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CHANGES IN THE INVERTEBRATE FAUNA, APPARENTLY ATTRIBUTABLE TO SALINITY CHANGES, IN THE BAYS OF CENTRAL TEXAS[1]

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ABSTRACT—Previous studies on the invertebrate fauna of the bays of central Texas have been undertaken during periods of very low or highly variable salinity conditions. From 1948 to 1953 an extended drought with accompanying low river runoff caused salinities in these bays to increase to record highs, with little variation between maximum and minimum salinities during any particular month. Coincident with this extended high salinity period, the biotic communities within the bays changed considerably. Not only was there an invasion of many marine or open-Gulf species of invertebrates, but also a change was observed in the growth and appearance of the oyster reefs, one of the principal biotic assemblages. Another probable result of increased salinities was the disappearance of low-salinity mollusks which previous workers had found to be extremely abundant during the periods of low salinity.

This extended series of hydrographic observations should be useful to the paleoecologist in interpreting environmental changes in megafossil assemblages. Observations of this nature should prove useful in interpreting sedimentary facies, since many of the species involved occur as fossils at least as far back as the Pliocene. If the normal euryhaline fossil assemblages suddenly produce large numbers of high-salinity organisms such as sea urchins, corals and open-Gulf mollusks, one could assume that there had been drought conditions, with extended high salinities. These conditions can also be recognized by abrupt changes in shell structure of the common oyster, *Crassostrea virginica* (Gmelin), as well as the absence of the known low-salinity mollusks.

INTRODUCTION

A NUMBER of major papers have been published on the biological and hydrographic aspects of the shallow bays of the central Texas coast. Few of these studies have coincided with the recent drought conditions, and little information is available on the effects of droughts upon these bays and their fauna. As a result of the published work on this region (Galtsoff, 1931; Gunter, 1945, 1950a; Collier and Hedgpeth, 1950; Ladd, 1951; Puffer and Emerson, 1953; and Hedgpeth, 1953), the relationships of the faunal composition of the bays to the salinity regime have been established in general terms. In 1950–53 the author made an ecological study of the bays in the Rockport area (Fig. 1); this was begun as part of the regular oyster survey for the Texas Game and Fish Commission

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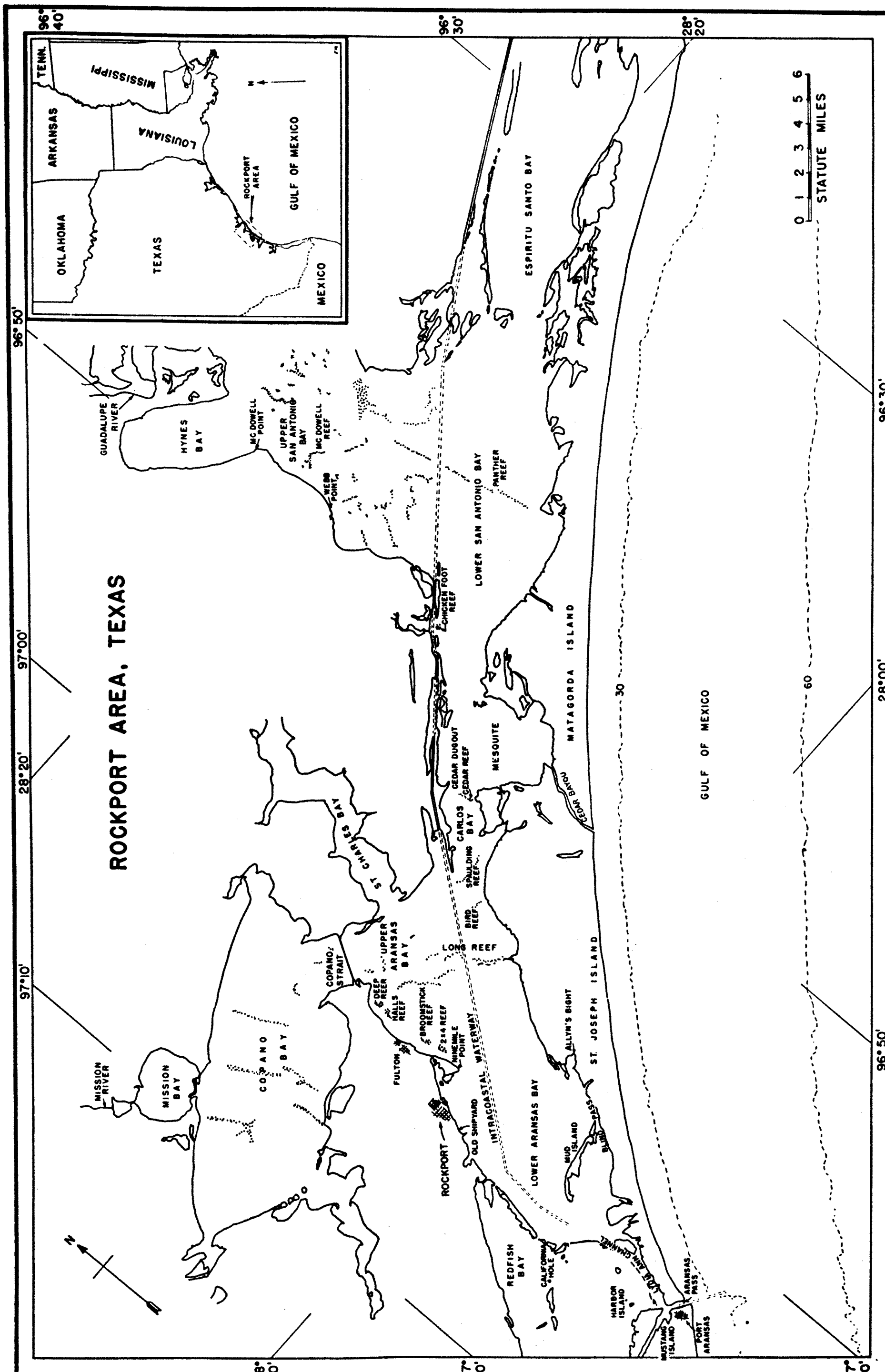

FIG. *1*—Location map.

and continued as part of the field work of Project 51, American Petroleum Institute. It was observed that the distribution of certain marine invertebrates, especially mollusks and echinoderms, differed from that indicated by previous major studies, which were undertaken during times of comparatively heavy rainfall. During the author's observations, salinities in the bays were much higher than during years of higher rainfall and greater stream discharge.

Salinity data for the years 1948–52 were determined by titration by the staff of the Marine Laboratory of the Texas Game and Fish Commission and by the staff of the Department of Oceanography, Texas A. & M. College for the American Petroleum Institute Project 51. For the period from March, 1952, to September, 1953, hydrometer readings from the U. S. Coast and Geodetic Survey tide station at Rockport, Texas, were used. The manner in which salinity values were obtained in the published data is given in the references cited in the captions for the various graphs.

River discharge data for the years 1936 to 1951 were obtained from the Surface Water Supply Papers of the U. S. Geological Survey. For the period from 1951 to September, 1953, data were supplied by Mr. S. D. Breeding of the Austin, Texas, office of the Surface Water Branch of the U. S. Geological Survey. Rainfall data for Victoria, Texas, were obtained from the *Local Climatological Summary of Victoria*, published by the U. S. Weather Bureau.

Faunal collections in the area were obtained by the use of shell and oyster dredges, oyster tongs, otter and beam trawls, Navy Electronics Laboratory snapper-type grab, and orange-peel grab, and by beach collecting. Over 500 stations were occupied as part of this study, and several stations in Aransas Bay were occupied weekly. The echinoderms and corals were identified by Dr. J. Wyatt Durham and Mr. Elton Puffer of the Museum of Paleontology, University of California, Berkeley, and the majority of the mollusks by Dr. Thomas E. Pulley, University of Houston, Texas, and Messrs. William K. Emerson and Elton Puffer of the Museum of Paleontology, University of California, Berkeley.

