THE DISTRIBUTION OF RECENT FORAMINIFERA IN TIMBALIER BAY, LOUISIANA

by Christopher L. Ostrom

ABSTRACT

The species composition and distribution of 26 species of the living and dead Recent benthic foraminiferal faunas of Timbalier Bay, Louisiana, were determined. There are four species complexes: (1) species endemic to marshes, (2) open Gulf species, (3) bay species, and (4) barrier island marsh species. Predominant species were *Ammonia beccarii* varieties *parkinsoniana* and *tepida, Elphidium gunteri, E. matagordanum, E. poeyanum, E. vadescens, Ammotium salsum, Ammobaculites dilatatus*, and *Quinqueloculina tenagos*.

Low total populations and standing crops of benthic Foraminifera correlate with sediments exhibiting high percentages of sand and low percentages of both organic material and calcium carbonate. Low species diversities were related to extremes in salinity and sediment type, as well as to the barrier island marsh environment. Of the parameters studied, salinity and sediment type were the most important factors limiting the distribution of foraminiferal species within Timbalier Bay. Patterns of species distribution did not appear to be related to the location of oil and gas facilities. Comparisons with a previous study of Timbalier Bay indicated that little change has occurred in the foraminiferal fauna over the past 15 years.

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INTRODUCTION

Several investigations of the ecology and distribution of Recent benthic Foraminifera have been completed within the past 30 years, especially since the introduction by Walton (1952) of an efficient and reliable method of staining living Foraminifera. Distribution of selected taxa of benthic Foraminifera have been correlated with numerous environmental parameters and combinations of parameters, including grain size and organic content of the sediment, salinity, temperature, dissolved oxygen concentration, availability of food, depth, and bottom topography. A few studies have demonstrated that species diversity, abundance of individuals, and the presence of certain species of Foraminifera can be used as indicators of specific environmental conditions. Because it has been shown that benthic Foraminifera may be sensitive to changes in environment, the distribution and ecology of benthic Foraminifera have been measured in the northern Gulf Coast Region, including Timbalier Bay, to determine the effects, if any, of oil and gas production there.

Any study of Recent Foraminifera in the northern Gulf of Mexico must include reference to the early classic taxonomic works of d'Orbigny (1839), Brady on the Challenger collections (1884), and Cushman (1922), and to texts by Phleger (1960) and Murray (1973), which summarize and integrate much of the principal work on the ecology of Recent Foraminifera. The results of some previous investigations suggest that it is possible that impacts from oil and gas development activities in Timbalier Bay might be reflected in patterns of distribution of selected taxa of benthic Foraminifera. For example, Morin (1971) observed that the normal distribution of one species was extended toward the source of the oil spill following the 1969 Santa Barbara oil spill. Watkins (1961) and Bandy et al. (1964a, 1964b, 1964c) demonstrated that sewage pollution in southern California was indicated by the absence of living Foraminifera directly beneath sewage outfalls, few Foraminifera where the sewage was heavily concentrated, and flourishing populations where sewage was diluted. Clark (1971) showed that total populations reflected the effects of an aquaculture outfall in Clam Bay, Nova Scotia.

Investigations of the distribution of benthic Foraminifera, and of the relationship between patterns of species distribution and measured environmental parameters, have been conducted in coastal areas adjacent to the Mississippi River Delta and along the coastlines of Texas and Alabama. Lowman (1949), Parker et al. (1953), Phleger (1954, 1956), Bandy (1956), and Lamb (1972) found patterns of change in the distribution of foraminiferal taxa that were associated with changes in salinity. Phleger (1955) and Lankford (1959) both recognized faunal assemblages in the eastern Mississippi Delta region that were correlated with bottom water-masses of variable physical and chemical composition. Lehman (1957) used statistical methods to show that distribution patterns of Foraminifera in Matagorda Bay, Texas, were the result of a complex interaction of many ecological factors. Salinity, organic content of the sediment, the extent and nature of water currents, and turbulence were the more important parameters limiting the distribution, while temperature, depth, and turbidity were thought to have little effect. Phleger and Lankford (1957) examined seasonal occurrences of living benthic Foraminifera in several southwest Texas bays, and found that living populations in lower bays were similar during all seasons, whereas in upper bays the largest living populations occurred in November and January.

An earlier ecological study of the Foraminifera of Timbalier Bay was made by Waldron (1957). Twenty-three species were found within the bay. Waldron was able to divide them into two groups, an upper bay facies characterized by fluctuating salinities and a lower bay facies with relatively high constant salinities. Two stations with a sandy bottom had unique faunas. Waldron stated that salinity and grain size of the sediment influenced foraminiferal distribution, but pH, Eh, alkalinity, and the concentration of sulphates, phosphates, nitrates, and carbohydrates had no apparent effect.

The objectives of my investigation of the distribution and ecology of Recent benthic Foraminifera collected from Timbalier Bay were: (1) to provide a detailed description of the foraminiferal distribution, (2) to determine whether or not patterns of species distribution and species diversity may be related to measured changes in environmental parameters, and (3) to compare the current foraminiferal fauna of Timbalier Bay with the fauna described by Waldron approximately 15 years earlier.

MATERIALS AND METHODS

Selection of stations

The location and description of the stations sampled are shown in table 1 and figure 1. The locations of two oil fields in Timbalier Bay (figure 2) were taken from Barrett (1971) and the general circulation pattern from Waldron (1957). The sand in the area of Station 2 was believed to be derived from an eroded natural levee (Waldron 1957). Station 3 was located on an oyster reef, which had a high calcium carbonate content. Stations 8-12 had high sand contents.

Stations 18, 20, and 22 were sampled during a preliminary OEI study of Timbalier Bay. Stations 1-12 were selected to form a north-

TABLE 1 -- STATION LOCATIONS

Station Number	Date Sampled	Latitude	Longitude	Remarks
1	9/72	N 29° 13.50'	W 90° 18.50'	
2	9/72	N 29° 12.50'	W 90° 18.50'	On eroded natural levee, thus high sand content.
3	9/72	N 29° 11.50'	W 90° 18.50'	On oyster reef, thus high shell hash content.
4	9/72	N 29° 09.50'	W 90° 18.50'	
5	9/72	N 29° 08.50'	W 90° 18.50'	
6	9/72	N 29° 07.50'	W 90° 18.50'	
7	9/72	N 29° 06.50'	W 90° 18.50'	
8	9/72	N 29° 05.50'	W 90° 18.50'	Near oil rigs.
9	9/72	N 29° 04.50'	W 90° 18.50'	
10	9/72	N 29° 04.22'	W 90° 18.50'	
11	9/72	N 29° 04.22'	W 90° 18.50'	Near beach.
12	9/72	N 29° 04.22'	W 90° 18.50'	In marsh environment.
13	10/73	N 29° 08.43'	W 90° 17.88'	Replicate of Waldron's (1957) station.
14	10/73	N 29° 07.44'	W 90° 14.93'	
15	10/73	N 29° 05.77'	W 90° 20.29'	
16	10/73	N 29° 06.22'	W 90° 22.95'	
17	10/73	N 29° 07.88'	W 90° 22.21'	Replicate of Waldron's (1957) station.
18	8/72	N 29° 09.50'	W 90° 20.95'	
19	10/73	N 29° 10.00'	W 90° 21.00'	
20	8/72	N 29° 10.60'	W 90° 20.40'	
21	10/73	N 29° 11.11'	W 90° 21.19'	Replicate of Waldron's (1957) station.
22	8/72	N 29° 11.50'	W 90° 21.44'	
23	10/73	N 29° 11.70'	W 90° 23.10'	Replicate of Waldron's (1957) station. In oyster reef.
24	10/73	N 29° 15.00'	W 90° 21.70'	Replicate of Waldron's (1957) station.
25	10/73	N 29° 14.20'	W 90° 19.30'	Replicate of Waldron's (1957) station.
26	10/73	N 29° 11.30'	W 90° 17.35'	Replicate of Waldron's (1957) station.
27	10/73	N 29° 11.14'	W 90° 19.06'	Replicate of Waldron's (1957) station. In oyster reef.
		Philo Brice Platform is located at: N 29° 11.50'	W 90° 21.65'	
28	9/72	100 m. off Philo Brice Platform at a heading of 020° magnetic		
29	9/72	463 m. off Philo Brice Platform at a heading of 020° magnetic		
30	9/72	925 m. off Philo Brice Platform at a heading of 020° magnetic		
31	9/72	100 m. off Philo Brice Platform at a heading of 110° magnetic		
32	9/72	463 m. off Philo Brice Platform at a heading of 110° magnetic		
33	9/72	925 m. off Philo Brice Platform at a heading of 110° magnetic		
34	9/72	100 m. off Philo Brice Platform at a heading of 200° magnetic		
35	9/72	463 m. off Philo Brice Platform at a heading of 200° magnetic		
36	9/72	925 m. off Philo Brice Platform at a heading of 200° magnetic		
37	9/72	925 m. off Philo Brice Platform at a heading of 290° magnetic		

