THE VELIGER

The Veliger 32(2):130–146 (April 3, 1989)

Correlation of Live Mollusks with Sediment and Bathymetry on the Texas Inner Shelf[1]

by

THOMAS R. CALNAN

Bureau of Economic Geology, The University of Texas at Austin,
Austin, Texas 78713, U.S.A.

AND

THOMAS G. LITTLETON

1700B Trinity Place, College Station, Texas 77840, U.S.A.

Abstract. An extensive survey of the macroinvertebrate populations of the Gulf of Mexico on the inner shelf of the Texas coast was initiated in 1976. The focus of this inventory was (1) identification and enumeration of the macrofauna, (2) description of faunal communities, and (3) correlation of distribution and abundances, including sediment and faunal relationships. This report summarizes the molluscan data from that survey. Although other inventories of mollusks on the inner shelf have been undertaken, this is the most extensive regional survey conducted on the Texas Gulf Coast.

One hundred forty-one species of mollusks (82 gastropods, 56 bivalves, and 3 scaphopods) were found in 554 benthic samples from stations located 1–11 miles (1.6–17.6 km) offshore from Sabine Pass to Brownsville, Texas. Both numbers of species and numbers of individuals of gastropods, bivalves, and scaphopods are greater on the South Texas inner shelf (Brownsville to Corpus Christi) than in areas northeast of Corpus Christi.

Cluster analysis separated the fauna into three assemblages—a nearshore assemblage, characterized by sandy substrates, a transitional assemblage characterized by substrates of sandy mud, and an outer assemblage characterized by substrates of less-sandy mud. All three are found on the inner shelf except in the Port Lavaca and Beaumont-Port Arthur areas. Faunal-sediment associations indicate that more molluscan species occur in sand than in mud, and the most abundant species are found where the sand fraction is high (80–100% sand). Analysis of the bathymetric distribution of mollusks shows that the mean number of species is highest in a depth range of 18–60 ft (6–18 m). Many species are most abundant at either shallower-water stations (stations from 18.0–36.1 ft or 5.5–11.0 m deep) or deeper-water stations (stations from 47.9–60.0 ft or 14.6–18.3 m deep).

INTRODUCTION

Molluscan populations from the inner shelf of the Texas coast were studied in 6672 surficial bottom samples, including 3940 from the inner shelf and 2732 from the bay-estuary-lagoon system, collected at regularly spaced intervals of 1 mi (1.6 km). This inventory of the State-owned submerged lands (Figure 1) provides an extensive spatial data base on sediment texture, sediment geochemistry, and benthic macroinvertebrates. The focus of the biological analyses was (1) identification and enumeration of the macrofaunal species, (2) identification and delineation of characteristic faunal assemblages, (3) correlation of dis-

[1] Publication authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin.

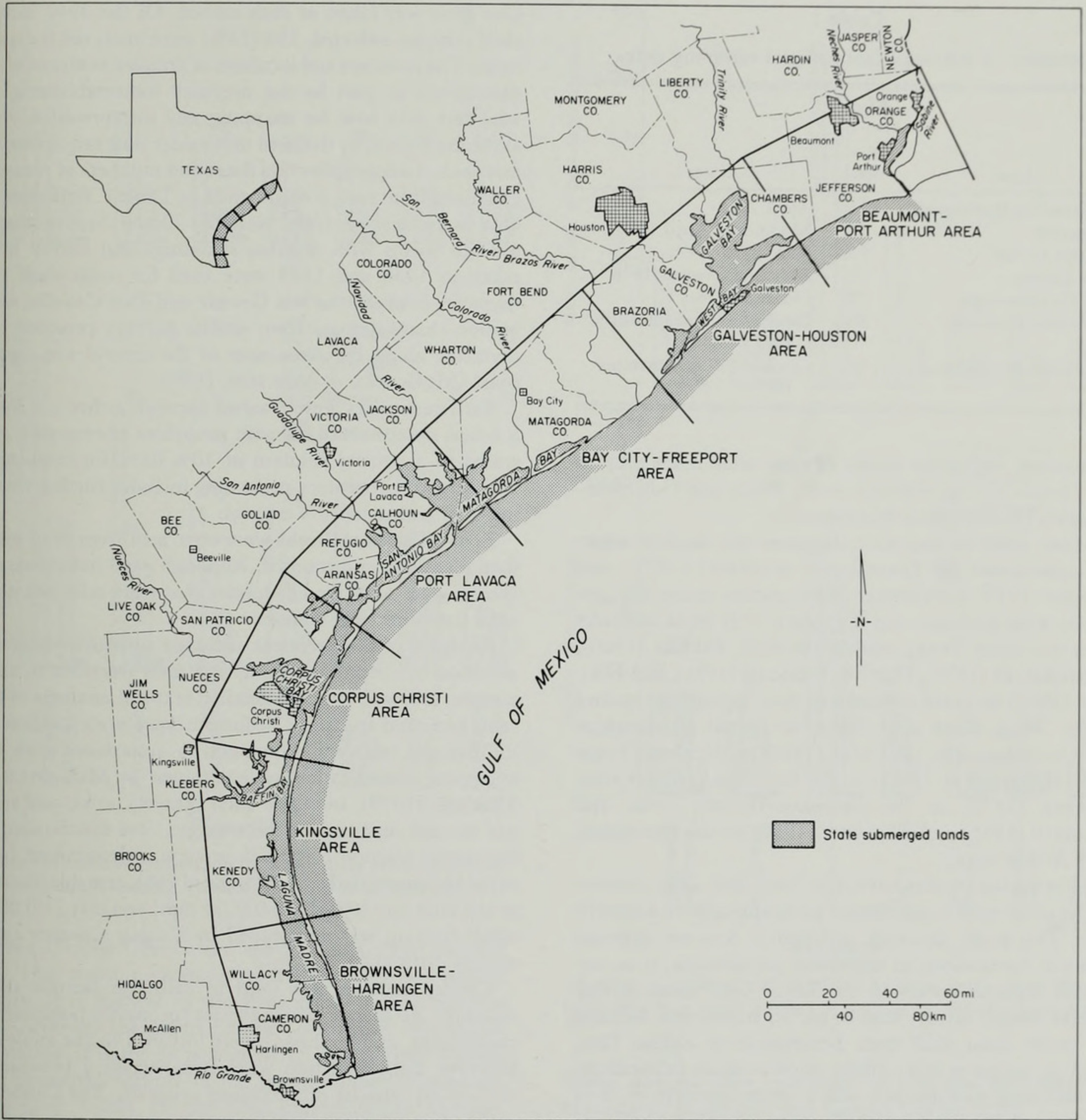


Figure 1

Index map showing seven areas that include the submerged coastal lands of Texas (modified from McGowen & Morton [1979] and Brown [1972–1980]).

tributions and abundances with physical and biotic factors, and (4) faunal relationships. Records are for live-collected animals except as noted.

Maps and reports derived from the study are being published as a series of atlases of the Texas coast, divided into seven areas (Figure 1) similar to those defined in Brown (1972–1980) and in McGowen & Morton (1979). Atlases available for Corpus Christi (White *et al.*, 1983), Galveston-Houston (White *et al.*, 1985), Brownsville-Harlingen (White *et al.*, 1986), Beaumont-Port Arthur (White *et al.*, 1987), and Bay City-Freeport (White *et al.*, 1988) areas contain discussions on the distribution of mollusks, polychaetes, and crustaceans. Each atlas has sections on invertebrate distributions related to sediment and bathymetry, benthic assemblages, and species diversity, and an appendix listing species, numbers of individuals, and locality data. Dead-collected mollusks were also identified and listed, but because of time and financial

Table 1

Number of stations examined and sampling dates.

Area	Number of stations	Dates
Brownsville-Harlingen	113	April 1976
Kingsville	81	March and April 1976
Corpus Christi	73	May 1976
Port Lavaca	72	May and October 1976
Bay City-Freeport	79	October 1976
Galveston-Houston	80	October 1976; September 1977
Beaumont-Port Arthur	56	October 1976; September 1977

constraints, individual counts of these were made only in the Corpus Christi (WHITE *et al.*, 1983) and Galveston-Houston (unpublished data) areas.

Many other studies have discussed the shallow-water mollusks from the Texas coast. ANDREWS (1977) and MOORE (1979) summarized early studies concerned primarily with mollusks, and TREECE (1979) listed mollusks from the South Texas continental shelf. PARKER (1960), DEFENBAUGH (1976), FLINT & RABALAIS (1981), and HILL *et al.* (1982) included mollusks in their assemblage studies of the Texas inner shelf. Substrate-faunal relationships were investigated by HILL *et al.* (1982) on the South Texas shelf, HARPER *et al.* (1981) on the Bay City-Freeport area, HARPER (1970) on the Galveston-Houston area, and HULINGS (1955) and KENNEDY (1959) on the Beaumont-Port Arthur area.

Most earlier studies have data from only a few stations on the inner shelf or are limited geographically to a specific area. This study, however, although it does not examine seasonal fluctuations in molluscan populations, is an extensive regional survey of the Texas Gulf Coast having greater sample density than do earlier studies and includes the entire inner shelf from Brownsville to Sabine Pass. Such an extensive study allows more accurate delineations of molluscan distributions and a better measure of their diversity. Additionally, identification, mapping, and characterization of inner-shelf molluscan populations provide an important spatial data base that is useful in predicting and measuring the effects of a multitude of activities (such as food production, energy production, recreation, resource extraction, industrial processing, and transportation) on the coastal ecosystem.

MATERIALS AND METHODS

Surficial sediment samples analyzed for this study were taken with a Smith-McIntyre grab sampler (capacity of 0.46 ft^3 or 0.013 m^3) at sites spaced approximately 1 mile (1.6 km) apart on the inner continental shelf to a distance of about 11 miles (17.6 km) seaward of the Gulf shoreline. One grab was taken at each station. Of the 3940 inner-shelf samples collected, 554 (14%) were analyzed for mollusks. The numbers and locations of samples analyzed were determined in part by the necessity for establishing an adequate data base for mapping and interpretation and, at the same time, by the need to consider time requirements and costs. Sample-collection dates and numbers of samples examined from each area are given in Table 1. Bathymetric data were derived from National Ocean Survey maps. Smooth sheets with original soundings and survey lines taken in 1938 and 1939 were used for inner-shelf bathymetry between the Rio Grande and Pass Cavallo; navigation charts derived from similar surveys provided bathymetry along the remainder of the central and upper coast (MCGOWEN & MORTON, 1979).