This work was made possible by the generous assistance of the staff of the Marine Laboratory, Rockport, Texas, and the staff of the American Petroleum Institute Project 51 at Scripps Institution of Oceanography at La Jolla, California. For invaluable assistance and coöperation, the author is particularly grateful to Drs. Joel W. Hedgpeth, Francis P. Shepard, Carl L. Hubbs, and Robert S. Arthur of Scripps Institution; Dr. Gordon Gunter and Mr. Martin W. Burkenroad of the Institute of Marine Science, University of Texas; Messrs. F. M. Dougherty and Byron B. Baker of the U. S. Navy Hydrographic Office, Suitland, Maryland; Messrs. E. D. McRae and Dewey W. Miles, formerly of the Rockport Marine Laboratory; and Messrs. Ernest Simmons, Robert Hofstettor and Howard Lee of the present staff of the Marine Laboratory. Sincere appreciation is extended to Mr. Cecil Reid, Chief Marine Biologist of the Texas Game and Fish Commission, and to Mr. J. L. Baughman, formerly of the Marine Laboratory, now of the Copano Research Foundation, for the use of their facilities and for data on file at the Marine Laboratory. The author also extends grateful appreciation to Mr. James Moriarty and Miss Majorie Browne of Scripps Institution for the preparation of the charts and graphs.

I. SALINITY, RIVER DISCHARGE AND RAINFALL RECORDS

A. Aransas Bay.—According to Collier and Hedgpeth (1950), the mean annual salinity of Aransas Bay for a "normal year" is approximately 19 to 20°/₀₀. This is further emphasized in a mimeographed report by Williams and Whitehouse (1952), which summarizes the previously published data and discusses the chlorinity data of the 1951–52 field seasons of A.P.I. Project 51. Although most of the data published before 1947 have been reviewed by Williams and Whitehouse (1952) and Whitehouse and Williams (1953), these summaries do not include salinity determinations made during the critical years of 1948, 1949, 1950, early 1951, 1952, and 1953. Hedgpeth (1953), however, cites salinity averages by months from 1948 through 1951, which were obtained from the United States Coast and Geodetic Survey tide station at the Marine

Laboratory of Rockport, Texas. Four months' data are missing from these years, and the accuracy of readings at the tide station is somewhat in doubt. After September, 1947, the mean monthly salinities remained above 20°/₀₀, and they remained above 30°/₀₀ from June, 1950, until September, 1952, attaining the very high value of 42°/₀₀ in August, 1951 (Fig. 2). A record 14-inch rainfall in the Rockport area in September, 1951, had no great effect on the average salinities in Aransas Bay. Somewhat increased rainfall in the Aransas Bay area and in the San Antonio-Guadalupe River drainage basin in late 1952 and early 1953, however, caused a considerable drop in salinity.

There has been a partial elimination of the gradients in salinity facies in Aransas Bay as determined by Ladd (1951). The differences in salinity between Lydia Ann Channel and lower Aransas Bay and those of upper Aransas Bay near Carlos Bay and in the Copano Strait were 5.6°/₀₀ in November, 1951, and 2.2°/₀₀ in January, 1952. During Ladd's investigation, the difference in salinity between opposite ends of Aransas Bay was approximately 12°/₀₀.

Salinities in Aransas Bay have consistently risen above 20°/₀₀ during the summer

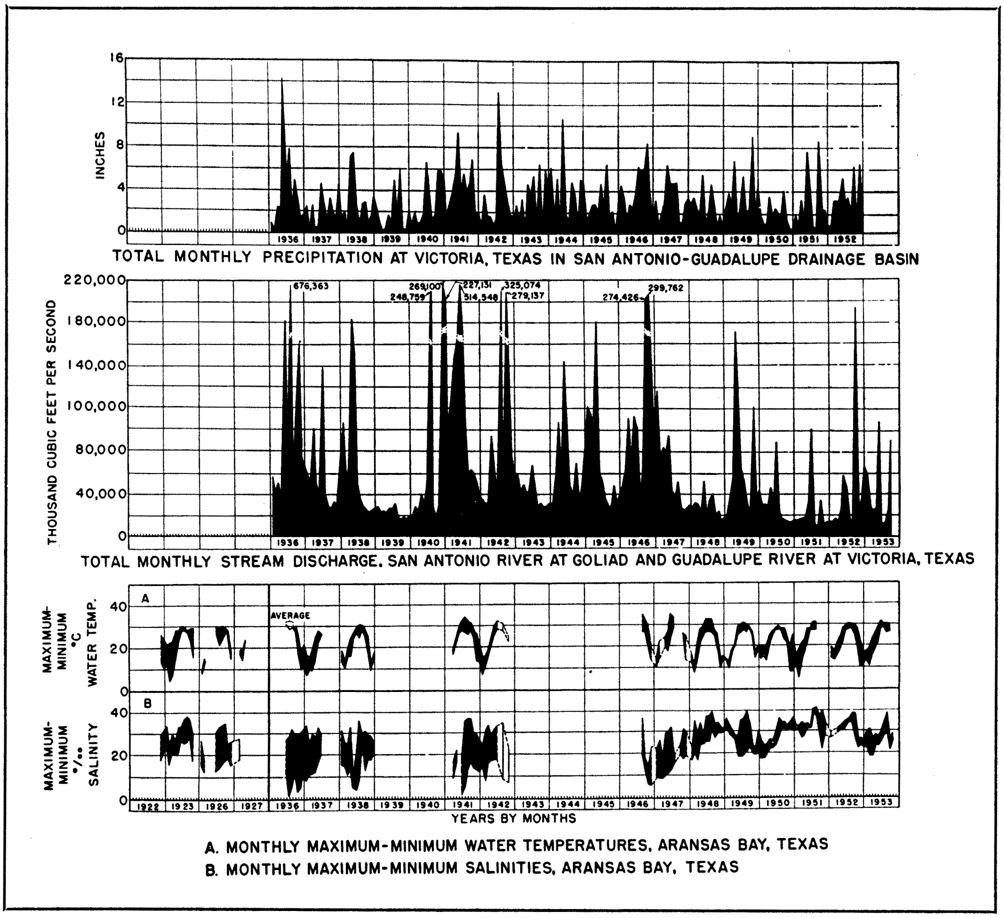

FIG. 2—Comparison of water temperatures and salinities of Aransas Bay, Texas, with rainfall and river discharge in the San Antonio-Guadalupe river system. Salinities and water temperature data from 1922–23 (Collier and Hedgpeth, 1950), from 1926–27 (Galtsoff, 1931), and from 1936–46 (Collier and Hedgpeth, 1950).

months in the past, but the change in salinity can best be demonstrated in the ranges between maximum and minimum values during each month. Between 1926 and 1947, the salinity has ranged from 10 to 30°/₀₀ during most of the months, even in the summer. After 1947 the difference between maximum and minimum became very small at all seasons (Fig. 2), although there were very few readings for some months. During the months of moderately high rainfall in the years 1936, 1941, 1942, 1946, and 1947, salinity conditions in Aransas Bay were highly variable throughout the year and appear to be somewhat more concentrated in the low range of salinities from 5 to 25°/₀₀ (Fig. 2). However, during years of drought, in 1948 to 1952, in the Rockport Bays, salinities were far less variable and were more concentrated in the upper range (25 to 40°/₀₀).

B. San Antonio Bay.—San Antonio Bay has also shown a gradual increase in salinity since 1950, in spite of heavy discharges from the Guadalupe River in June, September and October, 1951 (Fig. 2). Galtsoff (1931) states that in 1926 salinity values for upper San Antonio Bay were in the neighborhood of 4 to 10°/₀₀ and for lower San Antonio Bay from 10 to 17°/₀₀. Baker (1950) found salinity ranges from 13.1 to 24.4°/₀₀ in lower San Antonio Bay in 1950. In 1951, the author found salinity values ranging from 20.3 to 32.1°/₀₀ in lower San Antonio Bay and Mesquite Bay, whereas the A.P.I. field party from Scripps Institution obtained salinity values of from 23.90 in upper San Antonio Bay to 41.42°/₀₀ in lower San Antonio Bay in July and August, 1951. These are the highest salinities to be recorded from this usually low salinity bay. Williams and Whitehouse (*op. cit.*) state that salinities in lower San Antonio Bay still ranged from 27.39 to 31.16°/₀₀ (converted from chlorinities) in January and February, 1952, although upper San Antonio Bay salinity values were much lower. Salinities in late 1953 were still well above the "normal" of 10 to 17°/₀₀ as suggested for San Antonio Bay by Ladd (1951).

C. Copano Bay.—In the spring and summer of 1951, salinities were generally higher in Copano Bay than in Aransas Bay. At no time during the period from July, 1950, to August, 1951, was a salinity lower than 32.2°/₀₀ observed in Copano Bay. The highest observed salinity was 40°/₀₀, and the mean for that period was about 36°/₀₀ (Fig. 3). The maximum-minimum range is much narrower and the rise more spectacular for Copano Bay than in Aransas Bay, as can be observed by comparing figures 2 and 3. Higher salinities are to be expected in shallower Copano Bay in relation to periods of reduced rainfall and high evaporation over the Copano watershed, as pointed out by Collier and Hedgpeth (1950). River runoff from Mission River is so slight during dry years (as compared to the San Antonio-Guadalupe rivers), that practically no freshening of this bay can occur. Evaporation, then, can have a very telling effect upon this shallow enclosed bay.

