tenuipes	13	8	10
13. Acanthephyra micropthalma	20	11	16
Galatheid crabs			
1. Munidopsis sigsbei	24	3	14
2. Munida longipes	20	4	13
3. Munida valida	39	9	21
4. Munidopsis simplex	12	6	9
5. Munida forceps	27	6	19
6. Munidopsis longimanus	12	6	9
7. Munidopsis nitida	22	9	16
8. Munidopsis alaminos	13	7	10
Polychelid lobsters			
1. Stereomastis sculpta	63	17	36
2. Polycheles typhlops	45	20	34
3. Polycheles validus	80	17	49
4. Polycheles crucifer	39	13	26
Nephropid lobsters			
1. Nephropsis aculeata	47	12	38
2. Nephropsis agassizii	37	14	25
3. Nephropsis rosea	53	12	30
4. Acanthacaris caeca	58	41	47
Brachyuran crabs	Carapace width (mm)		
1. Lyreidus bairdii	21	5	12
2. Bathyplax typhla	32	6	17
3. Geryon quinquendens	145	5	72
4. Acanthocarpus alexandri	43	6	24
5. Portunus spinicarpus	42	27	34
6. Ethusina abyssicola	14	5	10

Asteroids	Max.	Min.	Ave.
	Major radius (mm)		
1. *Nymphaster arenatus*	90	18	60
2. *Plutonaster intermedius*	111	11	51
3. *Dytaster insignis*	86	8	47
4. *Astropecten americanus*	82	20	56
5. *Ampheraster alaminos*	62	42	50
6. *Litonotaster intermedius*	25	16	19
7. *Doraster constellatus*	239	80	149
8. *Astropecten nitidus*	40	15	30
9. *Goniopecten demonstrans*	138	8	94
10. *Persephonaster echinulatus*	55	7	33

Echinoids (also showing change in size with depth)

1. *Phormosoma placenta*	Horizontal diameter (mm)		
360-730 m	103	13	62
730-1100	89	13	62
1100-1470	68	7	28
1470-1840	70	22	40
1840-2210	78	18	67
2210-2580	74	53	67
2. *Brissopsis alta*			
170-180 m	64	20	30
190-210	48	31	43
230-240	62	43	54
270-285	61	34	43

Holothuroids	Lengths (mm)		
1. *Molpadia musculus*	46	18	33
2. *Molpadia blakei*	38	25	31
3. *Molpadia barbouri*	67	21	43
4. *Mesothuria lactea*	370	30	250
5. *Echinocucumis hispida*	24	5	18
6. *Deima blakei*	110	17	66
7. *Benthodytes lingua*	356	150	240

Food Habits of Selected Key Species

Fishes

Demersal fishes of deep water feed primarily upon components of the epifauna or infauna, including some meiofaunal types, and/or pelagic forms swimming close to the bottom. The latter includes fishes as well as various invertebrates, particularly crustaceans and squids. This observation agrees with Bright's (1968) conclusion that deep-sea bottom fish display three modes of feeding: (1) predation upon small, truly benthonic organisms, ordinarily accompanied by ingestion of significant amounts of sediment; (2) predation upon small benthopelagic or planktonic organisms; and (3) active predation upon large macrobenthonic, planktonic, or nektonic organisms. Marshall (1966), however, concludes that the species of fish living near the deep-sea floor feed largely on invertebrates. This is very much in agreement with findings of this study and those of Rayburn (1975). Rayburn examined the stomach contents of 378 individuals of seven species that are important members of the slope fauna. These findings are summarized in Table 6-16.

Some of the principal features in this table are that the first four are apparently very dependent upon polychaete annelids and gammaridean crustaceans. Nezumia hildebrandi and Halosaurus guntheri, though in separate families, have very similar patterns of food preferences. These two species have overlapping vertical distributions (see Table 6-10), but Nezumia generally predominates. The food preferences of these two species contrast sharply with that of the benthopelagic macrourid Bathygadus vaillanti which displays a low incidence of polychaetes, but a high level of calanoid copepods and substantial indications of predation on other fishes. The only other species having fish remains in the stomach was Cariburus zaniophorus, but in most other ways the feeding habits of Bathygadus and Cariburus (in the same family - Macrouridae) are different. Dibranchus atlanticus, one of the batfishes, is the only one that had high levels of bivalves in its food list. This, however, points up another fact about food preferences, viz., that they may change markedly with depth. For instance, Rayburn (1975) found that at shallow depths in its vertical range (150-1250 M) 80% of the Dibranchus atlanticus ate bivalves and less than 10% had polychaetes, whereas at intermediate depths this ratio was completely reversed and gammarid amphipods increased along with the polychaetes.

The above tends to support the contention that within reasonable limits, these deep-sea fishes are opportunistic feeders. In any given area, however, they are nonetheless selective feeders. Another general fact seems to emerge from the information in Table 6-16, to the effect that these fishes are very dependent in one way or another upon organisms that live in the sediments. The fact that cumaceans are so generally eaten, particularly by such macrourids as Cariburus zaniophorus and the ophidiid Bassozetus normalis may well indicate that they swarm out of the sediments into the water column much as they do in shallow water. It is probably in the layer of water next to the bottom that such fishes as Bathygadus vaillanti (a macrourid) and Monomitopus agassizii (an ophidiid) feed upon calanoid copepods.

Other slope fishes have varied feeding preferences (see Bright, 1968); e.g., the flathead (Percophididae), Peristedion greyae, feeds upon calanoid copepods in large number, as does Dibranchus atlanticus and the brotula (Ophidiidae) Diplacanthopoma brachysoma. The flatheads Bembrops gobioides and B. anatirostris are distinctly carnivorous, feeding upon such carideans as Glyphocrangon; the same is true also of Chaunax pictus. The synaphobranchid eels apparently feed upon polychelids from time to time, a fact that indicates that these crustaceans do move about in the water column. A large number of types of fishes feed upon deep-sea benthic squids. The more important of these not shown in Table 6-16 are the sharks (Squalidae) Etmopterus spinax and E. pusillus. The chimaerid Hydrolagus mirabilis appears to prefer bivalves, cumaceans, and gammarids.

Invertebrates

The most significant invertebrate species of the slope assemblages on which some data on feeding habits are found among the Crustacea (particularly isopods, carideans, and brachyurans), and also the Echinodermata (Asteroidea, Echinoidea, and Holothuroidea). The most fascinating of these may well be the giant isopod Bathynomus giganteus which is an active predator of fishes. Some of the carideans have been found to have bivalves in

Table 6-16. Principal food organisms of selected continental slope fishes. Numbers equal percent of total fish examined with item in stomach. Principal or unusual percentages underlined. Fish species are in order _N. hildebrandi_, _C. zaniophorus_, _H. guntheri_, _D. intronigra_, _D. atlanticus_, _B. vaillanti_, and _M. agassizii_.

	FISH SPECIES						
Food Organism	Nezumia	Cariburus	Halosaurus	Dicrolene	Dibranchus	Bathygadus	Monomitopus
Polychaeta	_90_	_90_	_90_	_80_	20	15	15
Gammaridea	_60_	_85_	_60_	_65_	25	30	_50_
Tanaidacea	_40_	35	20	20	10	10	35
Ostracoda	35	10	15	_45_	20	20	_65_
Cumacea	30	_60_	30	20	0	10	20
Cyclopoida	30	10	15	20	5	5	10
Forams	30	25	35	_40_	15	5	10
Calanoida	25	0	35	25	25	_40_	_45_
Unidentified crustacea	25	15	25	15	_45_	25	40
Bivalvia	20	0	25	5	_45_	0	0
Isopoda	18	_45_	20	30	5	10	15
Harpacticoida	15	0	5	5	5	0	5
Fish	0	_8_	0	0	0	_15_	0
Caridea	5	0	5	10	0	5	0
Stomatopods	0	10	0	5	0	0	0
Squids	5	0	5	5	0	10	5
Brachyura	0	0	0	0	15	0	0
Gastropods	0	0	0	0	15	0	0

their stomachs. For instance, we found a Glyphocrangon nobilis taken at Station 687SK13A (1061 m) to have two bivalves of the species Yoldiella quadrangularis in its stomach. Many of the starfish are known to be predators upon bivalves, gastropods, sponges, and even forams and radiolarians.

By way of specific examples of asteroid feeding, the following species have been found to have these foods in the stomach:

1.	Dytaster insignis	bivalves (Neilonella guineensis)
2.	Dytaster insignis	sponge and forams
3.	Dytaster insignis	sargassum
4.	Astropecten nitidus	gastropods and bivalves
5.	Astropecten americanus	gastropods
6.	Nymphaster arenatus	sponge and forams
7.	Anthenoides piercei	small sponges
8.	Tethyaster grandis	echinoids (Brissopsis)
9.	Goniopecten demonstrans	gastropods, forams, radiolarians

The large holothurians and echinoids that have been investigated have had sediment-living organisms in their intestines.

Food Chains Involving Some Key Species

Sufficient data are not available to construct very meaningful food webs that will apply to the faunal assemblages of the continental slope. In this regard about the best one can do is to speculate from the few food chains that became apparent. Links in some of the more interesting of these have been given in the preceding section on food preferences. Here an attempt to extend them through other trophic levels shall be made. Some of them are quite surprising as, for example, the following:

A. Small Crustacea - Polycheles - Synaphobranchus - Bathynomus

(?)1. Small crustacea and other sediment inhabitants eaten by Polycheles

2. Polycheles eaten by Synaphobranchus oregoni (eel)

3. Synaphobranchus eaten by Bathynomus giganteus (isopod)

4. Bathynomus eaten by larger fish or perhaps it is the top carnivore.

B. Sediment materials - Brissopsis - Tethyaster

1. Sediment materials eaten by the sea-urchin *Brissopsis*
2. *Brissopsis* eaten by starfish *Tethyaster grandis*
3. *Tethyaster* eaten by ? or is it the terminal organism?

C. Detrital Materials - Bivalve - Caridean - Fish

1. *Tindaria amabilis* (bivalve) picks up detritus
2. *Tindaria* is eaten by *Glyphocrangon nobilis*
3. *Glyphocrangon* is eaten by a fish, possibly *Dibranchus*

A short-circuit of this is *Dibranchus* eating the bivalve directly.

D. Small Fish - Crab - Fish

1. Young *Benthochascon schmitti* (crab) eat small fish
2. *Benthochascon* (young) are eaten by *Dibranchus*

E. Plant Material - Echinoids - Fish

A variation on this chain is Plant Material - Asteroid - ?
The principal echinoid here is *Phormosoma placenta*; the principal asteroid is *Dytaster insignis*.

RELATIONSHIP OF FAUNAL ASSEMBLAGES TO ENVIRONMENTAL FACTORS

It is possible only to suggest what accounts for some of the assemblages or zonal boundaries that have been designated previously. Perhaps first consideration should be given to the physiography and topography of the bottom.

The fact that the continental shelf is broad and is the recipient of substantial river flows undoubtedly has a direct bearing upon the great diversity and productivity of the shelf fauna in the northern Gulf. Perhaps, the keen competition for space creates population pressures that force organisms to continually move outward. The path of least resistance in this regard is most likely seaward over the shelf edge and down the continental slope. The fact that many, many species of benthic organisms do just that and terminate at depths around 200 m seems to suggest that the shelf break as such is not an important barrier to distribution. Parenthetically, though, mention should be made of the fact that one may not be fully aware of the effects that the "hummocky zone" on the shelf-slope contact has on local faunal distribution simply because very little sampling has been done in an area with such irregular bottoms that dredges and trawls may be severely damaged. All indications point to the fact that physiography does not exert important controls on faunal distribution within the depth limits of this study (the escarpments on the lower slope very likely do). It is rather that other parameters that do exert strong influences on the fauna change either slowly or abruptly across the shelf and down the slope.

Among the more important of these factors are (1) temperature, (2) currents, (3) dissolved oxygen, (4) distribution of organic materials (foods), (5) the nature of sediments, and (6) biotic influences.

Certainly temperature, especially the extent of the low end of the range, must be the overriding factor controlling the distribution of the shelf groups. Near the 70 m isobath on the Texas shelf, which is near the boundary between the Inner and Outer Shelf Assemblages (and zones) of the Shelf Province, the average summer and winter temperatures of bottom water are about the same (19-20^{o}C, see Figs. 5-9 and 5-10). Near the limit of the Outer Shelf Assemblage around 110-120 m, there are some seasonal effects on the temperature of the bottom water, but this is about the deep point for any important seasonal flux. Finally, at some point between 200 and 250 m depth, where the Shelf Province terminates, the bottom waters are always colder than the coldest temperatures of inshore bottom waters, i.e., of those which are available. Keeping in mind that most of the shelf species are warm-water species and that most species on the slope are colder-water species, then this would be as important a break as the data indicate. As noted above, it is here that a line has been drawn separating the Shelf Province, as represented by the Shelf-Slope Transition Assemblage, and the beginning of the True Slope Assemblages.

Temperature cannot explain satisfactorily those faunal changes that are observed on down the slope. Here temperature ranges of 1 to 2°C seasonally seem hardly sufficient to effect any biotic shifts. Admittedly, the lines of demarcation between assemblages may not be as sharp as those where temperature is involved, but they are nonetheless there and the faunal assemblages are composed of sizeable numbers of species. Rather than temperature it is felt that currents and the distribution of low oxygen levels are important controlling factors (see Figs. 5-21 and 5-23).

The oxygen minimum layer extends from an average upper depth of 200 m down to around an average (east-west) of 700 m. This range spans two of the True Slope Faunal Assemblages described previously. Be advised, also, that the above depths are those at which the OML impinges upon the bottom. Upon adding to this the observation that substantial bottom currents exist on the slope and that they reverse direction at a point near the 450 m isobath, one has a possible explanation for faunal shifts near this isobath. Currents can account for some faunal shifts on at least two bases: (1) that their contents (particulate organic matter, pelagic larvae, salinity, dissolved oxygen) may be different, and (2) their speed and thus physical effects on some organisms may be very different. The former basis is of obvious importance; the latter can cause a sorting of current-loving and quiet water species.

It is easy to see that salinity will vary sufficiently as to have very important effects on inner shelf organisms, but it is doubtful that changes are sufficient on the slope to account for faunal shifts among the benthos.

Changes in the sediments are undoubtedly significant in the present context. On a seaward line, sediments may start coarse only to shift gradually to sands or mixtures of sand, silt, and clay, and then change abruptly on the slope to a predominance of often sticky clay. Unfortunately, it is not feasible to correlate the distribution of macroepibenthos with sediment type when the source of sediment knowledge is derived from point-source cores and faunal data from large-area trawlings. Much more definitive sediment-animal correlations can be derived from meiofaunal studies, especially when sections of the sediment cores are analyzed individually and not mixed. Such work is beyond the scope of the present study.

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Other factors that undoubtedly contribute to the nature of the assemblages and account in part for their vertical distributional limits are (1) hydrostatic pressure and (2) biotic interactions. Scientists are just now beginning to seriously study the effects of pressure on enzyme systems in benthic organisms. At one time this appeared to be a closed subject, the conclusion being that pressure was not particularly important. But logic demands that it can have important effects on distribution due to the fact that some metabolic enzymes can be rendered inoperative at only a few atmospheres. In this study, though relatively shallow, one may expect pressures up to 100 atmospheres. In many ways, particularly within the present depth limits, the biotic factor may be very important in shaping assemblages and must certainly create the internal workings and interdependencies that make of these groups, at least in some cases, true communities. The biotic factor may be positive as, for example, in the instance where one species follows another that is its principal food. On the other hand the biotic factor may be a negative influence as exemplified by one species encountering another that has similar habits and is highly competitive so that it predominates.

PART III. ECOLOGICAL SYNTHESIS

7. THE SLOPE ENVIRONMENT

PHYSICO-CHEMICAL CHARACTERISTICS

The continental slope and its superjacent water column do not constitute a closed and confined ecosystem. Lying between the continental shelf, on the one hand, and the open Gulf with its abyssal plain, on the other, the slope system is in many ways a transitional environment broadly influenced by processes occurring to either side. Very likely this concept of a transition applies more to the pelagic than to the benthic environments on and over the slope.

HORIZONTAL GRADIENTS IN THE SURFACE WATER

Hydrographically, the surface water of the slope may be derived from either the neritic or the oceanic areas. The resident surface water generally constitutes a mixture of shelf and Gulf water, but at any moment one or the other water mass may predominate. As noted in an earlier section, the temperature of the shelf water closely parallels the daily and seasonal temperature regimes of the air. This is less obviously the case for offshore Gulf waters where daily variation and seasonal extremes are dampened. Under the influence of river discharge, shelf water displays salinity patterns which are generally lower and more variable than those of the offshore waters. With respect to both temperature and salinity the slope waters stand intermediate between the patterns observed on the shelf and the open Gulf. This is not the case with dissolved oxygen, however. Since dissolved oxygen is derived through diffusion from the atmosphere and photosynthetic activity of phytoplankton, the dissolved oxygen of the surface waters is, in all cases, near saturation.

VERTICAL GRADIENTS IN THE WATER COLUMN

The surface water of the slope system is strongly influenced by shelf waters, whereas with increasing depth, the open Gulf water is the factor of primary influence. Seasonal temperature variation is suppressed with depth, and it has been noted that the depth of the 18°C isotherm is relatively constant (125-150 m). Below this depth seasonal temperature changes are little felt. Whereas the surface water temperature seasonally varies 8-9°C, the variation of 150 m is only 3.0°C and at 750 m only 1.0°C. As in the case of temperature, seasonal variation in salinity also decreases with depth.

Vertical gradients in temperature, salinity, and oxygen have been pointed out in a previous section. For temperature the gradient extends from values around 30°C at the surface to about 4°C at 1000 m; for salinity it extends from about 36 ppt. at the surface to 34.9 ppt. near the bottom; and for oxygen it extends from 5.0 ml/l to about 2.5 ml/l in the oxygen minimum layer, increasing to around 5.0 ml/l below the OML. Since several layered water masses are traversed in the vertical profile, the gradients undoubtedly display discontinuities at the layer interfaces. It has been noted that the OML is thicker (extending from 150-750 m) in the northeastern Gulf than in the northwestern Gulf (where it extends from 250-650 m).

Another major vertical gradient relates to the quantity of light penetrating to various depths in slope water. The few photometer studies which have been carried out in the area suggest that 50-60 m is the depth to which one percent of the incident solar radiation penetrates. Since available light energy controls the ability of phytoplankton to carry on photosynthesis, this depth may be taken as the lower boundary of the euphotic zone. Thus, the entire slope is in the perpetual darkness of the aphotic zone.

BOTTOM TOPOGRAPHY AND SURFACE SEDIMENTOLOGY

Topographically the upper continental slope of the northern Gulf of Mexico is naturally divided into two provinces. The western province, extending from the Rio Grande to a position slightly west of the Mississippi River delta, is referred to as the Texas-Louisiana diapiric complex. Although there is a gentle slope seaward, this province is marked by a very rough terrain including many hummocks, knobs, ridges, and valleys. This rough terrain extends through the eastern province, but here the irregularities are generally subsurface, having been buried by Mississippi River sediments which extend rather smoothly from the shelf to the deep Gulf. The eastern province is called the Mississippi Fan (or Mississippi Cone). The two provinces are separated by a prominent valley, the Mississippi Trough, and the eastern province is bounded on the east by the De Soto Canyon.

Surface sediments of the Texas-Louisiana diapiric complex consist largely of fine-grained particles, primarily clay with varying amounts of silt. This area is subject to little active sedimentation at the present time. Some coarser-grained particles of biogenic (probably coral) origin are encountered locally. The Mississippi Fan is undergoing active sedimentation at the present time, as silts and clays from the Mississippi River are being laid down in the area.

On a more local level, sediments around a given knoll (or hard bank) undoubtedly include materials which have been transported downhill from the knoll in a sorted and graded series. This phenomenon has been observed in detail in connection with the Flower Garden banks at the outer edge of the Texas shelf. In areas where sediment is actively accumulating from Mississippi River deposition, the bottom becomes structurally unstable and "slumping" may take place. Through this process gravity-generated currents of fine sedimentary materials proceed downslope and often out into the deep basin.

BOTTOM HABITAT DIFFERENTIATION

From the limited information available some things may be said about habitat differentiation on the bottom and in the near-bottom waters. For reasons not entirely clear depth, per se (or some combination of depth-related factors), tends to control the distribution of slope organisms around the world. This is complicated by the fact that vertically-layered water masses intersect the slope at various depths creating slight changes in the physics and chemistry of the bottom itself and the near-bottom waters. For example, on the northern slope of the Gulf of Mexico the coincidence of the oxygen minimum layer with the bottom marks a zone of organic-rich (=relatively unoxidized) sediments. Habitat differentiation may also be brought about by topographaphic irregularities and sediment composition (particle size, organic content, etc.). The physical devastation which accompanies slumping will locally denude or bury certain areas, and less vigorous water currents may exert local effects. Finally, it may be noted that some areas of the bottom may receive more food than others. Since photosynthesis is precluded in this lightless area, all the basic food materials must be imported from above. Thus, local increases in photosynthetic production of surface waters (as, for example, near the mouth of the Mississippi River) may be expected to be reflected in the increased production of benthic environments where the rich phytoplankton eventually settles. This is not to suggest that high benthic production will be expected directly below areas of high phytoplankton production, because of the slow rate of sinking of phytoplankton cells and because of the strong possibility of horizontal transport by water currents between the surface and the bottom.

SEASONALITY IN THE SLOPE ENVIRONMENT

Seasonal changes in temperature and light, so prominent in surface waters, are dampened with depth. Nevertheless, their effects may be felt in the slope environment. Wind-induced currents of the upper layers may be expected to induce some seasonal modifications in the strengths and directions of water currents in the deeper layers. Seasonal changes in production of organic matter in the surface waters should be reflected in seasonal variation in the benthic deposition of organic matter. Direct evidence of seasonality in the slope environment is lacking because no pertinent investigations have been carried out. However, it may be assumed that on the slope some slight seasonal changes do occur; that these changes are dampened with depth; and that in an otherwise relatively constant environment, these slight changes may be picked up by benthic organisms as coordinating cues for feeding, breeding, and other activities.

BIOLOGICAL DISTRIBUTION PATTERNS

DISTRIBUTION OF PLANKTON IN SURFACE WATERS

Data on plankton distribution in the northern Gulf of Mexico are quite meager, but a few patterns may be noted. The predominant feature is the change in species composition and abundance as one proceeds from the shelf to the offshore waters. Change in species composition has been noted for diatoms and dinoflagellates among the phytoplankters, and for copepods and chaetognaths among the zooplankters. In only a few cases has the surface slope water been clearly identified with specific plankton organisms. However, it has been noted that copepod species of the northern Gulf are distributed in bands parallel to the shore. Thus, the neritic shelf (20-200 m) is characterized by *Eucalanus pileatus* and *Paracalanus parvus*, whereas the waters over the slope proper are characterized by *Clausocalanus furcatus* and *Undinula vulgaris*. Detailed investigation of species distribution would undoubtedly reveal similar patterns within other planktonic groups.

Plankton abundance in surface waters of the northern Gulf clearly displays an onshore-offshore gradient from the dense populations of the shelf to the sparse populations of the open Gulf. Shelf populations of phytoplankton organisms tend to run around 0.2 - 9.0 x 10^6 cells/l, and open Gulf populations average about 1.0 x 10^2 cells/l. Those of the slope run around 1.3 - 12.0 x 10^2 cells/l, which is only slightly greater than the open Gulf values. Seasonal variation in phytoplankton abundance is quite high on the shelf but scarcely noticeable in open Gulf waters.

Zooplankton abundance shows similar patterns. The standing crop in shelf waters averages around 0.1 ml/m^3; that of the slope averages about 56 percent of that of the shelf; and that of the open Gulf averages about 90 percent of that of the slope. The shelf plankton is dominated by meroplankters (i.e., organisms which spend only portions of their lives in the plankton); whereas the open Gulf plankton is dominated by holoplankters (which spend their entire lives in the plankton). As in other cases, the slope zooplankton is intermediate in composition.

The general conclusions which may be reached are as follows: 1) the shelf phyto-and zooplankton are more abundant, more productive and seasonally more variable than the open Gulf plankton; 2) in these respects the slope plankton is intermediate, but closer to the condition of the open Gulf; and 3) each of the three regions is characterized by some species which are more or less specific to the particular zones. Thus, the gradients in habitat conditions, discussed earlier, are reflected in the composition and abundance of the planktonic life. Some east-west differences have been noted, especially among the diatom species, and these have been interpreted as representing the differences between normal Gulf waters and those influenced by Mississippi River water.