Shelf sediments were washed through either a 0.5- or a 1-mm sieve, narcotized with propylene phenoxytol, and stored in a neutral solution of 10% formalin containing rose bengal. Laboratory processing included further washing and storing in 70% ethanol.

Live-collected mollusks were separated from dead ones, then identified and counted. Although dead individuals of species were not counted, species that were collected dead were listed for each station.

Analyses of the sediment included quantitative determination of the gravel, sand, and mud fractions in each sample, followed by more detailed textural analyses of the sand and mud fractions. Sediment types are classified on the basis of relative percentages, in accordance with the triangular classification system shown in MCGOWEN & MORTON (1979), in which shell (gravel), sand, and mud are the end members of the triangle. Size distribution in the coarse fraction (>0.0625 mm) was determined by a rapid sediment analyzer (SCHLEE, 1966); size distribution in the mud (silt [0.0625 to 0.0039 mm] and clay [<0.0039 mm]) fraction was determined by Coulter Counter techniques (SHIDELER, 1976).

Cluster analysis was used to delineate benthic communities. All macrobenthic species (primarily polychaetes, crustaceans, and mollusks) were included in the analyses; however, data reduction was often necessary because of the limited capacity of the cluster program. The Canberra metric dissimilarity coefficient was used along with flexible sorting on the dissimilarity coefficients (CLIFFORD & STEPHENSON, 1975). For more details concerning computer procedures, see WHITE *et al.* (1987).

RESULTS AND DISCUSSION

One hundred forty-one species of mollusks were collected from the inner shelf, consisting of 82 gastropods, 56 bivalves, and 3 scaphopods. Numbers of molluscan species and individuals generally decrease from south to north (Figures 2, 3). Therefore, numbers of species and individuals of all three classes (Gastropoda, Bivalvia, and Scaphopoda) are more abundant on the South Texas inner shelf from Brownsville to the Corpus Christi area than they are

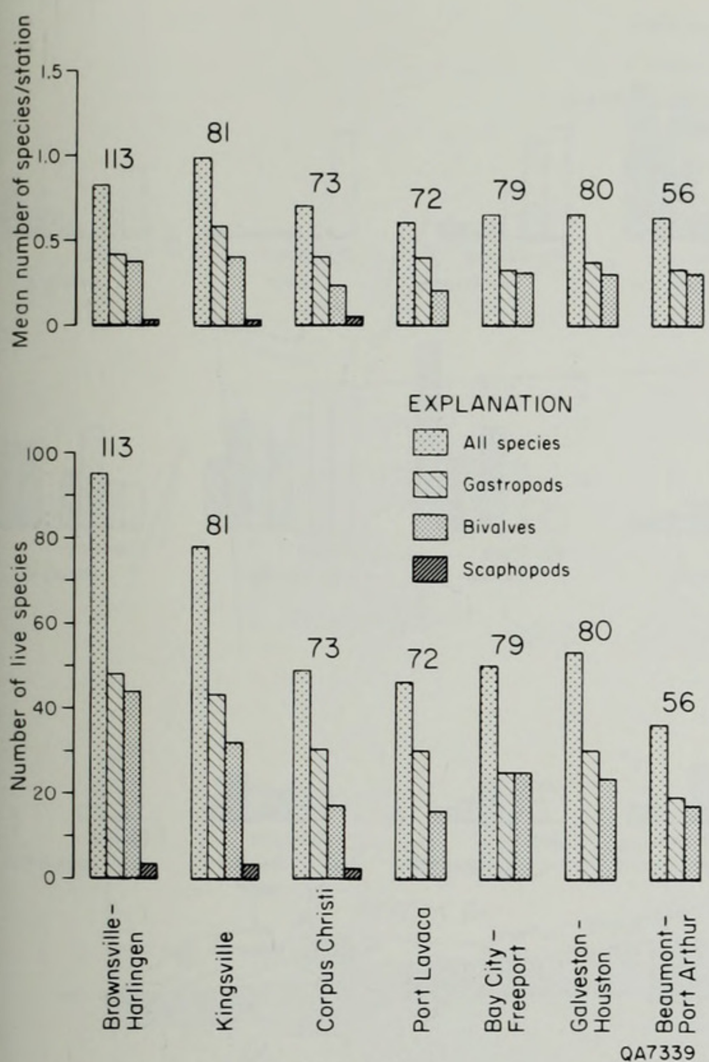


Figure 2

Numbers of molluscan species in the seven study areas. Numbers above bars equal number of stations examined in each area.

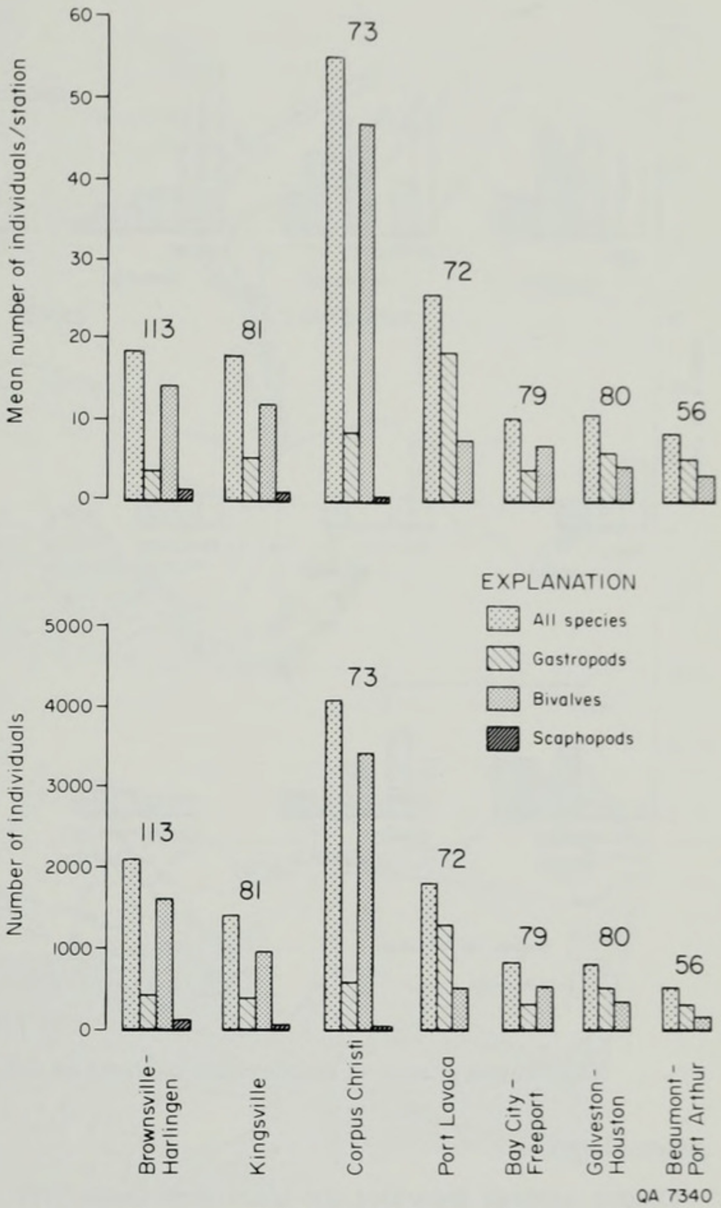


Figure 3

Numbers of mollusk individuals in the seven study areas. Numbers above bars equal number of stations examined in each area.

between Corpus Christi and the Beaumont-Port Arthur area. The mean number of bivalve species per station (Figure 2) is highest in the Brownsville and Kingsville areas, whereas the mean number of bivalve individuals per station (Figure 3) is highest in the Corpus Christi area, primarily because of the large number of *Abra aequalis* (Say, 1822). Of the 3242 individuals of *Abra* recovered from the Corpus Christi area, more than 50% were recovered from one station. If individuals of *Abra* were not included in counts of individual bivalves from each of the seven areas, then the number of bivalve individuals would be three times higher in the Brownsville-Harlingen area than in any of the other six areas.

Gastropod species are generally more abundant than bivalve or scaphopod species. Gastropod species are most numerous in the Brownsville and Kingsville areas (Figure 2), whereas both the mean number of individuals per station and the total number of individuals per station are highest in the Port Lavaca area (Figure 3), primarily because of the large numbers of *Nassarius acutus* (Say, 1822) recovered from the Port Lavaca area. Scaphopods (three species) were recovered only in the Brownsville-Harlingen, Kingsville, and Corpus Christi areas.

Several bivalve and gastropod species are most abundant (according to percent of the total number of stations) either on the southern (Brownsville-Harlingen, Kingsville, or Corpus Christi) or northern (Beaumont-Port Arthur or Galveston-Houston) coast (Figure 4). Species most abundant overall on the southern coast include *Linga amiantus* (Dall, 1901), *Parvilucina multilineata* (Toumey & Holmes, 1857), *Nucula proxima* Say, 1822, *Anadara transversa* (Say, 1822), and *Diplodonta soror* C. B. Adams, 1852. Abundant northern-coast species include *Nuculana concentrica* (Say, 1824), *Nassarius acutus* (Say, 1822), and *Parvanachis obesa* (C. B. Adams, 1845). *Abra aequalis* (Say, 1822) and *Natica pusilla* (Say, 1822) are abundant in all seven areas (Figure 4).