D. Redfish Bay.—Redfish Bay, on the west side of Aransas Bay and behind Harbor Island, is nearly landlocked, extremely shallow, and close to the higher salinity waters of Aransas Pass; therefore, it is usually subject to rather high salinities in the summer. In the absence of salinity data for earlier years. Little can be said concerning the changes in the bay except for the period since 1947. According to salinity values obtained by Hedgpeth (unpublished data), Baker (1950), and the author, salinities in Redfish Bay ranged from 39.8°/₀₀ at the peak of the dry season in 1950 to 21.7°/₀₀ in the winter months of 1949 and 1950. From October, 1947, to May, 1948, February to April, 1949, and October, 1949, to June, 1950, salinities remained below 30°/₀₀. After June, 1950, salinities rose above 30 and remained above 31°/₀₀ throughout 1950 and 1951.

E. Mesquite Bay.—The maximum and minimum salinities for Mesquite Bay are shown on figure 4. Although data are scarce during so-called wet years, it can be seen that in 1926, 1927, 1936, and 1937 salinities ranged between 4 and 19°/₀₀, and from 1947 to 1950 from 14 to 28°/₀₀. During these years salinities were still essentially those of a low- to medium-salinity bay. However, in 1950 and 1951 salinities were not obtained below 22°/₀₀, and at one time they ranged to above 40°/₀₀. A record of salinity values obtained by Mr. Ernest Simmons of the Marine Laboratory, taken approximately every two hours in the center of Cedar Bayou (Table 1),

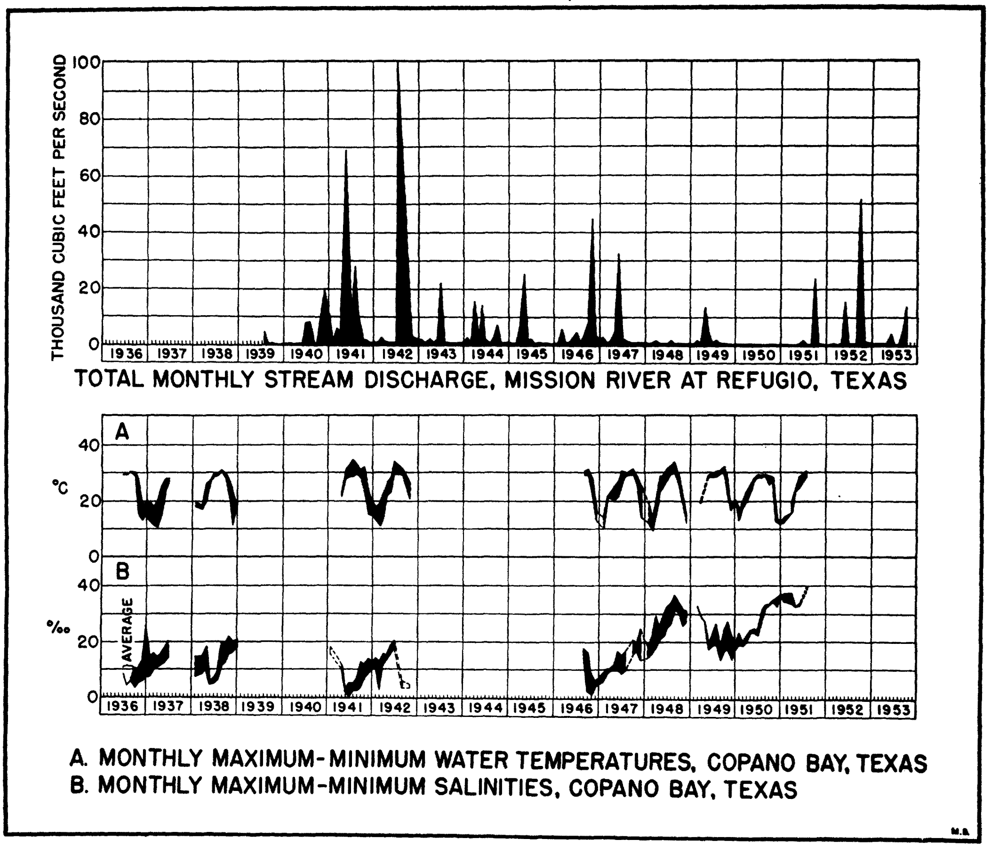

FIG. 3—Comparison of salinities, water temperatures of Copano Bay, and Mission River stream discharge. Salinity and water temperature data for 1936 to 1947 obtained from Collier and Hedgpeth (1950).

shows very little change (not more than 1.6°/oo) in salinity over a three day period. Since this period covered at least two complete astronomical tide cycles, it would appear that tides apparently do not bring enough Gulf water into Mesquite Bay to raise the salinity noticeably. From the above data it would appear that Mesquite Bay is more affected by river runoff and evaporation than by influx of Gulf water.

F. The Gulf of Mexico.—The salinities of the coastal fringe of the Gulf of Mexico in the vicinity of Port Aransas and Cedar Bayou have risen to a slight degree recently, according to the few data available (Fig. 4). Phleger (1951) notes that surface salinities taken off Corpus Christi, near Aransas Pass, by the *Atlantis* in 1935, ranged from about 31 to 33°/oo. These low values were attributed to fresh water runoff and occurred simultaneously with the very low salinities in the bays. Gunter (1945) states that the mean salinity of this coastal water is about 32°/oo. Salinity observations for the spring and summer of 1951 close to shore in the vicinity of Port Aransas indicated a range of from 36.19 to 39.90°/oo, 4 to 6 parts higher than during the "wet" years of 1935 to 1941.

G. General Considerations of River Discharge, Rainfall and Salinity.—In order to determine whether droughts are responsible for the increased salinities in the Rockport area, all available discharge data for the rivers which empty into these bays, as well as representative rainfall data from the drainage areas, have been plotted with the associated salinites and water temperatures.

TABLE 1.—RECORD OF SALINITIES TAKEN AT CEDAR BAYOU FROM 11:45 APRIL 18, TO 07:00 APRIL 21, 1950; SUPPLIED BY MR. ERNEST SIMMONS, T. G. & F. C.

Date	Hour	Salinity °/₀₀
4/18/50	1145	22.7
	1350	22.6
	1558	22.7
	1745	22.9
	2000	22.9
4/19/50	0730	22.6
	0900	22.1
	1355	22.5
	1455	22.4
	1715	22.9
	2000	22.9
4/20/50	0730	22.9
	0945	22.8
	1154	22.4
	1350	22.4
	1600	22.3
	1755	22.2
	2020	22.3
	2200	22.9
2/21/50	0700	23.7

When there are extended periods of heavy runoff from the San Antonio-Guadalupe and Mission rivers, as during 1936, 1938, 1941, 1942, 1946, and early 1947, there is a corresponding drop in salinities in the bays into which they empty for the same years (Figs. 2 and 3). According to these graphs the effect of increased runoff is felt in the bays within less than a month, and likewise, as soon as the runoff is reduced, salinity values rise rather rapidly to the values occurring prior to the runoff. The total rainfall by months in the drainage areas of the San Antonio-Guadalupe rivers is also reflected in the total monthly discharge figures of these rivers (Fig. 2).