DISTRIBUTION OF NEKTONIC SPECIES OF THE APHOTIC ZONE OF THE SLOPE

The nektonic species of the Gulf of Mexico are poorly known, and very little may be said about the geographic distribution and abundance of most of the species which have been recorded from the Gulf. However, it is likely that most of the nektonic species of the aphotic zone may be found in the waters above the slope at the appropriate depth levels. The total number of species known to be present in the northern Gulf nektonic fauna includes 41 species of cephalopods, 6 species of penaeid shrimp, 22 species of caridean shrimp, 10 species of mysid shrimp, and 56 species of fishes. These lists are clearly incomplete. On the basis of frequency in collections, the following species are presumed to be rather common in waters over the slope: about a dozen cephalods, 2 penaeid shrimp, 3 caridean shrimp, 4 mysid shrimp, and an indeterminate number of fishes. Approximate depth distribution of many species has been given, and vertical migration patterns of a few species have been noted.

DISTRIBUTION OF BENTHIC ANIMALS OF THE SLOPE

Whereas, the planktonic biota of the surface waters may be viewed primarily as transitional between that of the shelf and that of the deep Gulf, such is not the case with the benthic fauna. Most of the benthic inhabitants of the slope are not found elsewhere, and together they constitute a complex and abundant true slope fauna. Some of the outer shelf species do spill over onto the upper slope, but most of these have disappeared by a depth of 200-250 m. Beyond that depth the fauna is truly slope in character.

The obvious features of the benthic fauna of the slope are the depth-related limitations of individual species and of the faunal breaks in the species assemblages. Faunal breaks have been noted at the following depth ranges:

175-225 m - major break
350-450 m - minor break
500-550 m - major break
750-800 m - major break
1000-1050 m - ?

On this basis it seems clear that about five more or less distinct depth-related faunal assemblages characterize the benthic slope fauna of the northern Gulf within the depth range of the present study. It is likely that additional assemblages characterize the fauna of the deeper slope beyond the depth range of this study. The observed faunal breaks clearly reflect, in part, discontinuities in physical and chemical factors of the benthic environment. These include known current patterns and the upper and lower limits of the oxygen minimum layer. However, not all the faunal breaks can be accounted for on the basis of physical and chemical factors, and it is not unlikely that biological factors are also involved.

THE SLOPE ECOSYSTEM - BASIC ECOLOGICAL CONCEPTS

EXCHANGE PROCESSES

As demonstrated above, the surface waters of the continental slope are in continuity with those of the shelf and the open Gulf. The upper slope waters, thus, constitute a zone of mixing and reflect physical and chemical properties intermediate between those of the shelf and the open Gulf. Tidal and wind-generated currents undoubtedly induce complete flushing over short time spans.

Deeper water layers of the slope area are in continuity with those of the open Gulf. Although the residence time of water in the deep slope area must be considerably longer than at the surface, flushing undoubtedly takes place here, as well. In the absence of external barriers, the slope ecosystem must be considered an open system, i.e., one in which exchange with the outside is perhaps as important as the internal dynamics of the system itself.

RESIDENCE VS. TRANSIENCE OF SPECIES

Planktonic organisms are carried passively by water currents. Hence, they are swept into and out of the area with the water masses. However, since planktonic species typically exhibit rapid reproductive response to favorable environmental conditions, a few planktonic species which find the slope environment especially favorable are able to maintain resident populations here, even though many individuals get swept away by the currents.

Nektonic species are free-swimming and are capable of maintaining themselves in an area, despite the water currents, or of migrating to favorable areas. It seems likely that a number of nektonic species inhabit the slope waters as year-around residents, but little direct information on this point exists. However, a great deal of information points to the fact that many of the predatory species are seasonal transients in the area, appearing primarily during the warmer months of the year. These include the billfishes, tunas, dolphin, wahoo, jackfishes, mackerels, and other highly mobile forms.

Benthic and near-bottom species must be primarily, if not exclusively, residents. Their ability to populate other areas rests largely in the production and transport of planktonic larvae.

The open nature of the ecosystem is, thus, reflected in the plankton, nekton, and to some extent, the benthic species. In all three instances, however, there is apparently a resident group of species which constitutes the true slope biota. The percentage of true resident species likely increases with depth, reaching its maximum in the benthic inhabitants.

INTERNAL DYNAMICS - PRODUCTION, CONSUMPTION, DECOMPOSITION

Biological production involves the creation of living organic matter, either through photosynthesis (primary production) or through consumption of other organic matter (secondary production). In the slope environment, as elsewhere in the world oceans, primary production is limited to the euphotic zone. Such material may then be consumed locally, transported out of the area horizontally, or transported to deeper layers of the slope system. In addition, organic matter produced elsewhere (especially on the shelf) may be imported into the slope system.

Consumer species are found at all levels of the water column and on the bottom. Those species inhabiting the euphotic zone may utilize locally-produced or imported food sources, but those which inhabit the aphotic zone are dependent entirely upon production which comes from the upper layers or from outside the system.

Decomposition of non-living organic matter (corpses of dead organisms, fecal material, shed exoskeletons, secretions, etc.) takes place primarily through the action of bacteria, fungi, and protozoans. Such microbes themselves become food for larger consumer species which feed upon decomposing organic matter (organic detritus). Although likely of some importance as a food source for consumer species in the euphotic zone, organic detritus assumes a prominent role in aphotic waters, and it must be the chief food resource of the benthic environment. The rate of decomposition is inversely proportional to temperature. Therefore, microbial action is greatly retarded in the chilly environment of the aphotic zone, and organic matter imported from above must have quite a long residence time, especially in the benthic sediments.

INTERNAL DYNAMICS: VERTICAL AND HORIZONTAL TRANSPORT

Transport of nutrients and organisms involves the displacement of materials from one area to another. It may take place by a variety of means. Horizontal transport may involve the passive movement of dissolved and suspended matter by wind or water currents or it may entail active swimming by nektonic species.

Vertical water currents may transport dissolved and suspended materials upward (through upwelling) or downward (through water mass sinking). Materials may also be transported upward by gravitational floating (if particles become less dense than water, as through the incorporation of gas bubbles in the carcasses of dead organisms) or by gravitational sinking of dense particles and dead organisms. In addition, vertical migrations of animals in the water column are known to occur on daily and seasonal bases, and large amounts of organic matter may be transported by this means. Finally, it may be noted that some benthic organisms may pass portions of their life cycles in the water column.

SYSTEM COORDINATION AND REGULATION

Ecosystem processes cannot be based upon random events. Environmental signals, however subtle, must serve as cues to initiate biological activities, insuring simultaneous response of different members of the same species, and coordinating simultaneous and sequential activities of different species within the system. In all ecosystems so far studied, the general signals are provided by the physical environment, and specific recognition cues are provided by individuals within each species. The former often relate to seasonal and daily weather phenomena, and the latter may be based upon visual display, behavior pattern, sound or light production, release of specific chemical cues, and the like.

Very little is known about the signals and communication devices important in the life histories of most slope organisms. Within the euphotic zone light and other well known weather factors undoubtedly supply the primary information required. Although such factors become subdued with depth, at least some of the seasonally induced changes of the surface waters must reach the bottom in "coded" form. Slight modifications of currents, nutrients or sediments from above, or of temperature or salinity may supply the information necessary to trigger breeding, spawning, release of larvae, feeding, etc. Individual species recognition may be accomplished through photophores, specific chemicals (taste and odor), sound and other vibrations, and touch. These modifications or adaptations are only hints at what must be a very complex and sensitive communication system in the deeper waters of the slope.

THE SLOPE ECOSYSTEM - A CONCEPTUAL MODEL

Although many gaps exist in our knowledge of the slope ecosystem, enough information is now available to permit development of rough conceptual models of the composition and dynamics of this complex system. In essence, the slope system of the northern Gulf of Mexico is a long, tortuous three-dimensional wedge of water and bottom extending from the Mexican border (on the southwest) to about the level of the De Soto Canyon off the Florida panhandle (on the northeast). To reduce this lengthy system to some manageable proportions and to enhance analysis of geographic variability, it is convenient to mentally subdivide the total length into segments of perhaps ten to twenty miles length. Analysis of a typical segment can be made, and then comparison between different segments may be carried out to indicate variability.

MODEL OF A SLOPE SEGMENT

A typical segment of the slope ecosystem consists of three functionally distinct but interrelated layers (see Fig. 7-1). The uppermost layer, extending from the surface to a depth of 50-60 m, is the euphotic zone. This layer receives sufficient light to support photosynthesis, and it is, in effect, the zone of plant production. Beneath the euphotic zone, and extending to the bottom region, is a wedge of water which is devoid of sunlight. This is the aphotic zone where photosynthesis cannot occur and where the processes of food consumption, biological decomposition, and nutrient regeneration take place in the cold, dark, stable waters. The lowermost layer is the bottom itself together with the contiguous water a few meters in thickness. This is the benthic zone, repository of sediments from above, where nutrient storage and regeneration take place in association with the solid and semi-solid substrate. Each of these zones has much in common with the others, but each is sufficiently distinct to merit individual separation and analysis. In Figure 7-2, these three zones are shown in block diagram. Arrows indicate the flows between zones as well as the directions of exchange with the outside.

In developing a conceptual model of nutrient and energy flow within the slope ecosystem, it is first necessary to identify the "reservoirs" wherein nutrients and energy are temporarily stored and the "pathways" by which they are imported, exported, or transferred. The first approach to such a model is given in Figure 7-3. Although in many ways an oversimplification of the real situation, this model serves to identify the major features and key processes of the system. Each of the three zones is conceived as a simple five-reservoir food chain (phytoplankton through top predators). Each reservoir provides nutrients and energy to the next reservoir within a given food chain, and each exchanges with its comparable reservoir of the adjacent zone(s). Furthermore, each reservoir gains (or imports) energy

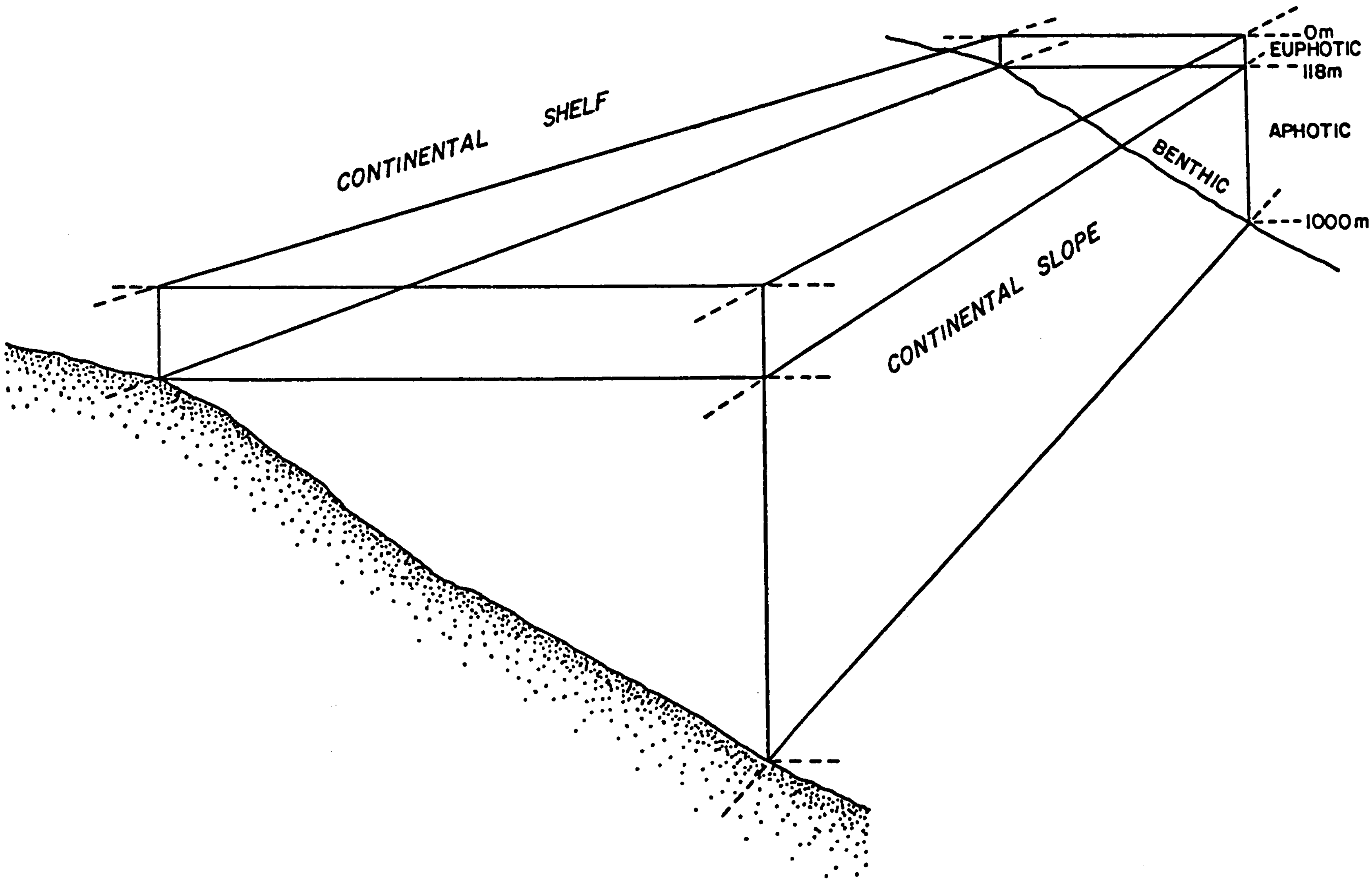

Fig. 7-1. Model of a typical segment of the continental slope ecosystem showing euphotic, aphotic, and benthic zones.

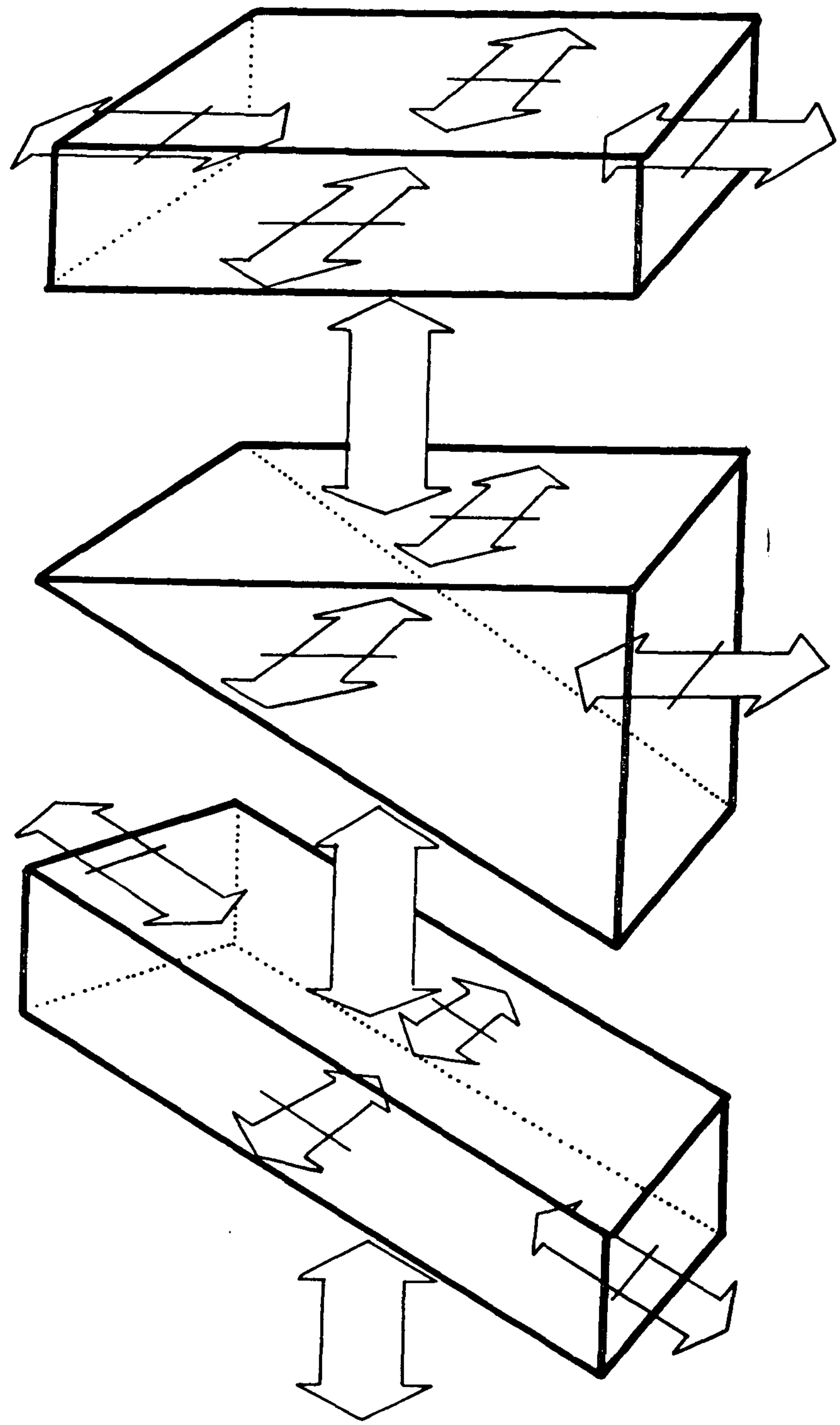

Fig. 7-2. Block diagram representation of the three zones of a typical segment of the continental slope ecosystem illustrating energy flows between zones and with the outside.

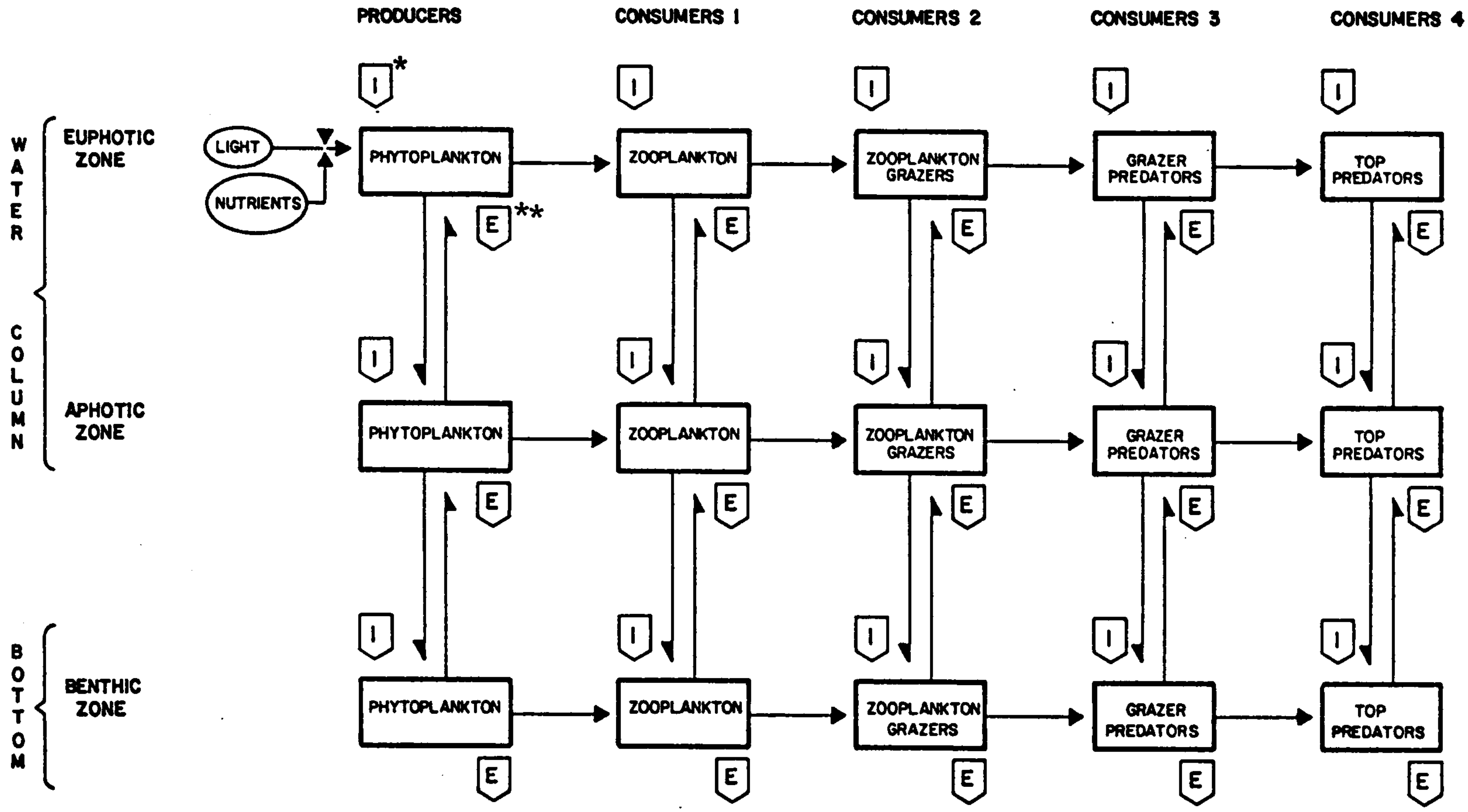

Fig. 7-3. Conceptual model of nutrient and energy flow within the continental slope ecosystem.
* I = Import
** E = Export

and nutrients from outside the system, and each loses (or exports) energy and nutrients to the outside.

In operation, sunlight and nutrients enter the system through photosynthetic activity of the phytoplankton of the euphotic zone. By various mechanisms the energy and nutrients of the phytoplankton become transferred throughout the three interlocking food chains. In the end all the nutrients are passed through the biological system to non-living reservoirs within the system (dissolved and particulate matter of the water column and the sediments) or to the outside. The energy has all been passed through the biological system and is dissipated through respiration (as heat), is stored in one of the non-living reservoirs, or is passed to the outside.

Lacking from the diagram are reservoirs for dissolved and non-living particulate organic matter, sediments, and decomposer organisms (such as bacteria and fungi). Each food chain is, in reality, a complex food web rather than a simple chain, and each group of consumer organisms often feeds from several of the reservoirs rather than only from the single reservoir below. However, to include all these factors in the diagram would be to obscure its purpose, i.e., to conceptualize the key features of the system.

In order to move closer to reality, a second model is presented (Figure 7-4) which is only a slight elaboration of the first. In this model the chief components of each reservoir are identified on the basis of the best information currently available for the slope ecosystem. Some of the reservoirs are subdivided to provide a clearer picture of the real situation. For example, the first reservoir of the food chain of the aphotic zone is subdivided to include the living phytoplankton imported from above as well as the dead and decomposing organic matter coming primarily from above. Most of the benthic food chain is subdivided to include those organisms which utilize primarily the supra-benthic water from those associated chiefly with the bottom itself.