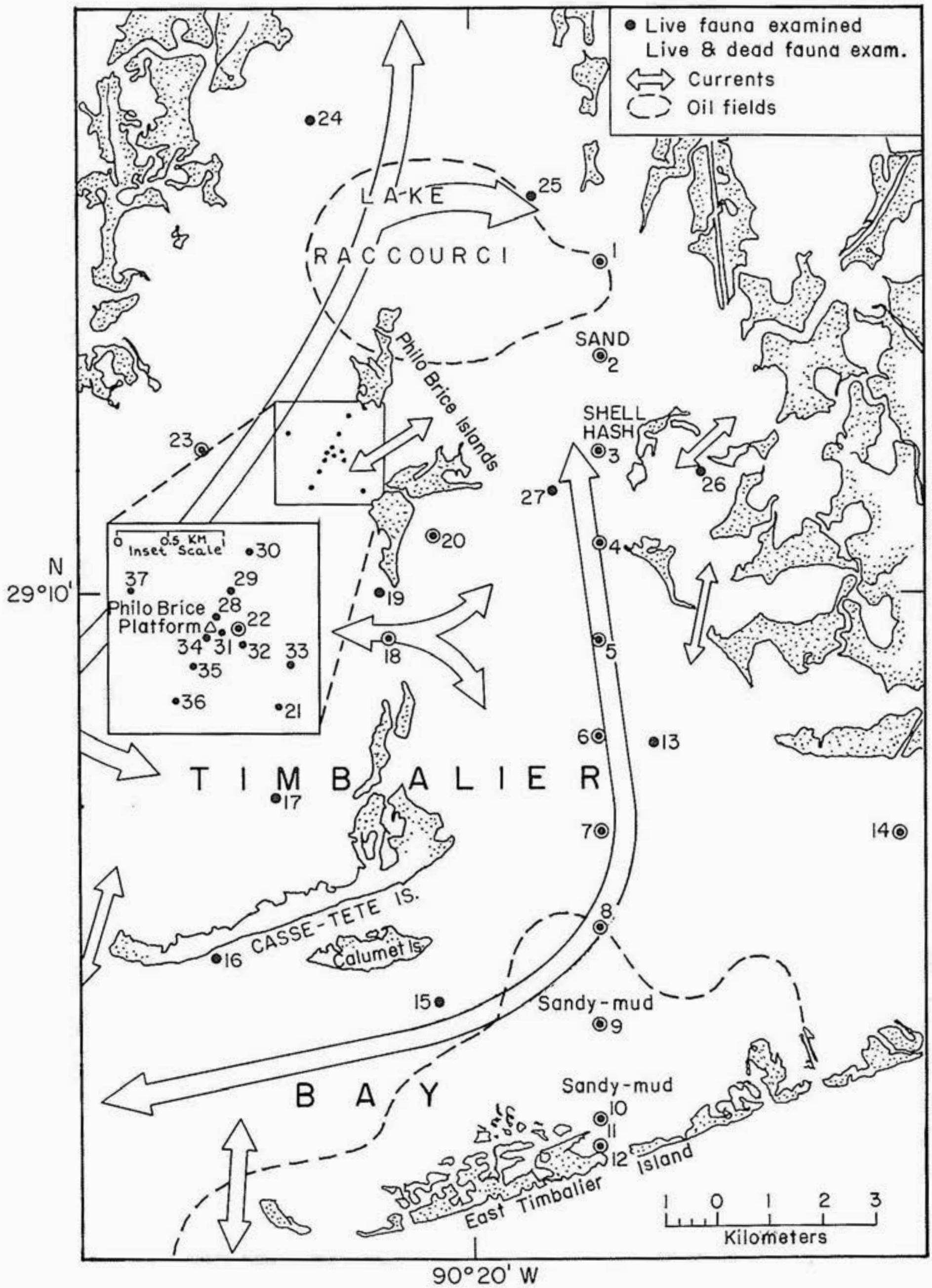

FIG. 1. STATION LOCATIONS.

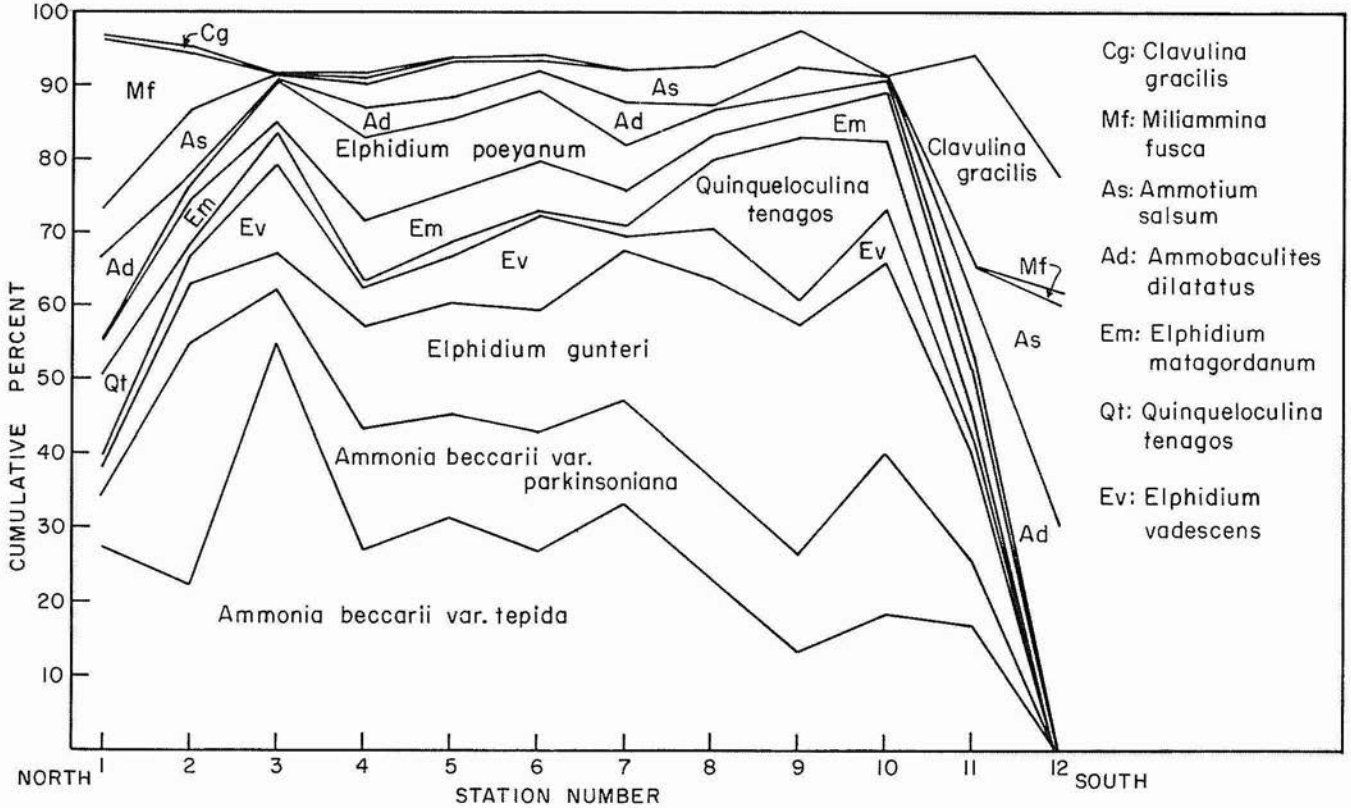

FIG. 2. CUMULATIVE GRAPH OF PERCENTAGES OF FORAMINIFERAL SPECIES at stations along a north-south transect of Timbalier Bay.

south transect of the entire bay. Stations 28-37 were chosen to form four short transects originating at the Philo Brice Island Platform. Stations 13, 17, 21, and 23-37 were established to coincide with those taken during Waldron's earlier study. Stations 14-16 and 19 were selected to increase the coverage of the sampling to include the entire area of the bay.