In order to demonstrate more clearly the long term changes in salinity in the Texas bays, a graph was prepared showing the total yearly river discharge for the San Antonio-Guadalupe rivers as compared with the yearly average salinities in Aransas Bay (Fig. 5). According to this graph those periods from 1934 to approximately 1948 show correspondingly high runoff and low salinity. Starting in 1947, river discharge became less and less (associated with decreased rainfall), and the average yearly salinities increased from 20 to 35°/₀₀. Prior to 1947, average yearly salinities ranged from 15 to 20°/₀₀. This graph has been expanded to in-

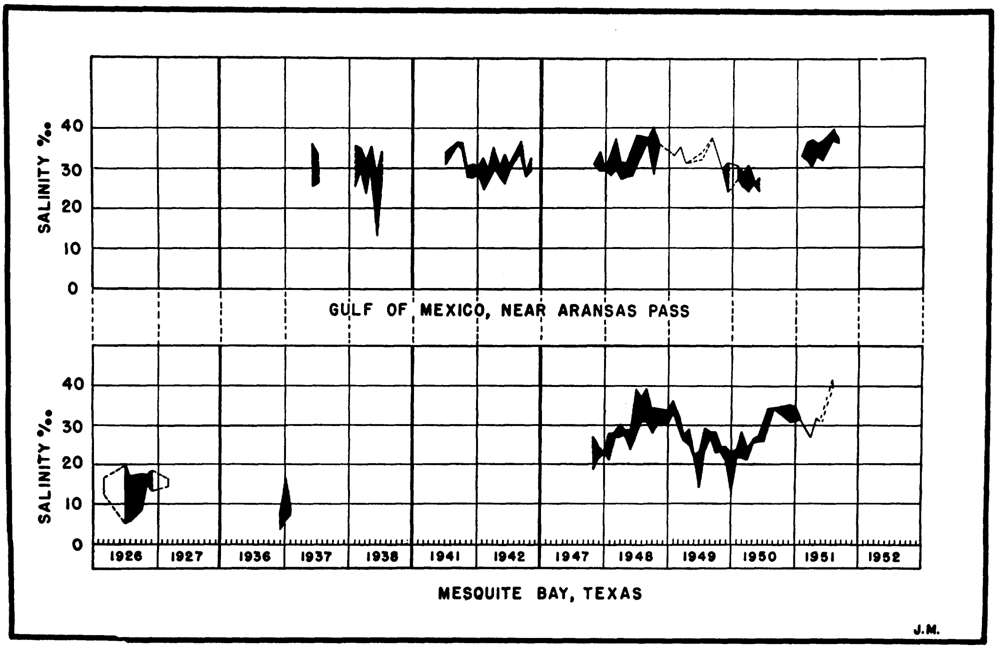

FIG. 4—Comparison of salinity data from Mesquite Bay and the Gulf of Mexico. Data for 1926–1927 from Galtsoff (1931), for 1936–1947 from Collier and Hedgpeth (1950).

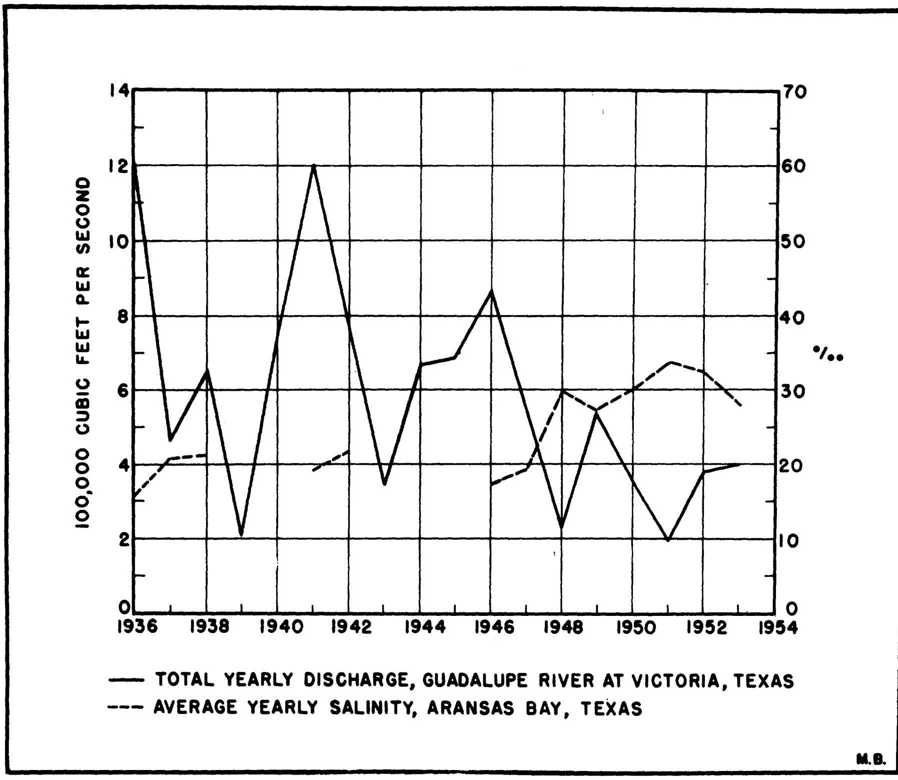

FIG. 5—Comparison of total yearly discharge of Guadalupe River with average yearly salinity of Aransas Bay, Texas.

clude monthly mean salinities and monthly mean river discharge (Fig. 6) for Aransas Bay in order to demonstrate the relationships between salinity and river discharge on a monthly basis. Again it may be observed that with monthly increases in river discharge, salinity decreases are reflected in Aransas Bay within a month. The rise in salinities from February, 1948, through 1953 is depicted somewhat more spectacularly in the plots of the mean salinities than in maximum and minimum salinity graphs, although the significant narrow range of salinity during the drought years is not apparent.

II. BIOLOGICAL CONDITIONS

A. The Change in Salinity in Relation to Oyster Reef Conditions.—Previous marine biological studies have been made in the central Texas coastal area during periods of much lower salinities than have been observed during 1948 to 1953. The composition of the biotic communities has changed considerably during this high salinity period. One organism which appeared to be considerably affected by the increased salinity was the oyster, *Crassostrea virginica* (Gmelin), which is the principal component of the extensive shell reefs in this area. The salinity increase was briefly noted by Puffer and Emerson (1953) and was cited as a possible explanation for reduced production of oysters in the Texas bays. This mollusk has been the most studied organism in the local bays, receiving considerable attention from Galtsoff (1931, 1942), Gunter (1950a), Baughman and Baker (1950), Puffer and Emerson (1953), and various investigators for the Texas Game and Fish Commission throughout the past 50 years. It is generally considered that this oyster is best adapted to an estuarine environment, with a salinity of 12 to 19°/oo (Ladd, 1951 and Gunter, 1953), and does not form extensive reefs in areas of high salinity. However, Korringa (1952) states that experimental evidence conflicts with field observations, and no definite conclusion can be drawn as to exact salinity preferences. Amemiya (1926) determined in the laboratory the lower and upper salinity limits of the developmental stages of the American oyster, *C. virginica*. Amemiya found that below 15°/₀₀ and above 30°/₀₀, abnormal segmentation of the oyster larvae took place, and very few shell-bearing larvae were formed. Such developmental abnormalities could very well limit populations in waters of either very low or very high salinity.

A change in the growth-rate and meat condition of the oyster was noted during the period of increased salinity (1950–1952). According to Byron B. Baker (personal communication) oysters from 1948 to the fall of 1950, were thin, flabby and tasteless, even when they were not spawning. Glycogen-content tests by the Texas A. & M. Research Foundation (unpublished communication in the files of the Texas Game and Fish Commission), showed a very low glycogen content for oysters in Aransas Bay during the period of 1948 to 1950. For several years, when the salinities were generally below 25°/₀₀, no appreciable shell growth was observed in oysters larger than