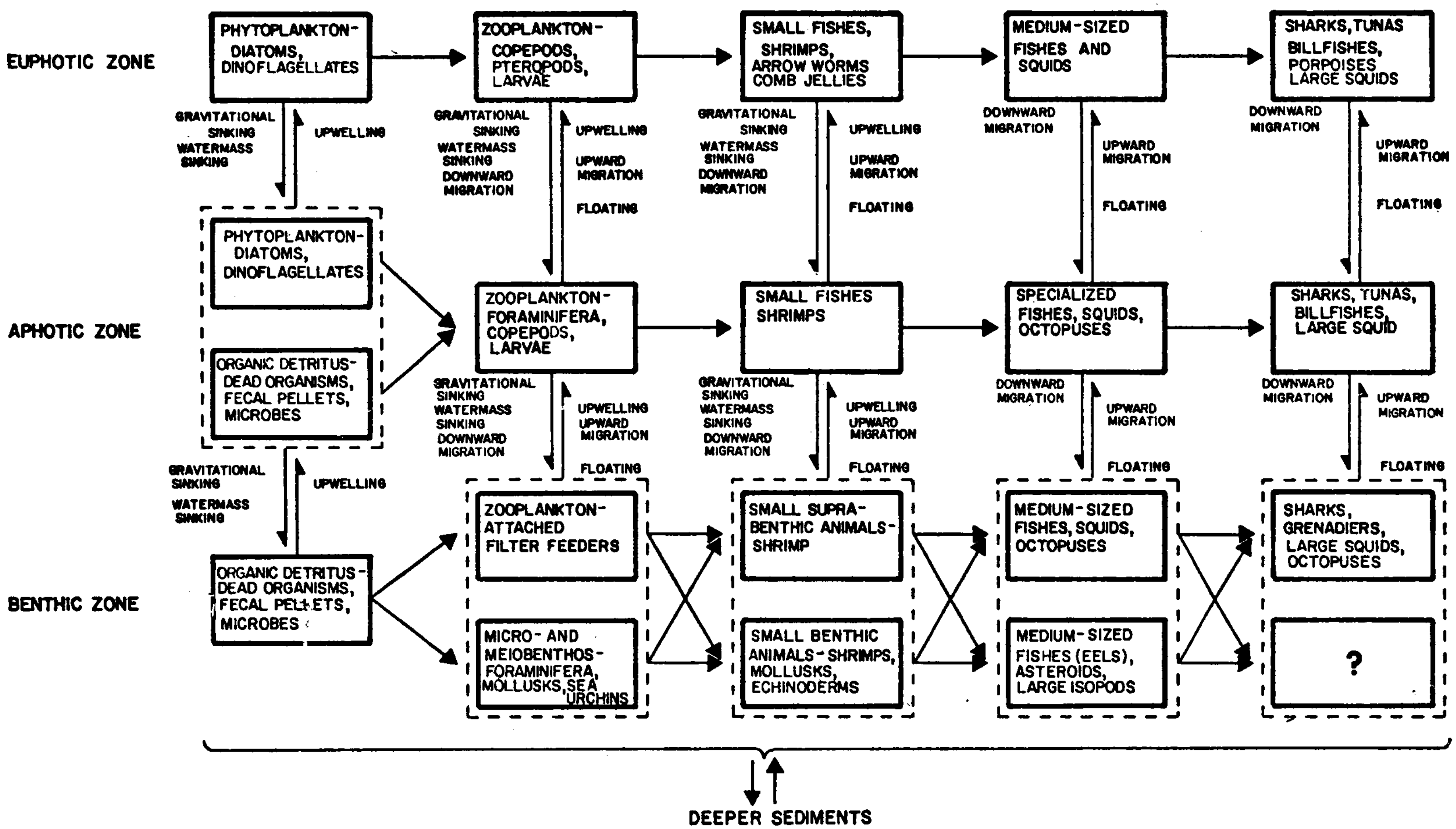

Fig. 7-4. Model of nutrient and energy flow within the continental slope ecosystem elaborating on the chief components of the energy reservoirs.

The second model also provides information concerning those processes by which materials and energy are transferred from one zone to another. As noted earlier, passive transfer occurs through vertical transport by water mass movement (upwelling or sinking), gravitational sinking of heavy particles (corpses and fecal pellets), and upward floating of particles which have densities less than that of sea water. Active transfer takes place through vertical migration (of zooplankton and other organisms) as well as through the active swimming movements of larger animals.

The next step in model building would normally entail the provision of quantitative data for each of the reservoirs and for turnover rates, and then the development of mathematical equations to simulate the transfer of nutrients and energy from one reservoir to another. Mathematical treatment of nutrient and energy flow in other marine systems provides techniques for approaching the slope system of the northern Gulf, but the necessary quantitative information is lacking. This problem may be illustrated by an example. The amount of phytoplankton energy available for supporting the consumer species of the surface waters may be expressed by the following equation:

$$\Delta_A = (\Delta_L + \Delta_I) - (\Delta_R + \Delta_S + \Delta_E)$$

where the terms are defined as follows:

Δ_A = phytoplankton energy available to the consumers

Δ_L = photosynthetic production by the locally resident phytoplankton

Δ_I = phytoplankton imported from other areas

Δ_R = phytoplankton energy lost through respiration

Δ_S = phytoplankton lost to the euphotic zone through sinking

Δ_E = phytoplankton exported to other areas

Limited data suggest that local phytoplankton production (Δ_L) amounts to about 38 $mgC/m^2/day$ (El-Sayed, 1972). This value can readily be expressed in terms of caloric content and extrapolated to the entire euphotic zone of the slope for a year. Data are also available for calculating expected respiratory loss (Δ_R). Some information is available for the estimation of sinking rates (Δ_S). However, solution of this basic equation rests largely upon estimation of import-export rates, and here the literature fails us completely. These difficulties are compounded for the higher trophic levels and for the deeper layers. Therefore, considering the present state of our knowledge, a mathematical model of the slope system would simply be an effort to express our ignorance with a greater degree of sophistication. Since virtually nothing is known concerning transfer rates, such treatment would add little to the visual presentation.

One final step may be taken, however, to provide further insight into the reality of the slope ecosystem. This involves the presentation of lists of organisms known for the slope ecosystem and presumed to occupy each level of the three food chains. From the extensive species lists available only those organisms are listed which appear to be dominant (on the basis of size, abundance, or presumed influence on the system). These lists are given in Appendix A.

GEOGRAPHIC VARIABILITY IN THE SLOPE ECOSYSTEM

The above discussion presents a picture of the composition and dynamics of a typical segment of the slope ecosystem. However, limited information suggests that from Texas to Florida not all the segments are identical. In general view, perhaps three geographic regions may be distinguished: the western, central, and eastern regions. The western region (in effect the slope off most of the Texas coast) lies off a continental shelf which is adjacent to arid, poorly drained lands of high clay composition. The central region (off the Louisiana, Mississippi, and Alabama coasts) is dominated by the Mississippi River and several other large silt-bearing rivers. This region is also most influenced by tropical waters of the Gulf Loop Current. The eastern region (off the northern Florida coast) is influenced by low-flow clearer streams, by sandy and calcareous shelf development, and by currents which have passed over the carbonate-rich west Florida continental shelf. Floral and faunal differences appear in terms of presence-absence as well as relative abundance of species. Such differences have been noted in the plankton, the benthic inhabitants, and the fishery potential of each region (see Section 8 on Fishery Potential).

UNIQUENESS OF THE SLOPE ECOSYSTEM

The models presented might apply, in principle, to any area of the open ocean, and it is important to identify the unique features of the slope ecosystem as a further aid to the understanding of this system. These unique features derive from the following factors: proximity of the land, adjacency of the shelf, influence of major river systems, adjacency of the bottom, great depth distribution of the bottom, and slope of the bottom.

As mentioned earlier, the surface waters of the slope system derive from the mixing of shelf and oceanic waters. This imports a higher turbidity; higher nutrient level; generally higher biological standing crops, production rates, and species diversity; and greater seasonal variability than would normally be encountered in open Gulf surface waters. Proximity to the shelf means that the upper slope is subject to sedimentation of the finer particulate bottom materials swept off the shelf and which gradually drop out of suspension in the quieter slope waters. Proximity of the mouths of major rivers results in the accumulation of large quantities of river-borne sediments which pile up on the shelf and then slump, creating powerful turbidity currents which sweep downslope to the Gulf bottom. Adjacency to the bottom provides a greater interface for bottom-water column interrelations at all depths. The great depth distribution of the bottom provides a stratified benthic habitat for a large number of depth-limited species. The steeper bottom slope permits gravity-based particle sorting, hence, habitat and nutrient diversification for the benthic animals.

In overview, the slope environment provides for high biological productivity and high organic diversity in contrast with the lower production and monotonous environment of the open Gulf. The slope environment is a unique area of intense biological activity. It is certainly no accident that the chief predators of the sea (sharks, tunas, billfishes, etc.) concentrate here. It houses an ecosystem which is poorly studied and barely understood. The area should be studied in great detail to provide the quantitative information upon which a sophisticated interpretation may be based.

VULNERABILITY OF THE SLOPE ECOSYSTEM

It has been pointed out earlier that the slope ecosystem is a unique marine system characterized by high production and high diversity, and that the deeper in the pelagic column and on the slope one gets, the more unique and interesting the fauna and the system become.

Chemical pollution or other modification of the euphotic zone should have only temporary adverse effects upon the euphotic zone itself because mixing and dilution should occur and because surface water currents should sweep the contaminated water away. However, the deeper layers are nutritionally dependent upon the surface layers in very complex and subtle ways. Therefore, any interference with production in the surface layers or with vertical biological and physical transport mechanisms should have adverse effects at some point downstream of the site of contamination upon the aphotic and benthic portions of the system. For example, oil pollution of the surface or intermediate waters might be expected to interfere with feeding and vertical migrations of the zooplankton. This, in turn, would reduce the standing crops of zooplankton and decrease food availability to those animals of the aphotic and benthic zones which depend upon the zooplankton or their fecal pellets for food.

Direct chemical contamination of the aphotic and benthic zones is likely to occasion several serious consequences. The fauna of these zones tends to be more unique and more especially adapted to the prevailing local conditions than those of the surface waters. Physiologists have concluded that deep-water animals have very narrow ranges of tolerance to most environmental factors studies. In this respect they are not like estuarine and other hardy coastal animals which are adapted to survive in highly variable environments. Deep-sea animals are sensitive to even minor shifts in environmental factors. This generalization, based primarily upon studies of benthic animals, undoubtedly applies to the pelagic species of the aphotic zone, as well. Just in terms of maintaining life, the fauna of the aphotic and benthic zones must be considered very vulnerable to chemical pollution.

A great many of the species of the aphotic and benthic zones are filter-feeders and must strain their food from the water. Suspended oily materials would be expected to gum up and heavy concentrations of suspended silt would be expected to clog up the delicate feeding mechanisms. The planktonic larvae of the benthic species should be especially vulnerable to such action. Many other species are deposit feeders which glean organic particles by sorting through the surface sediments. Deposition of heavy silt layers or of petroleum products upon the bottom surface should be devastating, especially to those benthic species which possess limited powers of locomotion.

Finally, there is the major suite of problems associated with underwater "blow-out" and slumping. A major underwater "gusher" would send enormous quantities of petroleum into the aphotic and benthic environments of the slope. Without question, such an event would wreak widespread havoc throughout these delicate systems because of the quantities of petroleum and because of the diversity of petroleum fractions involved. Such an event would also likely be accompanied by significant slumping, and this would result in faunal devastation in a wide path down-slope from the primary event.

Unfortunately, little solid information is available upon which definite prediction can be based. Therefore, a major vulnerability is a lack of knowledge and understanding. One likely would not be in a position to diagnose trouble when it began or to demonstrate the cause if many of the aphotic and benthic populations were suddenly eradicated. Some knowledge of the directions and velocities of the deep current patterns would at least permit prediction of the directions and rates of spread from point-source contamination. However, absolutely nothing is known about ways of ameliorating the effects of deep-water petroleum contamination or of slumping or widespread siltation of the aphotic or benthic zones. Therefore, predictability would not appear to serve any useful purpose in protecting the deep-water ecosystem. The technology of prediction and protection lag for behind the technology of exploitation. However, as suggested in an earlier section of this report, there are some biologically related techniques that might be used to discern geographic areas of the slope that have a history of slumping. These areas could be designated as hazardous drilling sites, and lease rights would not be offered for sale. In this context, predictability would serve to protect the most vulnerable parts of the slope ecosystem.

PRECAUTIONARY MEASURES TO PROTECT THE SLOPE ECOSYSTEM

It is socially and economically desirable to permit maximum safe exploitation of the petroleum resources of the outer shelf and upper slope while minimizing potential hazards to the slope ecosystem. Guidelines for reducing the ecological hazards are given below.

1. Drilling leases should, at first, be limited to those areas of stable bottom where slumping and underwater blowout are least likely to occur. With advancing technology perhaps some of the less stable bottoms might be tried on an experimental basis.

2. In relatively unstable areas drilling should be limited to those seasons of the year which are considered safest. By and large, this means those seasons when storms are least likely, when bottom currents are most propitious, and when visibility at the drilling head is greatest (i.e., when bottom turbidity is the lowest).

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3. In carrying out drilling operations in deep water every effort should be made to employ the safest technology available. Automatic shut-off devices should be employed. Drilling muds and other effluents should be barged to relatively safe disposal sites (presumably in off-slope deep water). Drilling rigs should be exceptionally sturdy and firmly anchored deep into the bottom.

4. Buffer zones should be provided between major areas of drilling activity to provide refuge for fauna which may be needed to repopulate disturbed areas. With such species refuges available recovery will be possible from even major underwater disasters.

5. Ecological monitoring of key drilling sites should be carried out before, during, and after the construction and drilling activities to provide a background of specific information on the ecological effects. Present knowledge is rather general and does not provide the definite information required as the basis for sound and long-term management decisions.

6. General ecological surveys of the slope ecosystem should be initiated immediately to provide a broader base of factual information about the slope ecosystem to provide information required for decision-making as the drilling operations procede into less-stable bottoms and into deeper waters of the slope. Specifically needed is knowledge of the deeper current patterns, water mass characteristics, faunal distribution in relation to hydrographic parameters, and tolerances of deep-water fauna to heavy turbidity and high levels of petroleum hydrocarbons.

7. The technology for amelioration of the effects of deep-water blowout and heavy turbidity should be developed as soon as possible. For example, it may be possible to develop vertical sleeves to surround drilling sites. Sediments would, thus, be deposited locally, and any petroleum released would be contained and funneled to the surface where it could be handled mechanically or chemically.

PART IV. FISHERY POTENTIAL

8. ASPECTS OF NORTHERN GULF FISHERY RESOURCES

At the present time the commercial fishery potential of the continental slope of the northern Gulf of Mexico is not being exploited in any systematic way. Nor has the fishery potential of the area ever been fully discussed in the literature. Therefore, the present section is, of necessity, based upon scattered reports of exploratory operations carried out by state and federal agencies as well as upon scientific reports of species present which are known or presumed to be of commercial importance. Where possible, information concerning abundance or catch rate is included to aid in assessing the economic potential of pursuing a fishery located in deep water about a hundred miles from the nearest land. The most comprehensive information concerning the fishery production and potential of the northern Gulf shelf is found in various articles and reports appearing in the Commercial Fisheries Review, and the best compilation of this information has been published by the Russian and Cuban investigators (Bogdanov, 1969).

TRAWLABLE FISHES AND INVERTEBRATES

Various reports on trawl catches by the exploratory fishing vessel OREGON indicate that in deeper water (90 to 900 m) macrourids or grenadiers predominate in the fish catch. At present there is no market for these rat-tailed fishes. In 1960 Captiva and Rivers reported that trawling for snappers and groupers on suitable bottoms at depths of 37 to 90 m produces catches exceeding those obtained by hand-line vessels working the same area. Following this lead the Texas Parks and Wildlife Department engaged in exploratory trawling during the months of July and October, 1967 at depths of 90 to 550 m off the Texas coast to assess the potential for a deep-water bottom fishery (Gaille, 1969). The results of this brief survey are presented in Table 8-1. Five species were captured, wenchman snapper (_Pristipomoides aquilonaris_), longspine scorpionfish (_Pontinus longispinis_), spotted hake (_Urophycis regius_), Gulf hake (_U. cirratus_), and

Table 8-1. Numbers and weights of five species of commercially valuable fishes captured in trawl samples off the Texas coast in depths of 70 to 550 m. Results are expressed in terms of numbers and weights captured per hour of trawling time using a 45-ft. trawl with 2 1/4-inch stretch mesh (after Gaille, 1969).

Depth (m)	Wenchman Snapper		Longspine Scorpionfish		Spotted Hake		Gulf Hake		Gulf Silver Hake	
	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.
70	-	-	-	-	-	-	-	-	-	-
90	50	25	-	-	-	-	-	-	-	-
130	75	35	25	9	-	-	-	-	-	-
165	100	48	50	17	30	15	-	-	-	-
240	10	5	30	12	-	-	32	37	8	4
300	-	-	-	-	-	-	58	40	2	1.5
365	-	-	-	-	-	-	84	40	3	2
460	-	-	-	-	-	-	10	12	6	6
550	-	-	-	-	-	-	15	18	11	8

gulf silver hake (Merlucius magnoculus). All are edible, and the most abundant fish, the wenchman snapper has superior food qualities. Gaille (1969) also noted that the snapper often occurs in dense schools and that over 400 pounds have been caught in a single 2-hour drag at a depth of 146-165 m off south Texas. It was concluded that the snapper, at least, may exist in commercial quantities, and the same may be true for the Gulf hake.

The royal red shrimp (Hymenopenaeus robustus) is another trawlable species of the continental slope of potential commercial importance. Bullis (1956) reported on extensive trawling by the OREGON throughout much of the Gulf in the 185 to 550 m depth. "The distributional picture that emerged from this work showed royal red shrimp to be present throughout the Gulf of Mexico on all types of bottom in a depth range of 190 to 270 fms (348-474 m), with a maximum range of 150 to 400 fms (274-732 m). Royal reds show no apparent seasonal variation in average size, and no uniform size dominates the catch..." The general pattern of distribution of the royal red shrimp in the northern Gulf is shown in Fig. 8-1. The species is concentrated on trawlable bottoms southeast of the mouth of the Mississippi River (Fig. 8-2), and some commercial fishing for the species has been carried out in this area. Exploratory trawling in this area produced catches of 90 to 120 pounds per 3-hour drag. As a gourmet food, the royal red shrimp is highly marketable.

Off the Texas coast results were not as promising with captures running only about 5 to 30 pounds per 3-hour drag (Springer and Bullis, 1956; Bullis and Thompson, 1965). In the exploratory trawling off Texas reported by Gaille (1969) the maximum yield per 2-hour drag was 25 pounds, and usually less than 5 pounds were caught. Whereas the royal red shrimp is found off the Texas coast, present indications are that its harvest is not economical in this area.

The red crab, Geryon quinquedens, is another trawlable species of potential commercial value known to occur on the continental slope of the northern Gulf of Mexico. This species has been studied to some extent along the Atlantic coast. Haefner and Musick (1974) summarized existing knowledge concerning this species and reported on their own exploratory studies

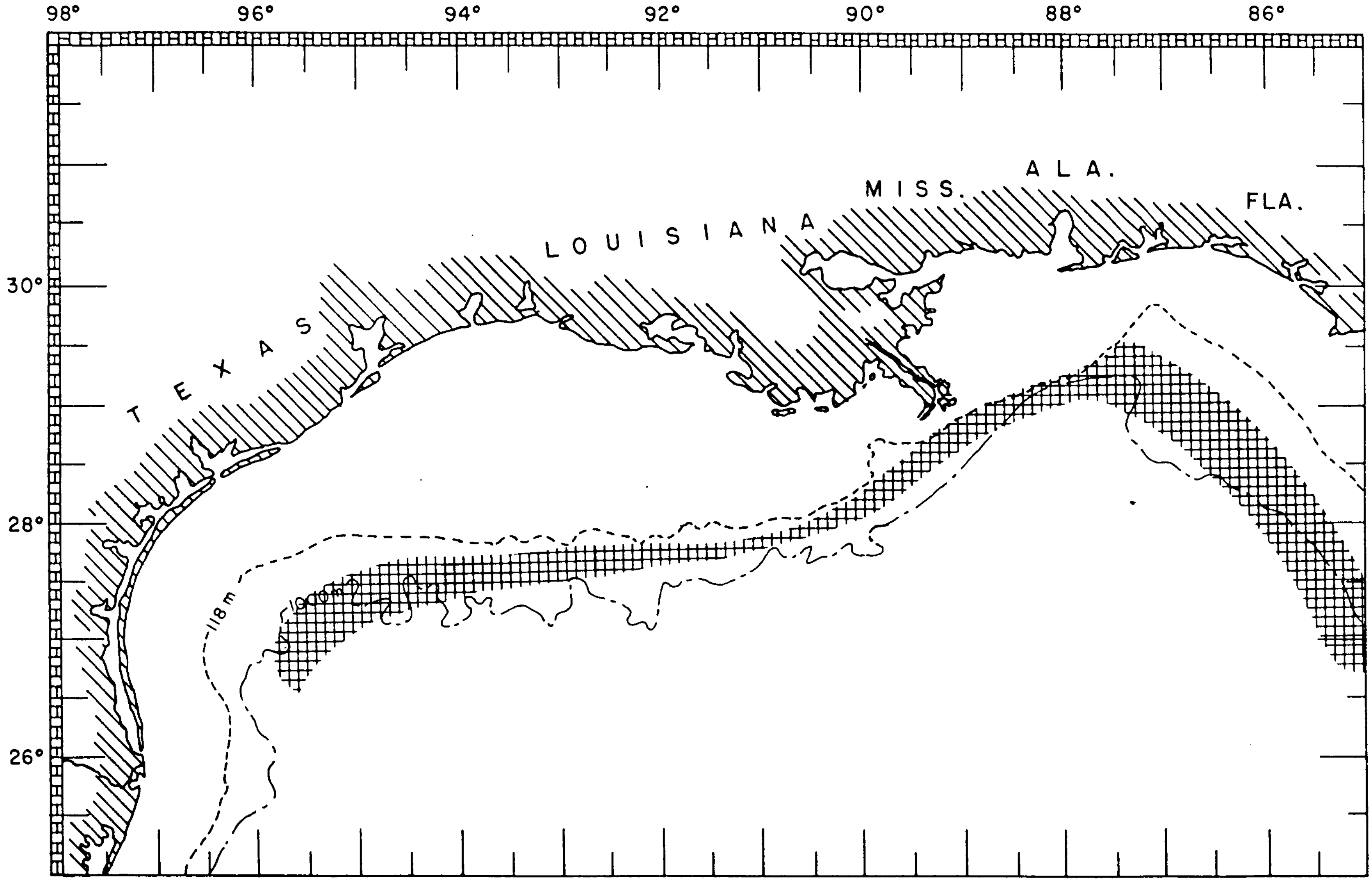

Fig. 8-1. Distribution of Royal Red Shrimps (Hymenopenaeus robustus) in the northern Gulf continental slope area (after Bullis, 1956).

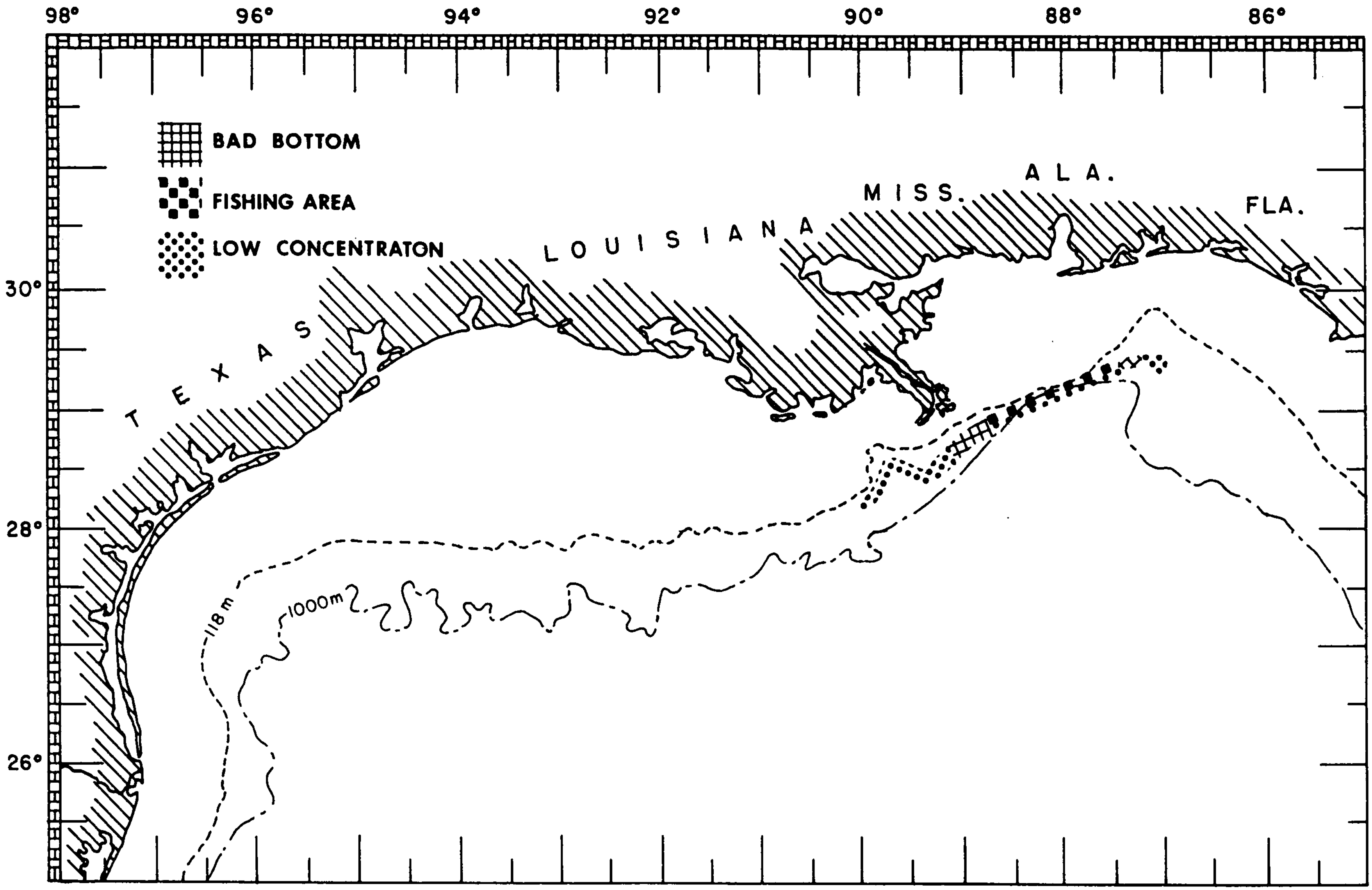

Fig. 8-2. Mississippi Delta Royal Red Shrimp grounds showing areas of fishing concentrations and bad trawling bottom (after Bullis, 1956).

carried out around the Norfolk Canyon off the mouth of Chesapeake Bay. The red crab has been taken off the Atlantic coast in depths of 183 to 1830 m. In the Norfolk Canyon area the largest catches occurred at depths of 350 to 465 m, and two half-hour drags between 325 and 510 m produced 152 pounds of red crabs. Outside of the canyon 665 pounds were taken in eleven drags. It has also been found that the species can readily be taken in quantity in lobster-pot traps. Traps set between 595 and 1355 m averaged over 11 pounds of crabs per trap.