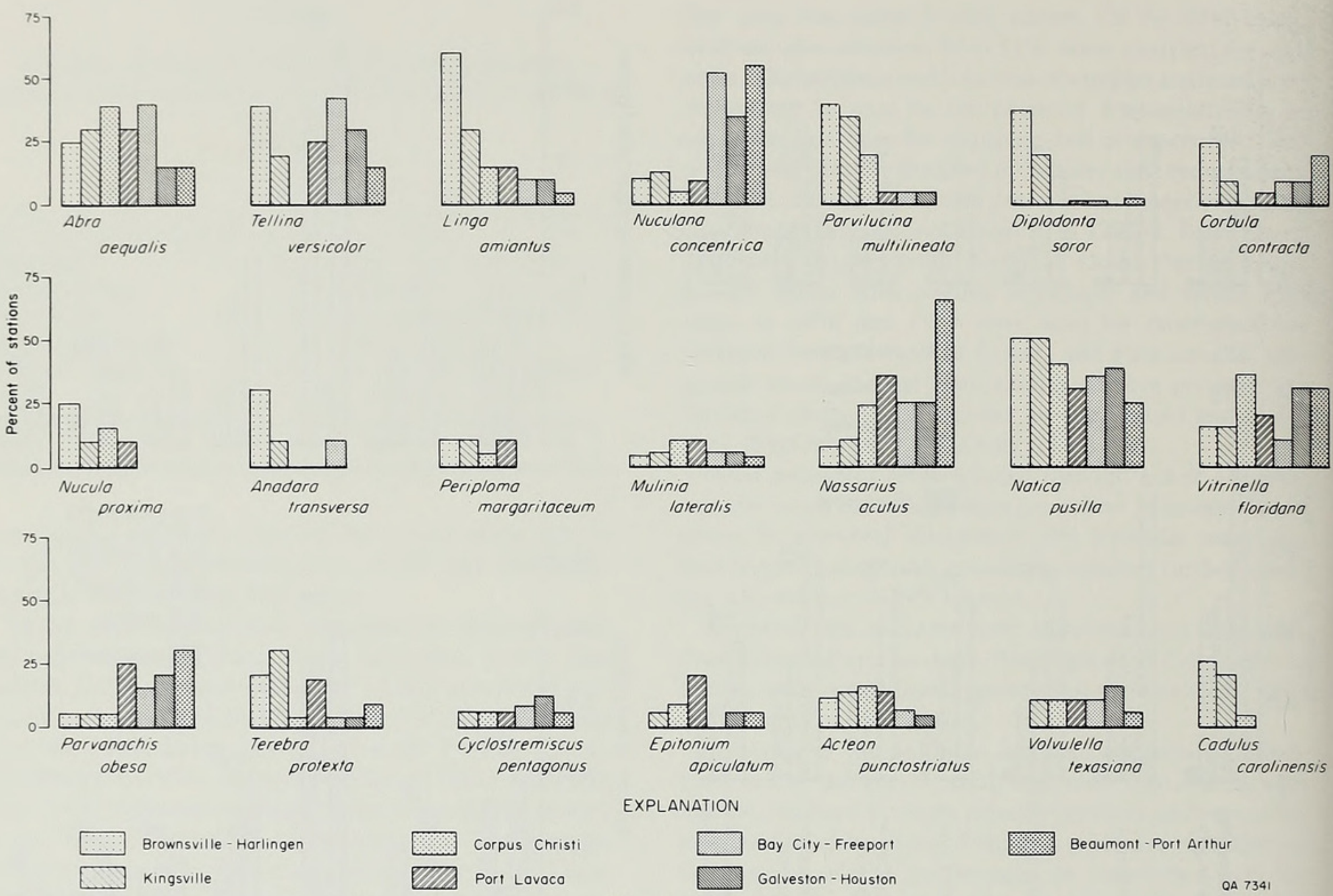


Figure 4

Distribution of some of the abundant mollusks according to the percentage of all stations in the seven study areas.

Assemblages

Cluster analysis separated the inner-shelf fauna (primarily polychaetes, mollusks, and crustaceans) into three assemblages—a nearshore assemblage characterized by sandy substrates (average of 81% sand), a transitional assemblage characterized by substrates of sandy mud (average of 43% sand), and an outer assemblage with substrates of less-sandy mud (average of 28% sand). All three assemblages are present on the inner shelf except in the Beaumont-Port Arthur area, which lacks the nearshore assemblage, and the Port Lavaca area, which has no outer assemblage (Figures 5, 6). The mean numbers of species and individuals per station are highest in the nearshore assemblage and lowest in the outer assemblage (Table 2).

Most of the abundant mollusks can be separated into five species groups (Figure 7) according to their frequency of occurrence within the three assemblages. Frequency of occurrence is defined as the percentage of the total number of stations in which a species is found in an assemblage. Species group I contains five species (*Natica pusilla, Abra aequalis, Tellina versicolor* DeKay, 1843, *Nassarius acutus,* and *Linga amiantus*) that are abundant in all assemblages; species in groups II (*Parvilucina multilineata, Acteon punctostriatus* (C. B. Adams, 1840), *Mulinia lateralis* (Say, 1822), *Periploma margaritaceum* (Lamarck, 1801), *Parvanachis obesa, Epitonium apiculatum* (Dall, 1889), and *Oliva sayana* Ravenel, 1834) and III (*Diplodonta soror, Terebra protexta* Conrad, 1845, *Cadulus carolinensis* Bush, 1885, and *Anadara transversa*) are most abundant in the nearshore or transitional assemblage, respectively; species in group IV (*Vitrinella floridana* Pilsbry & McGinty, 1946, *Nuculana concentrica, Nucula proxima, Corbula contracta* Say, 1822, and *Volvulella texasiana* Harry, 1967) are most abundant in the transitional or outer assemblage; and species in group V (*Turbonilla* sp. B, *Cantharus cancellarius* (Conrad, 1846), *Cyclostremiscus pentagonus* (Gabb, 1873), *Dentalium texasianum* Philippi, 1848, and *Nuculana acuta* (Conrad, 1831)) are not abundant in any assemblage.

Parker (1960) described an inner-shelf assemblage between depths of 10 and 66 ft (3–20 m) located primarily along the central coast in the Port Lavaca and Corpus Christi areas. Characteristic mollusks included the bivalves *Atrina serrata* (Sowerby, 1825), *Dinocardium robustum* (Lightfoot, 1786), *Dosinia discus* (Reeve, 1850), *Raeta plicatella* (Lamarck, 1818), and *Spisula solidissima* (Dillwyn, 1817). Stanton & Evans (1971) delineated two

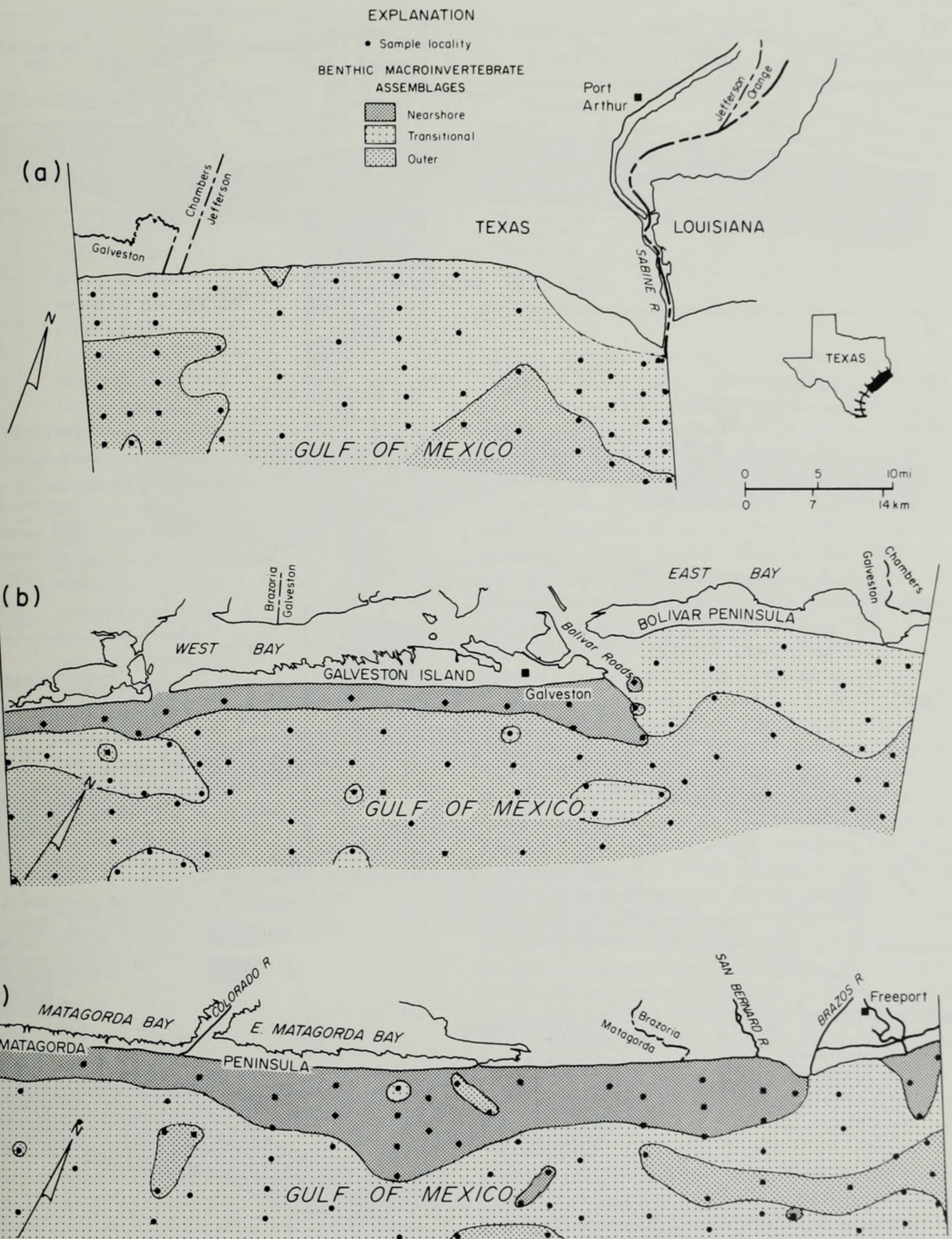


Figure 5

Benthic macroinvertebrate assemblages and sample localities in the Beaumont-Port Arthur (a), Galveston-Houston (b), and Bay City-Freeport (c) areas.