Collection and treatment of samples

Populations of benthic Foraminifera were analyzed from sediment samples obtained from cores collected by divers as described by Williams and Jones (1974). Each core sample from Stations 13-17, 19, 21, and 23-27 was prepared for foraminiferal analysis by removing the top 1 cm of sediment and overlying water. A solution was prepared of 1 g rose Bengal and 1 liter of 50% ethanol, which was added to the sediment to preserve and stain the living Foraminifera. This procedure was a modification of the staining technique described by Walton (1952).

Core samples from Stations 1-12, 18, 20, 22, and 28-37 were used for both Foraminifera and sediment analyses and were therefore treated differently. After the layer of water directly above the sediment was collected, the top 5 cm of sediment were extruded and cut lengthwise into four equal sections. One of the sections was added to the layer of water and was mixed with the rose Bengal-ethanol solution. The remaining three sections of sediment were used for the sediment analyses described by Williams and Jones (1974).

All samples were washed through a 63 μ sieve to remove the silts and clays. Samples from Stations 13, 17, 21, and 23-27, established during Waldron's study, were subsequently washed through a 149 μ sieve to separate the Foraminifera into two size fractions. The larger size fraction, greater than 149 μ, was the same as that used by Waldron.

After drying, the Foraminifera were separated from the denser components of the sediment by flotation with carbon tetrachloride. After flotation, the remaining sediment was examined with a binocular microscope and the residual Foraminifera were collected by hand with the help of a fine camel's hair brush. The Foraminifera were dried and stored in labeled envelopes.

Analysis of Foraminifera

A random sample of 300 dead specimens, and all living specimens from Stations 1-12, 14, 18, 20, 22, and 23 were selected for identification. Only the living Foraminifera were identified from the remaining stations. Tentative species identifications were made from the descriptions and illustrations presented by Andersen (1953, 1961, and 1971), Bock (1967 and 1971), Kornfeld (1931), Phleger and Parker (1951), Todd and Brönnimann (1957), and Warren (1957). Verification of species identifications was made by comparison with type specimens at the Smithsonian Institution in Washington, D. C., under the guidance of Ms. Ruth Todd.

The internal diameter of the core liner used in collecting the samples was 5.7 cm, thus the surface area of the sediment samples analyzed from Stations 13-17, 19, 21, and 23-27 was 25.5 cm^2. The surface area of sediment samples from Stations 1-12, 18, 20, 22, and 28-27 was 6.4 cm^2. Studies by Boltovskoy (1966) and Brooks (1967) demonstrated that while a substantial number of Foraminifera live beneath the sediment surface, the greatest proportion of living benthic Foraminifera are found within the top 1 cm of sediment. Because of the difference in surface area sampled, the data generated from the 6.4 cm^2 sample were multiplied by four to compare with the surface area sampled with the larger corer.

Total populations were only estimated for the samples having a surface area of 6.4 cm^2 and depth of 5 cm at Stations 1-12, 14, 18, 22, and 23, and were expressed as the number of living and dead specimens per 32 ml of sediment. Total populations were estimated as follows: After all the living, and 300 dead, specimens were removed for identification purposes, the remaining Foraminifera were divided into eight equal portions by using a sediment splitter. The specimens in one of the portions were counted, multiplied by eight, then added to the number of living and dead specimens previously removed to give the estimated total population. The accuracy of the splitting technique was evaluated by comparing the number of specimens in splits from the same sample. The percentage of error in three such comparisons ranged from 7% to 20%.

Distribution of individual species throughout the bay was analyzed by examination of the relative and absolute abundances of the species at each station. Relative abundance of a species refers to the percentage of either the standing crop or the total population that is contributed by the species at a station. Absolute abundance of a species refers to the percentage of the total number of either living or dead specimens of that species from all the stations that were found at any given station.

Measured environmental parameters

In situ physical and chemical measurements made by other workers in conjunction with the OEI, and considered in the present study, included: (1) salinity measured to within ± 0.3 parts per thousand; (2) temperature measured to within ± 0.5° C; (3) dissolved oxygen (ppm) measured to within ± 1% of the observed value; and (4) sediment characteristics including: (a) grain size according to weight percentages at 0.25 phi size intervals; (b) percentage of organic matter by ignition loss;

and (c) percentage of calcium carbonate by weight loss after acidification. The methods used to measure these parameters are described in the OEI handbook (Menzies 1973).

RESULTS AND DISCUSSION

Most abundant species

Twenty-six species of benthic Foraminifera were common in Timbalier Bay. The relative percentages of living and dead specimens of each of the 26 species have been calculated for each station (tables 2 and 3).

A few species predominated. Foraminiferal species comprising greater than 1% of the total number of living and dead specimens identified are listed in table 4. Only 11 taxa comprise greater than 1%, and 3 greater than 10% of the dead population. Only 10 taxa comprise greater than 1%, and 3 greater than 10% of the living population. Specimens of *Ammonia beccarii* formed 40.9% of the dead foraminiferal population in Timbalier Bay, and 59.1% of the live population. *A. beccarii* and species of *Elphidium* were also dominant in Copano Bay, Aransas Bay, Mesquite Bay, San Antonio Bay (Parker et al. 1953), and Matagorda Bay (Lehman 1957) along the Texas coast; in Mobile Bay, Alabama (Lamb 1972); and in Barataria Bay, Louisiana (Lowman 1949).

A cumulative graph shows the relative abundances of the dominant foraminiferal forms identified from the dead populations from stations along a north-south transect of Timbalier Bay (figure 2). It illustrates the major faunal trends within Timbalier Bay. The upper portion of the bay, in the Lake Raccourci area (Station 1), is characterized by an abundance of arenaceous forms such as *M. fusca* and species of *Ammotium*. These species are also abundant, along with *C. gracilis*, at Station 12, the marsh station at East Timbalier Island. The middle portion of Timbalier Bay (Stations 3-10) is characterized by an abundance of calcareous forms such as *A. beccarii* varieties *tepida* and *parkinsoniana*, *Q. tenagos*, and species of *Elphidium*. Stations 2 and 11 represent transition zones between the middle bay and the Lake Raccourci and East Timbalier Island marsh areas. Station 3, located on an oyster reef, displayed an unusually high relative percentage of *A. beccarii* var. *tepida*. Relative percentages of both *E. gunteri* and *Q. tenagos* tend to increase toward the lower portion of Timbalier Bay (in Stations 7-10), while *A. beccarii* var. *tepida*, *E. poeyanum*, *E. vadescens*, and *E. matagordanum* tend to decrease in abundance in the lower bay.