The red crab is widely distributed on the continental slope of the northern Gulf of Mexico, where Pequegnat (1970) has reported it from depths of 365 to 1465 m. Although a species of very fine edible qualities and one which has been fished commercially on the east coast, the red crab has neither been explored nor exploited in the Gulf.

The "trashfish" potential of the continental slope has hardly been investigated. In view of the generally abundant supply of such resources on the shelf proper it would certainly not be economical to pursue a high-cost, low-yield resource on the slope. Nevertheless, as a supplement to other types of commercial operations, the "trashfish" may eventually assume some economic importance.

BOTTOM LONGLINE POSSIBILITIES

Results of exploratory bottom longline operations in the western and eastern sections of the continental slope of the northern Gulf were reported by Nelson and Carpenter (1968). The distribution of bottom longline sets is shown in Fig. 8-3. The most abundant fish species, by number and weight, was the tilefish, Lopholatilus chamaeleonticeps. This valuable food fish has been taken commercially off the middle Atlantic states since the early 1900's (Bigelow and Schroeder, 1953) where annual landings have reached 12 million pounds. The total depth range of the species in the Gulf was 165 to 410 m with primary concentration between 275 and 365 m.

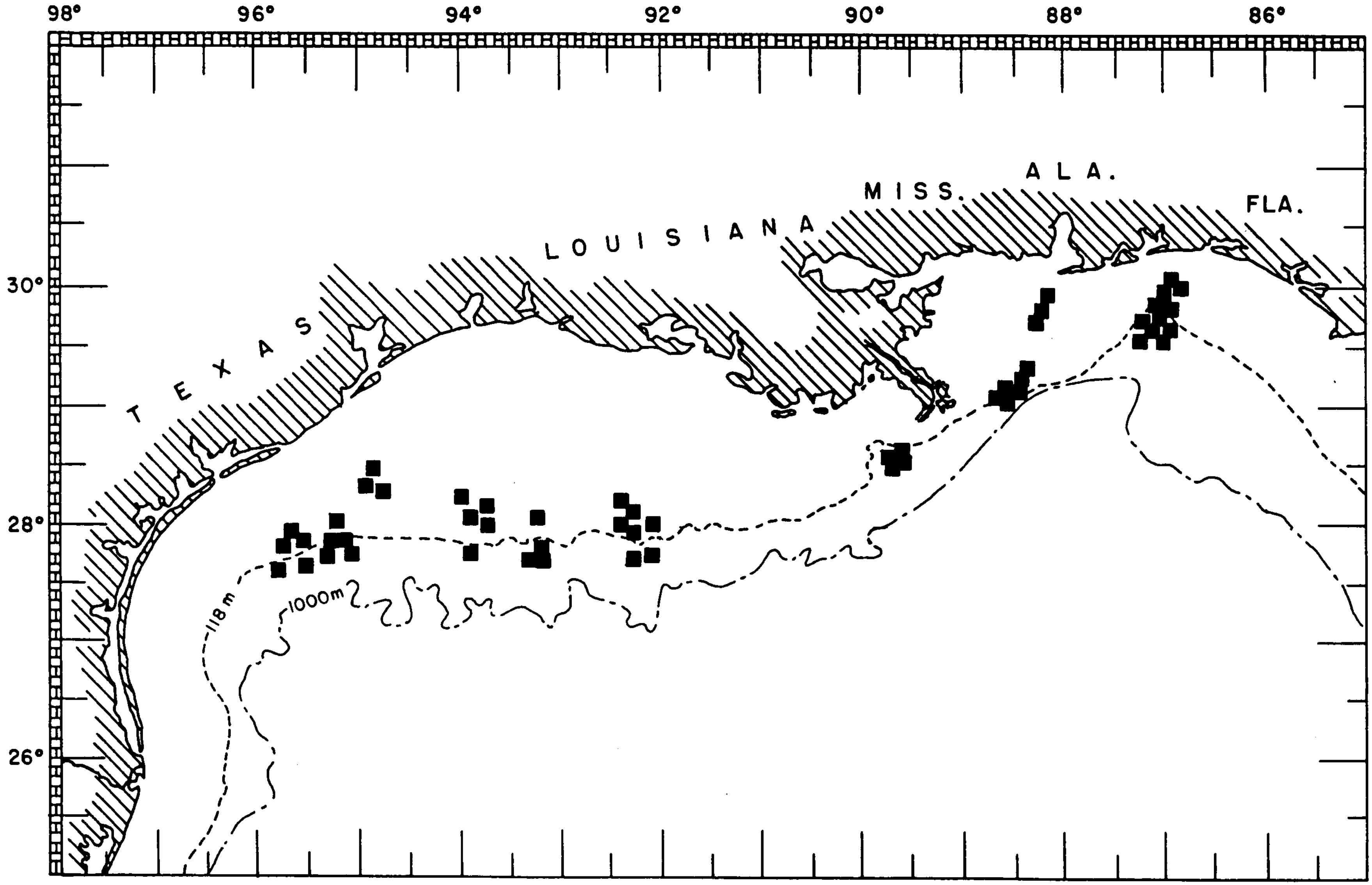

Fig. 8-3. Bottom longline sets made on R/V OREGON II Cruise 1 in the northern Gulf (after Nelson & Carpenter, 1968).

Highest catches of tilefish were made off the Texas coast where catches averaged about 1/2 pound per hook (at 365 m). The largest catch approached 1 pound per hook (285 pounds per 300-hook longline). All six longline sets between 275 and 365 m off Texas caught tilefish.

In the eastern Gulf longline sets caught tilefish with less frequency. The most abundant single catch in this sector consisted of 104 pounds per 300-hook line set at 320 m along the eastern edge of DeSoto Canyon.

Besides the tilefish, the other foodfish taken in abundance was the yellowedge grouper, Epinephelus flavolimbatus. Again, the highest catches were made off the Texas coast with one set at 183 m yeilding 271 pounds, or nearly one pound per hook. The warsaw grouper, Epinephelus nigritus, averaged 10 pounds per 300 hooks at 183 to 230 m off Texas. Other fishes which were taken in smaller quantities included the red snapper (Lutjanus campechanus), vermillion snapper (Rhomboplites aurorubens), wenchman (Pristopomoides aquilonaris), scamp (Mycteroperca phenax), red grouper (Epinephelus morio), black grouper (Mycteroperca bonaci), porgies (Sparidae), and Gulf hake (Urophycis cirratus). Sharks, which are at present of no commercial value, made up about a third of the total bottom longline catch.

In summary, the most productive longlining area was the Texas coast where peaks of foodfish abundance were noted at about 183 m (several species of grouper, of which the yellowedge grouper predominated) and 365 m (where the tilefish was most abundant). Nelson and Carpenter (1968) conclude that the Texas coast is the only part of the Gulf that appears to offer commercial potential for bottom longlines, especially since such gear can be fished on both rough and smooth bottoms. They suggest that a trawling potential appears likely throughout the depth range of the northern Gulf where the bottom is not excessively rough. Since most of the area appears trawlable by the roller-rigged fish trawls, they conclude that, "certainly a tilefish potential exists."

HOOK AND LINE SNAPPER FISHING

Hook and line snapper fishing was formerly limited to banks and irregular bottom areas in relatively shallow water of the shelf. However, during the 1950's snapper fishermen equipped with power reels, stainless steel wire lines, and electronic aids for determining position, depth, and likely fishing areas, extended the depth range of their fishing activities to at least 275 m. The catch consists of a variety of excellent food fishes including the red snapper (*Lutjanus campechanus*), red grouper (*Epinephelus morio*), and gag (*Mycteroperca microlepis*). In deeper water the Brazilian snapper (*Lutjanus aya*) is taken in quantity, especially on Little Campeche Bank in 73 to 137 m south of Freeport, Texas. The distribution of potential snapper fishing banks along the outer shelf and upper slope of the northern Gulf is shown in Figs. 2-5 and 2-8 (Section 2).

MIDWATER TRAWL FISHING

Above the outer continental shelf and upper slope in the general region from central Louisiana eastward to about the level of Pensacola, Florida large schools of clupeids and carangids have been reported. One such report (Anonymous, 1969) indicated that the exploratory vessel OREGON II had encountered large schools of round herring (*Etrumeus teres*) and rough scad (*Trachurus lathami*) just off the bottom in 200 m of water off the Louisiana coast. Bogdanov (1969) reported taking two tons of round herring in 1/2 hour of trawling in deep water south of Pensacola. He noted that sonar recordings indicated large dense schools of round herring are found over a significant area and that during the day these fishes remained somewhat above the bottom at a depth of 80 to 93 m, but that during the night they rise to within 10 to 17 m of the surface. From such reports it would appear that a significant fishery potential exists in the northeastern Gulf for these commercially valuable species if they can be captured. Mid-water trawling would seem to be the method of choice.

PELAGIC LONGLINE AND PURSE SEINE FISHING

Iwamoto (1965) reviewed the results of surface school sightings and longline fishing by the exploratory vessel OREGON in the northern Gulf of Mexico and assessed the fishery potential of the tuna stocks of the area. Commercially exploitable stocks of four species of tuna are found in the northern Gulf area. These include the skipjack tuna (Euthynnus pelamis), a yellowfin tuna (Thunnus albacares), blackfin tuna (Thunnus atlanticus), and bluefin tuna (Thunnus thynnus). The area of principal sightings and longline catches lies in the water above the 183 to 1830 m depth contours. Tuna schools were found to be present at all seasons of the year, but they seem to be more abundant in the northern Gulf during the summer and fall months. Tuna schools have been located most frequently east and southeast of the mouth of the Mississippi River, (Figs. 8-4, 8-5, & 8-6), but this may be related to the fact that exploratory operations have been most extensive in this area.

During September, 1951 Bullis (1955) reported sighting nine schools of blackfin tuna in one day off the Mississippi and Louisiana coasts, with the schools averaging an estimated 100 to 500 tons each. Springer and Bullis (1954) reported that on one cruise, schools of blackfin, yellowfin, and skipjack tuna, sometimes pure and sometimes mixed, were seen every day of the trip. Catches of over 600 pounds per 100 hooks were noted.

Bogdanov (1969) reported on Russian and Cuban longline investigations on the northern Gulf coast. Their results essentially substantiate the findings of the OREGON. They also provide information concerning a variety of other high quality pelagic fishes which may be taken on longlines in the Gulf (Table 8-2).

Purse seines have apparently not yet been tried commercially for the capture of tuna and other large pelagic fishes in the Gulf of Mexico, but Iwamoto (1965) noted that they should prove quite successful in the

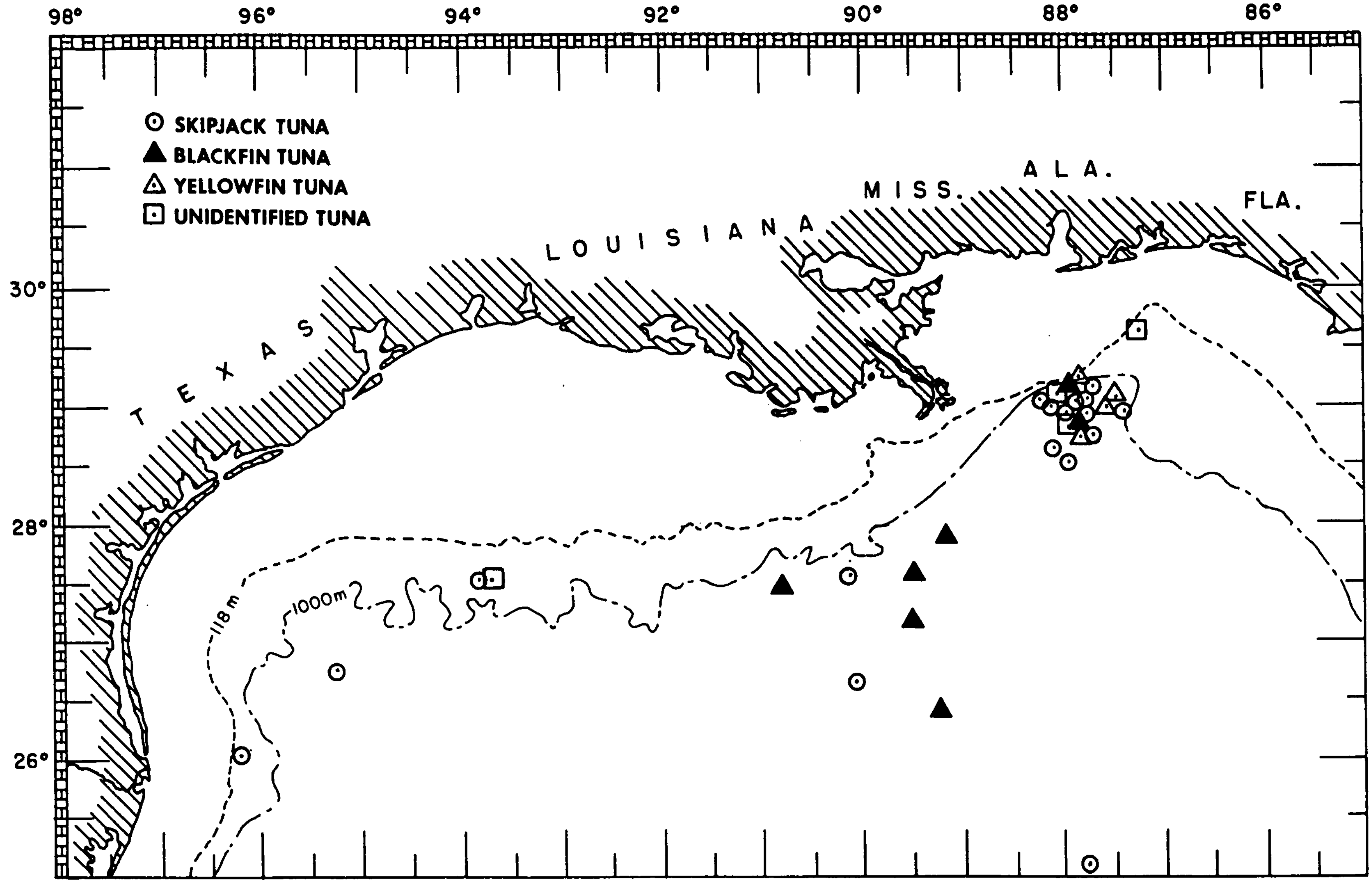

Fig. 8-4. Surface tuna sightings during April, May, and June (after Iwamoto, 1965).

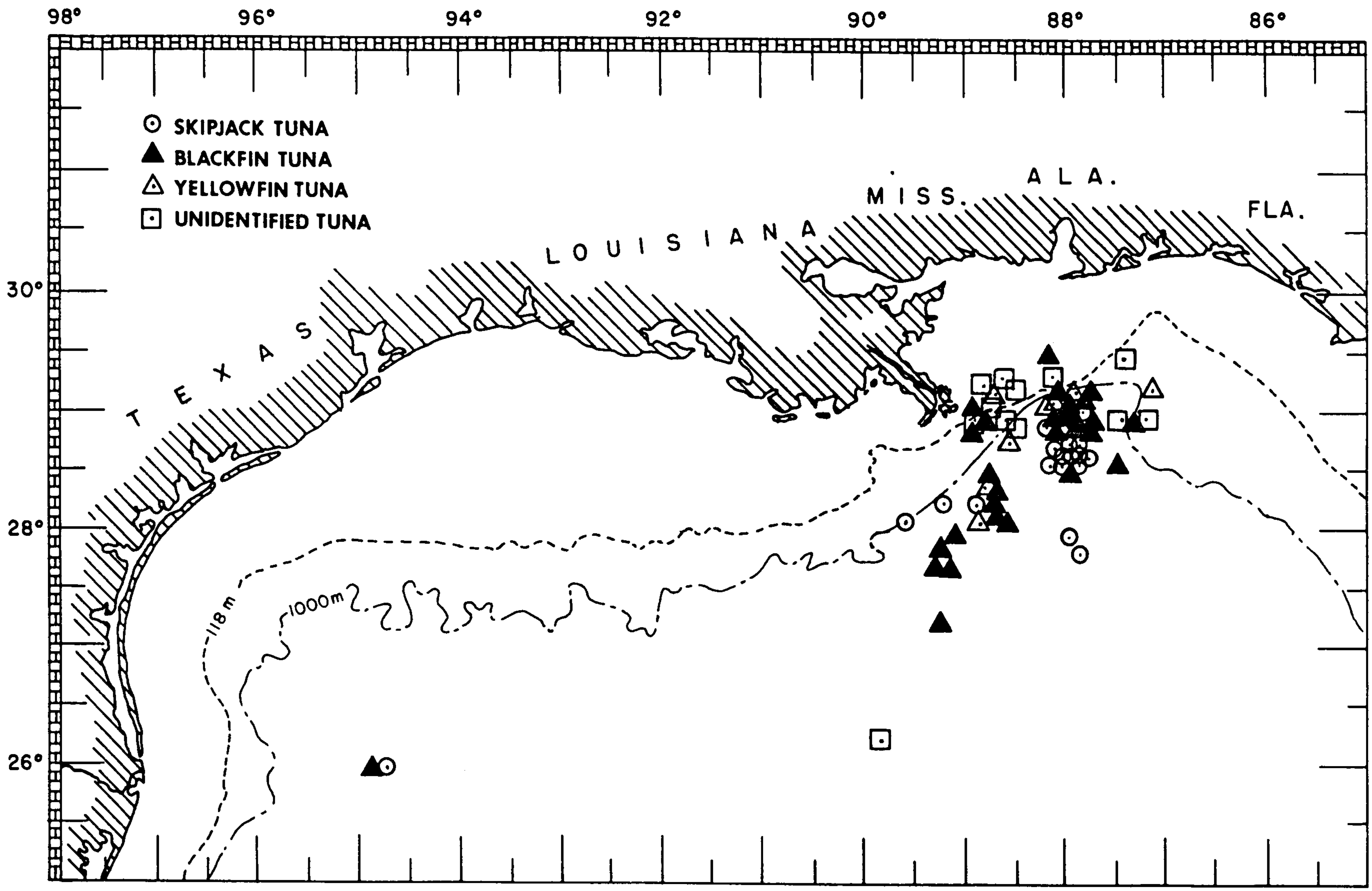

Fig. 8-5. Surface tuna sightings during July, August, and September (after Iwamoto, 1965).

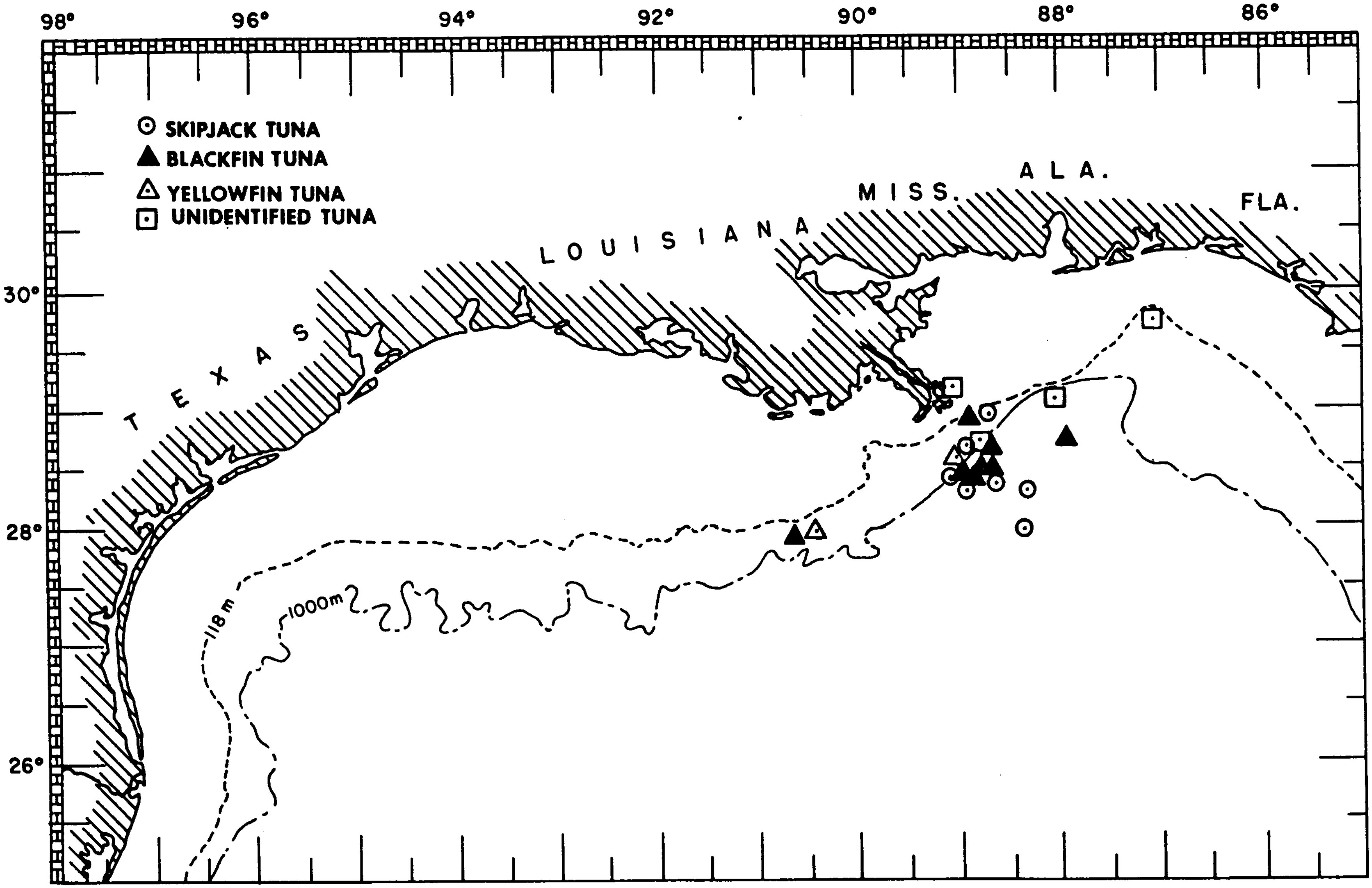

Fig. 8-6. Surface tuna sightings during October, November, and December (after Iwamoto, 1965).

Table 8-2. Pelagic fishes of potential commercial importance known to inhabit the waters above the continental slope of the northern Gulf of Mexico. Data from many sources.