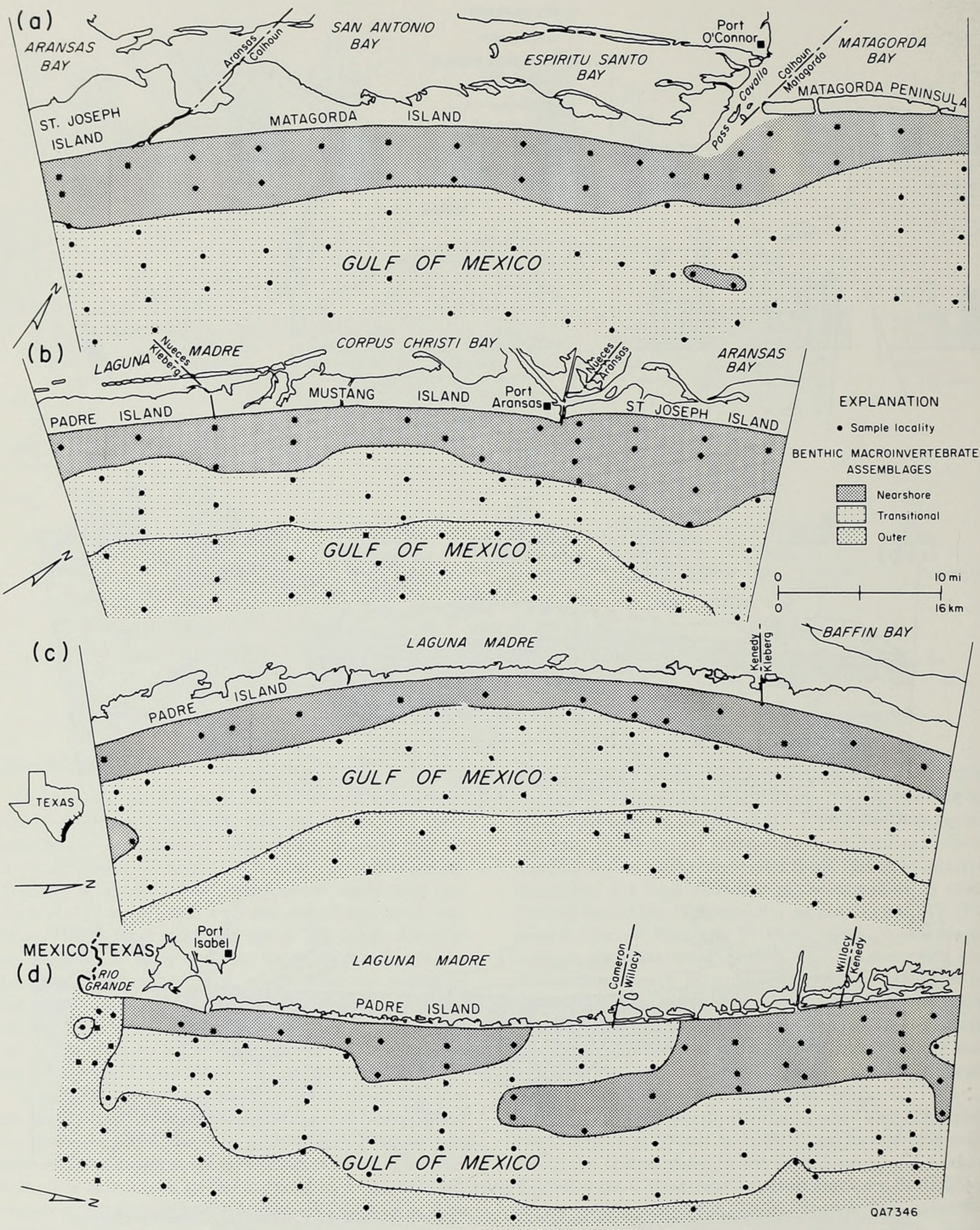


Figure 6

Benthic macroinvertebrate assemblages and sample localities in the Port Lavaca (a), Corpus Christi (b), Kingsville (c), and Brownsville-Harlingen (d) areas.

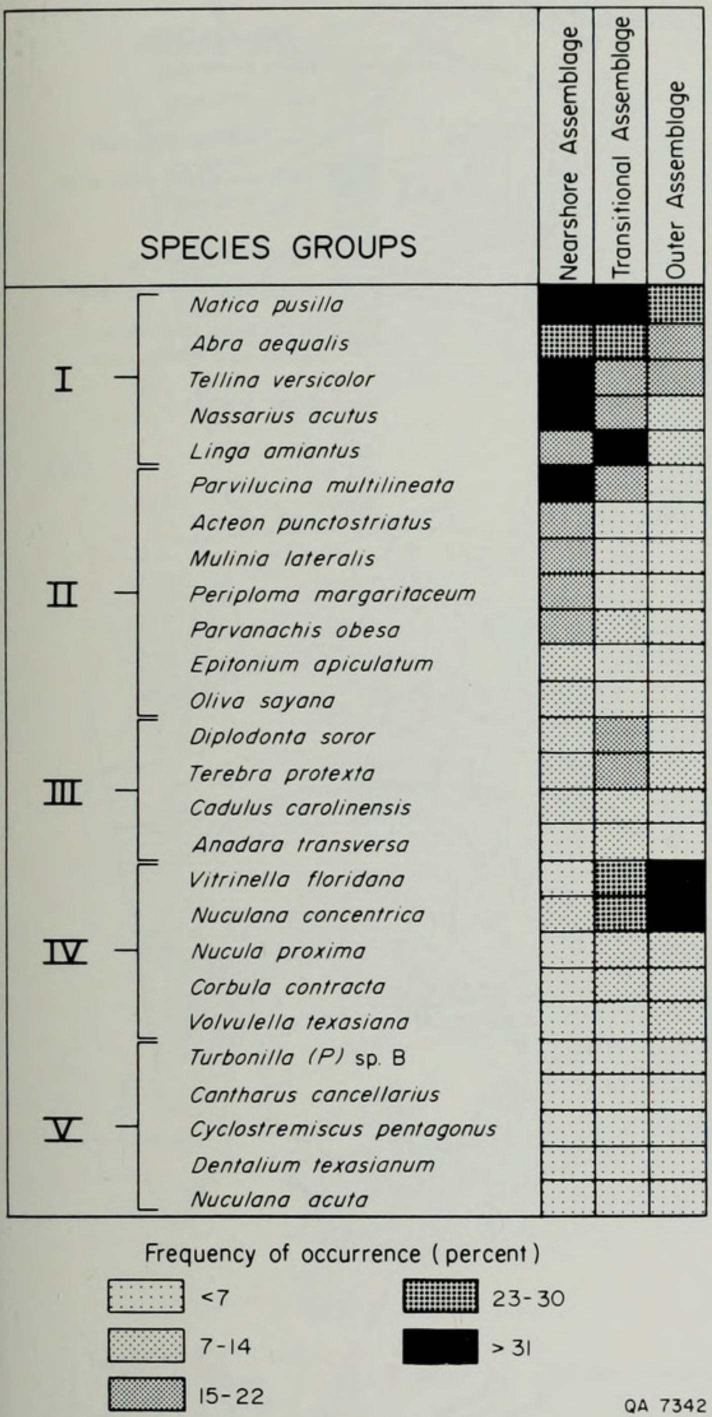


Figure 7

Frequency of occurrence of the most abundant mollusks according to the percentage of the total number of stations in each assemblage. Special groups are indicated by Roman numerals.

communities of shelled macrofauna south of the Mississippi River Delta and eight communities east of the delta. Faunal distribution south of the delta was closely correlated with water depth, bivalve feeding type, and substrate texture. East of the delta, faunal patterns reflected the nature of the water mass or distance from the delta front, water depth on the shelf away from the delta, and subdivision of the shelf by the Chandeleur-Breton Islands. Defenbaugh (1976) studied the benthic macroinvertebrates on the continental shelf of the northern Gulf of

Table 2

Characteristics of benthic faunal assemblages.

Assemblage	Total number of stations	Mean number of molluscan: Species per station	Mean number of molluscan: Individuals per station	Mean percent sand per station	Approximate depth range (m)
Nearshore	134	6	49	81	5.5-20.1
Transitional	263	5	14	43	4.3-27.4
Outer	157	3	5	28	5.5-29.3

Mexico primarily between Corpus Christi, Texas, and Pensacola, Florida, in a depth range of 59-600 ft (18-183 m). Based upon the results of his study and published and unpublished literature, Defenbaugh delineated an inner-shelf assemblage that occurred at depths of 13-66 ft (4-20 m) in soft mud, mixed sand and mud, or sand, and characteristic species included a large number of mollusks, such as *Nuculana concentrica* Say, 1824, *Anadara ovalis* (Bruguière, 1789), *Anadara transversa* (Say, 1822), *Noetia ponderosa* (Say, 1822), *Atrina serrata* (G. B. Sowerby, 1825), *Architectonica nobilis* (Röding, 1798), *Polinices duplicatus* (Say, 1822), *Anachis obesa* (C. B. Adams, 1845), and *Nassarius acutus* (Say, 1822). Flint & Rabalais (1981) delineated six station groupings of infaunal species, including a shallow-water group at depths of 33-89 ft (10-27 m), recovered from 25 collection sites (depths of 33-427 ft or 10-130 m) on the South Texas Outer Continental Shelf. The shallow-water group was found at four stations within the State-owned submerged-lands boundary. Molluscan species that made up more than 1% of the fauna in the shallow group included *Tellina versicolor* and *Anadara transversa*. Hill *et al.* (1982) delineated four assemblages in an area extending from Matagorda Peninsula in the north to the Rio Grande in the south and seaward to about the 656-ft (200-m) isobath. The 66-ft (20-m) isobath was the general inshore boundary. Three of the assemblages (two in the northern and one in the southern part of their study area) occurred within the State-owned submerged-lands boundary from the Brownsville-Harlingen to the Port Lavaca area.