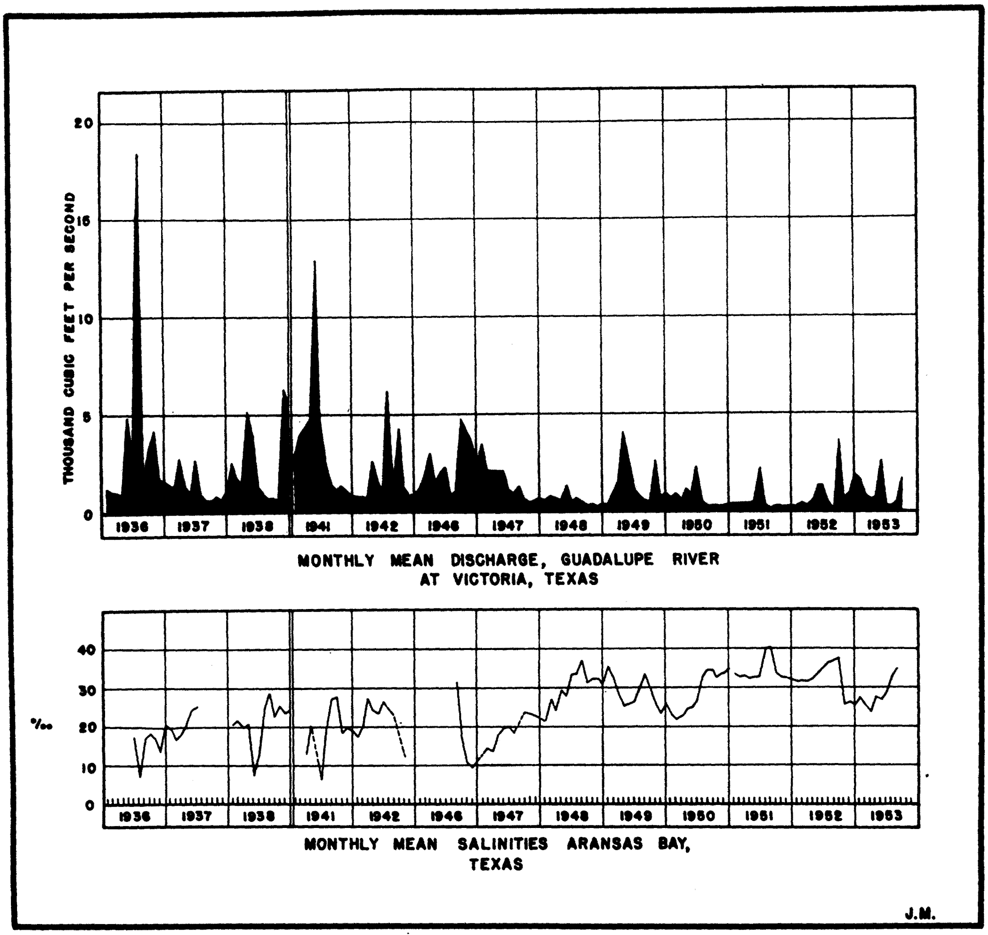

FIG. 6—Comparison of monthly mean salinities of Aransas Bay, Texas, with monthly mean river discharge of Guadalupe River, Texas.

two or three inches. After the salinities had risen above 30°/₀₀ a definite change was observed in most of the oysters. The rate of new shell growth increased in old oysters (those with very thick but stubby valves). In less than two months, many old oysters produced new extensions of the valves of two or three centimeters in length, and by March, 1951, most oysters observed had long, highly-colored, crenulated valves of new, sharp growth. Many oyster men and biologists native to this locality stated that such rapid and long growth had previously never been observed in so short a period. Oyster glycogen-content increased fairly rapidly, according to tests performed by the author. It is generally considered that oysters are at their best in Aransas Bay during the winter months, as intense spawning activity saps their vitality whenever water temperatures remain above 20°C for any length of time (Gunter, 1942). During the spring and summer of 1951, most of the oysters sampled were of exceptional fatness

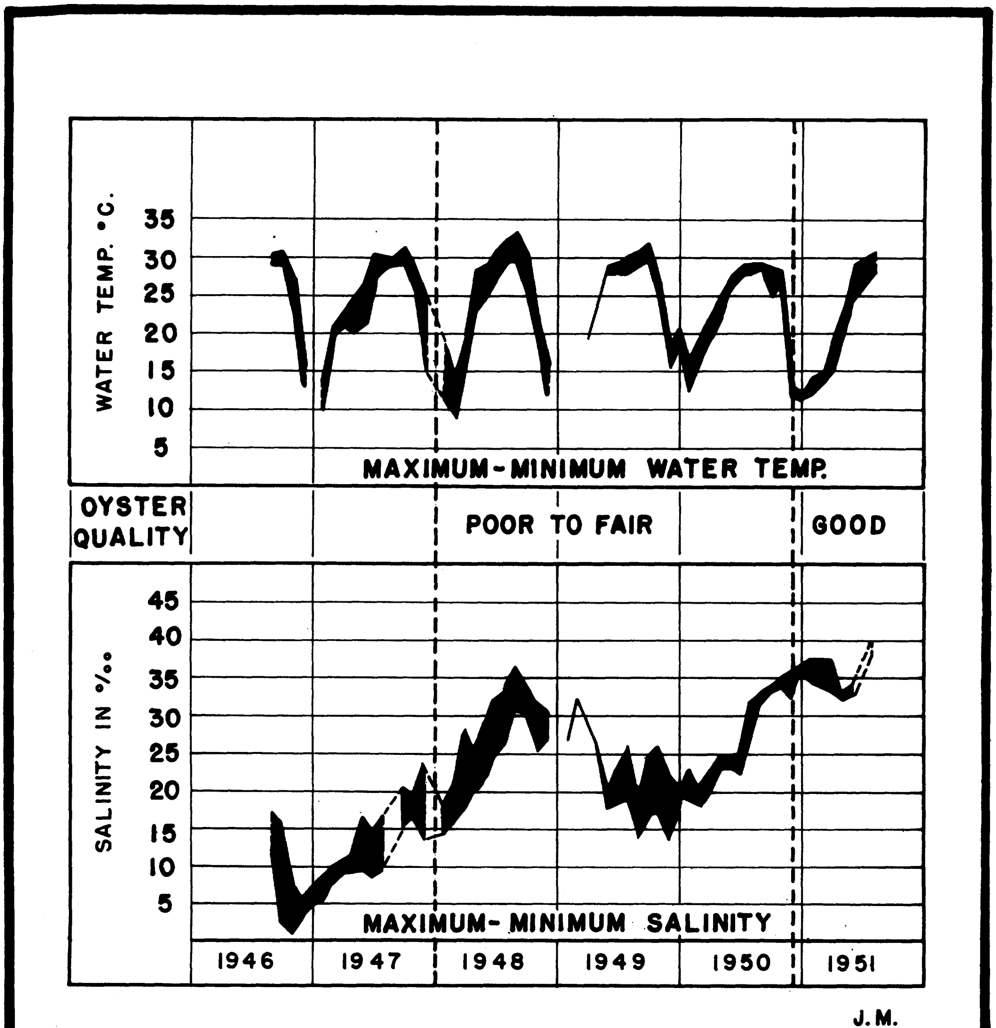

FIG. 7—Comparison oyster quality (determined by glycogen analysis and other oyster quality tests) with water temperature and salinities of Copano Bay, Texas.

and quality, even though in spawning condition (Fig. 7). A change in oyster appearance and quality was again observed during January through March, 1952. Instead of rapid new growth, as in the previous year, most oysters had little new growth, although they were of continued high quality. Oysters were reported to be dying in large numbers in Copano Bay during 1952 (R. Hoffstettor, personal communication), although in 1951 Copano Bay oysters were larger than previously observed for several years. It might be mentioned that with the declining salinities of the latter part of 1953, oyster production is apparently improving in Aransas Bay.

An indication of a change in the faunal composition of the oyster reefs in central Texas bays is the presence of large numbers of the small oyster, *Ostrea equestris* Born. This oyster is normally found in waters of high salinity, and seldom occurs abundantly in any of the bays, although it has always been present in Lydia Ann Channel and Aransas Pass (J. W. Hedgpeth, personal communication). Examination of oyster spat from Copano Bay in March, 1952, revealed that almost half of the small oysters of from an inch to an inch and a half in diameter were adults of *Ostrea equestris*. Samples of spat obtained from Long Reef, Tin Can Reef, and other small reefs in Aransas Bay were composed of over 50 per cent *O. equestris*. This oyster never grows very large; but it could supply a shell base for the common oyster to set when the bays return to lower salinity. Large numbers of *O. equestris* in old *C. virginica* reefs buried in Recent and possibly Pleistocene sediments probably indicate high salinity conditions at the time of deposition.

B. Apparent Faunal Changes in the Aransas Bay System.—During the period of extended high salinity, many organisms were collected in Aransas Bay which had never been reported from this area before, including some previously considered characteristic of the Gulf waters. The most unusual of the "marine invasions" into the bays was that by various echinoderms usually confined to waters of higher salinity, and rare or not hitherto reported in Aransas Bay proper. These include large numbers of starfish, abundant *Luidia clathrata* (Say) and rare *L. alternata* (Say). Other echinoderms collected year-round were many sand dollars, *Mellita quinquesperforata* (Leske), two species of sea urchins, *Arbacia punctulata* (Lamarck) and *Lytechinus variegatus* (Leske), and five species of ophiurans, *Ophiolepis elegans* Lütken, *Hemipholis elongata* Say, *Amphiodia limbata* (Grube), *Ophioderma* sp., and *Ophiothrix* sp. Hedgpeth (Whitten, Rosene and Hedgpeth, 1950) reports two brittle stars, *Hemipholis elongata* and *Ophiactis* sp., one sand starfish, *Astropecten antillensis* Lütken, and the sea urchins, *Arbacia punctulata* and *Lytechinus variegatus*, from the vicinity of Port Aransas and Aransas Pass in the open Gulf. In the present collections, except for the brittle stars which have been found over most of the sand-slit-clay bottoms of Aransas Bay, parts of Copano, Mesquite and lower San Antonio Bays, most of the echinoderms have been collected from the northeast end of Lydia Ann Channel, near Mud Island, and in the southeastern section of Aransas Bay. Although the Mud Island area has always presented a somewhat different faunal appearance from the rest of Aransas Bay, the echinoderms mentioned above have not been noted in previous publications (which, however, did not attempt to catalogue the fauna of Aransas Bay) or at least have not been observed as year-round residents.