Family	Species	Comman Name
Alepisauridae	Alepisaurus ferox	Longnose lancetfish
Carangidae	Elagatis bipinnulatus	Rainbow runner
Coryphaenidae	Coryphaena hippurus	Dolphin
Sphyraenidae	Sphyraena spp.	Barracudas
Gempylidae	Ruvettus pretiosus	Oilfish
Thunnidae	Acanthocybium solanderi	Wahoo
	Auxis thazard	Frigate mackerel
	Euthynnus alletteratus	Little tunny
	Euthynnus pelamis	Skipjack tuna
	Sarda sarda	Atlantic bonito
	Thunnus alalunga	Albacore
	Thunnus albacares	Yellowfin tuna
	Thunnus atlanticus	Blackfin tuna
	Thunnus obesus	Bigeye tuna
	Thunnus thynnus	Bluefin tuna
Xiphiidae	Xiphias gladius	Swordfish
Istiophoridae	Istiophorus platypterus	Sailfish
	Makaira nigricans	Blue marlin
	Tetrapterus albidus	White marlin

capture of the blackfin and skipjack tuna, both of which form large dense schools at the surface. These two species made up seventy percent of the surface sightings.

Over the continental slope both east and west of the mouth of the Mississippi River there is clearly a commercially exploitable pelagic fish population consisting primarily of tunas and their relatives, but including other species. American efforts to exploit this resource have not been very successful (Iwamoto, 1965). Antiquated longline gear was tried, and this produced only moderate results. Purse seines, very successful elsewhere, have yet to be tried. Meanwhile, Japanese and possibly Cuban fishermen have been making good catches of the larger pelagic fishes.

SUMMARY OF COMMERCIAL FISHERY POTENTIAL

Although considerable exploratory work remains to be carried out, the principal features of the commercial fishery potential of the outer shelf and slope waters of the northern Gulf coast may be stated with some precision and assurance. In the eastern sector (essentially, from mid-Louisiana to the vicinity of Pensacola, Florida) three basic fishery types are supportable: these include bottom trawling for royal red shrimp, midwater trawling for clupeids and carangids, and surface longlining and purse seining for tunas and other large pelagic species. In the western sector (from mid-Louisiana to the south Texas border) the most effective fishing is for bottom and near bottom species. This includes bottom trawling for snappers and groupers (at about 183 m) and tilefish (at about 366 m), bottom longlining, and hook and line fishing on the snapper banks. At present none of these fishery potentials is being fully exploited.

Considerable exploratory work is yet to be carried out, and there is ample room for life history research and development of innovative capture techniques before the deepwater fishery resource can be fully harvested. The trashfish potential needs to be assessed. Markets should be developed for sharks, which are often the most abundant fishes captured by various hook-and-line methods. The elusive red crab (Geryon) should be studied, and life histories, depth distributions, and seasonal abundance of all of the major commercially potential species should be investigated. Modern longlining techniques should be tried, purse seines should be employed, midwater trawls should be investigated, and roller-rigged trawls should be employed more widely. Above all, fishermen should be encouraged to equip themselves with a variety of gear types so that a flexible approach to the deepwater harvest could be mounted.

PART V. CONCLUSIONS

In the foregoing sections documentation has been given to substantiate the assertion that the upper continental slope supports a very diverse and productive benthos. Over 400 species of animals have been cited here as belonging to one or another of the faunal assemblages that have been designated and briefly described.

Results of this study also support the contention that the fauna of the continental slope need not be considered transitional between the faunae of the continental shelf and the abyssal plain. Indeed, the composition of the slope benthos is faunistically separable from that of the shelf or the abyss. The importance of the slope to the biology of the oceans is measured not alone by its species diversity (greater than previously imagined) and production, but also by its great areal extent. Even though the shelves of the northern Gulf are wide, they are not as wide as the slope, and world wide they have many times less area than the continental slope.

It is to be expected that the lines of demarcation between faunal provinces and zones and their realities, viz., the faunal assemblages, will become less distinct as depth increases, say, down to 1000 m, but it does not follow from this that the assemblages are any less real or important. If indeed the assemblages result in large part in shallow water from such physical factors as temperature ranges, then it would be expected that assemblages might be more extensive in deep waters with their nearly constant temperature. There are some indications in this work that such may be true. But until one becomes fully aware of the differential physiological controls exerted upon individual species by pressure and until one is better able to assess the biological interactions on the slope and the controls these exert, the tendency is to remain equivocal. The distribution of food is a powerful control of distribution. All organisms can tolerate various temperature conditions, but no macrofaunal organism can survive starvation indefinitely.

When a study of the full range of depth in the Gulf is complete one shall be in a position to answer the above question. Meanwhile, there can be no doubt that the slope benthos is important to the welfare of the Gulf ecosystem. It is not beyond the realm of possibility that some organisms on the slope will become more widely utilized in fisheries, but this direct exploitation should not be used as the only economic guide to the worth of the slope benthos. This report only alludes to the true fisheries potential (including greater sports fishing in oceanic waters) of the northern Gulf. There are potentials there going to waste. But the tie-in with the slope is an important one - some of these large species, even including true sword fishes, feed in part on the slope epifauna. Moreover, it is the benthos that in these offshelf waters sustain much pelagic life through their production of pelagic larvae.

Mention has been made of the vulnerability of the slope ecosystem to various environmental perturbations. It is only to be hoped that management of exploitation of the upper slope will be executed with sufficient perspicacity as to prevent its decimation in given areas prior to achieving a full understanding of its contribution to the welfare of the entire Gulf system.

Just how important this role is cannot be judged at this time, but one glimmering warrants pause. From what is known of primary production in the northern Gulf and the extraction of organics in fisheries (both sports and commercial) there is a major hiatus in the matter and energy balance. In short, there does not seem to be enough energy conversion by phytoplankters to satisfy man's harvest let alone a host of other usurpers. Much more conversion of energy must be going on somewhere. Perhaps much of it is being done by shelf benthos, but some of it is surely going on down the slope, especially where the shelf is narrow. If this proves to be the case, and it could be judging from the diversity indices presented here, then damage to the upper slope benthos will slow down the entire thermodynamic machine.

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APPENDIX A

LISTS OF BENTHIC FAUNAL ASSEMBLAGES OF FISHES AND INVERTEBRATES ALONG ISOBATHS OF THE CONTINENTAL SLOPE OF THE NORTHERN GULF OF MEXICO

TERECO CORPORATION
P. O. Box 2848
College Station, Texas 77840
Telephone (713) 846-7087 or 846-0211

BENTHIC FAUNAL ASSEMBLAGES

100 METERS

FISHES (38 Species)

DOMINANTS

1. Haliuetichthys aculeatus
2. Pristipomoides aquilonaris
3. Serranus atrobranchus
4. Synodus foetens
5. Caulolatilus sp.
6. Centropristis philadelphica

OTHERS

7. Bembrops anatirostris
8. Bembrops gobioides
9. Breviraja sp.
10. Brotula barbata
11. Chaetodon sedentarius
12. Coelorhynchus caribbaeus
13. Congrina flava
14. Cyclopsetta chittendeni
15. Decodon puellaris
16. Diplectrum bivittatum
17. Engyophrys senta
18. Hemanthias vivanus
19. Kathetostoma albigutta
20. Lutjanus campechianus
21. Malacocephalus occidentalis
22. Merluccius bilinearis
23. Monolene sp.
24. Neomerinthe hemingwayi
25. Ogcocephalus parvus
26. Parasudis truculentus
27. Peristedion gracile
28. Poecilopsetta beanii
29. Pontinus longispinus
30. Porichthys porosissimus
31. Prionotus rubio
32. Prionotus stearnsi
33. Raja lentiginosa
34. Rypticus maculatus
35. Saurida brasiliensis
36. Trichopsetta ventralis
37. Urophycis cirratus
38. Zalieutes mcgintyi

DECAPOD CRUSTACEA

PENAEIDEA

1. Penaeus duorarum
2. Sicyonia brevirostris
3. Solenocera vioscai

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida forceps
2. Munida irrasa

BRACHYURA

1. Portunus spinicarpus
2. Raninoides louisianensis
3. Anasimus latus
4. Calappa springeri
5. Leiolambrus nitidus
6. Iliacantha subglobosa
7. Acanthocarpus alexandri
8. Goneplax barbata
9. Chasmocarcinus cylindricus
10. Pyromaia cuspidata
11. Portunus sayi
12. Podochela sidneyi

ASTEROIDEA

1. Astropecten cingulatus
2. Tethyaster grandis
3. Goniaster tessellatus

ECHINOIDEA

1. Brissopsis atlantica

100 Meters (cont'd)

GASTROPODA

1. *Antillophos candei*
2. *Polystira albida*

SCAPHOPODA

1. *Dentalium laqueatum*
2. *Dentalium ceratum*

TERECO CORPORATION
P. O. Box 2848
College Station, Texas 77840
Telephone (713) 846-7087 or 846-0211

150 METERS

FISHES (33 Species)

DOMINANTS

1. Ancylopsetta dilecta
2. Pristipomoides aquilonaris
3. Pontinus longispinus
4. Trichopsetta ventralis
5. Monolene sp.
6. Haliuetichthys aculeatus

OTHERS

7. Bellator militaris
8. Bembrops anatirostris
9. Bembrops gobioides
10. Caulolatilus sp.
11. Centropristis philadelphica
12. Citharichthys cornutus
13. Coelorhynchus caribbaeus
14. Congrina flava
15. Decodon puellaris
16. Dibranchus atlanticus
17. Hemanthias vivanus
18. Malacocephalus occidentalis
19. Merluccius bilinearis
20. Neomerinthe hemingwayi
21. Ogcocephalus vespertilio
22. Parasudis truculentus
23. Poecilopsetta beanii
24. Prionotus rubio
25. Prionotus stearnsi
26. Raja lentiginosa
27. Saurida brasiliensis
28. Scorpaena agassizii
29. Steindachneria argentea
30. Syacium papillosum
31. Synodus poeyi
32. Urophycis cirratus
33. Zalieutes mcgintyi

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Solenocera vioscai
2. Parapenaeus longirostris
3. Hymenopenaeus tropicalis

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida forceps
2. Munida irrasa
3. Munida longipes

BRACHYURA

*1. Acanthocarpus alexandri
*2. Raninoides louisianensis
3. Iliacantha subglobosa
4. Parthenope agona
5. Stenocionops spinimana
6. Osachila tuberosa
7. Palicus sicus
8. Calappa angusta
9. Parthenope pourtalesii
10. Pyromaia arachna
11. Pyromaia cuspidata
12. Podochela sidneyi
13. Palicus obesus
14. Chasmocarcinus cylindricus
15. Anasimus latus

ASTEROIDEA

1. Astropecten nitidus
2. Cheiraster echinulatus
3. Rosaster alexandri
4. Anthenoides piercei
5. Coronaster briareus
6. Luidia barbadensis
7. Tethyaster grandis

ECHINOIDEA

1. Brissopsis atlantica
2. Brissopsis alta
3. Stylocidaris affinis
4. Stylocidaris sp.
5. Genocidaris maculata
6. Conolampas sigsbei
7. Lytechinus euerces

150 Meters (cont'd)

OPHIUROIDEA

1. *Ophiostigma isocanthum*
2. *Ophioderma* sp.
3. *Ophiophragma filograneus*

MOLLUSCA

GASTROPODA

1. *Murex beanii*
2. *Conus mazei*
3. *Sconsia striata*
4. *Polystira albida*
5. *Antillophos candei*

SCAPHOPODA

1. *Dentalium laqueatum*
2. *Dentalium ceratum*
3. *Dentalium stenoschizum*

CEPHALOPODA

1. *Semirossia tenera*

200 METERS

FISHES (51 Species)

DOMINANTS

1. Pontinus longispinus
2. Bembrops anatirostris
3. Monolene sp.
4. Pristipomoides aquilonaris
5. Urophycis cirratus
6. Lepophidium brevibarbe

OTHERS

7. Ancylopsetta dilecta
8. Bembrops gobioides
9. Bythites sp.
10. Callionymus agassizi
11. Caulolatilus sp.
12. Citharichthys cornutus
13. Citharichthys gymnorhinus
14. Coelorhynchus caribbaeus
15. Congrina flava
16. Decodon puellaris
17. Dibranchus atlanticus
18. Gnathagnus egregius
19. Gonioplectrus hispanus
20. Hemanthias leptus
21. Hoplunnis macrurus
22. Hoplunnis schmidtii
23. Hoplunnis tenuis
24. Lophius sp.
25. Malacocephalus occidentalis
26. Merluccius bilinearis
27. Muraenesox sp.
28. Myrophis punctatus
29. Neobythites gillii
30. Neomerinthe beanorum
31. Neomerinthe hemingwayi
32. Ophichthus sp.
33. Parahollardia lineata
34. Parasudis truculentus
35. Physiculus fulvus
36. Poecilopsetta beanii
37. Prionotus beanii
38. Prionotus rubio
39. Prionotus stearnsi
40. Raja lentiginosa
41. Saurida brasiliensis
42. Steindachneria argentea
43. Syacium papillosum
44. Synodus poeyi
45. Trichopsetta ventralis
46. Uroconger syringinus
47. Urophycis cirratus
48. Urophycis floridanus
49. Urophycis regius
50. Xenomystax atrarius
51. Zalieutes mcgintyi

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Parapenaeus longirostris
2. Solenocera vioscai
3. Penaeopsis megalops
4. Solenocera necopina
5. Hymenopenaeus tropicalis

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

*1. Munida forceps
2. Munida flinti
3. Munida irrasa
4. Munida sculpta
5. Munida longipes

BRACHYURA

*1. Acanthocarpus alexandri
*2. Thalassoplax angusta
*3. Raninoides louisianensis
*4. Pyromaia arachna
5. Lyreidus bairdii
6. Chasmocarcinus cylindricus
7. Eucratodes agassizii
8. Calappa angusta

200 Meters (cont'd)

BRACHYURA (cont'd)

9. _Osachila tuberosa_
10. _Cyclodorippe antennaria_
11. _Benthochascon schmitti_
12. _Anasimus latus_
13. _Palicus dentatus_
14. _Palicus sicus_
15. _Solenolambrus typicus_
16. _Stenocionops spinimana_
17. _Iliacantha subglobosa_
18. _Pyromaia cuspidata_
19. _Parthenope agona_
20. _Podochela sidneyi_
21. _Palicus obesus_
22. _Ethusa microphthalma_
23. _Euphrosynoplax clausa_
24. _Myropsis quinquespinosa_
25. _Collodes leptocheles_
26. _Tetraxanthus rathbunae_

ASTROIDEA

1. _Anthenoides piercei_
2. _Luidia elegans_
3. _Astropecten nitidus_
4. _Cheiraster echinulatus_
5. _Luidia barimae_
6. _Rosaster alexandri_
7. _Tethyaster grandis_

ECHINOIDEA

1. _Brissopsis atlantica_
2. _Brissopsis alta_
3. _Brissopsis elongata_
4. _Hypselaster limicolus_
5. _Stylocidaris affinis_

OPHIUROIDEA

1. _Ophiosphalma_ sp.
2. _Ophiomusium_ sp.

250 METERS

FISHES (22 Species)

DOMINANTS

1. Poecilopsetta beanii
2. Steindachneria argentea
3. Coelorhynchus caribbaeus
4. Bembrops anatirostris
5. Hymenocephalus cavernosus
6. Parasudis truculentus

OTHERS

7. Ancylopsetta dilecta
8. Bembrops gobioides
9. Bythites sp.
10. Dibranchus atlanticus
11. Gnathagnus egregius
12. Lepophidium brevibarbe
13. Malacocephalus occidentalis
14. Merluccius bilinearis
15. Monolene sp.
16. Mystriophis sp.
17. Physiculus fulvus
18. Pristipomoides aquilonaris
19. Squalus cubensis
20. Trichopsetta ventralis
21. Urophycis cirratus
22. Urophycis regius

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Penaeopsis megalops
2. Parapenaeus longirostris
3. Hymenopenaeus robustus
4. Solenocera necopina
5. Solenocera vioscai

CARIDEA

DOMINANTS (in rank order)

1. Parapandalus willisi
2. Plesionika tenuipes
3. Systellaspis affinis

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida longipes
2. Munida forceps

BRACHYURA

*1. Lyreidus bairdii
*2. Acanthocarpus alexandri
3. Benthochascon schmitti
4. Ethusa microphthalma
5. Euphrosynoplax clausa
6. Myropsis quinquespinosa
7. Collodes leptocheles
8. Stenocionops spinosissima
9. Palicus gracilis
10. Parthenope agona
11. Pyromaia arachna
12. Thalassoplax angusta
13. Palicus sicus
14. Iliacantha subglobosa

ASTEROIDEA

1. Astropecten americanus
2. Tethyaster grandis
3. Anthenoides piercei

ECHINOIDEA

1. Brissopsis alta
2. Brissopsis atlantica
3. Hypselaster limicolus
4. Stylocidaris affinis

BIVALVIA

1. Nuculana acuta
2. Yoldia solenoides

250 Meters (cont'd)

GASTROPODA

1. Gemmula periscelida
2. Polystira albida
3. Sconsia striata
4. Antillophos candei
5. Conus mazei

SCAPHOPODA

1. Dentalium laqueatum
2. Cadulus sp.

CEPHALOPODA

1. Semirossia equalis
2. Semirossia tenera

TERECO CORPORATION
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300 METERS

FISHES (14 Species)

DOMINANTS

No dominants

OTHERS

1. Bembrops anatirostris
2. Bembrops gobioides
3. Bythites sp.
4. Coelorhynchus caribbaeus
5. Dibranchus atlanticus
6. Gnathagnus egregius
7. Hymenocephalus cavernosus
8. Malacocephalus occidentalis
9. Merluccius bilinearis
10. Parasudis truculentus
11. Poecilopsetta beanii
12. Physiculus fulvus
13. Urophycis cirratus
14. Urophycis regius

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Penaeopsis megalops
2. Parapenaeus longirostris
3. Hymenopenaeus robustus
4. Hymenopenaeus debilis
5. Solenocera vioscai

CARIDEA

DOMINANTS (in rank order)

1. Systellaspis affinis
2. Pasiphaea merriami
3. Pontocaris caribbaeus
4. Plesionika tenuipes
5. Nematocarcinus rotundus
6. Parapandalus willisi

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida longipes
2. Munida forceps

BRACHYURA

* 1. Lyreidus bairdii
* 2. Acanthocarpus alexandri
3. Benthochascon schmitti
4. Ethusa microphthalma
5. Myropsis quinquespinosa
6. Collodes leptocheles
7. Palicus gracilis
8. Parthenope agona
9. Pyromaia arachna
10. Thalassoplax angusta
11. Palicus sicus
12. Iliacantha subglobosa

ASTEROIDEA

1. Astropecten americanus

ECHINOIDEA

1. Hypselaster limicolus
2. Brissopsis atlantica
3. Brissopsis alta
4. Agassizia excentrica
5. Echinolampas depressa
6. Stylocidaris affinis

BIVALVIA

1. Astarte cf. nana
2. Yoldia solenoides

300 Meters (cont'd)

GASTROPODA

1. *Gemmula periscelida*
2. *Polystira albida*
3. *Oocorys bartschi*
4. *Antillophos candei*
5. *Conus mazei*

SCAPHOPODA

1. *Dentalium laqueatum*
2. *Cadulus* sp.

CEPHALOPODA

1. *Semirossia equalis*
2. *Semirossia tenera*

TERECO CORPORATION
P. O. Box 2848
College Station, Texas 77840
Telephone (713) 846-7087 or 846-0211

350 METERS

FISHES (15 Species)

DOMINANTS

1. Coelorhynchus caribbaeus
2. Bembrops gobioides

OTHERS

3. Bembrops anatirostris
4. Bythites sp.
5. Dibranchus atlanticus
6. Gnathagnus egregius
7. Hymenocephalus cavernosus
8. Malacocephalus occidentalis
9. Merluccius bilinearis
10. Parasudis truculentus
11. Physicullus fulvus
12. Poecilopsetta beanii
13. Saccogaster maculatus
14. Urophycis cirratus
15. Urophycis regius

DECAPOD CRUSTACEA

DOMINANTS

1. Penaeopsis megalops
2. Solenocera vioscai
3. Hymenopenaeus robustus
4. Hymenopenaeus debilis

CARIDEA

DOMINANTS

*1. Plesionika tenuipes
2. Nematocarcinus rotundus
3. Systellaspis affinis
4. Parapandalus willisi
5. Pasiphaea merriami

ERYONIDEA

1. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida longipes
2. Munida forceps

BRACHYURA

1. Lyreidus bairdii
2. Palicus gracilis
3. Benthochascon schmitti
4. Parthenope agona
5. Pyromaia arachna
6. Thalassoplax angusta
7. Ethusa microphthalma
8. Collodes leptochela
9. Acanthocarpus alexandri
10. Palicus sicus
11. Iliacantha subglobosa

ASTEROIDEA

1. Astropecten americanus

ECHINOIDEA

1. Brissopsis alta
2. Stylocidaris affinis
3. Agassizia excentrica

BIVALVIA

1. Nucula sp.A
2. Nuculana hebes
3. Yoldia solenoides
4. Astarte cf. nana

OPHIUROIDEA

1. Amphilimna olivacea
2. Amphiura semiermis

350 Meters (cont'd)

GASTROPODA

1. *Antillophos candei*
2. *Gemmula periscelida*
3. *Conus mazei*
4. *Oocorys bartschi*

SCAPHOPODA

1. *Dentalium circumcinctum*
2. *Pulsellum pressum*
3. *Cadulus* sp.
4. *Dentalium laqueatum*

CEPHALOPODA

1. *Semirossia equalis*
2. *Semirossia tenera*
3. *Rossia bullisi*

400 METERS

FISHES (21 Species)

DOMINANTS

1. Bembrops gobioides
2. Dibranchus atlanticus
3. Coelorhynchus carminatus
4. Peristedion greyae
5. Malacocephalus occidentalis
6. Symphurus piger

OTHERS

7. Bembrops anatirostris
8. Breviraja sinusmexicanus
9. Bythites sp.
10. Chaunax pictus
11. Chlorophathalmus agassizii
12. Gnathagnus egregius
13. Hymenocephalus cavernosus
14. Merluccius bilinearis
15. Parasudis truculentus
16. Physiculus fulvus
17. Poecilopsetta beanii
18. Trachyscorpis cristulata
19. Urophycis cirratus
20. Urophycis regius
21. Urophycis tenuis

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

* 1. Penaeopsis megalops
* 2. Hymenopenaeus robustus
3. Hymenopenaeus debilis
4. Plesiopenaeus edwardsianus
5. Solenocera vioscai

CARIDEA

DOMINANTS

1. Parapandalus willisi
2. Systellaspis affinis
3. Plesionika tenuipes
4. Plesionika edwardsii
5. Sabinea tridentata
6. Nematocarcinus rotundus
7. Pasiphaea merriami

ERYONIDEA

1. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida longipes
2. Munidopsis tridentata
3. Munidopsis longimanus
4. Munidopsis robusta
5. Munidopsis polita

BRACHYURA

1. Lyreidus bairdii
2. Benthochascon schmitti
3. Acanthocarpus alexandri
4. Rochinia crassa
5. Palicus gracilis
6. Palicus sicus
7. Parthenope agona
8. Dicranodromia ovata
9. Thalassoplax angusta
10. Pyromaia arachna
11. Collodes leptocheles
12. Geryon quinquedens
13. Ilicantha subglobosa
14. Ethusa microphthalma

400 Meters (cont'd)

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

ASTEROIDEA

* 1. *Astropecten americanus*
* 2. *Doraster constellatus*
3. *Nymphaster arenatus*

ECHINOIDEA

1. *Stylocidaris affinis*
2. *Podocidaris sculpta*
3. *Palaeobrissus hilgardi*
4. *Araeosoma fenestratum*
5. *Brissopsis alta*
6. *Agassizia excentrica*

BIVALVIA

1. *Amygdalum politum*
2. *Abra longicallis*
3. *Nuculana platessa*
4. *Yoldia solenoides*

OPHIUROIDEA

1. *Amphiura semiermis*

GASTROPODA

1. *Antillophos candei*
2. *Scaphander watsoni*
3. *Gemmula periscelida*
4. *Conus mazei*
5. *Oocorys bartschi*

SCAPHOPODA

1. *Pulsellum pressum*
2. *Dentalium circumcinctum*
3. *Cadulus* sp.
4. *Dentalium laqueatum*

CEPHALOPODA

1. *Semirossia tenera*
2. *Rossia bullisi*

450 METERS

FISHES (22 Species)

DOMINANTS

1. Hymenocephalus cavernosus
2. Bembrops gobioides
3. Dibranchus atlanticus
4. Urophycis cirratus
5. Symphurus marginatus
6. Scytelichthys sp.