Sediment Type and Molluscan Distributions

Sediments of the Texas inner shelf consist of gravel (shell), sand, and mud (silt and clay) (Figures 8, 9). The gravel-sized fraction is minor and is composed predominantly of shell and some rock fragments (Morton & Winker, 1979). The offshore extent of dominantly sand sediments varies greatly (McGowen & Morton, 1979). On the upper coast from Bolivar Roads to Sabine Pass, shelf sediments lack sand, and mud is the most extensive sediment (Figures 8a, b). Sand deposits are thin and limited to a narrow strip parallel to the beach and upper shoreface

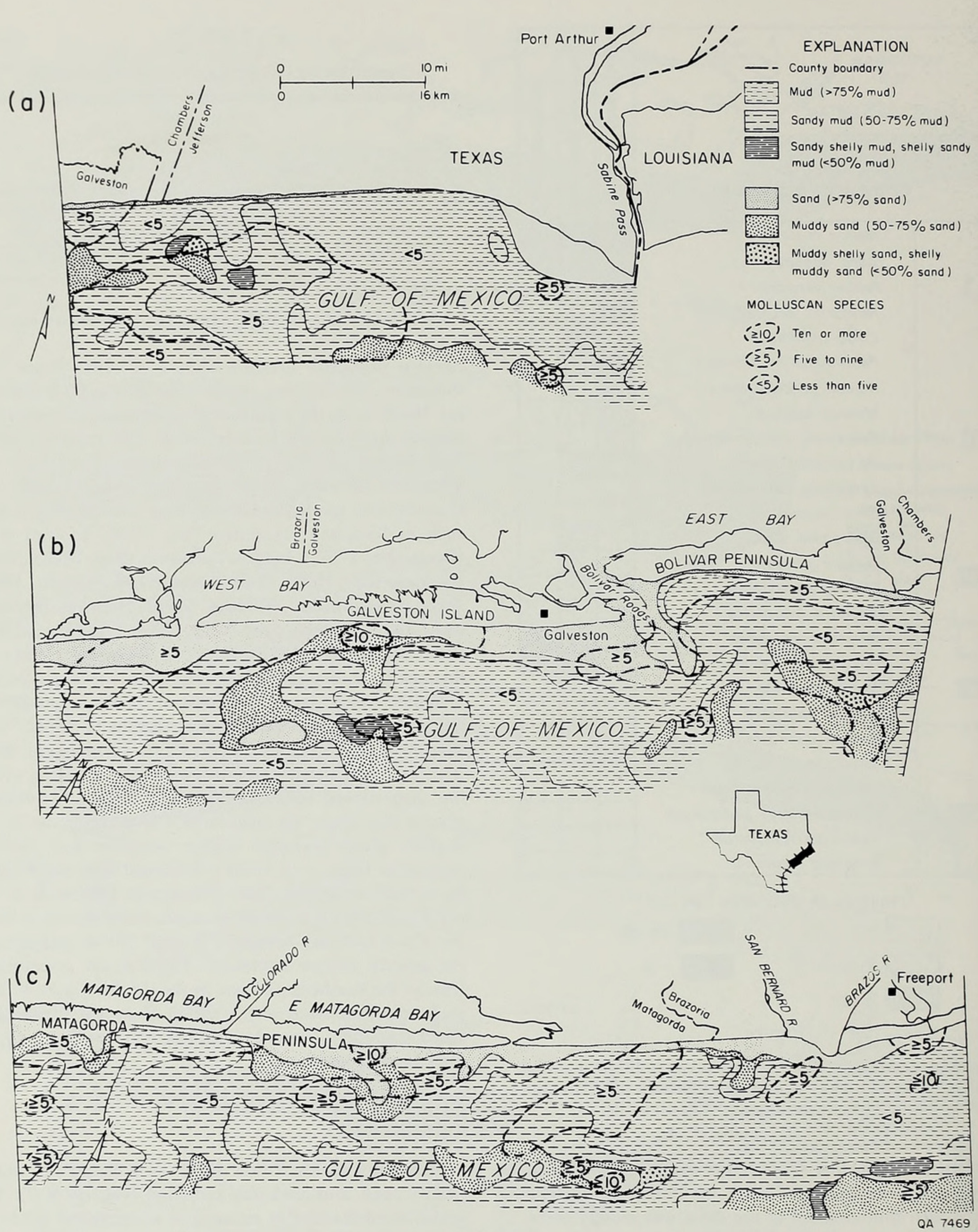


Figure 8

Distribution of gravel (shell), sand, and mud in the Beaumont-Port Arthur (a), Galveston-Houston (b), and Bay City-Freeport (c) areas (modified from WHITE *et al.*, 1985, 1987, 1988). Dashed lines delineate areas with similar numbers of molluscan species.

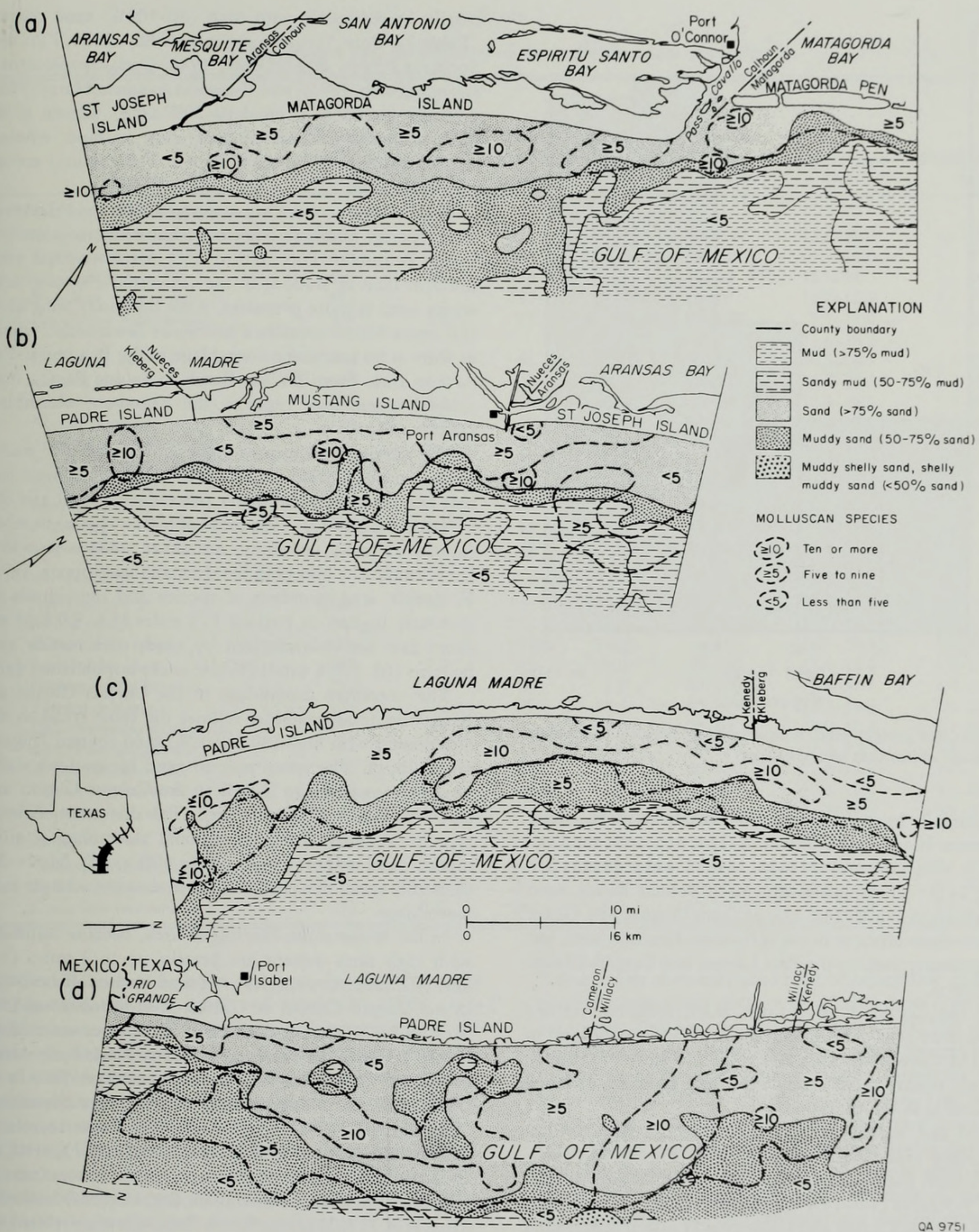


Figure 9

Distribution of gravel (shell), sand, and mud in the Port Lavaca (a), Corpus Christi (b), Kingsville (c), and Brownsville-Harlingen (d) areas (modified from WHITE *et al.*, 1983, 1986, in press, and unpublished data). Dashed lines delineate areas with similar numbers of molluscan species.

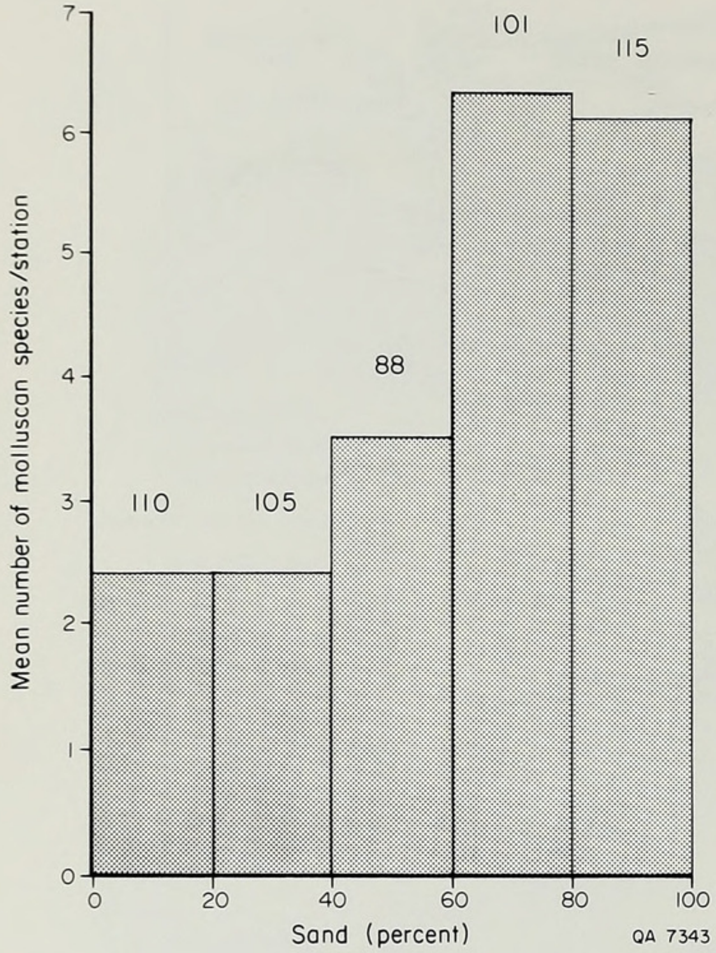


Figure 10

Mollusks and percent sand. Numbers above bars equal number of stations within that sediment type.

and generally less than 0.5 mile (0.8 km) from shore. Along Galveston Island in the Galveston-Houston area, sand extends 1 mile (1.6 km) offshore, where water depths are about 24 ft (7.3 m); just southwest of Bolivar Roads, sand extends up to 3 miles (4.8 km) offshore (Figure 8b). Grain size decreases offshore in the Galveston-Houston area, but less gradually than on the Port Lavaca and Corpus Christi inner shelf.