Groups of species

Analysis of the distributions of relative and absolute abundances of

TABLE 2

Relative Percentages of Dead Benthic Foraminifera

LOCATION	Timbalier Bay, Louisiana																					
STATION	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17a	17b	18	19	20
LIVING POPULATION (per 25cc)	316	224	472	684	92	192	656	228	216	280	32	44	208	256	26	44	71	329	262	164	293	152
Ammobaculites crassus	2.5	3.6	1.3	0	0	0	0	0	0	0	0	9.1	13.5	0	0	0	5.6	0	0	0	0	7.9
Ammobaculites dilatatus	0	0	0	0	0	2.1	0	1.8	0	1.4	0	9.1	0	0	0	2.3	0	0	0	0	0	0
Ammobaculites exiguus	0	0	0	0	0	0	0	0	1.9	0	0	18.2	5.8	0	0	0	0	0.3	0	0	0	0
Ammonia beccarii var. *parkinsoniana*	19.0	21.4	35.0	9.4	26.1	2.1	16.5	3.5	7.4	5.7	0	0	0	14.5	3.8	0	8.5	1.8	2.7	0	2.4	5.3
Ammonia beccarii var. *tepida*	51.9	50.0	38.1	80.1	21.7	45.8	47.6	26.3	31.5	15.7	37.5	45.5	0	7.8	19.2	6.8	12.7	5.5	16.0	43.9	4.1	60.5
Ammonia pauciloculata	0	1.8	0.6	4.7	0	0	0	0	0	0	0	0	0	0	0	2.3	2.8	0	0	2.4	1.0	0
Ammotium fragile	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0	0	0	0
Ammotium salsum	11.4	12.5	10.7	0	0	12.5	0.6	3.5	14.8	5.7	0	9.1	55.8	1.2	3.8	9.1	0	7.6	5.7	4.9	1.0	2.6
Arenoparrella mexicana	0	0	0	0	0	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina lowmani	0	0	0	0	0	0	2.4	1.8	3.7	1.4	0	0	0	0	0	0	0	0	0.4	7.3	0	0
Bolivina striatula	0	0	0	2.9	0	2.1	8.5	1.8	11.1	2.9	0	0	0	0.8	0	0	1.4	0.3	1.5	9.8	0.7	5.3
Buliminella elegantissima	0	0	0	0	0	2.1	1.8	1.8	1.9	1.4	0	0	0	0	0	4.5	0	0	0	0	0	0
Elphidium gunteri	0	0	2.5	0.6	8.6	8.3	1.8	0	0	48.5	12.5	9.1	0	8.2	3.8	0	8.4	2.4	0.8	7.3	0	5.3
Elphidium matagordanum	3.8	3.6	8.8	0.6	8.7	18.7	4.3	36.8	18.5	7.1	0	0	11.5	2.0	0	0	2.8	0	8.4	22.0	1.4	5.3
Elphidium poeyanum	0	1.8	2.5	1.2	30.4	2.1	4.9	5.3	3.7	0	0	0	0	0	23.1	2.3	4.2	1.2	0.4	2.4	1.7	7.9
Elphidium vadescens	1.3	0	0	0	0	0	8.5	1.8	1.9	0	50.0	0	0	53.5	3.8	4.5	8.5	77.2	53.8	0	33.8	0
Gaudryina exilis	0	0	0	0	0	0	0.6	3.5	1.9	1.4	0	0	1.9	0	0	6.8	0	0	0	0	0	0
Haplophragmoides wilberti	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0	0	0	0
Miliammina fusca	5.1	1.8	0	0	0	0	0	0	0	0	0	0	1.9	2.7	26.9	2.3	2.8	0	0	0	1.4	0
Palmerinella gardenislandensis	0	0	0	0	0	0	0.6	10.5	1.9	4.3	0	0	0	2.3	0	13.6	21.1	3.0	9.5	0	0.7	0
Quinqueloculina tenagos	3.8	3.6	0	0.6	4.3	2.1	1.2	0	0	0	0	0	0	7.0	15.4	45.5	16.9	0.6	0.8	0	51.9	0
Tiphotrocha comprimata	0	0	0	0	0	0	0	0	0	1.4	0	0	3.8	0	0	0	0	0	0	0	0	0
Trochammina inflata	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.2	0	0	0	0	0

TABLE 3

Relative Percentages of Living Benthic Foraminifera

LOCATION	Timbalier Bay, Louisiana																		
STATION	20	21	22	23	24	25	26	27a	27b	28	29	30	31	32	33	34	35	36	37
LIVING POPULATION (per 25cc)	152	98	72	346	461	474	125	41	253	0	92	428	40	776	360	228	76	112	148
Ammobaculites crassus	7.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammobaculites dilatatus	0	3.1	11.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia beccarii var. *parkinsoniana*	5.3	1.0	5.6	4.6	66.4	17.5	60.0	2.4	15.0	0	34.8	28.0	0	23.7	25.6	3.5	36.8	14.3	43.2
Ammonia beccarii var. *tepida*	60.5	3.1	16.7	52.3	32.8	70.9	16.0	34.1	71.0	0	43.5	57.0	50.0	61.3	55.6	7.0	42.1	39.3	29.7
Ammonia pauciloculata	0	0	0	0.6	0.2	0.2	2.4	2.4	0	0	0	0	0	0	1.1	1.8	0	3.6	2.7
Ammonia rolshauseni	0	0	0	0	0	0.2	1.6	4.9	0	0	0	0	0	0	0	0	0	0	0
Ammotium salsum	2.6	19.4	0	0.9	0	1.3	0.8	14.6	0.4	0	0	0	0	0	0	1.8	0	0	2.7
Bolivina lowmani	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	1.8	0	3.6	0
Bolivina striatula	5.3	0	5.6	2.0	0	0	0	0	0	0	8.7	5.6	0	7.2	1.1	54.4	5.3	7.1	2.7
Elphidium gunteri	5.3	4.1	16.7	0.6	0.7	0.8	1.6	0	4.3	0	0	1.9	0	1.0	6.7	5.3	5.3	10.7	8.1
Elphidium limosum	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elphidium matagordanum	5.3	0	11.1	0	0	0	0.8	0	0	0	0	0.9	20.0	0	0	3.5	5.3	3.6	0
Elphidium poeyanum	7.9	0	11.1	1.2	0	0.4	1.6	0	0	0	0	2.8	0	2.1	1.1	17.5	0	7.1	0
Elphidium vadescens	0	68.4	0	28.0	0	6.1	14.4	29.3	7.5	0	8.7	2.8	30.0	2.6	7.8	0	0	7.1	0
Gaudryina exilis	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0.5	0	0	0	0	2.7
Haplophragmoides wilberti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7
Miliammina fusca	0	1.0	5.6	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7
Palmerinella gardenislandensis	0	0	0	0.3	0	0	0.8	4.9	0.4	0	0	0	0	0	0	0	0	0	0
Quinqueloculina lamarckiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.6	0
Quinqueloculina tenagos	0	0	0	9.0	0	2.5	0	4.9	0.8	0	4.3	0	0	1.0	0	1.8	0	0	2.7
Trochammina inflata	0	0	5.6	0	0	0	0	0	0	0	0	0	0	0	1.1	1.8	5.3	0	0

TABLE 4 -- RELATIVE PERCENTAGES OF SPECIES FROM LIVING AND DEAD FORAMINIFERAL POPULATIONS IN TIMBALIER BAY

DEAD FAUNA		LIVING FAUNA	
Species	Percent of Total Number of Dead Specimens Identified	Species	Percent of Total Number of Living Specimens Identified
Ammonia beccarii var. *tepida*	27.5	*Ammonia beccarii* var. *tepida*	41.9
Elphidium gunteri	16.1	*A. beccarii* var. *parkinsoniana*	17.2
Ammonia beccarii var. *parkinsoniana*	13.4	*Elphidium vadescens*	10.7
Elphidium vadescens	6.0	*Bolivina striatula*	4.6
Elphidium poeyanum	5.4	*Ammotium salsum*	4.3
Elphidium matagordanum	5.3	*Elphidium matagordanum*	4.2
Quinqueloculina tenagos	5.2	*Elphidium gunteri*	4.1
Ammotium salsum	4.9	*Quinqueloculina tenagos*	3.7
Ammobaculites dilatatus	4.4	*Elphidium poeyanum*	2.7
Clavulina gracilis	2.5	*Palmerinella gardenislandensis*	1.0
Miliammina fusca	2.3		
All Others	1.0	All Others	1.0

the species identified in the Timbalier Bay samples, combined with information concerning the distribution of these species from previous studies, revealed that there were four species complexes represented in the present study. The species composition, relative abundance of species, and geographic distribution characterizing each complex are described below.

(1) Species endemic to marshes:

Ammoastuta inepta
Arenoparella mexicana
Haplophragmoides species
Jadammina polystoma
Miliammina fusca
Tiphotrocha comprimata
Trochammina inflata

In earlier studies (Parker et al. 1953; Phleger 1965) these species were commonly reported from marsh environments. In the present study, specimens of these species were most abundant in stations near marshes and occurred in relatively low numbers in the bay. Presumably those species present within the bay were transported there from marsh areas. One species from this group, *M. fusca*, was a major component of both the living and dead foraminiferal fauna in areas of the bay adjacent to marshes. The probable explanation for the abundance of *M. fusca* in some bay stations is that living populations of this species have radiated into the bay environment from neighboring marshes.