OTHERS

7. Bembrops anatirostris
8. Breviraja sinusmexicanus
9. Bythites sp.
10. Chaunax pictus
11. Chlorophthalmus agassizii
12. Coelorhynchus carminatus
13. Gnathagnus egregius
14. Malacocephalus occidentalis
15. Merluccius bilinearis
16. Parasudis truculentis
17. Peristedion greyae
18. Physciculus fulvus
19. Poecilopsetta beanii
20. Symphurus piger
21. Urophycis regius
22. Urophycis tenuis

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Penaeopsis megalops
2. Hymenopenaeus robustus
3. Hymenopenaeus debilis
4. Plesiopenaeus edwardsianus
5. Solenocera vioscai

CARIDEA

DOMINANTS

*1. Heterocarpus ensifer
2. Parapandalus willisi
3. Pontophilus gracilis
4. Nematocarcinus rotundus
5. Systellaspis affinis
6. Plesionika tenuipes
7. Pasiphaea merriami

ERYONIDEA

1. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata

PAGUROIDEA

1. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida longipes
2. Munida valida
3. Munidopsis polita
4. Munidopsis robusta
5. Munidopsis longimanus

BRACHYURA

1. Lyreidus bairdii
2. Ethusa microphthalma
3. Palicus gracilis
4. Bathyplax typhla
5. Benthochascon schmitti
6. Geryon quinquedens
7. Rochinia crassa
8. Iliacantha subglobosa
9. Pyromaia arachna
10. Thalassoplax angusta

450 Meters (cont'd)

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Astropecten americanus
2. Doraster constellatus
3. Nymphaster arenatus

ECHINOIDEA

1. Phormosoma placenta
2. Brissopsis alta
3. Agassizia excentrica

OPHIUROIDEA

1. Amphichilus daleus
2. Amphioplus tumidus
3. Amphiura semiermis

BIVALVIA

1. Amygdalum politum
2. Abra longicallis

GASTROPODA

1. Gemmula periscelida
2. Scaphander watsoni
3. Conus mazei
4. Oocorys bartschi

SCAPHOPODA

1. Dentalium circumcinctum
2. Pulsellum pressum
3. Cadulus sp.
4. Dentalium laqueatum

CEPHALOPODA

1. Semirossia tenera
2. Rossia bullisi
3. Pteroctopus tetracirrhus
4. Benthoctopus januari

500 METERS

FISHES (26 Species)

DOMINANTS

1. Dibranchus atlanticus
2. Nezumia hildebrandi
3. Coelorhynchus carminatus
4. Bembrops gobioides
5. Malacocephalus occidentalis
6. Hymenocephalus cavernosus

OTHERS

7. Bathygadus macrops
8. Bembrops anatirostris
9. Breviraja sinusmexicanus
10. Bythites sp.
11. Chaunax pictus
12. Chlorophthalmus agassizii
13. Conger oceanicus
14. Gnathagnus egregius
15. Hydrolagus alberti
16. Merluccius bilinearis
17. Merluccius magnoculus
18. Parasudis truculentus
19. Peristedion greyae
20. Physiculus fulvus
21. Poecilopsetta beanii
22. Symphurus marginatus
23. Symphurus piger
24. Urophycis cirratus
25. Urophycis regius
26. Urophycis tenuis

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Hymenopenaeus robustus
2. Hymenopenaeus debilis
3. Aristaeomorpha foliacea
4. Aristaeus antillensis
5. Solenocera vioscai
6. Penaeopsis megalops
7. Plesiopenaeus edwardsianus

CARIDEA

DOMINANTS

*1. Glyphocrangon longleyi
*2. Plesionika holthuisi
3. Plesionika martia
4. Plesionika polyacanthomerus
5. Pasiphaea merriami
6. Nematocarcinus rotundus
7. Systellaspis affinis
8. Plesionika tenuipes
9. Pontophilus gracilis

ERYONIDEA

1. Polycheles typhlops
2. Stereomastis sculpta

NEPHROPIDEA

1. Nephropsis aculeata
2. Nephropsis rosea
3. Acanthacaris caecus

PAGUROIDEA

1. Porcellana sigsbeiana
2. Sympagurus pictus
3. Sympagurus pilimanus

GALATHEOIDEA

*1. Munida valida
*2. Munidopsis robusta
3. Munidopsis erinaceus
4. Munidopsis polita
5. Munida longipes
6. Munidopsis alaminos
7. Munidopsis longimanus

BRACHYURA

1. Bathyplax typhla
2. Benthochascon schmitti
3. Trichopeltarion nobile
4. Rochinia crassa
5. Ethusa microphthalma

500 Meters (cont'd)

BRACHYURA (cont'd)

6. Iliacantha subglobosa
7. Pyromaia arachna
8. Thalassoplax angusta
9. Palicus gracilis
10. Geryon quinquedens
11. Lyreidus bairdii

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Persephonaster echinulatus
2. Midgardia xandaros
3. Plinthaster dentatus
4. Nymphaster arenatus
5. Doraster constellatus
6. Astropecten americanus

HOLOTHUROIDEA

1. Molpadia musculus
2. Mesothuria lactea
3. Hedingia albicans
4. Molpadia oolitica

ECHINOIDEA

1. Phormosoma placenta
2. Agassizia excentrica
3. Brissopsis alta

OPHIUROIDEA

1. Amphiura semiermis
2. Amphitarsus nike
3. Ophiochiton grandis
4. Amphiophiura sp.
5. Ophiopyren sp.

BIVALVIA

1. Amygdalum politum
2. Abra longicallis

GASTROPODA

1. Gaza superba
2. Scaphander watsoni
3. Gemmula periscelida
4. Conus mazei
5. Oocorys bartschi

SCAPHOPODA

1. Dentalium circumcinctum
2. Pulsellum pressum
3. Cadulus sp.
4. Dentalium laqueatum

CEPHALOPODA

1. Semirossia tenera
2. Rossia bullisi
3. Pteroctopus tetracirchus
4. Benthoctopus januari

550 METERS

FISHES (39 Species)

DOMINANTS

1. Coelorhynchus carminatus
2. Hymenocephalus cavernosus
3. Dibranchus atlanticus
4. Peristedion greyae
5. Malacocephalus occidentalis
6. Chlorophthalmus agassizii

OTHERS

7. Bathygadus macrops
8. Bathygadus vaillanti
9. Bembrops anatirostris
10. Bembrops gobioides
11. Benthodesmus atlanticus
12. Breviraja sinusmexicanus
13. Bythites sp.
14. Chaunax nuttingi
15. Chaunax pictus
16. Conger oceanicus
17. Etmopterus schultzi
18. Etmopterus spinax
19. Gadella maraldi
20. Gadomus longifilis
21. Gnathagnus egregius
22. Halosaurus guntheri
23. Hydrolagus alberti
24. Laemonema barbatulum
25. Merluccius bilinearis
26. Merluccius productus
27. Neobythites marginatus
28. Nezumia hildebrandi
29. Physiculus fulvus
30. Physiculus kaupi
31. Poecillopsetta beanii
32. Raja clarkii
33. Scyliorhinus profundorum
34. Symphurus marginatus
35. Urophycis chesteri
36. Urophycis cirratus
37. Urophycis regius
38. Ventrifossa atlantica
39. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Hymenopenaeus robustus
2. Aristaeomorpha foliacea
3. Penaeopsis megalops
4. Plesiopenaeus edwardsianus
5. Hymenopenaeus debilis
6. Aristaeus antillensis
7. Solenocera vioscai

CARIDEA

DOMINANTS

*1. Glyphocrangon longleyi
*2. Plesionika holthuisi
3. Plesionika acanthonotus
4. Pontophilus gracilis
5. Nematocarcinus rotundus
6. Systellaspis affinis
7. Pasiphaea merriami
8. Plesionika polyacanthomerus

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata
2. Nephropsis rosea
3. Acanthacaris caecus

PAGUROIDEA

1. Sympagurus pictus
2. Sympagurus pilimanus
3. Porcellana sigsbeiana

550 Meters (cont'd)

GALATHEOIDEA

1. Munida valida
2. Munidopsis robusta
3. Munidopsis alaminos
4. Munidopsis serratifrons
5. Munidopsis polita
6. Munidopsis erinaceus
7. Munidopsis longimanus

BRACHYURA

1. Bathyplax typhla
2. Rochinia crassa
3. Benthochascon schmitti
4. Geryon quinquedens
5. Trichopeltarion nobile
6. Palicus gracilis
7. Ethusa microphthalma
8. Thalassoplax angusta
9. Iliacantha subglobosa
10. Pyromaia arachna
11. Lyreidus bairdii

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Nymphaster arenatus
2. Plinthaster dentatus
3. Doraster constellatus
4. Cheiraster enoplus
5. Midgardia xandaros
6. Persephonaster echinulatus
7. Astropecten americanus

HOLUTHUROIDEA

1. Mesothuria lactea
2. Molpidia cubana
3. Molpadia musculus
4. Molpadia oolitica
5. Hedingia albicans

ECHINOIDEA

1. Phormosoma placenta

OPHIUROIDEA

1. Amphioplus sp. B
2. Ophioleptoplax sp.
3. Ophiopyren sp.
4. Ophiochiton grandis

BIVALVIA

1. Amygdalum politum
2. Abra longicallis
3. Propeamussium sp.

GASTROPODA

1. Gaza superba
2. Gemmula periscelida
3. Conus mazei
4. Oocorys bartschi

SCAPHOPODA

1. Dentalium circumcinctum
2. Pulsellum pressum
3. Cadulus sp.
4. Dentalium laqueatum

CEPHALOPODA

1. Semirossia tenera
2. Rossia bullisi
3. Pteroctopus tetracirrhus
4. Benthoctopus januari

600 METERS

FISHES (29 Species)

DOMINANTS

1. Bathygadus macrops
2. Dibranchus atlanticus
3. Ventrifossa atlantica
4. Chaunax pictus
5. Nezumia hildebrandi
6. Diplacanthopoma brachysoma

OTHERS

7. Barathronus bicolor
8. Bathygadus vaillanti
9. Benthodesmus atlanticus
10. Breviraja sinusmexicanus
11. Bythites sp.
12. Cariburus zaniophorus
13. Coelorhynchus carminatus
14. Conger oceanicus
15. Etmopterus schultzi
16. Etmopterus spinax
17. Gadella maraldi
18. Gadomus longifilis
19. Halosaurus guntheri
20. Hymenocephalus cavernosus
21. Malacocephalus occidentalis
22. Merluccius bilinearis
23. Peristedion greyae
24. Poecilopsetta beanii
25. Promyllantor sp.
26. Raja clarkii
27. Symphurus atlanticus
28. Symphurus marginatus
29. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Hymenopenaeus debilis
2. Hymenopenaeus robustus
3. Aristaeomorpha foliacea
4. Plesiopenaeus edwardsianus
5. Penaeopsis megalops
6. Solenocera vioscai
7. Aristaeus antillensis

CARIDEA

DOMINANTS

*1. Pasiphaea merriami
*2. Plesionika holthuisi
3. Nematocarcinus rotundus
4. Plesionika acanthonotus
5. Glyphocrangon longleyi
6. Pontophilus gracilis
7. Systellaspis affinis
8. Plesionika polyacanthomerus

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata
2. Nephropsis rosea
3. Acanthacaris caecus

PAGUROIDEA

1. Sympagurus pictus
2. Sympagurus pilimanus
3. Dardanus insignis
4. Uroptychus nitidus
5. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida valida
2. Munidopsis erinaceus
3. Munidopsis alaminos
4. Munidopsis longimanus
5. Munidopsis polita
6. Munidopsis robusta

BRACHYURA

1. Bathyplax typhla
2. Ranilia constricta

600 Meters (cont'd)

BRACHYURA (cont'd)

3. Iliacantha subglobosa
4. Lyreidus bairdii
5. Rochinia crassa
6. Palicus gracilis
7. Trichopeltarion nobile
8. Benthochascon schmitti
9. Pyromaia arachna
10. Thalassoplax angusta
11. Ethusa microphthalma
12. Geryon quinquedens

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Nymphaster arenatus
2. Cheiraster enoplus
3. Midgardia xandaros
4. Goniopecten demonstrans
5. Doraster constellatus
6. Pseudarchaster n. sp.
7. Ceramaster sp. A
8. Astropecten antillensis
9. Pteraster militaroides
10. Astropecten americanus
11. Plinthaster dentatus
12. Persephonaster echinulatus

HOLOTHUROIDEA

1. Ypsilothuria talismani
2. Hedingia albicans
3. Bathyplotes natans
4. Molpadia musculus
5. Mesothuria lactea
6. Molpadia oolitica
7. Molpadia cubana

ECHINOIDEA

1. Phormosoma placenta

OPHIUROIDEA

1. Ophiopyren sp.
2. Bathypectinura tesselata
3. Ophiochiton grandis

BIVALVIA

1. Amygdalum politum
2. Abra longicallis
3. Propeamussium sp.

GASTROPODA

1. Gaza superba
2. Scaphander clavus
3. Oocorys bartschi
4. Gemmula periscelida
5. Conus mazei
6. Scaphella gouldiana

SCAPHOPODA

1. Dentalium circumcinctum
2. Pulsellum pressum
3. Dentalium laqueatum
4. Cadulus sp.

CEPHALOPODA

1. Semirossia tenera
2. Benthoctopus januari

650 METERS

FISHES (27 Species)

DOMINANTS

1. Nezumia hildebrandi
2. Bathygadus macrops
3. Coelorhynchus carminatus
4. Etmopterus pusillus
5. Cariburus zaniophorus
6. Bythites sp.

OTHERS

7. Barathronus bicolor
8. Bathygadus vaillanti
9. Benthodesmus atlantica
10. Chaunax pictus
11. Dibranchus atlanticus
12. Diplacanthopoma brachysoma
13. Etmopterus schultzi
14. Etmopterus spinax
15. Gadella maraldi
16. Gadomus longifilis
17. Halosaurus guntheri
18. Malacocephalus occidentalis
19. Merluccius bilinearis
20. Peristedion greyae
21. Poecilopsetta beanii
22. Promyllantor sp.
23. Raja clarkii
24. Symphurus marginatus
25. Synaphobranchus oregoni
26. Venefica procera
27. Ventrifossa atlantica

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Aristaeomorpha foliacea
2. Plesiopenaeus edwardsianus
3. Hymenopenaeus robustus
4. Solenocera vioscai
5. Penaeopsis megalops
6. Hymenopenaeus debilis
7. Aristaeus antillensis

CARIDEA

DOMINANTS

*1. Plesionika holthuisi
2. Plesionika polyacanthomerus
3. Systellaspis affinis
4. Glyphocrangon longleyi
5. Glyphocrangon alispina
6. Nematocarcinus rotundus
7. Pasiphaea merriami
8. Psalidopus barbouri
9. Pontophilus gracilis
10. Plesionika acanthonotus

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis aculeata
2. Nephropsis rosea
3. Acanthacaris caecus

PAGUROIDEA

1. Sympagurus pilimanus
2. Sympagurus pictus
3. Uroptychus nitidus
4. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida valida
2. Munidopsis erinaceus
3. Munidopsis robusta
4. Munidopsis longimanus
5. Munidopsis polita
6. Munidopsis alaminos

BRACHYURA

1. Lyreidus bairdii
2. Bathyplax typhla
3. Trichopeltarion nobile
4. Benthochascon schmitti
5. Rochinia crassa

650 Meters (cont'd)

BRACHYURA (cont'd)

6. Geryon quinquedens
7. Ethusa microphthalma
8. Thalassoplax angusta
9. Pyromaia arachna

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Ceramaster sp. A
2. Doraster constellatus
3. Cheiraster mirabilis
4. Zoraster fulgens
5. Goniopecten demonstrans
6. Midgardia xandaros
7. Plinthaster dentatus
8. Persephonaster echinulatus
9. Pseudarchaster n. sp.
10. Cheiraster enoplus
11. Nymphaster arenatus

HOLTHUROIDEA

1. Paracaudina sp.
2. Ypsilothuria talismani
3. Hedingia albicans
4. Bathyplotes natans
5. Molpadia musculus
6. Mesothuria lactea
7. Molpadia oolitica
8. Molpadia cubana

ECHINOIDEA

1. Phormosoma placenta

OPHIUROIDEA

1. Ophiochiton grandis
2. Ophiopyren sp.
3. Bathypectinura tesselata

BIVALVIA

1. Amygdalum politum
2. Propeamussium sp.
3. Abra longicallis

GASTROPODA

1. Oocorys bartschi
2. Gemmula periscelida
3. Conus mazei
4. Gaza superba
5. Scaphander clavus

SCAPHOPODA

1. Dentalium circumcinctum
2. Cadulus sp.
3. Dentalium laqueatum
4. Pulsellum pressum

CEPHALOPODA

1. Semirossia tenera
2. Benthoctopus januari

700 METERS

FISHES (28 Species)

DOMINANTS

1. Synaphobranchus oregoni
2. Nezumia hildebrandi
3. Dibranchus atlanticus
4. Bathygadus macrops
5. Diplacanthopoma brachysoma
6. Etmopterus spinax

OTHERS

7. Barathronus bicolor
8. Benthodesmus atlanticus
9. Cariburus zaniophorus
10. Chaunax pictus
11. Dicrolene intronigra
12. Gadella maraldi
13. Gadomus arcuatus
14. Gadomus longifilis
15. Halosaurus guntheri
16. Hydrolagus media
17. Hydrolagus mirabilis
18. Malacocephalus occidentalis
19. Merluccius bilinearis
20. Monomitopus agassizii
21. Peristedion greyae
22. Poecilopsetta beanii
23. Promyllantor schmitti
24. Promyllantor sp.
25. Raja clarkii
26. Symphurus marginatus
27. Venefica procera
28. Ventrifossa atlantica

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Plesiopenaeus edwardsianus
2. Benthesicymus bartletti
3. Hymenopenaeus debilis
4. Aristeus antillensis
5. Hymenopenaeus robustus
6. Solenocera vioscai
7. Penaeopsis megalops

CARIDEA

DOMINANTS

*1. Glyphocrangon alispina
*2. Nematocarcinus rotundus
3. Plesionika holthuisi
4. Pontophilus gracilis
5. Pasiphaea merriami
6. Plesionika polyacanthomerus
7. Plesionika acanthonotus
8. Glyphocrangon nobilis
9. Heterocarpus oryx
10. Acanthephyra armata
11. Systellaspis affinis
12. Psalidopus barbouri

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis rosea
2. Nephropsis aculeata
3. Acanthacaris caecus

PAGUROIDEA

1. Sympagurus pilimanus
2. Sympagurus pictus
3. Uroptychus nitidus
4. Parapagurus pilosimanus
5. Porcellana sigsbeiana

GALATHEOIDEA

1. Munida valida
2. Munidopsis alaminos
3. Munidopsis longimanus
4. Munidopsis polita
5. Munidopsis robusta
6. Munidopsis erinaceus

700 Meters (cont'd)

BRACHYURA

1. *Bathyplax typhla*
2. *Lyreidus bairdii*
3. *Trichopeltarion nobile*
4. *Pyromaia arachna*
5. *Rochina crassa*
6. *Geryon quinquedens*
7. *Ethusa microphthalma*
8. *Thalassoplax angusta*

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

ASTEROIDEA

1. *Doraster constellatus*
2. *Plinthaster dentatus*
3. *Cheiraster enoplus*
4. *Persephonaster echinulatus*
5. *Pseudarchaster* n. sp.
6. *Midgardia xandaros*
7. *Cheiraster mirabilis*
8. *Nymphaster arenatus*
9. *Goniopecten demonstrans*
10. *Zoraster fulgens*

HOLOTHUROIDEA

1. *Mesothuria lactea*
2. *Molpadia oolitica*
3. *Molpadia musculus*
4. *Molpadia barbouri*
5. *Hedingia albicans*
6. *Benthodytes sanguinolenta*
7. *Ypsilothuria talismani*
8. *Bathyplotes natans*
9. *Molpadia cubana*

ECHINOIDEA

1. *Phormosoma placenta*

OPHIUROIDEA

1. *Ophiopyren* sp.
2. *Bathypectinura* sp.
3. *Ophiochiton grandis*
4. *Bathypectinura tesselata*

BIVALVIA

1. *Abra longicallis*
2. *Amygdalum politum*
3. *Propeamussium* sp.

GASTROPODA

1. *Gaza superba*
2. *Scaphander clavus*
3. *Pleurotomella* (cf. *agassizii*)
4. *Leucosyrinx subgrundifera*
5. *Leucosyrinx* (cf. *sigsbei*)
6. *Leucosyrinx verrilli*
7. *Volutomitra* (cf. *bairdii*)
8. *Oocorys bartschi*

SCAPHOPODA

1. *Dentalium circumcinctum*
2. *Cadulus* sp.
3. *Dentalium laqueatum*
4. *Pulsellum pressum*

CEPHALOPODA

1. *Semirossia tenera*
2. *Benthoctopus januari*

750 METERS

FISHES (30 Species)

DOMINANTS

1. Synaphobranchus oregoni
2. Bathygadus vaillanti
3. Nezumia hildebrandi
4. Dicrolene intronigra
5. Promyllantor sp.
6. Cariburus zaniophorus

OTHERS

7. Barathronus bicolor
8. Bathygadus macrops
9. Bathypterois longipes
10. Bathytroctes sp.
11. Benthodesmus atlanticus
12. Chaunax pictus
13. Dibranchus atlanticus
14. Diplacanthopoma brachysoma
15. Etmopterus schultzi
16. Etmopterus spinax
17. Gadomus arcuatus
18. Gadomus longifilis
19. Halosaurus guntheri
20. Hydrolagus mirabilis
21. Leptoderma macrops
22. Malacocephalus occidentalis
23. Merluccius bilinearis
24. Monomitopus agassizii
25. Poecilopsetta beanii
26. Promyllantor schmitti
27. Raja clarkii
28. Symphurus marginatus
29. Trachonurus sulcatus
30. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Hymenopenaeus debilis
3. Hymenopenaeus robustus
4. Penaeopsis megalops
5. Aristeus antillensis
6. Solenocera vioscai
7. Plesiopenaeus edwardsianus

CARIDEA

DOMINANTS

*1. Glyphocrangon alispina
*2. Nematocarcinus rotundus
3. Plesionika holthuisi
4. Pontophilus gracilis
5. Acanthephyra armata
6. Plesionika polyacanthomerus
7. Systellaspis affinis
8. Pasiphaea merriami
9. Plesionika acanthonotus
10. Psalidopus barbouri
11. Glyphocrangon nobilis
12. Heterocarpus oryx

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis rosea
2. Nephropsis aculeata
3. Acantharis caecus

PAGUROIDEA

1. Parapagurus pilosimanus
2. Sympagurus pictus
3. Uroptchus nitidus
4. Porcellana sigsbeiana
5. Sympagurus pilimanus

GALATHEOIDEA

1. Munidopsis longimanus
2. Munida valida
3. Munidopsis erinaceus
4. Munidopsis sigsbei
5. Munidopsis polita
6. Munidopsis robusta
7. Munidopsis alaminos

750 Meters (cont'd)

BRACHYURA

1. *Bathyplax typhla*
2. *Thalassoplax angusta*
3. *Geryon quinquedens*
4. *Lyreidus bairdii*
5. *Ethusa microphthalma*
6. *Trichopeltarion nobile*
7. *Rochinia crassa*

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

ASTEROIDEA

1. *Cheiraster mirabilis*
2. *Nymphaster arenatus*
3. *Brisingella verticellata*
4. *Plutonaster intermedius*
5. *Doraster constellatus*
6. *Persephonaster echinulatus*
7. *Midgardia xandaros*
8. *Goniopecten demonstrans*
9. *Zoraster fulgens*
10. *Psilaster cassiope*
11. *Plinthaster dentatus*
12. *Pseudarchaster* n. sp.