Large numbers of the sea pansy or sea liver, *Renilla mülleri* Kölliker, and an increasing number of colonies of whip coral, *Leptogorgia setacea* (Pallas), have also been taken during all seasons around Mud Island, and in the Intracoastal Waterway, well up into Aransas Bay as far as Rockport. It was observed that strands of whip coral in the center of Aransas Bay were smaller than those living closer to Gulf waters. Those obtained directly off Rockport were from two to three inches tall, whereas those found near Mud Island and in nearshore Gulf waters were two to three feet long. The author also found living star coral, *Astrangia astreiformis* Milne Edwards and Haime, in Aransas Bay as far northeast as the old shipyard at Rockport. Many lumps of dead coral have also been found in Lydia Ann Channel and around Mud Island. Ladd (1951) lists this coral as abundant in lower Aransas Bay, near the passes into Redfish

Bay and Lydia Ann Channel, and his observations have been confirmed by Hedgpeth (personal communication). A map, figure 8, shows the farthest advance of the open Gulf organisms. Neither Gunter, Hedgpeth, Reed (1941), nor Ladd lists *Renilla* or *Leptogorgia* as inhabitants of Aransas Bay, or even Lydia Ann Channel which is usually more saline than the bays. Hedgpeth (personal communication) suggests that *Renilla* may have always been present in small numbers in Lydia Ann Channel.

A wide occurrence of tectibranchs, which Hedgpeth (Whitten, Rosene, and Hedgpeth, 1950) lists as probably *Tethys floridensis* Pilsbry, was also noted in the spring of 1951. In 1951, hundreds of these large (4 to 10 inches long) animals were observed in all parts of Aransas Bay and Corpus Christi Bay. Whether this influx of sea hares can be associated with the increase in salinity, or is part of a resurgent population, is a matter for speculation. Hedgpeth (1950) and Reed (1941) state that they are usually found on beaches after storms, but are occasionally taken in the bays.

The distribution of two arthropods, *Penaeus setiferus* (Linné) and *Callinectes*

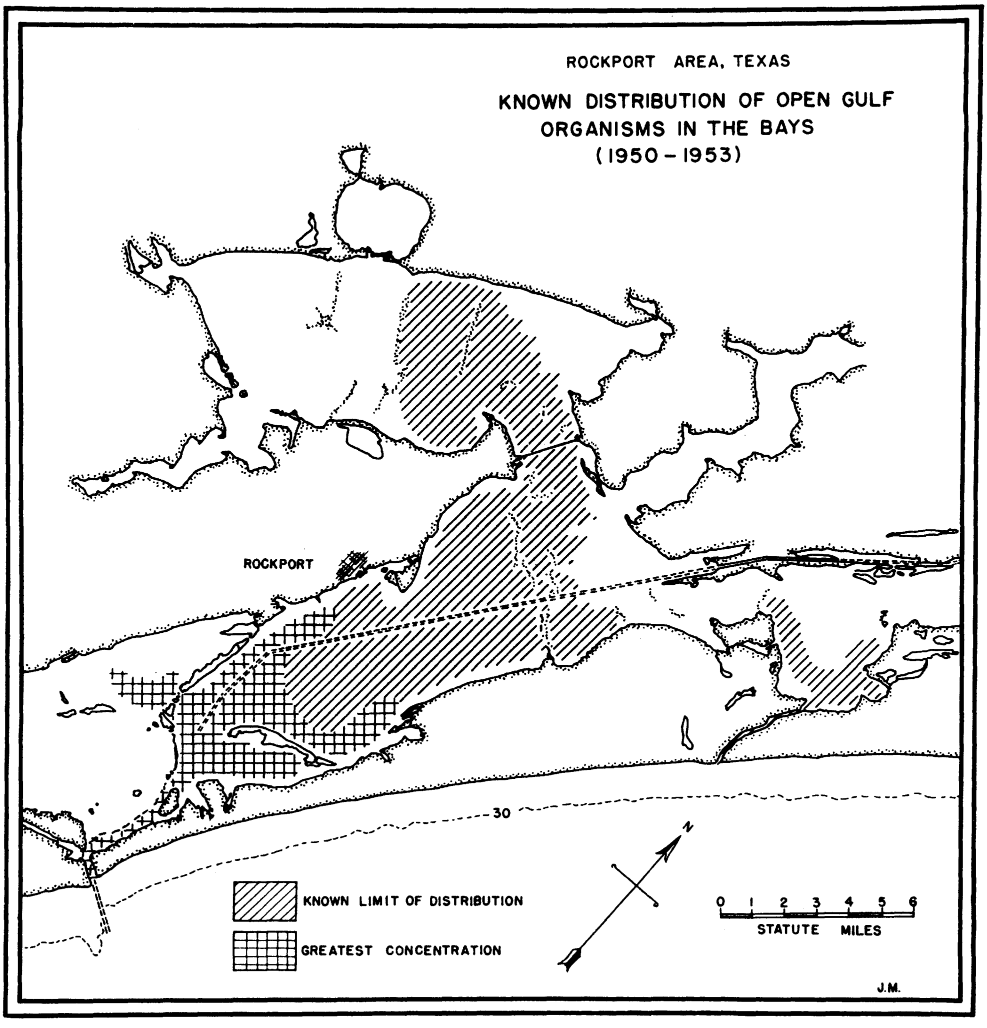

Fig. 8

danae Smith, also appears to have changed during this high-salinity period, and it may or may not have been associated with the salinity change. Of the two, *P. setiferus*, the common commerical or white shrimp, has shown the greater change. Prior to 1949, when the salinity was low, this shrimp formed the major portion of the commerical net hauls of shrimp in the Texas bays in the fall. According to Hildebrand and Gunter (1953), however, production of white shrimp in Texas fell from 2 to 7 million pounds from 1949 to 1951. An analysis of otter-trawl catches taken by the author during the fall of 1951 and spring of 1952 showed that only one to five per cent of the total shrimp consisted of *P. setiferus*, while juveniles of *P. aztecus* Ives and *P. duorarum* Burkenroad comprised the bulk of the shrimp catch. Gunter (1950) discussed the seasonal abundance of all three species of shrimp in detail, and emphasized that *P. setiferus* occurs in vast abundance and supports the commerical catch in the fall. Burkenroad (1951) states that in the Aransas Bay area the sharp decline in the numbers of young white shrimp is probably associated with the recent high salinities. Hildebrand and Gunter (1953) indicate that there is a high correlation between the production of white shrimp and the increase or decrease of rainfall. Since, as indicated in the discussion of the physical-chemical factors, there is a rather high degree of association between rainfall, runoff and salinity in the Texas bays, it is reasonable to assume that salinity has been at least partly responsible for the decrease in shrimp. Hildebrand and Gunter state that the correlation may be either with salinity *per se* or with some unknown factor governed by salinity.

The abundance of *Callinectes danae*, which in the summer of 1951 and spring of 1952 was far more numerous than in the previous year, may also be asssociated with high salinity. This crab is commonly known as the Gulf crab, and is smaller than the common edible blue crab, *Callenictes sapidus* Rathbun. Gunter (1950) compares catches of the Gulf crab from Aransas Bay and the Gulf of Mexico in 1941 and 1942, and shows very few individuals present in Aransas Bay, as compared to the large numbers in the open Gulf at the same time. Daugherty (1952), however, made collections of *C. danae* during the early portions of this period of increased salinity and observed that far greater numbers of this crab were present in the bays than previously, and that they were present there throughout the year. Personal observations during 1950, 1951, and 1952 also showed an increase in numbers of the Gulf Crabs in the bays, although actual counts were not made from month to month. Hauls taken in March, 1952, contained many more Gulf crabs than blue crabs, and at times the Gulf crabs constituted a major portion of the total trawl catch.