On the Corpus Christi inner shelf, sediment texture grades from sand through muddy sand and sandy mud to mud (McGowen & Morton, 1979) (Figure 9b). Bands of sand, muddy sand, sandy mud, and mud are oriented subparallel to the shoreline.

Sand and muddy sand dominate in the Brownsville-Harlingen area (White *et al.,* 1986) (Figure 9d). Sediments with high sand content (80 to 100%) are present from 1–9 miles (1.6–14.4 km) offshore. On the inner shelf in the Corpus Christi and Galveston-Houston areas, sand is not as abundant, and muds usually dominate at stations closer to shore.

More molluscan species are found in sand than mud. The mean number of species per station is highest in the 60–80%-sand range and lowest in the 0–40%-sand range (Figure 10). Most of the abundant mollusks occur primarily in sediments with high (80–100%) sand content (Table 3). Only *Nuculana concentrica* Say, 1824, *Vitrinella floridana* Pilsbry & McGinty, 1946, *Cyclostremiscus pentagonus* (Gabb, 1873), and *Volvulella texasiana* Harry, 1967, are most abundant in mud (0–20% sand). Eleven of the most abundant mollusks do not occur in mud, whereas only two species (*N. concentrica* and *V. texasiana*) are not present in sand.

Because more species are associated with sand than with mud, species numbers (species richness) at most stations in the Beaumont-Port Arthur area are lower and more uniform than at stations in the Galveston-Houston area, where sand is more prevalent. Also, the sandy zone along Galveston Island contains a nearshore assemblage, whereas there is no nearshore assemblage in the Beaumont-Port Arthur area. From Bolivar Roads to Sabine Pass, a transitional assemblage replaces the nearshore assemblage (Figures 5a, b).

The median and mean numbers of species per station in the Corpus Christi area increase with higher sand content and decrease with higher percentages of silt and clay (White *et al.,* 1983). This trend of higher species numbers (species richness) at sandy, nearshore stations is evident for all mollusks and both bivalves and gastropods. In the Kingsville area, numbers of species and individuals are generally highest at stations 1–5 miles (1.6–8.0 km) offshore that are characterized by sandy and muddy sand bottoms (60–100% sand) (White *et al.,* unpublished data).

The nearshore assemblage in the Corpus Christi and Kingsville areas generally follows the same trend as that of sediment with high (80 to 100%) sand content (Figures 6b, c, 9b, c). The mean percent sand for stations with a nearshore assemblage is 88% in the Corpus Christi area and 97% in the Kingsville area. The dominant sediment type for stations with a transitional assemblage is either muddy sand or sandy mud (20 to 60% sand). Muds (less than 20% sand) are predominant at stations with an outer assemblage.

In the Brownsville-Harlingen area, because sediments with high sand content are present up to 9 miles (14.4 km) offshore, more species are found farther offshore than in the Corpus Christi or Galveston-Houston areas (Figures 8b, 9b, d). Stations with any of the three assemblages in the Brownsville-Harlingen area are relatively sandy, averaging 92% in the nearshore assemblage, 70% in the transitional assemblage, and 53% in the outer assemblage.

Hill *et al.* (1982), too, found a significant correlation between the number of macrobenthic infaunal species and the amount of sand in the sediment. All the factors (number of species, number of individuals, and biomass) studied by Hill *et al.* (1982) on the South Texas shelf correlated best with high sand-to-mud ratios. A series of regression analyses showed that number of species, number of individuals, and biomass increased with increases in sand-to-mud ratios, the largest occurring where the sand-to-mud ratios exceeded 1.00.

Probably the primary factor accounting for the high

Table 3

Abundance and distribution of the most abundant mollusks.

Species	Total number of individuals	Percent of all (11,795) individuals	Total number of stations	Percent of all (554) stations	Predominant sediment type (% sand)	Predominant depth range (m)	Depth range (m)
Bivalvia							
Abra aequalis	4305	36.5	154	27.8	80–100	12.8–18.3	5.5–29.3
Tellina versicolor	621	5.3	148	26.7	80–100	9.1–11.0	3.7–27.4
Linga amiantus	462	3.9	136	24.5	60–80	14.6–18.3	5.5–29.3
Nuculana concentrica	412	3.5	133	24.0	0–40	11.0–12.8	3.7–29.3
Parvilucina multilineata	335	2.8	97	17.5	80–100	9.1–11.0 16.5–18.3	5.5–20.1
Diplodonta soror	236	2.0	65	11.7	60–80	16.5–18.3	5.5–25.6
Mysella planulata	204	1.7	8	1.4	80–100	16.5–18.3	3.7–25.6
Corbula contracta	137	1.2	58	10.5	60–80	12.8–14.6	9.1–29.3
Nucula proxima	106	0.9	56	10.1	60–80	14.6–18.3	9.1–29.3
Anadara transversa	79	0.7	36	6.5	60–80	18.3–20.1	3.7–25.6
Periploma margaritaceum	72	0.6	31	5.6	80–100	9.1–11.0	3.7–20.1
Strigilla mirabilis	62	0.5	17	3.1	80–100	14.6–16.5	9.1–20.1
Mulinia lateralis	57	0.5	29	5.2	80–100	5.5–11.0	3.7–12.8
Tellina iris	45	0.4	14	2.5	80–100	7.3–11.0	3.7–14.6
Solen viridis	30	0.3	20	3.6	80–100	12.8–14.6	7.3–23.8
Gastropoda							
Nassarius acutus	1261	10.7	134	24.2	80–100	9.1–11.0	3.7–20.1
Natica pusilla	552	4.8	232	41.9	80–100	11.0–18.3	3.7–29.3
Vitrinella floridana	406	3.4	121	21.8	0–40	16.5–20.1	5.5–29.3
Parvanachis obesa	239	2.0	83	15.0	80–100	11.0–14.6	5.5–20.1
Cyclostremella humilis	212	1.8	10	1.8	80–100	5.5–9.1	5.5–9.1
Terebra protexta	136	1.2	79	14.3	60–80	16.5–18.3	5.5–27.4
Cyclostremiscus pentagonus	111	0.9	29	5.2	20–40	11.0–12.8	9.1–29.3
Epitonium apiculatum	94	0.8	25	4.5	80–100	7.3–9.1	5.5–16.5
Acteon punctostriatus	93	0.8	52	9.4	80–100	12.8–14.6	3.7–27.4
Volvulella texasiana	58	0.5	46	8.3	0–20	12.8–16.5	9.1–29.3
Polinices duplicatus	42	0.4	29	5.2	80–100	9.1–11.0	5.5–20.1
Scaphopod							
Cadulus carolinensis	96	0.8	47	8.5	80–100	16.5–18.3	9.1–23.8
Dentalium texasianum	42	0.4	26	4.7	60–80	16.5–18.3	9.1–25.6
Dentalium eboreum	35	0.3	24	4.3	80–100	9.1–11.0	9.1–18.3

number of species (species richness) in predominantly muddy sand (60–80% sand) and sandy (80–100% sand) substrates is structural complexity or heterogeneity of the substrate. Coarse and heterogeneous sediments in sublittoral samples are generally more structurally complex and, seemingly as a result, have higher diversities than fine and homogeneous sediments (Gray, 1974). For example, Craig & Jones (1966) found that, although species number does not necessarily correlate with diversity (Gray, 1974), numbers of both epifaunal and infaunal species in the Irish Sea were highest in the coarsest sediments or gravel, followed by muddy sand, sand, and mud, in that order. In later studies, Sanders (1968), Boesch (1972), and Gray (1974) substantiated the claim and noted that fauna on stable, sandy bottoms are generally more diverse than those on muddy bottoms because of the greater variety of microhabitats in coarser sediments.

Substrates of muddy sand may be better able to support benthic communities that are trophically more diverse than substrates with homogeneous muds or sands. The optimal substrate for both deposit and suspension feeders may be muddy sands or predominantly sandy substrates having an integral but smaller percentage of silt and clay. Harry (1976) found that substrates with moderate amounts of silt and clay lend a certain rigidity to sandy substrates allowing the tunnels of burrowers to remain open. On the other hand, substrates with large amounts of clay and organic matter have reduced capillary circulation and increased chances of having anaerobic conditions (Purdy, 1964). And whereas deposit feeders have special feeding and respiratory adaptations to deal with these conditions, most suspension-feeding species cannot tolerate large amounts of silt and clay. Even small increases in the silt-clay content of substrates may clog interstitial spaces and

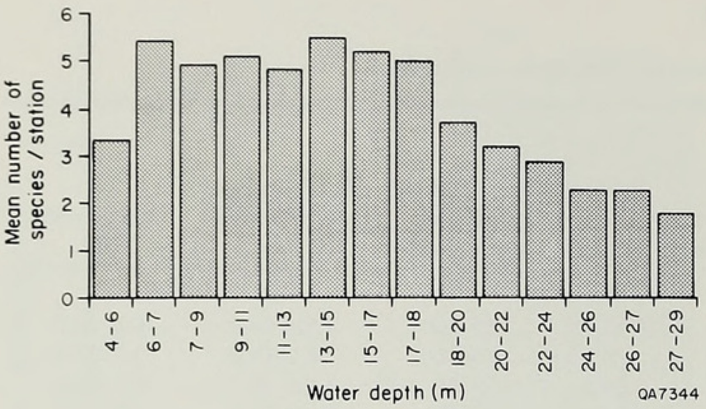


Figure 11

Distribution by depth (m) of the mean number of species per station.

slow oxygen diffusion to sediment depths (COULL, 1985). But aside from respiratory concerns, there are feeding problems, too. Sediments that consist predominantly of silts and clays are indicative of feeble currents that allow the fine particles to settle out; therefore, there is less food in the water column for suspension feeders (SANDERS, 1958).

Complete homogeneity of sand is not the ideal condition for high diversity either. Substrates in nearshore areas, where sand content may range from 90 to 100%, are unstable, and many benthic organisms are not suited to substrate mobility (PURDY, 1964). Additionally, substrates having greater than 90% sand have low total organic carbon values, and thus fewer deposit feeders that feed on the organics in the sediment will survive (PURDY, 1964).