HOLOTHUROIDEA

1. *Mesothuria lactea*
2. *Hedingia albicans*
3. *Bathyplotes natans*
4. *Molpadia cubana*
5. *Molpadia musculus*
6. *Molpadia öölitica*
7. *Benthodytes sanguinolenta*
8. *Molpadia barbouri*

ECHINOIDEA

1. *Phormosoma placenta*
2. *Brissopsis* sp.

OPHIUROIDEA

1. *Ophiopyren* sp.
2. *Ophiosphalma monoplax*
3. *Bathypectinura* sp.
4. *Ophiochiton grandis*
5. *Ophiura lepida*
6. *Bathypectinura tesselata*

BIVALVIA

1. *Amygdalum politum*
2. *Abra longicallis*
3. *Propeamussium* sp.

GASTROPODA

1. *Scaphander clavus*
2. *Volutomitra* (cf. *bairdii*)
3. *Colus* sp.
4. *Bulla* (cf. *abyssicola*)
5. *Leucosyrinx subguindifera*
6. *Leucosyrinx verrilli*
7. *Oocorys bartschi*
8. *Leucosyrinx* (cf. *sigsbei*)
9. *Pleurotomella* (cf. *agassizii*)

SCAPHOPODA

1. *Dentalium laqueatum*
2. *Pulsellum pressum*
3. *Dentalium obscurum*
4. *Cadulus* sp.
5. *Dentalium circumcinctum*
6. *Dentalium perlongum*

CEPHALOPODA

1. *Semirossia tenera*
2. *Benthoctopus januari*

TERECO CORPORATION
P. O. Box 2848
College Station, Texas 77840
Telephone (713) 846-7087 or 846-0211

800 METERS

FISHES (32 Species)

DOMINANTS

1. Bathygadus vaillanti
2. Dibranchus atlanticus
3. Nezumia hildebrandi
4. Dicrolene intronigra
5. Cariburus zaniophorus
6. Cariburus mexicanus

OTHERS

7. Aldrovandia affinis
8. Barathronus bicolor
9. Bathygadus favosus
10. Bathygadus macrops
11. Bathytroctes antillarum
12. Bathytroctes sp.
13. Benthodesmus atlanticus
14. Chaunax pictus
15. Cynomacrurus sp.
16. Diplacanthopoma brachysoma
17. Etmopterus schultzi
18. Etmopterus spinax
19. Gadomus arcuatus
20. Gadomus longifilis
21. Halosaurus guntheri
22. Hydrolagus mirabilis
23. Malacocephalus occidentalis
24. Merluccius bilinearis
25. Monomitopus agassizii
26. Myxine sp.
27. Oxygadus occa
28. Promyllantor
29. Raja clarkii
30. Synaphobranchus oregoni
31. Trachonurus sulcatus
32. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Hymenopenaeus debilis
3. Plesiopenaeus edwardsianus

CARIDEA

DOMINANTS

*1. Nematocarcinus rotundus
*2. Glyphocrangon alispina
3. Glyphocrangon aculeata
4. Plesionika holthuisi
5. Heterocarpus oryx
6. Pasiphaea merriami
7. Pontophilus gracilis
8. Acanthephyra armata
9. Plesionika polyacanthomerus
10. Psalidopus barbouri
11. Glyphocrangon nobilis

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles typhlops

NEPHROPIDEA

1. Nephropsis rosea
2. Nephropsis aculeata
3. Acanthacaris caecus

PAGUROIDEA

1. Parapagurus pilosimanus
2. Sympagurus pilimanus
3. Uroptychus nitidus
4. Porcellana sigsbeiana

GALATHEOIDEA

1. Munidopsis alaminos
2. Munidopsis longimanus
3. Munida valida
4. Munidopsis subspinoculata
5. Munidopsis spinosa
6. Munidopsis tridentata
7. Munidopsis sigsbei
8. Munidopsis robusta

TERECO CORPORATION
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800 Meters (cont'd)

BRACHYURA

1. Lyreidus bairdii
2. Bathyplax typhla
3. Geryon quinquedens

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Plutonaster intermedius
2. Persephonaster echinulatus
3. Plinthaster dentatus
4. Pseudarchaster n. sp.
5. Midgardia xandaros
6. Cheiraster mirabilis
7. Nymphaster arenatus
8. Goniopecten demonstrans
9. Zoraster fulgens
10. Doraster constellatus

HOLOTHUROIDEA

1. Mesothuria lactea
2. Euphronides kerheveri
3. Echinocucumis hispida
4. Molpadia musculus
5. Benthodytes sanguinolenta
6. Molpadia barbouri
7. Bathyplotes natans

ECHINOIDEA

1. Phormosoma placenta
2. Brissopsis sp.

OPHIUROIDEA

1. Bathypectinura sp.

BIVALVIA

1. Propeamussium sp.
2. Abra longicallis

GASTROPODA

1. Scaphander clavus
2. Leucosyrinx subgrundifera
3. Leucosyrinx cf. sigsbei
4. Volutomitra cf. bairdii
5. Pleurotomella cf. agassizii
6. Leucosyrinx verrilli
7. Oocorys bartschi

SCAPHOPODA

1. Dentalium perlongum
2. Dentalium circumcinctum
3. Dentalium laqueatum
4. Cadulus sp.
5. Pulsellum pressum
6. Dentalium obscurum

CEPHALOPODA

1. Semirossia tenera
2. Benthoctopus januari

850 METERS

FISHES (27 Species)

DOMINANTS

1. Bathygadus vaillanti
2. Dibranchus atlanticus
3. Nezumia hildebrandi
4. Dicrolene intronigra
5. Cariburus zaniophorus
6. Monomitopus agassizii

OTHERS

7. Aldrovandia affinis
8. Barathronus bicolor
9. Bathygadus favosus
10. Bathygadus macrops
11. Bathytroctes sp.
12. Cariburus mexicanus
13. Diplolychnus sp.
14. Etmopterus spinax
15. Etmopterus schultzi
16. Gadomus arcuatus
17. Gadomus longifilis
18. Halosaurus guntheri
19. Hydrolagus mirabilis
20. Malacocephalus occidentalis
21. Monolene sp.
22. Oxygadus occa
23. Promyllantor sp.
24. Raja clarkii
25. Synaphobranchus oregoni
26. Trachonurus sulcatus
27. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Plesiopenaeus edwardsianus
3. Hymenopenaeus debilis

CARIDEA

DOMINANTS

*1. Nematocarcinus rotundus
*2. Pontophilus gracilis
3. Glyphocrangon aculeata
4. Glyphocrangon alispina
5. Parapandalus richardi
6. Plesionika holthuisi
7. Plesionika polyacanthomerus
8. Psalidopus barbouri
9. Glyphocrangon nobilis
10. Heterocarpus oryx
11. Acanthephyra armata

ERYONIDEA

1. Stereomastis sculpta

NEPHROPIDEA

1. Nephropsis aculeata
2. Acanthacaris caecus

PAGUROIDEA

1. Parapagurus pilosimanus
2. Sympagurus pilimanus
3. Uroptychus nitidus
4. Porcellana sigsbeiana

GALATEOIDEA

1. Munidopsis longimanus
2. Munidopsis sigsbei
3. Munida valida
4. Munidopsis robusta
5. Munidopsis spinosa

BRACHYURA

1. Bathyplax typhla
2. Geryon quinquedens

850 Meters (cont'd)

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Nymphaster arenatus
2. Goniopecten demonstrans
3. Zoraster fulgens
4. Plutonaster intermedius
5. Cheiraster mirabilis
6. Midgardia xandaros
7. Pseudarchaster n. sp.
8. Plinthaster dentatus
9. Persephonaster echinulatus
10. Doraster constellatus

HOLOTHUROIDEA

1. Mesothuria lactea
2. Molpadia musculus
3. Bathyplotes natans
4. Molpadia barbouri
5. Benthodytes sanguinolenta
6. Echinocucumis hispida
7. Protankyra sluiteri

ECHNOIDEA

1. Plesiodiadema antillarum
2. Phormosoma placenta
3. Hemiaster expergitus
4. Brissopsis sp.

OPHIUROIDEA

1. Amphiura sp.
2. Bathypectinura sp.

BIVALVIA

1. Propeamussium sp.
2. Abra longicallis

GASTROPODA

1. Leucosyrinx (cf. sigsbei)
2. Volutomitra (cf. bairdii)
3. Pleurotomella (cf. agassizii)
4. Leucosyrinx verrilli
5. Scaphander clavus
6. Oocorys bartschi

SCAPHOPODA

1. Dentalium perlongum
2. Dentalium circumcinctum
3. Dentalium laqueatum
4. Dentalium obscurum
5. Pulsellum pressum
6. Cadulus sp.

CEPHALOPODA

1. Semirossia tenera
2. Benthoctopus januari

900 METERS

FISHES (24 Species)

DOMINANTS

1. Bathygadus vaillanti
2. Nezumia hildebrandi
3. Synaphobranchus oregoni
4. Dicrolene intronigra
5. Monomitopus agassizi
6. Halosaurus guntheri

OTHERS

7. Aldrovandia affinis
8. Barathronus bicolor
9. Bathygadus favosus
10. Bathygadus macrops
11. Cariburus mexicanus
12. Cariburus zaniophorus
13. Chimaera monstrosa
14. Dibranchus atlanticus
15. Gadomus arcuatus
16. Gadomus longifilis
17. Ilyophis brunneus
18. Malacocephalus occidentalis
19. Oxygadus occa
20. Promyllantor sp.
21. Raja bathyphila
22. Raja clarkii
23. Trachonurus sulcatus
24. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Hymenopenaeus debilis
3. Plesiopenaeus edwardsianus

CARIDEA

DOMINANTS

*1. Nematocarcinus rotundus
2. Glyphocrangon alispina
3. Glyphocrangon aculeata
4. Heterocarpus oryx
5. Glyphocrangon nobilis
6. Pontophilus gracilis
7. Plesionika holthuisi
8. Acanthephyra eximia
9. Acanthephyra armata
10. Plesionika polyacanthomerus
11. Psalidopus barbouri

ERYONIDEA

1. Stereomastis sculpta

NEPHROPIDEA

1. Nephropsis agassizii
2. Nephropsis aculeata
3. Acanthacaris caecus

PAGUROIDEA

1. Parapagurus pilosimanus
2. Lithodes agassizii
3. Sympagurus pilimanus
4. Uroptychus nitidus
5. Porcellana sigsbeiana

GALATHEOIDEA

1. Munidopsis longimanus
2. Munidopsis sigsbei
3. Munidopsis abbreviata
4. Munidopsis robusta
5. Munidopsis spinosa
6. Munida valida

BRACHYURA

1. Geryon quinquedens
2. Rochinia umbonata
3. Bathyplax typhla
4. Ethusina abyssicola

900 METERS (cont'd)

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

ASTEROIDEA

1. *Nymphaster arenatus*
2. *Plutonaster intermedius*
3. *Persephonaster echinulatus*
4. *Zoraster fulgens*
5. *Goniopecten demonstrans*
6. *Cheiraster mirabilis*
7. *Midgardia xandaros*
8. *Pseudarchaster* n. sp.
9. *Plinthaster dentatus*
10. *Doraster constellatus*

HOLOTHUROIDEA

1. *Mesothuria lactea*
2. *Molpadia musculus*
3. *Molpadia* sp.
4. *Molpadia barbouri*
5. *Bathyplotes natans*
6. *Benthodytes sanguinolenta*
7. *Echinocucumis hispida*

ECHINOIDEA

1. *Phormosoma placenta*
2. *Plesiodiadema antillarum*
3. *Hypselaster brachypetalus*
4. *Brissopsis* sp.

OPHIUROIDEA

1. *Bathypectinura* sp.
2. *Ophioplinthaca dipsacos*

BIVALVIA

1. *Propeamussium* sp.
2. *Abra longicallis*

GASTROPODA

1. *Oocorys bartschi*
2. *Scaphander clavus*
3. *Mangelia exsculpta*
4. *Volutomitra* cf. *bairdii*
5. *Pleurotomella* cf. *agassizii*
6. *Leucosyrinx verrilli*
7. *Leucosyrinx* cf. *sigsbei*

SCAPHOPODA

1. *Dentalium perlongum*
2. *Cadulus* sp.
3. *Dentalium laqueatum*
4. *Dentalium obscurum*
5. *Dentalium circumcinctum*
6. *Pulsellum pressum*

CEPHALOPODA

1. *Semirossia tenera*
2. *Neorossia* sp.
3. *Benthoctopus januari*

950 METERS

FISHES (33 Species)

DOMINANTS

1. Dicrolene intronigra
2. Synaphobranchus oregoni
3. Gadomus longifilis
4. Monomitopus agassizii
5. Nezumia hildebrandi
6. Cariburus zaniophorus

OTHERS

7. Aldrovandia affinis
8. Aldrovandia gracilis
9. Alepocephalus agassizii
10. Barathronus bicolor
11. Bathygadus favosus
12. Bathygadus macrops
13. Bathygadus vaillanti
14. Bathypterois viridensis
15. Bathypterois quadrifilis
16. Cariburus mexicanus
17. Conocara mcdonaldi
18. Coryphaenoides sp.
19. Dibranchus atlanticus
20. Gadomus arcuatus
21. Grenurus grenadae
22. Halosarus guntheri
23. Histiobranchus bathybius
24. Ilyophis brunneus
25. Malacocephalus occidentalis
26. Oxygadus occa
27. Penopus macdonaldi
28. Raja fuliginea
29. Scyliorhinus profundorum
30. Squalogadus intermedius
31. Stephanoberyx monae
32. Trachonurus sulcatus
33. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Plesiopenaeus edwardsianus
3. Hymenopenaeus debilis

CARIDEA

DOMINANTS

*1. Nematocarcinus rotundus
*2. Glyphocrangon aculeata
*3. Heterocarpus oryx
4. Glyphocrangon alispina
5. Glyphocrangon nobilis
6. Acanthephyra armata
7. Psalidopus barbouri
8. Pontophilus gracilis
9. Acanthephyra eximia

ERYONIDEA

1. Stereomastis sculpta

NEPHROPIDEA

1. Nephropsis agassizii
2. Nephropsis aculeata
3. Acanthacaris caecus

PAGUROIDEA

1. Parapagurus pilosimanus
2. Lithodes agassizii
3. Uroptychus nitidus
4. Porcellana sigsbeiana

GALATHEOIDEA

1. Munidopsis sigsbei
2. Munidopsis spinosa
3. Munidopsis abbreviata
4. Munida valida
5. Munidopsis spinoculata
6. Munidopsis robusta
7. Munidopsis longimanus

950 METERS (cont'd)

BRACHYURA

1. Geryon quinquedens
2. Bathyplax typhla
3. Homolodromia paradoxa
4. Cymonomus cf. quadratus
5. Rochinia umbonata
6. Ethusina abyssicola

OTHER CRUSTACEA

ISOPODA

1. Bathynomus giganteus

ASTEROIDEA

1. Goniopecten demonstrans
2. Plutonaster intermedius
3. Persephonaster echinulatus
4. Cheiraster mirabilis
5. Nymphaster arenatus
6. Zoraster fulgens
7. Plinthaster dentatus
8. Psilaster patagiatus
9. Midgardia xandaros
10. Doraster constellatus
11. Pseudarchaster n. sp.

HOLOTHUROIDEA

1. Molpadia musculus
2. Molpadia barbouri
3. Molpadia sp.
4. Mesothuria lactea
5. Echinocucumis hispida
6. Benthodytes sanguinolenta
7. Bathyplotes natans

ECHINOIDEA

1. Plesiodiadema antillarum
2. Brissopsis sp.
3. Phormosoma placenta

BIVALVIA

1. Brevinucula verrillii
2. Propeamussium sp.
3. Abra longicallis

GASTROPODA

1. Mangelia exsculpta
2. Volutomitra cf. bairdii
3. Pleurotomella cf. agassizii
4. Leucosyrinx verrilli
5. Leucosyrinx cf. sigsbei

SCAPHOPODA

1. Dentalium callithrix
2. Dentalium perlongum
3. Dentalium circumcinctum
4. Pulsellum pressum
5. Entalina platamodes
6. Cadulus sp.
7. Dentalium laqueatum
8. Dentalium obscurum

CEPHALOPODA

1. Neorossia sp.
2. Benthoctopus januari

1000 METERS

FISHES (28 Species)

DOMINANTS

1. Dicrolene intronigra
2. Stephanoberyx monae
3. Nezumia hildebrandi
4. Synaphobranchus oregoni
5. Squalogadus intermedius
6. Aldrovandia affinis

OTHERS

7. Aldrovandia gracilis
8. Alepocephalus agassizi
9. Bathygadus macrops
10. Bathygadus vaillanti
11. Bathypterois quadrifilis
12. Bathytroctes melanocephalus
13. Cariburus mexicanus
14. Cariburus zaniophorus
15. Conocara mcdonaldi
16. Coryphaenoides sp.
17. Dibranchus atlanticus
18. Gadomus longifilis
19. Grenurus grenadae
20. Halosaurus guntheri
21. Ilyophis brunneus
22. Malacocephalus occidentalis
23. Monomitopus agassizii
24. Oxygadus occa
25. Raja fuliginea
26. Scyliorhinus profundorum
27. Trachonurus sulcatus
28. Venefica procera

DECAPOD CRUSTACEA

PENAEIDEA

DOMINANTS

1. Benthesicymus bartletti
2. Hepomadus tener
3. Plesiopenaeus edwardsianus
4. Funchalia taaningi
5. Hymenopenaeus aphoticus
6. Hymenopenaeus debilis

CARIDEA

DOMINANTS

*1. Nematocarcinus rotundus
*2. Glyphocrangon aculeata
3. Glyphocrangon nobilis
4. Heterocarpus oryx
5. Pontophilus gracilis
6. Glyphocrangon alispina
7. Acanthephyra eximia

ERYONIDEA

1. Stereomastis sculpta
2. Polycheles crucifer

NEPHROPIDEA

1. Nephropsis agassizii
2. Nephropsis aculeata

PAGUROIDEA

1. Lithodes agassizii
2. Parapagurus pilosimanus
3. Uroptychus nitidus
4. Catapaguroides microps

GALATHEOIDEA

1. Munidopsis sigsbei
2. Munidopsis spinosa
3. Munidopsis simplex
4. Munidopsis robusta
5. Munidopsis longimanus
6. Munidopsis abbreviata
7. Munidopsis spinoculata

BRACHYURA

1. Geryon quinquedens
2. Homolodromia paradoxa
3. Ethusina abyssicola

1000 METERS (cont'd)

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

ASTEROIDEA

1. *Goniopecten demonstrans*
2. *Nymphaster arenatus*
3. *Plinthaster dentatus*
4. *Zoraster fulgens*
5. *Plutonaster intermedius*
6. *Midgardia xandaros*
7. *Pseudarchaster* n. sp.

HOLOTHUROIDEA

1. *Echinocucumis hispida*
2. *Benthodytes sanguinolenta*
3. *Deima blakei*
4. *Pelopatides* sp.
5. *Molpadia barbouri*
6. *Mesothuria lactea*
7. *Bathyplotes natans*
8. *Molpadia musculus*

ECHINOIDEA

1. *Plesiodiadema antillarum*
2. *Phormosoma placenta*
3. *Brissopsis* sp.

OPHIUROIDEA

1. *Ophiochiton* sp.

BIVALVIA

1. *Tindaria amabilis*
2. *Abra longicallis*
3. *Nucula pernambucensis*
4. *Tindariopsis agathida*
5. *Yoldiella quadrangularis*
6. *Propeamussium* sp.
7. *Neilonella* sp. A
8. *Yoldiella pachia*
9. *Brevinucula verrillii*

GASTROPODA

1. *Mangelia exsculpta*
2. *Volutomitra* cf. *bairdii*
3. *Pleurotomella* cf. *agassizii*
4. *Leucosyrinx verrilli*
5. *Leucosyrinx* cf. *sigsbei*

SCAPHOPODA

1. *Dentalium perlongum*
2. *Pulsellum pressum*
3. *Dentalium callithrix*
4. *Dentalium laqueatum*
5. *Dentalium ensiculus*
6. *Entalina platamodes*
7. *Dentalium obscurum*
8. *Cadulus* sp.
9. *Dentalium circumcinctum*

CEPHALOPODA

1. *Neorossia* sp.
2. *Benthoctopus januari*
3. *Opisthoteuthis agassizii*

1050 METERS

FISHES (29 Species)

1. *Gadomus longifilis*
2. *Dicrolene intronigra*
3. *Monomitopus agassizi*
4. *Nezumia hildebrandi*
5. *Aldrovandia gracilis*
6. *Ilyophis brunneus*
7. *Stephanoberyx monae*
8. *Bathypterois quadrifilis*
9. *Squalogadus intermedius*
10. *Bathygadus vaillanti*
11. *Grenurus grenadae*
12. *Dibranchus atlanticus*
13. *Alepocephalus agassizi*
14. *Barathronus bicolor*
15. *Cariburus mexicanus*
16. *Scylliorhinus profundorum*
17. *Halosaurus guntheri*
18. *Bathygadus favosus*
19. *Bathytroctes melanocephalus*
20. *Cariburus zaniophorus*
21. *Conocara mcdonaldi*
22. *Malacocephalus occidentalis*
23. *Nezumia bairdi*
24. *Oxyodon occa*
25. *Platytroctes apus*
26. *Raja fuliginea*
27. *Raja oregoni*
28. *Trachonurus sulcatus*
29. *Venefica procera*

DECAPOD CRUSTACEA

PENAEIDEA

1. *Hymenopenaeus debilis*
2. *Plesiopenaeus edwardsianus*
3. *Benthesicymus bartletti*
4. *Funchalia taaningi*
5. *Hymenopenaeus aphoticus*
6. *Hepomadus tener*

CARIDEA

1. *Glyphocrangon alispina*
2. *Pontophilus gracilis*
3. *Nematocarcinus rotundus*
4. *Glyphocrangon nobilis*
5. *Heterocarpus oryx*
6. *Glyphocrangon aculeata*
7. *Acanthephyra eximia*

ERYONIDAE

1. *Stereomastis sculpta*
2. *Polycheles crucifer*

NEPHROPIDAE

1. *Nephropsis aculeata*
2. *Nephropsis agassizii*

GALATHEOIDEA

1. *Munidopsis longimanus*
2. *Munidopsis sigsbei*
3. *Munidopsis spinosa*
4. *Munidopsis abbreviata*
5. *Munidopsis spinoculata*
6. *Munidopsis simplex*

PAGUROIDEA

1. *Uroptychus nitidus*
2. *Lithodes agassizii*
3. *Parapagurus pilosimanus*
4. *Catapaguroides microps*

BRACHYURA

1. *Geryon quinquedens*
2. *Ethusina abyssicola*
3. *Homolodromia paradoxa*

OTHER CRUSTACEA

ISOPODA

1. *Bathynomus giganteus*

1050 METERS (cont'd)

ASTEROIDEA

1. Pseudarchaster n. sp.
2. Midgardia xandaros
3. Nymphaster arenatus
4. Goniopecten demonstrans
5. Odontaster hispidus
6. Plutonaster intermedius
7. Zoraster fulgens

HOLOTHUROIDEA

1. Molpadia musculus
2. Mesothuria lactea
3. Molpadia barbouri
4. Benthodytes sanguinolenta
5. Echinocucumis hispida
6. Deima blakei

ECHINOIDEA

1. Plesiodiadema antillarum
2. Phormosoma placenta
3. Brissopsis sp.

OPHIUROIDEA

1. Ophiochiton sp.

BIVALVIA

1. Abra longicallis americanus
2. Propeamussium sp.
3. Brevinucula verrillii
4. Nucula pernambucensis
5. Tindariopsis agathida
6. Yoldiella quadrangularis
7. Neilonella sp. A
8. Yoldiella pachia
9. Tindaria amabilis

GASTROPODA

1. Leucosyrinx verrilli
2. Pleurotomella cf. agassizii
3. Volutomitra cf. bairdii
4. Leucosyrinx cf. sigsbei
5. Mangelia exsculpta
6. Pleurotomella cf. chariessa
7. Leucosyrinx tenoceras

SCAPHOPODA

1. Dentalium perlongum
2. Pulsellum pressum
3. Cadulus sp.
4. Dentalium callithrix
5. Entalina platamodes
6. Dentalium ensiculus
7. Dentalium laqueatum
8. Dentalium circumcinctum
9. Dentalium obscurum

CEPHALOPODA

1. Neorossia sp.
2. Benthoctopus januari
3. Opisthoteuthis agassizi

APPENDIX B

SYSTEMATIC LIST OF SPECIES FROM NORTHERN GULF OF MEXICO CONTINENTAL SLOPE STUDY AREA STATIONS

1. LIST OF DEMERSAL FISHES - Page B2
2. LIST OF BENTHIC INVERTEBRATE SPECIES - Page B7

TERECO CORPORATION
P. O. Box 2848
College Station, Texas 77840

1. LIST OF DEMERSAL FISHES FROM NORTHERN GULF OF MEXICO CONTINENTAL SLOPE STUDY AREA STATIONS

CLASS AGNATHA - JAWLESS FISHES

FAMILY MYXINIDAE - HAGFISHES

Myxine sp.