(2) Open Gulf species:

Ammobaculites exiguus
Ammonia pauciloculata
Ammonia rolshauseni
Bolivina lowmani
Bolivina striatula
Buliminella sp. cf. *B. bassendorfensis*
Buliminella elegantissima
Gaudryina exilis
Quinqueloculina lamarckiana

Earlier studies (Phleger 1951; Parker et al. 1953; Phleger 1954; Bandy 1954, 1956) demonstrated that these species were common, and often abundant, in the open Gulf, and occasionally occurred in small numbers in the southernmost portions of bays in the northern Gulf region. In the present study these species were commonly observed in low frequencies in the middle and lower portions of Timbalier Bay. One species from this group, *B. striatula,* was a major component of the living foraminiferal fauna at several middle and lower bay stations. Dead specimens of *B. striatula*, however, were not abundant in any of the bay stations. It is generally accepted by those who have conducted studies in this area that living populations of some open Gulf species on occasion, such as during periods of low fresh water inflow, radiate into Timbalier Bay.

(3) Barrier island marsh species:

One sample was collected directly from a marsh area on East Timbalier Island, Station 12, and another from a beach adjacent to the barrier island marsh, Station 11. The species *Clavulina gracilis* was found in abundance only at Stations 11 and 12, and characterized the barrier island marsh foraminiferal fauna. *Ammotium* and *Ammobaculites* species were also abundant in the barrier island marsh. The only calcareous species represented at Station 12 was *Elphidium matagordanum*, which was previously reported from a barrier island marsh by Parker.

(4) Bay species:

Ammobaculites species	*Elphidium gunteri*
Ammotium species	*E. matagordanum*
Ammonia beccarii var. *parkinsoniana*	*E. poeyanum*
Ammonia beccarii var. *tepida*	*E. vadescens*

These species were the major components of the foraminiferal fauna throughout Timbalier Bay. Evidence from earlier foraminiferal studies in the northern Gulf of Mexico, especially from Parker's, indicated that these bay species form two ecologic groups. One group, comprising mainly variants of *Ammobaculites* and *Ammotium*, was generally restricted to the brackish water environments of estuaries and marshes, and was perhaps endemic to these areas. The second group, composed mainly of *Ammonia* and *Elphidium*, was abundant in the open Gulf as well as estuaries. Parker hypothesized that *E. gunteri* and varieties of *A. beccarii* were originally offshore species that invaded bays and estuaries during periods of low fresh-water runoff. Phleger's observation that low salinities restricted these species to the area outside of the barrier islands along the Mississippi coast supported this hypothesis.

Groups of stations with similar faunas

Percentage of similarity values were calculated using the method described by Sanders (1960) from comparisons of the relative abundances of dead foraminiferal species in Stations 1-12, 14, 18, 20, 22, and 23. The percentage of similarity values were arranged in a trellis diagram to show groups of stations with similar faunas (figure 3). The species composition of these groups of stations was re-examined to determine those species of Foraminifera that characterized the groups. The five faunal groups from within Timbalier Bay are:

(1) *Miliammina fusca* fauna

A foraminiferal fauna characterized by an abundance of *M. fusca* and large numbers of *Ammotium* and *Ammobaculites* species was reported from Station 1, in the eastern portion of Lake Raccourci. This fauna was not observed at Stations 24 and 25 in the Lake Raccourci area. Waldron recorded large numbers of *M. fusca* from Coal Tar Bay, a marshy area just north of Station 1. It is believed that the *M. fusca*

	3	20	22	23	4	18	5	7	6	8	14	10	9	1	2	11	12
3																	
20	65																
22	69	84															
23	65	72	72														
4	54	76	77	69													
18	57	78	74	66	75												
5	60	83	83	77	85	81											
7	58	79	81	74	75	77	85										
6	60	80	77	79	83	77	87	78									
8	53	68	75	71	70	68	75	74	72								
14	45	60	64	62	69	64	69	64	72	72							
10	46	60	65	65	65	62	66	63	68	79	87						
9	40	54	61	59	58	53	61	64	58	81	74	69					
1	46	53	52	54	56	49	56	57	51	55	49	47	49				
2	44	60	55	58	67	63	65	61	63	60	58	54	54	59			
11	40	55	56	55	58	49	61	61	56	58	52	57	61	52	53		
12	2	9	7	8	12	6	10	13	6	7	5	1	9	20	14	31	

KEY
% similarity: 0-30; 31-50; 51-70; 71-100

FIG. 3. STATIONS WITH SIMILAR FAUNA.

fauna is characteristic of low salinity marshes and adjacent bay areas along the Lake Raccourci shoreline.

(2) Oyster reef fauna

Station 3 was located on an oyster reef, which exhibited a high percentage of shell hash in the sediment. The assemblage at Station 3 was characterized by unusually high percentages of *Ammonia beccarii* var. *tepida*, and large numbers of *A. beccarii* var. *parkinsoniana* and *Elphidium* species. Other stations exhibiting large amounts of shell hash in the sediment, Stations 23 and 27B, also displayed unusually large proportions of living *A. beccarii* var. *tepida*. Oyster reefs seem to be characterized by high relative percentages of *A. beccarii* var. *tepida*.

(3) Bay fauna

Stations 4-8, 18, 20, and 22, which represented the major portion of Timbalier Bay, were characterized by a group of species considered to be the typical bay fauna. The bay fauna was composed of high relative percentages of *A. beccarii* varieties *tepida* and *parkinsoniana*, moderate relative percentages of *Ammotium salsum*, *Ammobaculites dilatatus*, *Elphidium gunteri*, *E. matagordanum*, *E. poeyanum*, and *E. vadescens*, and low relative percentages of the typical marsh and offshore species.

(4) *Elphidium gunteri* fauna

Stations 8, 9, and 10 were represented by a foraminiferal fauna that was similar to the bay fauna, but was differentiated from the typical bay fauna by a greater proportion of *E. gunteri*, and a low proportion of arenaceous species. The fauna at Station 8 was similar to the bay fauna, and the station apparently represented a transition zone between the two faunal groups.

(5) Barrier island marsh fauna

The barrier island marsh station located on East Timbalier Island, Station 12, was represented by a foraminiferal fauna composed of large numbers of *Clavulina gracilis*, an abundance of other arenaceous species, and a small number of one calcareous species, *E. matagordanum*. Station 11, located on the northern edge of East Timbalier Island, exhibited a large number of *C. gracilis*, but also a large number of calcareous species, indicating that it represented a transition zone between the bay and barrier island marsh faunas.

Species diversity

Measures of species diversity were calculated to serve as indicators of environmental variability within Timbalier Bay. The mean S value (number of species per station) for the dead foraminiferal data was 17, with a range of 11-23 species per station and a standard deviation of 3. The number of species at each station that formed 5% or more of the total population ranged from 5 to 7 species, with a mean of 6 and a standard deviation of 0.5. The mean S value for the living Foraminifera was 8, with a range of 0-13 and a standard deviation of 3. The number of species representing 5% or more of the standing crop averaged 4 per station, with a range of 0-9 and a standard deviation of 1.5. A trend of decreasing species richness for both the living and dead fauna was apparent in the upper bay and Lake Raccourci area, and in the southernmost portion of the bay.

Shannon-Weaver H' values (Shannon and Weaver 1963) were calculated from the living and nonliving faunal data to reflect species