Finally, biological interactions related to sediment distribution, such as trophic group amensalism, may also affect molluscan distribution. Suspension feeders may be unable to coexist with deposit feeders in muddy bottoms because of sediment instability produced by the deposit feeders. Such instability, termed "trophic group amensalism" (RHODES & YOUNG, 1970), inhibits suspension feeders and sessile epifauna by clogging filtering mechanisms, resuspending and burying larvae, and discouraging the settlement of larvae of suspension feeders and adults of sessile epifauna (RHODES & YOUNG, 1970). The reworked muddy surface is limiting to suspension feeders when the surface becomes mobile (RHODES & YOUNG, 1970).

Bathymetry and Molluscan Distributions

Shelf bathymetry near the Gulf of Mexico shoreline is characterized by a relatively steep slope, ranging from 6 ft/mile (1.8 m/km) near Sabine Pass in the Beaumont-Port Arthur area to 30 ft/mile (6 m/km) in the Brownsville-Harlingen area. The slope becomes more gradual beyond a distance of about 1 mile (1.6 km) offshore. At approximately 10 miles (16 km) offshore, the slope decreases, ranging from 1 ft/mile (0.2 m/km) in the Beaumont-Port Arthur area to 9–12 ft/mile (1.8–2.4 m/km) in the Brownsville-Harlingen area. Depths at stations 11 miles (17.6 km) offshore range from 40 ft (12.5 m) in the Beaumont-Port Arthur area to 96 ft (29.3 m) in the Brownsville-Harlingen area.

Analysis of the bathymetric distribution of all the mollusks sampled shows that the mean number of species per station is greatest in depths of 18–60 ft (6–18 m) (Figure 11). The mean number of species per station at this depth is 5.1, whereas the mean at stations at 60–96 ft (18–29 m) depths is 2.7. Mean numbers of species decrease from 5.0 to 1.8 as depth increases from 60 to 96 ft (18 to 29 m) (Figure 10). This decrease is similar to the decrease noted by PARKER (1960), in which the average number of macrobenthic species (primarily mollusks) decreased from 5.7 in his shallowest depth zone of 1–10 fathoms (2–18 m) to 1.0 in the next deepest zone of 10–20 fathoms (18–37 m). Both PARKER (1960) and HILL *et al.* (1982) found that the average number of macrobenthic species and individuals were highest at stations in their shallowest depth zones of 0–131 ft (0–40 m) and 1–10 fathoms (2–18 m), respectively.

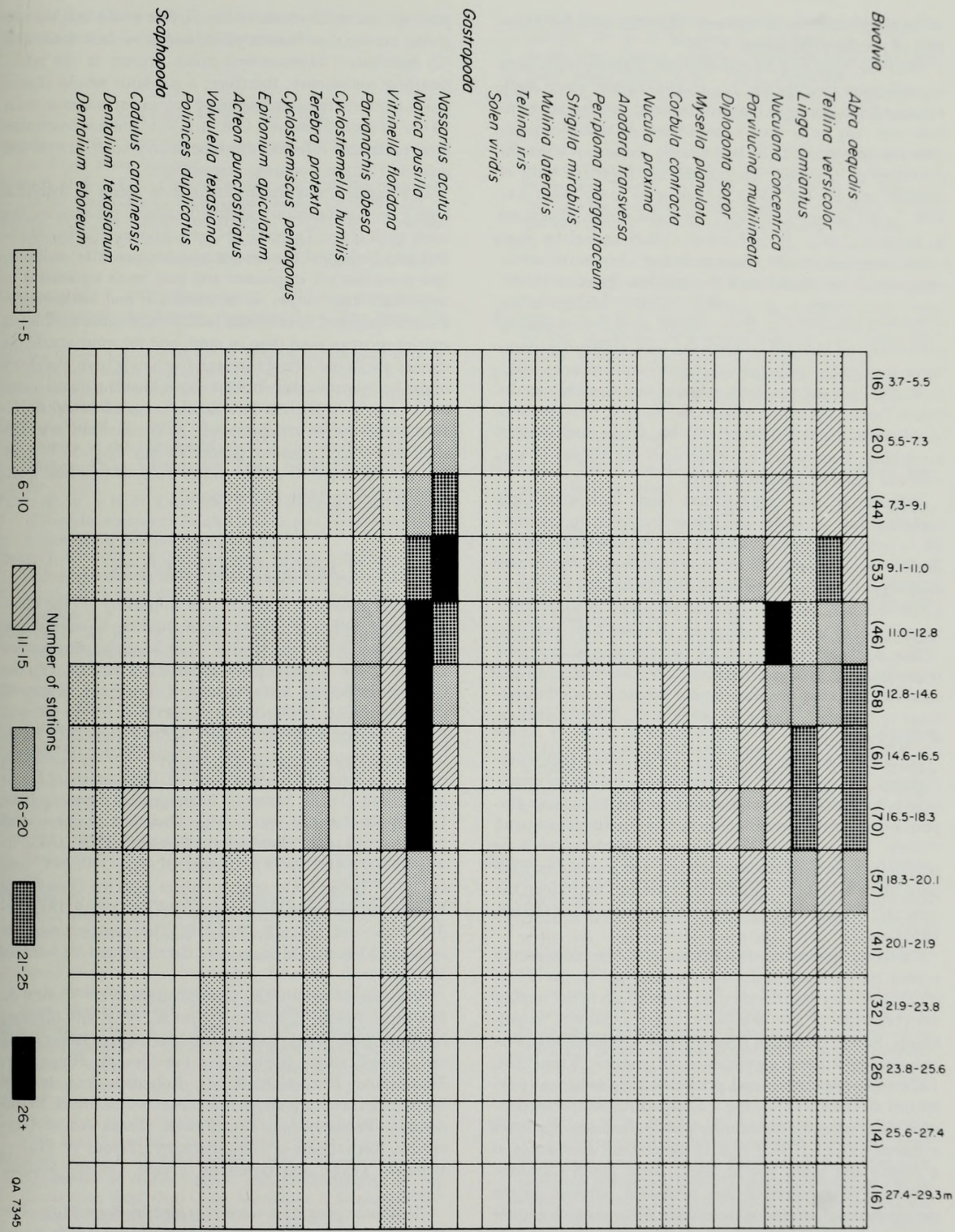
Many species are most abundant either at shallower-water stations (stations from 18.0–36.1 ft or 5.5–11.0 m deep) or deeper-water stations (stations from 47.9–60.0 ft or 14.6–18.3 m deep) (Figure 12). Species most abundant in shallower water include *Mulinia lateralis* (Say, 1822), *Periploma margaritaceum* (Lamarck, 1801), *Tellina iris* Say, 1822, *Tellina versicolor* DeKay, 1843, *Cyclostremella humilis* Bush, 1897, *Nassarius acutus* (Say, 1822), *Epitonium apiculatum* (Dall, 1899), and *Dentalium eboreum* Conrad, 1846. Those species most abundant in deeper water include *Mysella planulata* (Stimpson, 1857), *Nucula proxima* Say, 1822, *Anadara transversa* (Say, 1822), *Strigilla mirabilis* (Philippi, 1841), *Vitrinella floridana* Pilsbry & McGinty, 1946, *Terebra protexta* Conrad, 1845, and *Dentalium texasianum* Philippi, 1848. Many species that are most abundant in the shallower- or deeper-water group also occur at other depths; only *Nuculana concentrica* and *Natica pusilla* occurred at all depths (12.1–96.1 ft or 3.7–29.3 m) (Figure 12).

Some of the physical parameters that are related to water depth and that affect molluscan distributions are (1) sediment distribution; (2) nutrient availability (FLINT & RABALAIS, 1981); (3) turbidity (PARKER, 1960); (4) changes in bottom-water temperature (PARKER, 1960; HILL *et al.*, 1982); (4) oxygen levels (HILL *et al.*, 1982); and (5) hydrodynamic processes, such as the turbulence of water flow,

→

Figure 12

Distribution by depth (m) of the most abundant mollusks. Numbers in parentheses equal total number of stations within each depth range.


Bivalvia
Abra aequalis
Tellina versicolor
Lingo amiantus
Nuculana concentrica
Parvilucina multilineata
Diplodonta soror
Mysella planulata
Corbula contracta
Nucula proxima
Anadara transversa
Periploma margaritaceum
Strigilla mirabilis
Mulinia lateralis
Tellina iris
Solen viridis
Gastropoda
Nassarius acutus
Natica pusilla
Vitrinella floridana
Parvanachis obesa
Cyclostremella humilis
Terebra protexta
Cyclostremiscus pentagonus
Epitonium apiculatum
Acteon punctostriatus
Volvulella texasiana
Polinices duplicatus
Scaphopoda
Cadulus carolinensis
Dentalium texasianum
Dentalium eboreum
(16) 3.7-5.5
(20) 5.5-7.3
(44) 7.3-9.1
(53) 9.1-11.0
(46) 11.0-12.8
(58) 12.8-14.6
(61) 14.6-16.5
(70) 16.5-18.3
(57) 18.3-20.1
(41) 20.1-21.9
(32) 21.9-23.8
(26) 23.8-25.6
(14) 25.6-27.4
(16) 27.4-29.3m
Number of stations
1-5
6-10
11-15
16-20
21-25
26+
QA 7345

the settling velocities of sediment particles, and the transport of particles (SANDERS, 1958).

Sediment type and bathymetry are primary influences on molluscan distribution, but on the shallow inner shelf, extreme fluctuations in temperature and salinity are common and may be at least as significant to molluscan distribution as is substrate or bathymetry. Bottom-water temperatures on the inner shelf of the northwestern Gulf of Mexico and off the South Texas coast range from 14–16°C in the winter to 27–28°C in the summer (RABALAIS & BOESCH, 1987). Both PARKER (1960) and HILL *et al.* (1982) emphasized the effect of changes in bottom-water temperature on zonation of the infauna. PARKER (1960) noted that waters in the northern Gulf of Mexico in the 1- to 12-fathom (2- to 22-m) depth zone are constantly turbulent and virtually isothermal, and bottom temperatures are similar to the prevailing air temperatures. HILL *et al.* (1982) found that bottom-water temperatures on the South Texas shelf reflect seasonally changing temperatures to a depth of about 230–262 ft (70–80 m) and that infaunal assemblage boundaries correlate with the bottom of this seasonal water-temperature layer.