Considered somewhat unusual for these Texas bays was the occurrence of 23 species of living mollusks which usually occur in waters of high or oceanic salinity and have never been reported living in these bays before. Because of the large number of species of mollusks involved, and the fact that many other investigators have dealt with their distribution here in the past, a table has been prepared comparing the distribution of the mollusks during the times of high salinity and during the times of low salinity (Table 2). The majority of collections of mollusks from the Texas bays have been made during times of reduced salinity; therefore, the species of mollusks said to be indicative of the bays are quite different from those which are now abundant, although most of the species found previously are still present. However, *Rangia cuneata* (Gray), a low salinity mollusk, has virtually disappeared. At the time his collections were made in upper San Antonio Bay (1940), when the salinities ranged from 4 to 9°/₀₀, Ladd collected large numbers of *Rangia*, of which most were living. Burkenroad (personal communication) also states that he has found large populations of *Rangia* living in this locality during times of very reduced salinity. During the summer of 1951 and spring of 1952, when salinities were generally much higher (11 to 20°/₀₀), no living specimens of *Rangia* were taken in San Antonio Bay although extensive collections were made throughout all of the bay. Associated with *Rangia* is the minute gastropod, *Littoridina sphinctostoma* Abbott and Ladd, which Ladd found alive only in waters of very low salinity. In 1940 it was said to be

TABLE 2.—DISTRIBUTION OF MARINE MOLLUSKS IN RELATION TO SALINITY IN CENTRAL TEXAS BAYS, 1893–1953

A—Alive. D—Dead. X—Reported, condition not stated. L—Alive, not reported before.

Species	Collector																			
	Singley, to 1892[1]		Mitchell, 1894[2]		Cross & Parks, 1935[3]		Reed, 1936–41[4]		Ladd, 1940[5]		Gunter, 1941–42[6]*		Hedgpeth, 1946–48[7]*		Pulley, 1947–50[8]		Emerson & Puffer 1951–52[9]		Parker & Lee 1951–53[10]	
	Bay Salinity Range																			
	Unknown		Unknown		2–25°/₀₀		2–25°/₀₀		5–35°/₀₀		5–35°/₀₀		7–39°/₀₀		9–40°/₀₀		20–42°/₀₀		20–42°/₀₀	
	Occurrence																			
	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay
GASTROPODA																				
Diodora cayenensis	D								D						X	X				
Neritina virginea		A				X				A						X				A
Littorina irrorata				A		A		X					A	A		X	D	D		A
Littorina nebulosa													A		X				A	
Littorina ziczac										A			A		X	X				
Littoridina sphinctostoma										A							D	D		D
Architectonica nobilis			D		X										X		D		D	
Vermicularia fargoi		D		A	X				D	D					X			A		A
Caecum pulchellum									D	D					X		D	D		D
Modulus modulus	D			D					D	D					X			D	D	D
Bittium varium		D						X	D	D						X	D	D		D
Cerithidea pliculosa		D		A			X		D	A						X	D	D		D
Cerithium variabile		D		D		X	X		D	A					X		D	D		D
Seila adamai	D														X					
Epitonium angulatum	D					X	X			D					X			D		L
Epitonium rupicolum							X								X			D		L
Janthina janthina			D	D			X								X				D	
Janthina globosa						X									X				D	
Niso interrupta	D														X					
Odostomia impressa		D							D	A						X		A		A
Crepidula fornicata	D			D	X								A		X		D	D	D	L
Crepidula glauca					X	X	X		D	A						X				
Crepidula plana				A	X				A	D					X		D	A	A	A
Strombus alatus	D		A		X		X								X				D	L
Natica pusilla			A		X				A	D					X	X	D	L	A	L
Polinices duplicata	D		A		X		X		A	D			A		X		D	L	A	L
Sinum perspectivum	D				X										X			L	A	L
Simnia uniplicata															X		D	L	A	L
Phalium granulatum	D		D		X		X						A		X		D		A	
Distorsio clathrata			D		X										X		D		D	
Tonna galea			A		X		X				A				X				D	
Murex fulvescens	D		D		X		X								X				D	
Murex pomum					X	X	X										D		D	D
Thais haemostoma haysae-floridana				A	X	X		X	A		A		A	A		X	D	D	A	A
Anachis avara semiplicata		D							A	A			A	A	X			A	A	A
Anachis obesa	D								A	A						X		A	A	A
Mitrella lunata	D									A						X		A		A
Nassarius vibex	D			A					D	A						X	D	D	D	D
Nassarius acutus	D					X			A	A			A		X		D	D	A	A
Fasciolaria distans	D		D		X		X						A		X		D	D	D	D
Fasciolaria gigantea			D		X										X				D	
Fasciolaria tulipa			D		X										X				D	
Cantharus cancellaria					X	X			A	A					X	X	A	D	A	A
Cantharus tinctus													A						A	
Busycon spiratum	D		A		X		X		A	D	A				X		D		D	
Busycon perversum		D	A		X	X	X		D		A				X	X	D	L	A	L
Oliva sayana	D		A		X				A						X		D	D	A	L
Olivella mutica	D				X				A	D					X				A	
Cancellaria reticulata															X					L

Marginella apicina		D													X					
Mangelia cerinella	D															X		L		
Terebra cinerea							X								X		D		A	
Terebra dislocata	D						X								X		D		D	
Terebra protexta		D								D								D		
Actaeon punctostriatus															X			D		
Acteocina canaliculata	D									A						X		D		A
Bulla occidentalis		D		D		X							A			X	D			L
Haminoea elegans				A												X				D
Melampus coffeus				A		X										X		D		D
Siphonaria pectinata													A	A						A
SCAPHOPODA																				
Dentalium texasianum		D							D	A					X	X		D	D	A
PELECYPODA																				
Nuculana acuta		D								A					X			A	D	A
Nuculana eborea										A					X	X				A
Anadara ovalis		D	D	A	X				A	A					X		D	A	D	A
Anadara chemnitzi															X		D			
Anadara braziliana		A			X		X		D						X		D		D	
Anadara secticostata					X														D	
Aandara transversa		D	D		X				A	A					X		D	A	D	A
Arca umbonata			D												X		D		D	
Noetia ponderosa	D				X		X		A	D					X		D	D	A	D
Brachidontes recurvus		A		A	X			X		A			A	A		X				
Brachidontes exustus		A		D												X		A		A
Lithophaga bisulcata													A							
Volsella demissa granosissima		D		A																
Modiolus tulipus						X	X			A					X		D		D	
Atrina rigida		D		A		X	X			A						X		D	D	A
Atrina serrata			D	D	X		X								X		D		D	
Aequipecten gibbus amplicostatus		A			X	X	X		D	A						X	D	A	D	A
Aequipecten gibbus concentricus	D				X	X											D	D	D	
Anomia simplex		D		A		X			D	A			A	A		X	D	A	D	A
Ostrea equestris											A		A	A	X		D	A	D	A
Crassostrea virginica		A		A	X	X		X	D	A		A	A	A		X	D	A	D	A
Crassinella martinicensis		A							D	A								D	D	A
Cardita floridana		D	D	D					D	D					X	X	D	D	D	D
Polymesoda caroliniana				A												X	D		D	
Polymesoda floridana		A		D						D						X		D		
Diplodonta punctata															X			L		
Diplodonta semiaspera																		D		
Anodontia schrammi															X		D	D	D	D
Anodontia alba				D											X		D	D	D	L
Lucina amiantus									D						X				A	L
Lucina crenella		D			X				D	D					X			D		D
Lucina floridana									D						X		D		D	
Lucina pectinata	D			A						A					X	X	D	D	D	
Dinocardium robustum	D		A		X		X		D	D					X		D	D	D	D
Laevicardium laevigatum	D		D												X		D	D	D	D
Laevicardium mortoni				A	X					A					X	X		A		A
Trachycardium muricatum	D			A	X		X		A	A					X	X	D	A	D	A
Anomalocardia cuneimeris									D	A						X	D	A	D	A
Chione cancellata		D	D			X			A	A					X	X	D	A	D	A
Chione intapurpurea															X				D	D

* Collection only made on living forms.
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[10] Data compiled by Robert H. Parker and Howard K. Lee for the Texas Game and Fish Commission and A.P.I. Project 51 during the years 1950 through 1953.

(*Continued on next page*)

TABLE 2.—*Continued*

A—Alive. D—Dead. X—Reported, condition not stated. L—Alive, not reported before.