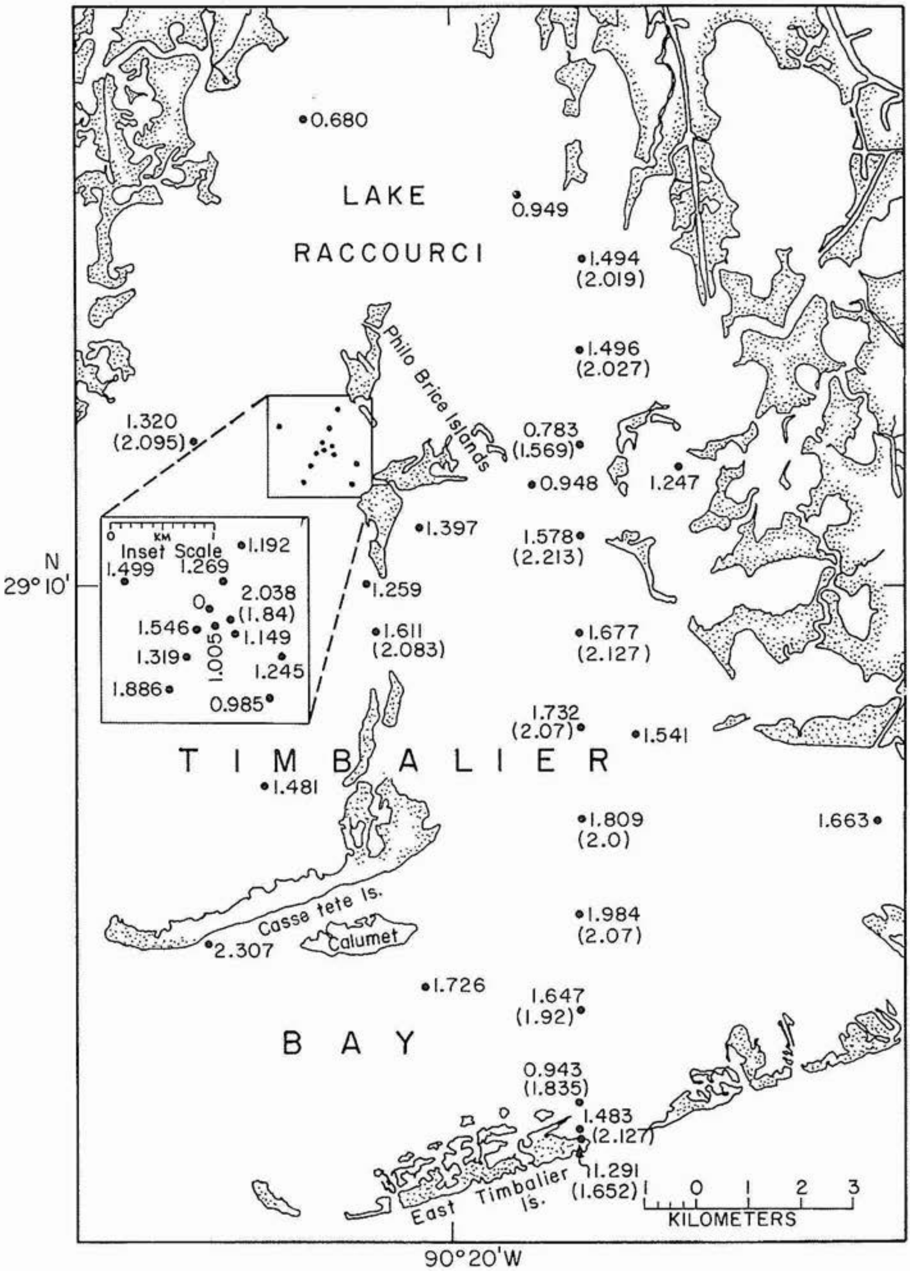

FIG. 4. SHANNON-WEAVER (H ′) INDEX OF SPECIES DIVERSITY VALUES for the living and dead benthic foraminiferal fauna (upper figure denotes living and lower figure denotes dead Foraminifera).

evenness (figure 4). Areas having relatively low H′ values, thus dominance by a few species, in both the living and nonliving faunas were: (1) the oyster reef represented by Station 3, (2) the barrier island marsh represented by Station 12 and the adjacent area represented by Station 10, and (3) some stations near the Philo Brice Island Production Platform. The Lake Raccourci area, Stations 24 and 25, also displayed lower diversity in the living fauna.

Comparisons between patterns of species distribution and measured environmental parameters

Waldron concluded that the distribution of species of benthic Foraminifera in Timbalier Bay was limited by salinity, sediment type, and water movements. Environmental parameters measured in Timbalier Bay during the OEI included salinity, temperature, dissolved oxygen, and sediment characteristics including grain size, percentage of calcium carbonate, and percentage of organic material.

Temperatures varied seasonally from a low of 8.5° C in January 1973 to a high of 39° C during the summer months. There were no areal temperature gradients. Dissolved oxygen concentrations (DO) ranged from 2.0 to 13.0 mg/l, varied inversely with the temperature, and showed no lateral trends throughout the bottom water of the bay. Because DO and temperature measurements show no areal gradients within the bay, I conclude that these parameters do not limit the distribution of the species observed during this study.

The grain size, percentage of calcium carbonate, and percentage of organic material data for Stations 1-12 are shown in table 5, along with the total populations expressed as the average number of specimens per species.

Figure 5 shows a correlation between sediment characteristics, foraminiferal faunas, and numbers of Foraminifera. Sandy sediments were associated with lower concentrations of organic material and smaller Foraminifera counts. Sediments with higher percentages of silt and clay had correspondingly higher concentrations of organic material, and higher Foraminifera counts. Cluster analysis, based upon the 10 most abundant species, produced a dendrogram display with three main branches that corresponded to the three sediment types—sandy, silt and clay, and shell hash.

Salinities fluctuated seasonally and exhibited an increasing trend from the northern to southern portion of the bay. Seasonal changes in salinity values (figure 6) ranged from 12 to 26 ppt in the upper portion of the bay (north of the Philo Brice Islands), from 15 to 29 ppt in the middle portion (south of the Philo Brice Islands and north of Casse-tete Island), and from 24 to 31 ppt in the lower portion (south of Casse-tete

TABLE 5 -- RELATIONSHIP BETWEEN SEDIMENT CHARACTERISTICS AND POPULATIONS OF BENTHIC FORAMINIFERA

Station	% $\geq$ 2mm (shell hash)	.037mm $\leq$ % $\leq$ 2mm (sand)	% $\leq$ .037mm (silt & clay)	Percent CO_3	Percent Organic Material	Total Population Living and Dead Average Number Per Species
1	1	38	61	7.40	6.50	1,621
2A	1	61	39	6.55	4.99	1,382
2B	1	50	49	6.85	5.91	
3	44	23	34	72.32	5.29	778
4	1	59	40	7.60	4.81	1,059
5	1	74	25	4.36	2.72	839
6	1	54	45	7.05	4.81	1,845
7	2	55	43	7.55	4.26	902
8	1	62	36	7.00	3.60	1,721
9	1	96	4	4.40	1.79	613
10	1	84	15	4.50	2.10	435
11	1	85	14	4.45	2.39	200
12	1	82	17	5.74	3.09	116

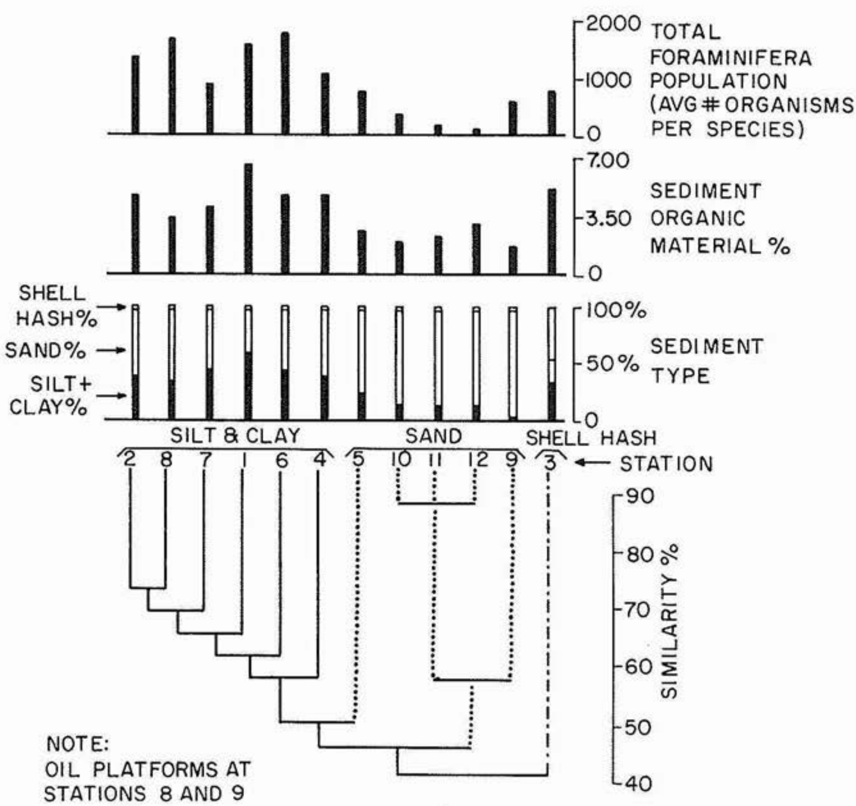

FIG. 5. RELATIONSHIP BETWEEN FAUNAL GROUPS, TOTAL POPULATIONS, AND SEDIMENT CHARACTERISTICS. (The lowered values for Station 7 were the result of a partial loss of sample.)