CLASS CHONDRICHTHYES - CARTILAGINOUS FISHES

FAMILY CHIMAERIDAE - CHIMAERAS

Chimaera monstrosa Linnaeus, 1758
Hydrolagus alberti Bigelow & Schroeder, 1951
Hydrolagus mirabilis Collett, 1904
Hydrolagus sp. (cf. *media*)

FAMILY RAJIDAE - SKATES

Breviraja sinusmexicanus Bigelow & Schroeder
Raja bathyphila Holt & Byrne
Raja clarkii Bigelow & Schroeder
Raja fuliginea Bigelow & Schroeder
Raja lentiginosa Bigelow & Schroeder

FAMILY SCYLIORHINIDAE - CAT SHARKS

Scyliorhinus profundorum Goode & Bean, 1894

FAMILY SQUALIDAE - DOGFISH SHARKS

Etmopterus pusillus (Lowe, 1839)
Etmopterus schultzi Bigelow et al., 1953
Etmopterus spinax (Linnaeus, 1758)
Squalus cubensis Howell-Rivero, 1936

CLASS OSTEICHTHYES - BONY FISHES

FAMILY ALEPOCEPHALIDAE

Alepocephalus agassizii Goode & Bean, 1882
Bathytroctes melanocephalus Vaillant, 1888
Bathytroctes sp.
Conocara mcdonaldi Goode & Bean, 1895
Leptoderma macrops Vaillant, 1888

FAMILY BATHYPTEROIDAE

Bathypterois longipes Gunther, 1878
Bathypterois quadrifilis Gunther, 1878

FAMILY BOTHIDAE - LEFTEYE FLOUNDERS

Ancylopsetta dilecta (Goode & Bean, 1883)
Citharichthys cornutus (Gunther)
Citharichthys gymnorhinus Gutherz & Blackman, 1970
Monolene sp. (cf. *sessilicauda*)
Trichopsetta ventralis (Goode & Bean, 1885)

CLASS OSTEICHTHYES - BONY FISHES (cont'd)

FAMILY CALLIONYMIDAE - DRAGONETS
Callionymus agassizi (Goode & Bean, 1896)

FAMILY CHAUNACIDAE
Chaunax nuttingii Garman, 1896
Chaunax pictus Lowe, 1846

FAMILY CHLOROPTHALMIDAE - GREEN EYES
Chlorophthalmus agassizii Bonaparte, 1840
Parasudis truculentus (Goode & Bean, 1895)

FAMILY CONGRIDAE - CONGER EELS
Conger oceanicus (Mitchill)
Congrina flava (Goode & Bean, 1888)
Promyllantor schmitti Hildebrand, 1940
Promyllantor sp.
Uroconger syringinus Ginsburg

FAMILY CYNOGLOSSIDAE - TONGUEFISHES
Symphurus marginatus (Goode & Bean, 1886)
Symphurus piger (Goode & Bean, 1888)

FAMILY GADIDAE - CODFISHES
Gadella maraldi Risso, 1810
Laemonema barbatulum Goode & Bean, 1883
Physiculus fulvus Bean, 1884
Physiculus kaupi Poey, 1865
Urophycis chesteri Goode & Bean, 1878
Urophycis cirratus Goode & Bean, 1896
Urophycis floridanus Bean & Dresel, 1884
Urophycis regius (Walbaum, 1792)

FAMILY HALOSAURIDAE
Aldrovandia affinis Alcock
Aldrovandia gracilis Goode & Bean, 1895
Halosaurus guntheri Goode & Bean, 1895

FAMILY LABRIDAE - WRASSES
Decodon puellaris (Poey, 1860)

FAMILY LUTJANIDAE - SNAPPERS
Pristipomoides aquilonaris (Goode & Bean, 1896)

CLASS OSTEICHTHYES - BONY FISHES (cont'd)

FAMILY MACROURIDAE - GRENADIERS

Bathygadus favosus Goode & Bean, 1886
Bathygadus macrops Goode & Bean, 1886
Bathygadus vaillanti Roule & Angel, 1933
Bathygadus sp.
Cariburus mexicanus Parr, 1946
Cariburus zaniophorus (Vaillant, 1888)
Cariburus sp.
Chalinura carapina (Goode & Bean, 1883)
Cetonurus globiceps (Vaillant, 1888)
Coelorhynchus caribbaeus (Goode & Bean, 1886)
Coelorhynchus carminatus (Goode, 1881)
Coryphaenoides sp.
Gadomus arcuatus (Goode & Bean, 1886)
Gadomus longifilis Goode & Bean, 1886
Grenurus grenadae Parr, 1946
Hymenocephalus cavernosus (Goode & Bean, 1886)
Malacocephalus occidentalis Goode & Bean, 1886
Nezumia bairdii (Goode & Bean, 1877)
Nezumia hildebrandi Parr, 1946
Nezumia sp.
Oxygadus occa Goode & Bean, 1886
Steindachneria argentea Goode & Bean, 1895
Trachonurus sulcatus (Goode & Bean, 1886)
Trachonurus sp.
Ventrifossa atlantica Parr, 1946

FAMILY MACROUROIDIDAE

Squalogadus intermedius Grey, 1959

FAMILY MERLUCCIIDAE

Merluccius bilinearis (Mitchill, 1814)

FAMILY MURAENESOCIDAE - PIKE CONGERS

Hoplunnis macrurus Ginsburg, 1951
Hoplunnis schmidtii Kaup, 1860
Hoplunnis tenuis Ginsburg
Muraenesox sp.

FAMILY NETTASTOMATIDAE - SORCERERS - EELS

Nettastoma melanura Rafinesque, 1810
Venefica procera (Goode & Bean, 1883)

CLASS OSTEICHTHYES - BONY FISHES (cont'd)

FAMILY OGCOCEPHALIDAE - BATFISHES
Dibranchus atlanticus Peters, 1876

FAMILY OPHICHTHIDAE - SNAKE EELS
Myrophis punctatus Lutken, 1852
Mystriophis sp.
Ophichthus sp.

FAMILY OPHIDIIDAE - CUSK-EELS & BROTULAS
Barathronus bicolor Goode & Bean, 1885
Bassozetus normalis Gill, 1883
Bythites sp.
Cataetyx sp.
Dicrolene intronigra Goode & Bean, 1883
Diplacanthopoma brachysoma Gunther, 1887
Lepophidium brevibarbe (Cuvier, 1829)
Luciobrotula sp. (cf. *corethromycter*) (Cohen, 1964)
Monomitopus agassizi (Goode & Bean, 1895)
Neobythites gillii Goode & Bean, 1885
Neobythites marginatus Goode & Bean, 1883
Penopus macdonaldi Goode & Bean, 1895
Porogadus catena Goode & Bean, 1885
Saccogaster maculatus Alcock, 1889
Xyelacyba myersi

FAMILY PERCOPHIDIDAE - FLATHEADS
Bembrops anatirostris Ginsburg, 1955
Bembrops gobioides (Goode, 1880)

FAMILY PERISTEDIIDAE
Peristedion greyae Miller, 1967

FAMILY PLEURONECTIDAE - RIGHTEYE FLOUNDER
Poecilopsetta beanii (Goode, 1881)

FAMILY SCORPAENIDAE - SCORPIONFISHES
Pontinus longispinus Goode & Bean, 1896

FAMILY SERRANIDAE - SEA BASSES
Hemanthias leptus (Ginsberg)

FAMILY STEPHANOBERYCIDAE
Stephanoberyx monae Gill, 1883

CLASS OSTEICHTHYES - BONY FISHES (cont'd)

FAMILY SYNAPHOBRANCHIDAE
Histiobranchus bathybius Gunther, 1877
Synaphobranchus oregoni Castle, 1960

FAMILY TRIACANTHODIDAE - SPIKEFISHES
Parahollardia lineata (Longley)

FAMILY TRICHIURIDAE - CUTLASSFISHES
Benthodesmus atlanticus Goode & Bean, 1881

FAMILY TRIGLIDAE - SEAROBINS
Prionotus beanii Goode, 1896
Prionotus rubio Jordan, 1886
Prionotus stearnsi Jordan & Swain, 1884

FAMILY URANOSCOPIDAE - STARGAZERS
Gnathagnus egregius (Jordon & Thompson)

2. LIST OF BENTHIC INVERTEBRATE SPECIES FROM NORTHERN GULF OF MEXICO CONTINENTAL SLOPE STUDY AREA STATIONS

PHYLUM ANNELIDA - SEGMENTED WORMS

CLASS POLYCHAETA

FAMILY AMPHARETIDAE

Melinna ?maculata Webster, 1879

FAMILY AMPHINOMIDAE

Chloeia ?viridis Schmarda, 1861

FAMILY APHRODITIDAE

Aphrodita sp.

FAMILY CAPITELLIDAE

Notomastus latericeus Sars, 1851

FAMILY EUNICIDAE

Eunice norvegica (Linnaeus, 1767)
Eunice pennata (Müller, 1776)
Eunice sp.
Marphysa sanguinea (Montagu, 1815)

FAMILY FLABELLIGERIDAE

Diplocirrus capensis Day, 1961

FAMILY GONIADIDAE

Goniada sp. A
Goniada sp. B

FAMILY LUMBRINERIDAE

Ninoë nigripes Verrill, 1873

FAMILY MALDANIDAE

?*Asychis biceps* (Sars, 1861)
Maldane sarsi Malmgren, 1866

FAMILY NEPHTYIDAE

Nephtys ?hombergi Savigny, 1818

FAMILY ONUPHIDAE

Hyalinoecia tubicola (Müller, 1776)
Onuphis microcephala Hartman, 1944
Onuphis sp.
Rhamphobrachium agassizi Ehlers, 1887

FAMILY OPHELIIDAE

Ophelina cylindricaudata? (Hansen, 1882)

FAMILY ORBINIIDAE

Orbinia sp.

FAMILY POLYODONTIDAE
Polyodontes lupina (Stimpson, 1856)

FAMILY SERPULIDAE
Protula tubularia (Montagu, 1803)

FAMILY SIGALIONIDAE
Leanira hystricis Ehlers, 1874
Sthenolepis ?*incisa* (Grube, 1877)
Sthenolepis sp.

FAMILY SPIONIDAE
Polydora websteri Hartman, 1943

FAMILY SYLLIDAE
Syllis sp.

PHYLUM MOLLUSCA
CLASS BIVALVIA
Abra longicallis americana Verrill & Bush, 1898
Aequipecten glyptus (Verrill, 1882)
Amygdalum politum (Verrill & Smith, 1880)
Anadara cf. *baughmani* Hertlein, 1951
Astarte cf. *nana* Dall, 1886
Limopsis aurita paucidentata Dall
Limopsis sp.
Malletia sp. A
Neilo sp. A
Neilonella sp. B
Nemocardium peramabile (Dall, 1881)
Nucula callicredemna Dall, 1890
Nucula pernambucensis Smith, 1885
Nuculana acuta (Conrad, 1831)
Nuculana bipennis (Dall, 1927)
Nuculana concentrica (Say, 1824)
Nuculana platessa (Dall, 1890)

Nuculana sp. A
Nuculana sp. B
Poromya sp.
Propeamussium sp. (cf. *dalli*)
Tindaria amabilis (Dall, 1889)
Tindariopsis agathida (Dall, 1890)
Yoldia solenoides Dall, 1881
Yoldiella quadrangularis (Dall, 1881)

CLASS CEPHALOPODA
ORDER OCTOPODA
Benthoctopus januari Hoyle, 1885
Japetella diaphana Hoyle, 1885

Opisthoteuthis agassizi Verrill, 1883
Pteroctopus tetracirrhus (Delle Chiaje, 1830)

ORDER SEPIOIDEA - CUTTLEFISH AND SEPIOLAS
Rossia bullisi Voss, 1956
Rossia tortugaensis
Semirossia equalis Voss, 1950
Semirossia tenera (Verrill, 1880)

ORDER TEUTHOIDEA - SQUIDS
Abralia veranyi (Rüppell, 1844)
Bathothauma lyromma Chun, 1906
Helicocranchia pfefferi Massy, 1907
Pholidoteuthis adami Voss, 1956

ORDER VAMPYROMORPHA - VAMPIRE SQUIDS
Vampyroteuthis infernalis Chun, 1903

CLASS GASTROPODA
SUBCLASS EUTHYNEURA
Bulla cf. *abyssicola*
Retusa cf. *domitus*
Scaphander clavus Dall
Scaphander watsoni Dall, 1881

SUBCLASS PROSOBRANCHIA
Antillophos candei (Orbigny, 1842)
Conus mazei macgintyi Pilsbry, 1955
Gaza superba (Dall, 1881)
Gemmula periscelida (Dall, 1889)
Hindsiclava alesidota (Dall, 1889)
Leucosyrinx sigsbei (Dall, 1881)
Leucosyrinx subgrundifera (Dall, 1888)
Leucosyrinx tenoceras Dall, 1889
Leucosyrinx verrilli (Dall, 1881)
Mangelia exsculpta (Watson, 1881)
Oocorys bartschi Rehder, 1943
Phalium granulatum (Born, 1778)
Pleurotomella cf. *agassizii* Verrill & Smith, 1880
Pleurotomella cf. *chariessa* Watson, 1879
Polystira albida (Perry, 1811)
Polystira tellea (Dall, 1889)
Scaphella dubia (Broderip, 1827)
Scaphella cf. *gouldiana* (Dall, 1887)
Sconsia striata (Lamarck, 1816)
Volutomitra cf. *bairdii*

CLASS SCAPHOPODA
Cadulus sp.
Dentalium callithrix

Dentalium circumcinctum Watson, 1879
Dentalium ensiculus
Dentalium laqueatum Verrill, 1885
Dentalium meridionale Pilsbry & Sharp, 1897
Dentalium ?obscurum
Dentalium perlongum Dall, 1881
Pulsellum pressum (Pilsbry & Sharp, 1897)

PHYLUM ARTHROPODA
CLASS CRUSTACEA
ORDER DECAPODA
SUBORDER NATANTIA - SHRIMPS
SECTION CARIDEA
Acanthephyra acutifrons Bate, 1888
Acanthephyra armata A. Milne-Edwards, 1881
Acanthephyra brevirostris Smith, 1885
Acanthephyra eximia Smith, 1884
Alpheus sp.
Bathypalaemonella serratipalma L. Pequegnat, 1970
Bathypalaemonella texana
Glyphocrangon aculeata A. Milne-Edwards, 1881
Glyphocrangon alispina Chace, 1939
Glyphocrangon longleyi Schmitt, 1931
Glyphocrangon nobilis A. Milne-Edwards, 1881
Heterocarpus oryx A. Milne-Edwards, 1881
Nematocarcinus ensifer (Smith, 1882)
Nematocarcinus rotundus Crosnier & Forest, 1973
Parapandalus willisi L. Pequegnat, 1970
Parapasiphaë cristata Smith, 1884
Pasiphaea merriami Schmitt, 1931
Plesionika acanthonotus (Smith, 1882)
Plesionika holthuisi Crosnier & Forest, 1968
Plesionika polyacanthomerus L. Pequegnat, 1970
Plesionika tenuipes (Smith, 1881)
Plesionika sp. (cf. acanthonotus (Smith, 1882))
Pontophilus gracilis Smith, 1882
Psalidopus barbouri Chace, 1939
Systellaspis affinis (Faxon, 1896)

SECTION PENAEIDEA
Aristaeomorpha foliacea (Risso)
Aristaeus antillensis A. Milne-Edwards & Bouvier, 1909
Benthesicymus bartletti Smith, 1882
Benthesicymus cereus Burkenroad, 1936
Benthesicymus iridescens Bate, 1881
Hepomadus tener Smith, 1884
Hymenopenaeus aphoticus Burkenroad, 1936
Hymenopenaeus debilis Smith, 1882
Hymenopenaeus robustus Smith, 1885
Parapenaeus longirostris (Lucas, 1849)

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<u>Penaeopsis megalops</u> (Smith, 1885)
<u>Plesiopenaeus armatus</u> (Bate, 1881)
<u>Plesiopenaeus edwardsianus</u> (Johnson, 1867)
<u>Solenocera necopina</u> Burkenroad, 1939
<u>Solenocera vioscai</u> Burkenroad, 1934

SUBORDER REPTANTIA
SECTION ANOMURA
SUPERFAMILY GALATHEOIDEA
FAMILY CHIROSTYLIDAE
<u>Uroptychus nitidus</u> (A. Milne-Edwards, 1880)

FAMILY GALATHEIDAE
<u>Munida flinti</u> Benedict, 1902
<u>Munida forceps</u> A. Milne-Edwards, 1880
<u>Munida longipes</u> A. Milne-Edwards, 1880
<u>Munida valida</u> Smith, 1883
<u>Munidopsis abreviata</u> (A. Milne-Edwards, 1880)
<u>Munidopsis alaminos</u> Pequegnat & Pequegnat, 1970
<u>Munidopsis erinaceus</u> (A. Milne-Edwards, 1880)
<u>Munidopsis longimanus</u> (A. Milne-Edwards, 1880)
<u>Munidopsis nitida</u> (A. Milne-Edwards, 1880)
<u>Munidopsis polita</u> (Smith, 1883)
<u>Munidopsis robusta</u> (A. Milne-Edwards, 1880)
<u>Munidopsis serratifrons</u> (A. Milne-Edwards, 1880)
<u>Munidopsis sigsbei</u> (A. Milne-Edwards, 1880)
<u>Munidopsis simplex</u> (A. Milne-Edwards, 1880)
<u>Munidopsis spinosa</u> (A. Milne-Edwards, 1880)
<u>Munidopsis</u> sp. (cf. <u>abreviata</u> (A. Milne-Edwards, 1880))

FAMILY PORCELLANIDAE
<u>Porcellana sigsbeiana</u> A. Milne-Edwards, 1880

SUPERFAMILY PAGUROIDEA
FAMILY LITHODIDAE
<u>Lithodes agassizii</u> Smith, 1882

FAMILY PAGURIDAE - HERMIT CRABS
<u>Catapaguroides microps</u> A. Milne-Edwards & Bouvier, 1892
<u>Paguristes</u> sp.
?<u>Parapagurus pilosimanus</u> Smith, 1879
<u>Sympagurus pictus</u> Smith, 1883
<u>Sympagurus pilimanus</u> (A. Milne-Edwards, 1880)

SECTION BRACHYURA - TRUE CRABS
<u>Acanthocarpus alexandri</u> Stimpson, 1871
<u>Bathyplax typhla</u> A. Milne-Edwards, 1880
<u>Benthochascon schmitti</u> Rathbun, 1931
<u>Chasmocarcinus cylindricus</u> Rathbun, 1900
<u>Collodes leptocheles</u> Rathbun, 1894

Ethusa microphthalma Smith, 1881
Ethusina abyssicola Smith, 1884
Euphrosynoplax clausa Guinot, 1969
Geryon quinquedens Smith, 1879
Homolodromia paradoxa A. Milne-Edwards, 1880
Lyreidus bairdii Smith, 1881
Myropsis quinquespinosa Stimpson, 1871
Palicus gracilis (Smith, 1883)
Palicus obesus (A. Milne-Edwards, 1880)
Pyromaia arachna Rathbun, 1924
Raninoides louisianensis Rathbun, 1933
Rochinia crassa (A. Milne-Edwards, 1879)
Rochinia umbonata (Stimpson, 1871)
Stenocionops spinosissima (Saussure, 1857)
Tetraxanthus rathbunae Chace, 1939
Thalassoplax angusta Guinot, 1969
Trichopeltarion nobile A. Milne-Edwards, 1880

SECTION MACRURA - LOBSTERS
SUPERFAMILY ERYONIDEA
FAMILY POLYCHELIDAE
Polycheles crucifer (Willemoes-Suhm, 1873)
Polycheles typhlops Heller, 1862
Polycheles typhlops parameter
Polycheles validus A. Milne-Edwards, 1880
Stereomastis sculpta (Smith, 1880)

SUPERFAMILY NEPHROPIDEA
FAMILY NEPHROPIDAE
Acanthacaris caeca (A. Milne-Edwards, 1881)
Nephropsis aculeata (Smith, 1881)
Nephropsis agassizii A. Milne-Edwards, 1880
Nephropsis rosea (Willemoes-Suhm, Ms.)

SUPERFAMILY THALASSINIDEA
FAMILY CALLIANASSIDAE
Callianassa latispina Dawson, 1967
Callianassa sp. (cf. marginata Rathbun, 1901)

ORDER ISOPODA
Bathynomus giganteus A. Milne-Edwards, 1879

PHYLUM ECHINODERMATA
CLASS ASTEROIDEA - STARFISH
Anthenoides piercei Perrier, 1881
Astropecten americanus (Verrill, 1880)
Astropecten antillensis Lütken, 1859
Astropecten sp.
Brisingella verticellata Verrill
Ceramaster sp.

Cheiraster enoplus Verrill, 1915
Cheiraster mirabilis (Perrier, 1881)
Cheiraster sp.
Doraster constellatus Downey, 1970
Dytaster insignis (Perrier, 1884)
Goniopecten demonstrans Perrier, 1881
Litonotaster intermedius (Perrier, 1884)
Midgardia xandaros Downey, 1971
Nymphaster arenatus (Perrier, 1881)
Odontaster hispidus
Persephonaster echinulatus Clark, 1941
Plinthaster dentatus (Perrier, 1884)
Plutonaster intermedius (Perrier, 1884)
Poranisca lepida
Pseudarchaster gracilis (Sladen, 1889)
Pseudarchaster sp.
Psilaster cassiope Sladen, 1889
Pteraster acicula (Downey, 1970)
Tethyaster grandis (Verrill, 1899)
Zoroaster fulgens Thomson, 1873

CLASS ECHINOIDEA - SEA URCHINS & SAND DOLLARS
Brissopsis alta Mortensen, 1907
Brissopsis atlantica Mortensen, 1907
Brissopsis sp.
Hemiaster expergitus Loven, 1874
Hypselaster brachypetalus H. L. Clark, 1917
Phormosoma placenta Thomson, 1872
Plesiodiadema antillarum (A. Agassiz, 1880)

CLASS HOLOTHUROIDEA - SEA CUCUMBERS
Bathyplotes natans (M. Sars, 1868)
Benthodytes sanguinolenta Theel, 1882
Benthodytes typica Theel, 1882
Deima blakei Theel, 1886
Echinocucumis hispida (Barrett, 1856)
Euphronides kerhervei (Herouard, 1902)
Euphronides violacea Perrier, 1896
Hedingia albicans
Mesothuria lactea (Theel, 1886)
Mesothuria lactea oxysclera Perrier, 1902
Mesothuria lactea zygothuria
Molpadia barbouri Deichmann, 1940
Molpadia blakei (Theel, 1886)
Molpadia cubana Deichmann, 1940
Molpadia musculus (Risso, 1826)
Molpadia oolitica (Pourtales, 1851)
Molpadia sp.
Paroriza prouhoi Herouard, 1902
Protankyra sluiteri Fisher, 1907
Ypsilothuria talismani

CLASS OPHIUROIDEA - BRITTLE STARS

Amphiophiura sp.
Amphioplus sp.
Amphiura sp.
Bathypectinura heros (Lyman, 1879)
Bathypectinura lacertosa (Lyman, 1883)
Bathypectinura tesselata
Bathypectinura sp.
Homalophiura sp.
Ophiochiton grandis Verrill, 1884
Ophiochiton sp.
Ophioleptoplax sp.
Ophioplax ljungmani Lyman, 1875
Ophioplinthaca dipsacos (Lyman, 1878)
Ophiopyren sp.
Ophiosphalma monoplax
Ophiura lepida (Lyman, 1878)
Ophiura sp.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.