Species	Singley, to 1892[1]		Mitchell, 1894[2]		Cross & Parks, 1935[3]		Reed, 1936–41[4]		Ladd, 1940[5]		Gunter, 1941–42[6]*		Hedgpeth, 1946–48[7]*		Pulley, 1947–50[8]		Emerson & Puffer 1951–52[9]		Parker & Lee 1951–53[10]	
Bay Salinity Range	Unknown		Unknown		2–25°/₀₀		2–25°/₀₀		5–35°/₀₀		5–35°/₀₀		7–39°/₀₀		9–40°/₀₀		20–42°/₀₀		20–42°/₀₀	
Occurrence	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay	Gulf	Bay
Chione clenchi															X				A	
Cyclinella tenuis			D						D	D					X	X				
Dosinia discus	D		D		X				A	D					X	X	D	D	A	L
Macrocallista nimbosa			D												X				D	D
Pitar texasiana															X	X	D	D	D	
Pitar cordata															X				A	
Mercenaria campechiensis texana	A		D	A		X			D	A					X	X	D	A	D	A
Coraliophaga coraliophaga															X					
Rupellaria typicum																X				L
Petricola pholadiformis		D		A	X			X	D							X				D
Anatina canaliculata	D		D	D	X				D						X		D		D	
Anatina lineata															X		D		A	D
Mactra brasiliana		D		A						D					X	X	D	D	D	A
Mulinia lateralis		D		A					D	A					X		D	A	A	A
Rangia cuneata		A		A						A						X	D	A	D	D
Spisula solidissima raveneli															X		D		D	
Donax texasiana	D	A			X		X		D						X		D	D	A	D
Tagelus divisus																X		L		L
Tagelus gibbus		D		A		X			D	D					X	X	D	D	D	A
Abra aequalis	D								A	D					X			L	A	L
Cumingia tellinoides		D								D					X					
Semele proficua			D												X	X		L		L
Semele purpurescens										D					X	X				D
Macoma constricta				A					D	D					X		D	D	D	D
Macoma mitchelli				A						A						X		A		A
Macoma tageliformis		D														X	D			D
Tellidora cristata									A						X			L	D	L
Tellina alternata	D		A			X			A						X		D	L	A	L
Tellina lineata									D						X	X		D		
Tellina versicolor		D							D						X		A		A	L
Ensis minor		A		A						A					X	X	D	A	D	A
Corbula conradi									D	A								A		
Barnea costata	D			A		X	X		D	D					X	X	D	D	D	D
Pholas campechiensis				D				X							X		D		D	
Martesia smithii										A								A		A
Lyonsia floridana	D									A						X		A	•	
Pandora trilineata					X				D	A					X	X		A	D	A
Periploma inaequalis				D					D						X	X	D	L	A	L
CEPHALOPODA																				
Spirula spirula	D		D	D	X				D						X		D		D	
Lolliguncula brevis					A	A	X				A	A	A					A	A	A
Loligo peali							X				A						A		A	
Octopus vulgaris							X				A	A	A	A						
AMPHINEURA																				
Ischnochiton papillosa									A	A								A		A

quite abundant in upper San Antonio Bay, but in 1951, no living examples were found. It is not certain, however, whether the living populations of *Rangia* and *Littoridina* have disappeared as a result of increased salinities, or from some other causes.

III. POSSIBLE PALEOECOLOGICAL INTERPRETATIONS

Observations of the sort noted in this paper should be of some value in analyzing the environments in which fossil assemblages existed during Pleistocene and possibly Pliocene times. Puffer and Emerson (1953) observed that the faunal aggregations present during extended periods of low salinity appear to differ from those present during periods of high salinity. As they indicated, large numbers of *Ostrea equestris* on top of the reefs of *Crassostrea virginica* indicate increased salinities. In fossil assemblages, the echinoderms, corals, and the Gulf mollusks now found living in the bays may also constitute valid criteria for recognizing essentially marine conditions in former estuarine waters. Associated with these faunal changes indicative of salinity change is the *Rangia-Littoridina* community of upper San Antonio Bay which evidently disappears under increased salinity conditions. Whereas *Ostrea equestris*, marine mollusks such as *Strombus alatus* Gmelin, *Sinum perspectivum* Say, *Simnia uniplicata* Sowerby, *Tellidora cristata* Recluz, and *Tellina versicolor* Dekay, echinoderms, and corals indicate high salinities of from 30 to 40°₀₀, the *Rangia-Littoridina* assemblage appears to be a good indicator of very low salinities of from 3 to 8°/₀₀. Changes in size of certain mollusks also appear to be asssociated with prolonged salinity changes. It has been noted by Ladd (1951), Mitchell (1894), and the author, for example, that *Rangia* attains a far greater size in waters of very low salinity, or in almost fresh water, than it does in more saline waters. From the center of San Antonio Bay to the delta of the Guadalupe River and into the main mouth of the Guadalupe in Mission Lake, *Rangia* becomes progressively larger. This relationship may exist because the juveniles are killed by the more saline water before attaining the normal size attained in nearly fresh water. A similar relationship of size to salinity exists in the pelecypod, *Mulinia lateralis*, although the salinity range is far greater (from 5 to at least 60°/₀₀). Examples of *Mulinia* from the hypersaline lagoon, Laguna Madre, south Texas, all tend to be much smaller than those from the waters of more normal salinity further north.

As previously mentioned, *C. virginica* appears to undergo considerable variation in shell shape with extreme variation in salinity. A similar change was also noted by Hedgpeth (1953 and personal communication) in a small oyster reef situated in the hypersaline waters of the Laguna Madre near Port Isabel, Texas. It is also possible that the oysters undergo this change in shell shape when the salinity varies intensely in either direction.

It has also been observed by Gunter (1938) that the oyster assumes a different shape under varying sediment conditions. Oysters which become buried under mud during rapid sedimentation will grow very long and narrow in order to maintain their water intake above the surface of the bottom. If oysters of this shape (commonly called "coon" oysters) are found in fossil assemblages, it might be assumed that the reef had undergone rapid silting. A somewhat similar phenomenon has been observed in Copano Bay during periods of very low salinity, when oysters supposedly grew too rapidly and formed dense clusters of long thin individuals. In the case of the silting of oysters, the dense clusters are not formed. The dense clustering and elongation of the individuals in the cluster may be related to food supply, which may become more abundant at low salinities. It may be noted here that the "coon" oysters differ somewhat in appearance from those affected by the prolonged high salinities, in that in the "coon" oyster the whole shell is elongated and thin rather than only the lips.

SUMMARY

1.—Published and unpublished salinity values from the bays and open Gulf of Mexico of the central Texas coast from 1922 until 1953 indicate that during the recent six-year drought the salinities have become much higher than prior to 1948. Previous studies have shown that salinities in the bays generally rose above 34°/₀₀ in the

summer months, but during most of the year ranged from 5 to 25°/₀₀. From 1948 to 1953, salinities increased to well over 36°/₀₀ and at times above 40°/₀₀, without any appreciable decrease in the winter months.

2.—Comparisons of the total monthly discharge from the rivers emptying into these bays, with the total monthly rainfall from representative areas in the drainage basin of the rivers for all years of salinity data, indicate that when river discharge and associated rainfall were high, the salinities were low for corresponding months; and conversely, when discharge and rainfall were low (as during the last six years) salinities were high.

3.—With the increase in salinity, the oysters in the Texas bays were observed to take on different shell characteristics such as thin, sharp, highly colored, and crenulated valves.

4.—During low-salinity years, the reefs were composed primarily of *Crassostrea virginica*, a typically euryhaline species, whereas with the increase in salinities, there was a corresponding increase in the number of small marine oysters, *Ostrea equestris*, a species characteristic of waters of higher salinity. In 1952, it was observed that well over half of the spat-size oysters were *Ostrea equestris*.

5.—During the period of extended high salinity in Aransas Bay, many organisms were collected which had not been previously noted from this area. The organisms most indicative of high salinities were the echinoderms and coelenterates. Many species of gastropods and pelecypods, which had been confined to the open Gulf and inlets, were found throughout Aransas and Copano bays. There was also a corresponding decrease and disappearance of low-salinity mollusks in San Antonio Bay which had formerly been abundant. Whether this disappearance of low-salinity mollusks from the now high-salinity San Antonio Bay is a direct result of salinity increase is also not known.

6.—*Penaeus setiferus*, the commercial white shrimp, virtually disappeared from the bays with the increase in salinity, while *Callinectes danae*, a more or less open Gulf crab, became extremely abundant in the bays.

7.—Such observations may have some significance to the paleoecologist in interpreting environmental changes associated with changes in the fossil assemblages.

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