Island). The north-south salinity gradient varied from 4 ppt in September 1972 to 12 ppt in July 1973. The gradient appears to vary inversely with the average salinity of the bay.

Because the sediment types observed in Timbalier Bay follow a north-south trend that generally coincides with the north-south trend in the salinity gradient, it is difficult to determine the relative significance of salinity in limiting the distribution of most of the species observed. It is apparent from the data on dead Foraminifera, however, that the relative abundance of *Elphidium gunteri* increases toward the southernmost portion of the bay, over a series of stations having a similar sediment type (i.e., Stations 2, 4, 6, 7, and 8). Lamb's study of Mobile, Alabama, indicated that salinity was the main controlling factor in the

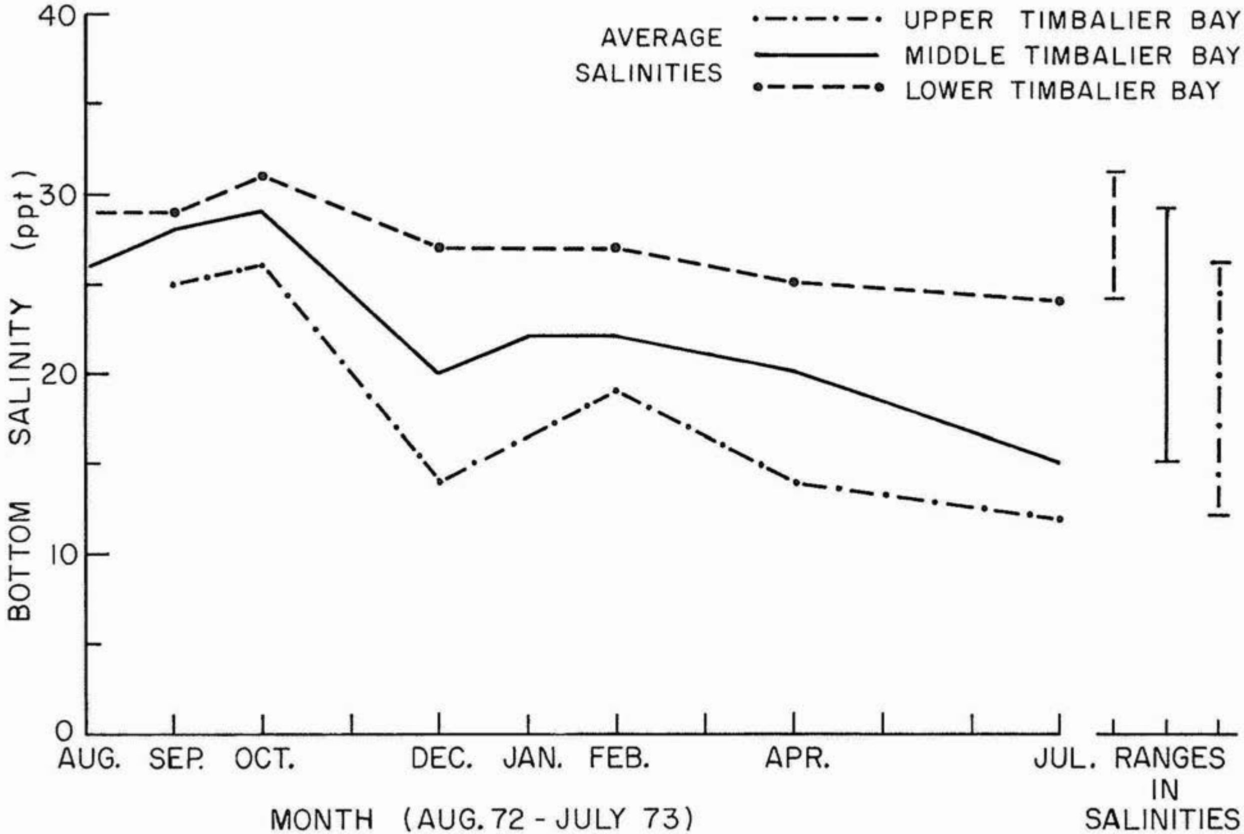

FIG. 6. SALINITY GRADIENT AND RANGES IN TIMBALIER BAY.

distribution of foraminiferal species. The foraminiferal species and range in salinity observed in the lower two-thirds of Mobile Bay were quite similar to those observed in Timbalier Bay.

In summary, the faunal and environmental data collected during the present study, combined with evidence from studies by Waldron and Lamb, strongly suggest that sediment characteristics and salinity were the major environmental parameters controlling the distribution of benthic Foraminifera in Timbalier Bay.

Comparison with previous study

Seasonal fluctuations of living populations of benthic Foraminifera in Stations 13, 17, 21, and 23-27 were analyzed in Waldron's earlier study. These stations were resampled and the living Foraminifera were analyzed from the same sediment size fraction (> 149 μ) examined by Waldron. The Morisita-Ono Index of Similarity between communities (Morisita 1959) was used to compare Waldron's results with the data from this study (table 6). The faunas observed during the two studies at Stations 24 and 27 were quite similar. The faunas observed during the two studies at Stations 25, 13, 23, 26, and 17 reflected some change, but were generally within the range of similarity values measured between groups of stations from the same regions of the bay in the present study (see figure 7, p. 469).

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REFERENCES CITED

Andersen, H. V. 1953. Two new species of *Haplophragmoides* from the Louisiana coast. Contributions, Cushman Foundation for Foraminiferal Research **4**(1):21-22.

———. 1961. Foraminifera of the mudlumps, lower Mississippi River Delta. Louisiana Geological Survey, Geological Bulletin **35**(2):1-208.

———. 1971. Key to Cenozoic foraminiferal families and genera of the Gulf Coastal Plain Province. School of Geoscience, Louisiana State University, Miscellaneous Publication 71-2.

TABLE 6

Morisita-Ono Index Values Comparing Foraminiferal Faunas

Observed in Waldron's and Present Study

Station Number	Number of Living Specimens		Similarity	Comments
	Waldron's Data	Present Data		
24	196	462	0.88	No change in foraminiferal faunas.
27	62	67	0.88	No change in foraminiferal faunas.
25	90	474	0.61	Some change in foraminiferal faunas.
13	86	58	0.60	Some change in foraminiferal faunas.
21	116	4	0.01	Small numbers of living specimens, thus data not reliable.
23	122	20	0.76	Small numbers of living specimens, thus data not reliable.
26	18	88	0.68	Small numbers of living specimens, thus data not reliable.
17	13	24	0.71	Small numbers of living specimens, thus data not reliable.