Salinities in near-shore waters range from open Gulf surface values of 36.4‰ to 20‰ or less after spring run-off or periods of high rainfall (FLINT & RABALAIS, 1981). Besides run-off from localized river discharges, freshwater discharges from the Mississippi and Atchafalaya rivers in Louisiana may produce reduced salinities in inner-shelf waters as far west as Galveston (RABALAIS & BOESCH, 1987). Reduced salinities in the late spring and increased nutrients may produce hypoxia in bottom waters in the summer. Hypoxic conditions may extend from off Louisiana to Freeport, Texas (HARPER *et al.*, 1981; RABALAIS & BOESCH, 1987).

Although physical parameters in the inner shelf environment are important in determining molluscan distribution, biological interactions, such as predation, may also play a major role. Predation by epibenthic fish, crabs, and shrimp, and by predatory infaunal organisms, such as polychaetes, nemerteans, crustaceans, and gastropods, have been shown to play significant roles in controlling the structure of many types of soft-bottom communities (REISE, 1984).

Predation pressures on mollusks in the predominantly muddy environment of the outer assemblage on the Texas inner shelf may be different than on mollusks in the sandier environments of the nearshore and transitional assemblages. Severe predation may decrease species diversity by reducing population densities of all species (VIRNSTEIN, 1977). However, low-level predation may enhance prey-species diversity by allowing less opportunistic species populations to enter the community and thus enhancing species richness. COULL (1985) studied meiofaunal abundance at a muddy and sandy site in North Inlet, South Carolina. COULL (1985) suggested that predation pressure on the meiofaunal community at the muddy site was much greater than on the community from the sandy site because (1) prey species occur closer to the surface at the muddy site giving potential predators easier access to their food, and (2) meiofaunal biomass was much greater in the mud-dwelling community; therefore, a predator would obtain much more energy from sorting 1 cm^3 of surface mud than 10 cm^3 of sand. However, COULL (1985) did not determine how predation affected the community structure of the mud-dwelling meiofaunal assemblage.

In summary, molluscan distribution seems to correlate highly with sedimentary and bathymetric patterns on the inner shelf of the Texas Gulf Coast. However, other physical and biological factors such as temperature, salinity, and predation are important and may be as significant to molluscan distribution as is substrate and bathymetry. Faunal-sediment associations indicate that more molluscan species occur in sand than in mud, and the most abundant species are found where the sand fraction is high. Analysis of the bathymetric distribution shows that the mean number of species is highest in a depth range of 18–60 ft (6–18 m), and that many species are most abundant at either shallower-water stations (stations from 18.0–36.1 ft or 5.5–11.0 m deep) or deeper-water stations (stations from 47.9–60.0 ft or 14.6–18.3 m deep).

ACKNOWLEDGMENTS

Financial assistance was provided in part by (1) the General Land Office of Texas, with funding in accordance with section 305 of the Coastal Zone Management Act for Coastal Zone Management Program (CZMP), (2) the Governor's Budget and Planning Office, with grants in accordance with section 308 of the same act for the Coastal Energy Impact Program (CEIP); CZMP and CEIP funding was administered by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and (3) the Minerals Management Service of the U.S. Department of the Interior. Contract numbers with the General Land Office were IAC(80-81)-1201, IAC(78-79)-1910, IAC(78-79)-0539, IAC(76-77)-1244, and IAC(76-77)-0833. Contract numbers with the Governor's Budget and Planning Office were CZ80M935019, IAC(80-81)-0865, and IAC(78-79)-1210. The contract number with the Minerals Management Service was 14-12-0001-30070.

Assisting in molluscan identifications were James A. DiGiulio, Joseph E. Sullivan, Lisa R. Wilk, and Stephen M. Robertson. Those individuals who assisted in verifying our identifications include the late Joseph Rosewater, Smithsonian Institution; Robert Robertson and the late Virginia Maes of the Academy of Natural Sciences, Philadelphia, Pennsylvania; Eric Powell, Texas A&M University, Department of Oceanography; Harold W. Harry, Bellaire, Texas; and Granville Treece, College Station, Texas.

Computer programs were provided by Scott Holt, The University of Texas Marine Science Institute, Port Aransas, and Rod Harwood, The University of Texas at Austin, Department of Geological Sciences.

LITERATURE CITED

ANDREWS, J. A. 1977. Shells and shores of Texas. University of Texas Press. 365 pp.

BOESCH, D. F. 1972. Species diversity of marine macrobenthos in the Virginia area. Chesapeake Science 13(3):206–211.

BROWN, L. F., JR. (project coordinator). 1972–1980. Environmental geologic atlas of the Texas Coastal Zone. The University of Texas at Austin Bureau of Economic Geology. 7 atlases.

CLIFFORD, H. T. & W. STEPHENSON. 1975. An introduction to numerical classification. Academic Press: New York. 220 pp.

COULL, B. C. 1985. The use of long-term biological data to generate testable hypotheses. Estuaries 8(2A):84–92.

CRAIG, G. Y. & N. S. JONES. 1966. Marine benthos, substrate and palaeoecology. Palaeontology 9(1):30–38.

DEFENBAUGH, R. E. 1976. A study of the benthic macroinvertebrates of the continental shelf of the northern Gulf of Mexico. Ph.D. Dissertation, Texas A&M University. 476 pp.

FLINT, R. W. & N. N. RABALAIS. 1981. Environmental studies of a marine ecosystem, South Texas Outer Continental Shelf. University of Texas Press. 240 pp.

GRAY, J. S. 1974. Animal-sediment relationships. Pp. 225–262. *In:* H. Barnes (ed.). Oceanography and marine biology, an annual review. Vol. 12. George Allen and Unwin Ltd: London.

HARPER, D. E., JR. 1970. Ecological studies of selected level-bottom macroinvertebrates off Galveston, Texas. Ph.D. Dissertation, Texas A&M University. 314 pp.

HARPER, D. E., JR., L. D. MCKINNEY, R. R. SALZER & R. J. CASE. 1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contrib. Mar. Sci. 24:53–79.

HARRY, H. W. 1976. Correlation of benthic Mollusca with substrate composition in lower Galveston Bay, Texas. Veliger 19(2):135–152.

HILL, G. W., K. A. ROBERTS, J. L. KINDINGER & G. D. WILEY. 1982. Geobiologic study of the South Texas Outer Continental Shelf. U.S. Geological Professional Paper 1238:36 pp.

HULINGS, N. C. 1955. An investigation of the invertebrate fauna from the shallow waters of the Texas coast. Master's Thesis, Texas Christian University, 87 pp.

KENNEDY, E. A., JR. 1959. A comparison of the molluscan fauna along a transect extending from the shoreline to a point near the edge of the continental shelf of the Texas coast. Master's Thesis, Texas Christian University. 135 pp.

MCGOWEN, J. H. & R. A. MORTON. 1979. Sediment distribution, bathymetry, faults, and salt diapirs on the submerged lands of Texas. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 31 pp., 7 maps.

MOORE, D. R. 1979. Molluscan exploration and research in and around the Gulf of Mexico. Bull. Amer. Malac. Union. 45th annual meeting. Corpus Christi, Texas. 5 pp.

MORTON, R. A. & C. D. WINKER. 1979. Distribution and significance of coarse biogenic and clastic deposits on the Texas inner shelf. Gulf Coast Association of Geological Societies, Trans. 29:136–146.

PARKER, R. H. 1960. Ecology and distributional patterns of marine macroinvertebrates, northern Gulf of Mexico. Pp. 302–337. *In:* F. P. Shepard, F. B. Phleger & T. H. van Andel (eds.), Recent sediments, northwest Gulf of Mexico. Amer. Assoc. Petrol. Geol.: Tulsa, Oklahoma.

PURDY, E. G. 1964. Sediments as substrates. Pp. 238–271. *In:* J. Imbrie & N. D. Newell (eds.), Approaches to paleoecology. John Wiley: New York.

RABALAIS, N. N. & D. F. BOESCH. 1987. Dominant features and processes of continental shelf environments of the United States. Pp. 71–147. *In:* D. F. Boesch & N. N. Rabalais (eds.), Long term environmental effects of offshore oil and gas development. Elsevier Applied Science: New York.

REISE, K. 1984. Predator control in marine tidal sediments. Pp. 311–321. *In:* P. E. Gibbs (ed.), Proceedings of the Nineteenth European Marine Biology Symposium. Cambridge University Press: New York.

RHOADS, D. C. & D. K. YOUNG. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. Jour. Mar. Res. 28(2):150–178.

SANDERS, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnol. Oceanogr. 3(3):245–258.

SANDERS, H. L. 1968. Marine benthic diversity: a comparative study. Amer. Natur. 102(925):1–40.

SCHLEE, J. 1966. A modified Woods Hole rapid sediment analyzer. Jour. Sediment. Petrol. 36:403–413.

SHIDELER, G. J. 1976. A comparison of electronic particle counting and pipette techniques in routine mud analysis. Jour. Sediment. Petrol. 46:1017–1025.

STANTON, R. J. & I. EVANS. 1971. Environmental controls of benthic macrofaunal patterns in the Gulf of Mexico adjacent to the Mississippi Delta. Gulf Coast Association of Geological Societies, Trans. 21:371–378.

TREECE, G. D. 1979. Living marine mollusks from the South Texas continental shelf. Texas Jour. Sci. 31(3):271–283.

VIRNSTEIN, R. W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. Ecology 58:1199–1217.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN, H. S. NANCE & K. E. SCHMEDES. 1983. Submerged lands of Texas, Corpus Christi area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 154 pp., 6 maps.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN, H. S. NANCE & K. E. SCHMEDES. 1985. Submerged lands of Texas, Galveston-Houston area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 145 pp., 6 maps.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN, H. S. NANCE & K. E. SCHMEDES. 1986. Submerged lands of Texas, Brownsville-Harlingen area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 138 pp., 6 maps.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN & H. S. NANCE. 1987. Submerged lands of Texas, Beaumont-Port Arthur area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 110 pp., 6 maps.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN & H. S. NANCE. 1988. Submerged lands of Texas, Bay City-Freeport area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication. 130 pp., 6 maps.

WHITE, W. A., T. R. CALNAN, R. A. MORTON, R. S. KIMBLE, T. G. LITTLETON, J. H. MCGOWEN & H. S. NANCE. In press. Submerged lands of Texas, Port Lavaca area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. The University of Texas at Austin, Bureau of Economic Geology Special Publication.