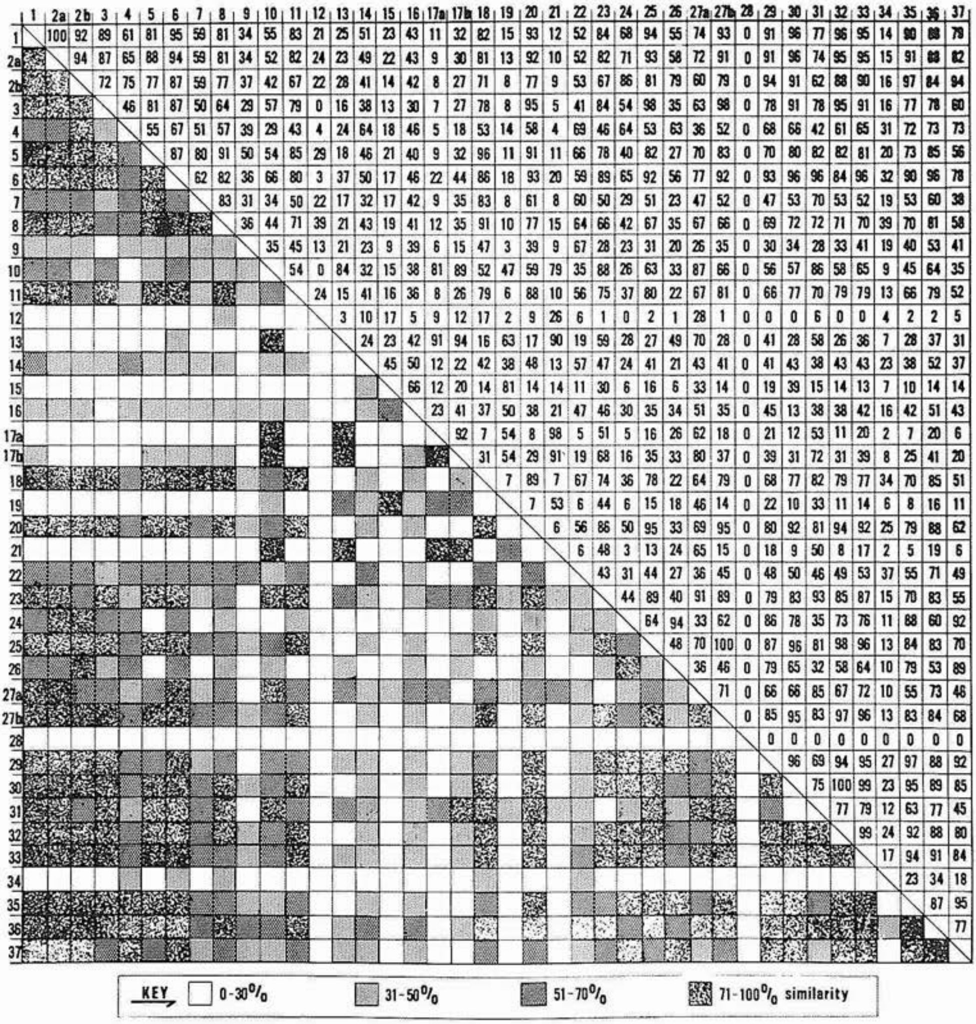

FIG. 7. FAUNAL SIMILARITY 1957 AND 1972.

Bandy, O. L. 1954. Distribution of some shallow-water Foraminifera in the Gulf of Mexico. Geological Survey Professional Paper 254-F.

———. 1956. Ecology of Foraminifera in the northeastern Gulf of Mexico. Geological Survey Professional Paper 274-G.

———, J. C. Ingle, and J. M. Resig. 1964a. Foraminiferal trends, Laguna Beach outfall area, California. Limnology and Oceanography **9**:112-123.

———, J. C. Ingle and J. M. Resig. 1964b. Foraminifera, Los Angeles County outfall area, California. Limnology and Oceanography **9**:124-137.

———, J. C. Ingle, and J. M. Resig. 1964c. Modification of foraminiferal distribution by the Orange County outfall, California. Ocean Science and Ocean Engineering **1**:54-76.

Barrett, B. B. 1971. Cooperative Gulf of Mexico estuarine inventory and study, Louisiana. Phase II, hydrology, and Phase III, sedimentology. Louisiana Wildlife and Fisheries Commission.

Bock, W. D. 1967. Monthly Variation in the Foraminiferal Biofacies on Thalassia and Sediment in the Big Pine Key Area, Florida. Ph.D. dissertation, University of Miami.

———. 1971. A handbook of the benthonic Foraminifera of Florida Bay and adjacent waters. Memoir 1: Miami Geological Society. A symposium on recent south Florida Foraminifera **3**:1-72.

Boltovskoy, E. 1966. Depth at which Foraminifera can survive in sediments. Contributions, Cushman Foundation for Foraminiferal Research **17**(2):43-45.

Brady, H. B. 1884. Report on the Foraminifera. *In* Voyage of HMS Challenger. Volume 9, pp. 1-814.

Brooks, A. L. 1967. Standing crop, vertical distribution, and morphometrics of *Ammonia beccarii* (L). Limnology and Oceanography **12**:667-684.

Clark, D. F. 1971. Effects of aquaculture outfall on benthic Foraminifera in Clam Bay, Nova Scotia. Marine Sediments **7**(2):76-84.

Cushman, J. A. 1922. The Foraminifera of the Atlantic Ocean. U.S. National Museum Bulletin **104**, part 3, p. 83.

Kornfeld, M. M. 1931. Recent littoral Foraminifera from Texas and Louisiana. Contributions of the Department of Geology, Stanford University **1**(3):77-101.

Lamb, G. M. 1972. Distribution of Holocene Foraminifera in Mobile Bay and the effect of salinity changes. Geological Survey of Alabama, Circular 82.

Lankford, R. R. 1959. Distribution and ecology of Foraminifera from east Mississippi Delta margin. American Association of Petroleum Geologists, Bulletin **43**(9):2068-2099.

Lehman, E. P. 1957. Statistical study of Texas Gulf Coast recent foraminiferal species. Micropaleontology **3**:325-356.

Lowman, S. W. 1949. Sedimentary facies in the Gulf coast. American Association of Petroleum Geologists, Bulletin **33**(12):1939-1997.

Menzies, R. J. 1973. A handbook on procedures and methods employed in the Offshore Ecology Investigation (OEI). Gulf Universities Research Consortium. Report No. 121.

Morin, R. W. 1971. Offshore foraminiferal populations. *In* R. L. Kolpack, ed., Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill, 1969-1970. Vol. II. Physical, Chemical and Geological Studies. Allan Hancock Foundation, University of Southern California.

Morisita, M. 1959. Measuring interspecific association and similarity between communities. Memoirs of the Faculty of Science, Kyushu University, Series E (Biol.) **3**(1):65-80.

Murray, J. W. 1973. Distribution and Ecology of Living Benthic Foraminiferids. New York: Crane, Russak and Company, Inc.

Orbigny, Alcide D. d'. 1839. Foraminifères. *In* Ramon De la Sagra, ed., Histoire Physique, Politique, et Naturelle de l'île de Cuba. Paris, pp. 1-224.

Parker, F. L., F. B. Phleger and J. F. Peirson. 1953. Ecology of Foraminifera from San Antonio Bay and environs, southwest Texas. Cushman Foundation for Foraminiferal Research, Special Publication **2**:1-75.

Phleger, F. B. 1951. Ecology of Foraminifera, northwest Gulf of Mexico. Part I. Foraminifera distribution. Geological Society of America, Memoir **46**:1-88.

———. 1954. Ecology of Foraminifera and associated microorganisms from Mississippi Sound and environs. American Association of Petroleum Geologists, Bulletin **38**(4):584-647.

———. 1955. Ecology of Foraminifera in southeastern Mississippi Delta area. American Association of Petroleum Geologists, Bulletin **39**(5):712-752.

———. 1956. Significance of living foraminiferal populations along the central Texas coast. Contributions, Cushman Foundation for Foraminiferal Research **9**(4):106-151.

———. 1960. Ecology and Distribution of Recent Foraminifera. Baltimore: Johns Hopkins Press.

———. 1965. Patterns of marsh Foraminifera, Galveston Bay, Texas. Limnology and Oceanography **10**, Supplement R:169-184.

——— and R. R. Lankford. 1957. Seasonal occurrences of living benthic Foraminifera in some Texas bays. Contributions, Cushman Foundation for Foraminiferal Research **8**(3):93-105.

——— and F. L. Parker. 1951. Ecology of Foraminifera, northwest Gulf of Mexico. Part II. Foraminiferal species. Geological Society of America, Memoir **46**:1-64.

Sanders, H. L. 1960. Benthic Studies in Buzzard's Bay. III. The Structure of the Soft Bottom Community. Limnology and Oceanography **5**:138-153.

Shannon, C. E. and W. Weaver. 1963. The Mathematical Theory of Communication. Urbana: University of Illinois Press.

Todd, R. and P. Brönnimann. 1957. Recent Foraminifera and Thecamoebina from the eastern Gulf of Paria. Cushman Foundation for Foraminiferal Research, Special Publication 3.

Waldron, R. P. 1957. A seasonal ecological study of Foraminifera from Timbalier Bay, Louisiana. Coastal Studies Institute, Louisiana State University. Technical Report 16, Part B, pp. 132-188.

Walton, W. R. 1952. Techniques for the recognition of living Foraminifera. Contributions, Cushman Foundation for Foraminiferal Research **3**(2):56-60.

Warren, A. D. 1957. Foraminifera of the Buras-Scofield bayou region, southeast Louisiana. Contributions, Cushman Foundation for Foraminiferal Research **8**(1):29-40.

Watkins, J. G. 1961. Foraminiferal ecology around the Orange County, California, ocean sewer outfall. Micropaleontology **7**:199-206.

Williams, S. E. and J. I. Jones. 1974. The distribution and origin of bottom sediments in Timbalier Bay, Louisiana. Unpublished manuscript.